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ARGONNE NATIONAL LABORATORY

Proceedings of the U.S. Department of Energy Energy Optimization of Water and Wastewater Management for Municipal and Industrial Applications Conference

December 10-13, 1979

New Orleans, Louisiana

Volume 1

ANL EES

ARGONNE NATIONAL LABORATORY

Energy and Environmental Systems Division

prepared for

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PROCEEDINGS OF THE U.S. DEPARTMENT OF ENERGY ENERGY OPTIMIZATION OF WATER AND WASTEWATER MANAGEMENT FOR MUNICIPAL AND INDUSTRIAL APPLICATIONS CONFERENCE

December 10-13, 1979
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Volume 1

compiled by

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prepared for

U.S. DEPARTMENT OF ENERGY
Assistant Secretary for Conservation and Solar Energy
Office of Buildings and Community Systems

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FOREWORD

These proceedings document the presentations given at the Energy Optimization of Water and Wastewater Management for Municipal and Industrial Applications Conference, sponsored by the Department of Energy (DOE). The conference was organized and coordinated by Argonne National Laboratory.

The conference focused on energy use and conservation in water and wastewater. Each session was led by an authority in that field.

Conference sessions and workshops were attended by consultants, federal, state and local government employees, industrial representatives, researchers, engineers, scientists, educators and other professionals involved with water and wastewater treatment.

The first three talks of the General Session -- Introduction, Welcome and DOE Perspective -- spell out the objectives and set the mood for the presentations that follow.

The General Session also reflects DOE's commitment to the support and development of waste and wastewater systems that are environmentally acceptable.

The conference proceedings are divided into two volumes. Volume 1 contains the General Session and Sessions 1-5. Volume 2 covers Sessions 6-12.

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CONFERENCE CHAIRPERSON: Donald Walter, Chief, Urban Waste and Municipal Systems Branch, U.S. Department of Energy

CONFERENCE DIRECTOR: Barbara Broomfield, Argonne National Laboratory

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	Peregrine White Argonne National Laboratory
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12.	Caroline Brooks Argonne National Laboratory
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GENERAL SESSION

Chairpersons: Charlotte Rines

Wes Boyar

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V. Wesley Boyar
Energy and Environmental Systems Division
Argonne National Laboratory

This morning I have the pleasure of introducing the main speakers. Before introducing them, however, I would like to mention two things. At the present time I am helping to coordinate Argonne's role in assisting the Department of Energy with the implementation of the Emergency Energy Conservation Act which was passed early in November. As some of you may know, that act provides not only for a rationing program, but for an extensive program of energy conservation measures to be implemented if the President declares that there is a national energy emergency such as a shortfall in petroleum supplies. In each of the states that declaration will serve as a trigger to set targets by which uniform reductions in various fuels must be accomplished. In developing the regulations that have to be published in the Federal Register in early February, we have reviewed a number of measures, and believe me, these measures are serious, indeed. They affect many aspects of our social and economic life. In fact it has been awesome to participate in debates with the National Governors Association and with other bodies regarding just how the states will attempt to meet the mandated targets.

The severity of the situation is obviously underscored by current conditions in Iran, and I think the potential for a severe energy emergency emphasizes its importance. If future emergencies in energy supply occur, the better base-load capacity we have the less severe will be the emergency measures with which we will all have to live. I think it is incumbent upon this group and groups such as this to work together, to share your expertise, to share your experiences, and to be able to expedite those projects that can increase the base-load supply of energy in this country.

It is very fortunate that we are able to hold a conference such as this, and I want to compliment Barbara Broomfield on its organization. It has been very well put together as evidenced by the fact that many groups from both the public sector and the private sectors are represented there. All of you have the chance to share your experiences and to walk away from this conference in a few days better able to expedite those projects with which you are involved, and I certainly hope you do so.

But this is not a conference on the Emergency Energy Conservation Act; it is, in fact, a conference on energy optimization in water and wastewater management. It might be appropriate at this time to state a few broad goals for the conference. The reason for this is that when you listen to various papers on very specialized and well developed topics, sometimes the specific goals of the overall conference may become obscured. So I want to emphasize that we must discuss the goals briefly now, and we are going to, in effect, monitor them by the end of the conference. There will be an evaluation procedure Wednesday afternoon and at other times. During this evaluation procedure, one of the questions we will ask of you is just how you think this conference has met these goals, or, in fact,

have other goals emerged. A second question we will ask is what key issues came up in the sessions or workshops you attended. Which issues could be put into the proceedings and passed along to the Department of Energy to show the energy-related concerns of the people who are active in water and wastewater management programs?

The goals we have set forth are four. The first is for the participants in the conference to identify new and emerging issues with respect to the energy component of water and wastewater management. Now, what are new and emerging issues? Certainly there are many. One is the tradeoffs necessary between the costs of environmental control projects and the costs of energy production facilities. Where are the conflicts between the two? How are those conflicts to be resolved? What are the baseline costs implementers must face if they are to comply with the various regulations? Another issue is the fact that industrial treatment and municipal wastewater treatment traditionally have been regarded as somewhat separate systems. But from the perspective of energy demand they must be treated similarly; in terms of the bottom-line financing and economic analysis this may be a new approach. These are just two examples of emerging issues.

A second goal is the direct exchange of information among all of the water resource professionals here. Project managers, researchers, and others will have the opportunity, especially in the workshops, to exchange information and ideas. I've often found that at conferences such as this, probably the most beneficial thing to me was to pick up somebody's card and remember his or her name. So later, when a specific issue arose in a project I was dealing with, I knew whom to call. We certainly encourage you to participate in this direct exchange of information and set it specifically as a goal. In other words, hand out your cards and talk to each other.

A third goal which is indeed broad and perhaps very presumptuous of us, is to identify the various roles of federal, state, and local agencies in water and wastewater management regarding the energy component. If anyone can do that at any conference, I think that we will see a miracle, but at the very least we can provide agencies with questions and articulate the concerns of the people in the field who are participating so that the agencies better know what is on your mind, what you want to know, whom you want to know about, and what information exists where. So, to clarify governmental roles and responsibilities is, in effect, a goal of letting the agencies know your concerns.

The fourth goal is to directly provide the Department of Energy with information on the progress and potential of the various water and wastewater projects now going on throughout the country. We want to hear the perspectives of government agencies, consultants, researchers, and other water resource professionals.

These then are our goals for this conference. We feel quite sincere about them, and hope that you will contribute to achieving them.

For one who is here primarily to introduce the speakers of the morning, I think I may have overstayed my time. Thank you for your tolerance.

I have the distinct pleasure now of introducing Dr. Walter Massey, the Director of Argonne National Laboratory and Professor of Physics at the University of Chicago. Dr. Massey received his B.S. from Moorehouse College in 1958 and his doctorate from Washington University in St. Louis in 1966. He first joined Argonne in 1966 as a post-doctoral fellow and was appointed Staff Physicist in 1967. Between 1968 and 1970, he was Assistant Professor at the University of Illinois and in 1970 joined the faculty of Brown University.

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ENERGY OPTIMIZATION OF WATER AND WASTEWATER MANAGEMENT FOR MUNICIPAL AND INDUSTRIAL APPLICATIONS CONFERENCE

Walter E. Massey
Director, Argonne National Laboratory

Welcoming Address

On behalf of the Department of Energy and Argonne National Laboratory, I would like to welcome you to this conference on Energy Optimization of Water and Wastewater Management. The organizers of this conference, Donald Walter, Chief, Urban Waste and Municipal Systems Branch, Department of Energy, and Barbara Broomfield of Argonne National Laboratory, and all the others involved should take a great deal of pride in assembling a group of participants such as those represented here today. This conference, if not unique, is certainly rare, not only with respect to the very important topic which you will address, but also with respect to the representation of the various sectors involved. Among the participants are representatives of state and municipal governments, federal agencies, manufacturing companies, industry, consulting firms, research organizations, academic institutions and professional societies. This diverse and broad mix of participants attests to the seriousness, as well as the ubiquity, of the issues you will discuss over the next three and one-half days.

Water management and wastewater management may not yet be household words, but your presence here in such numbers, and from such different backgrounds, indicates that the topic is more important than may have been recognized by the general public, or by the professional community itself. One of the aims of this conference is to address this point by stimulating an awareness of the energy aspects of water/wastewater management, and to indicate that the problems and the potential solutions to these problems are common to both commercial/industrial and governmental/municipal systems.

The organizers of the conference intend that your discussions and presentations will help to determine the magnitude and the urgency of the energy issue in water/wastewater management, and will also lead to the development of appropriate strategies for promoting the implementation and application of energy technologies in this area.

I am sure I need not lecture this audience on the larger issues of the seriousness and urgency of the energy situation in general in this country. Each day's news brings a further reminder of this fact, and almost weekly it seems, new books, articles and studies appear pointing out the seriousness of our present situation, and projecting the harsh future we will face unless realistic steps are taken now to reverse the trend of ever increasing energy consumption in this country. Although some of these studies and books reach slightly different conclusions concerning the relative importance to be given to various sources of energy, and modes of energy production, they all seem to reach two general conclusions: First, that the nation should take a balanced approach to meeting its energy needs, and all sources--coal, nuclear, synfuels, solar--should be developed as expeditiously as possible within the constraints of safety and environmental concerns; and, second, they all

seem to agree that increased conservation is the single most important step to be taken in order to have a positive effect on our energy situation in the short term. The two books which seem to be the most popular on this subject--Energy Future by Daniel Yergin and others, and Energy in America's Future: The Choices Before Us by Samuel Schurr and others, would both support these general recommendations. I am using the term "conservation" here in a generic sense to mean decreased energy demand, and increased efficiency in energy use.

There is another recent publication I would like to bring to your attention which also addresses these issues, and reaches the same general conclusions, but which is brief, highly readable, and gives an excellent overview of all the alternatives available to the nation in responding to the energy problem. This is an article by Harvey Brooks and Jack Hollander in the Annual Review of Energy entitled United States Energy Alternatives to 2010 and Beyond: The CONAES Study. The CONAES Study--CONAES being an acronym for Committee on Nuclear and Alternative Energy Systems--is a study done by the National Academies of Science and Engineering in response to a request from ERDA, the predecessor agency to the Department of Energy. Although the study was commissioned in 1975 and has apparently been complete for some time now, it has yet to be officially released by the National Academies.

However, Harvey Brooks was Co-Chairman of the Committee and Jack Hollander was its Executive Director, so that the article should be an accurate representation of the Committee's findings. The Committee consisted of over 40 experts in various areas, and was divided into panels; each panel investigating a specific issue such as "Demand and Conservation," "Supply and Delivery," and "Risk and Impact." Various models based on differing assumptions of rates of economic growth and energy consumption were constructed and used to project scenarios from now to the year 2010.

The study notes that the energy situation is difficult for the public to come to grips with because (and I quote) "The energy problem is not a crisis in the traditional sense, analagous to a military national emergency. It is, rather, a gradually deteriorating situation that could erupt into crisis at any time; nonetheless, a situation on which it is difficult to focus sustained public attention because the symptoms of crisis appear only sporadically and unpredictably, as in the 1973 oil embargo, the 1977 U.S. natural gas shortage, and the 1979 political upheaval in Iran." (I should note that the article was written prior to the present Iranian-United States crisis.)

To put the present energy problem in perspective, Brooks and Hollander point out that the United States now consumes about one-third of the World's energy production, but comprises only 6% of the World's population. This energy consumption in 1976 was about 75 quads and, of this, almost three-fourths, or about 55 quads, was supplied by oil and natural gas. Almost half of the 33 quads of oil which was consumed in 1976 was imported. This dependence on foreign oil, and especially from politically volatile regions, is the root of the present energy problem. However, Brooks and Hollander assert that "The magnitude of the problem is reflected less in the current

situation than in the consequences of extrapolating current trends. For example, if domestic energy consumption were to continue growing at the 1950-1972 annual rate of 3.4%, an annual energy requirement of 240 quads would be reached in the year 2010. By contrast, domestic energy production in the year 2010, projected by the CONAES study under assumptions of a continuation of recent policies and production trends, would be less than 80 quads. The gap of 160 quads is over 10 times current imports and about as much as current world petroleum production."

Fortunately, none of the books and studies done recently, including the CONAES committee's, believe such a scenario as this is likely. The rate of energy consumption in the U.S. has already begun to decrease from the 1950-1972 average, and changes in policies are taking place. However, this projection does emphasize the critical role energy consumption plays in our energy future, and it graphically illustrates the seriousness of the consequences of not drastically changing our policies and practices.

The recommendations of the CONAES committee--as related by Brooks and Hollander--also support the general conclusions I elucidated earlier. They conclude that:

> "The Nation's policy should be to develop a variety of options as a base for the evaluation of a combination of energy supply and end-use technologies, where mix can change continuously in response to new knowledge...," and that an effort should be made to "avoid entrapment in a technological monoculture."

This argument for diversity, as I noted earlier, is a theme which occurs in practically all of the serious studies of the energy problem. Diversity in energy sources and production modes can serve to maximize the possibility of the availability of energy for meeting future demands; and increased energy efficiency should be viewed as an "alternative energy source," for it clearly increases the availability of all other energy types.

Brooks and Hollander argue that "diversity is desirable, even at some sacrifice of economic efficiency, because a diversified energy system is more resilient, and a resilient system is more responsive to the unexpected: political events abroad, accidents, changes in public attitudes and the like.

The need for diversity, and the critical role to be played by energy conservation becomes apparent when it is realized that each available energy technology and energy source has some drawbacks, which contribute to uncertainties concerning its possible contribution to future energy supply. The potential environmental problems from an overly heavy reliance on coal have been noted in many studies and articles. The current public attitude towards nuclear energy, the debates about uranium supply, and the proliferation concerns surrounding the breeder reactor, all make the contributions of this technology much less certain than seemed apparent only five or six years ago. Although much progress is being made in solar energy development, unless drastic changes are made in policies of government intervention in the market place, few expect major contributions to U.S. energy supply in this century from this technology.

All of this only reinforces the need to seek ways to reduce energy demand and increase energy efficiency. The major conclusion of the CONAES study is that reduction of energy demand, and improvement of energy efficiency be accorded the highest priority in U.S. energy policy.

The work which you, the participants in this conference, are doing to optimize energy utilization in water and wastewater management is a critical component in the nation's effort to decrease demand and improve efficiency. If over the next few days you can make a beginning towards this effort, then this conference will have achieved its goals.

Again, Welcome, and I hope you have a stimulating and productive conference.

A DEPARTMENT OF ENERGY PERSPECTIVE ON WATER AND WASTEWATER TREATMENT

Charlotte Rines
Project Manager
Urban Waste and Municipal Systems Branch
U.S. Department of Energy

Certainly there has never been a period in the history of our country when it was more appropriate to have an energy conference, nor has there been a more appropriate time for people involved in water and wastewater treatment to gather to share information on ways to carry out water treatment processes more efficiently, using less costly technologies and saving energy.

This conference is intended to focus on more than efficient processes; it is also directed to the critical area of energy -- reducing energy use, recovering energy, and creating energy through water and wastewater treatment.

Through continuing research and developing technologies, the problems of water and wastewater treatment facilities can become part of the answer to a critical energy shortage the country now faces.

The municipalities and companies you represent have long recognized the problems, importance, and magnitude of water and wastewater treatment. However, we are now challenged with turning those problems into answers.

In meeting this challenge, the Department of Energy is developing a program to reduce energy consumption in existing and planned water and wastewater treatment facilities. The need for a strong program in this area is obvious. For instance:

- Treating municipal wastewater required nearly 40 million barrels of oil in 1978. We expect this will more than double over the next 20 years.

- The increase in yearly electricity and fuel consumption between now and the year 2000 will mean an additional cost of one billion dollars which municipal governments must pay to meet water and wastewater management obligations.

- Energy requirements for sewage treatment are increasing much faster than the national energy consumption average. For the United States as a whole, the energy required for sewage treatment is expected to increase 109% between 1977 and 1990, a significantly higher rate than the 44% increase expected in national energy consumption.

- The chemicals used in treatment processes are becoming more expensive, and supplies are limited. In addition, the production of these chemicals is often an energy-intensive process.

The problems of water and wastewater treatment are compounded by the fact that the processes are frequently dependent on petrochemicals and petrofuels.

The Department of Energy program in water and wastewater treatment seeks to reduce energy consumption and consequently costs through developing energy-saving technologies to use in the construction and operation of treatment plants. DOE establishes policy guidelines, encourages treatment plants to use energy-saving procedures, and makes information readily available about conservation of energy and energy recovery in wastewater and water management.

The near-term objective of the DOE program is to delineate and encourage the use of energy-conservative treatment technologies and energy recovery systems for wastewater/water treatment. The long-term objectives are to develop new technologies, modify existing processes, and integrate innovative concepts to minimize energy requirements of wastewater treatment.

The interests of the Department of Energy in water and wastewater intersect with the activities of other federal agencies. In order to avoid duplication of efforts and accentuate the program objectives, coordination with other federal agencies is important.

Generally, objectives for research, development, and demonstration projects now supported by DOE include the reduction of energy required to treat water and wastewater through studies of anaerobic filter applications, powdered activated carbon in digestion, aerobic-anaerobic processes, sludge management, and the utilization of unconventional and renewable sources of energy, such as solar and low-head hydropower. Also underway are studies to develop and improve methods to recover and utilize energy in water and wastewater systems; examples of such methods include heat recovery, utilization of digester gas, and thermal processing of sludge. In addition, the integration of new treatment technologies must be examined.

Areas marked as important for future research and development are: sludge dewatering, improvements in the efficiency and reliability of anaerobic digestion, alternative processes for upgrading energy recovery from sludge, biological systems research, on-site and small-scale technology developments, strategies for water conservation and wastewater reuse to reduce energy consumption, and application of renewable energy sources such as solar, wind, heat exchange, and low-head hydropower.

I'd like to briefly outline some of the projects DOE is currently sponsoring.

- A project at Oak Ridge National Laboratory, ANFLOW, involves anaerobic digestion in a treatment system. A 5000 gallons-per-day wastewater treatment pilot plant has operated for two years, and a scale-up facility to handle 50,000 gallons-per-day is near the construction stage. This system has proved to use less energy, produce less sludge, and result in methane which can be tapped as an energy source.

- A project at Battelle Memorial Institute has evaluated the effectiveness of adding powdered activated carbon (PAC) to enhance sludge digestion. Preliminary results indicate that stressed digesters benefit significantly from the addition of PAC at concentrations equal to 5% of the total solids in sludge. It is estimated that about 20% of anaerobic digesters could benefit from this technology.

- DOE has joined EPA and NASA to support the Reedy Creek Improvement District at Lake Buena Vista, Florida, in the demonstration of an environmentally acceptable water hyacinth wastewater treatment system designed to recycle water and nutrients.

- An outline has been completed and work is well underway on an energy conservation manual. Jointly sponsored with EPA, the manual will provide planners, designers, consultants, and other interested persons with the latest data on energy aspects of municipal wastewater treatment. This publication will emphasize the selection of suitable materials in the construction of production facilities, as well as operation and maintenance. Information will be included on the identification of energy consumption in wastewater treatment operations and construction of typical plants of various sizes.

- A study by Gloucester County Board of Chosen Freeholders in conjunction with Gilbert Associates will evaluate the technical and economic aspects of alternative methods to generate steam and electricity using solid and liquid waste as a primary energy source.

- Battelle Columbus Laboratories is also carrying out research that involves the use of an existing pilot plant to determine the technical feasibility of generating steam from combined wastes.

- A new sludge disposal system is being tested by the City of Harrisburg, Pennsylvania to determine the energy efficiency and conservation potential of the sludge drying process and to assess the effects of incineration of the sewage sludge on energy recovery and output at the existing waterwall incinerator.

- The Public Service Electric and Gas Research Corporation is assessing the use of sewage sludge as a fuel to provide supplemental energy for oil- and coal-fired utility boilers.

- Systems Technology Corporation is conducting a project which involves enzymatic hydrolysis of digester sludge to determine prospects for deriving energy from sludge residues.

- Columbia University is developing, analyzing, and testing membrane technology for sludge dewatering and for the production of organic acids and ammonia.

- Grumman Eco-systems Corporation is completing a technical, economic, and institutional analysis of sewage sludge co-disposal with solid waste. The primary objective of this study is to provide information on the operation and performance of co-disposal systems.

- Finally, a joint DOE/EPA project in Wilton, Maine, involves a passive building design, solar heaters for digesters, storage of digester gas for use as supplemental fuel in engine-generator sets, heat recovery from engine exhaust, and low-energy secondary treatment.

Of course, a major thrust of the program is to stimulate the exchange of information and technology in order to accelerate energy conservation activities. We would thus be remiss if we did not carry out a program of information or technology transfer. Our technology transfer program activities include conducting conferences such as this and smaller workshops aimed at specific groups and interests, publishing handbooks and newsletters, and providing a clearinghouse to handle other individual information needs.

Although the types of problems and experiences encountered in water and wastewater treatment may differ greatly across the country, there are two unifying problems -- costs and energy consumption. Water and wastewater treatment is a national problem and will continue to be a national concern.

I have outlined a program that may supply some answers to cost escalation and energy consumption. But even though possible solutions may originate in laboratories, be tested in pilot programs, and be supported and promoted by agencies in Washington, these problems will ultimately have to be sorted out and corrected at the level where people live and where decisions are made -- by you and by the people you work and deal with.

And that, basically, is what we hope you and the municipalities and companies you represent will gain through this conference and through other projects of DOE -- methods you can use and action you can take to turn water and wastewater treatment problems into answers.

ENERGY ASPECTS OF WATER REUSE

Robert S. Madancy
Office of Water Research and Technology
U. S. Department of Interior

The Office of Water Research and Technology (OWRT) of the U. S. Department of Interior conducts a broad water resources research, development and demonstration program under the provisions of Public Law 95-467, The Water Research and Development Act of 1978. The Act also authorizes a Water Resources Research and Technology Institute at a land grant College or University in each of the 50 states plus the District of Columbia, the Virgin Islands, Puerto Rico and Guam. The State Institutes are intended to serve as a focal point for water resources research and development within their state and are in fact conducting programs addressing a wide array of state and regional water management problems.

In addition to supporting the state institute programs, the Office of Water Research and Technology is authorized to conduct water resources research and development programs concerning water related problems of national interest. These programs currently include water reuse, water conservation, water problems of urbanizing areas, and saline water conversion, with additional efforts in groundwater management and legal, institutional and economic arrangements for water resources management. Many of these programs include significant energy considerations. Inasmuch as this conference is concerned with energy aspects of water and wastewater management, this paper will review one of the OWRT Research and Development programs dealing with both water supply and wastewater disposal, i.e., the Water Reuse Research and Development Program.

Surface water and groundwater supplies in major portions of the West and Midwest are either currently inadequate or are rapidly becoming inadequate to meet water demands. Localized instances of groundwater depletion or inadequate surface water supplies now exist in all of the 21 Water Resources Regions of the country. Groundwater depletions are resulting in exhausting water sources, diminishing stream flows, subsidence, and salt water intrusion. Surface water supplies in some locations will be inadequate for domestic uses, or inadequate for support of offstream industry, energy development and generation, irrigation or instream recreation. In some areas increased demands are expected to create conflicts between instream and offstream uses.

The total gross water usage in the United States is projected to increase from about 500 billion gallons per day (bgd) in 1975 to approximately 1,200 bgd in the year 2000. It appears obvious that water reuse and recycling, and increases in water use efficiencies will play key roles in meeting these increased water demands. Renovation of wastewater discharges for reuse and recycling appears to have major potential for supplementing fresh water supplies to meet municipal, industrial, and agricultural water demands. National fresh water withdrawals in 1975 are shown in Figure 1.

The total of 362 bgd withdrawals in 1975 was augmented by 139 bgd of reused or recycled water for a total gross use of 501 bgd. The reuse/recycle quantity is now projected to increase to 869 bgd by the year 2000. This indicates that more than 70 per cent of the gross amount of water used in the country may be reused (wastewater withdrawn by a user other than the discharge) or recycled (internal use by the original user prior to discharge). Over 95 per cent of the reused or recycled water is expected to be used in the steam electric and manufacturing industries. These projections indicate that fresh water supplied to manufacturing industries in the year 2000 will be recycled over 17 times, on a national average, before it is discharged (Figure 2). Seven major industries,(Primary Metals, Chemicals, Paper, Petroleum and Coal, Food, Textile and Transportation Equipment) currently account for more than 90 per cent of the total fresh water withdrawals for manufacturing industries.

The potential exists for increasing total water recycling in the seven major water-using industries alone, from about 53 bgd in 1975 to more than 290 bgd in the year 2000. Clearly the overall needs and potential for water reuse and recycling are great. Recent Federal legislation is having a significant impact on reuse and recycling as well as the increasing competition for available fresh water supplies. The Safe Drinking Water Act (P.L. 93-523) will indirectly affect the quality of wastewater discharges into streams used for public potable water supplies. Public Law 92-500 and Public Law 95-217 (The Clean Water Act of 1977) will also have impacts on wastewater reuse. These Acts will improve the quality of industrial wastewater discharges thereby reducing the incremental costs for renovation and recycling. The regulations implementing the 1977 Act clearly state that its provisions are intended to achieve greater use of systems which reclaim or reuse wastewater, productively recycle wastewater constituents and otherwise eliminate the discharge of pollutants, or recover energy.

The OWRT Reuse Program is a comprehensive one dealing with both technological and non-technological barriers to reuse. A substantial portion of the current program consists of research and development investigations of treatment processes and systems. The three basic categories of treatment processes currently being investigated include membrane processes, adsorption and oxidation processes (including ion-exchange) and new innovative processes. Membrane processes are being tested on municipal wastewaters as well as a variety of industrial process wastewaters including those in the food processing, paper, primary metals, chemical, and textile industries. Adsorption/oxidation processes such as biologically extended activated carbon (BAC) are being tested on food processing and petroleum refining wastewaters.

The OWRT Program also includes a significant amount of research in the social sciences aspects of water reuse. Social, legal, economic and institutional barriers, in many areas of the country, present greater obstacles to reuse than the need for adequate treatment technology. Current projects are analyzing the impact of Federal and State water allocation laws and regulations, the impact of water quality controls, regional water supply problems, the roles of various water agencies, the requirements for salinity control and other "non-hardware" considerations of water reuse.

There are many treatment systems that may be used in water reuse/recycle applications. OWRT has recently completed a major study to evaluate existing treatment systems. Twenty-four treatment systems resulting in 13 levels of treatment were evaluated as shown in Figure 3. Energy demands - both electricity and fuel will play a significant role in the types of treatment systems used in reuse applications. In many instances energy demands may be the deciding factors in determining reuse/recycle feasibility. Approximate energy demands for both power and fuel are shown for the various levels of reuse treatment systems in Figures 4 and 5. Secondary energy requirements, associated with production and transportation of treatment chemicals, have significant impact on some of the treatment levels as shown in Figures 6 and 7. Approximate energy requirements for specific chemicals are shown in Figure 8.

Summaries of potential reuse/recycle quantities and associated estimated power and fuel requirements are shown in Figures 9 and 10, respectively. Although these projections have been made based upon approximate assumptions of treatment requirements maximum potential reuse/recycle, and assumed typical conditions, they nonetheless indicate that energy requirements could be significant. Power demand could increase from about 100 billion Kwh/yr currently to about 700 billion Kwh/yr in the year 2000. The corresponding increase in fuel demands could be from about 700,000 Bil Btu/yr to more than 4,000,000.

It appears therefore that the potential sharp increase in water reuse/recycle during the next 20 years could carry with it a significant national increase in energy demands.

NATIONAL FRESH WATER WITHDRAWALS

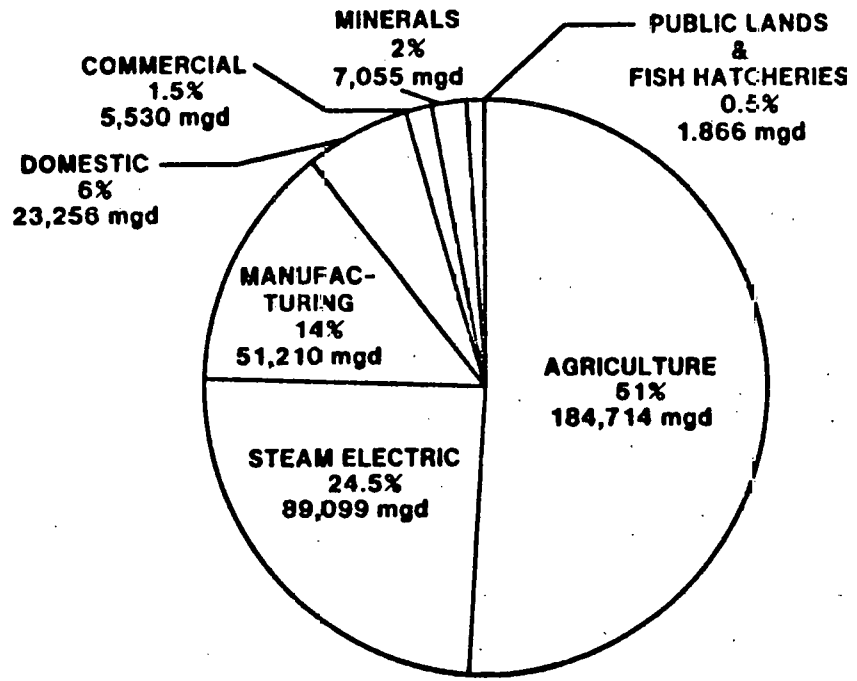


FIGURE 1

RECYCLE RATES IN U.S. MANUFACTURING INDUSTRIES

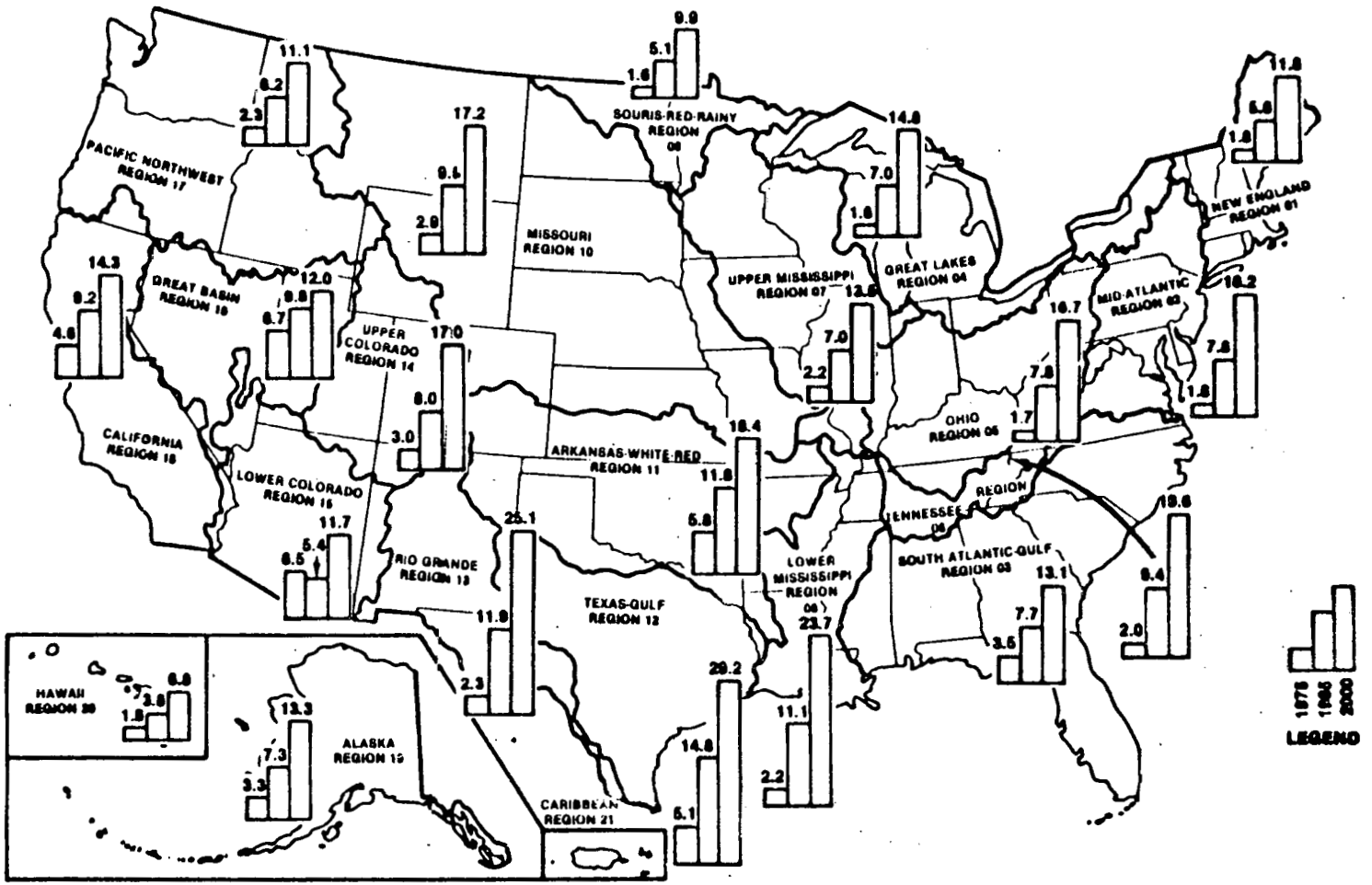


FIGURE 2

EVALUATION OF TREATMENT TECHNOLOGY

TREATMENT LEVEL	TREATMENT SYSTEM
1A	ACTIVATED SLUDGE
1B	TRICKLING FILTER
1C	ROTATING BIOLOGICAL CONTACTORS
2A*	2-STAGE NITRIFICATION
2B	ROTATING BIOLOGICAL CONTACTORS
2C	EXTENDED AERATION
3A	NITRIFICATION-DENITRIFICATION
3B	SELECTIVE ION EXCHANGE
4	FILTRATION OF SECONDARY EFFLUENT
5A	ALUM ADDED TO AERATION BASIN
5B	FERRIC CHLORIDE ADDED TO PRIMARY
5C	TERTIARY LIME TREATMENT
6A	TERTIARY LIME, NITRIFIED EFFLUENT
6B	TERTIARY LIME PLUS ION EXCHANGE
7	CARBON ADSORPTION, FILTERED SECONDARY EFFLUENT
8	CARBON, TERTIARY LIME EFFLUENT
9	CARBON, TERTIARY LIME, NITRIFIED EFFLUENT
10	CARBON, TERTIARY LIME, ION EXCHANGE
11	REVERSE OSMOSIS OF AWT EFFLUENT
12A	PHYSICAL-CHEMICAL SYSTEM, LIME
12B	PHYSICAL-CHEMICAL SYSTEM, FERRIC CHLORIDE
13A	IRRIGATION
13B	INFILTRATION-PERCOLATION
13C	OVERLAND FLOW

FIGURE 3

REUSE/RECYCLE SYSTEMS ENERGY DEMANDS — POWER

TREATMENT LEVEL	*TOTAL APPROX. ENERGY DEMAND (Million KWH/YR)		
	1 MGD	10 MGD	50 MGD
1	.5-.7	4-7	18-33
2	.6-1.2	4-12	31-57
3	.9-1.2	9-10	45-46
4	.8	6.5	31
5	.9-1.1	7.5-9.0	36-43
6	1.0	8.0	38-39
7	1.0	7.3	34
8	1.1	8.6	39
9	1.2	8.8	41
10	1.1	9.1	42
11	4.3	37	175
12	1.3	9.7-10.7	45-50
13	.5-.7	4.8-7.1	24-36

* Includes primary + secondary energy demands

FIGURE 4

REUSE/RECYCLE SYSTEMS ENERGY DEMANDS — FUEL

TREATMENT LEVEL	*FUEL (1000 MIL BTU/YR)		
	1 MGD	10 MGD	50 MGD
1	2.1-2.8	21-28	106-142
2	2.1-2.8	21-28	106-142
3	3.0-7.0	30-70	152-355
4	2.7	28	142
5	0.2-4.6	46-80	224-335
6	4.6-7.2	45-82	218-335
7	9.2	46	220
8	13.5	98	539
9	11.1	92	297
10	13.7	100	445
11	30.0	113	513
12	23-27	100-126	477-643
13	2	16-22	82-111

* Includes primary + secondary energy demands

FIGURE 5

REUSE/RECYCLE SYSTEMS ENERGY DEMANDS

SECONDARY ENERGY POWER REQUIREMENTS (1000 KWH/YR)

TREATMENT LEVEL	PLANT CAPACITY 1 MGD	10 MGD	50 MGD
1-5A 5C-10	36	367	1,836
5B	211	2,119	10,600
11	134	1,339	6,696
12A	241	2,400	12,000
12B	416	4,160	20,800
13	31	304	1,526

FIGURE 6

REUSE/RECYCLE SYSTEMS ENERGY DEMANDS

SECONDARY ENERGY FUEL REQUIREMENTS (MIL BTU/YR)

TREATMENT LEVELS	PLANT CAPACITY 1 MGD	10 MGD	50 MGD
1-2	3	29	144
3A	4,267	42,669	213,344
3B	212	2,114	10,569
4	4	34	169
5A	708	7,076	35,376
5B	38	379	1,896
5C	4,251	34,370	171,834
6A	1,871	10,679	53,365
6B	4,459	36,450	182,234
7	6,492	18,044	79,220
8	10,740	40,385	201,910
9	8,360	16,682	83,422
10	10,948	42,465	212,310
11	11,482	55,935	279,660
12A	26,823	52,541	262,688
12B	22,819	20,643	103,212
13	2	22	111

FIGURE 7

REUSE/RECYCLE SYSTEMS ENERGY DEMANDS

SECONDARY ENERGY REQUIREMENTS

	PRODUCTION	TRANSPORTATION
Activated Carbon	102 mil BTU/ton	1.12 mil BTU/ton
Alum	2	0.20
Lime	5.5	0.10
Methanol	36	1.44
Polymer	3	0.29
Sodium Chloride	4	0.16
Sulfuric Acid	1.5	0.29
Chlorine	2 KWH/lb	0.29 KWH/lb
Ferric Chloride	0.5	0.20
Sulfur Dioxide	0.2	0.05

FIGURE 8

POTENTIAL REUSE/RECYCLE SUMMARY (BGD)

	1975	2000
Steam Electric	57	517
Manufacturing Industries	61	316
Minerals Industries	21	32
Municipal	.8	4.8
	139.8	869.8

FIGURE 9

APPROX. POTENTIAL REUSE/RECYCLE ENERGY DEMANDS

	1975		2000	
	Power (MIL KWH/YR)	Fuel (BIL BTU/YR)	Power (MIL KWH/YR)	Fuel (BIL BTU/YR)
Steam Electric	46,000	253,000-385,000	412,000	2,266,000-3,450,000
Manufacturing Industries	48,000	240,000-360,000	256,000	1,280,000-1,920,000
Minerals Industries	16,000	84,000-168,000	25,000	128,000-256,000
Municipal	100	300-700	500	1,500-3,500

FIGURE 10

THE WATER INDUSTRY'S APPROACH TO WATER CONSERVATION

Jerome B. Gilbert
Vice President, Brown and Caldwell
President-Elect, American Water Works Association

We are seeing a basic change in public attitudes. Conservation has become a very popular topic. Although most people are beginning to believe that careful use of resources is desirable and beneficial, support and enthusiasm vary from place to place depending on local factors. Water users are not yet unanimous in their willingness to sacrifice; leadership in business and government is not yet clear about priorities for conservation.

On the whole, though, there is an increasingly positive attitude, which is the necessary foundation for any significant program to husband any valuable resource--water, oil, gas, electricity....and energy. Without the public's understanding, acceptance and cooperation, little of a lasting nature can be accomplished.

The American Water Works Association defines conservation as "effective means to prevent and minimize waste and to promote wise use." We don't think of conservation in negative terms, but rather in the positive "wise-use" way that encourages cooperation. We've distributed millions of water conservation booklets and have created award-winning television public service spots on this basic theme.

While this sort of public relations activity is very broadly based, the fact remains the maximum conservation effect can be achieved by working with relatively few water utilities.

The drinking water industry includes some 60,000 public water systems, of which 63 percent are investor owned and 37 percent government owned. The bulk of the investor utilities are extremely small, typically serving less than 2,500 people. Although more than 80 percent of the country's water systems fit this less-than-2,500 category, they serve only about 8 percent of the public. At

the other end of the scale, the largest one percent of our water systems, which serve at least 50,000 people, handle some 63 percent of the total population.

So you can see that concentrating conservation efforts among a relatively few systems promises benefits to a very large percentage of the population. Smaller systems shouldn't be ignored, of course, but the big ones are our best bet for rapid, meaningful results.

There are a number of basic programs in our industry that achieve conservation goals by simply emphasizing good management practices. For instance, metering the water provided to customers has several advantages. The most obvious is that customers tend to pay more attention to how much they use when the charge is based on that measured quantity instead of a flat rate. They conserve because it's in their own best interests.

We estimate about 83 percent of the government-owned water systems and 73 percent of the investor-owned systems use meters.

Accurate metering also helps a community determine how much water fails to reach customers; in other words, how much is being lost somewhere in the distribution system. We call it "unaccounted-for" water. Detection of losses can lead to the development of effective leak detection programs that not only reduce the cost of water production, but also support timely maintenance of the system.

It is not unusual for water systems to lose as much as 15 percent of their total production to leaks and other unaccounted-for losses. In some cities, where the pipelines are old and where maintenance has had low priority, the leakage losses may exceed 50 percent.

The utter waste of energy to treat and distribute water that never reaches its destination is obvious. But funds available to

communities remain limited. And drinking water, so long as it appears at the tap when a consumer wants it, remains a relatively low priority item in most community budgets.

The only time people really become conscious of water is during sustained periods of drought, such as much of the nation endured in 1976 and 1977. But the public's willingness to cooperate wholeheartedly when it perceives a real emergency is little short of amazing. For instance, in Marin County just north of San Francisco, citizens cut home water usage by 40 to 60 percent. They were encouraged by extremely high rates for higher use, but the accomplishment was largely a case of community self-discipline in the face of overwhelmingly obvious need.

In San Francisco itself, major use reductions were mandated, complete with severe punitive measures for failure to comply; measures that included flow restrictors in service pipelines; billing penalties; and even termination of service. The public response exceeded the city's goal of a 25 percent use reduction, which led to a need for higher rates. This resulted in nationwide publicity on the Johnny Carson show and other media about having to pay more for the privilege of using less.

In Denver, where construction of new treatment facilities was delayed for several years, successful measures to reduce peak demand have included public education and moderately severe lawn-sprinkling restrictions. Washington Suburban Sanitation Commission near the nation's capitol has distributed free shower flow-reduction devices and toilet tank dams.

Increasingly, water rates are being modified to affect water use and demand. So-called inverted rate structures charge heavy users more than people who use less water. But naturally, without 100 percent metering, most creative rate making won't be entirely successful.

The energy saving aspects of water conservation should be clearly defined. First, energy saving in the home is primarily a factor of having to heat less water. Toilet tank dams and lawn sprinkling bans don't save the homeowner energy because they don't save hot water. Second, at the production end, the major energy consumption points are treatment and distribution. Let's translate this into dollars and cents.

A few months ago, a survey of Los Angeles and some parts of Nevada indicated that for $100 expenditure in shower flow controls, faucet aerators, and hot-water-line insulation, a homeowner could expect to save about $8 a year if he had gas water heating and $22 a year with electric water heating. The actual amount of hot water not used would be some 13 gallons a day per home or about 5,000 gallons a year.

For the water system itself, a projection of typical costs of production indicate about 4.4 cents per thousand gallons was a reasonable energy cost for treatment and distribution in 1976--about 15 percent of total system operating cost. In 10 years (1986), the projection saw energy-related expense rising to 27 percent of the total, or about 13.2 cents a thousand gallons. And if treatment has to be modified to include such energy-intensive techniques as granular activated carbon filtration, the energy cost could be 30 percent of the total.

In other words, the cost of water delivered to the customer can be expected to increase 60 percent by 1986, while the energy component of that cost may increase three fold.

What about immediate savings? The St. Louis Water Company estimated last summer that it might reasonably expect to cut its energy requirements through good management by some 20 percent. However, since the firm uses only about 3 percent of the energy in the St. Louis area, a 20 percent reduction would represent a saving of just 6/10ths of 1 percent of the area's total energy consumption.

Our association is developing a Water Conservation Handbook that will bring together in one place the activities, programs, techniques, and practices of effective conservation by water on both an emergency and long-term basis, and for a variety of water utility situations. We expect the book to be off the press by late 1980.

The reason for such diversity of approach in the book is the great diversity of water supply situations throughout the United States and Canada. For instance, in the arid West and Southwest water is always in short supply or facing the threat of short supply. But in the humid East, around the Great Lakes and along major rivers, water is readily available and can be used at virtually whatever rate the community desires.

It is simply a fact of life that what works in one location won't necessarily work in another. There is no single program or policy that will cover all conditions.

In addition to geographic differences, our new handbook will address conservation variations inherent in different types of water supplies. Distribution of water that comes mostly from high ground can utilize gravity and is far more energy efficient, for instance, than water that must be pumped several times from source to treatment to storage to customer. In another case, salt water intrusion that is due, for instance, to overpumping of a coastal aquifer may lead to energy-intensive desalination systems. The need for pure drinking water may exceed the need to conserve energy in a case like that.

Adding to the diversity of location and source is an immense diversity of customer demand. There was a study by Johns Hopkins University nearly 17 years ago that explored the reasons behind different levels of customer demand for water during different times of day, week, and year. The goal, of course, was to find ways of matching peak and off-peak power requirements for pumping, treatment, and storage with peak consumer demands for water

service. Major potential savings in energy and the need for new facilities were clearly indicated.

The study was limited, but it showed great promise as a significant management tool if its investigation could be extended throughout the nation. The American Water Works Association Research Foundation has spearheaded an effort to revive and expand the Johns Hopkins Study, but unfortunately with little success. We had set aside $90,000 to support the effort but couldn't find enough other backers. It doesn't have high enough priority yet among water utilities and other organizations in the field, including the federal government.

An area where our Research Foundation has enjoyed good response is its monthly newsletter "Municipal Wastewater Reuse News." This 24-page publication goes to 3,900 subscribers who find its reports of activity in the reuse field an invaluable service.

Last July, we gave testimony in Washington in which we tried to make clear our dedication to the principle of water conservation, as well as our conviction that a pragmatic and flexible approach --not a simplistic search for a cure-all--was the only sensible way to proceed. We pointed out that measurable energy savings can only be achieved when a combination of practices is implemented; and that all conservation or energy-saving programs do not apply to all water systems. We especially emphasized (as we have here today) the great diversity of the 60,000 public water supply systems extant--their variations in size, age, source, treatment, and energy requirements.

We recommend that the federal role, at the outset, be one of defining energy conservation needs and setting appropriate goals, with the assistance of representatives of the water and power industries. We wanted to avoid the tendency to launch massive and costly programs without first establishing a sensible target that reasonable people can agree with.

We know from experience that communities will conserve water when they're convinced there's a good sound reason for it. We know companies will practice conservation when they recognize it's in their own best interests. And we know free-wheeling, native ingenuity can often produce solutions where a straightjacket of regulations and requirements becomes counter-productive.

Current events have accomplished the most difficult task, capturing the public's attention and beginning to convince everyone that a real energy problem actually does exist. Close coordination and cooperation on local, state, regional, and national levels is the only sensible road to travel now. It's a road that people in the water supply industry are firmly committed to.

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AREAS OF ACTIVITY OF THE AMERICAN PUBLIC WORKS ASSOCIATION

Stuart H. Brehm, Jr.
Executive Director
Sewerage and Water Board of New Orleans

First, let me thank the U.S. Department of Energy, the Urban Wastes and Municipal Systems, as well as the Argonne National Laboratory, for inviting the American Public Works Association (APWA) to present those areas of APWA activity that are oriented to energy conservation in public works. The growing need for energy conservation and the resulting economic benefits have long been the objects of concerted efforts by APWA. APWA currently has a task force appointed by the board of directors to consider all aspects of energy conservation as they affect public works activities. This task force is composed of representatives from each of APWA's institutes for professional development of association members. Through this structure, the task force is able to address itself to all aspects of public works activities. In particular, through the institute of water resources, it can address the matter of energy optimization of water and wastewater management.

As a manager for an organization responsible for water treatment, water distribution, and wastewater treatment and collection, I can assure you that this is an area of major significance in utilization of energy. I can cite one instance that will give you an idea of the magnitude of the problem. For our operations here in New Orleans, in particular for services of sewer, water, and storm water drainage, our energy cost in 1972 was $660,000. In 1979, our energy cost will run in excess of $5 million. Please bear in mind that these additional higher costs came about after we made modifications to our power system that brought about certain economies -- otherwise, the 1979 cost would have exceeded the $5 million figure.

As a further thought, this increased cost for energy does not include the added energy costs that we will experience when we commence the secondary treatment of sewage at our East Bank Sewage Treatment Plant, which is anticipated for the beginning of next year, as well as any additional energy costs resulting from changes in water treatment methods that would be mandated by the U.S. Environmental Protection Agency (EPA). So, you can see from a local standpoint what an acute interest APWA has in energy optimization.

In addition to the task force, APWA, representing each of the APWA institutes, through its research foundation, has also developed a series of water pollution treatment devices that use hydraulic force rather than mechanical force for operation. Such devices are energy conservative and include equipment that treats combined sewer overflows, degrits, and provides primary wastewater treatment. These water pollution treatment devices have been field tested in several locations throughout the United States and are now being incorporated in treatment procedures in other cities.

As a further effort to provide for energy optimization, the APWA Research Foundation has developed manuals of practice on the detection and reduction of infiltration and inflow from sewers to reduce treatment needs and transportation costs through (pipelines) as well as to reduce

receiving water pollution. All of the manuals of practice, when carried out, provide not only for a better sewage operation, but also further energy optimization.

Another arm of the APWA is its Education Foundation, which regularly conducts and presents two-day workshops on various public works aspects throughout the United States. Some of these workshops are directly energy-oriented. The workshop on equipment management, for example, is designed to provide instruction on effective operation and maintenance of vehicle fleets, including fuel conservation and control. Other workshops are conducted on sewer system maintenance to provide for the control of infiltration, inflow, and the best maintenance techniques.

Although not many people realize that building management is a major item of public works, this is another area where the APWA Education Foundation provides two-day workshops on how best to manage these physical facilities. Within each of the individual institute programs there is a focus on energy reduction through technical programs at the annual national meeting of the association, held in the fall of each year.

With the growing shortage of energy and the escalating costs of this energy, it becomes incumbent upon the public works official to provide old-and-forgotten or new methods of energy conservation and optimization if the urban areas of this nation are to survive. Here in New Orleans, we are now exploring the feasibility of co-disposal of solid wastes and sewage sludge in such a manner that the fuel requirements for the incineration of sewage sludge can be satisfied through the use of shredded solid waste and at the same time produce a heat recovery facility that can be utilized to provide the necessary energy to operate the total facility.

I recently returned from a trip to Harrisburg, Penn., to review that facility. I was pleased with what I saw. At the same time, I visited Memphis, Tenn., to review the new plants that are proposed there. Papers on these facilities will be presented at this conference. The procedures outlined in these papers either in their entirety or in part, have been demonstrated in pilot studies and pilot plants in various cities throughout the United States, and are highly innovative and encouraging. In some cities, the process has been used in field operations, either completely or in part. With the growing energy cost, it is becoming more apparent that the initial high capital cost for construction of such a facility would be offset by the savings from subsequent operation over the time required to amortize a capital outlay. This technique is relatively new; it has been in operation for only about ten years.

Many of the facilities currently constructed for such co-disposal heat recovery are actually second and in some cases third generation models, while all of the kinks and problems of the first generation model have not been ironed out. From the studies that are available today, we have reached certain conclusions. The first of these conclusions is that this type of co-disposal heat recovery facility is an engineeringly feasible facility. The second conclusion is that the efficiency of such an operation is proportional to the magnitude of the operation, i.e., the smaller the operation the less efficient and less energy optimized as opposed to the larger

operation providing better energy optimization. Precisely what we will do here in New Orleans has not been decided yet. A decision will probably not be reached until well into 1980, after we have had an opportunity to study the economics of the operation in detail. It is sufficient to say, however, that if solid waste disposal can be accomplished with sewage sludge disposal, while at the same time providing for heat recovery that can be utilized for further energy production, the process deserves very close scrutiny.

Most of the foregoing observations have been made as they relate to New Orleans today. The same comments are offered on behalf of APWA regarding energy optimization activities today. I believe that the national energy requirements, over and above the current energy requirements, that will be required to meet upcoming or existing regulations for water pollution control, water treatment, and air pollution are being entirely overlooked. To cite an example of my concern, let me point out that because of the proposed EPA energy regulations of February 1978 for water treatment under Public Law 93-523, some engineering studies were done on the cost of carbon regeneration that would be required for the then-proposed granular activated carbon filters for water treatment here in New Orleans. We calculated that the annual energy required for regeneration of the carbon, for utilizing the granule activated carbon filters, would be proportionate to the amount of fuel required to drive each registered automotive vehicle within the area parishes, of Orleans, Jefferson, St. Bernard and Plaguemines -- that is more than a million people for a distance of 5000 miles. This is only for one year's energy.

The water pollution control regulation is becoming more stringent for future wastewater discharges, in many instances requiring pretreatment by industry and tertiary treatment by municipalities. It can be anticipated that the energy requirements on a national basis for these additional requirements which are not in operation today, will be staggering. Again, it becomes apparent why APWA has such an interest in this area of energy optimization.

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ENERGY SAVINGS FOR WATER AND WASTEWATER TREATMENT

BY

*ALLEN CYWIN

U.S. EPA

ONE OF THE MAJOR FACTORS AFFECTING THE PURSUIT OF ENVIRONMENTAL QUALITY IN RECENT YEARS, HAS OF COURSE BEEN THE DEEPENING ENERGY CRISIS.

ENERGY CONSERVATION, WHICH HAD BEEN PRIMARILY OF INTEREST TO ENVIRONMENTALISTS AND CERTAIN ENERGY INTENSIVE INDUSTRIES IN THE PAST, IS NOW VERY MUCH A NATIONAL IMPERATIVE FOR EVERYONE IN THE UNITED STATES.

A RIGID LINKAGE BETWEEN ENERGY GROWTH AND ECONOMIC GROWTH IS NO LONGER ACCEPTED AS NECESSARY, AND THE IMPORTANCE OF ENERGY DEMAND MANAGEMENT IN FUTURE ENERGY PLANNING IS NOW BROADLY RECOGNIZED. THIS ETHIC IS IN HARMONY WITH ENVIRONMENTAL AND CONSERVATION PROGRAMS.

BEFORE WE TALK ABOUT ENERGY OPTIMIZATION OF WATER AND WASTEWATER MANAGEMENT FOR MUNICIPAL AND INDUSTRIAL APPLICATIONS -- LET US THINK OF ENERGY DEMAND.

THE WATER AND PARTICULARLY THE WASTEWATER INDUSTRY FACES A VERY SEVERE SITUATION WITH RESPECT TO ENERGY. WE MUST HANDLE THE LARGEST VOLUMES OF MATERIAL OF ANY INDUSTRY AND AT THE LOWEST OF COSTS. WE NOT ONLY ARE FACED WITH THE TRADITIONAL "ENERGY" ASPECTS FOR PUMPING, LIGHTING AND INCINERATION OR HAULING BUT ALSO ARE PLACING INCREASED DEMANDS IN SECONDARY ENERGY REQUIREMENTS BY VIRTUE OF THE VAST AMOUNTS OF MATERIALS AND CHEMICALS THAT OUR WATER INDUSTRY USES.

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PRESENTED AT THE "ENERGY OPTIMIZATION OF WATER AND WASTEWATER MANAGEMENT FOR MUNICIPAL & INDUSTRIAL APPLICATIONS CONFERENCE" - NEW ORLEANS, DEC. 10, 1979

THE PRIMARY ENERGY REQUIREMENTS FOR TYPICAL 10 MGD TREATMENT PLANTS AMOUNT TO APPROXIMATELY 5,000 KWH/DAY FOR SECONDARY TREATMENT AND WILL REQUIRE ABOUT 22,000 KWH/DAY FOR A SIMILAR 100 MGD PLANT. ORDERS OF MAGNITUDE HIGHER REQUIREMENTS (UP TO 15X) ARE REQUIRED FOR ADVANCED TREATMENT.

IN 1977, BATTELLE ESTIMATED THAT MOVING THE NATION, IN JUST THE MUNICIPAL AREA, FROM THE THEN STATUS QUO TO FULL SECONDARY TREATMENT, ACROSS THE NATION, WOULD DOUBLE THE ENERGY REQUIREMENTS FOR WASTEWATER TREATMENT TO APPROXIMATELY 26,000 BARRELS A DAY OF OIL. (18 MILLION BARRELS PER DAY WERE CONSUMED IN 1974).

*WE IN EPA ESTIMATED THAT THE INDUSTRIAL WASTEWATER EFFLUENT STANDARD REGULATIONS WOULD INCUR AN ENERGY PENALTY OF APPROXIMATELY 50,000 BARRELS A DAY FOR THE ELECTRIC POWER PLANT INDUSTRY AND 40,000 BARRELS A DAY FOR ALL OF THE OTHER INDUSTRIAL PLANTS. AS WE GET INTO THE NEXT ROUND OF PERMITS BASED ON A LARGER ARRAY OF TOXIC CONTAMINANT CONTROLS, THIS ESTIMATE SHOULD BE REVISED UPWARD.

ALTHOUGH WATER AND WASTEWATER TREATMENT PLANTS REPRESENT NOT THE MOST SIGNIFICANT AMOUNT OF NATIONAL ENERGY USE, STILL THE TREATMENT PROCESSES ARE WELL WORTH LOOKING INTO NOT ONLY FOR SAVINGS IN OIL BUT MOST IMPORTANTLY IN THE ANNUAL OPERATING BUDGETS OF PLANTS ALL OVER THE U.S.. MUNICIPALITIES (AND INDUSTRY) ARE STRAPPED FOR FUNDS TO KEEP THESE PLANTS OPERATING EFFICIENTLY AND ENERGY IS TAKING A BIGGER SLICE OF EACH YEAR'S BUDGET.

THE PRIMARY ENERGY CONSUMED FOR OPERATING WASTEWATER TREATMENT PLANTS INCLUDES HYDRAULIC ENERGY FOR PUMPING AIR AND WATER AND HEAT ENERGY USED BY PROCESSES SUCH AS ANAEROBIC DIGESTION OF SLUDGE OR FOR INCINERATION OF SLUDGE.

*"ENERGY IMPACTS OF WATER POLLUTION CONTROL", PROCEEDINGS OF THE AGRICULTURAL WASTE CONFERENCE OF CORNELL UNIVERSITY - APRIL 17, 1975 BY ALLEN CYWIN

THE CLEAN WATER ACT OF 1977 CONTAINS A NUMBER OF INNOVATIVE AND ALTERNATIVE TECHOLOGY PROVISIONS WHICH PROVIDES AN INCENTIVE TO AGGRESSIVELY STRIVE TO GAIN GREATER USE OF RECLAMATION, RECYCLING AND ENERGY CONSERVATION THROUGH THE CONSTRUCTION GRANTS PROGRAM. AMONG THE MORE IMPORTANT INNOVATIVE AND ALTERNATIVE TECHNOLOGY PROVISIONS ARE: (1)A 10% INCREASE IN THE FEDERAL SHARE FOR SUCH PROJECTS; (2) A SET-ASIDE OF FUNDS TO PAY FOR THE INCREASED FEDERAL SHARE; (3) A REQUIREMENT THAT INNOVATIVE AND ALTERNATIVE TECHNOLOGIES BE EVALUATED IN ALL STEP 1 CONSTRUCTION GRANT PROJECTS; (4) A 15% PREFERENCE IN THE COST-EFFECTIVENESS DETERMINATION; AND (5)ELIGIBILITY FOR 100% GRANTS SHOULD THE PROJECT FAIL AND NEED TO BE MODIFIED OR REPLACED.

AN ENERGY AUDIT SHOULD OF COURSE BE CONDUCTED WITHIN THE DESIGN AND EQUIPMENT SELECTION ALTERNATIVES FOR ALL WATER AND WASTEWATER FACILITIES! THE "CONSTRUCTION GRANTS REGULATIONS AND PROCEDURES" REQUIRES THAT "GRANTEES MUST PARTICIPATE IN THE NATIONAL ENERGY CONSERVATION PROGRAM BY FOSTERING, PROMOTING AND ACHIEVING ENERGY CONSERVATION IN THEIR GRANT PROGRAMS. GRANTEES MUST UTILIZE TO THE MAXIMUM PRACTICAL EXTENT THE MOST ENERGY - EFFICIENT EQUIPMENT MATERIALS AND CONSTRUCTION AND OPERATING PROCEDURES AVAILABLE."

ALTERNATIVE TECHNOLOGIES INCLUDE LAND TREATMENT OF EFFLUENT, BENEFICIAL UTILIZATION OF SLUDGES, ENERGY RECOVERY FROM SLUDGE PROCESSING AND ONSITE TREATMENT SYSTEMS. INNOVATIVE TECHNOLOGIES CAN INCLUDE RECLAMATION, RECYCLING AND RECOVERY OF WASTEWATER, IT'S CONSTITUENTS AND ENERGY. TO DATE A NUMBER OF PROJECTS FUNDED UNDER THIS PROGRAM RELATE TO ENERGY AND SOLID WASTE CO-DISPOSAL, WITH EXTENSIVE HEAT RECOVERY AND UTILIZATION.

WITH RESPECT TO BOTH MUNICIPAL AND INDUSTRIAL WATER AND WASTEWATER PROCESSES, THE UTILIZATION OF SYSTEMS ANALYSIS PROCEDURES IN CONCEPTUAL PLANNING IS BASIC TO ENERGY EFFICIENT DESIGNS. CONSIDERATION MUST BE GIVEN TO THE FULL IMPACT OF EACH COMPONENT ON THE WHOLE WITH PROPER ASSESS-

MENT OF ALTERNATIVES, TO ACHIEVE A LOW COST AND LOW ENERGY PLANT.

*EVENTUALLY, ONE MIGHT BE ABLE TO TIE NUMEROUS UTILITY SERVICES TOGETHER. FOR EXAMPLE, SOURCES OF DRINKING WATER MIGHT FIRST BE USED FOR INDUSTRIAL COOLING PURPOSES AND THEN WHEN DISTRIBUTED THROUGH A CITY CAN SAVE ON HOME ENERGY, HOT WATER HEATING AND ANY RESIDUAL BTU'S CAN HELP IN THE WASTEWATER TREATMENT PROCESSES.

ONCE THE BASIC WATER AND WASTEWATER TREATMENT PROCESSES HAVE BEEN SELECTED, A DETAILED EVALUATION SHOULD BE MADE OF THE RELATIVE EFFICIENCY OF THE VARIOUS TYPES OF EQUIPMENT APPLICABLE TO EACH PROCESS. THERE CAN, FOR INSTANCE, BE A SIGNIFICANT DIFFERENCE IN THE TRANSFER EFFICIENCY OFFERED BY DIFFERENT TYPES OF AERATION EQUIPMENT. EVEN A SMALL DIFFERENCE CAN JUSTIFY CONSIDERABLE ADDITIONAL INVESTMENT.

**CONSIDERATION ALSO MUST BE GIVEN TO THE FULL RANGE OF OPERATING CONDITIONS LIKELY TO BE ENCOUNTERED DURING THE LIFETIME OF THE FACILITY, (NOT JUST PEAK OR EXTREME CONDITIONS) WITH ADEQUATE FLEXIBILITY BUILT IN TO EFFICIENTLY COPE WITH THE ENTIRE RANGE. IN CERTAIN INSTANCES, THIS CAN BE ACCOMPLISHED BY INSTALLING MORE BUT SMALLER ITEMS OF EQUIPMENT. IN OTHER CASES, PROVISION FOR MANUAL AND SOMETIMES AUTOMATIC TURNDOWN IS APPROPRIATE. THIS IS PARTICULARLY TRUE OF CONTINUOUS OPERATING ITEMS SUCH AS PUMPS, BLOWERS, AND AERATORS.

USE OF OXIDATION PONDS, FIXED MEDIA FILTRATION, ANAEROBIC DIGESTION AND LAND APPLICATION OF SLUDGE SHOULD BE ENCOURAGED WHERE THESE LESS ENERGY INTENSIVE SYSTEMS ARE CONSISTENT WITH THE BASIC OBJECTIVES OF THE NPDES PERMIT CONDITIONS.

OTHER ENERGY RELATED CONSIDERATIONS PERTINENT TO DESIGN OF WASTE WATER SYSTEMS INCLUDE THE FOLLOWING:

1. SOLAR ENERGY AND HEAT PUMP RECOVERY TECHNIQUES SHOULD BE

*PATENT GRANTED TO ALLEN CYWIN
**PAPER BY W.E. FOSTER, AUGUST 31, 1977 BEFORE ASIWPCA

USED WHERE PRACTICAL FOR SPACE CONDITIONING. THE PROSPECT THAT THE COST OF ENERGY WILL CONTINUE TO ESCALATE SHOULD BE CONSIDERED WHEN EVALUATING THESE TWO SYSTEMS.

2. CONSIDERATION SHOULD BE GIVEN TO REDUCED VENTILATION OF NONCRITICAL AREAS.
3. CONSTANT CAPACITY PUMPS SHOULD BE USED WHERE CONTINUOUS FLOW PUMPING IS NOT ACTUALLY REQUIRED. DESIGNERS NEED TO RECOGNIZE THAT THE OPERATING EFFICIENCY OF VARIABLE SPEED DRIVERS IS LOWER AT REDUCED SPEEDS.
4. FIRST STAGE ANAEROBIC DIGESTERS SHOULD BE MIXED. NOT ONLY DOES THIS DECREASE THE SIZE OF THE STRUCTURE BY REDUCING THE REQUIRED RETENTION TIME, BUT IT ASSURES MORE EFFICIENT BIOLOGICAL REDUCTION RESULTING IN HIGHER LEVELS OF GAS PRODUCTION.
5. PROVISION SHOULD BE MADE FOR STORAGE AND MAXIMUM UTILIZATION OF DIGESTER GAS. LIMITED IN-PLANT GENERATION OF ELECTRICITY ALSO MAY BE JUSTIFIED IN CERTAIN INSTANCES.
6. PROPER DESIGN OF THE HOLDING TANK IS CRITICAL TO EFFECTIVE CHEMICAL CONDITIONING OF SLUDGE. MANY OF THE CONVENTIONAL CONDITIONING TANKS NOW AVAILABLE ARE HIGHLY INEFFICIENT DEVICES, AT LEAST FOR USE WITH LIME AND FERRIC CHLORINE.
7. ALL POSSIBLE SOURCES OF IN-PLANT RECOVERY OR RECYCLE OF HEAT SHOULD BE FULLY EVALUATED. AN EXAMPLE IS THE RECOVERY OF WASTE HEAT FROM INCINERATION.
8. USE OF THERMAL DEODORIZATION EQUIPMENT SHOULD BE AVOIDED. OTHER MEANS OF DEODORIZATION SUCH AS CHEMICAL PACKED TOWERS AND ACTIVATED CARBON ARE MUCH LESS ENERGY INTENSIVE.

OPERATIONAL CONSIDERATIONS

ONCE A WASTEWATER SYSTEM IS DESIGNED, THE PROCEDURES AND THE PHILOSOPHIES USED IN OPERATION WILL DETERMINE ACTUAL ENERGY CONSUMPTION. EVEN THE BEST AND MOST INNOVATIVE DESIGN CONCEPTS CAN BE LARGELY NEGATED BY IMPROPER OR CARELESS OPERATION OR BY OPERATION EXCESSIVELY KEYED TO CONVENIENCE OF OPERATING PERSONNEL.

OBVIOUSLY, ENERGY INTENSIVE SYSTEMS SUCH AS BIOLOGICAL TREATMENT OR NITRIFICATION BY AERATION OR OXYGENATION, AEROBIC DIGESTION, THERMAL CONDITIONING, SLUDGE INCINERATION, LIME RECALCINING, AND NITRATE REMOVAL, OFFER THE MOST POTENTIAL FOR ENERGY SAVINGS OR WASTAGE, DEPENDING ON ONE'S VIEWPOINT. OTHER AREAS WHICH CAN BE AFFECTED SIGNIFICANTLY BY OPERATIONAL PROCEDURES INCLUDE BUILDING HEATING AND COOLING AS WELL AS CHEMICAL INTENSIVE PROCESSES SUCH AS PHOSPHORUS REMOVAL, AND CHEMICAL CONDITIONING OF SLUDGE PREPARATORY TO DEWATERING.

INDUSTRY ALSO HAS THE ABILITY TO CONSIDER INTERNAL POLLUTION ABATEMENT MEASURES WHICH SHOULD BE DIRECTED AT BOTH REDUCING THE AMOUNT OF POLLUTANT DISCHARGES AT THEIR ORIGIN, AS WELL AS ENERGY REDUCTION. THE SMALLER THE VOLUME OF WATER OR WASTEWATER TO BE HANDLED; THE LESS ENERGY REQUIRED FOR HYDRAULIC MOVEMENT AND THE LESS SECONDARY ENERGY REQUIRED FOR CONSTRUCTION OF FACILITIES AND CHEMICAL ADDITIONS FOR TREATMENT.

AS A RESULT OF THE INDUSTRIAL WASTEWATER EFFLUENT STANDARDS PROGRAM, THERE HAVE BEEN A LARGE NUMBER OF ENERGY SAVINGS MADE IN INDUSTRIAL POLLUTION CONTROL.

1) LARGE CATTLE FEEDLOT OPERATIONS FORCED TO "NO-DISCHARGE" STANDARDS ARE DEVELOPING "BIO-GAS" TO HELP RUN THEIR INTERNAL OPERATIONS.
2) MAJOR SEGMENTS OF THE ORGANIC CHEMICALS INDUSTRY INCLUDING SOAPS AND DETERGENTS AND ADHESIVES AND SEALANTS ARE ABLE

TO PRODUCE MANY PRODUCTS BY PROCESSES WHICH ARE "DRY" BY DESIGN, WITH REDUCTIONS IN WATER AND ENERGY RELATED COMPONENTS.

3) IN THE FOOD INDUSTRY, "WATER CONSERVING PROCESSES" ARE COMING INTO PLAY AND RESIDUAL WASTEWATERS ARE BEING PLACED BACK ONTO THE LAND SUPPLYING NOT ONLY ADDITIONAL WATERS IN ARID REGIONS BUT ALSO NUTRIENTS AND IN AT LEAST ONE AREA OF MONTANA EXTENDING THE GROWING SEASONS SLIGHTLY BECAUSE OF THE HEAT IN THE RECYCLED WATER.

4) THE PULP AND PAPER INDUSTRY HAS CUT DOWN TREMENDOUSLY ON THE VERY LARGE VOLUMES OF WATER ONCE USED, REDUCING THE VOLUMES OF WASTE WATER TO BE HANDLED PER TON OF PULP BY 2/3 AND IN SOME PROCESSES GOING TO ZERO DISCHARGE.

IN ALL FAIRNESS, OF COURSE, SOME OF THE STANDARDS ARE ALSO ADDING TO ENERGY REQUIREMENTS, SINCE ONE MUST RECOGNIZE THAT INDUSTRY (WHICH WAS BY FAR THE MAJOR POLLUTER OF THE NATIONS WATERS) HAS GONE FROM A LARGELY NON OR LITTLE TREATMENT MODE IN 1972, TO FULL INDUSTRIAL WASTEWATER TREATMENT WITHIN A FIVE YEAR PERIOD. AND A GOOD PART OF OUR NATION'S WATERWAYS ARE MUCH THE CLEANER AND MORE USEFUL TO OUR CITIZENRY AS A RESULT!

THE CHALLENGE BEFORE ALL OF US IS TO CAPITALIZE ON THE ENERGY CONSERVATION MEASURES RECENTLY INTRODUCED AND TO MOVE THE WATER AND WASTEWATER TREATMENT FIELD FAR AHEAD OF RECENT ACHIEVEMENTS. WE HAVE THE BRAINPOWER AND NOW WE ALL NEED TO USE OUR WILL POWER TO DO SO!!

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CHANGING DESIGN STANDARDS AND ALTERNATIVES FOR ENERGY CONSERVATION

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I. INTRODUCTION

The widespread and rapidly growing concern over the national energy situation is bringing about the need for substantial changes in the design field of water and wastewater treatment. Facility design is for the most part conducted under guidelines and standards such as published by the Water Pollution Control Federation, Great Lakes - Upper Mississippi River Board of State Sanitary Engineers (more widely known as Ten State Standards), or New England Interstate Water Pollution Control Commission's TR-16. These guidelines are lacking in two major areas. One being that they are not tuned to present day's more stringent performance levels as required in the seven/thirty day averages or 85% effluent requirements. Instead, the guidelines are based more on average performance over a year's time. Secondly, existing standards do not focus sufficiently on today's energy situation. When the standards were developed energy played a relatively insignificant role in facility design. These standards are updated periodically but have not kept pace with the rapidly changing technology and energy situation. This paper addresses this latter problem.

In attempting to update or change design guidelines and standards, a major problem exists in regard to timeliness. It takes from 5 to 10 years from development of a new product to its acceptance and incorporation into design guidelines. This long lag time is caused by the extensive train of events that product development must undergo. A major portion of this delay is due to full scale field testing over an extended time period and over a wide range of operating conditions. This lag time can be minimized by utilization of manufacturers' test data. However, even the best of manufacturers' test data can be misleading, especially when one considers the wide range operating conditions such as temperature, organic loadings, and hydraulic shocks which wastewater treatment plants are subjected to. The 5 to 10 year lag time exists not only in guidelines but also in design texts due to the review and publication procedures. Moreover, this time delay is amplified by the fact that the energy situation has changed very rapidly in the past decade, even further widening the time gap. With both texts and design standards outdated, the practicing engineer is hampered in implementing energy-efficient facilities. In addition, review engineers are without back-up references needed to comfortably accept and therefore approve new energy-conscious designs. These review problems cause substantial project delays, increased costs, and wasted effort. The result is that in order to get a project approved by granting agencies in a timely and economical manner, he or she is forced into "old fashioned" designs.

II. LIMITING STANDARDS

A. General. In most design standards, certain minimum or maximum design values are set to insure proper operation. Examples of this are establishing minimum sphere sizes that raw wastewater pumps are capable of passing or maximum loadings allowed for biological treatment units. These standards have been determined on an empirical basis so that wastewater handling or treatment units can successfully operate over the wide range of conditions experienced for an extended time period. In most cases, these standards are conservative with a substantial safety factor built in to handle "worst case" situations, the result of which is inefficient operation during average conditions. These standards, therefore, limit the designer's choice of equipment or process design and prevent a person from implementing energy efficient systems.

Several alternative methods can be employed to handle "worst case" conditions. Instead of using conservative design standards, the system can be made more flexible, thereby altering the system to maximize efficiency for a given loading rate or problem condition. Another alternative would be to put a standby system on line to specifically handle the peak conditions. Finally, units can be installed upstream for pretreatment to eliminate the "worst case" conditions.

B. Examples.

1. Biological Treatment. In many design standards specific maximum loading rates or minimum aeration requirements are given. Figure 1 presents an example of a typical annual loading on a biological treatment system. By conventional thinking, a design loading would be chosen that approached the maximum loading expected. The entire biological process would then be sized based on this conservative design loading. Therefore, for that part of the year where the actual loading is less than the design loading, the system would be underloaded and/or operating at less than its maximum efficiency.

In order to have a treatment system operate more efficiently on a year-round basis, a dual treatment system can be employed. This would consist of a principal treatment unit process and a standby process. The principal system would be designed to treat the average loadings expected, say over a year's time period. Thus this system would be operating at maximum efficiency for the majority of the time. The standby system would be designed to come on-line to handle the above average loadings as they occur. An example of this could be utilizing a fixed film system as the principal process and followed by a suspended growth system as the standby. This example would be applicable to the situation where the occurrence of high loadings is predictable and of extended duration, e.g., annual temperature variations or seasonal variations in industrial waste discharges. Several weeks prior to the expected occurrence, the standby biological system could be started up in preparation for the increased loading. On the other hand, if variations in loading were not predictable or of short-term duration, a more flexible standby system could be employed such as chemical feed that would improve solid-liquid separation.

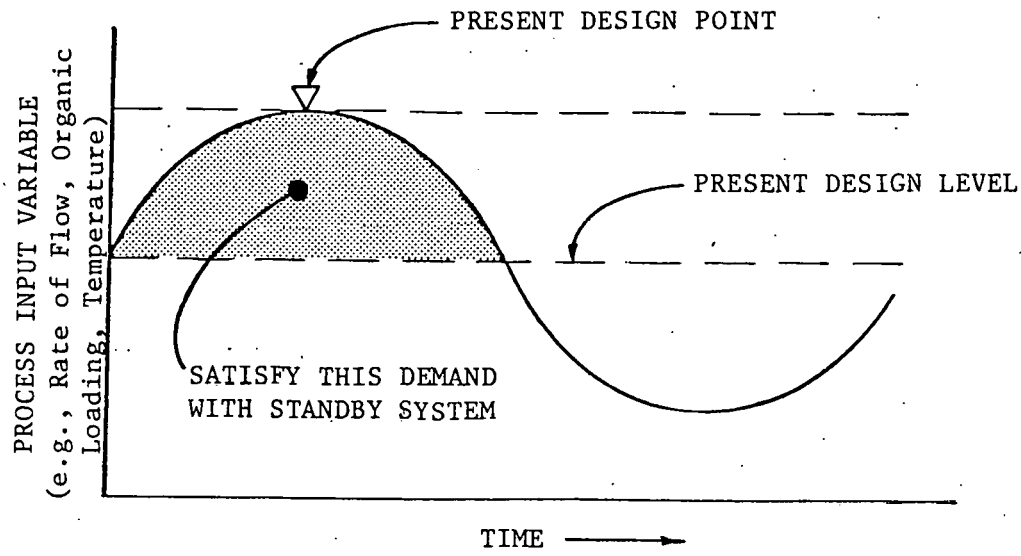
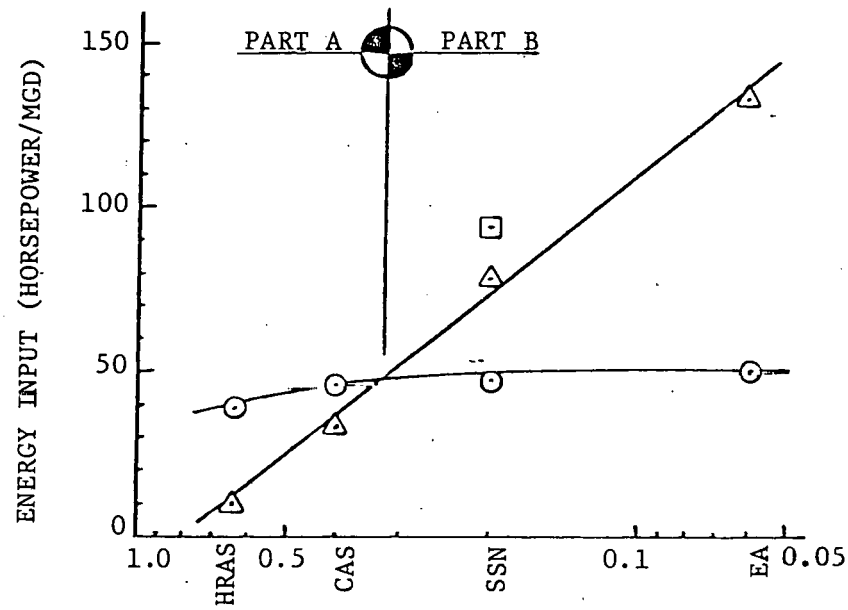


FIGURE 1 - PROCESS VARIATION RELATIVE TO DESIGN LEVELS

KEY

- ⊙ OXYGEN TRANSFER
- △ MIXING ENERGY
- ⊡ OXYGEN TRANSFER FOR TOTAL OF CBOD & NBOD

HRAS - HIGH RATE ACTIVATED SLUDGE
CAS - CONVENTIONAL ACTIVATED SLUDGE
SSN - SINGLE STAGE NITRIFICATION
EA - EXTENDED AERATION



ASSUMPTIONS

INFLUENT BOD_5=250 mg/l
BOD_5 TO AERATION=200 mg/l
TRANSFER EFFICIENCY=1.3#O_2HP.hr
MLVSS=1800 TO 3750 mg/l

FIGURE 2 - RELATIONSHIP BETWEEN OXYGEN TRANSFER AND MIXING POWER FOR SUSPENDED GROWTH ACTIVATED SLUDGE SYSTEM

The standby system may in itself be energy intensive, however, if it is only in use for a limited duration there may be an overall energy savings. In considering the present worth cost analysis of incorporating this dual-treatment scheme versus employing a single conservatively designed system, the dual treatment scheme may prove more costly due to a high capital cost. Nonetheless, the dual treatment alternative may be chosen in the name of energy conservation.

2. Aeration - Oxygen Transfer versus Mixing Requirements. Usually the most energy intensive process in a typical activated sludge wastewater treatment plant is the aeration process. The power utilized in aeration is needed for both oxygen transfer to satisfy the wasteload's demand and for mixing to keep solids in suspension. As shown in Figure 2, either oxygen transfer (Part A) or mixing (Part B) can be the controlling condition when determining the power requirements. The most energy-efficient system would be one which has an equal power requirement for both mixing and oxygen transfer. Referring to Figure 2 in Part A of the curve, more energy is supplied than needed for mixing, therefore there exists a potential for wasted power. As a possible energy saver, pretreatment can be employed to reduce oxygen demands. In this situation, an economic analysis should be made comparing the cost of pretreatment versus power savings.

In Part B of Figure 2, the engineer is limited in reducing energy requirements by a general design standard of requiring 1.0 horsepower per 1000 cubic feet of liquid mixed. However, there are alternative methods available to maintain sufficient mixing. For example, specific tank geometries could be employed that reduce "dead spaces" and decrease mixing energy gradient losses. Another possibility might be utilizing a separate low power mixing system independent of oxygen transfer. A way that this could be done is to have a rotating mixing blade on the tank bottom to circulate settling solids. Finally, by mixing on an intermittent basis, overall energy demand can be reduced. In this last example, an additional benefit might result from the periodic formation of low dissolved oxygen concentration or anoxic conditions. Under these conditions, denitrification may occur of a nitrified waste if sufficient organics are present. Thus, a certain amount of nitrogen removal may be achieved as well as energy savings.

3. Raw Wastewater Pumping. Most all design standards recommend that raw wastewater pumps be at least capable of passing a 3-inch diameter sphere or, in other words, be of the "Non-Clog" type. "Non-Clog" pumps are typically less efficient than standard centrifugal pumps. A small increase in efficiency can significantly reduce overall energy use since pumping usually consumes a large portion of a collection and treatment system's energy demand. This can be done by pretreating incoming wastewater to remove large solids and using standard centrifugal pumps. Such pretreatment could include screening, straining, comminution, or a combination of these. Here again, an increase in maintenance will result but the energy savings in pumping could in many cases counterbalance the increase in maintenance cost. Table 1 presents a comparison of the potential energy savings associated with incorporating pre-treatment in conjunction with using more efficient water pumps. This table indicates

a substantial savings in power of up to 41% for large pumps when substituting a standard centrifugal pump in place of a "Non-Clog" type.

TABLE 1 - ENERGY USE COMPARISON OF DIFFERENT PUMP TYPES

Design Point	Standard Centrifugal	"Non-Clog" Centrifugal			Vortex or Recessed Impeller Centrifugal		
	Brake Horse-Power	Brake Horse-Power	Increase In Power	Added Annual Cost	Brake Horse-Power	Increase In Power	Added Annual Cost
700 gpm @ 70'TDH	15	16	7%	$ 392	25	56%	$3,920
2100 gpm @ 70'TDH	47	55	17%	3,140	80	70%	12,940
3500 gpm @ 70'TDH	70	82	17%	4,710	155	121%	33,300
5800 gpm @ 70'TDH	120	141	18%	8,230	Not Available		
7000 gpm @ 70'TDH	142	200	41%	22,700	Not Available		

The idea of employing more efficient pumps is by no means new to the field of wastewater engineering. However, because of today's new economic situation of rapidly increasing power costs, this alternative should receive more attention. In general, as engineers develop profesionally, they make economic comparisons. The decisions resulting from these tend to stay with them and affect their future decisions. With the present situation of rapidly changing economics, the design engineer must wipe the slate clean and re-examine even one of the most basic processes such as pump selection.

III. LIMITED STANDARDS

In addition to those standards that limit the designer, there are standards that fail to sufficiently address a certain subject, hence making its implementation difficult. By not providing complete information on a specific process, design engineers and reviewers are left with too many unanswered questions. They are, therefore, forced to use more well-known or conventional processes; if they do implement the new process, they take the chance of finding themselves with a nonfunctioning or maintenance-intensive installation.

These limited standards exist for many of the newer processes. For example, land treatment of wastewater is a process presently encouraged by the United States Environmental Protection Agency. This process in itself is fundamentally very energy-efficient. However, land treatment is the most difficult treatment system to design properly due to the large number of uncontrollable and unknown factors. One of the major problems is evaluating a land treatment system's reliability and useful design life. Without the reliability and design life quantified, cost-effective comparison to other treatment systems becomes very difficult. Relative to other conventional secondary processes, the design standards pub-

lished on land treatment are very limited. Similar problems exist for Rotating Biological Contactors and Activated Biological Filters. Information regarding existing full-scale installations is not included in today's standards. Such data should include actual energy requirements, structural configurations, drive options, etc.

When comparing the energy efficiency of aeration systems, the method of aerator testing is critical and a wide range of test results can occur depending on the method used. There are different methods for either running the test and calculating performance parameters using the test results. This is a subject not fully addressed in design standards. With the large amount of power used in aeration, a thorough understanding of aerator performance testing is needed by design engineers. Ideally, a standardized test and parameter calculation procedure should be developed by the professional societies. Anyone involved in this type of evaluation can attest to the fact that the need is urgent. Presently the American Society of Civil Engineers is in the process of developing a uniform test procedure for aerator performance.

Various studies and publications are presently available that provide inventories and compare energy requirements for different treatment processes. These are helpful in making very preliminary evaluations, however, the information contained in these is limited. In order to develop energy usage over a range of flows, certain assumptions have to be made such as reactor loadings, efficiencies, etc. In actuality, these assumptions can vary widely and greatly affect energy requirements. Design factors can change dramatically for different geographic locations, wastewater characteristics, and for different process applications.

For example, the energy requirement curve for Rotating Biological Contactors in EPA publication MCD-32(2) shows that a 3.5 MGD standard media installation of 2.4 million square feet of contactor area consumes 800,000 kwh per year. Actual contractor bids on a recent project of the same size (3) show manufacturer energy consumption guarantees ranging from 420,500 kwh/yr to 784,200 kwh/yr. This represents a variation of 86%. When such a variation exists, one questions the usefulness of using such oversimplified energy curves for such an energy-intensive system. When comparing alternatives for a major energy consuming process such as an aeration system, even small variations in energy requirements can result in a large difference in overall energy consumption.

Another example of the limitations of energy requirement curves is seen in the comparison of various types of aeration devices. The curves show the energy consumed at design loadings; however, conditions vary widely from design loadings over a plant's life. Therefore, energy requirements or efficiencies of a system when it is turned down become important when identifying the most power-efficient unit.

The above examples illustrate that energy inventories of different treatment processes provide only a superficial picture. When eliminating alternatives for energy-intensive systems from consideration, these generalized curves can not be used. If curves are to be used, more de-

tail is required specific to manufacturer type and performance over a range of conditions. These limitations should be understood by the engineering community.

Process Design Manuals (P.D.M.) published by the U.S. E.P.A. are of noteworthy aid to engineers in communicating new technology. However, these are of limited value because of the relatively narrow source of the information. The majority of P.D.M.'s are authored only by a single contractor with some E.P.A. review. This obviously does not represent as wide a range of views as guidelines published under the auspices of the professional societies and associations which typically use multi-membered committees with broad representation.

IV. LACKING STANDARDS

A. General. Beyond the standards that limit the design or fail to provide sufficient information, are those standards that should be but are just not included in the design manuals. The main reason that these design standards are not included is the time lag problem previously mentioned. In many cases, information and equipment has been readily available on environmental products which are not discussed in the design standards. Technical articles have been written on these new processes, and products to implement the processes have been on the market for extended periods. However, without the support generated by independent professional evaluation, design engineers and regulatory reviewers can not confidently implement or reject these processes. There are examples of products or processes that have the potential for energy efficiency but are mentioned only briefly, if at all, in the design standards.

B. Biological Treatment Processes

1. Deep Shaft or U-Tube Activated Sludge. The basis behind these processes is enhanced oxygen transfer efficiency from deep submergence of entrained air. The air is injected into the mixed liquor at a shallow submergence, thereby reducing blower energy use. Manufacturers of the deep shaft process have exhibited at the Annual WPCF Convention for the past three years (4). In addition, this technology of enhanced O_2 transfer at deep submergence has been discussed in the literature for a longer time period, yet the accepted design manuals have not addressed it.

2. Fluidized Bed. This fixed film process purports to have very high energy efficiencies due to the fluidized bed principle and the associated high rate loading of the process (5). No design standards have been published on this system despite the fact that it was introduced several years ago and also has had numerous technical presentations at national conventions.

3. Anaerobic Treatment. Several anaerobic treatment processes are available to treat wastewater. Some examples are anaerobic filter, anaerobic contact, and the newer anaerobic expanded bed process. Anaerobic processes have been normally associated with specific applications in industrial waste treatment. This is due to popular beliefs that municipal wastewater is too variable in both flow and strength to sustain an

anaerobic process. However, recent information is indicating that the packed bed (filter) and expanded bed process can be successfully utilized for municipal wastewater treatment (6). The energy advantages are potentially tremendous for these processes as not only do they have lesser power requirements but they produce a valuable energy resource, methane gas. Standards should be published on these systems.

C. Disinfection

1. Mixing. Several new mixing devices have been marketed in the past few years that are promoted as greatly enhancing the mixing of a disinfectant gas with the wastewater (7). Through improved mixing, disinfectant usage is said to be greatly reduced, thus energy requirements decreased. This could have a significant impact in energy reduction associated with the production of both chlorine and ozone.

2. Alternative Disinfection Methods. Product lines, literature and technical articles are available for alternative disinfection processes such as ultraviolet light and chlorine dioxide (8). Both manufacturer and technical literature indicate that disinfection using UV light and ClO_2 consumes considerably less energy than conventional chlorine disinfection.

D. Motors and Drives. Premium motors have been developed that have increased efficiencies over other motor types. Although the efficiency differential is small, high energy costs magnify it to a position of importance. Motor control units are available that recover power losses associated with motor slip (9). Various types of variable-speed drive units are on the market with different efficiencies. The pulse-width-modulated adjustable frequency type has shown to have markedly higher efficiencies over the rated speed ranges (1). Incorporation of items such as these in wastewater pumping stations and treatment plants could save significant amounts of energy, yet relatively little is mentioned concerning these items in today's accepted design standards.

E. Building Design and Heating. Because this subject does not pertain directly to the water and waste engineering field, information in the design manuals is lacking. There are several methods to reduce heat loss from plant structures that the design engineer as well as the architect should be evaluating. One might say that this is not the design engineer's business, however, in treatment plant design the process controls the architectural design. Therefore, the design engineer and architect must coordinate in the early project stages and work together to produce energy-efficient building designs.

Emphasis ought to be placed on process and/or building structures underground. Ways to implement solar and wind energy into process design should be presented in standards. Devices such as heat pumps can utilize the heat contained in the treated plant effluent to heat structures. Other devices such as energy wheel and natural ventilation techniques have been successfully implemented in plants to conserve on building heating and cooling requirements but are only sparsely accepted. More consideration should be given to not heating or housing certain process equipment, where practical, to reduce energy requirements.

F. Sludge Disposal. Major energy savings can be incurred in sludge incineration by operating under the pyrolysis mode. The result of pyrolysis is solid char, liquid and gases, all of which have high fuel values (1). Combining municipal refuse with sludge can reduce dewatering requirements significantly while sustaining autogenous operation and can develop meaningful energy reductions based on decreased dewatering requirements.

G. Instrumentation. Through microprocessor instrumentation, successful applications have resulted from peak power demand shaving to reduce energy costs. The principle behind this is to automatically delay the starting of non-essential process equipment so as to prevent total plant power consumption from exceeding demand levels that would be billed under the expensive peak demand charge system. Once total plant demand dropped to a safe level, the equipment would then be automatically allowed to activate. Peak demand can also be reduced through installation of several smaller units (air blowers for example), rather than a single large unit. This would give a continuous lower demand rather than intermittent high demand, thereby avoiding high peak demand charges.

Instrumentation can also be employed to automatically adjust equipment output to match waste treatment demand. This can prevent inefficient over-treatment should influent load drop but equipment settings remain the same. An example of this would be using aeration tank dissolved oxygen concentration level to control the air supply. If influent load decreases, aeration tank D.O. would increase. Instrumentation can be incorporated to decrease the air supply until the desired D.O. concentration is obtained. Without such an automatic system, the air supply would be turned down manually. Until this occurs, energy is being wasted by over-aeration.

V. CONCLUSIONS

A. General. The foregoing discussion has cited many areas where existing standards can be improved to better expedite the implementation of energy-efficient treatment systems. Moreover, pressure is building continuously to opt for energy saving processes. This trend will continue as foreign energy supplies are constantly in danger of being cut off or increased in price and as domestic supplies are continuously coming under harsher environmental scrutiny. Only through the widely accepted design standards and manuals published by ASCE, WPCF, GLUMRB, etc. will new energy-conscious designs be implemented. This is because the design engineering and regulatory review community depends on these publications for thorough unbiased judgments and evaluation of collection and treatment system components.

B. Expedite and Standardize. Inclusion of new technology in the design standards must be expedited. Periodic revisions to design standards and manuals as presently practiced is not able to keep pace with the rapidly changing technology and energy situation. An improved method must be employed. One publication has used a unique updating system for years. Specifically, the system is the tentative versus standard labeling used by Standard Methods for the Examination of Water and Wastewater. By utilizing such a system, tentative guidelines could be published on treatment

systems that are still in the process of being tested and evaluated. Once the evaluation was completed, design parameters and guidelines could then be revised and published as standards. In addition, a technical communique' that would include the status of testing of new processes, new installations using improved systems, and new products on the market would greatly help keep the engineering profession abreast of developments.

Besides improving the communication of new technology, pilot and full scale testing procedures must be standardized. As previously mentioned with aerator performance, without a standardized testing procedure, comparative evaluation of treatment processes or equipment is close to impossible. As with design standards, these testing procedures need to be developed and published by the accepted professional associations in order to be confidently accepted by the engineering community.

C. Summary. The need for energy efficient water and wastewater treatment systems is here and will remain for an indefinite period of time. Presently, the implementation of new energy saving processes is lagging excessively behind the rapidly developing technology and deteriorating energy situation. Without the support of the established professional publications, design engineers and regulatory receivers can not and generally will not employ new designs. Both expediting publication of new technology to the engineering community and publicizing standards on performance testing procedures by WPCF, ASCE, GLUMRB, and others is required to successfully implement energy-efficient systems.

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THE VALUE OF WATER CONSERVATION IN THE EPA CONSTRUCTION GRANTS PROGRAM

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PURPOSE

The purpose of this paper is to communicate the value of water conservation in the EPA construction grants program. The value of this program is expressed in terms of monetary, water and energy resources savings. These savings are important because the direct savings to each household, motel, etc. is expected to provide the incentive required for a successful public information and education program. Such a program can produce additional savings by deferring new construction and operation of water supply and wastewater treatment facilities.

CURRENT GUIDELINES

EPA's current guidelines[1] require a cost-effectiveness evaluation of water pricing charges, water meters, addition of toilet dams and low-flow shower heads in existing homes, motels, hotels, institutions, and other establishments; and changes in laws and ordinances or plumbing codes requiring use of water saving devices in new homes, etc. The cost-effectiveness analysis must consider all costs of the proposed flow reduction program including administrative costs, the prospective energy savings, water supply savings and wastewater management surveys.

The current guidelines also require consideration of a public information program to aid in the implementation of the plan resulting from the cost-effectiveness analysis. The design of the wastewater treatment works must be based on the expected results of the implementation of the water conservation program.

HOUSEHOLD SAVINGS

The savings to an individual household have been calculated by

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Tiemens and Graham[2]. Here is the step-by-step procedure used:

1. Define the water conservation program.
2. Calculate the water reduction expected.
   a. for existing households
   b. for new households
3. Calculate the energy resources not consumed for households using water heaters fueled by
   a. natural gas
   b. electricity
   c. oil
4. Calculate the annual monetary savings using unit prices for water, natural gas, electricity and oil.

The water conservation program for existing household consists of three 5.7 liter (1.5 gal) displacement dams and two baths each equipped with fine spray showerheads. The savings calculated using the above procedures is shown in Table 1.

Table 1
EXISTING HOUSEHOLD WATER CONSERVATION SAVINGS

DAILY RESOURCE SAVINGS		ANNUAL COST SAVINGS
Water/Sewer	187 liters (48.8 gal)	$31
Energy	22.6 MJ (21,400 Btu)	$23
TOTAL		$54

The water conservation program for new households consists of 13 liter (3.5 gal) per flush toilets, fine spray showeheads, aerated kitchen and lavatory faucets, and water conserving automatic clothes washers and automatic dishwashers. The savings calculated using the above procedures is shown in Table 2.

TABLE 2

NEW HOUSEHOLD WATER CONSERVATION SAVINGS

DAILY RESOURCE SAVINGS		ANNUAL COST SAVINGS
Water/Sewer	284 liters (74.2 gal)	$52
Energy	42.9 MJ (40,700 Btu)	$44
TOTAL		$96

If a large number of households within a community decided to conserve water, unit prices would be likely to increase because of the need to recover the relatively large proportion of fixed costs for water and sewerage services. However, the energy savings would be likely to remain and still produce the cost incentive required to fuel the public information and education program.

3

NATIONWIDE SAVINGS

Here is the step-by-step procedure used to calculate nationwide savings by Tiemens and Graham[2]:

1. Calculate the flow reduction for existing households on a per capita basis and multiply by the existing population served by wastewater treatment facilities.

2. Calculate the flow reduction for new households on a per capita basis and multiply by the expected population increase to be served by new or expanded water supply and new wastewater treatment facilities.

3. Calculate the capital costs for water supply facilties not needed using a unit cost for pumping, storage, and water treatment.

4. Calculate the capital costs for wastewater treatment facilities not needed using preliminary treatment, pumping, primary settling, chlorination, and effluent outfall facilities in a typical activated sludge plant because sizing and costs of other units depend primarily on pollutant loadings rather than flow.

5. Calculate the capital cost of interceptors and collector pipes not needed based on Dr. Huang's calculations[2].

6. Calculate the annual monetary and natural resources savings by multiplying the annual household savings by the number of households in the nation in that year.

The effect of the nationwide water conservation program on the deferral of capital costs of water supply facilities, wastewater treatment facilities and interceptor and collector pipes is shown in Table 3.

TABLE 3

NATIONWIDE WATER CONSERVATION CAPITAL COST SAVINGS
TO SERVE 1990 POPULATION

FACILITIES	CAPITAL COST SAVINGS (in billion of 1978 $)
Water Supply	2.4
Wastewater Treatment	0.8
Wastewater Collection	1.0
TOTAL	4.2

4

The effect of the nationwide water conservation on energy savings is shown in Table 4.

TABLE 4

NATIONWIDE NATURAL RESOURCE AND COST SAVINGS DUE TO WATER CONSERVATION 1978-1990

RESOURCE SAVINGS			COST SAVINGS (in billions of $ 1979)
Water/Sewer	$5.5 \times 10^{10} m^3$	(14.6 trillion gal)	4.2
Gas	$3.3 \times 10^{18} J$	(3 trillion ft^3)	
Oil	$3.7 \times 10^{17} J$	(60 million bbl)	19.5
Electricity	$3.3 \times 10^{18} J$	(296 billion kw-hr)	
TOTAL			23.7

The average daily reduction in water supplied and in wastewater generated during the period 1978 through 1990 is 12 million cubic meters per day (3 billion gallons per day). Similarly, but on an annual basis, the energy savings is 5.7×10^{17} joules (0.5 quadrillion Btu).

PRESIDENTIAL TASK FORCE 11

The U.S. Environmental Protection Agency's position is its statutory goals are water quality and public health protection. Where construction grant assistance is involved, the evaluation of flow reduction measures to reduce needed reserve capacity is specifically provided for by the Clean Water Act of 1977. Additional legislation is necessary for implementing conservation measures unrelated to these goals.

The options developed and recommended to be implemented under the water conservation provision in the final report of the Presidential Task Force 11 are as follows[3]:

1. EPA will extend wastewater reclamation and reuse study areas beyond facility service areas.

2. EPA will prepare a Flow Reduction Handbook to insure a through analysis in the development of a flow reduction program tailored for the grant applicant's service area.

3. EPA will include guidance on water conserving rate structures in its Flow Reduction Handbook.

4. EPA will issue guidance encouraging states to use part of Section 109(b) grant funds to construct and operate reclamation and reuse training facilities.

5. EPA will develop an expanded Public Information and Education Program on land treatment, recycling and reuse of wastewater and flow reduction measures.

WATER SUPPLY WASTEWATER COORDINATION STUDY

The draft water supply-waste water coordination study[4] recommends to Congress the provision of financial incentives for municipal water conservation. Specifically EPA should provide a construction grants bonus of up to 5% for communities which can demonstrate a successful water conservation/wastewater flow reduction program and a penalty of up to 5% when per capita flows are excessive.

FLOW REDUCTION HANDBOOK

A flow reduction handbook will be produced by EPA which will stress the importance of developing a flow reduction program as opposed to a piecemeal approach. The handbook will describe procedures for developing these programs along with analytical methods to determine the cost savings expected for the program and the associated savings in water supply wastewater generation and energy consumption.

PUBLIC INFORMATION AND EDUCATION

EPA sponsored a Nationwide Conference on Water Conservation in 1978. Published proceedings[5] and a collection of readings on water conservation provided by this conference are supplemented by numerous publications, films, and workshops which were produced and distributed since that time. Additional publications are planned on water reuse/recycling and alternative innovative sewage treatment systems which will further reduce water consumption.

However, cost of actual conservation programs in a local community will have to be funded locally. These costs can be considerable if developed as an on-going program. This is necessary for sustained results. Household savings on energy costs can provide this incentive.

CONCLUSIONS

The value of water conservation is significant enough on a per household basis to provide the incentive required for a successful public information program.

EPA guidelines[1] have required since September 1978 the implementation of a cost-effective analysis of implementing a water conservation program. EPA will recommended in its Report to

Congress, Water Supply and Wastewater Coordination Study, December 1979, that EPA should provide a construction grants bonus of up to 5% for communities which can demonstrate a successful water conservation/wastewater flow reduction program and a penalty of up to 5% when per capita flows are excessive. The forthcoming Flow Reduction Handbook will provide the guidance for developing cost-effective water conservation programs suitable to achieve the bonuses and conversely define baseline water use which would not incur a penalty.

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THE CLEAN WATER ACT: ENERGY IMPACTS OF MUNICIPAL SLUDGE REGULATIONS

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1. INTRODUCTION

Under Section 405(d) of the Clean Water Act the U.S. Environmental Protection Agency (EPA) is required to issue guidelines for the disposal and utilization of municipal sewage sludge. EPA's intent is that these regulations will prevent the endangerment of public health and the environment by improper sludge disposal, while at the same time encourage practices which take advantage of the beneficial qualities of sludge. In the September 13, 1979 Federal Register, EPA issued regulations which address the application of sludge to land used for the production of food-chain crops. Regulations governing other methods of sludge disposal at publicly owned treatment works (POTW's), such as landfilling, thermal processing, and other landspreading practices (non-food-chain landspreading; giveaway or sale of sludge compost), are now in the process of being developed and will soon be publicly proposed.

Regulations which control sludge utilization and disposal will necessarily lead to certain adverse economic consequences. As part of the regulatory analysis assistance provided to EPA's Office of Solid Waste, Booz, Allen identified and quantified the nationwide costs and the energy impacts of the food-chain landspreading regulations. This paper describes the analysis which was done to determine the impacts those regulations will have on the energy use at POTW's nationwide.

The food-chain landspreading regulations address the control of cadmium, polychlorinated biphenyls (PCB's), and pathogens. The methodology described herein considers only the energy impacts associated with regulating cadmium additions to the soil, since only this aspect of the regulation was found to contribute significantly to the nationwide energy impacts. It should also be noted that the energy impact analysis considers only the impacts on current disposal practices. That is:

- The analysis considers only current food-chain landspreaders
- The analysis is based on current sludge quantities.

The identification of food-chain landspreaders and the estimation of the quantities of sludge currently being landspread is based on unpublished EPA case study data on sludge handling practices of POTW's across the nation.

Three major topics are discussed below:

- A Description of the Interim Final Regulations
- Methodology for Estimating the Nationwide Energy Impacts of the Regulations
- Results.

The following discussion focuses on these topics in sequence.

2. INTERIM FINAL REGULATIONS

The Interim Final Regulations offer two options to POTW's which intend to spread sludge on food-chain land once the regulations have been implemented:

- Option 1: Controlled Application Approach
- Option 2: Dedicated Facility Approach

Each option is designed to limit the movement of cadmium from sludge into the human food chain.

(1) Option 1: Controlled Application Approach

The first option is designed for POTW's which can meet three requirements as sludge is spread to food-chain land:

- Annual Limitation. The maximum allowable annual application rate of cadmium is controlled depending on the type of crop to be grown. For all accumulator crops (tobacco, leafy vegetables and root crops), a maximum rate of 0.5 kg Cd/ha is in force as soon as the regulations are implemented. For all other food-chain crops, a phased reduction in the maximum cadmium application rate is in force:

  - 2.00 kg Cd/ha until June 1984
  - 1.25 Kg Cd/ha from June 1984 until December 1986
  - 0.50 kg Cd/ha after December 1986.

This phased reduction theoretically coincides with the implementation of nationwide industrial pretreatment regulations which have the potential to significantly reduce the cadmium content of municipal sludge.

- Cumulative Limitation. The maximum allowable cumulative amount of cadmium applied to a hectare of land is defined in the regulations as a function of a soil's cation exchange capacity (CEC) and pH. In critical soils with

low CEC's and low pH's, a maximum cumulative application of 5.00 kg Cd/ha is allowed. In soils with high CEC and high or near neutral pH, the threat of plant uptake of cadmium is minimal and a maximum cumulative application of 20.00 kg Cd/ha is allowed.

- Soil pH Control. To control plant uptake of cadmium, the pH of the mixture of soil and sludge must be 6.5 or greater at the time of application. This restriction is not imposed on POTW's spreading sludge with the relatively low cadmium concentration of 2.00 mg/kg or less.

(2) Option 2: Dedicated Facility Approach

The second option is designed for POTW's which cannot meet the requirements of the controlled application option, but which have the resources and capabilities to closely manage and monitor the performance of their landspreading operations. This option permits operational flexibility in terms of the amounts of cadmium which are applied to food-chain land: no annual or cumulative cadmium limitations are imposed. However, cadmium movement into the food-chain is controlled by a set of operational requirements which include:

- Facility Operating Plan. A facility operating plan must be developed by a POTW prior to any food-chain landspreading activity. The plan must include procedures for dedicating the property for limited future use. Restrictions on future uses include:

  - food for direct human consumption may not be grown
  - animal feed crops may be grown, but only if the POTW can ensure the feed will not be consumed directly by humans
  - residential development will be discouraged by deed restrictions.

  The governing (state) agency must approve of the plan before sludge is spread on the site.

- Soil pH Control. The pH of the mixture of soil and sludge must be 6.5 or greater at the time of application or at the time the crop is planted, whichever occurs later.

These interim final regulations will impact the method by which municipalities dispose of wastewater treatment sludge. Alternate disposal may, in turn, lead to a change in the amount of energy consumed by the local government.

3. METHODOLOGY

The methodology for estimating the energy impacts was structured into three sequential tasks:

- Define existing conditions and project disposal practices as a result of the regulations
- Determine the unit energy requirements associated with methods of sludge disposal
- Estimate the increases in annual national energy requirements.

The key assumptions for each of these tasks are discussed in detail in the following sections.

(1) Existing Conditions and Projected Disposal Practices

The objective of this task was to determine the quantities of sludge which could continue to be spread to food-chain land when the regulations are implemented, and project those other disposal methods used in cases where continued food-chain land-spreading will be precluded. These projections rely on sludge data from over 350 municipalities referenced in an unpublished EPA report. For each POTW in the sample set, the following estimates were made:

- Tons of sludge which are currently being spread on food-chain land
- Tons of sludge which could/could not be spread under the cadmium limitations of the regulations.

The sludge data was disaggregated according to POTW size (small: < 1 mgd; medium: ≥ 1 mgd, ≤ 25 mgd; large > 25 mgd) in order to reflect different operating characteristics. It is important to note that the total quantity of sludge apportioned to the various disposal methods in the post-regulatory environment is the same as the amounts currently being landspread. In this manner, the resultant quantification of energy impacts can be attributed exclusively to the regulations, and not to any growth in sludge volumes to be disposed over time.

Annual limitations on cadmium were assumed to have an immediate impact on landspreading activities at POTW's in the survey. Depending on its sludge cadmium content, a POTW could be immediately precluded from continuing its current practice. The critical factors to be considered were the rate at which the sludge was applied to the land and the cadmium content of the sludge.

A key assumption made in the analysis is that the quantity of sludge currently being landspread would be unaffected by the cumulative cadmium limitations in the regulation. That is, when the cumulative cadmium limit is reached at a given disposal site, the methodology assumes that the POTW will continue disposing of sludge at an alternative site at no additional energy use. The validity of this simplifying assumption is not critical to the analysis because, as is supported in the data on over 350 POTW's, the life of sites utilized by most current landspreaders (landspreaders not precluded by the annual cadmium limitation) is longer than ten years. The cumulative restriction thus has little impact on POTW's throughout the nation.

The lowest economically viable sludge application rate was assumed to be 10 metric tons per hectare (mt/ha). That is, a POTW could not spread at a lower rate and still enjoy land-spreading as the cost-effective disposal option. By including this 10 mt/ha application in the analysis, the cadmium content in the sludge became the controlling factor. Sludge with sufficiently low cadmium content could continue to be landspread under the option 1 controls of the regulation. If the cadmium content of a sludge is sufficiently high as to preclude a POTW from continuing its food-chain landspreading operation, the methodology assumed an alternative method of sludge disposal for that POTW.

The interim final regulations permit POTW's to select either of two optional schemes for the application of sludge to food-chain land. This methodology assumes that if a large POTW is precluded from option 1 landspreading due to the high cadmium content of its sludge, it will elect to continue landspreading under option 2. The methodology assumes, however, that small and medium facilities will abandon landspreading altogether and select an alternative method of disposal. These assumptions are made because the option 2 landspreading regulations are tailored to large POTW's capable of developing and administering a responsible plan, and would be prohibitively expensive and administratively cumbersome for small and medium facilities. Nevertheless, some of these smaller facilities may select option 2, and to this extent the analysis is biased. Sludge which can no longer be landspread is distributed among alternative disposal methods according to the proporations currently devoted to those methods by each plant size category as indicated by the sample set.

The sludge currently being food-chain landspread by municipalities in the sample set is estimated to total 282,500 dry metric tons per year. Table I displays the projected methods of disposal for this sludge when the regulations are implemented.

TABLE I

PROJECTED DISPOSITON OF SLUDGE BY CURRENT LANDSPREADERS WHEN THE INTERIM FINAL REGULATIONS ARE IMPLEMENTED

Method of Disposal	POTW'S In Sample Set (Dry Metric Tons Per Year) Small (<1 mgd)	Medium (≥1 mgd, ≤25 mgd)	Large (>25 mgd)
Option 1 Food-Chain Spreading	3,700	76,100	111,000
Option 2 Food-Chain Spreading	0	0	58,000
Landfilling	400	21,300	0
Thermal Processing	N/A	6,900	0
Other (Non-Food-Chain Spreading)	100	4,600	0
Total	4,200	108,900	169,400

(2) Unit Energy Requirements

Associated with each method of sludge disposal shown in Table I is a unit energy requirement. Unit energy requirements for sludge disposal, as in all other aspects of wastewater treatment, can be broken down into three components: primary, secondary, and tertiary energy requirements. Primary energy is the energy used in the day to day operation of the sludge disposal practice, such as the fuel for trucks hauling sludge to the land disposal site. Secondary energy is the energy required to manufacture the chemicals or consumable materials used in sludge disposal, such as lime. Tertiary energy is the energy required to manufacture the equipment which processes or transports the sludge, such as filters, incinerators, trucks, or tractors. In this analysis, unit energy requirements include only primary and secondary energy components. Consequently, the unit energy requirements presented below may result in the understatement of energy impacts of the sludge disposal regulations, although this is not expected to be significant.

Unit energy requirements were developed for current landspreading practices, and for the regulated cadmium control options 1 and 2 landspreading. The energy requirements for alternative methods of disposal, such as landfilling, thermal processing, and non-food-chain landspreading were also developed. For all the above methods of disposal, unit energy requirements were based on 1, 10 and 25 mgd facilities to represent the three size categories of POTW's under consideration. Further, these facilities were assumed to generate a digested primary and waste activated sludge at a rate of 2700 gallons of liquid sludge at 6 percent solids per million gallons of sewage, and 1400 pounds of dry solids per million gallons of sewage.*

* Wastewater Engineering, Metcalf & Eddy, Inc., McGraw-Hill, New York, 1972, p. 581.

Unit energy requirements were developed in terms of Btu per year metric ton (mt) of sludge disposed. Because sludge disposal requires both electrical energy and fuel, all energy requirements are converted to Btu by assuming that electricity generation requires 10,500 Btu/kwh. The primary source of information for the unit energy requirements developed in Table II was an EPA Technical Report on energy use in municipal wastewater treatment.*

Unit energy use for current food-chain landspreading was assumed to be comprised of two components: energy for transport of liquid sludge to the disposal site and the energy for application of the sludge. Energy for transport was based on a one-way distance of 5, 10, and 20 miles for the small, medium, and large facilities, respectively. Truck transport was assumed for the small and medium facilities; pipeline transport was assumed for the large POTW unit energy needs.

TABLE II

UNIT ENERGY REQUIREMENTS
OF SLUDGE DISPOSAL

Method of Disposal	Unit Energy Use (10^6 Btu/mt)		
	Small POTW	Medium POTW	Large POTW
Current Landspreading	1.33	1.46	1.95
Option 1 & 2 Landspreading	2.88	3.01	3.50
Landfilling	0.7	1.02	N/A[1]
Thermal Processing	N/A[1]	16.8	N/A[1]
Non-Food-Chain Landspreading	1.33	1.46	N/A[1]

1- not applicable

Under options 1 and 2 food-chain landspreading, unit energy requirements were assumed to be the sum of current landspreading requirements plus the energy required to manufacture and spread lime in order to adjust soil pH to 6.5 (2.25 mt lime per hectare).

Landfilling unit energy requirements were assumed to be comprised of three components: energy for liquid sludge dewatering, transport of dewatered sludge, and landfilling of the dewatered sludge. Dewatering energy requirements were based on the use of sand drying beds for small POTW's, and vacuum filters for medium and large size POTW's. The energy for transport assumed truck transport at one-way distances of 10, 20, and 40 miles for the small, medium, and large POTW's. Bulldozer fuel requirements were assumed to represent the energy of landfilling.

* Energy Conservation in Municipal Wastewater Treatment, MCD-32 prepared for U.S. EPA Office of Water Program Operations, March 1978.

The unit energy requirements for thermal processing were based on sludge incineration by a fluidized bed furnace preceded by sludge dewatering with vacuum filters. No allowance for energy recovery was assumed. Both electrical energy and auxiliary fuel requirements were considered. Also, the energy requirements to transport and landfill dispose incinerator ash were included.

The unit energy requirements for non-food-chain landspreading were assumed to be the same as those for current food-chain landspreading: the energy of transport plus the energy of land application of liquid sludge.

(3) National Energy Requirements

The final step in the methodology ties together the results of the previous two tasks to project the national energy impacts of the food-chain landspreading regulations. The quantities of sludge in the sample set disaggregated to each disposal method were multiplied times the unit energy requirements for that disposal method in each of the POTW size categories to calculate the total energy requirements for sludge disposal in the sample set. The methodology then assumes that, because the data base used in the analysis accounts for only 38 percent of all sludge estimated to be landspread, a national projection of energy requirements could be derived by multiplying the energy use of the sample set by a factor of 2.6 (100/38). National energy requirements for projected disposal practices after the implementation of the regulations were compared to the requirements for current practices to determine the increase in energy use effected by the regulations. The results are presented in the next section.

4. RESULTS

The results of the analysis, as presented in Table III, indicate that the interim final regulations will double the annual national energy requirements for sludge disposal for those POTW's which are currently practicing food-chain landspreading. The annual energy use will increase from about 1.3×10^{12} Btu/year to 2.6×10^{12} Btu/year.*

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* The current total Annual National Energy Use is 78×10^{15} Btu/yr. (DOE Annual Report to Congress, 1978).

TABLE III

ENERGY IMPACTS OF REGULATION TO POTW'S CURRENTLY FOOD-CHAIN LANDSPREADING

POTW Size Category	Energy Use (10^9 Btu/yr.) Current Practice	Regulation	Percent Increase Due to Regulation
Small ($<$ 1 mgd)	6	11	83%
Medium ($\geq$ 1 mgd, $\leq$ 25 mgd)	159	380	139%
Large ($>$ 25 mgd)	330	593	80%
Total-Sample Set	495	984	100%
Nationwide Total	1,287	2,558	100%

Energy impacts, however, are only one of several impacts the regulations will impose on POTW's. Other impacts that must be considered are economic, as well as environmental. Actually, energy impacts represent only a portion of the total cost of the regulation.

Finally, we have estimated here only the energy impacts associated with the regulations covering one of many sludge disposal options: food-chain landspreading. Within the next year EPA will be publishing regulations covering all other options including: non-food-chain landspreading, bulk and bagged product sale or giveaway, thermal processing, landfilling, and surface impoundments. As with the present regulations energy use may further increase under these additional regulations if either the disposal option itself is made more energy intensive (e.g., lime addition) or municipalities are forced to select a more energy intensive option (e.g., thermal processing).

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ENERGY REQUIREMENTS AND THE POTENTIAL FOR ENERGY CONSERVATION IN MUNICIPAL WASTEWATER TREATMENT

by William F. Owen*

In light of the recent concern about energy consumption in all sectors of the U.S. economy, the purpose of this paper is to address the energy requirements of municipal wastewater treatment facilities, and the potential for energy conservation at these plants through energy efficient design and management. Initially, the key areas of energy concern in municipal wastewater treatment are identified, then the potential energy savings to be realized in these key areas are assessed. The primary data source for the estimates contained in this paper was the EPA's 1978 Needs Survey on Publicly-Owned Treatment Works[1] (POTWs), which is the most complete and current inventory data of its type available. Based on these data, relatively accurate energy-consumption estimates were possible.

ENERGY REQUIREMENTS FOR MUNICIPAL WASTEWATER TREATMENT

The 1978 Needs Survey indicated that approximately 15,000 treatment plants processed wastewater for the sewered population of 152,000,000 persons in 1978. That is, the sanitary wastes from about 69 percent of the total U.S. population (220,000,000) currently receives some type of centralized treatment. This fraction is expected to increase significantly by the year 2000, such that about 90 percent of the population will be served by POTWs. As such, the energy expended on treatment of wastewater in the U.S. can be anticipated to increase accordingly. In addition, the general level of treatment is also projected to increase over the next two decades, as illustrated in Figure 1. Presently, about 69 percent of the POTWs have capabilities for secondary treatment or better, but these facilities serve slightly less than 50 percent of the entire population. However, service by wastewater systems is on the increase. In the year 2000, approximately 88 percent of the U.S. population will be served by treatment plants with secondary treatment levels or better; furthermore, the general trend is towards higher levels of treatment, as is clearly illustrated in Figure 1. Based on these data, it can be surmised that energy needs for wastewater treatment will increase dramatically over the next 20 years according to the general trend towards the increase in population served

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by more sophisticated wastewater treatment facilities. Moreover, energy requirements for POTWs will, undoubtedly, represent a larger fraction of the nation's total energy consumption in the future.

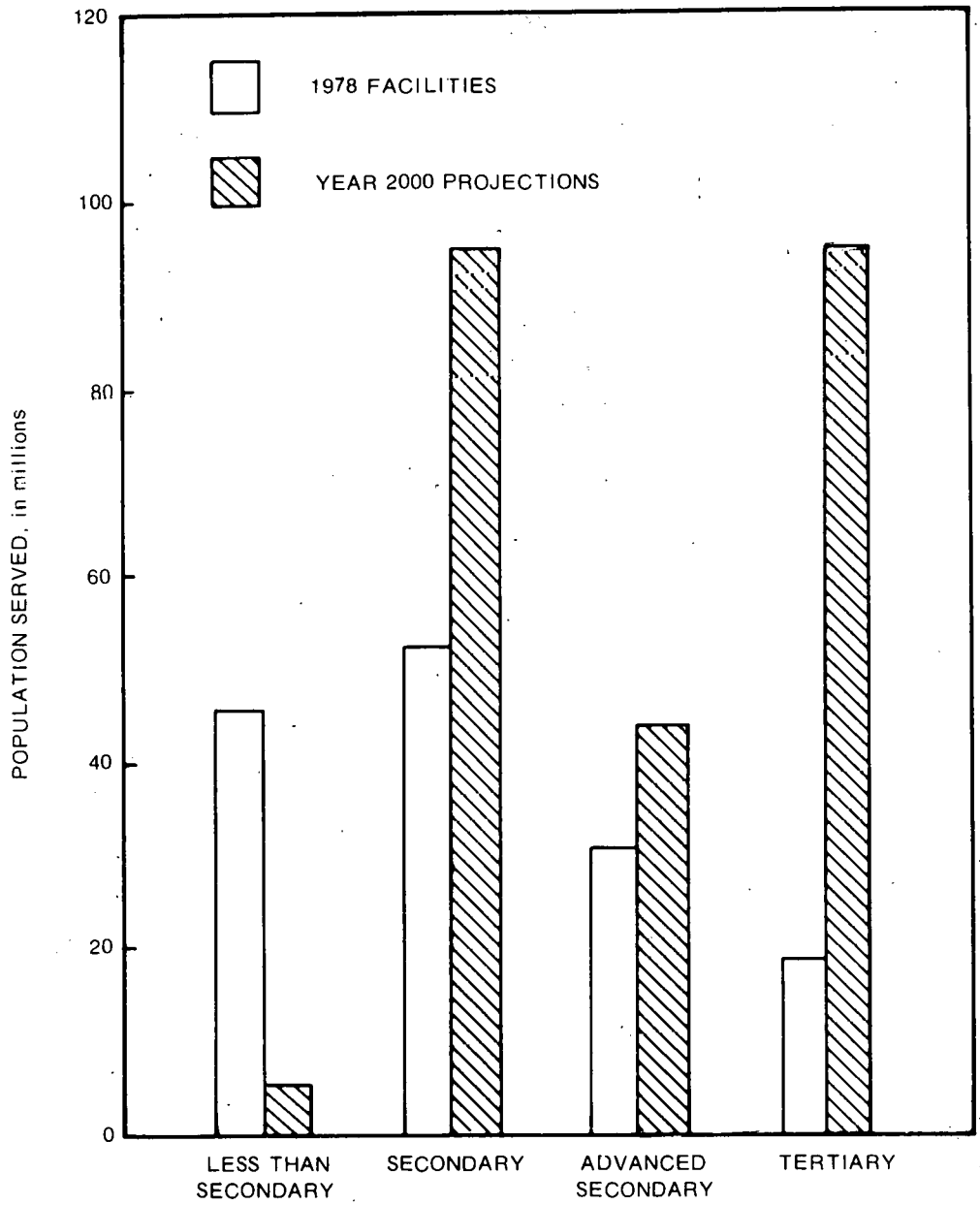


Figure 1. Population served by POTWs in 1978 and projected for year 2000 relative to various levels of treatment.

National Energy Consumption for Wastewater Treatment

Table 1 summarizes the national energy requirements for wastewater treatment and sludge treatment and disposal for existing facilities and those projected in year 2000. These data were obtained by summing the national energy consumption for individual unit processes, as based upon the total flow treated in the U.S. by each respective process. All energy values have been adjusted to account for losses which occur during use, transmission, and conversion.

TABLE 1. SUMMARY OF NATIONAL ENERGY NEEDS FOR MUNICIPAL WASTEWATER TREATMENT AND SLUDGE DISPOSAL IN THE U.S.

Item	Year		Percent Increase[1]
	1978	2000	
Number of Treatment Plants	14,800	20,800	41
Population Served	152,000,000	240,000,000	58
Energy Consumption, Btu/yr x 10^{12}			
Liquid Treatment Processes	135	244	81
Sludge Treatment Processes and Ultimate Disposal	101	176	74
TOTAL	235	419	78
Energy for POTWs as a Percent of the Total National Demand[2]	0.27	0.30	11

[1] Projected increase from 1978 to year 2000.
[2] Assumes National energy use of 87 x 10^{15} Btu/yr and 140 x 10^{15} Btu/yr, respectively, for 1978 and year 2000.

Several interesting facts are apparent from the data in Table 1. First, although energy consumption by POTWs is significant, 235 x 10^{12} Btu/yr, it represents only a small fraction of the total national demand (less than one-third of one percent). The portion consumed by wastewater treatment can be anticipated to increase by about 10 percent over the next 20 years, but will still remain a relatively small fraction of the total demand (0.3 percent).

The most striking change between the present situation and year 2000, as evident in Table 1, is the expected 78 percent overall increase in energy consumption for wastewater treatment and sludge disposal, an increase from 235 x 10^{12} to 419 x 10^{12} Btu/yr. This change is evenly distributed between increased

requirements for liquid- and sludge-treatment processes. It is due to more treatment plants (41 percent increase) serving a significantly larger population (58 percent increase) with more sophisticated and energy-intensive treatment.

Energy Consumption vs Plant Size

The distribution of energy needs among various sizes of plants is important from an energy-management standpoint. Obviously, it is easier to implement energy savings and conservation measures at large plants; however, less than one-half of one percent of treatment plants in the U.S. have flows greater than 50 mgd. Small treatment facilities are the most predominant. Over 60 percent of the plants have capacities of 100,000 gpd or less, and 88 percent of the plants are less than 1 mgd.

Relative to energy demand, however, the total flow processed by various plant sizes is more important than the number of treatment facilities. Figure 2 relates energy consumption by POTWs to treatment plant capacity. These data indicate that approximately one-half the energy consumed by POTWs is by facilities of 10 mgd capacity or less. The general conclusion to be drawn from Figure 2 is that energy consumption by POTWs is approximately evenly distributed among all sizes of plants. Therefore, in order to effect a significant impact on the total energy needs, it is important for energy programs and policy to be directed at all plant capacities, large and small.

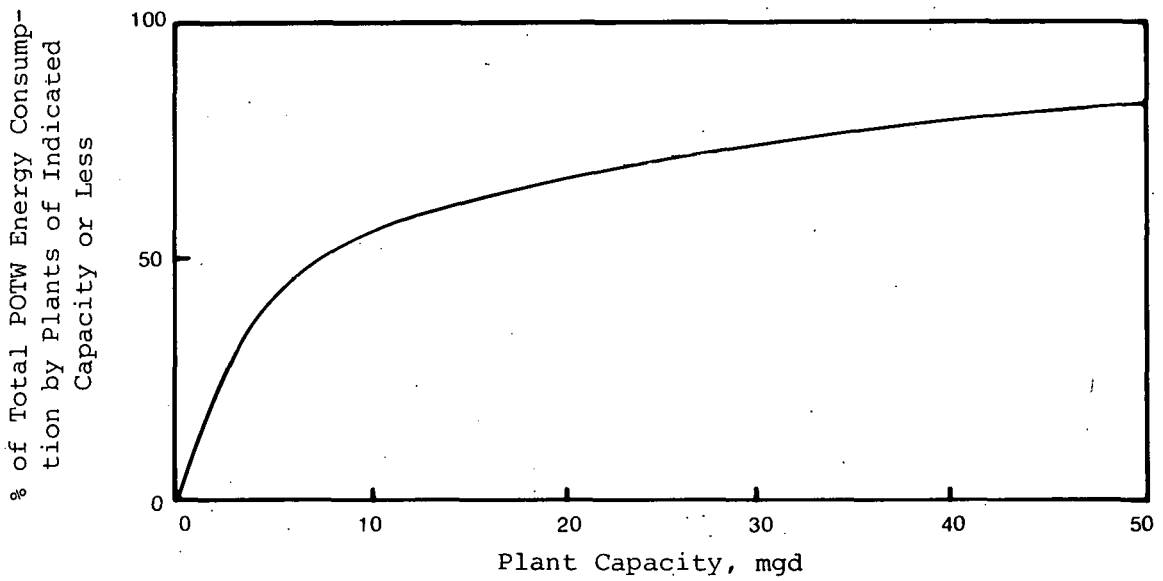


Figure 2. Energy consumption by POTWs relative to treatment plant capacity.

UNIT PROCESS ENERGY REQUIREMENTS

Figure 3 shows the annual energy consumption of the 10 most energy-consuming processes. Collectively, these 10 processes comprise over 90 percent of the total annual energy consumption by POTWs. From Figure 3, stabilization processes quite clearly manifest as the predominant energy consuming processes. Included in this category are: activated sludge, incineration, aeration ponds, and aerobic and anaerobic digestion. They comprise about 70 percent of the total energy consumed by POTWs. Sludge conditioning and dewatering processes are also important as they consume about 9 to 12 percent of the total demand. Conversely, preliminary and primary treatment processes are of little significance relative to the total energy picture. Surprisingly, advanced wastewater treatment (AWT) and tertiary processes represent only a small fraction of the 1978 energy consumption by POTWs. This trend is expected to change in the future, however, in order to meet more stringent discharge requirements. This point is illustrated by the large increase in energy consumption for nitrification and other tertiary processes which is expected over the next 20 years.

In order of precedence, the processes which contribute most significantly to the anticipated increase in energy consumption by POTWs are:

- Activated Sludge
- Conditioning/Dewatering
- Incineration
- Aerobic Digestion
- Tertiary Treatment
- Aeration Ponds, and
- Nitrification

Therefore, energy-efficient policy should be directed at the above processes in order to realize a significant impact in energy consumption at facilities which are planned or under construction. However, all of the processes in Figure 3 are targets for improving energy efficiency through changes in operational policy or retrofit modifications.

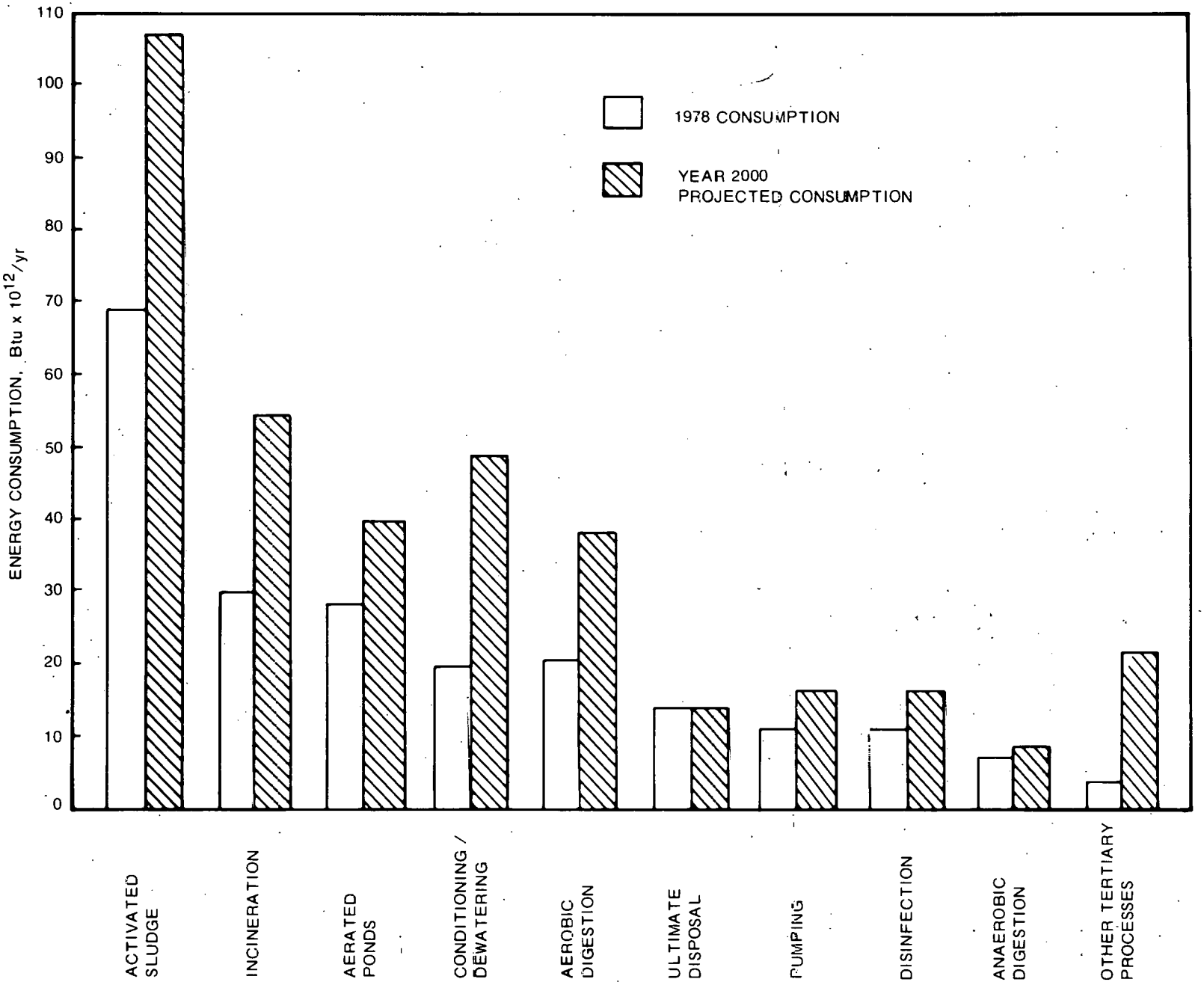


Figure 3. Annual energy consumption in the United States by the predominant energy-consuming wastewater treatment processes.

POSSIBLE NATIONAL ENERGY SAVINGS THROUGH UTILIZATION OF ENERGY-EFFICIENT WASTEWATER TREATMENT TECHNOLOGY

Energy savings can be realized in municipal wastewater plants through (1) retrofit modifications to existing facilities, (2) energy-efficient plant design and equipment selection for future installations, (3) improved operations and energy management at existing plants, and (4) adaption or modification of discharge standards to closely integrate environmental concerns with efficient energy management. The first two areas will be discussed in the following with emphasis on stabilization of organics.

Retrofit Modifications

Secondary Treatment Processes--

Many existing secondary treatment plants employ relatively inefficient aeration equipment due to their associated simplicity of operation and maintenance, and low initial costs. Such equipment could be replaced at selected facilities and result in a significant energy savings. For example, aeration energy requirements could be reduced approximately one-third by replacing coarse-bubble diffusers with more efficient fine-bubble diffusers, and could be cut almost in half by conversion to low-speed mechanical aerators or high-purity oxygen dissolution equipment.

Sludge Stabilization--

Anaerobic digestion is by far the most energy-efficient sludge treatment method and, conversely, aerobic digestion is quite inefficient. As such, a significant energy savings could be realized by converting existing aerobic digesters to anaerobic units. The feasibility of this concept would need be assessed on a case-by-case basis.

The net energy consumed by sludge stabilization processes is very sensitive to the moisture content of the feed sludge. Therefore, modifications that improve thickening and dewatering processes will generally improve the overall efficiency of subsequent sludge stabilization methods. For example, supplemental heating is required for anaerobic digestion, and the associated energy required to raise the water temperature of the feed sludge represents about 50 percent of the total energy consumed for this process. Thus, energy-efficiency could be improved

substantially for anaerobic digestion by processing thicker sludges. The upper limit in feed solids content, however, is about 10 to 12 percent DWS. Similarly, energy requirements for incineration are extremely sensitive to moisture content of the feed. The latent heat of vaporization of water is the single largest energy demand for incineration. Thus, from an energy perspective, the dryer the feed cake, the better. In fact, combustion of sludge is essentially impractical when the moisture content is greater than 70 percent, due to the associated high auxiliary fuel costs.

In 1972 approximately 25 percent of all municipal wastewater sludges (1,160,000 dry ton/yr) were processed by incineration[2], most of these installations do not have waste heat recovery equipment. If economizers and waste heat boilers were installed in these plants, about 25 to 45 percent of the total heat input to combustion (sludge plus auxiliary fuel) could be recovered from incinerator exhaust gases. Application of this proven technology therefore could save anywhere from 3.8 to 6.8 x 10^{12} Btu/yr.

Possibly the greatest potential energy savings lies in improving anaerobic digestion efficiency, digester gas recovery, and digester gas utilization. Typically, about 11 percent of the potential methane energy is recovered and used at facilities that have anaerobic digesters.[3] Inefficient energy management is due, in part, to poor design and operation of digestion facilities. Also, many plants do not digest all of their sludge due to operational constraints which are frequently caused by a lack of technical background. Furthermore, at many facilities, digester gas is simply flared as waste with little regard to energy recovery. All being considered, a significant amount of energy (ca. 43 x 10^{12} Btu/yr) is readily available and could be recovered and used with relatively simple retrofit modifications when applied in conjunction with improved operations. Proper education of engineering professionals and operations personnel would also be necessary to accomplish this goal.

Digester gas utilization could also be improved by employing dual-fuel, internal combustion engines with water-jacket and exhaust heat recovery. The thermal efficiency of this approach is quite high, on the order of 50 to 70 percent. The overall energy-efficiency of digestion could be improved even further by installing solar heating units to supplement 90 percent of digester heating requirements. This modification alone would potentially save 24 x 10^{12} Btu/yr at existing facilities, which could be used in IC engines.

Energy-Efficient Plant Design

The most efficient secondary treatment scheme is trickling filters using direct, mixed-media filtration. If all planned secondary plants were changed to incorporate this alternative, approximately 22 x 10^{12} Btu could be saved annually. Similarly, if the projected incineration and aerobic digestion designs were converted to anaerobic digesters, without specific regard to improved gas utilization, then an additional savings of 38 x 10^{12} Btu/yr could be realized. This savings could be improved upon by approximately 12 x 10^{12} Btu/yr through better recovery and utilization of digester gas at these facilities, and by an additional 6.6 x 10^{12} Btu/yr by employing solar heating. If these same measures were applied to the alternative plan mentioned above, which proposed anaerobic digesters in lieu of incinerators and aerobic digesters, then another 28 x 10^{12} Btu/yr could be conserved.

Total Possible Energy Savings

Table 2 summarizes the annual energy reduction which would be possible through adoption of all design and retrofit options previously covered, and Table 3 relates these savings to the total energy consumption by POTWs and the national consumption. As indicated, a significant savings is conceivable. Retrofit modifications could account for a 31 percent reduction in total energy consumption by POTWs, and incorporation of energy-efficient plant design might decrease demand another 19 percent. The overall, annual savings potential represents approximately 206 x 10^{12} Btu, or a 50 percent reduction in power consumption. This value corresponds to less than two-tenths of one percent of the total national energy demand estimate for year 2000 and is equivalent to over 34 million barrels of oil per year.

SUMMARY

In 1978, the total energy consumption by POTWs was approximately 235 x 10^{12} Btu, or 0.27 percent of the national demand, which is equivalent to 39 million barrels of oil. However, in order to meet future water quality goals, the level of treatment and total capacity of POTWs will increase over the next 20 years, which will result in about a 78 percent increase in energy consumption. The demand for industrial wastewater treatment may be as much as three times this quantity.[4] Energy use among various plant sizes is approximately evenly

TABLE 2. POTENTIAL ENERGY SAVINGS THROUGH ENERGY EFFICIENT PLANT DESIGN AND RETROFIT MODIFICATIONS

Design or Retrofit Option	Annual Energy Savings Btu/Yr x 10^{12}
Retrofit	
1. Improve Aeration Efficiency	16.0
2. Convert Aerobic Digesters to Anaerobic	18.4
3. Improve Digester Gas Recovery	43.4
4. Add Solar Heating to Anaerobic Digesters	24.4
5. Improved Thickening and Dewatering	19.1
6. Add Full Heat Recovery to Incinerators	6.8
Design Changes in Current Plant	
1. Employ Trickling Filters with Tertiary Filtration for Secondary Treatment	21.9
2. Use Anaerobic Digesters for Aerobic Units	38.0
3. Improve Digester Gas Recovery and Utilization	11.8
4. Add Solar Heating to Anaerobic Digesters	6.6
TOTAL POTENTIAL SAVINGS	206.4

TABLE 3. POTENTIAL ENERGY SAVINGS RELATIVE TO TOTAL CONSUMPTION BY POTWs AND THE NATIONAL CONSUMPTION

Category of Energy Savings	Btu/Yr x 10^{12}	Percent of Total Consumed by POTWs*	Percent of Total National Consumption†
Retrofit Modifications	128	31%	0.09%
Alternative Plant Design	78	19%	0.06%
TOTAL	206	50%	0.15%

*Total energy consumption by POTWs = 419 x 10^{12} Btu/yr.

†National energy consumption = 140 x 10^{15} Btu/yr.

distributed; therefore, energy conservation is equally important for large and small plants alike.

The primary goal of wastewater treatment is to stabilize, i.e., oxidize, organics prior to disposal in receiving waters, on land, or into the atmosphere. Thus, stabilization processes in wastewater and sludge treatment are the predominant energy consuming activities of POTWs. They comprise over 70 percent of the total demand.

Energy efficiency in wastewater treatment could be improved by (1) retrofit modifications, (2) improved operation and maintenance, (3) energy-efficient plant design, and (4) modification of discharge standards. Optimistically, over 100×10^{12} Btu could be saved annually through improved treatment plant design. More realistically, about half this amount, or 50×10^{12} Btu/yr, could be conserved. By employing similar energy-efficient retrofit measures to existing POTWs, this savings could easily be doubled. A conservative estimate would be that about 100×10^{12} Btu/yr could be saved by promoting energy-efficient plant design coupled with retrofit modifications to existing plants. This represents an approximate, 25 percent energy savings and over 16 million barrels of oil. Obviously, the economic feasibility of these concepts needs to be addressed.

ACKNOWLEDGMENTS

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ON THE COMPATIBILITY OF COST- AND ENERGY-EFFECTIVENESS FOR MUNICIPAL TREATMENT SYSTEMS

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1. INTRODUCTION

The selection, arrangement, and design of unit processes for wastewater treatment and sludge disposal can be made on the basis of several criteria. Among the most important are cost-effectiveness and energy-effectiveness (i.e., minimizing total costs or net energy consumption while meeting all requirements on effluent limitations and other standards). These two criteria play a significant role in the U.S. Environmental Protection Agency's multi-billion dollar Municipal Treatment Construction Grant Program. Increased federal funding is available to treatment systems meeting certain cost- or energy-effectiveness criteria under EPA's Innovative and Alternative (I/A) technology guidelines (U.S. Environmental Protection Agency, 1978).

If the material and labor inputs to a wastewater treatment system were priced according to their energy content alone, then the least-cost and least-energy systems would have the same designs (Heuttner, 1976). Since the market prices of these inputs are also influenced by such factors as relative scarcity and market imperfections, differences in designs are to be expected when satisfying each of these criteria separately.

In this paper the implications of designing on the basis of cost- and energy-effectiveness will be explored for a conventional municipal treatment system synthesized from 23 alternative unit processes. A computer model called EXEC/OP is used to efficiently identify least-cost and least-energy designs. The differences between these designs for variations in system design flow, effluent quality, and the price of energy will be examined. EXEC/OP will also be used to generate noninferior, or Pareto optimal designs that offer several alternative cost and energy trade-offs to the designer.

2. PROTOTYPE DESIGN PROBLEM

Figure 1 shows a multi-option flow diagram of a typical municipal treatment system for removing BOD and suspended solids. The three types of biological treatment units all include a final clarifier. The process labelled "Null" indicates that the option of no treatment is possible. Anaerobic digestion may be practiced using digester gas for digester heating only or for operating a gas recovery system that generates power. The land disposal options for sludge include truck transportation while multiple hearth incineration includes ash disposal. The mixing point for secondary and primary sludges occurs along the first dashed line in Figure 1 after which all secondary sludge processing terminates.

A computerized treatment system decision model called EXEC/OP is used to select the process option at each stage of treatment that will best meet a set of stipulated criteria on system cost, energy consumption, and effluent

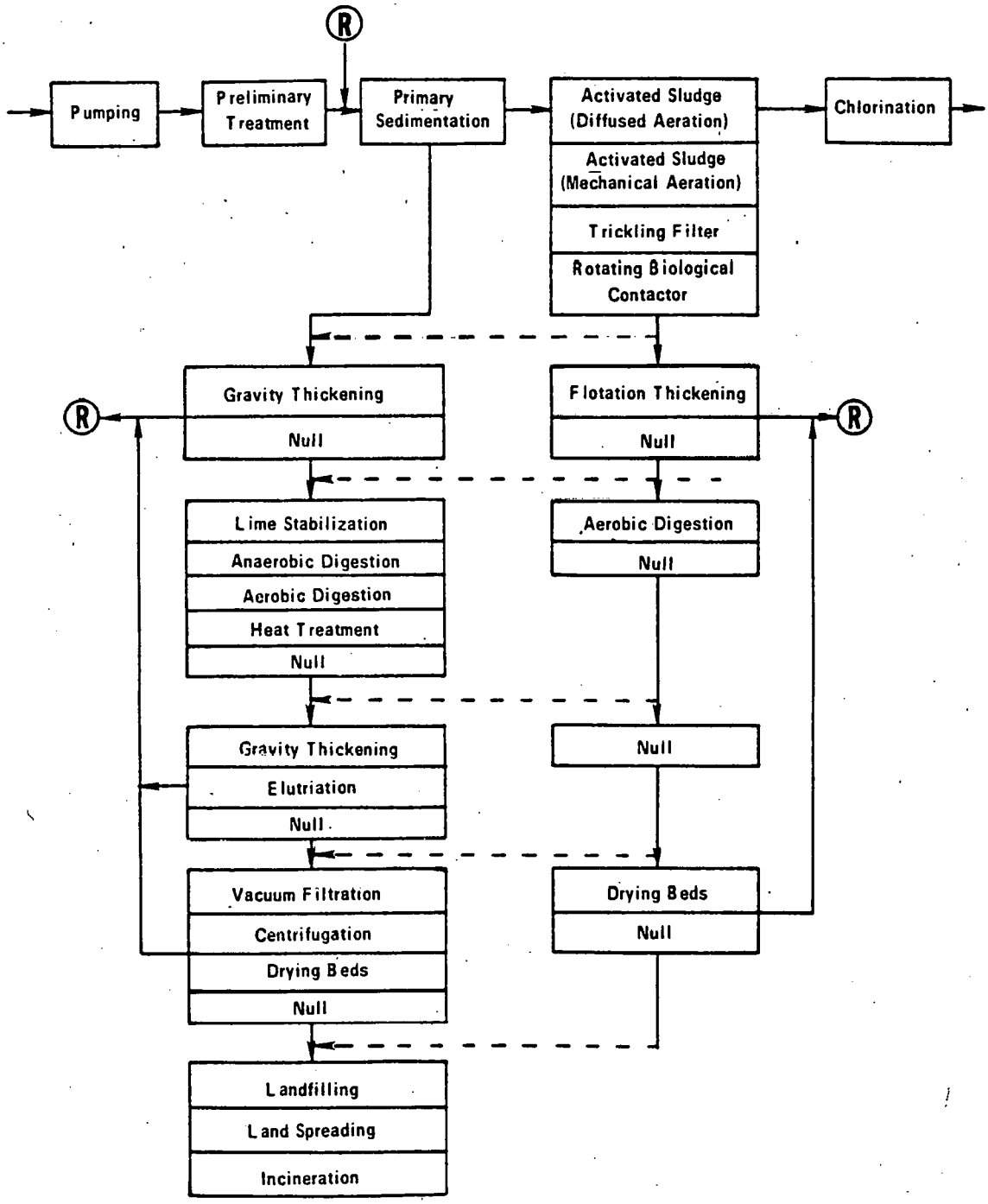


Figure 1. Multi-Option Flow Diagram for Prototype Design Problem

quality. Each treatment process in EXEC/OP is supplied with a mathematical model that predicts its cost, energy consumption, effluent quality and sludge or sidestream quality as a function of the influent waste stream and a set of design specifications supplied by the user. Table 1 lists the values assumed for the major input design parameters of the processes in Figure 1. Note that the distance to sludge disposal sites increases with system design flow to reflect the scarcity of near-by sites as the size of the metropolitan service area grows. Space limitations preclude listing the values of all input parameters as well as providing a complete description of EXEC/OP (see Rossman (1979) for more details). Most cost functions are taken from Patterson and Banker (1971) while energy consumption relationships are mainly from Smith (1973) and Wesner, et al. (1977).

The options shown in Figure 1 can be arranged into 11,520 different system configurations (13,824 when anaerobic digestion with and without gas recovery is considered as two distinct processes). A number of these are not feasible because EXEC/OP prohibits the land disposal of unstabilized sludge. Although the treatment options considered here show more variety in sludge disposal than in wastewater treatment, (a result of the current level of development of EXEC/OP) in theory it is possible to extend the methodology to include many other types of treatment as well.

The raw wastewater influent to the prototype system is taken to be typical domestic sewage with 200 mg/l BOD, 250 mg/l suspended solids (76% volatile), and 15 mg/l ammonia nitrogen. Table 2 lists various economic data assumed for this study. These were chosen to reflect June 1979 conditions. All heat energy from fuels is converted into equivalent kilowatt-hours by using an efficiency factor of 32.5% (10,500 BTU/kwh) as recommended in the EPA I/A Assessment Manual (U.S. Environmental Protection Agency, 1978). Lumping together electrical and heat energy like this may not be appropriate in all situations. When this is so, separate accounts should be kept and each form of energy should be treated as a separate design criterion.

TABLE 2. ECONOMIC DATA FOR PROTOTYPE PROBLEM

Labor Wage Rate	8.00 $/hr
Cost of Installed Concrete	344 $/cu yd
Cost of Chlorine	330 $/ton
Cost of Lime	45 $/ton
Cost of Ferric Chloride	128 $/ton
Cost of Polymer	2 $/lb
Cost of Electricity	0.04 $/kwh
Cost of Fuel	0.80 $/gal.
Cost of Land	1000 $/acre
Planning Period	20 yr
Discount Rate	7%

3. RESULTS FOR 30-30 STANDARDS

The prototype design problem is first analyzed with EXEC/OP for effluent standards of 30 mg/l BOD and 30 mg/l of suspended solids, the accepted defini-

TABLE 1. INPUT DESIGN PARAMETERS FOR PROTOTYPE PROBLEM

Process	Description
Raw Wastewater Pumping	Pumping head = 30 ft.
Preliminary Treatment	Includes grit removal, screening, and flow measurement
Activated Sludge[a]	MLVSS = 2500 mg/l; recycle ratio = 3.0; settler overflow rate = 600 gal/day/sq. ft.; 6% oxygen transfer efficiency for diffused aeration, 1.42 lb O_2/hp/hr for mechanical aeration
Trickling Filter[a]	Hydraulic loading = 20 mil gal/acre/day; specific surface area = 20 sq. ft/cu. ft.; Recirculation rate = 2; settler overflow rate = 600 gal/day/sq. ft.
Rotating Biological Contactor[a]	BOD removal rate constant = 7.0 gal/acre per day; number of stages = 4; settler overflow rate = 600 gal/day/sq. ft.
Primary sedimentation	Suspended solids removal = 50%.
Chlorination	Chlorine dose = 10 mg/l; contact time = 30 min.
Flotation Thickening	Underflow solids = 5%; solids loading rate = 72 lb/day/sq. ft.
Aerobic Digestion	Detention time 15 days for secondary and 18 days for combined sludge
Sand Drying Beds	Cake solids = 30%
Gravity Thickening	Underflow solids = 8% for primary sludge and 6% for combined sludge; loading rate = 25 lb/day/sq. ft. for primary and 8 lb per day/sq. ft. for combined sludge
Anaerobic Digestion	Detention time = 15 days; volatile solids destruction = 50%, gas production = 15 scf/lb VSS destroyed
Lime Stabilization	Lime dosage = 400 lb/ton dry solids
Heat Treatment	Temperature = 190°F
Elutriation	Washwater ratio = 3; underflow solids = 7% for primary and 5% for combined sludge; loading rate = 25 lb/day/sq. ft. for primary and 8 lb/day/sq. ft. for sludge combined
Vacuum Filtration[b]	Dewatering rate = 10-18 gph/sq. ft.; lime dosage = 0-250 lb/ton of solids; ferric chloride dosage = 0-100 lb/ton of dry solids
Centrifugation[b]	Cake solids = 19-40%; feed rate = 60-160 gpm; solids recovery = .85-.95
Landfilling[c]	1-way haul distance = 5 - 25 mi.
Land Spreading[c]	1-way haul distance = 10 - 30 mi; Nitrogen application limit = 600 lb/acre/yr;
Incineration	Number of furnaces = 2., mass loading = 2. lb/sq.ft./hr.; heat value of volatiles = 10,000 BTU/lb.

[a]These processes are also required to meet a specified 5-day BOD and suspended solids effluent limit

[b]Exact values of design parameters depends on type of sludge being treated

[c]Haul distance varies with design flow of system.

tion of secondary treatment. Figures 2 and 3 plot the unit cost and net energy requirements of both the least-cost and least-energy systems as a function of average design flow. Costs represent annual amortized capital, operation and maintenance exclusive of miscellaneous structures and laboratories. Net energy consumption includes the direct energy requirements of all operations minus any power produced from digester gas. This power is also given a cost credit equal to the price of electricity. Energy for building space heating and production of chemicals is not included.

The least-cost systems for 30-30 standards all employ activated sludge with mechanical aeration. Sludge disposal schemes for various size ranges are shown in Table 3. The least-energy systems are the same at all design flows. As might be expected, they employ the trickling filter, thickening of mixed primary and secondary sludges, anaerobic digestion with gas recovery, second stage thickening, sand drying beds, and landfilling. (When digester gas recovery is excluded as an option, lime stabilization replaces the sludge thickening - anaerobic digestion combination in the least-energy systems).

TABLE 3. SLUDGE DISPOSAL SCHEMES FOR LEAST-COST SYSTEMS AT 30-30 STANDARDS

Process for Combined Primary and Secondary Sludges	Design Flow, MGD 5-10	10-20	20-40	40-50	50-100
Gravity Thickening	x	x	x	x	x
Lime Stabilization	x				
Anaerobic Digestion		x	x	x	
Digester Gas Recovery				x	
Second Stage Thickening		x	x	x	
Vacuum Filtration			x	x	x
Sand Drying Beds		x			
Land Spreading	x				
Landfill		x	x	x	
Incineration					x

For the assumptions made here gas recovery is only cost-effective within the size ranges of 40-50 MGD. This accounts for the dip in the energy curve of the least-cost systems in Figure 3. Below this range gas recovery is uneconomical because either lime stabilization is cheaper than anaerobic digestion or because the cost of recovery is greater than the value of the energy produced. Above this range incineration of raw sludge is more economical because of the longer haul distances to land disposal sites. Economies of scale in energy consumption are much weaker than those for costs and are virtually non-existent above 20 MGD.

An interesting figure to compute is the cost elasticity of energy, or the percent energy savings divided by the percent cost increase between the least-cost and least-energy systems. The higher this number, the more favorable is the trade-off that substitutes energy savings for cost increases. Figure 4 plots the elasticity as a function of design flow. For 30-30 standards the best looking cost-energy trade-offs occur at plant sizes between 10 and 20 MGD.

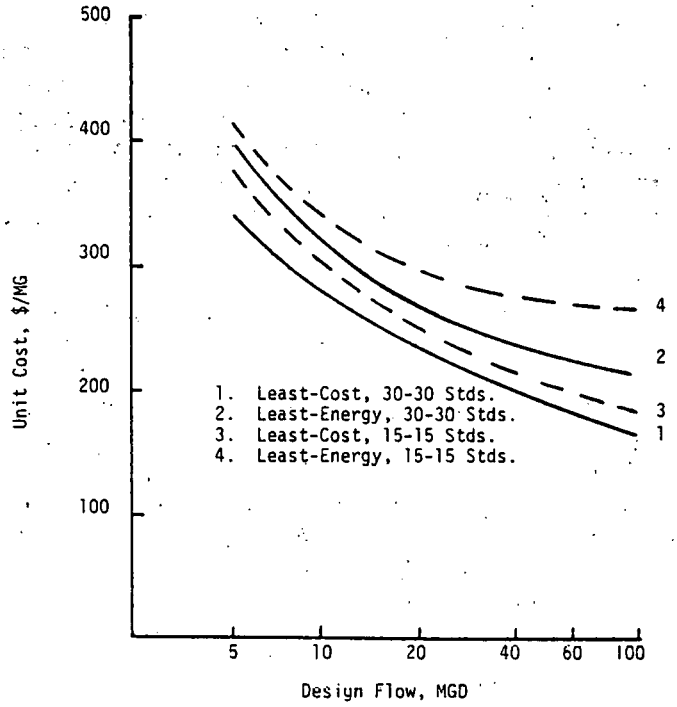


Figure 2. Unit Cost of Least-Cost and Least-Energy Designs

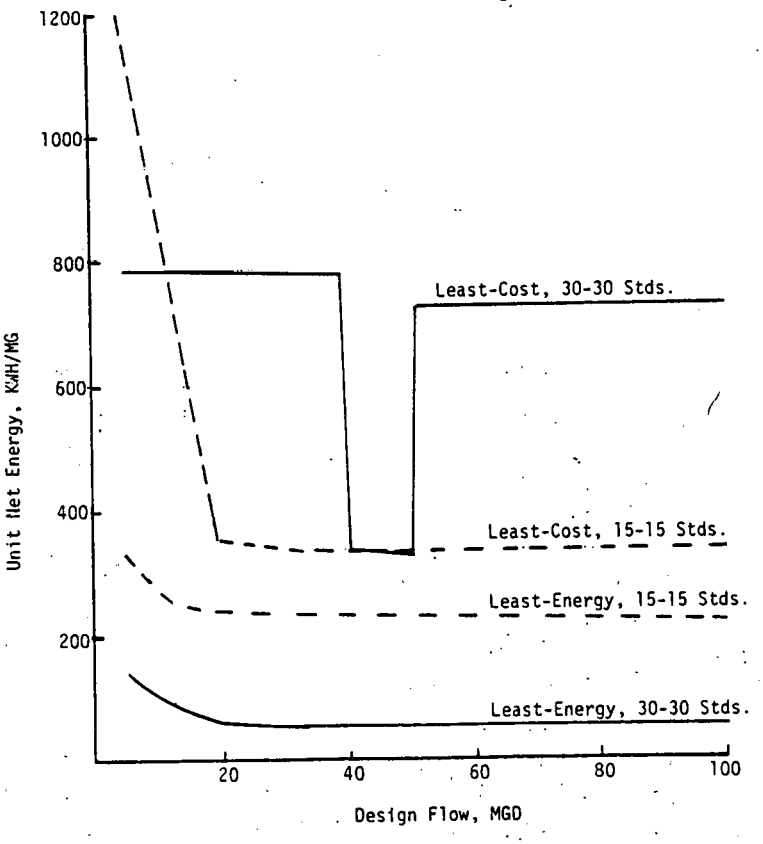


Figure 3. Unit Net Energy of Least-Cost and Least-Energy Designs

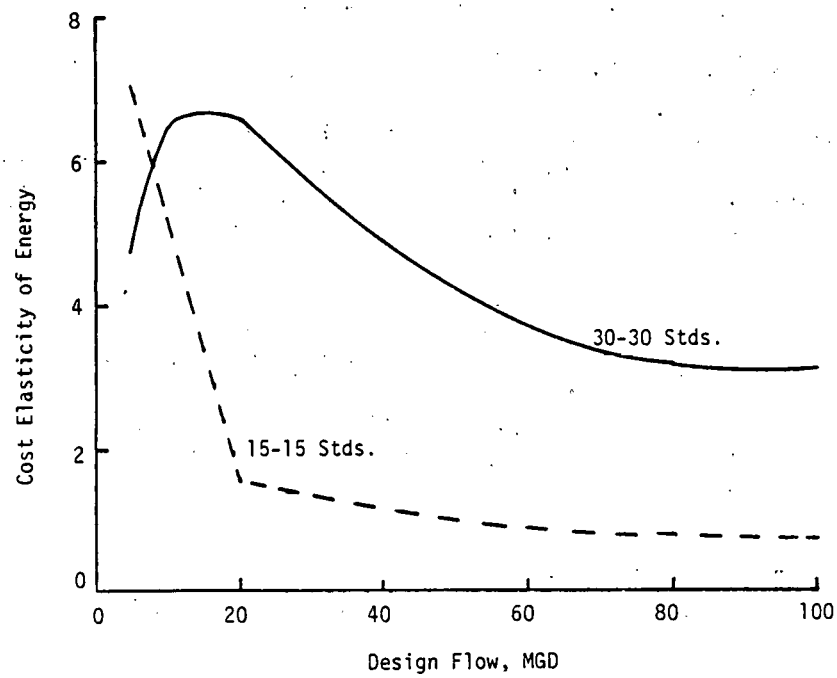


Figure 4. Cost Elasticity of Energy V. Design Flow

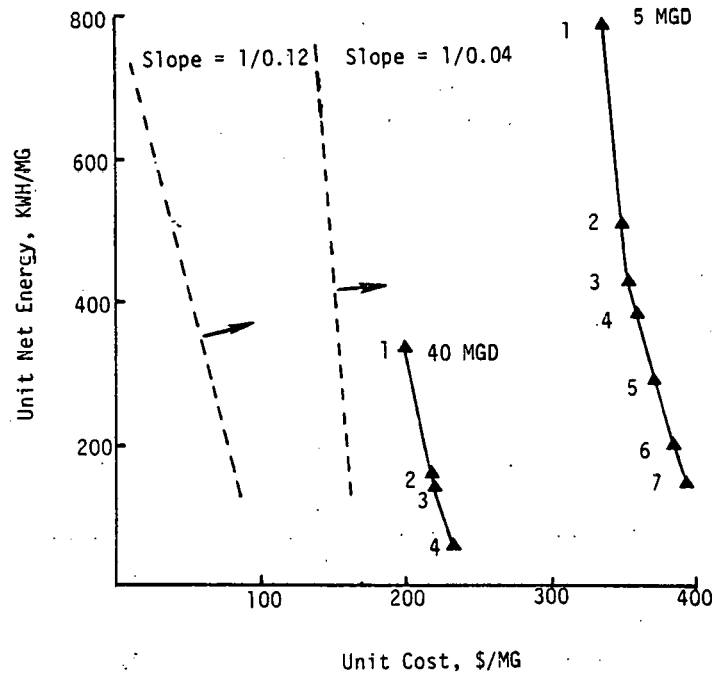


Figure 5. Trade-off Curves for 5 MGD and 40 MGD Systems

4. RESULTS FOR 15-15 STANDARDS

Determination of least-cost and least-energy designs is repeated using effluent standards of 15 mg/l BOD and 15 mg/l suspended solids. It is assumed that suitably sized activated sludge units and rotating biological contactors are capable of meeting these limits but the trickling filter is not. The resulting cost and energy values for the designs meeting the two criteria are also shown in Figures 2 and 3. The process choices for the least-cost systems are as follows: (a) all size systems use activated sludge with mechanical aeration, (b) below 10 MGD the designs are the same as those for 30-30 standards, (c) above 10 MGD disposal of combined sludge is by thickening, anaerobic digestion, second stage thickening, centrifugation, and landfilling; (d) digester gas recovery is practiced at all plant sizes above 20 MGD. The process choices for the least-energy systems are the same as for 30-30 standards except the rotating biological contactor replaces the trickling filter.

At 15-15 standards the gap between the least-cost and least-energy systems is reduced. The shape of the cost elasticity curve also changes as shown in Figure 4. The attractiveness of cost-energy trade-offs at 15-15 standards is much lower than at 30-30 standards.

5. EFFECT OF ENERGY PRICES

Table 4 shows the net energy consumption for the least-cost designs of a 5 MGD and a 40 MGD system meeting 30-30 standards under progressively higher energy costs. For the 5 MGD system, energy prices must increase three-fold before lime stabilization is replaced by anaerobic digestion with gas recovery. To cost-effectively replace activated sludge with the trickling filter, energy costs must rise by an unrealistic rate of 500%. A similar picture holds for the 40 MGD system - no change in process selection occurs until a five-fold increase in energy costs is reached. Thus it appears that energy reduction through digester gas recovery is more easily influenced by the market price of energy than is replacement of activated sludge by attached growth biological treatment.

TABLE 4. NET ENERGY CONSUMPTION FOR LEAST-COST SYSTEMS AT 30-30 STANDARDS

Electricity Cost, $/kwh	Fuel Cost, $/gal.	Energy Cost Index	Net Energy, kwh/MG 5 MGD	40 MGD
0.04 - 0.12	0.80 - 2.40	1 - 3	791	344
0.12 - 0.20	2.40 - 4.00	3 - 5	510	344
0.20 - 0.40	4.00 - 8.00	5 - 10	216	96
1.2	24	30	149	

7. NONINFERIOR DESIGNS

The analysis of the prototype design problem has focused on either the least-cost or least-energy systems. Yet within the framework of a multi-objective decision problem a designer may want to explore the cost and energy trade-offs available with designs intermediate to these two extremes. The resulting designs of interest should only include those which are noninferior, or Pareto optimal with respect to all others. These are designs for which no other alternative has both lower values of cost and net energy consumption (Keeney and Raiffa, 1976).

One method for identifying noninferior alternatives is to solve a sequence of least-cost design problems where net energy consumption is required to be at or below progressively tighter levels. EXEC/OP was used in this manner to identify noninferior designs for the prototype system at 30-30 standards and at design flows of 5 and 40 MGD. The cost and energy values of these designs are plotted in the form of trade-off curves in Figure 5.

A designer viewing a plot such as Figure 5 may proceed in several ways to select a final design. For example, with regard to the 5 MGD system, the designer may feel that a move from the least-cost alternative 1 to alternative 3 (a 46% energy reduction at a 4% cost increase) is more worthwhile than a move to alternative 7 (an 82% energy reduction at a 17% cost increase). Through additional comparisons like these a final design decision can be reached.

Alternatively the designer may wish to adopt a cost-benefit approach by assuming a numerical value for the social cost of energy consumption. A final design choice can be made by plotting a straight line on Figure 5 whose slope is the reciprocal of this value and moving it parallel to itself until it first hits an alternative plotted on the trade-off curve. For example, if the true value of energy were assumed to be 0.12 $/kwh then this procedure would pick alternative 3 as the best design for the 5 MGD system. Using 0.04 $/kwh (the price of electricity in the prototype problem) results in choosing the least-cost system, alternative 1.

By using this procedure in reverse, that is, first choosing a noninferior design on the trade-off curve and then computing the slope of the tangent to it, an imputed energy value can be attached to the design selected. For example, by choosing alternative 5 for the 5 MGD system in Figure 5 energy is implicitly valued at about 0.13 $/kwh. This figure can be compared with the market price of energy (0.04 $/kwh for electricity and 0.063 $/kwh for fuel oil in this example) to assess the impliciations of such a choice.

8. CONCLUSIONS

The specific results obtained in this study cannot be expected to hold true for all design situations. However certain general trends can be observed. The two most significant design changes which will close the gap between the least-cost and least-energy systems are the replacement of activated sludge treatment with an attached growth process and the use of anaerobic digestion with gas recovery in sludge treatment. These changes can result in significant energy savings at rather modest increases in cost. However the imputed cost of energy associated with these changes can be much higher than its market price.

For secondary levels of treatment, increases in energy prices are much more influential in making digester gas recovery cost-effective than in making any changes in the most cost-effective mode of biological wastewater treatment. Different size treatment systems can display different elasticities for substituting energy reductions for cost increases. Several alternative designs displaying different, noninferior cost and energy combinations can be generated by determining the least-cost design as progressively tighter constraint levels are applied to energy consumption. For the choice of any particular design among these, it is possible to infer a "true" value of energy implicit in such a choice.

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WASTEWATER TREATMENT PLANT ENERGY AUDIT

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Until the oil embargo of 1973, not much thought was given to the consequences of ever decreasing energy sources by the general populous of the United States. Awareness increased during the winter of 1976, as industries and schools in numerous cities were forced to close due to shortages of natural gas. The foreign oil cutbacks earlier this year kindled a general awareness that energy conservation must become a way of life.

The methods and techniques employed to conduct an energy use analysis for the Marinette, Wisconsin, municipal wastewater treatment plant including an equipment inventory analysis, acquisition of operating records, and on-site data collection are reviewed. Also, energy usage analysis of existing processes and sludge handling systems are discussed.

The existing 4.5 MGD wastewater treatment plant, constructed in 1971, provides secondary treatment, phosphorus removal, and chlorination of the effluent. The major process units of the

plant consist of the following: grit removal basin, primary clarifiers, aeration tanks, secondary clarifiers, and a chlorine contact chamber. The sludge removed in the treatment processes is dewatered on a vacuum filter and incinerated in a multiple-hearth incinerator. The residue ash from the incinerator is hauled to the City's sanitary landfill for ultimate disposal.

The plant operating records indicate that the wastewater treatment process is achieving reductions of over 90 percent of the influent biochemical oxygen demand, suspended solids, and phosphorus concentrations of all combined wastewater flow which is processed through the treatment plant. Comparing the effluent quality of Marinette's wastewater treatment plant to the Environmental Protection Agency's definition of secondary treatment reveals that the City's wastewater treatment plant is achieving excellent operating results. The operation and maintenance cost of the wastewater treatment plant during 1978 was approximately $304,000.

In order to develop a familiarity of the wastewater treatment plant processes and equipment which later will be analyzed for efficient energy usage, an equipment data inventory analysis should be performed at the start of an energy analysis study. The wastewater treatment plant design data, construction plans, and specifications should be reviewed by the audit team to gain the necessary insight as to the plant's general physical layout, equipment, and treatment process functions. The audit team should consist of mechanical, electrical, and sanitary engineers since the expertise of each discipline is required for the energy analysis.

Once plans, specifications, equipment, and process familiarity are gained, available equipment submittal/approval drawings

for the installed equipment should be reviewed. All installed equipment should be identified and tabulated. Information relative to the description and type of equipment, equipment manufacturer, rated capacity, rated efficiency, and motor nameplate data should be able to be obtained in this matter. In addition to providing required information relative to equipment characteristics, the equipment data inventory analysis provides further insight relative to the type of on-site data collection required.

Operating records, energy usage, and operating costs of the wastewater treatment plant are required to assess the relative costs and relative energy intensity/efficiency of various treatment equipment, process, and sludge handling systems. Also, in order to prepare comparisons between existing systems and possibly more efficient alternate systems, the relative operating cost and power or energy usage of the units or systems are required.

The utilities serving the wastewater treatment plant, essentially energy providers, should be identified and subsequentially contacted to acquire data regarding quantitative recorded usage and cost rate structures. Financial records should be obtained from the owner of the wastewater treatment plant and reviewed to determine energy, labor, chemical, maintainence, debt service, and other miscellaneous operating costs.

Once the work efforts involved in assembling, analyzing, and reviewing the information described under the operating records and equipment data inventory/analysis presented earlier are completed, determination of what type of field data should be collected can be made. Arrangements for the field trip to the wastewater treatment plant should be arranged with the city officials and plant operators.

Electrical field data gathered at the Marinette plant included motor nameplate data, operating field data, voltage current draw, and power factor measurement for each motor or motor system of 5 HP or larger. Voltage, current, and power factor measurements were used to calculate the electrical power input to the motors in KW. The information was used to calculate motor and system efficiencies.

In an effort to identify any process operations that might be suitable for heat recovery systems, equipment surface, and cooling air temperatures were taken with hand held thermometers. Units such as blowers, large variable speed motors, and the incineration system were checked in this manner. A combination gas analyzer was used to test the incinerator exhaust gases for indications of poor efficiency due to either incomplete combustion or excess combustion air.

Normal operating schedules for each system were obtained through discussion with the operators so an estimate of annual operating hours could be made for each motor included in the study. Additional operation schedule information was available from plant records.

In order to evaluate the performance of the various pumping systems, flow and pressure data were collected. Flow data was obtained from plant meters where available. On process lines without flow meters, flow data was measured and recorded with a portable clamp-on flow meter. Pump suction and discharge pressure data was measured with a pressure gauge. Pressure data could only be collected on pumps where taps and petcocks were originally installed. Independent tachometer readings for the variable speed pumping equipment were taken to verify the speed indicated at the pump control panels.

Aeration blower data collected included ammeter air flow rate and discharge pressure. Discharge pressure values were obtained utilizing pressure gauges originally installed with the equipment.

In addition to the technical and operating data collected, a number of photographs were taken to serve as visual references during the preparation of the report and to serve as an illustration of the equipment used.

With the field data collected for each of the process and sludge handling systems to be investigated, the energy usage analysis can commence. The evaluation should include a cost-effectiveness analysis of replacing nonefficient motors with high efficiency or smaller motors, replacement of existing pumps with more efficient units, and a discussion of how individual process and sludge handling systems could be replaced, modified or operated more efficiently to reduce energy consumption.

The cost-effectiveness analysis is suggested to be made in general accordance with the Environmental Protection Agency guidelines. The selection of a useful service life, usually the design year of the wastewater treatment plant, should be used for this analysis.

The energy usage analysis at the Marinette plant resulted in several energy conservation and operational procedure recommendations. Among the noteworthy are the following:

1. Replacement of 110 HP aeration blower motors with 75 HP units proved to be cost-effective.

2. Replacement of the coarse bubble diffusers with a fine bubble system showed the annual aeration power usage/cost could be reduced by approximately 50 percent. A more detailed study was recommended.

3. The raw wastewater pump field data showed a wire to water efficiency of about 30 percent. Equipment data indicates the field condition efficiency should have been in excess of 60 percent. An annual power savings of $5,000 could be realized if the system performed to its rated efficiency.

An estimate of the existing and projected sludge quantities is necessary to review the performance of existing solids processing systems and to conduct a cost-effectiveness analysis of various sludge processing alternatives.

Sludge treatment and disposal represent a major segment of the operating cost and energy consumption of a wastewater treatment system. Sludge handling costs as high as 50 percent of the total treatment costs are common. The solids content of various sludge streams such as primary sludge, gravity or air flotation thickners, digested sludge, vacuum filters or sludge press feed, and dewatered sludge should be analyzed and evaluated for the optimum operating concentration. A decrease from the optimum solids content has a drastic effect on sludge volume and associated energy and operating costs.

Treatment and disposal of sludge generated by wastewater treatment plant processes could be accomplished through numerous schemes. Several potential alternate sludge processing schemes should be discussed and investigated to determine the most cost-effective process. An energy use analysis of the systems being investigated should be included as part of the investigation.

The alternatives identified as having the potential for reducing total sludge processing costs and energy consumption at Marinette were:

1. Vacuum Filtration and Incineration: Optimization of Existing Sludge Processing

2. Sludge Storage, Vacuum Filtration, and Incineration

3. Anaerobic Digestion, Vacuum Filtration, and Filter Cake Disposal.

4. Anaerobic Digestion, Sludge Storage, and Liquid Sludge Disposal

A cost-effectiveness analysis was performed to determine which sludge processing alternate would minimize total resource costs until 1990 - the design year of the existing wastewater treatment facilities. Annual operating and maintenance costs, future costs, and salvage values were converted to a single payment present worth using factors computed at 6-5/8 percent interest. The values of various operating cost components such as labor, electric power, and natural gas were current market values. Inflation of prices and wages was not considered.

A summary of the cost-effectiveness analysis including values for the estimated energy requirements for the alternatives is presented in Table 1.

Optimization of existing vacuum filtration and incineration sludge processing had the lowest present worth of the alternatives analyzed. However, this alternate is the most energy intensive. The 1978 total energy value is more than double

TABLE 1

SUMMARY OF ALTERNATIVE SLUDGE PROCESSING COST EFFECTIVENESS ANALYSIS

	Vacuum Filtration Incineration (Existing Process)	Sludge Storage Vacuum Filtration Incineration	Anaerobic Digestion Vacuum Filtration Filter Cake Disposal	Anaerobic Digestion Sludge Storage Liquid Sludge Disposal
Total Present Worth	$808,000	$1,050,000	$1,146,000	$1,197,000
Initial Capital Cost	0	$ 260,000	$ 714,000	$1,005,000
Annual O&M Cost[1]	$105,000	$ 73,000	$ 41,000	$ 23,000
Annual Electric Power:				
-KW-hrs.	119,000	84,500	38,700[2]	0[2]
-1978 Value (2.84¢/kw-hr.)	$ 3,400	$ 2,400	$ 1,100[2]	0[2]
Annual Natural Gas:				
-Therms	271,600	103,200	---	---
-1978 Value (20.15¢/Therm)	$ 54,700	$ 20,800	---	---
Annual Diesel Fuel:				
-Gallons	---	---	1,450	8,700
-1978 Value (95¢/gallon)	---	---	$ 1,380	$ 8,270
1978 Total Energy Value	$ 58,100	$ 23,200	$ 2,400	$ 8,270

[1]Based on 1978 Labor, Electric Power, Natural Gas, & Diesel Fuel Costs. Price escalation for these items was not included in the analysis.

[2]Assumption made that the energy value of the methane produced will offset the electric power required for the process.

the value of the second most attractive alternate - sludge storage, vacuum filtration, and incineration. The most cost-effective alternate also has the highest annual operating and maintenance costs. Even though this alternate had the highest operating and maintenance cost and the comparatively high energy consumption value, the annual costs are more than offset by the zero initial capital investment and the relatively short present worth analysis period which minimized the annual cost component.

The most energy conserving alternate, anaerobic digestion followed by vacuum filtration and filter cake disposal, had a 1978 total energy value approximately 3 percent of that for the most cost-effective alternate. The initial capital cost in the present worth analysis more than offsets the dollars that can be saved with less energy consumption.

Anaerobic digestion with sludge storage and liquid land disposal of sludge had the least annual operating and maintenance costs. However, it requires the greatest initial capital investment.

Wastewater treatment plant energy usage analysis should emphasize the potential for energy savings by improving existing process performance and operation. Potential savings should be presented in simple monetary terms to provide an incentive for municipalities to optimize rather than sustain operation of the plant.

To conduct such an analysis, existing process operational data for a minimum of three months and preferably a year is considered essential. Facilities design may not provide the necessary data collecting instruments and the operators may not collect the necessary data on a routine basis if it is not

required to sustain plant operation. Engineering estimates can be made if budget restraints prevent the necessary data collection. The result of such a study may not be able to accurately estimate the value of potential savings, but can identify areas where further investigation is suggested and energy savings may be realized.

At least two separate site visits should be scheduled for the preparation of complex energy analysis reports. The first trip would be to record nameplate data from the equipment, collect historical operating records, and develop a general understanding of how the systems are operated. The team would then spend the next period of time analyzing and drawing general conclusions. During this period, it may be discovered that there are specific parameters related to systems that are essential to the study, but not included in the operating records. On the second trip, additional data subsequently found to be essential could be collected. Also, the operating staff of the facility could be requested to collect additional data on a daily basis if required.

It should be noted and taken into account that a program of this nature requires a substantial amount of time, effort, and involvement of the facilities operating staff. The operators have intimate knowledge of the day-to-day operation, control, and weaknesses of the various systems. The operators should accompany the audit team during the site visits and at the end of each visit should be scheduled to review the observations.

At the completion of the report, the findings, recommendations, and possible energy savings should be reviewed with the facility supervisor and operating personnel. Detail review of the recommendations and input from the operating staff is essential for implementation of energy conservation techniques.

MULTIPURPOSE RESERVOIR OPERATION FOR ENERGY EFFICIENT WASTEWATER MANAGEMENT

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1. INTRODUCTION

Reservoir benefits from water quality improvement are presently not allowed in multipurpose project justification, pursuant to PL 92-500, a national mandate for treatment before discharge. Energy studies, however, indicate that some high levels of effluent treatment may be done more efficiently instream than in plant (Heggen, 1979). This is not to suggest a return to "solution by dilution", but rather that in some cases, streamflow might be an effluent polisher less environmentally costly than high degree waste treatment plants.

An effective national policy of environmental-energy management must consider decision impact in both areas. For wastewater discharges downstream from a reservoir, augmented receiving flow may reduce the degree of upgraded treatment necessary to protect water quality. These treatment energy expenses foregone are a benefit derived from the reservoir.

The summer of 1973 critical environmental conditions in Oregon's Willamette River, brought on by a 25-year natural low flow, were mitigated by secondary level wastewater treatment and late summer reservoir released from U.S. Army Corps of Engineers reservoirs. These reservoirs, as shown in Figure 1, store spring runoff for summertime irrigation, recreation, and navigation benefits (Huff, 1976). The reservoirs are drained to low levels to store fall and winter flood flows. It is fortuitous for water quality management in the main-stem Willamette that this annual drawdown augments the river's low flows, and thereby helps dilute and transport degrading wastes from the basin during late summer.

This paper discusses the energy costs and benefits of existing reservoir employment in water quality management.

2. TREATMENT-AUGMENTATION ALTERNATIVES

To determine the energy-apportioned costs of reservoirs used for water quality control, it is necessary to evaluate the sensitivity of water quality to reservoir operation and the sensitivity of water quality to degrees of point source treatment. Eight levels of treatment were hypothesized. Level A represents typically primary municipal treatment and a correspondingly low degree of industrial treatment. Level D represents the actual 1973 secondary treatment levels employed. Level G was chosen to represent likely upgrading to high-level secondary performance for both municipal and industrial dischargers. Level H represents a hypothesized zero-discharge condition. Levels B, C, E, and F represent intermediate degrees of wastewater treatment. The first two rows of Table 1 indicate BOD and Kjeldahl nitrogen river loadings under each treatment level. The third, fourth and fifth rows estimate treatment expenses in 1973 dollars.

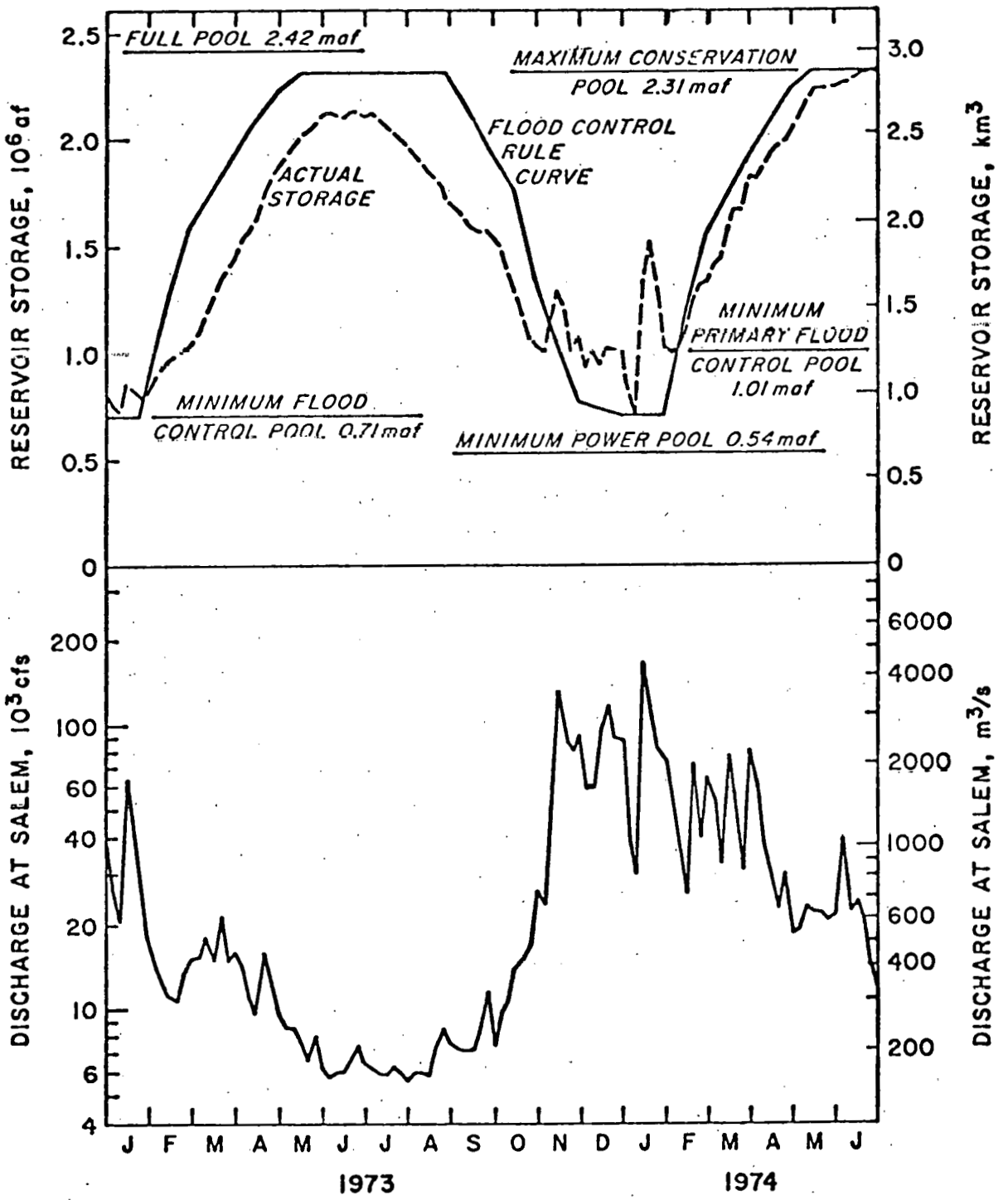


FIGURE 1. Willamette reservoir rule curve, storage (top), and discharge at Salem (bottom).

TABLE 1. Discharges and Treatment Costs

		TREATMENT LEVEL							
		A	B	C	D	E	F	G	H
Discharge (kg/d	BOD_5	192037	102614	42265	32124	22510	21661	21661	0
	KjdN	31660	26167	22541	21920	18031	16731	6253	0
Dollars (million)	Capital	154.72	174.96	233.65	248.33	303.62	312.66	317.10	
	OMR annual	4.41	5.30	7.28	8.16	9.29	10.31	10.67	
	Total annual	16.14	19.41	27.57	30.11	35.64	37.45	38.33	100
Direct Energy (TJ)	Capital	1928	2127	2702	2846	3477	3566	3609	
	OMR annual	218	249	328	363	415	467	479	
	Total annual	282	323	431	473	550	606	620	1600
Primary Energy (TJ)	Capital	7324	8508	11940	12799	15661	16190	16449	
	OMR annual	391	463	628	701	800	891	919	
	Total annual	669	800	1137	1253	1476	1593	1635	4000

To model reservoir operation, a no-augmentation base was identified and low, same and high level of augmentation were selected relative to the study year, 1973. A discharge of 88 m^3/s represents a typical unregulated Willamette dry-year low flow. A flow balance for August, 1973 indicates that without augmentation, this discharge would have taken place. Discharge above 88 m^3/s may therefore be designated as augmentation derived from reservoirs.

The August 1973 mean discharge of 186 m^3/s represents augmentation under presently-authorized operation. A 126 m^3/s discharge represents a level of decreased augmentation. An upper limit to augmentation from existing reservoirs was estimated to be 255 m^3/s (Heggen, 1978).

3. WATER QUALITY

For Willamette water quality modeling, dissolved oxygen has been determined to be an appropriate parameter (Hines, 1979). The dissolved oxygen quality of the Willamette River was simulated for each level of wastewater treatment at four levels of augmentation from reservoirs.

A water quality index parameter was taken to be the 10 percent lower confidence level of the difference between simulated dissolved oxygen and August, 1973 dissolved oxygen at 17 evenly-spaced stations from river km 8 to 84. A quality designated by an index of 0.3 mg/ℓ would indicate that 90 percent of these stations would be at least 0.3 mg/ℓ above the reported dissolved oxygen of 1973. Results of water quality simulation is summarized in Figure 2. Note that the actual 1973 water quality (index 0.00 at 186, D) could have been achieved by treatment slightly below secondary (level C) and high flow (255 m^3/s) or treatment in the tertiary range (above level G) and no augmentation (88 m^3/s).

4. DOLLAR COST ALLOCATION

The allocated reservoir cost for water quality is a function of the reservoirs' ability to reduce the need for alternative wastewater treatment

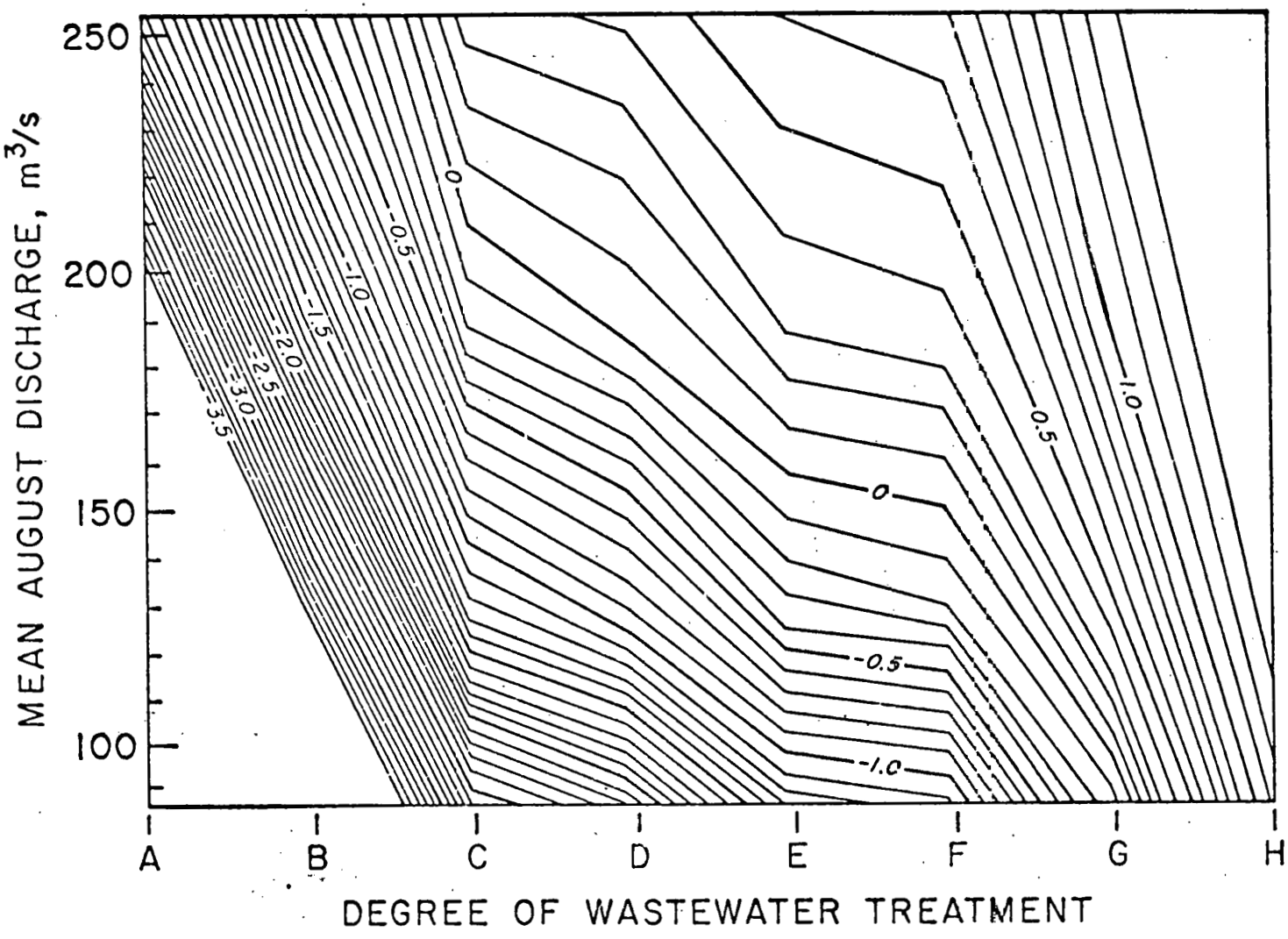


FIGURE 2. Dissolved oxygen index response surface, mg/ℓ.

facilities. This information may be taken from Figure 2, the water quality index response surface and Table 1, summary of treatment costs. Where a management plan of treatment and augmentation yields the same water quality as does a no-augmentation management alternative, the difference in treatment cost is the alternative water quality cost required in reservoir cost allocation. For example, cost of treatment in 1973 when discharge was 186 m^3/sec was \$30.11 million annually (level D). To maintain a 0 mg/ℓ water quality index without augmentation, discharge at 88 m^3/sec, treatment above level G would have been required. Were this level of treatment provided, cost would be \$42.54 million. Subtracting the alternative water quality cost is \$12.43 million (Heggen, in publication).

Using a standard seperable-cost, remaining-benefit cost allocation procedure, the reservoir cost allocatable to water quality control was determined for alternative management strategies of treatment and augmentation. These costs, along with treatment costs from Table 1 are given in Table 2.

TABLE 2. Treatment, Augmentation, and Total Annual Costs

(Million 1973 Dollars)

Mean August Discharge m^3/s	Treatment Level							
	A	B	C	D	E	F	G	H
255	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	3.66	2.14	5.93	6.00	6.41	6.55	8.87	
	19.80	23.68	33.50	36.11	42.05	44.00	47.20	100.00
186	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	1.76	2.14	2.73	3.04	4.31	4.28	7.87	
	17.90	21.55	30.30	33.15	39.95	41.73	46.20	100.00
127	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0.56	1.28	2.03	1.89	0.74	0.34	4.51	
	16.70	20.69	29.60	32.00	36.38	37.79	42.84	100.00
88	16.14	19.41	27.57	30.11	35.64	37.45	38.33	
	0	0	0	0	0	0	0	
	16.14	19.41	27.57	30.11	35.64	37.45	38.33	100.00

At the intermediate augmentation level employed in 1973 and with the actual level D treatment, the allocated annual cost is slightly over \$3 million. This represents approximately seven percent of the reservoir's total annual cost. This \$3 million achieves the same water quality that an additional \$12 million in treatment facilities would have achieved without augmentation.

5. ENERGY COSTS

Strategies of environmental control require energy both directly, as high grade fuel (coal, oil, gas) or power consumed in the final step of pollution control, e.g., electricity to build and operate reservoirs, and indirectly, as high grade fuels consumed to mine the iron, to forge the steel, to

fabricate the equipment, and to produce concrete.

To assess the energy impact of low flow augmentation, both direct and indirect energy requirements are of interest. Direct needs are of immediate concern within a region where power is in short supply. Indirect needs are of major concern to the economy as a whole, of which the region is but a part. It is necessary to reduce energy costs to a common unit. The fossil fuel equivalent "primary" joule is selected as a measure. This unit represents a joule of energy obtained from coal, oil, or gas wells. Where hydro or nuclear electricity is consumed, its fossil fuel equivalent is considered, i.e., the units of fossil fuels required to generate that quantity of electricity. Primary energy cost for any activity is the equivalent final cost of that activity to the world's fossil energy stock.

Input/Output analysis (I/O) is an application of general equilibrium theory to empirically interrelated activities. An open system is modeled as linearly interdependent sectors of production and consumption; coefficients relating each sector's output to inputs are assumed to be fixed. Perturbations of output from the total system yield shifts of production within the system. These internal shifts reflect the sector inflows and outflows necessary to satisfy new exogenous requirements, endogenous mass balance, and constant input-to-output factors.

The solved I/O energy model is of the form,

$$\underline{E} = \underline{\underline{\varepsilon}}\ \underline{Y}$$

where $\underline{E}$ = the primary energy consumed directly and indirectly

$\underline{Y}$ = the final demand in dollars for goods

$\underline{\underline{\varepsilon}}$ = a dollar-to-energy transformation, the "primary" energy coefficient

In addition, direct energy demand can be expressed,

$$\underline{E} = \underline{\underline{R}}\ \underline{X}$$

where $\underline{E}$ = the energy directly consumed

$\underline{X}$ = the total production in dollars of goods

$\underline{\underline{R}}$ = a dollar-to-energy transformation, the "direct" energy coefficient

I/O coefficients ε and R have been calculated (Herendeen, 1974). Values modified for the 1973 Willamette Valley study are shown in Table 3.

These dollar-to-energy coefficients may be applied to pollution control costs and energy costs result. Resulting treatment energy costs are given in Table 1. These costs, combined with allocated reservoir energy costs are illustrated in Figure 3.

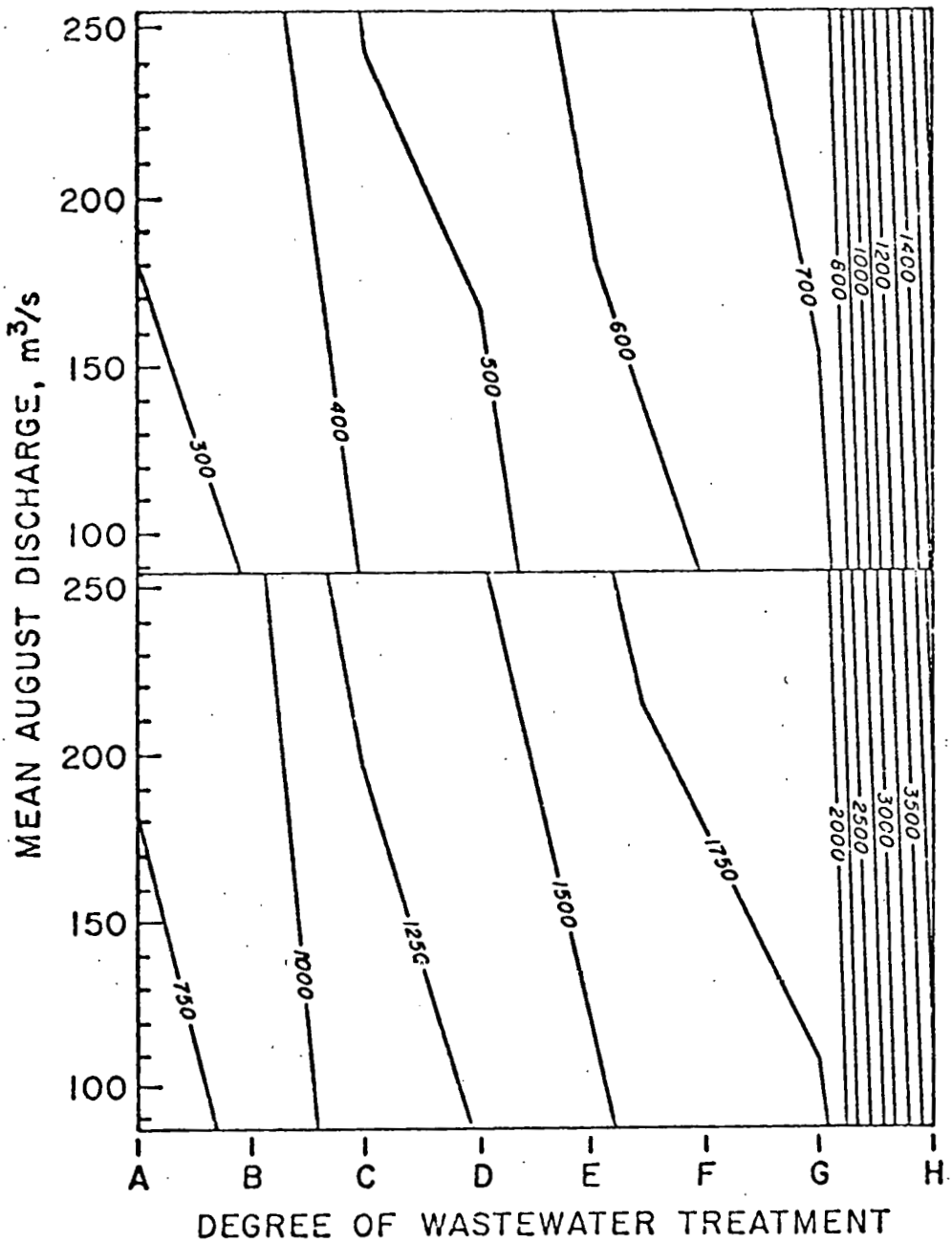


FIGURE 3. Annual direct (top) and primary energy cost (bottom) of water quality control response surfaces, TJ.

TABLE 3. Input/Output Direct and Primary Energy Coefficients

Activity	Construction MJ/1973 Dollar		OMR MJ/1973 Dollar	
	Direct	Primary	Direct	Primary
Municipal treatment	9.81	58.49	52.11	89.91
Interceptors, outfalls, lift stations	14.39	39.22	52.11	89.91
Industrial pretreatment	9.81	58.49	35.34	81.22
Industrial treatment	9.81	58.49	35.34	81.22
Reservoirs	12.48	40.76	16.29	31.10

6. DISCUSSION

Figure 3 and Figure 2 may be compared to judge the energy efficiency of water quality management alternatives. Management may be judged efficient if a given water quality is achieved with a minimal energy cost, or alternatively, if a given energy cost yields the highest water quality achievable with that energy. It is noted that while primary energy costs are approximately three times the direct cost, the likeness of the two response surfaces in Figure 3 indicates that basin management directed toward direct energy efficiency will be essentially in accord with primary energy efficiency and vice versa.

Efficient management indicates that augmentation should be maximized before secondary treatment is employed. As secondary treatment is upgraded (levels E, F, and G), a portion of augmentation might be cut back, as incremental improvement in water quality at this point is obtained more energy efficiently with plant improvement. If water quality is to be further improved, augmentation should again be maximized, as the marginal energy cost of treatment exceeds the marginal energy cost of augmentation for an incremental gain in water quality.

The current use of reservoirs for high, but not maximized releases for water quality protection represents an environmental strategy that is reasonably energy effective. Eighty direct TJ (220 primary) might be saved per year if augmentation were increased and some treatment energy had not been used. On the other hand, if the reservoirs were not employed, an annual additional 180 direct TJ (380 primary) would be required for treatment to achieve 1973 water quality.

It appears from the energy perspective that diseconomy of scale is substantial for water quality improvement above the 1973 level. As a rule of thumb, energy costs double with a 1 mg/ℓ improvement in river dissolved oxygen.

For continued environmental protection in the Willamette basin, flow augmentation provides marginal water quality benefits at three-fold less energy cost than does point source treatment.

If the direct energy used for pollution control (510 TJ) is compared to basin energy use for 1973 (350,000 TJ), between 0.1 and 0.2 percent of basin

power consumption went in 1973 for water quality management. For water quality's share of reservoir costs, 37 TJ were used. Of the 473 TJ used for treatment, 86 were used to halt discharges to the Willamette and 387 were used to treat discharges. Industrial pollution control required 166 TJ; municipalities, 307 TJ. Of this direct energy, 363 TJ were consumed in treatment operation and 147 TJ represented the fuels for annualized construction.

In 1973, 1373 equivalent TJ of fossil fuel were required to directly and indirectly support Willamette pollution regulation. The reservoirs' share of this total was 120 TJ. Of the 1253 needed for treatment tactics, 515 TJ were needed for industrial control and 738 TJ were required by municipalities.

It is suggested that policies of energy efficient wastewater management be of regional scope, encouraging pollution control tactics that achieve primary energy savings, not direct energy cost minimization. To illustrate from Table 3, a capital dollar spent on flow augmentation may entail an extra 2.67 MJ over the direct energy associated with a dollar for municipal treatment, but represents 17.33 MJ less energy consumption from the primary stockpile.

For a treatment plant to be truly energy self sufficient, it should generate enough excess energy to pay its primary energy cost. This is shown in Table 3 to be approximately three times its direct energy consumption. Thus a plant that just satisfies its OMR energy needs has achieved only a 1:3 energy benefit/cost ratio. In 1973, the reservoirs operated with an energy benefit/cost ratio of 17:1 (Heggen, 1978).

It should be noted that these energy-based conclusions are similar in nature to management conclusions based on dollar values alone. This suggests a scheme of hierarchal management in which dollar analysis might be used to initially identify superior alternatives, and energy analysis, the more difficult study, might be used for finer discrimination.

In summary, where low-flow augmentation is employed in concert with point-source wastewater treatment, the marginal energy cost of augmentation for water quality protection is seen to be below the marginal energy cost for treatment in this case study. This indicates that the role of augmentation might properly be expanded as further pollution control is called for. Energy analysis considering only direct power needs is inadequate for regional planning; analysis should account for the total or primary energy cost of any alternative.

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INNOVATIVE AND ALTERNATIVE TECHNOLOGIES FOR ENERGY UTILIZATION IN WASTEWATER TREATMENT PLANTS

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INTRODUCTION

According to the first law of thermodynamics, energy cannot be created or destroyed. It can, however, be used and recovered for use again. Wastewater treatment plants with high energy requirements and with a high potential for energy recovery should be prime targets for application of techniques for energy conservation, recycling, reuse, and for use of alternative energy sources. A number of energy sources such as anaerobic digestion, incineration, pyrolysis, waste heat recovery, heat pump, and solar energy are discussed here.

ANAEROBIC DIGESTION

Anaerobic digestion is the most commonly used process for stabilizing high-strength organic waste. Methane gas is produced during the anaerobic digestion of sludge. The volume of methane gas generated in anaerobic digestion is dependent upon the nature and volume of the wastes. Current data indicate that the amount of gas produced is 0.93 to 1.23 m^3/kg (15 to 20 ft^3/lb) of volatile organic matter destroyed (1). The gas produced usually contains 60 to 70 percent methane; the rest is mainly CO_2.

Digester gas can be used onsite for generation of electricity, and as fuel in internal combustion engines to drive pumps and blowers, and offsite in a natural gas supply system.

The overall heating value of the gas ranges between 22.6 x 10^3 and 26.4 x 10^3 kJ/m^3 (600 and 700 Btu/ft^3) (2). Thus, from 378.5 liters (100 gallons) of domestic sewage (daily average per capita use in the United States), approximately 686 kJ (656 Btu) of heat theoretically will be available. Utilization of digester gas in internal combustion engines to produce electricity and to drive pumps and blowers will reduce electricity production in power plants, which in turn will reduce fossil fuel consumption. Figure 1 shows the energy requirements for a digester gas utilization system. Figure 2 shows digester heat requirements for primary sludge. Table 1 presents the average total energy which can be obtained from digester gas. The net energy from the digester gas can be obtained by subtracting

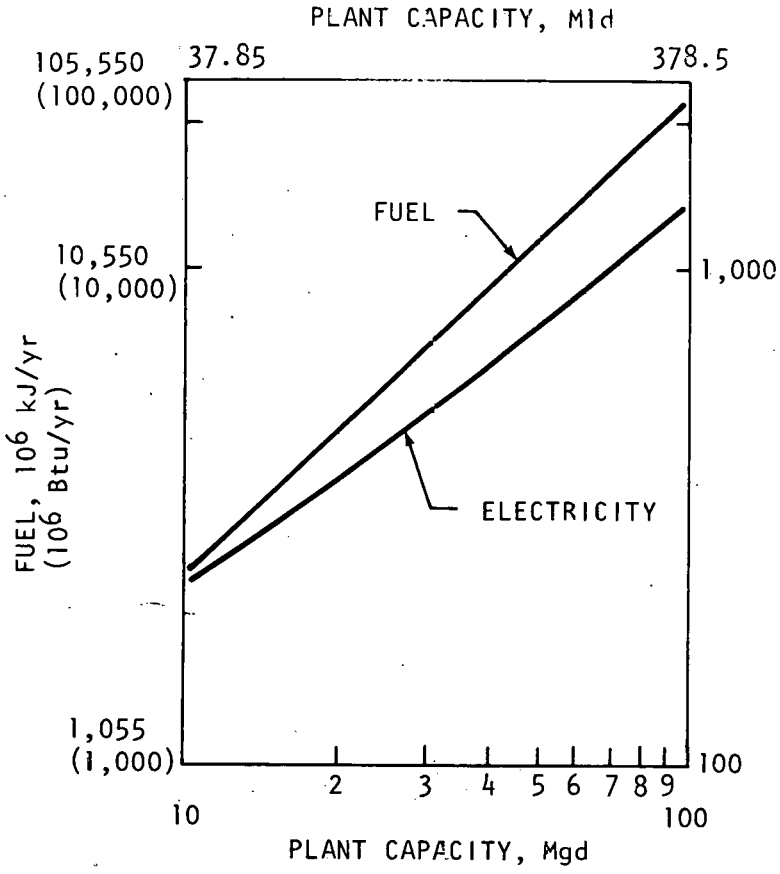


Figure 1. Digester Gas Utilization System Energy Requirements (1)

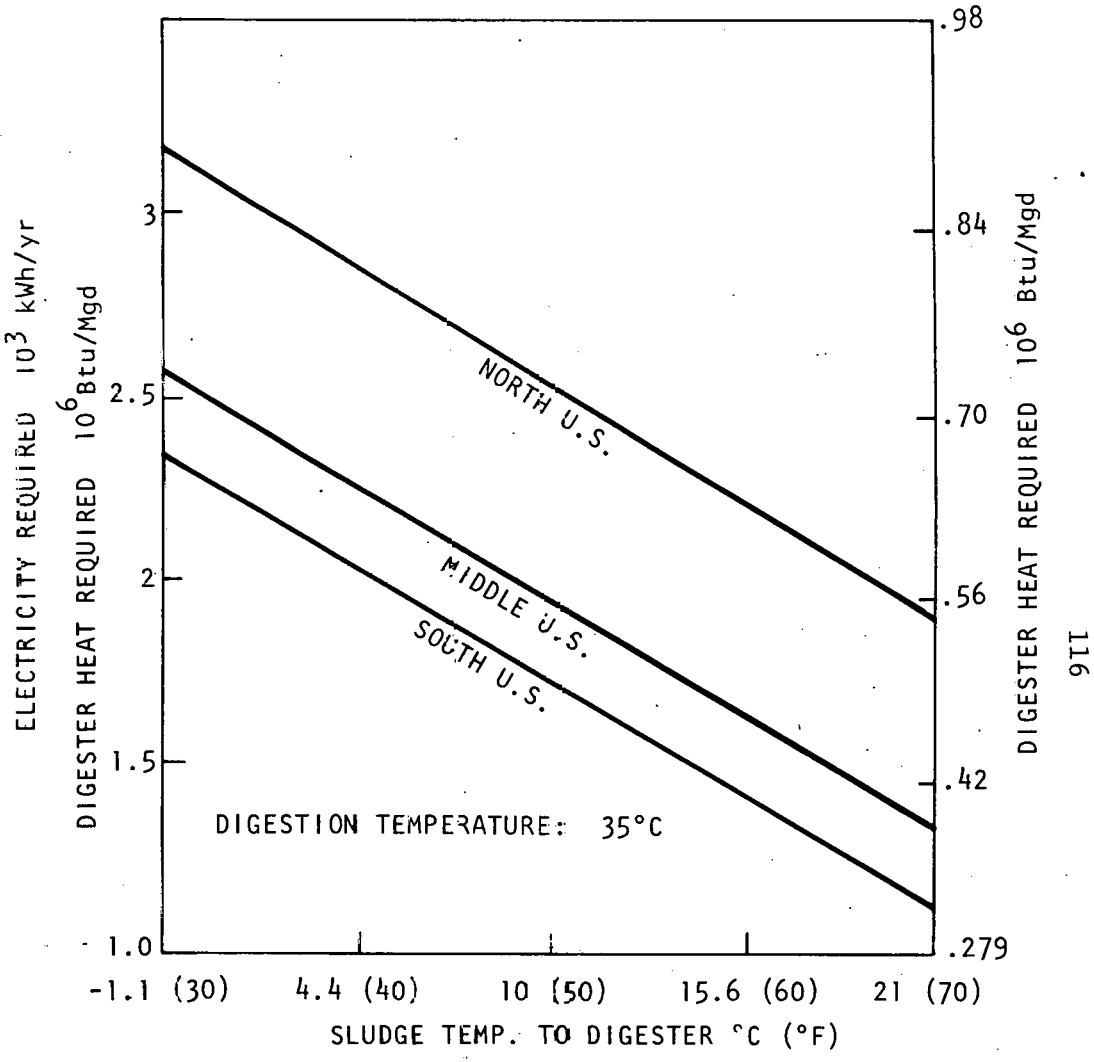


Figure 2. Anaerobic Digester Heat Requirements for Primary Sludge (1)

the gas utilization system energy requirement in Figure 1 and the heat requirement in Figure 2 from the energy yield in Table 1.

TABLE 1. DAILY ENERGY RECOVERY OF DIGESTER GAS PER 3.785 MLD (1 MGD) OF CAPACITY (2)

Total dry solids to digester	951 kg/day (2,096 lb/day)
Volatile solids destroyed	328 kg/day (723 lb/day)
Gas production	304 m^3/day (10,845 ft^3/day)
Heat available	6.86 MkJ/day (6.5 MBtu/day)
Power IC engine, hp	38
Power engine generator,kW	24
Heat recovery, IC engine	1.71 MkJ/day (1.62 MBtu/day)

The construction cost, as well as the operation and maintenance cost of anaerobic digesters per unit of wastewater flow, decreases with increasing size. For fuel generation alone, anaerobic digestion does not appear to be economically feasible (3). However, production of anaerobic digester gas in a wastewater treatment plant will minimize usage of energy from outside sources. It has been estimated (3) that for a 378.5 Mld (100 Mgd) plant, assuming that the generating facility operates 80 percent of the time, the unit electricity cost is $0.006/MJ ($0.022/kWh). A similar calculation for a 37.85 Mld (10 Mgd) plant gives $0.144/MJ ($0.04/kWh) as the unit electricity generation cost.

Anaerobic digestion of municipal sludge has great potential for complementing current efforts in the disposal of waste. It will help minimize environmental impacts on sludge removal and foster a resource conservation ethic. While the use of digester gas in internal combustion engines can create objectionable noise, the noise level can be reduced by using engine silencers.

INCINERATION

Sludge incineration involves drying and combustion. Drying and combustion can be performed in separate units or in one furnace. The heat generated by the incineration of sludge can be utilized for heating and drying of incoming sludge, production of steam for space heating, powering mechanical equipment, or generating electricity.

The heat produced from incineration can be recovered as steam and reused. Auxiliary fuel may be needed for the incineration of sewage sludge. Figure 3 illustrates the heat recovery from an incinerator as a function of the flue gas temperature and the type of sludge incinerated.

The potential air pollutant emissions from the incineration of municipal sewage sludge are combustible gases or vapors, particulates, and inorganic gases. Proper design of the furnace system and careful operator control are required for the abatement of emissions. The advantage of incineration is that the sludge problem is handled onsite, thus greatly reducing the pollution resulting from transportation.

Reference 4 indicates that for a multiple hearth incinerator, for a wet sludge feed of 453 kg/hr (1,000 lb/hr), the construction cost is $1.3 million, the operation and maintenance labor requirements are 2,300 hours per year, and maintenance material costs are $5,000 per year.

PYROLYSIS

Pyrolysis is the decomposition of organic matter in the absence of oxygen (or in an oxygen-deficient atmosphere). Gas, oil, char, and water vapor are produced by the reaction. Pyrolysis can generally be classified into two processes. The first process, true pyrolysis, operates by applying heat external to the reaction chamber. The second process, called partial combustion and gasification, requires the addition of small amounts of air or oxygen into the reactor.

Figure 4 shows the energy that can be recovered by pyrolysis in a rotary kiln reactor. The figure indicates that the net energy output is increased as the ratio of the amount of refuse to sludge is increased. Also, if the feed to the reactor consists solely of sludge, then there is no net energy output.

One of the most often cited advantages of pyrolysis over incineration is the system's reduced potential for air pollution. However, onsite waste heat boilers may create emission problems. Chars produced are a potential pollution source. In certain systems, slagging pyrolysis processes produce a sterile, inert frit which should reduce the waste disposal problem. However, if this material is quenched, it may create problems of liquid effluent disposal.

Since pyrolysis is in the developmental stage, the economics are not well defined. It has been estimated (5) that the capital cost for a pyrolysis system ranges from $12,128 to $69,460 per metric ton-day ($11,000 to $63,000 per ton-day) and annual operating and maintenance cost is approximately $20 per metric ton ($181 per ton). A system that would handle 453

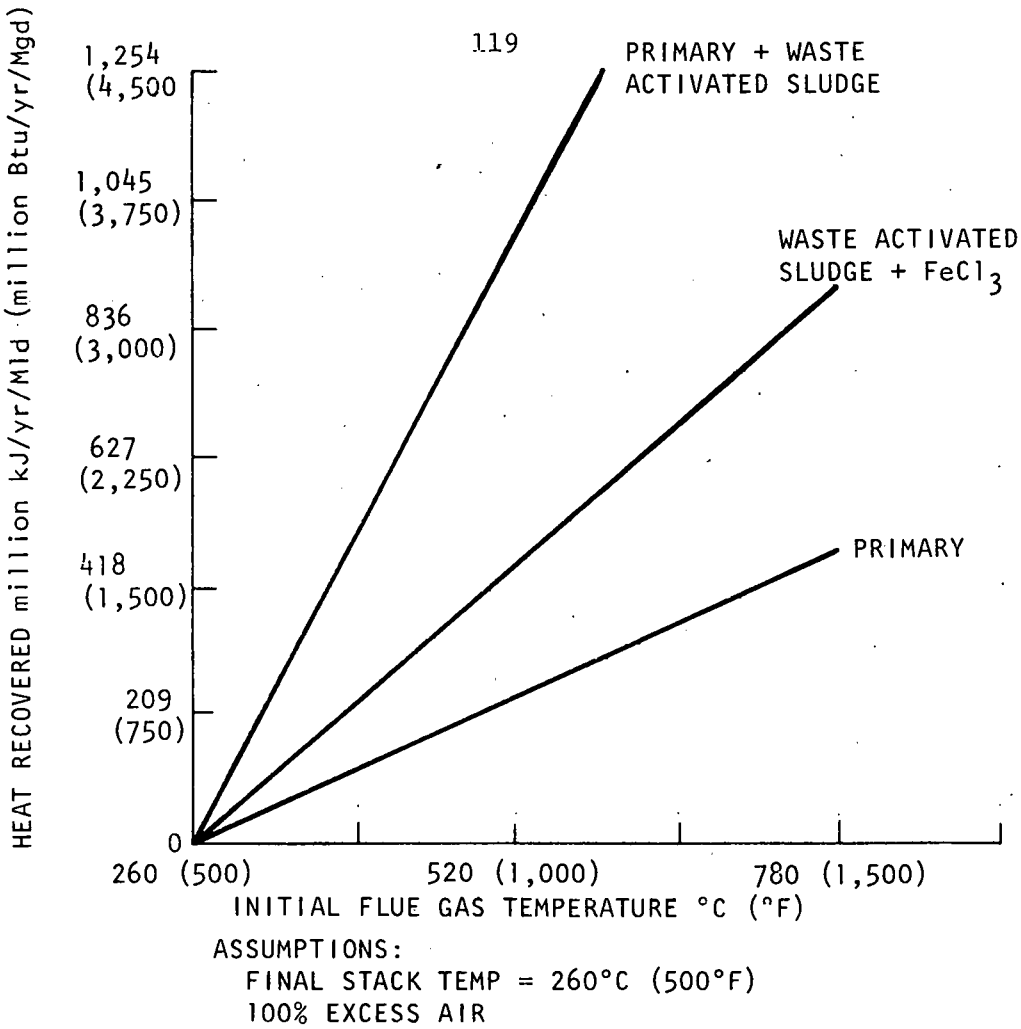


Figure 3. Heat Recovered from Incineration of Sludge (4)

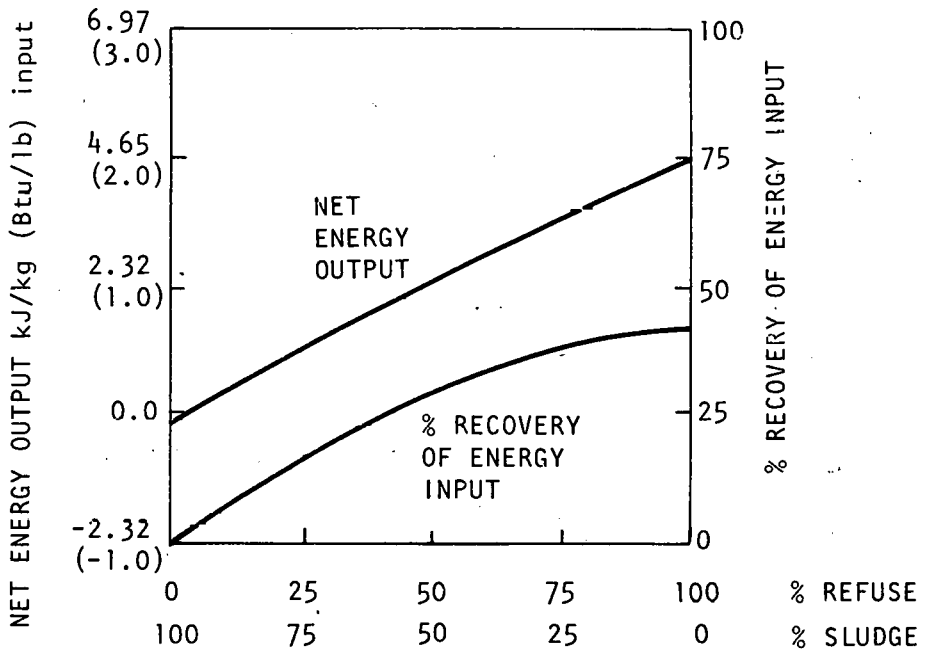


Figure 4. Energy Recovery Rotary Kiln Reactor Pyrolysis System (4)

kg/hr (1,000 lb/hr) of sludge, on a 50 percent sludge-to-refuse basis would have a construction cost of approximately $1.4 million and an operating cost of about $15,000 per year.

WASTE HEAT RECOVERY

Heat recovery units can be used to recover waste heat from the jacket cooling water and exhaust gas of internal combustion engines for use in space heating, water heating, and process heating. Heat recovery has been used successfully for many years, particularly with large slow-speed engines. The use of heat recovery equipment will increase the overall efficiency of the process.

Another device for recovering waste heat is the energy wheel. In a wastewater treatment plant, there are many areas where large volumes of outside air are required for ventilation. This air eventually becomes contaminated and cannot be recirculated. The entire amount of incoming air must be heated. The energy wheel, a rotary air-to-air heat exchanger, recovers the heat from the contaminated air before it is exhausted. The wheel rotates through the exhaust air stream and draws in heat. The contaminated air is purged and the wheel rotates through the outside air stream, where it gives up the heat.

In an internal combustion engine, approximately 30 percent of the total heat input is rejected to the exhaust and approximately 20 percent to the jacket cooling water.

Recovery of the waste heat will increase the overall efficiency of the internal combustion engine. The energy wheel recovers heat from contaminated air, reduces size requirements for heating equipment, and saves energy. However, the energy wheel requires a hot gaseous waste stream to operate effectively.

The reuse of waste heat reduces thermal pollution created at the wastewater treatment plant. Less fuel and/or electricity will be consumed at the wastewater treatment plant. Since most exhaust heat recovery units act as silencers, noise levels emanating from the engines will also be reduced.

At the Cleveland Southerly Waste Treatment Center, use of an energy wheel permits an annual saving in fuel costs of approximately $8,000, based on an 1,800-hour year (6).

HEAT PUMP

The treated effluent discharge from a wastewater treatment plant contains a relatively large amount of energy which can be recovered and reused or recycled. It is an excellent source of heat for the heat pump. In areas where the winter temperature is low, the effluent will usually have a significantly higher temperature than the ambient air. In such cases, the heat pump system can probably recover enough heat to supply the space heating needs of the plant (6).

Use of the heat pump system helps to recover some of the heat which would otherwise be lost in the wastewater effluent. The heat pump system can provide a three- to five-fold increase in kJ/hr/kW (Btu/hr/kW) when compared to direct electric resistance heating (6). Figure 5 shows the energy requirements of heat pumps, assuming 1,000 operating hours per year.

The environmental impact of the heat pump, if any, appears to be positive rather than negative. It aids in reducing the temperature of the effluent wastewater. The working fluid (a possible environmental contaminant) is sealed in the system to prevent leakage.

A measure of the economic impact can perhaps be made by comparing the fuel costs of an oil-fired heating system with the energy costs of a heat pump system. It has been estimated (6) that at current prices, the cost for generating one million Btu per hour of heat is $5.32 using oil and $3.72 using an electric heat pump. Wesner, et al. (4) estimated that for a 1,055 kJ/hr (1,000 Btu/hr) water-to-water/water-to-air heat pump, the construction cost is $34,000, the operation and maintenance labor requirement is 1,800 hours per year, and maintenance-material cost is $1,000 per year.

SOLAR ENERGY

Solar energy can be utilized for heating anaerobic digesters. Raw sludge is warmed by injection into a solar heat storage tank/heat exchanger. The preheated sludge then enters the digester. Use of solar energy to maximize gas production and minimize the time of digestion increases the available energy for onsite utilization. Sewage sludge digestion is often heated by burning fuels such as digester gas or oil -- utilization of solar energy would decrease the amount of gas or oil required for digester heating and thus conserve these products for other power generation. A number of different methods of adding solar heat to digester systems have been investigated (8), such as:

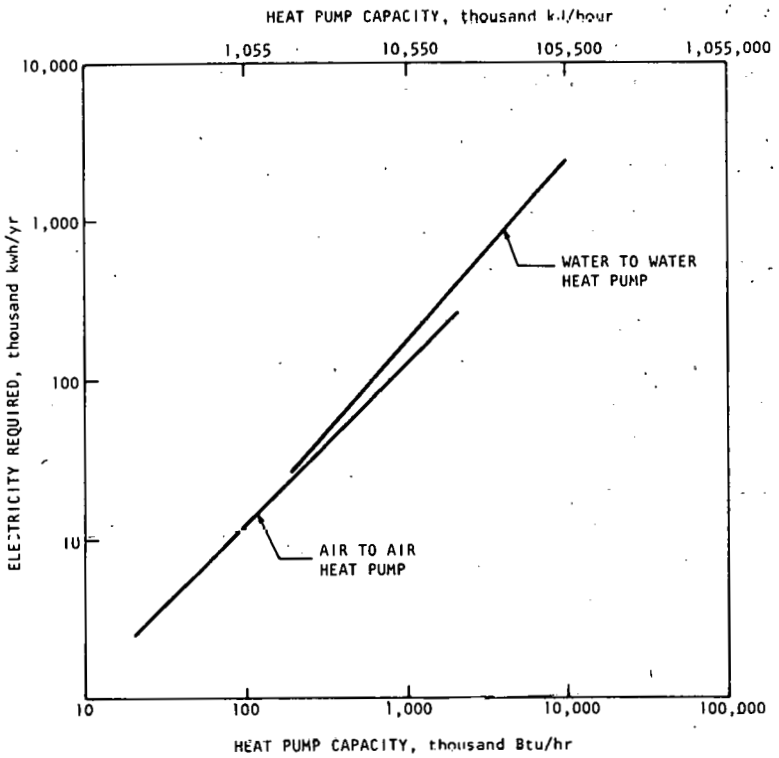


Figure 5. Heat Pump Energy Requirements (4)

- Sludge, either raw or partially digested, pumped directly through a solar collector
- Sludge heated by solar-heated water circulated within the digester
- Cold, raw sludge heated prior to entering the digester
- Recycling sludge from the digester to a solar heat exchanger
- Combinations of the above methods.

Preheating of the raw sludge appears to be the method by which the sludge temperature can be maintained with least problems (7).

Solar energy may also be used for running pumps in a wastewater treatment plant. A parabolic, tracking solar collector heats water which supplies the input energy to the power package through heat exchangers and is then recirculated to the collectors in a closed-loop system. That thermal energy heats liquid freon until it becomes a gas which runs the turbine powering the pump.

Solar energy can be collected in various ways for space and water heating in wastewater treatment plants. A solar collector faces south and heats cold water in a heat exchanger. The heated water is stored in a tank. The water from the supply system is heated by passage through the storage tank. During insolation periods, water is pumped through the heat exchanger and solar collector. Space heating can be accomplished by passing the hot water to hot water heating coils.

The usage of solar energy is expected to create no adverse environmental impact at the treatment plant. Electric power demand will be reduced, thus reducing tho fuel burned at power plants. This will reduce air pollution, water pollution, and solid waste disposal problems at the power plants. Utilization of solar energy for space heating applications does not require any new types of materials, and reduces pollution.

A recent study (8) concludes that heating anaerobic digesters by solar energy is economically feasible. Costs of solar systems vary considerably. Custom-designed systems could cost as high as $\$860/m^2$ ($\$80/ft^2$). The commercial flat-plate collectors are between \$43 and $\$161/m^2$ (\$4 and $\$15/ft^2$). The total flat-plate collector system cost for the expensive models is about $\$269/m^2$ ($\$25/ft^2$) which includes auxiliaries and installation (4).

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ENERGY USE IN SECONDARY WASTEWATER TREATMENT PLANTS[a]

Henry H. Benjes, Jr.[b]

The energy used in wastewater treatment is only one consideration in process selection and generally has been of secondary concern. In the actual operation of wastewater treatment facilities, the progressive requirement for better quality and the increasing unit cost for energy has resulted in energy use becoming a larger and larger portion of the operating budget. The amount of energy required to achieve secondary treatment has been reported to vary from 750,000 kilowatt hours/million gallons per day/year (kwh/mgd/yr) to 2,500,000 kwh/mgd/yr, depending upon the process used (1). The wide range in energy requirements is an indication that energy use may be affected greatly by the process selected.

This presentation provides relative energy use for unit processes typically used in secondary treatment plants and a comparison of energy use by competing secondary treatment processes. The relative energy use for different functions in a secondary treatment plant is shown on Figure 1. The major requirement and the area of potential major energy savings is biological treatment and sludge disposal.

The scope of this presentation is limited to liquid treatment process and excludes energy use by sludge disposal processes. However, the general liquid process used will influence the appropriateness of the process selected for stabilizing and disposal of biological sludges.

EFFECT OF BIOLOGICAL TREATMENT PROCESS ON SLUDGE PROCESS

Any form of suspended growth treatment will result in a sludge that is less dense and more difficult to concentrate than will an attached-growth system. Also, with suspended growth systems, it is not acceptable practice to waste excess biological sludge to the primary clarifier for co-settling, while it is acceptable with attached growth biological treatment systems to do so. The

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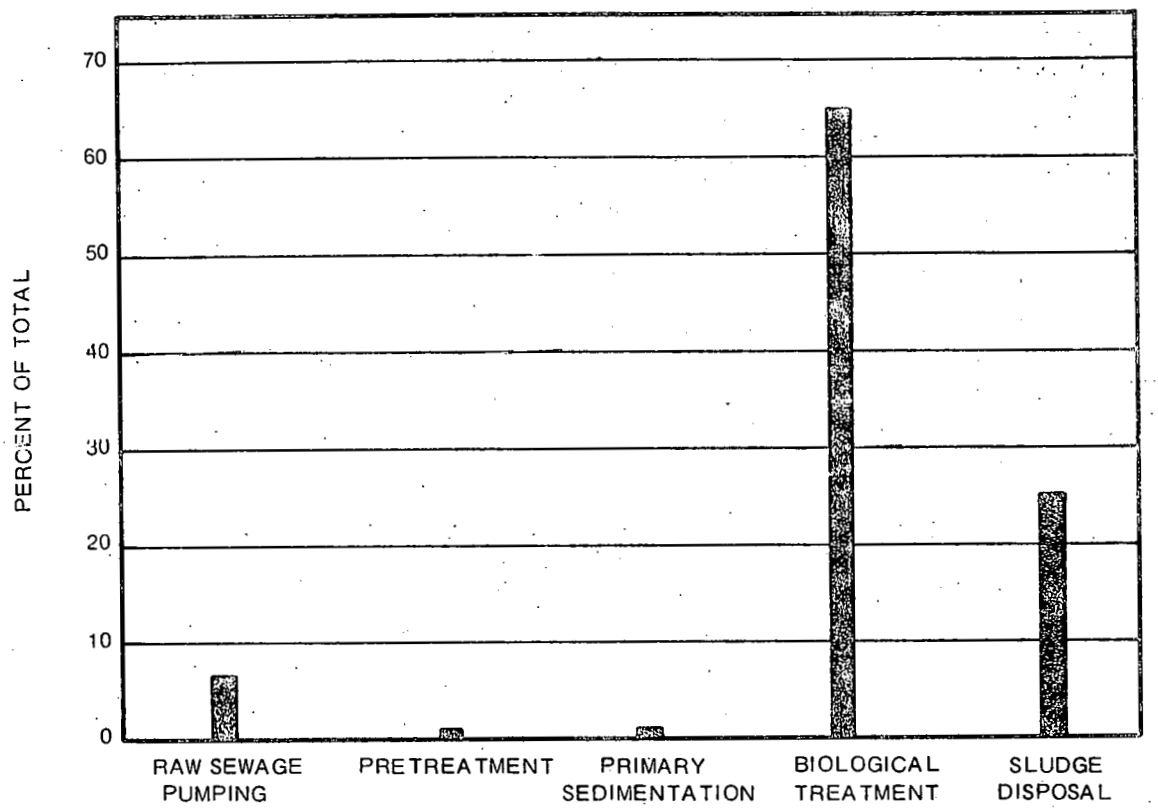


Figure 1. RELATIVE ENERGY REQUIREMENTS FOR SECONDARY TREATMENT PLANT FUNCTIONS

significance of the different character of the waste sludge on energy use is best reviewed by example.

Consider the solids stabilization/disposal system shown on Figure 2. The trickling filter process may be arranged to waste the excess biological solids to the primary clarifier for co-settling and thickening and subsequent anaerobic digestion. The sludge mixture is co-digested and typically concentrated by clarification in a second digester. The thickened sludge is hauled to disposal and a supernatant returned to the liquid process. The supernatant is generally troublesome, causing extra organic loading on the liquid process and should be accounted for in the design. A sludge concentration of three to five percent is typically hauled.

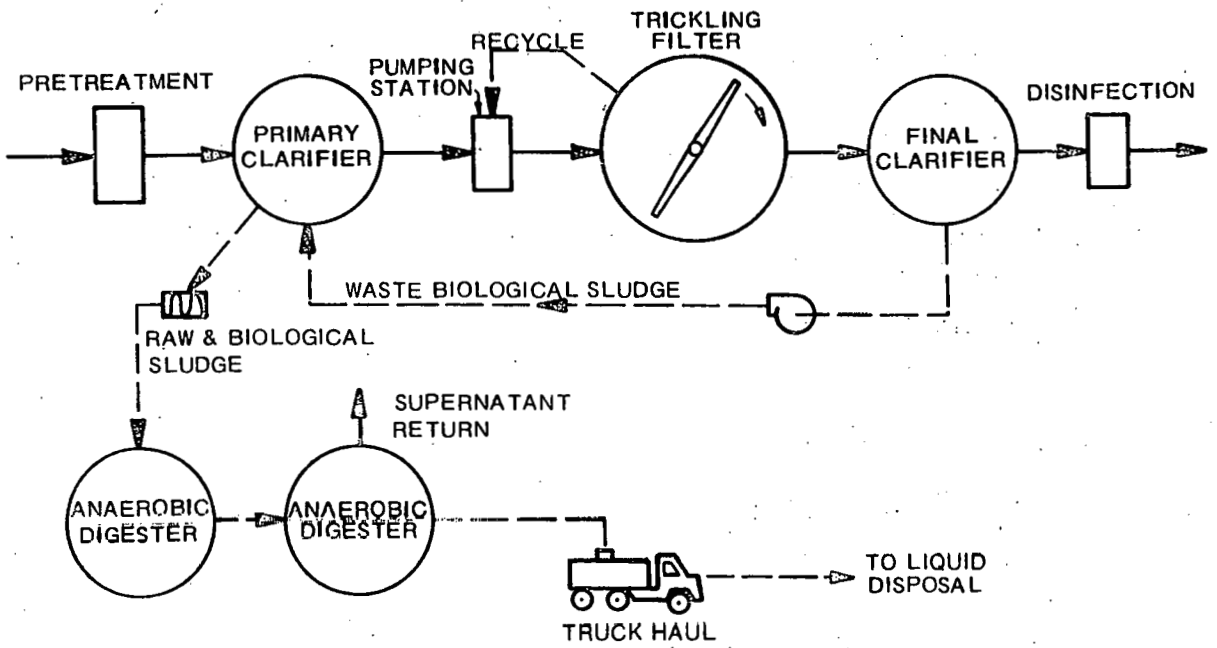
The suspended growth process, on the other hand, keeps the waste biological sludge separate from the raw sludge until entree to the anaerobic digester. Since no supernatant separation will occur in the anaerobic digester, it is necessary to concentrate the waste biological sludge prior to digestion. No second digester need be provided except for sludge storage, which may be included in the design features of the primary digester. A sludge concentration of about three percent dry weight solids is typically hauled.

The relative energy use for these two processes is shown on Table 1. For the purposes of this example, the suspended growth waste biological sludge thickening is provided by using a liquid/liquid solid bowl centrifuge which requires no chemical aid. For this example, the extra energy requirement for sludge processing and disposal associated with a suspended growth system is about 12 percent greater than that for an attached growth system.

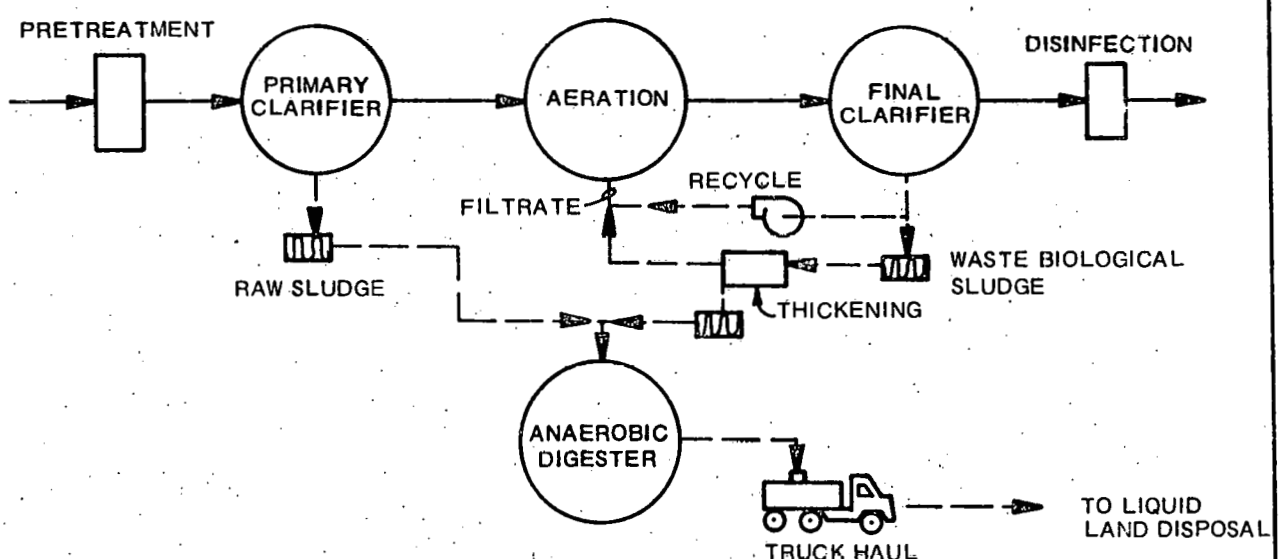
It is intended that this example provide a perspective for examples which follow. The energy use for the biological treatment process alone does not reflect a complete picture; the biological treatment process selected will affect the process applicable for sludge processing and, consequently, the energy usage.

BIOLOGICAL TREATMENT

Energy use by biological treatment processes will be reviewed for four processes:



ATTACHED GROWTH PROCESS SCHEMATIC



SUSPENDED GROWTH PROCESS SCHEMATIC

Figure 2. BIOLOGICAL WASTE TREATMENT SCHEMATICS

TABLE 1

SLUDGE DISPOSAL ENERGY REQUIREMENTS

10 MGD FLOW RATE

Attached Growth	1000 kwh/year
Waste Biological Sludge Pumping 50 gpm @ 25 feet TDH	4
Raw Sludge Pumping 23 gpm @ 40 feet TDH	3
Digester Mixing 60 hp	436
Digester Heating 3500 x 10^6 Btu/year	1018
Sludge Hauling 7.5 mg/year 10,750 gallons fuel	470
Equivalent Energy Total	1931
Per mgd	193

Suspended Growth	
Waste Biological Sludge Pumping 50 gpm @ 25 feet TDH	4
Raw Sludge Pumping 23 gpm @ 40 feet TDH	3
Waste Sludge Thickening 50 gpm	145
Thickened Sludge Pumping 8 gpm @ 40 feet TDH	1
Digester Mixing 60 hp	436
Digester Heating 3500 x 10^6 Btu/year	1018
Sludge Hauling 10.2 mg/year 14,600 gallons fuel	640
Equivalent Energy Total	2247
Per mgd	225

- Trickling Filters
- Activated Sludge
- Rotating Biological Contactors
- Trickling Filters in Series with Activated Sludge

The process design of the above processes has been outlined and the energy use associated with each process estimated (2).

TRICKLING FILTERS

Trickling filters in this presentation refer to stationary media where the wastewater and recycle water are passed over the media. The energy use included in the examples provided are associated with wastewater pumping and the final clarifier sludge collection drive. The wastewater pumping is by far the greatest use of energy and is a function of the height of the media and the flow rate.

Rock media trickling filters are generally shallow in depth and have large surface areas. When the surface wetting rate is high, the media performs better than when the surface wetting rate is low. However, greater surface wetting rates are accompanied by greater energy requirements. To use lower wetting rates, greater trickling filter volumes are required. A relationship for rock media trickling filters is shown on Figure 4 indicating the annual energy use for trickling filters of varying volume, and a related variation in pumping to produce an equivalent effluent quality. Influent waste strength (BOD_5) to the trickling filter is 135 mg/l and the effluent waste strength (BOD_5) is 30 mg/l.

Trickling filters using fabricated media are similar in concept to rock media trickling filters, but are constructed to greater depths and have higher unit wetting rates (higher pumping rates). Unlike the rock media trickling filter which is designed for widely varying wetting rates, the fabricated media trickling filter is normally designed at 0.75 gpm/sq ft or more. The comparable energy requirement for fabricated media trickling filters is also shown on Figure 3.

If the trickling filter is used to provide something less than secondary effluent quality, the energy requirement is reduced greatly. The energy

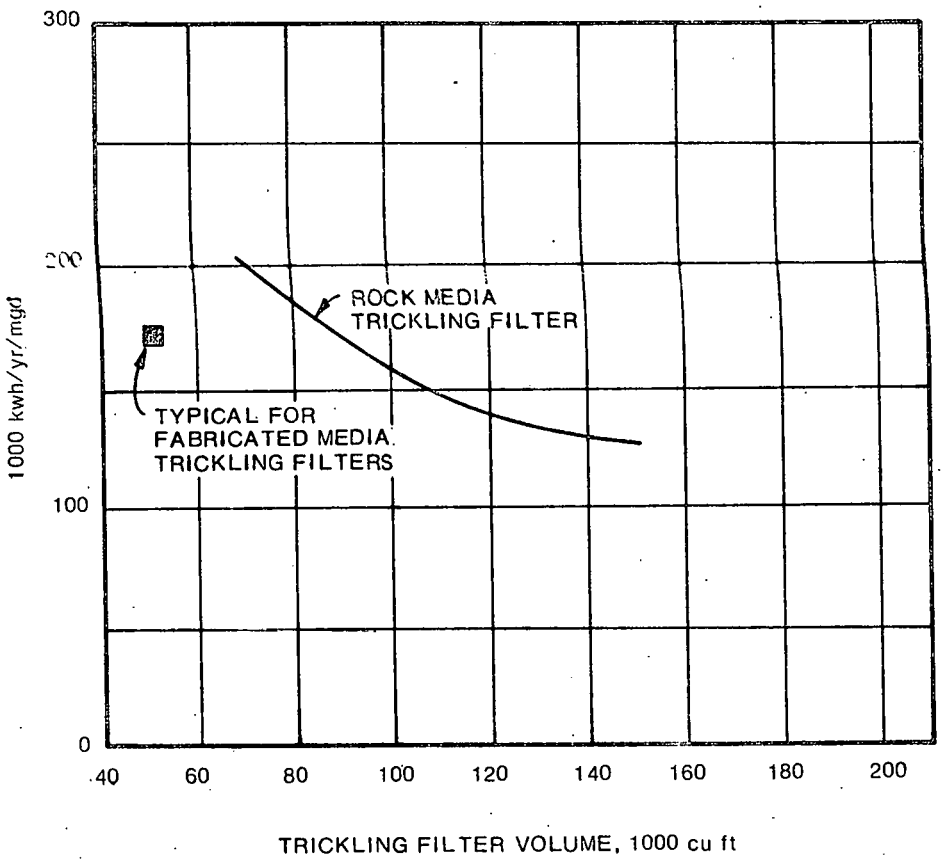


Figure 3. VARIATION IN ENERGY REQUIRED FOR REACHING SECONDARY EFFLUENT QUALITY WITH TRICKLING FILTER

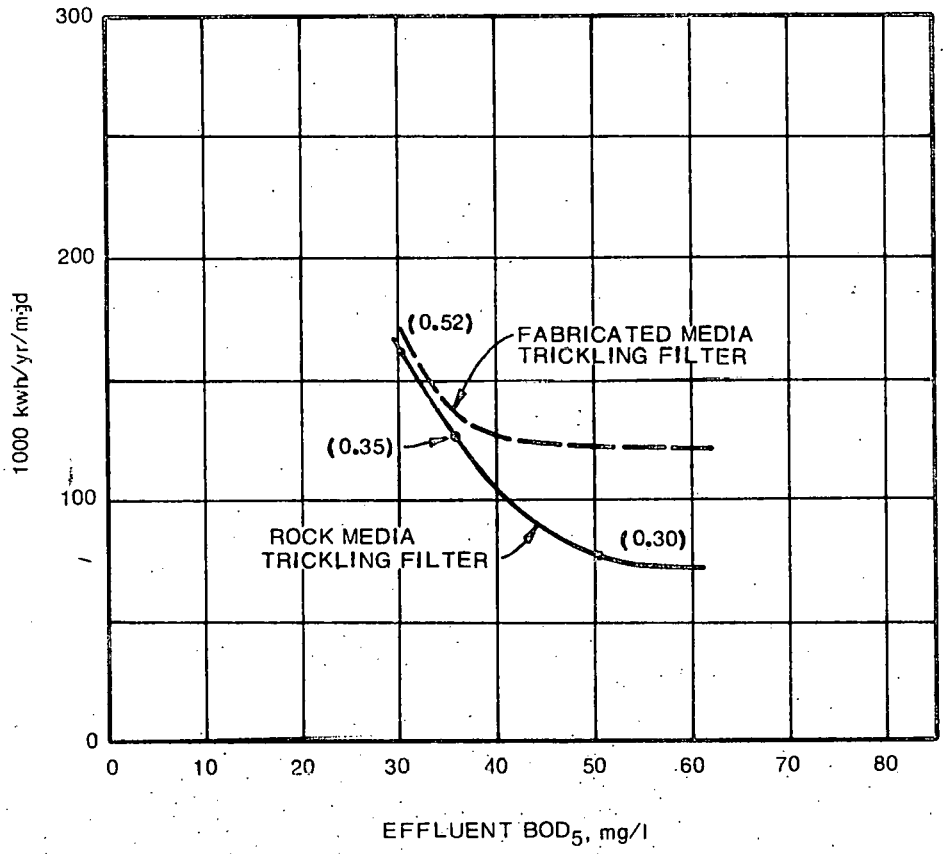


Figure 4. ENERGY REQUIREMENT FOR VARYING EFFLUENT QUALITY FROM TRICKLING FILTERS.

requirements for trickling filter processes at varying effluent qualities are shown on Figure 4. The values in parenthesis represent the unit energy use per pound of BOD_5 removed (kwh/lb BOD_5). The higher requirement for effluent quality results in greater unit requirement for energy.

ACTIVATED SLUDGE

The energy required for activated sludge processes includes energy for oxygen transfer (aeration), return sludge pumping and the final clarifier drive mechanism. Oxygen transfer is a function of the applied BOD_5 and the solids retention time in the system. For conventional secondary treatment systems, the oxygen required is about 1.1 pounds of oxygen per pound of BOD_5 applied. The energy requirement for oxygen transfer depends on the type of aeration device used. The efficiency of various aeration systems has been reported to be (3,4) as follows:

	Clean water kwh/lb O_2 transferred	Wastewater kwh/lb O_2 transferred*
Surface aeration (low speed units)(3)	2.5	1.50
Surface aeration (high speed units)(3)	2.0	1.20
High purity oxygen (PSA)(4)	1.77	1.07
High purity oxygen (cryogenic)(4)	2.38	1.44
Diffused aeration coarse bubble (3)	1.5	0.90

*Based on $\alpha = 0.80$, $\beta = 0.95$, dissolved oxygen = 2.0, temp. = $20^{\circ}C$

For an influent waste strength of 135 mg/l, the unit energy required (kwh/mgd/year) is shown on Table 2. The return sludge flow rate is assumed to be 50 percent of the raw waste flow and the final clarifier drive mechanism energy usage is taken to be 5000 kwh/mgd/year.

TABLE 2

ENERGY REQUIREMENTS FOR ACTIVATED SLUDGE USING VARIOUS AERATION DEVICES

1000 KWH/YEAR/MGD

	Mixer	Blower	Return Sludge	Clarifier	Total
Submerged Turbine	229	128[1]	21	5	383
Surface Aeration (Low Speed)	274	-	21	5	300
Surface Aeration (High Speed)	343	-	21	5	369
High Purity Oxygen (PSA)	148	120	21	5	294
High Purity Oxygen (Cryo)	148	81	21	5	255
Diffused Air (Coarse Bubble)	-	456	21	5	482
Diffused Air (Fine Bubble)	-	295[2]	21	5	321

[1]Assumed 14% transfer to sewage
[2]Assumed 6% transfer to sewage

ROTATING BIOLOGICAL MEDIA

Rotating biological media is provided with mechanical drive or air assisted rotation. The rotating media, using standard density media, results in using 925,000 square feet of effective surface area per million gallons treated (2). No liquid recycling is required. The amount of energy required for mechanical driven and air driven rotating media is:

	1000 kwh/mgd/year		
	Rotating Media	Clarifier	Total
Mechanical Driven Media	295	5	300
Air Driven Media	371	5	376

TRICKLING FILTER IN SERIES WITH ACTIVATED SLUDGE

In treatment systems, the effluent quality from trickling filters is difficult to predict and high effluent quality is difficult to achieve; however, the trickling filter does require less energy than activated sludge systems as shown by the preceding information, especially when lower quality trickling filter effluent quality is produced. As a compromise to reduce energy requirements and to retain the capability to produce a high effluent quality, the coupled trickling filter/activated sludge process has often been used.

The trickling filter precedes the activated sludge process reducing the oxygen demand substantially and the activated sludge process energy requirements are reduced to that necessary to stabilize the balance of the organics. The process always provides the trickling filter first in the series and no intermediate clarification is provided. A schematic is shown on Figure 5. Typical energy requirements are as follows for an influent waste strength of 135 mg/l of BOD_5.

	KWH/Year/MG
Trickling Filter Recirculation	113
Activated Sludge Oxygen Supply*	150
Return Sludge Pumping	21
Final Clarifier Drive	5
TOTAL	289

*Surface aeration

SUMMARY

The general requirements for secondary treatment processes have been presented for various competing processes. The comparable energy requirements are shown on Figure 6. Energy requirements are one consideration in the selection of a secondary treatment process. Capital and other operating costs also require serious consideration; however, the continuing social and political concern to reduce energy usage will increase the amount of consideration given to energy used by competing processes.

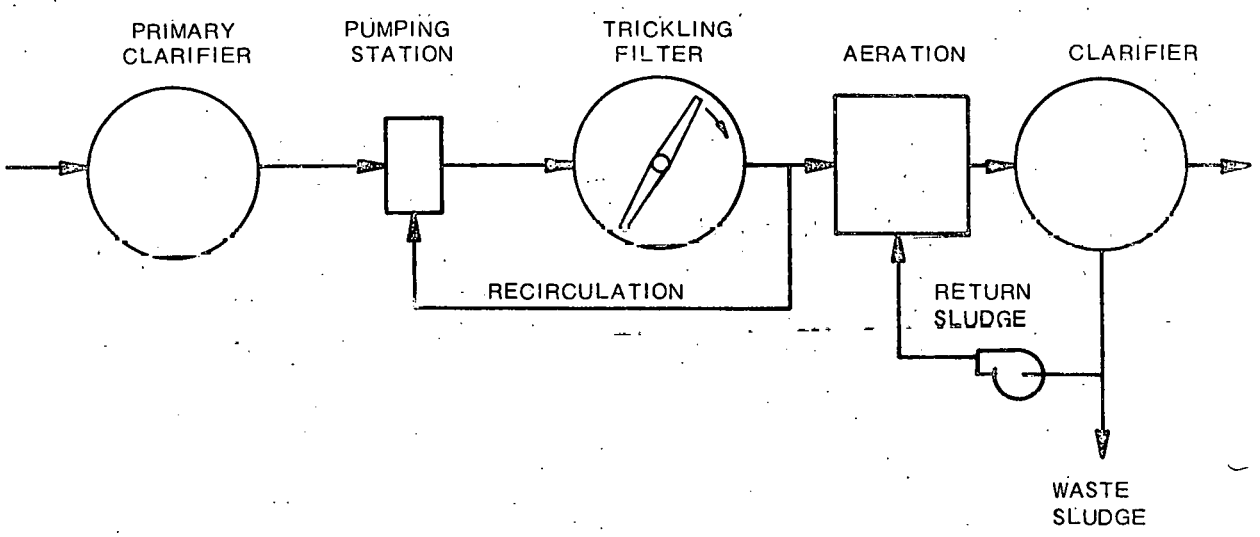


Figure 5. COUPLED TRICKLING FILTER / ACTIVATED SLUDGE SCHEMATIC

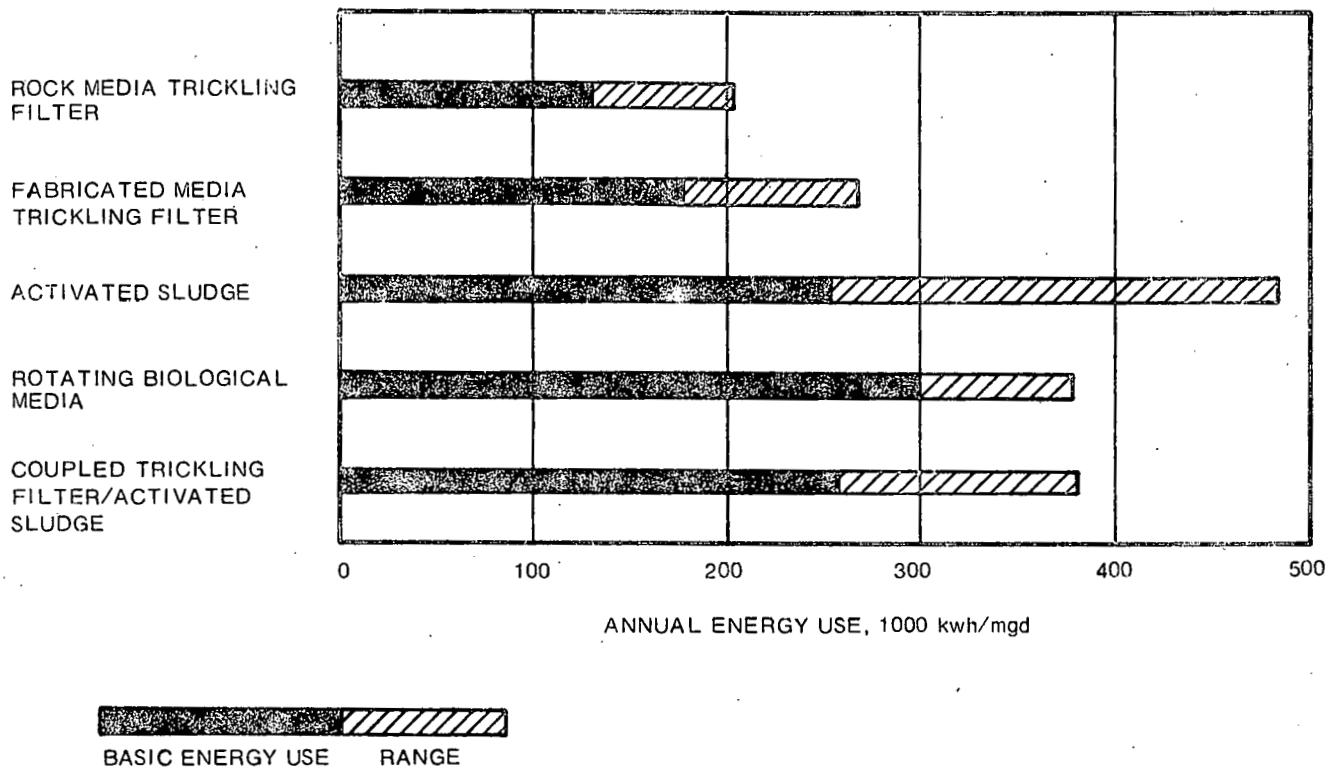


Figure 6. COMPARISON OF ENERGY USE BY COMPETING SECONDARY TREATMENT PROCESSES

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ECONOMIC ASSESSMENT OF DIGESTER GAS UTILIZATION

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Ever since it was recognized that a combustible gas was produced when sewage solids were digested anaerobically, the gas has been put to beneficial use. As early as 1895 gas was collected from septic tanks and used for lighting in the City of Exeter, England (Metcalf and Eddy, 1972). Anaerobic digestion and gas utilization began in this country early in this century. Digester gas was typically used to heat the digester and plant buildings, but energy requirements of early treatment facilities were low, so complete utilization of the gas was not required. When more energy-intensive treatment technologies, such as activated sludge, began to be applied, alternate energy forms were relatively inexpensive and the digester gas resource was often overlooked. This price competition actually caused a decrease of digester gas utilization during recent decades (Galwardi, 1975). With the dramatic cost increases of fossil fuels in recent years, digester gas has become an economically viable energy resource when used in certain applications.

Many schemes of utilizing digester gas have been applied or proposed. The myriad of technically feasible end uses are constrained by the capital cost of providing gas utilization equipment and by the fact that standby fuel sources would still be required. Offsite uses are constrained by the proximity of the user to the treatment plant and the cost of alternate sources of energy.

The purpose of the research described in this paper was to estimate the extent of utilization within wastewater treatment plants and compare the economics of three common utilization schemes on a generic level. The review of existing utilization draws heavily on a survey conducted by Spencer et al. (1978), and on analysis of EPA's STORET data base. The economic analysis estimates the total energy costs of activated sludge plants with the various utilization schemes. Plant energy demands were adopted from studies by Wesner et al. (1978), Galwardi (1975), and Smith (1973). Capital costs were adopted from Means (1979) and Dames and Moore (1978).

THE RESOURCE IN PERSPECTIVE

The sewage digester gas resource is small when compared with other unconventional forms of gas production, but its utilization can be cost-effective in certain specific applications. Spencer et al. (1978), estimated that 75% of the gas produced in wastewater treatment plants is presently being utilized. The value of the estimated 17 million cubic feet of methane flared each day in the United States in 1978 was $27,500, but the value of the 18 million cubic feet per day expected to be flared in 1985 would be $73,000. To keep these figures in perspective, consider the fact that this flared gas represents only 0.04% of the 14.3 quads of natural gas consumed annually in the United States (AGA, 1978), or the fact that a single commercially sized coal gasification facility would produce more than ten times the energy wasted by digester gas flaring throughout the nation. Although the scale of the digester gas resource seems insignificant when compared with the total U.S.

energy demand, utilization of any energy resource is cost-effective if the value of the energy it replaces exceeds the cost of the utilization scheme. Much of the purchased energy that can be replaced with digester gas is derived from fossil fuels. The opinion that replacing fossil energy with renewable energy has benefits beyond economics is spreading throughout society (Lovins, 1977 and Schumacher, 1973).

EXISTING DIGESTER GAS UTILIZATION

The 60 wastewater treatment plants surveyed by Spencer et al. (1978), represent a wide range of plant sizes. Table 1 shows the trend of increased gas utilization with increased plant size. Plants with capacities of less than 10 MGD utilized an average of 77% of their gas. The anomaly in the 50 MGD to 100 MGD group is due to two plants (San Francisco and Toledo) which use essentially none of their gas.

TABLE 1. Mean Percentages of Digester Gas Utilization in Wastewater Treatment Plants by Plant Capacity -- As Reported by Spencer et al., (1978)

	Less Than 10 MGD	10 to 20 MGD	20 to 50 MGD	50 to 100 MGD	More Than 100 MGD
Number of Plants Included in Survey	10	8	12	13	17
Number of Plants Reporting Gas Utilization Data	10	5	10	12	17
Mean Percentage of Gas Utilized	51	61	73	61	77

Plant size is also a factor in the end use of gas. While heating digesters and buildings with digester gas is common in plants of all sizes, no plant smaller than 10 MGD reported using gas for any other purpose. Only two of the 30 plants smaller than 50 MGD generated electricity while eight of the 30 plants larger than 50 MGD did so. This tendency can be explained by energy economies-of-scale. While gas production increases linearly with plant flow (with wide variations between plants), energy requirements of wastewater treatment increase less than linearly with flow. Many small plants produce just enough gas to heat digesters while larger plants are able to satisfy other energy demands with digester gas.

As show in Table 2, analysis of EPA's STORET data base indicates that of 4,237 treatment plants with anaerobic digesters, 896 use the gas to heat buildings but not to power internal combustion engines, 85 plants use the gas to power engines but not to heat buildings, and 66 plants use the gas for both building heat and engines. Presumably, most of the plants use digester gas to heat the digesters, but this information was not included in the data. The average size of plants within a group increases as the utilization scheme gets more complicated. The mean size of all the plants with anaerobic digesters

included in the listing is 2.6 MGD while the mean plant sizes for plants utilizing the gas was 3.4 MGD, 7.8 MGD, and 13.6 MGD for plants heating buildings, running engines, and both, respectively.

TABLE 2. Utilization of Digester Gas in the United States as Indicated by Unpublished EPA Data

EPA Region	Plants with Building Heat Only		Plants with Engines Only		Plants with Engines and Building Heat	
	Number of Plants	Mean Flow (MGD)	Number of Plants	Mean Flow (MGD)	Number of Plants	Mean Flow (MGD)
U.S.	896	3.5	85	7.8	66	13.6
I	75	3.1	3	49.7	12	3.6
II	4	11.4	5	1.8	0	-
III	132	6.2	21	1.6	10	4.2
IV	11	1.1	1	0.3	0	-
V	234	1.6	32	9.4	17	6.8
VI	31	4.6	3	4.8	4	13.4
VII	182	1.7	4	1.1	10	8.2
VIII	51	3.5	1	7.1	2	12.3
IX	59	9.6	12	9.7	6	72.4
X	117	3.5	3	9.0	5	20.8

TECHNICALLY FEASIBLE OFFSITE UTILIZATION SCHEMES

Because wastewater treatment plants are usually net consumers of energy, they cannot be relied on as a group to provide energy to offsite users. There may, however, be certain situations where sale of gas to other users is economically feasible. One such case cited often in the literature is the Joint Water Pollution Control Plant of Los Angeles County (California) Sanitation District. This plant is a net energy producer due to its large size (340 MGD), its low energy requirements (due mostly to primary treatment), and the fact that it receives raw sludge from other plants (Adams et al., 1978). Other factors that may influence a decision to sell digester gas include the proximity of potential users and the cost and availability of alternate energy sources.

Although there are many technically feasible offsite end uses for digester gas, few have actually been applied due to economic constraints. Before any revenues can be received from the sale of digester gas or its energy, considerable capital investments are required for a transportation system. In addition to a transportation system, gas cleaning and upgrading facilities would often be required to make the digester gas competitive with commercially available energy products.

Potential offsite end uses for digester gas include space heating, process heat, or compressed gas sales. Space heat could be provided in the form of hot water or steam to schools, commercial developments, or well planned

residential developments that are in close proximity to the wastewater treatment plant. One problem with providing space heat is the incongruity between seasonal demands for space heat and the constant supply of digester gas. Process heat could be provided to light industry by steam or gas pipelines from the wastewater treatment plant. Digester gas could also be compressed and sold as bottled gas for use in rural areas or vehicles.

Because the economic feasibility of offsite utilization of digester gas is site specific, a cost accounting analysis would be beyond the scope of this generic study.

TECHNICALLY FEASIBLE ONSITE GAS UTILIZATION SCHEMES

The latent energy contained in the chemical bonds of methane molecules may be readily converted to at least three other useful forms, all of which have applications in wastewater treatment plants. Digester gas may be burned in a boiler with its energy being recovered as heat; it may be used to power internal combustion engines or gas turbines to produce mechanical energy; and the mechanical energy may then be used to turn generators to produce electricity.

From an energy recovery perspective, the most efficient conversion is from gas to heat, while the least efficient conversion is from gas to electricity. From an economic perspective, however, the relative efficiencies of the energy systems are not readily apparent. To achieve economic efficiency, there must be compatability between energy form and end use demand. The largest and most constant energy demand within a wastewater treatment plant is for mechanical energy (Smith, 1973). Demand for heat is small in comparison and has radical seasonal variations. Electricity is compatible with most every end use demand, but gaining this versatility involves added expense.

ECONOMIC ANALYSIS OF ONSITE UTILIZATION

Many factors affect the overall cost of providing energy to operate a wastewater treatment plant. Among the more obvious factors are electric rates, gas rates, and fuel oil costs. Other, less obvious factors include construction costs, labor rates, and digester gas production. As shown by Spencer et al. (1978), gas production is widely variable between plants. For this analysis the median gas production rate found by Spencer et al., of 5,100 cubic feet of methane per million gallons of treated flow is assumed. Energy, construction, and labor costs are also quite variable between geographic regions. For this analysis, typical aggregate U.S. costs are used in all situations.

The cost of energy includes the cost of fuel, the cost of equipment for utilizing the fuel, and the cost of operating and maintaining that equipment. A component of an energy system is cost effective only if the sum of the three cost components is less than the cost of utilizing energy from all alternate systems.

DESCRIPTION OF SELECTED ONSITE UTILIZATION SCHEMES

All of the feasible digester gas energy conversion methods have many variations within the real world. Some plants divide their digester gas among several end uses and many plants do not attempt to use all the gas. Identification and analysis of the myriad energy systems in use or planned was beyond

the scope of this study. Three hypothetical wastewater treatment plant energy systems are described and analyzed below. In each of these hypothetical schemes, the combustion of digester gas occurs in exactly one type of utilization equipment. Plants in the real world may use the gas in combinations of end uses. The optimal combination of end uses would have to be determined on a case-by-case basis.

Heat Generation Scheme

A schematic of a heat generation system operating with digester gas is shown in Figure 1. Digester gas is burned in a boiler and steam is used to heat the digester and buildings. No high pressure storage is provided so the gas is used as it is produced. When demand for heat exceeds energy production, natural gas is purchased to meet demand. When digester gas production exceeds demand for heat, the excess gas is wasted. Mechanical energy demands of the plant are satisfied with purchased electricity.

Mechanical Energy Generation Scheme

A schematic of a mechanical energy generation system operating with digester gas is shown in Figure 2. Digester gas is mixed with 10% fuel oil (based on energy value) and burned in a diesel type internal combustion engine. No high pressure storage is provided so the gas is used as it is produced. Mechanical energy is produced with 35% thermal efficiency and is used to satisfy part of the plant's demand for mechanical energy. The remainder of the mechanical energy demand is satisfied with purchased electricity. Heat is recovered from the engine with a thermal efficiency of 25% and is used to heat digesters or buildings. When the demand for heat exceeds the recovered heat, natural gas is purchased and burned in a boiler.

Electrical Generation Scheme

A schematic of an electrical generation system operating with digester gas is shown in Figure 3. Digester gas is mixed with 10% fuel oil (based on energy value) and burned in a diesel type internal combustion engine. No high pressure storage is provided so the gas is used as it is produced. The engine is directly coupled to an electrical generator. Electricity is produced with 30% thermal efficiency and is used to satisfy part of the plant's purchased electrical demand. The remainder of the electrical demand is satisfied with purchased electricity. Heat is recovered from the engine with a thermal efficiency of 25% and is used to heat digesters or buildings. When the demand for heat exceeds the recovered heat, natural gas is purchased and burned in a boiler.

COMPARISON OF ONSITE UTILIZATION SCHEMES

Energy and cost analyses for the three energy systems described above were performed for three sizes of activated sludge plants in the central United States. The plant sizes of 1 MGD, 10 MGD, and 50 MGD were chosen arbitrarily to identify economies-of-scale. Activated sludge plants were selected because they are the most energy-intensive type of secondary treatment and are likely to be the most prevalent type of plant in the future. Energy demands and gas production rates for typical activated sludge plants are shown in Table 3.

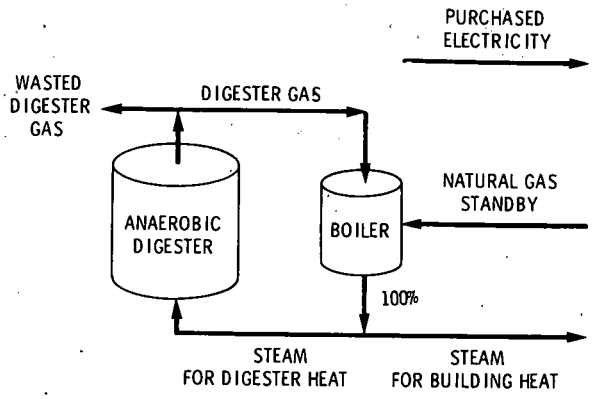


FIGURE 1. Schematic of Heat Generation Scheme

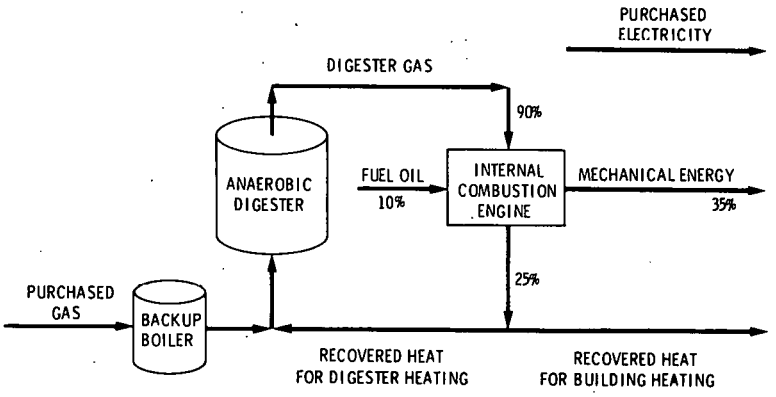


FIGURE 2. Schematic of Mechanical Energy Generation Scheme

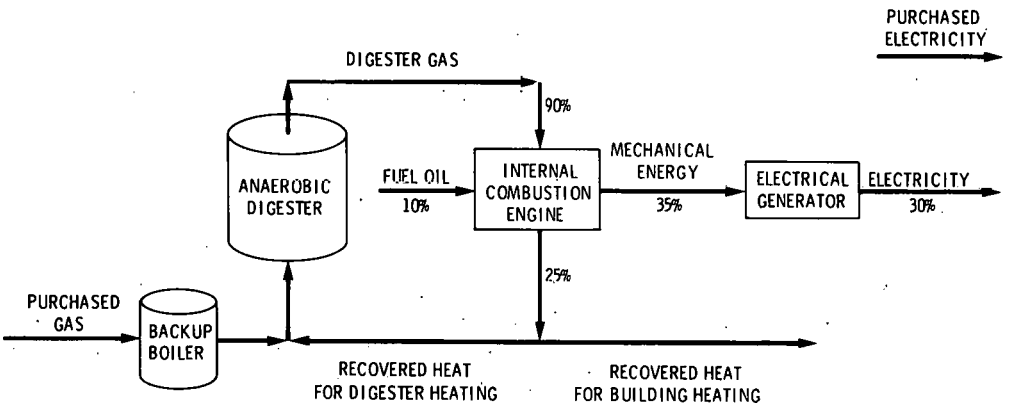


FIGURE 3. Schematic of Electrical Generation Scheme

The costs for each of the wastewater treatment plant energy systems include annualized capital costs of major equipment, operational and maintenance labor and maintenance material costs, fuel costs for backup and dual-fuel systems, and electricity costs for providing plant energy demands not provided by digester gas. Capital and operating costs for the anaerobic digesters are not included as these are considered treatment costs rather than energy costs. Appurtenance to major equipment are assumed to cost the same for each option.

TABLE 3. Activated Sludge Plant Energy Demand and Production

Location	Plant Size MGD	Digester Gas Production Million BTU/Month	Annual Digester Heat Demand Million BTU/Year	January Digester Heat Demand Million BTU/Month	Annual Building Heat Demand Million BTU/Year	January Building Heat Demand Million BTU/Month	Aerator Mechanical Energy Demand Million BTU/Month	Pump Mechanical Energy Demand Million BTU/Month	Other Plant Energy Demand Million BTU/Month	Total Plant Energy Demand Million BTU/Month
Central	1	148	820	125	75	25	70	18	45	208
	10	1,480	7,400	1,000	710	120	700	160	212	1,750
	50	7,400	35,800	4,800	3,550	600	3,500	800	800	8,380
Northern	1	148	1,180	200	180	35	70	18	45	246
	10	1,480	10,600	1,800	1,560	320	700	160	212	2,090
	50	7,400	51,000	8,700	7,800	1,600	3,500	800	800	10,000
Southern	1	148	340	55	40	12	70	18	45	165
	10	1,480	3,000	500	380	95	700	160	212	1,350
	50	7,400	14,000	2,400	1,900	475	3,500	800	800	6,430

Unit energy costs versus plant sizes are tabulated in Table 4 and shown graphically in Figure 4 for plants in central U.S. locations. The least cost system is the mechanical energy generation scheme. The cost of purchased electricity is actually greater when electricity is produced onsite than when only mechanical energy is produced. This is due to the loss of efficiency when mechanical energy is converted to electricity and back again. The cost of purchased gas for heating is lowest for the heat generation scheme. This is because direct combustion of gas in a boiler is the most efficient means of recovering heat. Total energy costs, however, are highest for the heat generation scheme because all of the mechanical and electrical energy demands of the plant must be satisfied with purchased electricity.

TABLE 4. Energy Costs in Typical Activated Sludge Plants in a Central U.S. Location

Utilization Scheme	Plant Size MGD	Cost of Fuel Oil $/Year	Cost of Engine Operation $/Year	Cost of Electrical Generation $/Year	Cost of Purchased Electricity $/Year	Cost of Heating System $/Year	Cost of Purchased Gas $/Year	Total Energy Costs $/Year	Energy Cost Per Million Gallons
Heat Generation	1				18,700	500	50	19,300	52.7
	10				151,000	2,100	Zero	153,000	42.0
	50				717,000	9,200	Zero	726,000	39.8
Mechanical Energy Generation	1	750	2,000		10,700	500	1,000	15,000	41.0
	10	7,500	7,800		71,000	2,100	8,000	96,400	26.4
	50	37,500	23,000		318,000	9,200	32,000	420,000	23.0
Electrical Generation	1	750	*	3,000	11,700	500	1,000	17,000	46.4
	10	7,500	*	10,000	80,400	2,100	8,000	108,000	29.6
	50	37,500	*	45,000	366,000	9,200	32,000	490,000	26.8

*Included in electrical Generation cost.

SENSITIVITY ANALYSIS

The cost accounting analysis in Figure 4 employs average energy and equipment costs as of mid-1979. These costs are changing rapidly and at a given time vary considerably between locations. In order to estimate the effect of a change in a given parameter a sensitivity analysis was performed. Table 5 shows the effects on the total energy costs of 50% increases of various parameters in the 10 MGD plants in central locations. Decreasing the parameters by 50% would result in the same percentage change in total energy costs, but in the opposite direction.

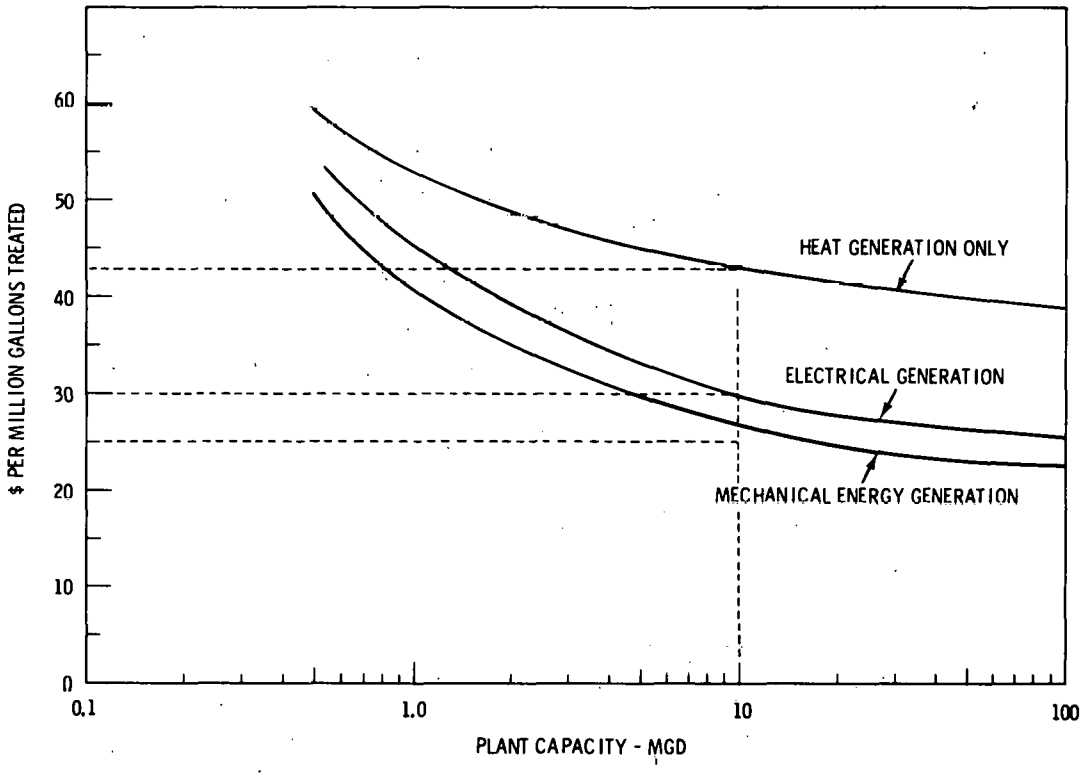


FIGURE 4. Energy Costs for Hypothetical Wastewater Treatment Plants in Central U.S. Locations

In all cases the most dominant parameter affecting total energy costs is the cost of electricity. A 50% increase in the power rate would cause total energy costs to increase 36.8% in a plant with mechanical energy generation, 37.2% in a plant producing electricity, and 49.9% in a plant generating heat only. Increases in mechanical energy requirements also cause relatively large increases in total energy costs, but this is because the increased demand must be satisfied with purchased electricity.

Increases in construction and operating costs have only small effects on the overall energy costs of wastewater treatment plants. Increases in energy demands typically cause significant increases in total plant energy costs because the increased demands are assumed to be satisfied with purchased electricity.

TABLE 5. Sensitivity Analysis of Energy Cost Parameters in Central 10 MGD Activated Sludge Plants

Parameter	Assumed Value	Heat Generation Scheme: Effect of 50% Increase on Total Energy Costs	Mechanical Energy Generation Scheme: Effect of 50% Increase on Total Energy Costs	Electrical Generation Scheme: Effect of 50% Increase on Total Energy Costs
Natural Gas Costs	$\$2/10^6$ BTU	Zero	+4.1%	+3.7%
Fuel Oil Costs	\$0.60/Gallon	Zero	+3.9%	+3.5%
Electricity Costs	40 mills/kWh	+49.3%	+36.8%	+37.2%
Construction Costs		+0.7%	+2.1%	+2.4%
O&M Costs		+0.7%	+3.0%	+3.2%
Gas Production	5100 scf of CH_4 Per Million Gallons	Zero	-11.2%	-7.3%
Heat Demand	8.1×10^9 BTU/yr	+0.8%	8.4%	+7.5%
Mechanical Energy Demands	1.0×10^{10} BTU/yr	+39.5%	+62.7%	+56.0%
Other Plant Energy Demands	2.5×10^9 BTU/yr	+9.7%	+15.5%	+13.8%

Cursory costs analyses may be performed on any plant by calculating the ratios of the actual energy cost parameters with those assumed in this analysis and prorating the percentage effects shown in Table 5. More detailed cost analyses would have to consider seasonal variations in heat demands as well as other site-specific factors.

CONCLUSIONS

Economies-of-scale allow larger plants to utilize a higher percentage of digester gas than smaller plants, and larger plants tend to have more sophisticated utilization schemes. Offsite utilization of digester gas may be economically feasible, but this must be determined on a case-by-case basis. In typical activated sludge plants the most cost effective digester gas utilization scheme is to produce mechanical energy and use it to power pumps or aerators. The most sensitive parameter affecting the total cost of energy in a typical activated sludge plant is the cost of electricity.

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ENERGY SAVINGS IMPLEMENTED FROM VALUE ENGINEERING STUDIES ON WASTEWATER TREATMENT PLANTS AND THE TECHNIQUES OF LIFE CYCLE COSTING USED TO ESTIMATE THE SAVINGS

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INTRODUCTION

This paper presents the results of the following energy and chemical saving design alternatives which were generated and implemented as a result of VE (Value Engineering) studies:

1. Use of capacitor load banks to increase the power factor on induction motors of 15 horsepower and larger.
2. Use of waste pickle liquor (from steel mills) as a source of ferric chloride for sludge conditioning.
3. Use of fine bubble diffused aeration system.

In each case, annual savings were calculated using estimated annual electrical or chemical usage.

The alternatives described herein are not presented as systems that apply in all situations; rather the alternatives are presented for evaluation for potential application in design systems. Designers should pursue the general practice of locating, if possible, users of designs in question to find out, first hand, the users' experience and to apply that information in his own evaluation process.

1. USE OF CAPACITOR LOAD BANKS TO INCREASE POWER FACTOR

As Designed: The system as designed (prior to the VE study) indicated that capacitor banks for power factor correction were not incorporated in original design. Power factor was shown to be 0.8.

VE Alternative: Add capacitor load banks to all motors 15 HP and larger as follows to increase power factor of load from 0.8 to 0.95 and increase performance of drive motors: 1-250 HP 1-900 HP; 3-450 HP; 1-300 HP; 2-200 HP; 6-75 HP; 19-60 HP; 1-30 HP; 1-15 HP.

Advantages: 1) The first year electrical cost saving was calculated to be $21,430 which was due to the reduced electrical demand charges. (See LCC Analysis below.)

2) Redesign cost would be minimal

3) Motors would operate more efficiently.

Disadvantages: 1) Initial capital cost increased by $35,500 for installation of capacitors and auxiliary equipment.

2) Additional annual maintenance cost of approximately $1,065 (conservative estimate) due to maintenance of capacitors. (See LCC Analysis below.)

Discussion: The electrical rate of the utility company includes a penalty charge for low-power factor. Installation of power capacitors in the plant distribution system within the plant makes it unnecessary for the utility company to supply the reactive power (i.e., the non-working "wattless" power) required by the inductive electrical equipment connected to it. The utility company's savings in reduced generation, transmission, and distribution costs are passed on to the plant.

A second source of savings (not included in this alternative) possible through the use of power factor correction capacitors is in the form of increased capacity of the electrical distribution system. Installation of capacitors to furnish the non-productive current requirements of the plant makes it possible to increase the plant connected load without a corresponding increase in the size of the transformers, conductors, and protective devices serving the load.

LCC Analysis: The additional capital expenditure of $35,500 (required to purchase and install the capacitors and auxiliary equipment) was determined from standard cost references. However, the increase in annual maintenance cost was estimated since relatively little recorded data is available concerning maintenance cost of equipment. The VE team used a rule of thumb estimate of three percent of equipment cost to estimate the maintenance cost. This was approximately $1,065 which the VE team judged to be an upper limit. Past experience with this type of equipment indicates that little or no maintenance would be required over a 20-year period.

The estimated electrical cost savings of $21,430 (due to the increased power factor which saved approximately 7,788 KW per

year), was calculated using the utility company's demand rate schedule. It is obvious that the cost elements indicate that the use of capacitors is cost effective. However, it is interesting (and informative) to examine Table I which illustrates the differences in total cost impact by using various economic parameters of discount rates and inflation rates. That is, the values in Table I illustrate the total cost impact using:

(1) 7 percent discount rate;

(2) 7 percent discount coupled with an 8 percent annual inflation rate;

(3) 8 percent discount coupled with a 12 percent annual inflation rate.

TABLE I. LCC SUMMARY OF CAPACITOR LOAD BANKS

Additional Capital Investment	$117,936
Net Annual Savings, First Year Only (21,430 - 1,065)	20,365
Present Worth of $20,365 over 20 Years:	
At 7% Discount	215,755
At 7% Discount and 8% Inflation	449,639
At 8% Discount and 12% Inflation	609,891

The above rates were chosen merely to illustrate the difference in the total LCC impact under various conditions of discount and inflation rates. Obviously, these parameters cannot be forecast with any degree of accuracy.[1] However, perhaps the most significant point that is brought out is that some consideration must be given to inflation and must be subsequently included in the LCC calculations in order to achieve a reasonable degree of realism in the total cost impact. The only guideline offered here to assist in the selection of discount and inflation rates would be that anything less than 7% discount and 8% inflation is probably unrealistic

2. USE WASTE PICKLE LIQUOR (FROM STEEL MILLS) AS A SOURCE OF FERRIC CHLORIDE FOR SLUDGE CONDITIONING

As Designed: Provide purchased $FeCl_3$ solution at 40% dry weight basis for use as one of chemical conditioning agents.

1) It should be noted here that the various utilities (i.e., electricity, coal, oil, gas, etc.) would inflate at different rates.

VE Alternative: Obtain free waste pickle liquor from nearby steel plant. This pickle liquor is from the use of HCl (hydrochloric acid) for pickling steel. Pickle liquor is expected to contain a minimum of 21 percent $FeCl_2$ and must be oxidized to $FeCl_3$ with chlorine gas.

Advantages:

1) Annual cost savings of $63,600 due to reduced chemical procurement. (See LCC Analysis below.)
2) Redesign cost would be minimal.
3) Resource recovery (i.e., utilizes a waste product of steel-making process.

Disadvantages:

1) Initial capital investment of $56,000 is required for purchase of equipment.
2) Quality control analysis required on a continuing basis since pickle liquor may contain some suspended solids and trace oil and grease.
3) Requires oxidation system to convert from $FeCl_2$ to $FeCl_3$; therefore, chlorine gas must be purchased.
4) Effect of pickle liquor use on dewatering rate and equipment is unknown. Must test before accepting.

Discussion: The initial investment required for converting $FeCl_2$ to $FeCl_3$ would be through utilization of existing tanks at the plant site. The investment consists of:

Rubber-lined tank truck for transportation of pickle liquor from mill to plant:	$40,000
Relocate existing 12,000 gallon tank for receiving pickle liquor	2,000
Chlorinator for pickle liquor	5,000
Two positive displacement pumps	5,000
Piping/electrical	4,000
TOTAL ADDED INVESTMENT	$56,000

LCC Analysis: The cost savings for the first year of operation was estimated at $63,600 as follows:

Ferric Chloride required	$81,800
Cost of pickle liquor	--0--
Cost of chlorine	14,600
Analytical Costs	1,900
Maintenance	1,700
NET SAVINGS	$63,600

Table II indicates present worth values of the $63,000 over 20 years range from $673,778 to $1,904,693 (depending on conditions of discount and inflation rates). Therefore, the ratio of savings to investment ranges from 12 to 34 which not only indicates an attractive design alternative, but allows considerable room for unforeseen contingencies. The designer concurred with the recommendation to develop the waste pickle liquor as a source of iron for use in conditioning the sludge.

TABLE II. LCC SUMMARY OF PICKLE LIQUOR ALTERNATIVE

Additional Capital Investment	$56,000
First Year Savings	$63,600
Present Worth of $63,600 over 20 Years	
At 7% discount	$673,778
At 7% discount and 8% inflation	$1,404,161
At 8% discount and 12% inflation	$1,904,693

(See discussion under Table I.)

3. USE FIXED PIPING FINE BUBBLE DIFFUSED AERATION SYSTEM

As Designed: Fine bubble aeration system was designed with swing diffuser pipe system. (Plant average flow is 50 MGD.)

VE Alternative: Use fixed piping fine bubble diffused aeration system.

Advantages:
1) Annual operating cost savings based on first year power cost would be $70,000.
2) Initial construction cost savings of $115,000 on aeration equipment.
3) Increased oxygen transfer efficiency.
4) The fixed pipe system permitted option of using Tee wall or retaining the as designed Wye wall without affecting "roll" characteristics.

Disadvantages:
1) Aeration basins must be drained to clean diffusers.
2) Fixed diffusers are more prone to breakage than pipe.
3) Air must be filtered.
4) Clogging of fine holes may present a maintenance problem (see discussion below).
5) Annual maintenance cost increase of approximately $5,000.

Discussion: Prior to implementation of this alternative, the designer visited an existing 200 MGD WWTP in England which had been using the system for almost 20 years. Clogging of fine holes was not experienced by the plant. Two maintenance men were assigned full time to cleaning the diffusers which consisted of draining the tank and either acid clean or burning out the diffusers in a kiln. The two men completed cleaning cycles every 9 to 11 years. Total head loss experienced over this period was less than one inch. The estimate for annual maintenance was therefore conservatively estimated to be $5,000 more than for the swing diffuser system.

LCC Analysis: The total savings in this situation was enhanced because savings were realized on the initial construction cost as well as on energy. Table III summarizes the savings.

TABLE III. SUMMARY OF SAVINGS USING FINE BUBBLE DIFFUSED AERATION

Initial Capital Cost Savings	$115,000
Net Annual Savings, First Year Only:	
$70,000 - $5,000 =	65,000
Present Worth of $45,000 over 20 Years	
at 7% discount	$688,610
at 7% discount and 8% inflation	$1,435,070
At 8% discount and 12% inflation	$1,946,620

Here again, the present worth of the annual savings is shown using various combinations of discount and inflation rates, all of which indicate substantial savings. In any event, the data strongly indicates that fine bubble diffusion systems are strong candidates for evaluation for potential use in aeration systems.

CONCLUSION

The design alternatives presented herein illustrate significant energy savings with relatively little or no initial caiptal investment. This is not always the case. Energy saving designs often require significant additional capital expenditures which must be carefully evaluated against estimated annual savings. In addition, the multitude of variables which must be considered in the design of any system demands a methodical and painstaking evaluation process which should be performed so as to increase

to the maximum extent possible, the reliability and cost effectiveness of that design. This is no easy task. However, it is hoped that the information presented herein will serve to assist the designer in his awesome evaluation process.

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THE BCT PROCESS
A NEW WASTE HEAT AND WATER RESOURCE MANAGEMENT TECHNOLOGY

R. L. Lancaster
Tower Systems, Inc.

ABSTRACT

Tower Systems' new Binary Cooling Tower (BCT) process is a major breakthrough in heat transfer technology that will have a significant impact on waste heat and water resource management systems.

The process can use wastewater to extract waste heat and conversely waste heat to evaporate wastewater. The process also conserves fresh water by dry cooling or by substituting waste for fresh water in evaporative cooling systems.

The process is unique, and was recently demonstrated in an industry sponsored pilot plant test at a major western utility. This test showed that the process could concurrently reduce wastewater volume by 96%, reduce water consumption by 17%, and improve process cooling.(1)

The paper describes the background leading to the development of the process, how the process works and how it can be integrated into new or existing systems to perform a number of functions including wastewater volume reduction and process cooling. Economic considerations, materials of construction, operation and maintenance are also discussed.

BACKGROUND

Wastewater and waste heat are two of the most abundant and undesirable byproducts of industry and, until now, have been treated as separate problems. Ironically, one of the largest sources of wastewater is a product of waste

(1) Pilot Demonstration - MCT Process - Zero Discharge For The Sunrise Station, Rickie Slate, Craig T. Zeien, Wm. Sanderson, Presented at 40th Annual Meeting International Water Conference, Nov. 1, 1979.

heat rejection in evaporative cooling towers where, as evaporation occurs, a portion of the circulating water is discharged from the system as "blow-down" to keep dissolved and suspended contaminates from reaching concentration levels where they will precipitate and cause scale or fouling in condenser tubes and other process cooling equipment.

Growing political pressures on water reuse and increasing costs of waste-water management have forced industry to seek all means available to optimize water recycling in these cooling systems.

Various types of softening processes are currently being designed and installed that are theoretically capable of 50 cycles of concentration or more. The fundamental disadvantage of these systems is that they are an integral part of the process and in the event of failure or upset, can risk the primary processing system.

THE BINARY COOLING TOWER (BCT) PROCESS

The BCT process overcomes these problems by completely segregating the primary process water cooling system from a secondary cooling system consisting of air, water or both. The cooling fluid does not come in contact with the primary process loop so problems of scaling and corrosion, although unlikely, would be confined to the cooling, or secondary loop.

The BCT process is an extension of four well known technologies:

1. Evaporative cooling towers
2. Dry cooling towers
3. Water treatment and softening processes
4. Falling-film heat exchangers

Heat Transfer System

The combination of these technologies is made possible by Tower Systems' new high-efficiency non-metallic heat exchanger development. This new device is a thin panel non-metallic falling-film type heat exchanger. A number of these panels are assembled with various spacing configurations to

form a module (Figure 1). A predetermined number of these modules are installed in a BCT unit that is similar in appearance to an induced draft crossflow cooling tower (Figure 2). The modules are installed so that the induced air flows across the external surface of each heat exchanger.

The heat exchanger/fill system in the BCT unit performs the following functions:

a) Separates two fluid systems
b) Extracts heat from a closed loop primary process cooling circulating water system.
c) Transfers this heat to a secondary cooling system consisting of air or water/air, and,
d) Dispels this extracted heat as latent and/or sensible heat to the flowing air.

Circulating Water Systems

The BCT process differs from conventional cooling towers in that it has two circulating water systems.

Hot water from a condenser or other waste heat source enters the BCT unit where it is distributed on the inside surfaces of the heat exchanger panels. Heat is extracted, and the cooled water is pumped back to its source.

Water or wastewater from a secondary circulation system enters the BCT and is distributed on the outside surfaces of the heat exchanger panels where it is exposed to induced air flow that is discharged to atmosphere.

The two separate fluids co-flow as a film down opposite sides of the heat exchanger surfaces.

When the secondary system is inactive, the BCT functions as a dry cooling tower.

The Tower Systems Binary Cooling Tower can function in several capacities for many purposes. A few of the more readily apparent applications are:

Figure 1
Heat Transfer Module

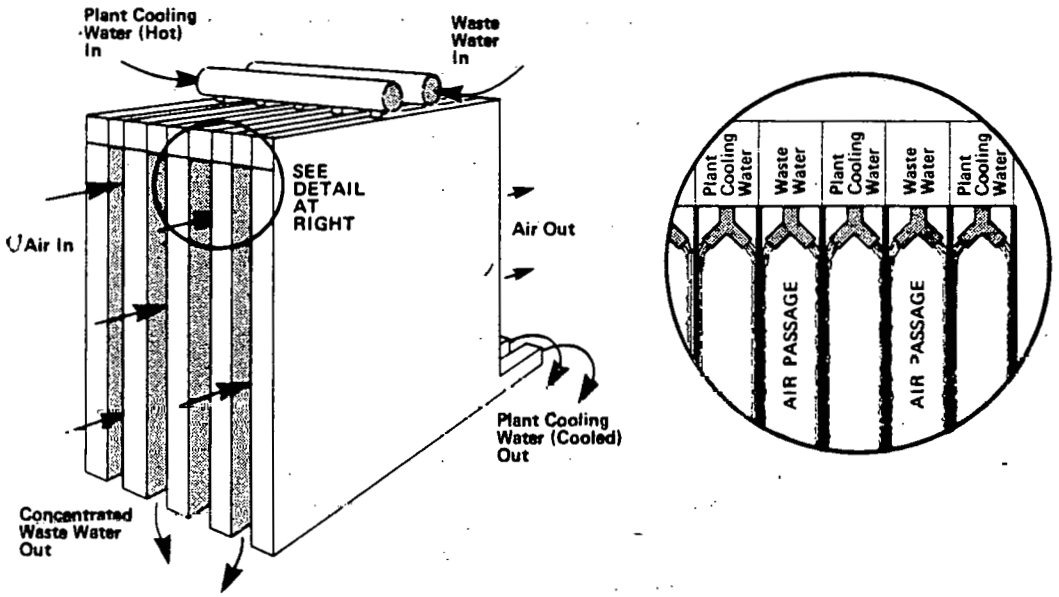
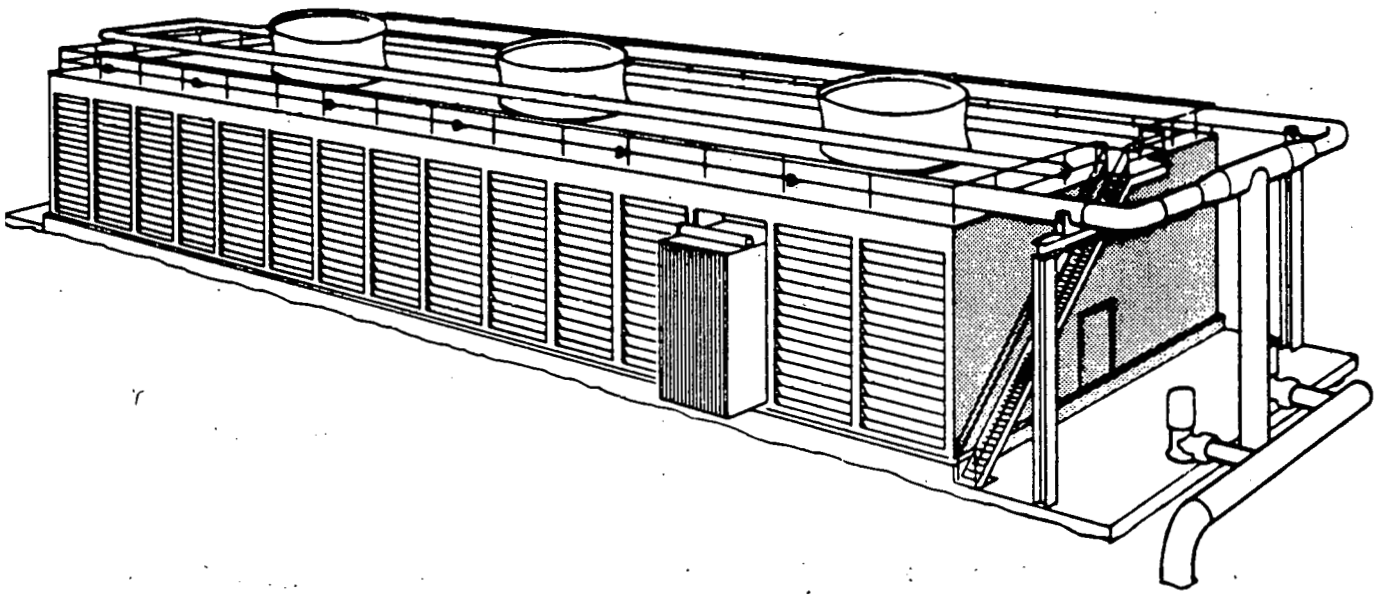


Figure 2
Module Location in Commercial MCT



WASTEWATER COOLING

The unique heat exchanger construction and the separation of the primary and secondary cooling loops in the BCT permits the use of wastewater as an evaporative cooling medium. All wastewaters are potentially useable in the BCT as the wastewater is segregated from the primary system. When wastewater is used, the BCT also performs as an excellent wastewater volume reduction device as well as a cooling tower.

In wastewater cooling, wastewater is continually recirculated and evaporated in the atmospherically exposed secondary circulating water system until desired concentration levels are obtained. Concentration levels of up to 200,000 TDS are achievable in this loop depending on the wastewater chemistry and treatment. Makeup water to the secondary loop normally consists of wastewaters desired to be concentrated or blowdown in the case of tandem operation with wet cooling towers.

Active chemical control is required to control the scaling and fouling potential of the secondary wastewater loop within an acceptable operating range. Control methods include pH adjustment and various softening processes. Biocides and corrosion inhibitors may be added if required.

Wastewater cooling applications can range from partial sharing of process cooling when operating in tandem with conventional evaporative cooling towers in a wastewater volume reduction mode to handling 100% of process cooling when sufficient wastewater is available and the economics are favorable.

TANDEM OPERATIONS WITH CONVENTIONAL COOLING TOWERS

Combined System Effects

When integrated into cooling systems with evaporative cooling towers for wastewater volume reduction, the BCT unit provides additional process cooling or reduces the size of the evaporative units required. In these systems varying degrees of operational flexibility in wastewater evaporation

or process cooling would be available. As an example, both the BCT unit and the cooling tower would operate at full load for maximum cooling. Alternately, maximum wastewater evaporation is obtained by shutting down cooling tower fans to increase hot water temperatures.

As a backup unit for cooling towers, the BCT unit offers redundancy and increased reliability to cooling systems. Figure 3 shows a typical BCT system integration for tandem operation with conventional cooling towers for wastewater volume reduction.

Retrofits

The BCT process lends itself particularly well to situations where excess wastewater problems exist and additional circulating water cooling could be advantageous. In these applications, the energy requirements of wastewater reduction are potentially offset by the energy recovered due to added cooling and improved process efficiency.

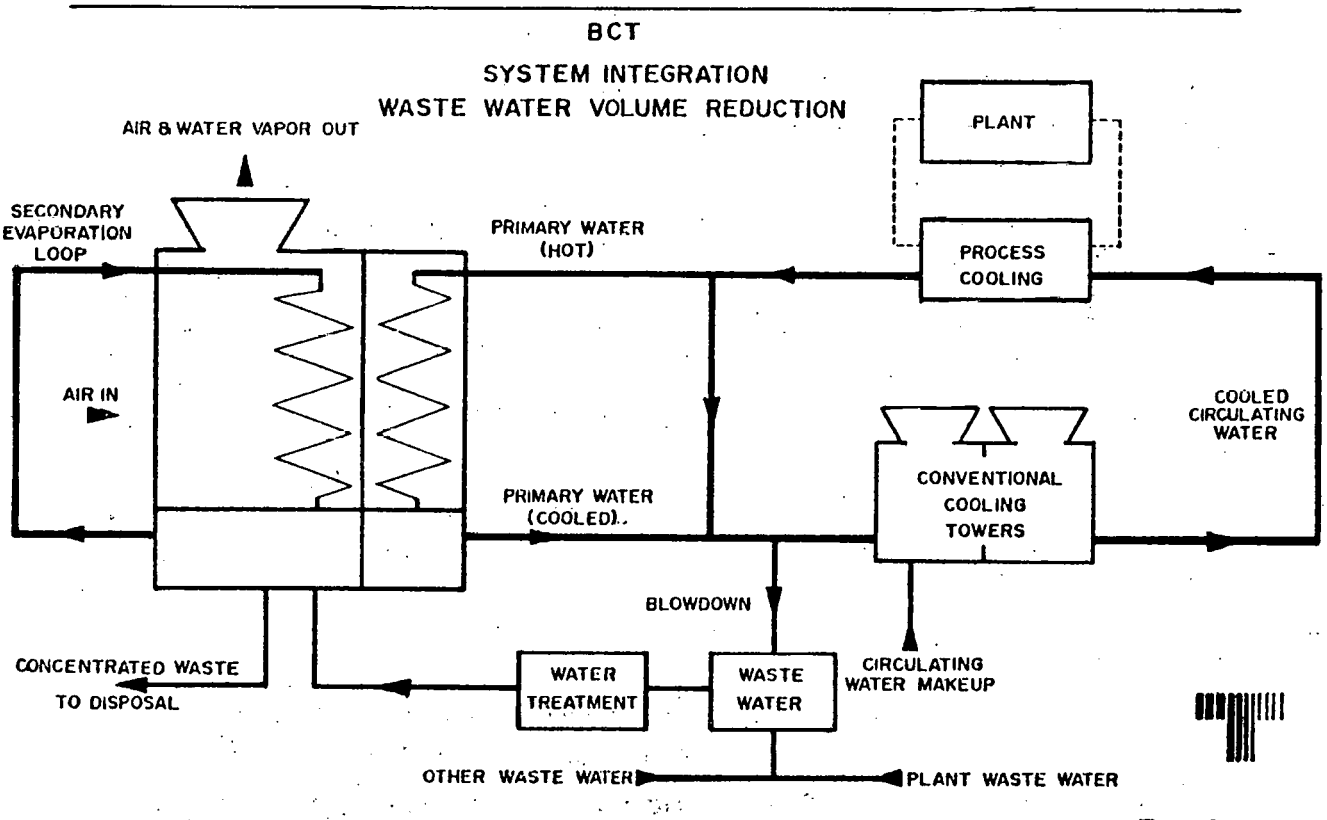


FIGURE 3

Sizing Parameters

In blowdown and other wastewater volume reduction applications with conventional cooling towers, the key sizing parameter of the BCT unit is the temperature of the circulating hot water. Each 15 degree increase in temperature nearly doubles the capacity of the BCT to evaporate wastewater, or halves its size for a given requirement. Water chemistry of the wastewater, the other key parameter, is important because as the concentration levels increase, evaporation decreases. Typical levels of concentration are in the area of 100,000 total dissolved solids (TDS) and this level varies as a function of economic trade-offs with solar ponds and/or other downstream disposal methods for handling the concentrated waste.

Water Treatment Costs

Reduction of wastewater volume, on-site containment, reduced water requirements and ultimately, closed loop dry or wet/dry cooling systems, all have the potential of substantially reducing overall water treatment costs.

Comparative Studies

The BCT process, when compared to alternate solutions for wastewater volume reduction, differs in that its installation in the circulating water system reduces the wastewater volume by effecting the cause (by reducing fresh water evaporation, makeup and blowdown) as well as treating the resultant reduced blowdown.

Because of its unique design criteria and multiple system effects, each application of the BCT process for wastewater volume reduction must be evaluated in terms of its impact on the total water management system.

WATER/WASTEWATER ENHANCED DRY COOLING

The BCT is a dry cooling tower in its simplest form. It can operate as a dry tower in any of its applications by merely shutting off the secondary loop. It is always a wet/dry tower based on current definition.

100% dry cooling is generally considered cost prohibitive because of the high costs and energy penalties associated with the designs required to meet high peak dry bulb temperatures. The more generally acceptable solution is to design systems for evaporative cooling during these high temperature dry bulb peaks. This is called wet/dry "peak shaving" and as little as 10% wet cooling can significantly reduce the costs.

The BCT process is more aptly defined as a water enhanced dry cooling tower than a wet/dry tower. Current definitions and designs of conventional wet/dry systems are generally some combination of wet cooling towers and fin tube hardware.

Until now, wet/dry cooling systems have only been considered as a last resort. The novel design of the BCT and its ability to use low quality wastewaters for evaporative enhancement will offer new alternatives for cooling system designers.

Figure 4 depicts a typical BCT "wastewater enhanced" primary cooling schematic.

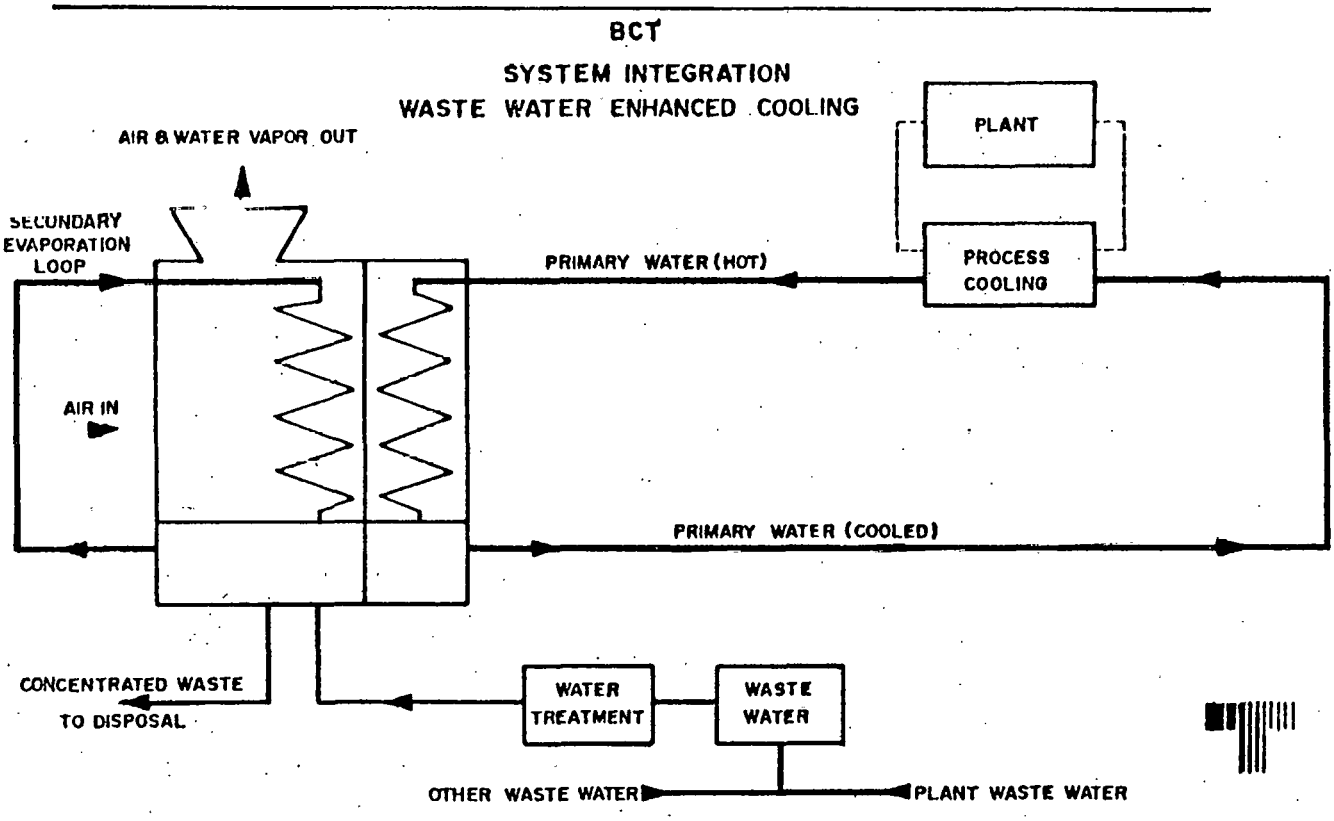


FIGURE 4

SITING

The capability of the BCT process to evaporate wastewater instead of fresh water for process cooling opens new industrial and power plant site locations that were previously unsuitable because of poor water quality.

WATER CONSERVATION

In all of its applications, the BCT process performs as a water conservation device by dry cooling, by substitution of wastewater in evaporative systems, or by optimizing water reuse.

MATERIALS OF CONSTRUCTION

Common, inexpensive materials of construction are used throughout the BCT system, including concrete, plastic, treated wood, iron and steel. Portions of the system exposed to brine are generally non-metallic.

The active mechanical devices include motors, pumps, fans and valves, which are all available off the shelf.

All secondary loop piping and heat transfer surfaces are non-metallic and not subject to corrosion. The only metallic hardware in the loop are the centrifugal pumps which are selected for corrosion life, maintainability and performance on the basis of economics.

OPERATION AND MAINTENANCE

The BCT unit operates in a benign low temperature and low pressure environment. The exterior is exposed to weather and the interior is exposed to water, usually containing treatment chemicals and contaminants.

The BCT unit can be operated with individual sections running or with individual heat transfer modules isolated, making total on-line maintenance feasible and practical. Single point failures can degrade but not terminate operation. Design margin and active control are provided to avoid upset

conditions and it is designed for immediate startup or shutdown.

Plant operation and maintenance tasks are readily performed with existing plant personnel and mechanical resources.

TOWER SYSTEMS, INC.

Tower Systems, Inc. was formed in May 1978, for the purpose of developing, manufacturing and marketing waste heat and water resource management systems.

The company's headquarters and manufacturing facilities are located in Tacoma, Washington.

RECARBONATION OF WASTEWATER USING THE ROTATING BIOLOGICAL CONTACTOR

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ABSTRACT

Biological treatment and recarbonation are recorded as separate processes within the water and wastewater industry. Recarbonation has traditionally consisted of carbon dioxide gas generated by burning a fuel such as coke, oil, or gas. The use of microorganisms for biological recarbonation, in which carbon dioxide gas is produced by the microorganisms as organic matter is oxidized, has become accepted practice for the activated sludge process. Biological recarbonation has not been previously recommended as a capability of the rotating biological contactor (RBC) process. The significance of using the RBC process for secondary treatment and recarbonation is that effective reductions of BOD_5, ammonia-nitrogen, and phosphorus can all occur within this system. Studies indicated that the RBC process for secondary treatment and recarbonation of wastewater is compatible with the low-level/lime addition technique for phosphorus removal. Thereby, expensive recarbonation requirements and the energy intensive activated sludge process are both avoided. The pilot RBC process provided effective BOD_5 removal when subjected to an influent pH of 9.5 and a hydraulic loading of 2.0 gpd/sq. ft. RBC process effluent pH values ranged generally between pH 7.2 to pH 7.5. Occurrence of biological recarbonation across the RBC treatment train reduced pH levels to about pH 8.5 in stage 1, pH 8.0 in stage 2, pH 7.5 in stage 3, and pH 7.2 in stage 4. Methods to further increase the recarbonation effect of the RBC process include step feed of the wastewater, recirculation of flow, and removal of the wall between stage 1 and stage 2. The implication is that many wastewater treatment plants can be upgraded with low energy requirements and extensive use of existing facilities.

RECARBONATION OF WASTEWATER USING THE ROTATING BIOLOGICAL CONTACTOR

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INTRODUCTION

Carbon, as carbon dioxide, is readily available through atmospheric cycles and from natural carbonate alkalinity for assimilation by organisms present in receiving waters. Nitrogen can be drawn from the atmosphere by nitrogen-fixing bacteria, or is available in various forms from surface runoff. However, phosphorus is not available through atmospheric cycles and it is further limited by its sedimentation cycle. For this reason, phosphorus most frequently limits excessive eutrophication, and is the most controllable nutrient found in man's wastewaters.[1,2]

Chemical and biological wastewater treatment processes can result in significant reductions of phosphorus. Chemical-biological removal is accomplished with the same chemicals used in purely chemical-physical removal. The chemicals can be added to raw, degritted sewage; to the primary effluent; to the aeration tank or trickling filter; to the secondary clarifier influent or effluent. The choice of chemical and point of addition depend on effluent standards, alkalinity, pH, sludge dewatering, sludge disposal, chemical costs and chemical availability.

Low-level lime addition has recently been applied prior to activated sludge aeration basins with favorable results. Activated sludge aeration basins contain enough buffering capacity due to microbial activity to reduce the elevated pH to a reasonable level for biological treatment, normally below pH 8.5. The buffering capacity of rotating biological contactors has not been considered for pH adjustment. Consequently, lime addition has not been considered for pH adjustment, nor for use in wastewater treatment systems, except as a tertiary process employing higher pH levels and a recarbonation requirement.

The RBC process was selected for evaluation of its ability to provide recarbonation of high pH wastewaters (pH 9.5) and to nitrify these same wastewaters. The choice of this treatment scheme considered the relatively low energy and operating costs of the RBC process, simplicity of operation, and flexibility with respect to the upgrading of existing treatment plants.

This paper describes phosphorus removal by low-level lime (pH 9.5) precipitation in the primary clarifier, followed by biological recarbonation

using the rotating biological contactor (RBC). Of equal importance in this research effort was to show the enhancement of nitrification by the chemically induced increase in pH. Goals were set to provide criteria for upgrading existing Army wastewater treatment facilities to meet NPDES permit limitations, as opposed to research directed toward completely replacing such facilities.

Phosphorus Removal

Phosphorus removal encompasses several technologies. Biological, chemical-physical, chemical-biological and physical techniques have successfully removed phosphorus from wastewaters. Biological techniques employ microorganisms to remove phosphorus through synthesis, metabolic processes and adsorption incorporating the phosphorus into biological solids. Chemical-physical techniques utilize precipitation, coagulation, flocculation, adsorption, sedimentation and filtration to incorporate the phosphorus in a chemical sludge. Common chemicals used include lime, iron salts, alum, sodium aluminate and polyelectrolytes. Rare earth elements have also successfully precipitated phosphorus. All of these techniques involve the conversion of soluble phosphorus to a solid form amenable to conventional solid-liquid separation technology.

High-Lime Treatment

High pH (lime) treatment of wastewaters is usually associated with tertiary processes for phosphorus or ammonia removal. These processes operate at a pH value of approximately pH 11.0 and therefore result in increased sludge production. At pH 11.0 magnesium precipitation is essentially complete. Formation of hydroxyapatite [$Ca_5OH(PO_4)_3$] and tricalcium phosphate [$Ca_3PO_4)_2$] begins at pH 9.0 and precipitation proceeds toward completion with approximately 80 percent removal occurring at pH 9.5 to pH 10.0. The increased dosage of lime required to achieve a pH value of 11.0 not only increases the amount of chemical sludge produced, but also creates a requirement for a recarbonation process prior to effluent discharge. This technique implies an obvious increase in construction and operation and maintenance costs.

Low-Level Lime

Low-level lime dosing to achieve a pH of 9.5-10.0 can reduce phosphorus to levels to meet the biological system's nutrient demands, without an excessively high pH. Schmid and McKinney[3] used relatively low doses of lime (150 mg/l) in a primary system operating at a pH of 9.5 to achieve 80 percent total phosphorus removals, 60 percent BOD removals and 90 percent reduction of suspended solids. They report that both the orthophosphates and condensed phosphates can be readily precipitated with lime in conjunction with recarbonation in the secondary treatment system by microbial production of CO_2. Their combined system removed 90-95 percent of the total phosphorus in a[2] domestic wastewater containing 40-50 mg/l total phosphorus (as PO_4) with lime doses generally less than 150 mg/l as calcium hydroxide. Miller, et al.[4] and Cavagrano et al.[5] have shown the importance of coagulant aids for effective solid-liquid separation of precipitated calcium. Ferric chloride at doses of 5 mg/L (as Fe) appear to be most effective.

Recarbonation

The source of carbon dioxide for lowering effluent pH levels can be liquid CO_2, a by-product of fuel combustion, stack gases from sludge incinerators or recalcining furnaces, or from the biological oxidation of organic matter. All of these recarbonation techniques require the construction, operation and maintenance of additional plant processes, except for biological recarbonation. Carbon dioxide production through biological oxidation of organics is accomplished in the secondary treatment process thereby requiring no new construction.

While low-level lime addition techniques precipitate about 80 percent of the available phosphorus,[3] additional phosphorus is removed through biological assimilation (about 1 percent of the BOD_5 reduction).[6] Figure 1 depicts the physical and biological aspects of phosphorus removal. Additional phosphorus removal after secondary treatment is possible by chemical addition for precipitation in the secondary clarifier and filtration. The assimilation of phosphorus was fairly constant irrespective of chemical addition, but the final effluent concentrations were significantly reduced during chemical addition. Phosphorus removal is not the only added benefit of biological recarbonation, but enhancement of nitrification is also achieved (Table 1). The nitrification can be attributed to the greater organics removal before secondary treatment processes and to a more optimal pH for nitrifier activity.

TABLE 1. THE EFFECT OF LOW-LEVEL LIME ADDITION ON NUTRIENT REMOVAL. RBC INFLUENT pH VALUES WERE 9.3 AND 7.1 FOR WASTEWATERS WITH AND WITHOUT LIME ADDITION, RESPECTIVELY. THE HYDRAULIC LOADING RATE WAS 3.0 gpd/sq ft

Parameter	Percent Removed	
	With Lime Addition	Without Lime Addition
BOD_5-Unfiltered	88	87
BOD_5-Filtered	92	92
TOC-Filtered	64	45
COD-Filtered	70	71
Phosphorus-Soluble (as P)[a]	37	24
NH_3-N	83	40

a. Due to assimilation only, does not include chemical precipitation.

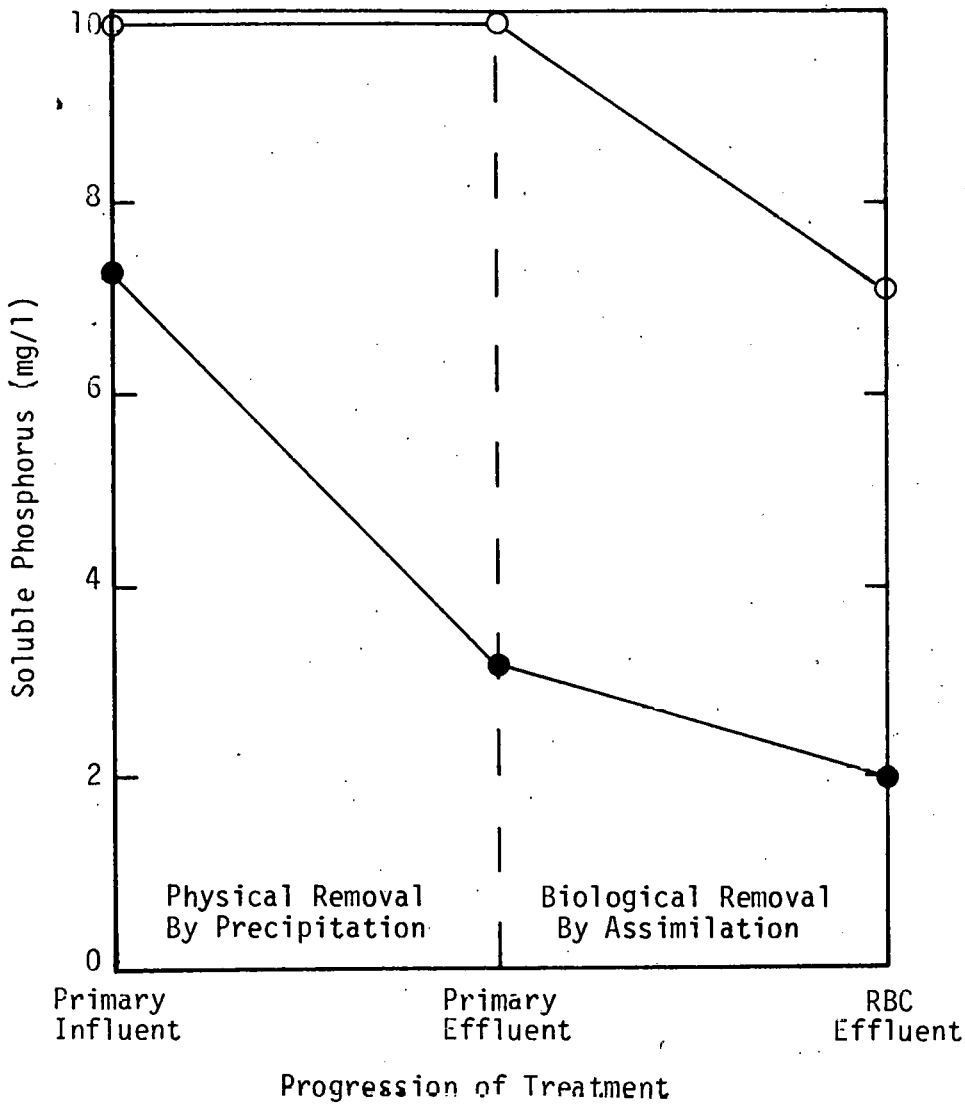


Figure 1. Physical and Biological Aspects of Phosphorus Removal are Depicted. Solid circles represent wastewater treated with lime to achieve a pH value of 9.5 followed by primary settling for removal of phosphorus precipitate. Open circles are results from control experiments where no chemical was added to the wastewater. The hydraulic loading rate on the RBC was 3.0 gpd/sq ft.

Table 1 shows data supporting the desirability of the biological recarbonation process. While the overall BOD_5 removal was unaffected, the ammonia-nitrogen and phosphorus removals were significantly increased by the low-level lime addition process prior to secondary treatment. Table 2 demonstrates that there is process stability for phosphorus removal with respect to hydraulic loading. Figure 2 shows that biological recarbonation of the wastewater was achieved at three hydraulic loading rates. The extent of pH depression was a function of the flow rate. Also it should be noted that the pH values within the RBC are in an optimal range for nitrification. However, nitrification decreased when the organic load applied increased concomitantly with the elevation of hydraulic loading rates.

TABLE 2. COMPARISON OF NUTRIENT REMOVAL AT THREE HYDRAULIC LOADING RATES

Parameter	Mean Concentrations Hydraulic Loading (gpd/sq ft) 2.1	3.0	4.0
pH			
Primary Effluent pH[a]	9.5	9.3	9.4
RBC Effluent pH[a]	7.0	7.2	7.9
Phosphorus (as P), mg/l			
Influent Soluble Phosphorus	10.5	7.2	9.7
Primary Effluent Soluble Phosphorus	3.8	3.2	3.3
RBC Effluent Soluble Phosphorus	2.3	2.0	2.0
Ammonia (as N), mg/l			
RBC Influent Ammonia	17.0	15.6	20.9
RBC Effluent Ammonia	2.4	2.7	18.6

a. Median value.

Benefits of Lime Pretreatment

Lime addition before primary clarification has been recognized as a standard design option for use with the activated sludge system. This process shares with the RBC process, many of the desirable aspects of wastewater pretreatment with lime. However, the operation and maintenance costs and increased requirements for manpower utilization by the activated sludge process, in comparison to the RBC process, help to make the RBC the system of choice. Table 3 shows that 32 percent of the total BOD_5 was removed upon low-level lime pretreatment, whereas only 16 percent of the total BOD_5 was

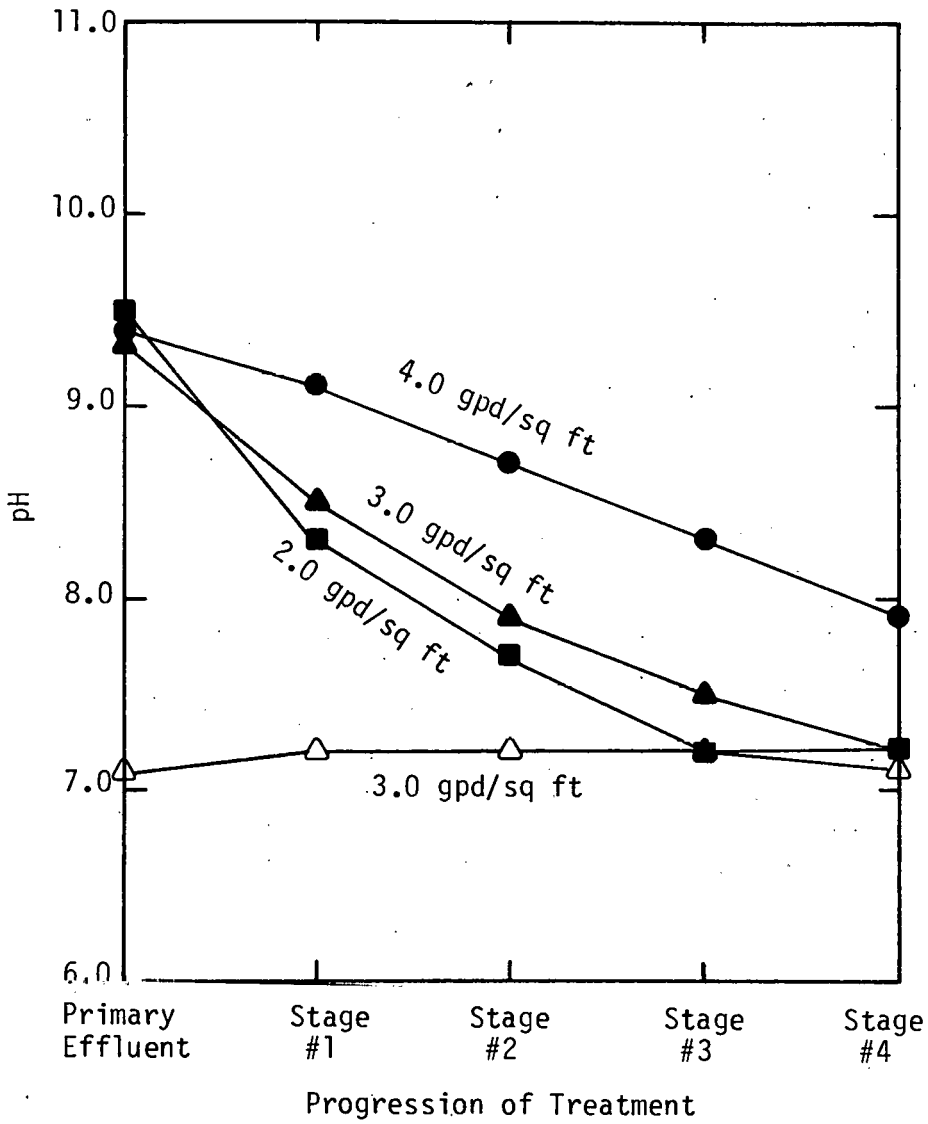


Figure 2. The Depicted pH Values are Expressed as a Function of the Biological Treatment Received. Circles, triangles, and squares represent the biological recarbonation effect on wastewater at 2.0, 3.0, and 4.0 gpd/sq ft, respectively. The solid symbols represent wastewater which was pre-treated with lime for phosphorus removal. The open triangles show the constancy of pH values when no lime was added.

TABLE 3. COMPARISON OF UNFILTERED BOD_5 REMOVAL WITH AND WITHOUT LIME PRETREATMENT IN PRIMARY AND SECONDARY TREATMENT PROCESSES

	Without Lime Pretreatment	With Lime Pretreatment
Influent BOD_5 (mg/l)	146	144
Primary Effluent BOD_5 (mg/l)	123	98
Secondary Effluent BOD_5 (mg/l)	19	18
Percent Removed by Primary Clarification	16	32
Percent Removed by Secondary Treatment	85	82

removed without chemical addition. The effect of reduced organics to the secondary treatment process is a reduction in the production of secondary sludge. Table 4 compares predicted quantities of sludge produced in systems incorporating lime pretreatment, or lime addition as tertiary treatment compared to primary and secondary treatment without chemical addition. Approximately three times as much chemical sludge is produced as gravity settled sludge,[7] but considering the decreased organic load on the secondary treatment process, the overall effect would no more than double the sludge production.[3] Furthermore, dewatering, handling, and transporting chemically-settled sludge requires less effort than typical primary and secondary sludges. The increase in sludge production, therefore, benefits organically overloaded plants yet facilitates sludge handling and transportation.

TABLE 4. PREDICTED QUANTITIES OF SLUDGE PRODUCED BY VARIOUS TREATMENT PROCESSES

	Lime Sludge Produced, lb/MG		
	Without Pretreatment	With Lime Pretreatment	With Tertiary Lime Treatment
Primary Sludge[6]	1041	3644	1041
Secondary Sludge[6]	833	312	833
Tertiary Sludge[3]	--	--	6650
Total Sludge Produced	1874	3956	8524

In addition to reducing the organic loading on the RBC process by lime pretreatment, recarbonation by the microbial population produce carbon dioxide which forms carbonate alkalinity necessary for nitrification after the initial BOD_5 has been removed. The resultant pH after recarbonation is also in the optimal range for nitrification (Figure 2). Nitrification is further enhanced since the availability of the RBC media surface area for nitrifying organisms increased as the surface area requirements for heterotrophic organisms declines with decreased BOD_5 loading.

Overall plant efficiency can be improved by maximizing the usage of chemical-physical processes in conjunction with biological processes, rather than to construct and operate separate unit processes for each parameter to be treated. Combining the low-level lime treatment process for phosphorus removal with biological recarbonation in the RBC process can, therefore, result in a high quality effluent at minimal costs.

Conclusions

1. Phosphorus levels in the secondary effluent of 2.0 mg/l (as P) or less are attainable by combining low-level lime addition with biological treatment processes.

2. The RBC process can recarbonate a wastewater stream without deleterious effects to the microorganisms.

3. Recarbonation by the RBC process was decreased by increased flow rates from 2.0 to 4.0 gpd/sq. ft.

4. Lime pretreatment allows for a decreased organic load on the biological treatment system and therefore a decrease in secondary sludge production.

5. The decreased organic load applied to the RBC as a result of lime pretreatment reduced RBC media surface area requirements for heterotrophic populations.

6. Biological oxidation of organics present in the high pH primary effluent produced an excellent environment for nitrification (low BOD, adequate alkalinity, pH between 7.0 and 8.0).

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WASTEWATER TREATMENT AND ENERGY RECOVERY WITH ANAEROBIC ROTATING BIOLOGICAL CONTACTORS

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The continuing development of ever more stringent industrial effluent discharge standards coupled with rapidly escalating energy costs encourages the development of new approaches for the treatment of high strength carbonaceous wastewaters. Aerobic treatment designs for high strength wastewaters are usually constrained by energy intensive mixing, oxygen transfer or sludge handling processes. Previous experimental work with overloaded conventional rotating biological contactors[1,2,3] led to the concept of the anaerobic rotating biological contactor (AnRBC) for the low cost treatment of high strength wastewaters. Based on the bench scale pilot plant data presented below, it appears that the AnRBC process can attain high quality effluents with relatively low energy inputs.

AnRBC CONCEPT

Conceptually the AnRBC is similar to conventional aerobic rotating biological contactors in that microorganisms become attached to and grow on rotating discs that are partially submerged in the wastewater as shown schematically in Figure 1. Microorganism attachment to the rotating surfaces provides long mean cell retention times in the reactor, which in turn encourages the development of the slow growing methanogenic bacteria responsible for the conversion of low molecular weight compounds to methane.

However, unlike conventional RBC units, the AnRBC is enclosed in an airtight housing with an anoxic atmosphere maintained above the liquid. Also, the depth of submergence is substantially greater than in conventional aerobic units. Groups of discs are separated into sequential compartments (stages) by baffles to prevent short circuiting through the reactor unit. The wastewater is passed from stage to stage, along with sloughed biomass, through holes in the baffles and the product gases are collected by a manifold connected to each stage above the water surface.

AnRBC EXPERIMENTS

Two identical four stage bench scale reactors were constructed from plexiglass as shown in Figure 1. The inside diameter and disc diameters were 13.97 cm and 12.70 cm respectively. The discs were fixed to a horizontal shaft that was rotated by an external variable speed motor. The first stage of each reactor was preceded by a small mixing chamber to insure uniform distribution of substrate to the first stage. The liquid level in

the reactor was controlled by a dynamic head tube similar to a vented inverted siphon on the reactor effluent line. For the treatment studies described below, the reactor contained about 5.27 liters of liquid and was operated with about 70 percent of the disc area submerged. The total disc surface area was about 1.01 m^2 (10.91 ft^2) and was equally divided between the four stages. Grab samples were obtained from valved ports in each stage. Tracer studies with clean discs indicated that the AnRBC reactor could be considered to behave hydraulically like four independent complete mix reactors in series. Construction details have been presented elsewhere.[4]

Data were obtained from a series of eight experiments with a synthetic wastewater containing sucrose and ammonium salts as the sole carbon and nitrogen sources. Other inorganic salts were added to the feed solution as indicated in Table 1. These soluble wastewater constituents are biochemically similar to those that might be expected to result from food, bottling and some organic chemical processing industries. Data were collected under quasi-steady state conditions when gas production and effluent soluble TOC varied by less than ±5 percent for three successive days.

Figures 2 and 3 indicate how AnRBC treatment responded to variations in loading conditions. The effects of flow rate for constant influent substrate concentrations are illustrated in Figure 2 with soluble TOC removal varying from a low of about 46 percent at a nominal reactor hydraulic detention time of 2.2 hours to 96 percent at a hydraulic detention time of 17.5 hours. Figure 3 demonstrates that reactor performance is also dependent on influent substrate concentration for constant flow rate conditions. Figure 4 illustrates the combined effects of mass loading on performance for these experiments. Up to a mass loading rate of about 21.7 g TOC/m^2/day (60.5 g COD/m^2/day or 37.3 g BOD_5/m^2/day) soluble substrate removal exceeded 95 percent and appeared to be independent of influent substrate concentration or flow rate over the range of values investigated. Although the data points shown in Figure 4 could have been connected with a smooth curve, a sharp discontinuity in mass removal appears at this critical loading rate. Volatile acid alkalinity (VAA), pH, alkalinity and gas composition data, although not shown due to space limitations, support the concept that the methanogenic reactions were incomplete for mass loading rates higher than 21.7 g TOC/m^2/day.

Total gas production was found to be related to the substrate utilization rate as shown in Figure 5. Product gas composition was about equally divided between CO_2 and CH_4 for experiments 1,2,5 and 7. The CH_4 fraction decreased to about 45 percent for Experiments 3 and 6 and further decreased to about 40 percent for Experiments 4 and 8. Since pH, VAA and TOC removal data indicated incomplete reactions for Experiments 4 and 8, total gas yield was conservatively estimated as 1.76 m^3 per Kg soluble TOC removed. Thus, the limiting potential energy available by methane recovery from the AnRBC process is dependent on the mass loading conditions employed.

When stage data from all eight experiments are displayed as shown in Figure 6, a series of pseudo-first order reactions are evident. These reactions can be described by an empirical equation of the form

$$\ln C = \ln C_i - K_f T \ , \qquad (1)$$

where C is the soluble substrate concentration (mg/l) remaining at time T (hours) and K_f is a pseudo-first order rate constant dependent on the initial substrate concentration C_i. For these experiments, the data shown in Figure 6 can be described as

$$\ln C = \ln C_i - (0.3744 - 7.96 \times 10^{-5} C_i) T . \qquad (2)$$

The data scatter in Figure 6 is surprisingly small when one considers that a simple pseudo-first order expression is being used to describe the result of a complex series of anaerobic reactions and interactions that were only partially complete for some of the loading conditions employed. Of course, the empirically determined constants in Equation 2 are only valid for the conditions employed in this study. One would expect the constants to change as a function of substrate type, disc diameter, rotational speed, etc. However, these data serve to illustrate the treatment capability of the process and provide the basis for estimating energy requirements.

Other operational parameters that were monitored during these studies included solids production and process sensitivity to adverse conditions. Solids yield varied from a low of 0.2 (Experiment 2) to a high of 0.6 (Experiment 6) and averaged about 0.3 grams of solids generated per gram of TOC removed. A predictive yield equation that depends on the initial substrate concentration and system detention time has been presented elsewhere.[4] Of special interest was the insensitivity of this anaerobic process to oxygen shocks and starvation periods. On two occasions, burst feed lines resulted in air being pumped through the reactor for two days. In both cases the AnRBC system completely recovered within two days. Process recovery was also complete within two days following a one week period of no feeding. Thus this anaerobic process appears to be highly tolerant of oxygen shocks and fluctuating feed conditions. Because the microorganisms are attached to the discs, the AnRBC process is probably able to resist hydraulic shocks that would otherwise result in washout for a suspended culture system.

ENERGY CONSIDERATIONS FOR PROCESS SCALE-UP

Estimating prototype performance based on bench scale data obtained under ideal laboratory conditions is subject to numerous errors and unforeseen problems. However, the following two examples will point out the potential energy advantages of the AnRBC process. It is assumed that conventional twelve foot diameter plastic discs will be used for the prototype installation. Based on torque measurements made with clean, full size discs with an additional 45 percent allowance for the mass of microorganisms adhering to the discs as well as motor and gear box losses, it is assumed that 4 HP will be more than sufficient to rotate a shaft carrying 9300 m^2 (100,000 ft^2) of media. As will be seen later, net energy requirements are relatively insensitive to motor horsepower requirements. The following analysis also ignores external pumping requirements, product gas compressor requirements and heat losses from the reactor. This latter loss is assumed to be offset by a heat exchanger operating between the AnRBC effluent and the influent streams. Because the direct scale-up of bench scale aerobic RBC data has been previously shown to lead to poor prototype design[3], the effective area used in these examples has been reduced by 25 percent from 9300 m^2 to 6975 m^2 per shaft.

EXAMPLE 1 - HIGH QUALITY EFFLUENT REQUIRED (95% Removal)

Using the critical load of 21.7 $g/m^2/day$ from Figure 4 as a basis for design, the mass of TOC that will be removed per day can conservatively be estimated as

$$21.7\ g/m^2/d \times 9300\ m^2 \times 0.75 \times 0.95 = 143{,}800\ g\ TOC\ day\ .$$

Using the gas production rate indicated by Figure 5 and a value of 50 percent methane in the product gas yields

$$CH_4/day = 143.8\ Kg\ TOC/day \times 1.76\ m^3/Kg\ TOC \times 0.5 = 126.5\ m^3/day\ CH_4\ .$$

Therefore the potential energy available from this methane is

$$126.5\ m^3/day \times 35{,}800\ KJ/m^3 = 4.529 \times 10^6\ KJ/day\ .$$

Assuming that 75 percent of the methane energy content can be converted to useful heat, the net available energy becomes 3.57×10^6 KJ/day/reactor.

Energy input to the reactor will be required to turn both the discs and to heat the wastewater to a temperature of 35°C. The 4 HP will require an input of about 258,000 KJ/day, far below the energy equivalent of the methane produced by the reactor. However, the energy required to heat the influent wastewater to a reactor operating temperature of 35°C is dependent on both the influent temperature and the concentration of biodegradeable TOC. For this design example, the product of the flow rate and influent TOC concentration is

$$21.7\ g/m^2/day \times 9300\ m^2 \times 0.75 = 151{,}358\ g/day\ .$$

Thus, an influent concentration of 2000 mg/l yields a flow rate of 75,679 l/day. The minimum energy required to heat this flow for a 20° temperature increase is

$$q = 75{,}679\ Kg/day \times 4200\ J/Kg\text{-}^\circ C \times 20^\circ C = 6.357 \times 10^6\ KJ/day\ .$$

Figure 7 demonstrates the interactions between influent substrate concentration, required temperature change and net energy requirements. The solid portions of the curves represent the region where experimental evidence is available. The dashed portions of these curves represent projections for a well buffered wastewater. The vertical difference between any point on a curve and the 3.6×10^6 KJ/day line represents the net energy yield or input requirement for the reactor. At first glance the breakover points for energy equivalence for 5°, 10° and 20°C temperature changes appear to be around 800, 1700 and 3000 mg/l TOC, respectively. The region below the horizontal line and above the appropriate temperature curve represents the potential energy recovery available from high strength wastewater treatment with the AnRBC process.

EXAMPLE 2 - LOWER EFFLUENT QUALITY REQUIREMENTS (68% REMOVAL)

This example illustrates an AnRBC energy balance for conditions when a

lower effluent quality is acceptable. Based on the data obtained from Experiment 6 (shown in Figures 4 and 5) and a 45 percent methane content in the product gas, it can be shown that a loading of 33.4 g TOC/m^2/day will yield about 123.8 m^3/day of methane with the same areal safety factor used in the previous example. Using the same procedure for estimating energy availability as in the previous example, gives a useable energy yield from product methane of 3.32×10^6 KJ/day/reactor. Again, it is conservatively estimated that 4 HP of electrical energy will be required to rotate the shaft. Figure 8 illustrates substrate concentration and heating requirement effects on total energy requirements. This family of curves has been shifted to the right relative to those shown in Figure 7 due to the larger volumes of water that must be heated.

CONCLUSIONS

The two conservative conceptual design examples presented above illustrate the ability of the AnRBC process to minimize or even produce net energy while concurrently treating high strength carbonaceous wastewaters. Of course, additional experimental work will be required to determine operational parameters before the process can be applied to a specific wastewater. Multiple units operating in parallel can be used to treat large flow rates with the potential for producing excess heat for other inplant uses. Where discharge limitations dictate tighter effluent requirements than obtainable with the process, the AnRBC process can be used effectively as the first step in an anaerobic-aerobic treatment train.

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TABLE I

AnRBC FEED*

CONSTITUENT	CONCENTRATION
$C_{11}H_{22}O_{11}$	Variable
$MgSO_4 \cdot 7\ H_2O$	60.0 mg/l
KCl	120.0 mg/l
$MgCl_2 \cdot 6\ H_2O$	300.0 mg/l
$CaCl_2 \cdot 6\ H_2O$	100.0 mg/l
$CoCl_2 \cdot 6\ H_2O$	14.2 mg/l
$FeCl_2 \cdot 4\ H_2O$	90.0 mg/l
$(NH_4)Cl_2$	**
$(NH_4)_2\ HPO_4$	**
$NaHCO_3$	***

$$\frac{BOD_5}{TOC} = 1.72 \quad , \quad \frac{COD}{TOC} = 2.79 \quad , \quad \frac{COD}{BOD_5} = 1.62$$

* Tap water was used to provide trace nutrients.

** Amount added depended on influent carbon concentration. The N and P concentrations were maintained in excess of a C:N:P ratio of 150:15:1.

*** 3000 mg/l for Experiments 1-4, 6000 mg/l for Experiments 5-8.

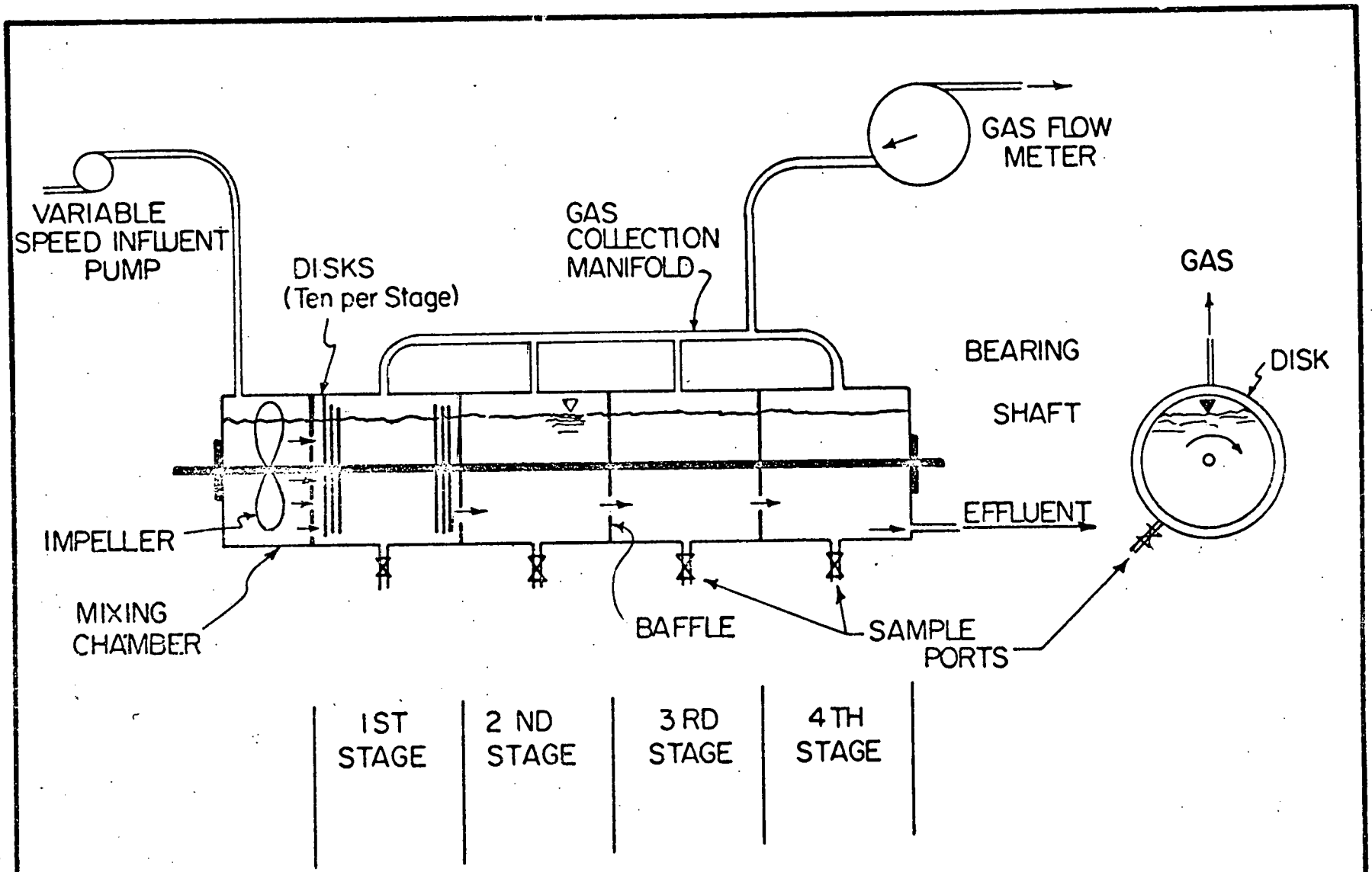


FIGURE 1 ANAEROBIC ROTATING BIOLOGICAL CONTACTOR

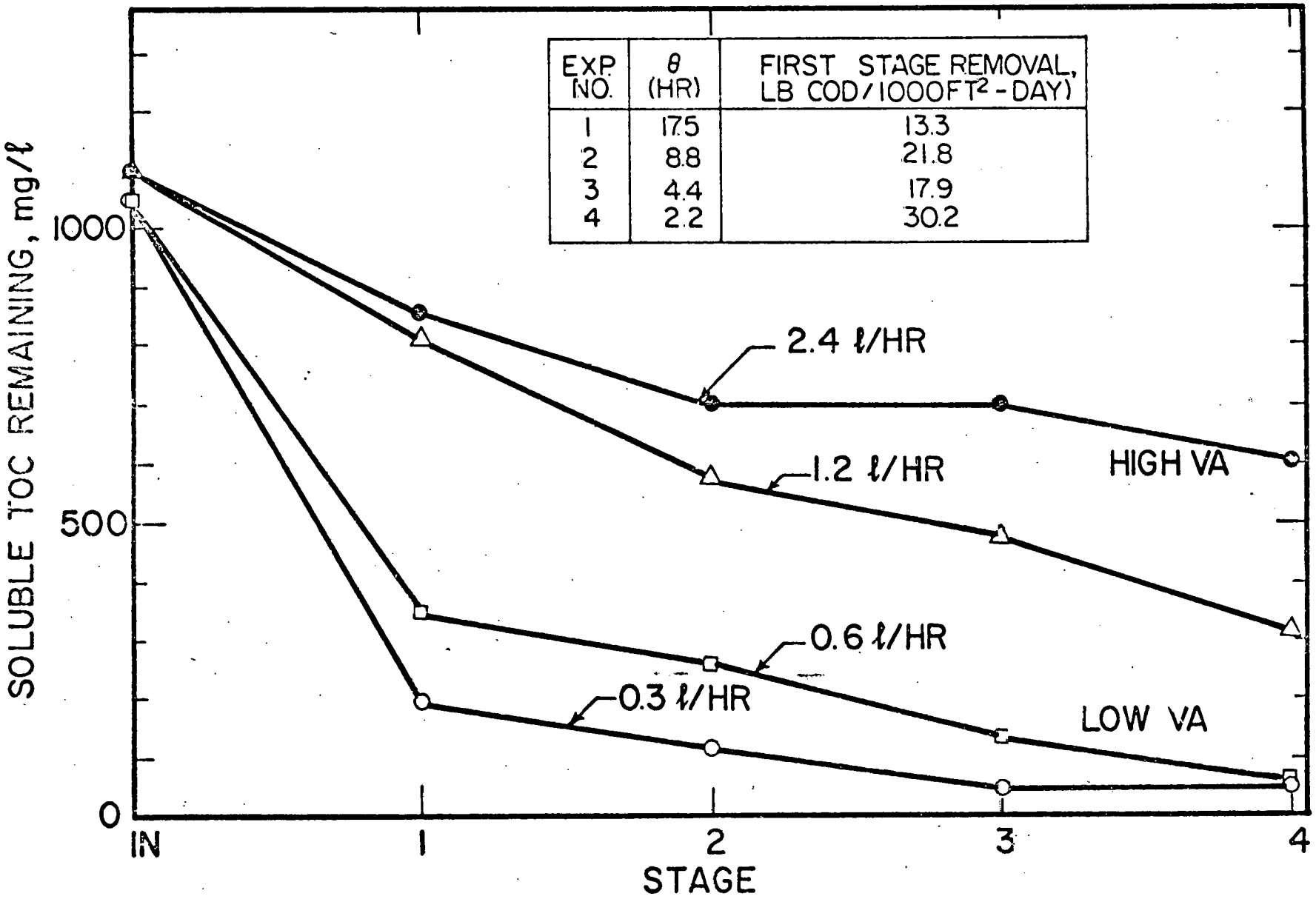


FIGURE 2 EFFECT OF FLOW RATE ON An RBC TREATMENT

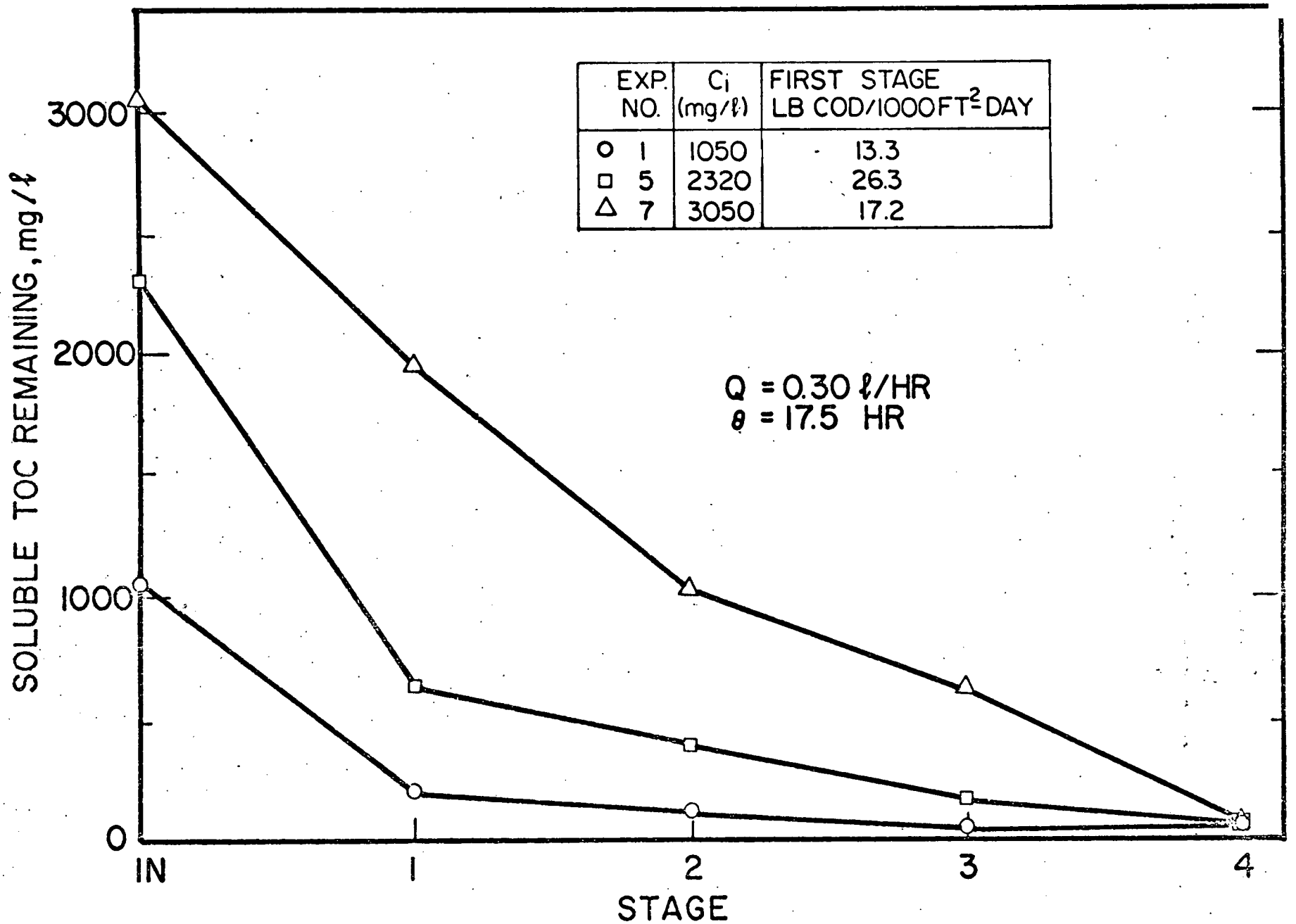


FIGURE 3 SUBSTRATE CONCENTRATION EFFECTS

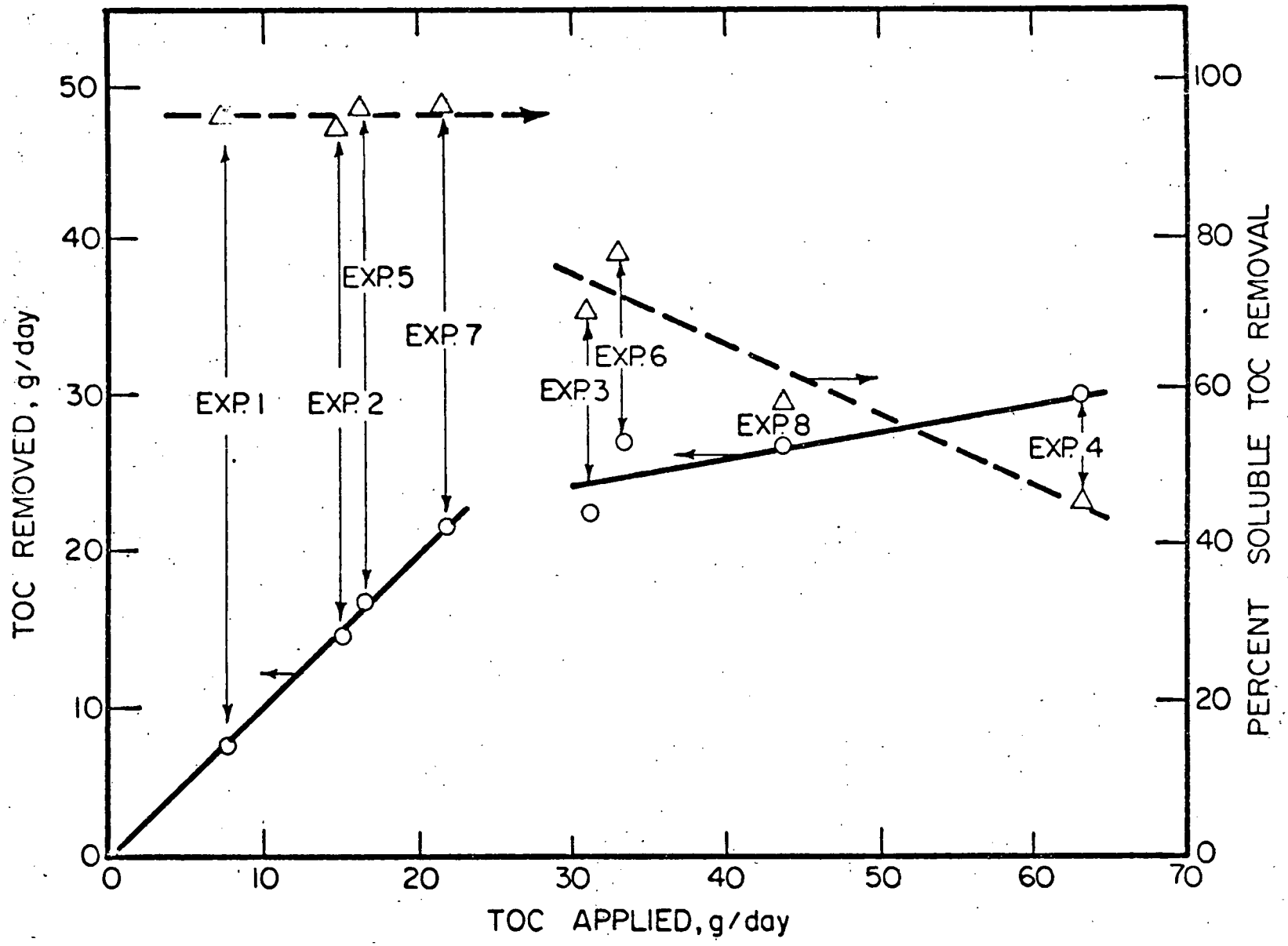


FIGURE 4 SOLUBLE TOC REMOVAL

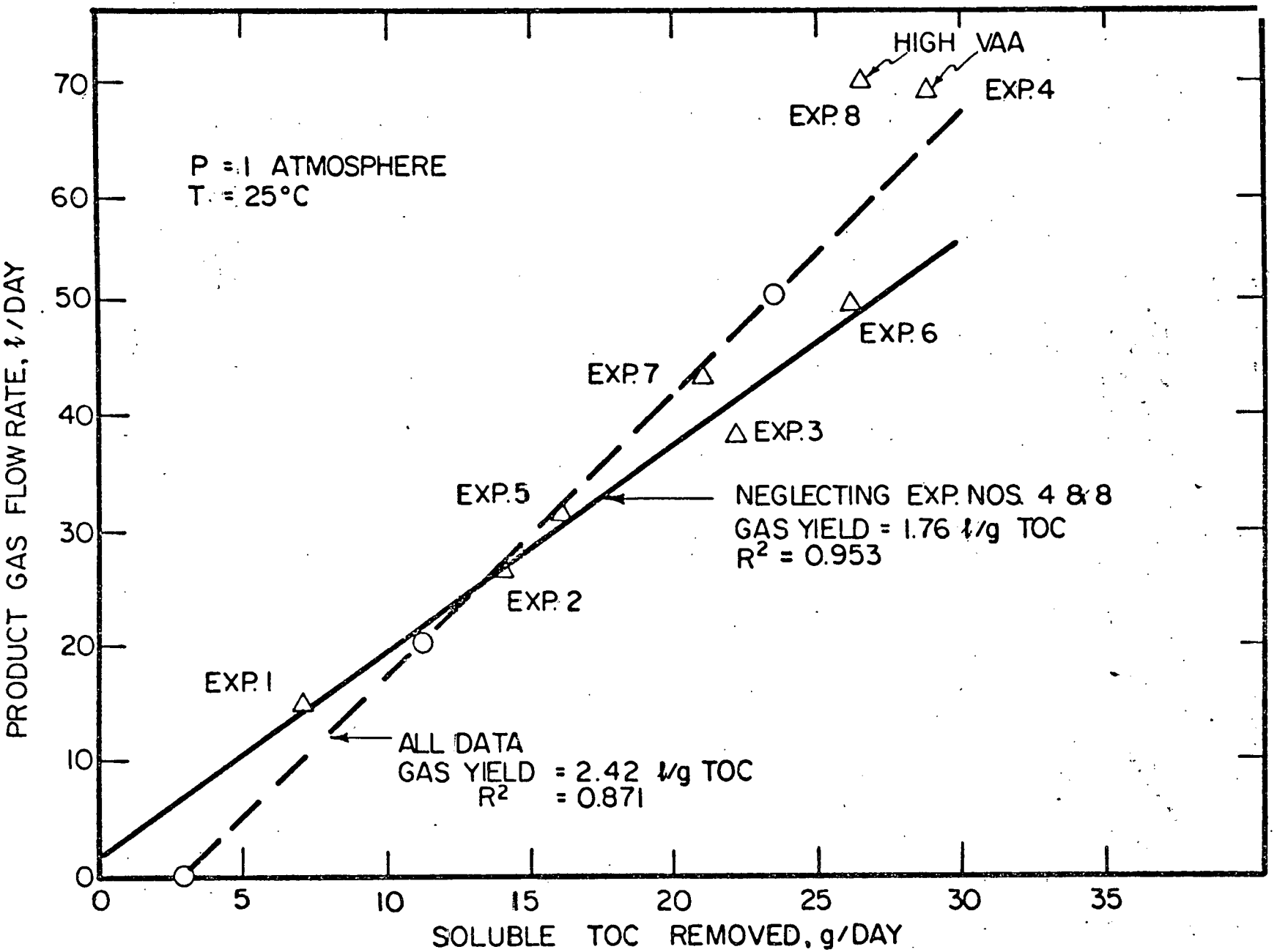


FIG. 5 TOTAL GAS PRODUCTION

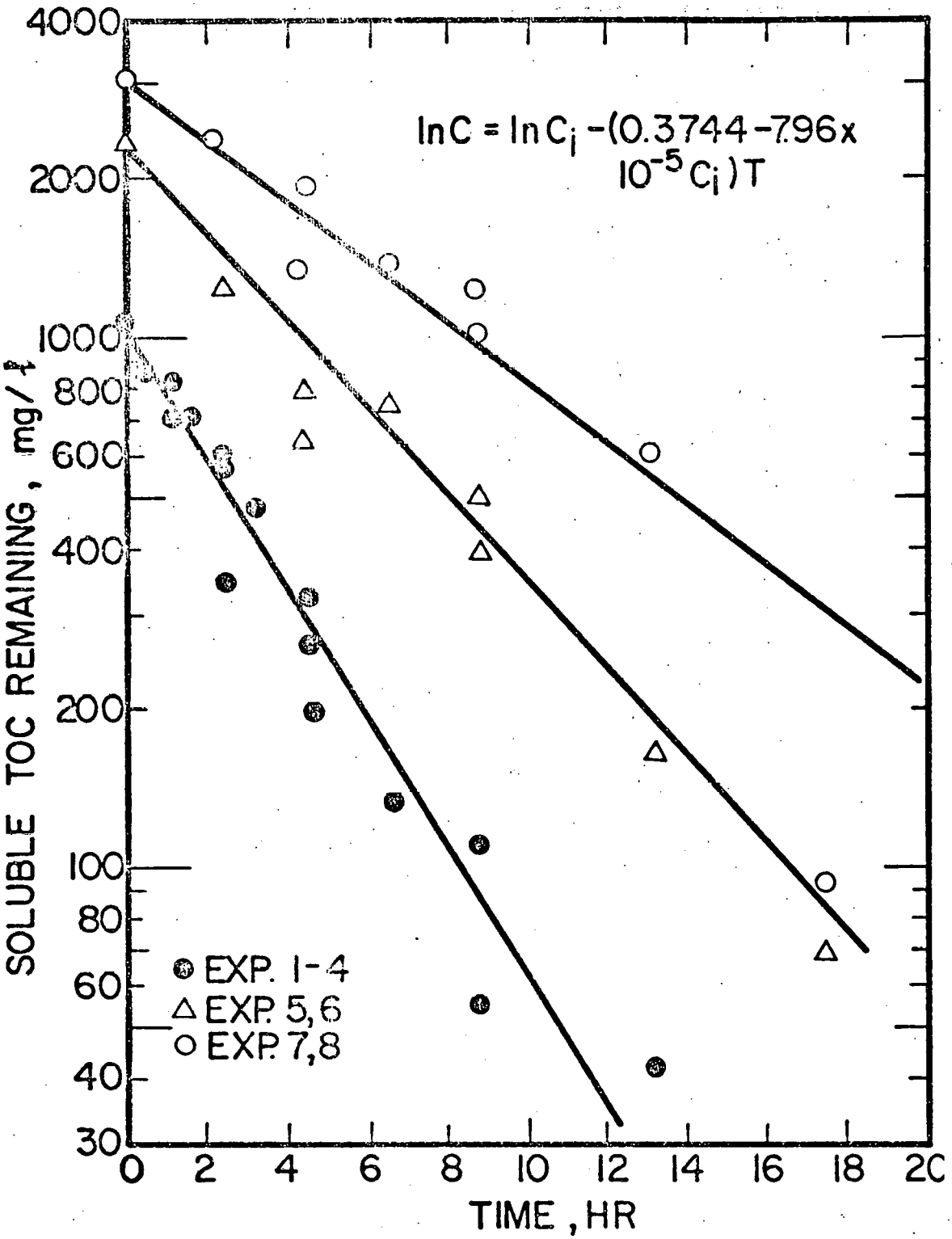


FIGURE 6 PREDICTED TOC VALUES

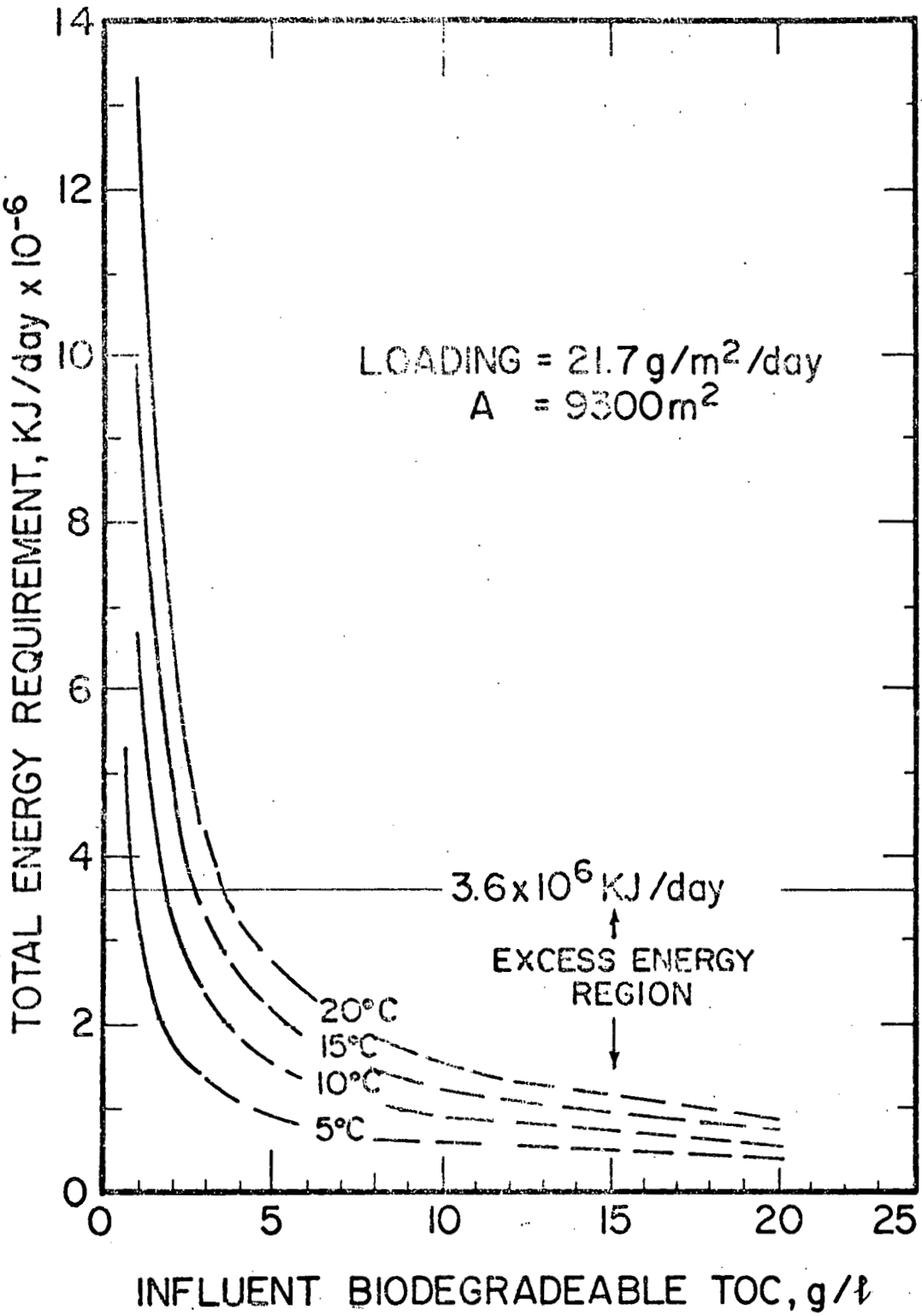


FIGURE 7 INFLUENT SUBSTRATE CONCENTRATION AND TEMPERATURE EFFECTS ON ENERGY REQUIREMENTS, 95% REMOVAL

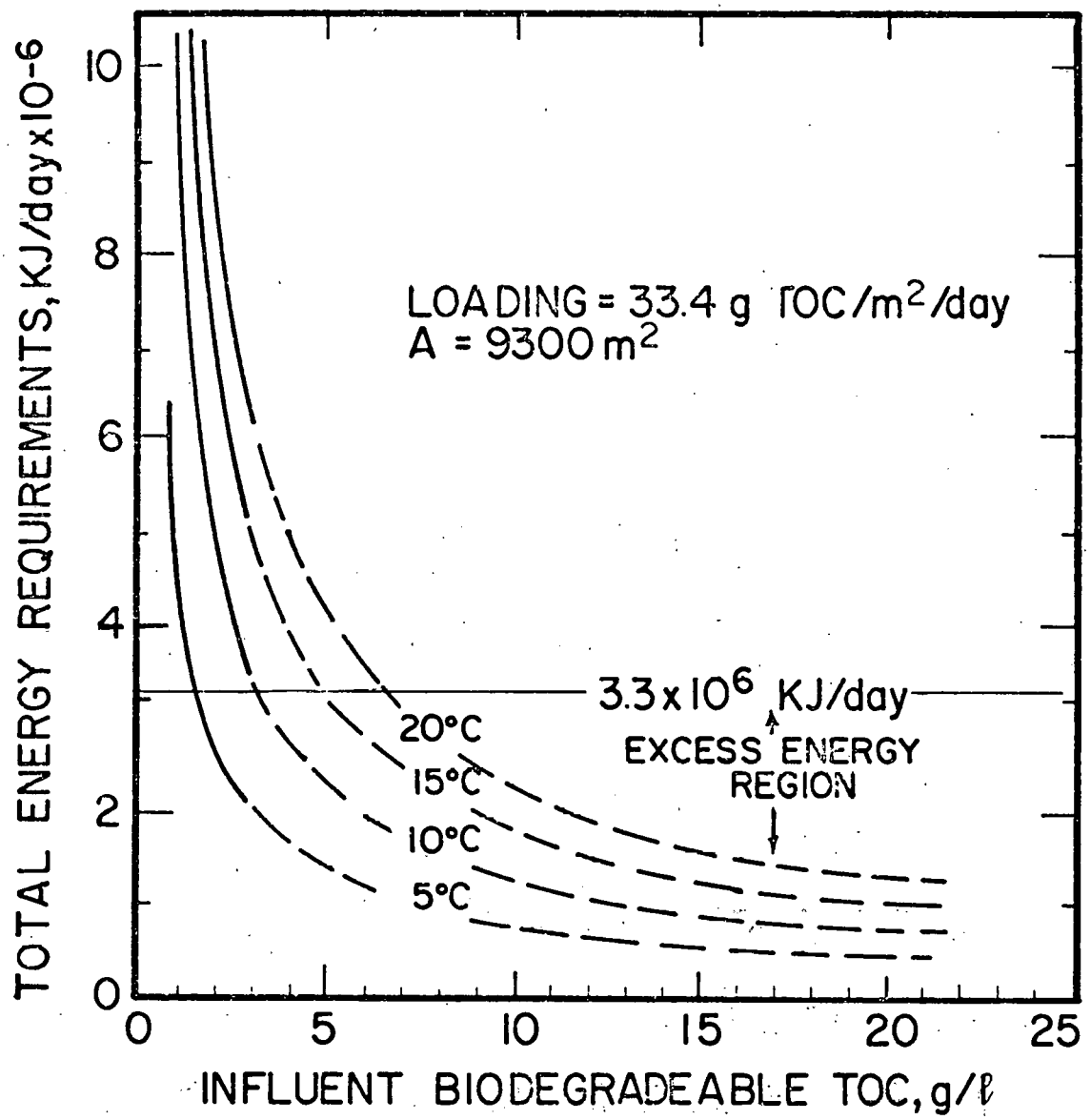


FIGURE 8 INFLUENT SUBSTRATE CONCENTRATION AND TEMPERATURE EFFECTS ON ENERGY REQUIREMENTS, 68% REMOVAL

THE FEASIBILITY OF AN ANAEROBIC UPFLOW FIXED-FILM PROCESS FOR TREATING SMALL SEWAGE FLOWS*

INTRODUCTION

Compliance with requirements to discharge a high quality of treated wastewater to the environment has generally led to the installation of energy intensive systems. The activated sludge process which requires large amounts of energy for aeration to maintain an aerobic microbial population is an example of this technology. Subsequent limitations on the availability of energy have dictated that a high priority be given to conserving energy at every consumption level.

The Oak Ridge National Laboratory (ORNL), under contract with the United States Department of Energy, is developing an anaerobic, fixed-film wastewater treatment system. The ANFLOW process (an acronym derived from the anaerobic, upflow mode in which the system operates) was evaluated during a two-year pilot testing program at a municipal site in Oak Ridge, Tennessee using a biolgical reactor designed to treat 5,000 gpd of municipal wastewater. In order to evaluate the engineering applicability of this process, ORNL retained Associated Water and Air Resources Engineers, Inc. (AWARE) to develop system process designs based upon performance of the pilot-scale system. Conceptual designs were prepared for flows of 0.05 and 1 mgd for typical domestic wastewaters to meet secondary treatment criteria. These designs were used as a basis for estimating capital and operating costs of the system which were compared to the costs for treatment using conventional treatment alternatives.

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PILOT PLANT DESCRIPTION

A schematic diagram of the pilot plant unit is shown in Figure 1. The pilot column consisted of a 5-ft diameter cylindrical fiberglass reinforced plastic column and had an overall height of 18.3 ft. A 10-ft section of the column was packed with 1-in. Raschig unglazed, ceramic rings provided by the Norton Company (Akron, Ohio). A constant feed rate to the column was maintained using an electronic control linked between a magnetic flow meter and a pneumatically operated 3-way control valve. Hydraulic loading rates ranging from 4.0 to 26.5 cu m/day were evaluated.

A heat exchanger was provided as a contingency for heating the influent wastewater during winter months. To minimize heat losses, the entire column was covered with 4-in. of insulation. The heat exchanger system was used only for a 3-mo period during the winter of 1977. At all other times, temperature of the influent wastewater was that which normally occurred.

Feed for the ANFLOW unit was withdrawn from the headworks of the Oak Ridge East Sewage Treatment Plant, immediately downstream of a comminutor. Off-gas from the column was sampled and analyzed using an on-line gas chromatograph. The total off-gas volume was measured using a wet test meter. Continuous monitoring of pH and temperature was accomplished with on-line probes placed upstream and downstream of the anaerobic system.

PILOT SYSTEM PERFORMANCE

A detailed discussion of the ANFLOW data were fully set out in the project report (1) and were presented along with subsequent data collected by ORNL in a recent paper (2). Since the results of the pilot testing program are critical to an understanding of the ANFLOW system, a review of

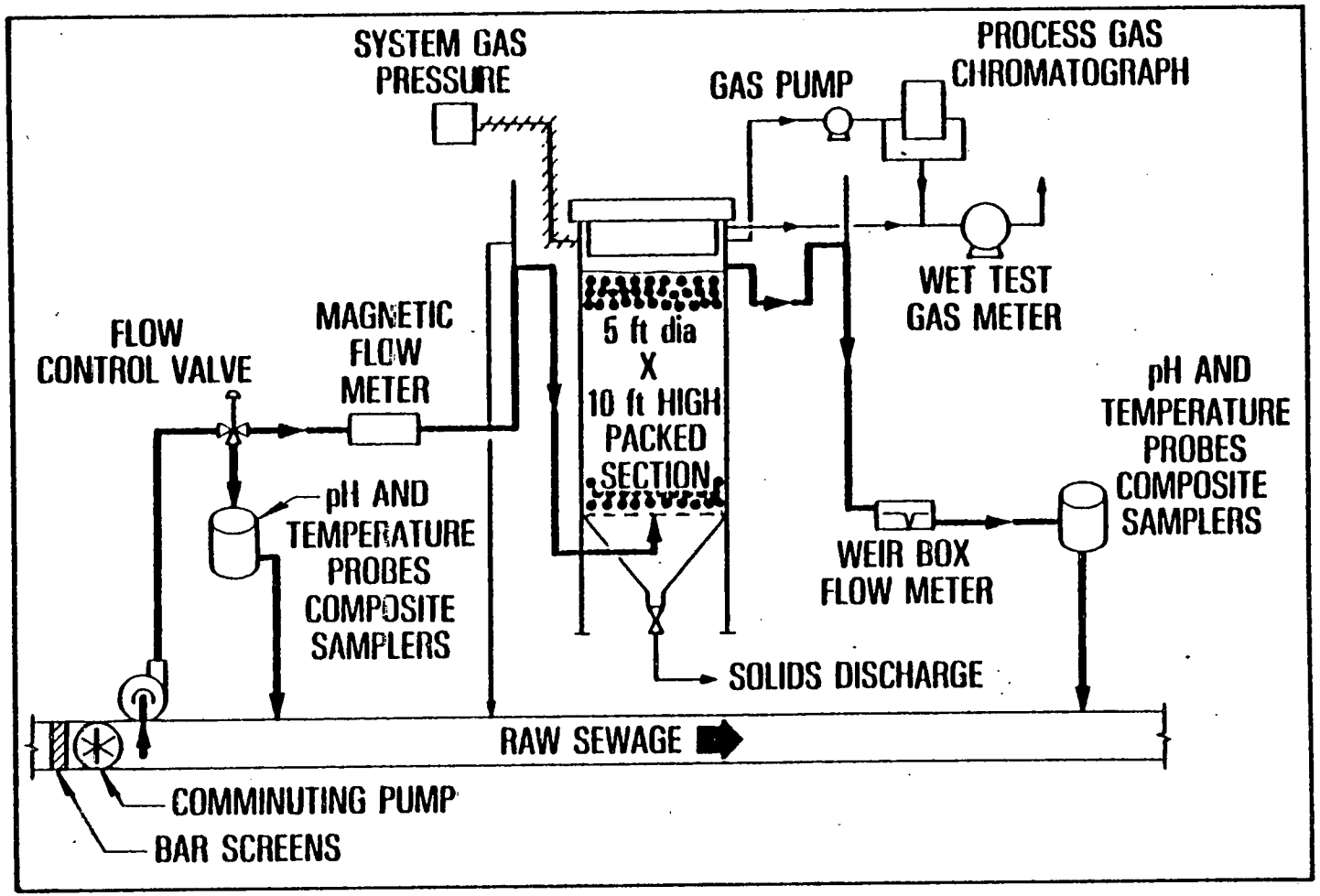


FIG. 1. ANFLOW PILOT PLANT FLOWSHEET

system performance as observed in the initial pilot testing program is presented below.

Performance of the pilot plant is summarized in Table 1. As illustrated in Table 1, the ANFLOW column was very effective in removing suspended solids. Based on the average values, suspended solid removals ranged from 30 to 79 percent. The organic removal appeared to be primarily by bioflocculation and sedimentation of the influent suspended solids. This observation is based on the relationship shown in Figure 2.

To develop a design kinetic substrate removal relationship, several models were evaluated and it was decided to use a first order model and to assume plug-flow conditions within the reactor bed. This model has theoretical basis and was selected because it described observed data better than alternative models considered.

The integrated form of the kinetic equation is given by:

$$\frac{S_e}{S_o} = e^{-Kt}$$

where:

S_e = effluent organic concentration, mg/l

S_o = influent organic concentration, mg/l

K = reaction rate constant, day $^{-1}$

t = actual detention time in the column, day

Although data correlation using this model should be based on soluble effluent COD values, this information was generally unavailable in literature data used for comparison with ANFLOW results.

The ANFLOW and literature data are plotted in Figure 3. The ANFLOW data points for all weekly and monthly averages were grouped (based on organic loading rates) together into six points as shown in Figure 3. A

TABLE 1

PILOT PLANT PERFORMANCE SUMMARY

Hydraulic Loading Rate (gpm/sq ft)	Organic Loading Rate[a] (lb/1,000 cu ft-day)		Length of Operating Period (days)	Influent			Effluent					Off-gas (l/day)	Off-gas Composition	
	TOC	BOD		TOC (mg/l)	BOD (mg/l)	TSS (mg/l)	TOC Mg/l)	BOD (mg/l)	TSS (mg/l)	pH	Temp (°C)		Methane (%)	Carbon Dioxide (%)
0.07	8	17	50	99	209	223	32	84	46	6.7	24.6	92.5	70.0	4.6
0.14	14	19	72	82	113	101	34	50	25	6.8	19.6	95.3	54.9	2.6
0.14	9	15	62	41	92	90	15	44	20	6.7	12.8	50.9	--	--
0.21	25	38	95	100	150	156	62	71	64	6.6	15.3	27.7	44.5	2.7
0.25	24	31	36	82	107	122	42	61	85	7.3	20.6	43.8	55.1	3.1
0.21	33	34	33	132	134	184	52	60	60	7.2	22.4	140.2	64.6	4.2

[a]Calculated using 200 cu ft volume (empty bed).

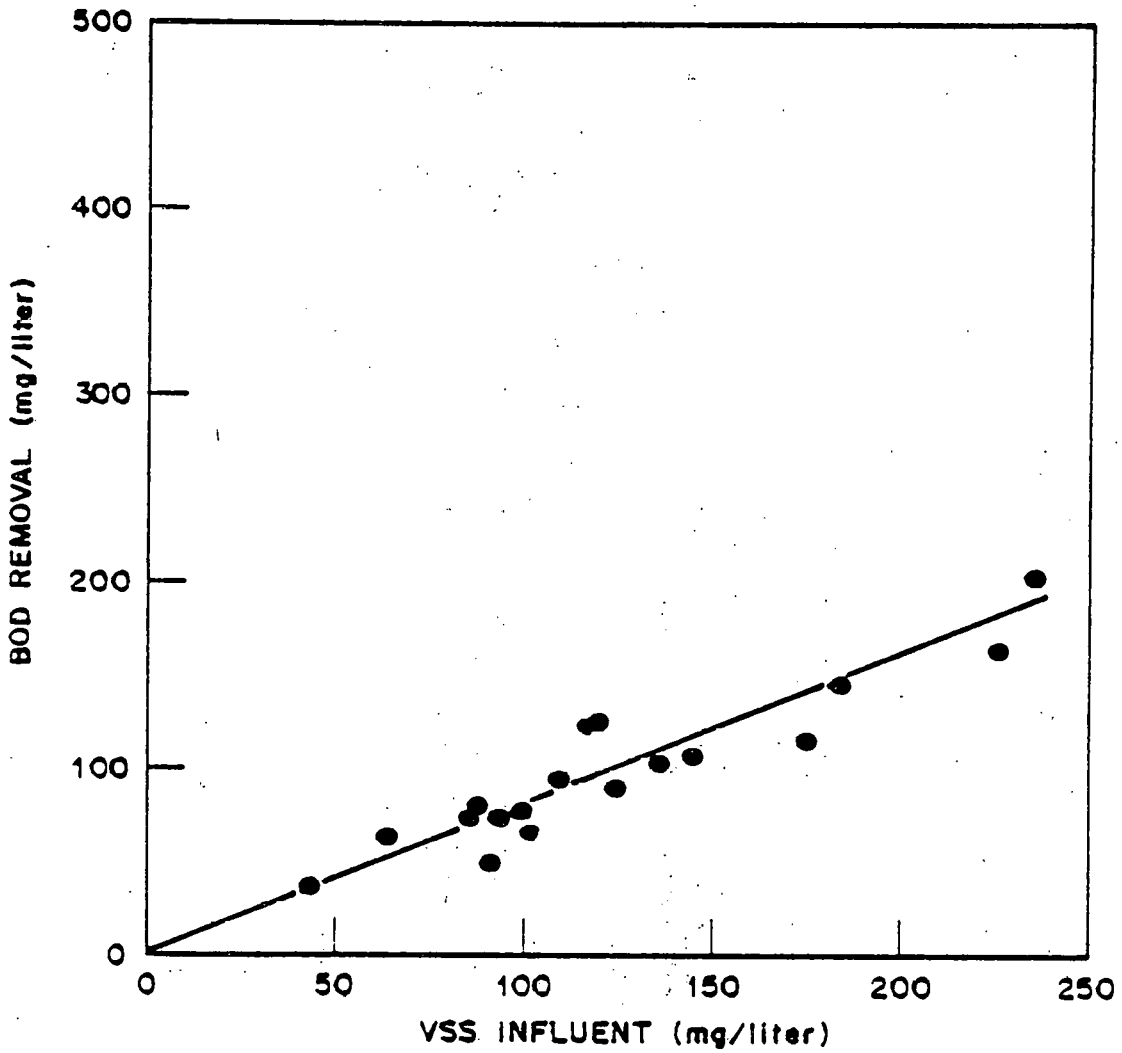


FIG. 2. CORRELATION OF BOD REMOVED WITH INFLUENT VSS

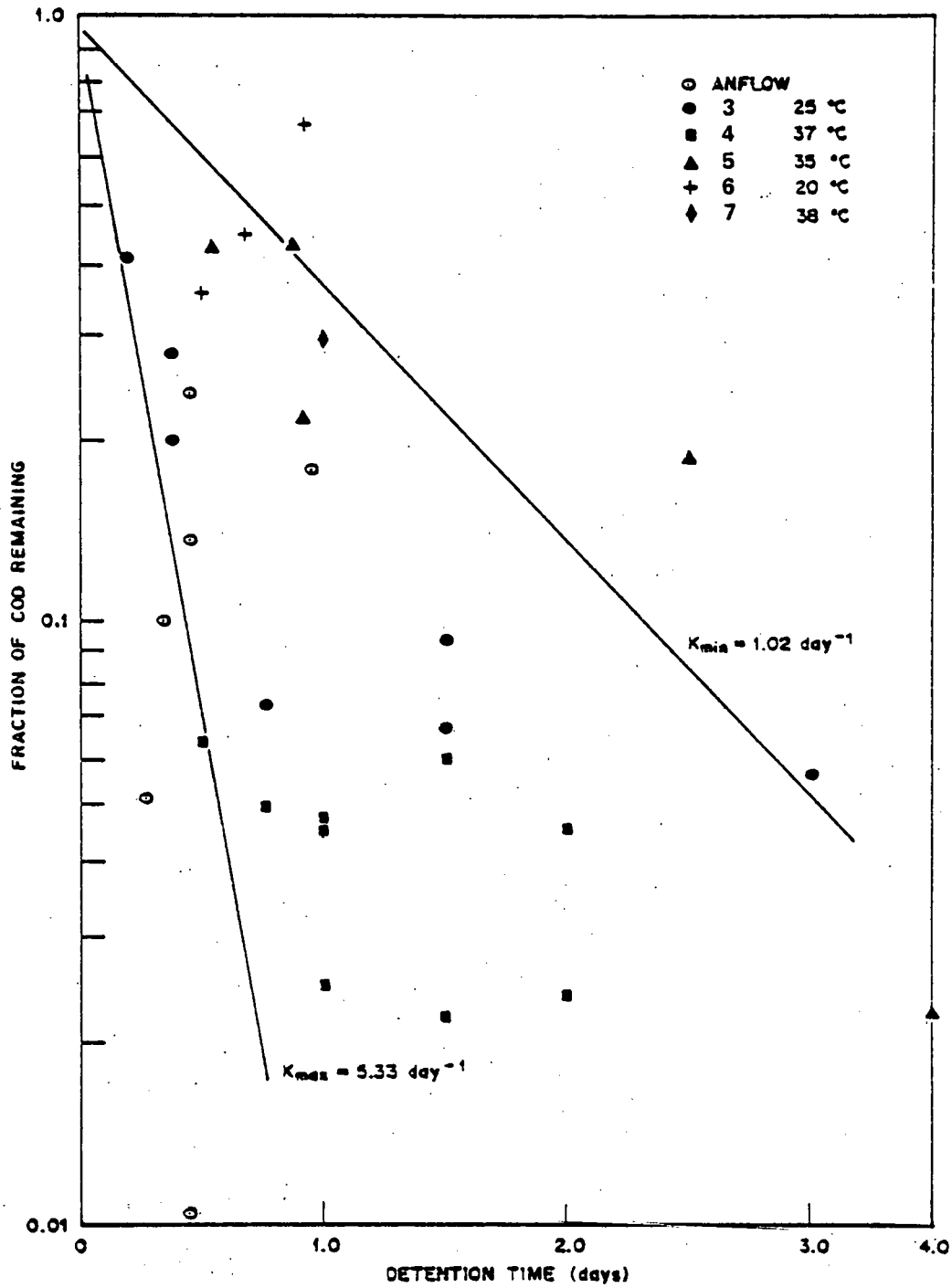


FIG. 3. ANAEROBIC COD REDUCTION CHARACTERISTICS

large data scatter was evident in the results plotted in Figure 3, which was most likely due to the wide variations in waste characteristics, column temperature, column packing characteristics, etc., for the literature derived data. Of the data presented in Figure 3, only those from ANFLOW results and Reference 6 involved treatment of domestic wastewater. Other data describe the treatment of industrial or synthetic wastewaters. Additionally, it was necessary to make some assumptions in calculating the organic concentrations and the detention times for the literature data. Based on these limitations and the data scatter shown, it was concluded that the rate constant to be considered for design should range from 1.0 to 5.0 day^{-1} at $20^{0}C$.

ANFLOW SYSTEM CONCEPTUAL DESIGNS

Influent and Effluent Characteristics

ANFLOW system designs were developed for average waste flows of 0.05 and 1.0 mgd and for peak hourly flows of 180 and 2,400 gpm, respectively. The wastewater characteristics used for these designs are summarized in Table 2. Although design examples were developed for "weak" and "strong" wastewater strengths during this investigation, only the designs for the more concentrated wastewater are presented in this paper.

Treatment objectives were based on EPA secondary treatment standards which require 30-day average BOD and TSS concentrations of 30 mg/l and maximum 7-day average values for these constituents of 45 mg/l each. In addition, a minimum removal of 85 percent is required for both constituents based on a consecutive 30-day average. Since nitrogen limitations are not included in the current guidelines, neither oxidation or removal of nitrogen was included in these designs. If nitrogen removal is required for a

TABLE 2

WASTEWATER CHARACTERISTICS FOR DESIGN EXAMPLES

Quality Characteristics	Value
BOD, mg/l	300
TOC, mg/l	300
COD, mg/l	1,000
TSS, mg/l	350
VSS, mg/l	275
Settleable Solids, ml/l	20
TKN, mg/l	85
NH_3-N, mg/l	50
Temperature[a], Summer, °C	20
Winter, °C	15

[a]Influent sewage temperature.

specific application, the design approach would require modification accordingly.

Design Basis

Data from the pilot investigation were used as the basis for developing anaerobic filter process designs. AWARE experience with other systems was used to supplement the pilot plant data base in developing the designs. This initial design evaluation served to indicate areas of concentration for further pilot and demonstration-scale work should this evaluation indicate a favorable feasibility for the ANFLOW process.

In addition to developing a basis of design for the ANFLOW system, it was necessary to select attendant processes required for a complete treatment system employing the anaerobic filter and to construct process designs for these processes in addition to developing the design for the filter itself. A summary of process design parameters used as the basis of these designs is presented in Table 3. A flow diagram of the ANFLOW system is presented in Figure 4. A process design summary is presented in Table 4.

Pretreatment. Pretreatment facilities included in the design were bar screening, grit removal, comminution of solids, equalization, and solids grinding. Requirements for the bar screening and grit chambers were typical of those used in conventional treatment systems. It was felt that both comminution and grinding of influent suspended solids would be required to ensure that the anaerobic filter did not prematurely clog due to the presence of unacceptably large suspended solids. The system was

TABLE 3

SUMMARY OF DESIGN CRITERIA AND PARAMETERS

Parameter	Value
Pretreatment Facilities	
Bar Screen	
Volume of Screenings, cu ft/mil gal	3.5
Moisture Content of Screenings, percent	80
Method of Cleanings, Small Plant	Manual
Large Plant	Mechanical
Comminutor	
Largest Size of Particle to be Passed, in.	0.25
Minimum Number of Units	2
Grit Chamber (large Plant Only)	
Maximum Overflow Rate, gpm/sq ft	30
Minimum Size of Sand Particles to be Removed, mm	0.2
Volume of Grit, cu ft/mil gal	4.0
Moisture Content of Grit, percent	60
Equalization Tank	
Volume, Percent of Average Daily Flow, Small Plant	25
Large Plant	20
Air Supply, cfm/1,000 sq ft	1.5
Power Consumption Rate, hp/100 cfm	4.0
ANFLOW System	
Packing Media	1-in. Raschig Rings
Reaction Rate Constant @ 20°C, day^{-1}	5.0
Average Hydraulic Loading Rate, gpm/sq ft	0.10
Maximum Hydraulic Loading Rate, gpm/sq ft	0.15
Solids Yield Coefficient, g TSS/g BOD Removed	0.2
Non-Degradable Fraction of VSS	0.3
Effluent TSS, mg/l	35
Effluent Insoluble BOD/VSS Ratio	0.76
Effluent Polishing Facilities	
Aeration and Degasification	
Rate of Air Supply cfm/1,000 cu ft	16
Depth of Aeration Basin, ft	10
Power Consumption Rate, hp/100 cfm	4.0
Upflow Sand Filter	
Maximum Head Loss, ft	6.0
Depth of Bed, ft	5.0
Media Effective Size, mm	1.0
Media Uniformity Coefficient	1.2
Average Hydraulic Loading Rate, gpm/sq ft	3.0
Specific Deposit, lb SS/sq ft-ft head loss	0.05
Effluent SS, mg/l	15
Backwash Rise Rate, gpm/sq ft	35
Backwash Duration, min	10
Chlorination	
Cl_2 Dosage, lb/mil gal	50
Mixing Time, sec	10-30
Minimum Contact Time, min	30
Sludge Handling	
Sludge Surge Tank	
Volume, Fraction of ANFLOW Bed Volume	0.7
or, Number of Backwash Volumes	1.5
SS in ANFLOW Drainage Slurry, percent	2
Settling Time for ANFLOW Drainage Slurry, hr	6
Underflow Concentration, percent SS	3
Sludge Drying Beds	
Solids Loading lb/sq ft-yr	25
SS in Applied Sludge, Percent	3
SS in Dried Sludge, Percent	35

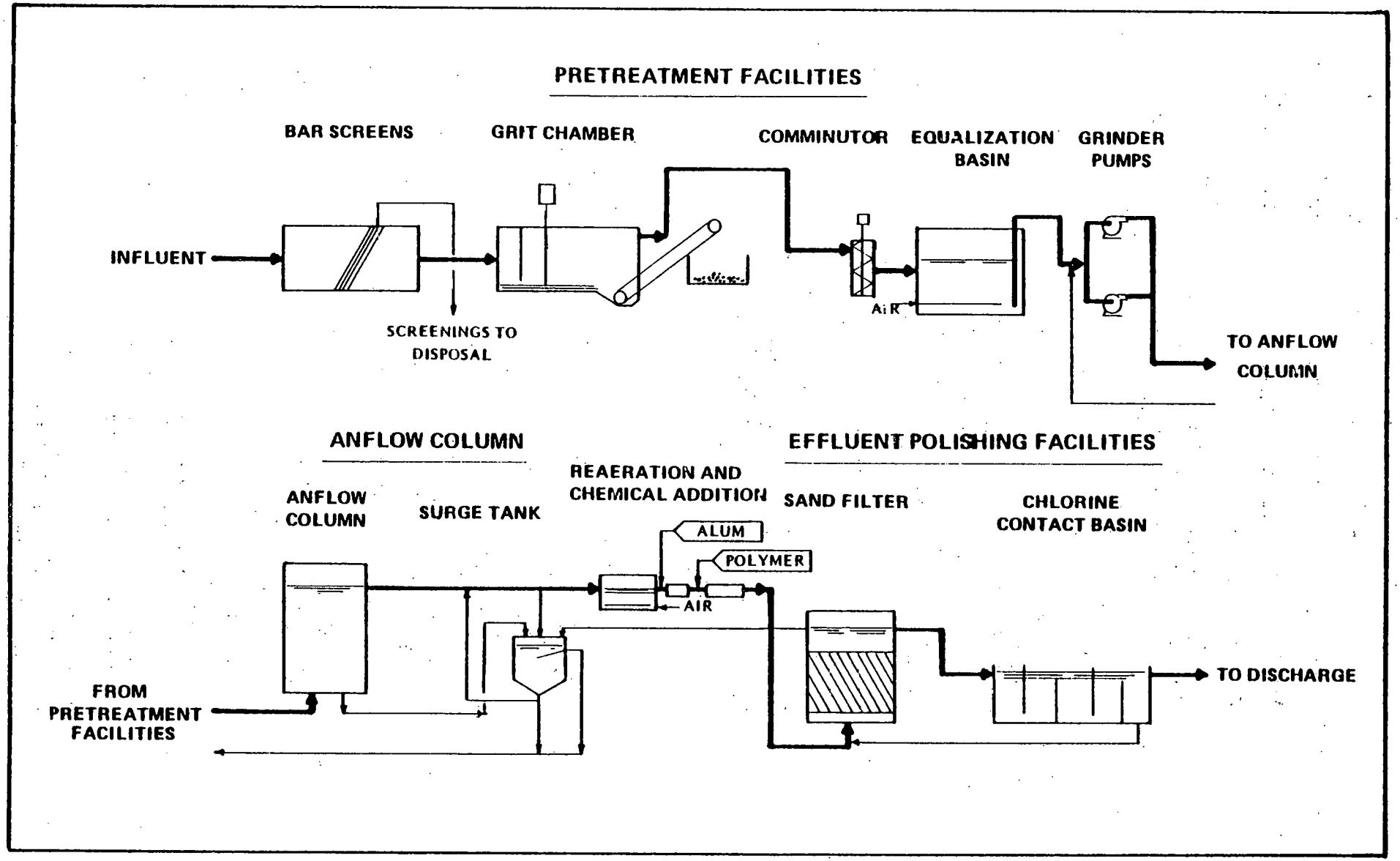


FIG. 4. ANFLOW SYSTEM PROCESS FLOW DIAGRAM

TABLE 4

ANFLOW SYSTEM PROCESS DESIGN SUMMARY

Process Unit	Parameter	Plant Size 0.05 mgd	Plant Size 1.0 mgd
Bar Screen			
	Channel Width, ft	0.5	2
	Screenings Volume, cu ft/day	0.18	3.5
	SS in Screenings, lb/day	3.3	64
Comminutor			
	No. of Units	2	2
Grit Chamber			
	Width, ft	1	4
	Length, ft	5.5	20
	Grit Volume, cu ft/day	0.2	4
	SS in Grit, lb/day	12.4	248
Equalization Basin			
	Volume, mil gal	0.0125	0.20
	Power Required, hp	1	12
Grinder Pump			
	No. of Units	2	2
Anaerobic Filter			
	Detention Time, hr	18	18
	Voids Volume, mil gal	0.037	0.74
	Total Volume, 1000 cu ft	7.06	141.2
	Surface Area, 1000 sq ft	0.706	14.12
	Number of Columns	4	4
	On-side Length of Column, ft	13	60
	COD Loading Rate, lb/1000 cu ft-day	59.0	59.0
Aeration System			
	Detention Time, hr	3.2	3.2
	Basin Volume, mil gal	0.0067	0.13
	Air Required[a], cfm	18	362
	Power Required, hp	0.75	15
Upflow Sand Filter			
	Surface Area, sq ft	12.5	242
	Number of Cells	2	2
	Backwash Volume, 1000 gal	2.2	42.9
Chlorination Facilities	Chlorine Dosage, lb/day	2.5	50
	Maximum Chlorine Dosage, lb/day	7	105
	Rapid Mix Section Volume, gal	60	800
	Contact Basin Volume, 1000 gal	5.4	72
Surge Tank			
	Volume, gal	3,300	65,000
	Solids Accumulation, lb/day	82	1,650
	Column Drainage Volume, gpd	490	10,000
Sand Drying Beds			
	Area, acres	0.03	0.55

[a]An additional 25 percent included for handling the wastewater immediate and chemical oxygen demands.

designed to provide influent suspended solids of 0.5 mm of less downstream of the grinder pumps. Equalization was included in order to provide conditions most suitable for biological treatment and to minimize the size requirements for downstream operations based on peak flow sizing requirements. Aeration was included in the equalization basin design for mixing and to prevent uncontrolled septicity of the waste. Primary clarification was not included because of the relatively small size of the example systems and because of the advantage associated with degrading primary solids in the anaerobic filter.

Anaerobic Filter. The ANFLOW system design was based on a substrate reaction rate constant, K, of 5.0 $days^{-1}$ and a hydraulic loading rate of 0.15 gpm/sq ft. Design at this hydraulic loading rate would, based on the initial pilot plant experience, reduce the possibility of high effluent suspended solids concentrations. The filter columns were designed to be operated in an upflow mode. No problems with clogging of the filter media were observed during pilot-scale testing in an similar flow configuration.

The pilot investigation was conducted using a 10-ft bed depth packed with 1.0-in. Raschig rings. No data were gathered concerning BOD and suspended solids removal along the depth of the column. Available bench-scale data from preliminary testing indicated that a 6-ft column performed as effectively as a 10-ft column when both were loaded at similar rates. Reports in the literature also indicate that extra benefits derived from extending the bed depth beyond 6 ft are marginal (3). However, some examples exist in which greater than 20-ft bed depths were used (8). For this design a 10-ft column depth was selected since this was the height of

the pilot column. A more thorough evaluation of the effect of column depth on treatment performance was left for future investigations.

Very limited data were available on the performance of the ANFLOW system using different packing materials. The amount of active biomass attached to the rings relative to that in the void volume had not been determined at the time this evaluation was performed. Therefore, the significance of the specific surface of the packing could not be determined during this investigation. Furthermore, since Raschig rings appeared to have geometrical characteristics (specific surface, void volume, physical strength, etc.) which were favorable for this application and since these rings were used in the pilot investigations, they were also employed in this design. Despite this selection, it was felt that other packings could be used. The principal requirements are that the packing provide for suspended solids retention in the filter and having an adequate surface area for biomass attachment. Substitution of an alternative packing manufactured from plastic or stone could result in a significant cost savings for the anaerobic system. (The sensitivity of the total ANFLOW system costs to the packing employed was evaluated. This is discussed subsequently.)

The column was sized to provide an effluent BOD of 30 mg/l from the entire treatment system. This corresponded to an effluent soluble BOD from the ANFLOW system of 25 mg/l. The column off-gas will contain methane, carbon dioxide, nitrogen, and small amounts of other gases. This gas represents a source of energy for power generation. Energy available from the gas generation assumed for these designs is illustrated in Table 5.

TABLE 5

ANTICIPATED ANFLOW SYSTEM GAS PRODUCTION AND ENERGY PRODUCTION

Parameter	Plant Size	
	0.05 mgd	1 mgd
Off-Gas, cu ft/day	1,780	35,820
Power Recovery[a], hp	11	225

[a]Calculated using the relationship: $P = 0.98Q\ \Delta TOC$

where:

P = power, hp
Q = treated waste flow, mgd
ΔTOC = TOC removed, mg/l

Effluent Polishing Facilities. To reduce the effluent suspended solids and BOD for discharge, the pilot results indicated that additional treatment using aeration and filtration should be considered. Aeration of the anaerobic filter effluent would provide for methane stripping and aeration.

An upflow sand filter was included in the design to control suspended solids and insoluble BOD in the anaerobic filter effluent. Based on initial pilot plant results using granular media filtration, some difficulty may occur in achieving low filtrate suspended solids concentrations. Therefore, chemical conditioning using alum and polymer was included in this design. The upflow sand filter would function as an aerobic biological reactor. It was assumed that at least 5 mg/l of soluble BOD removal would be achieved in this system designed at a loading rate of 3 gpm/sq ft employing a 5-ft sand depth. Backwash water would be recycled to the filter from the chlorine contact basin located downstream of the filter.

Either chlorination or ozonation facilities would be required to achieve adequate control over fecal coliforms. A conventional plug-flow chlorine contact basin and chlorination system were included in this design.

Sludge Handling Facilities. Intermittently, sludge must be discharged from the ANFLOW system. Since the quantity of solids generated from the anaerobic treatment system would be relatively small, sand drying beds were included in the design for sludge dewatering. It was assumed that underflow from sand drying beds would be recycled to the head end of the treatment system.

COMPARATIVE COST ANALYSIS

In order to determine the economic attractiveness of the ANFLOW process, comparative cost estimates were developed for complete municipal domestic wastewater treatment and sludge handling systems utilizing the ANFLOW process and the activated sludge process. The activated sludge process was selected for comparative purposes because of its predominance in municipal wastewater treatment. The basis for cost development is presented in subsequent sections. Costs were developed from readily available cost curves and were supplemented with vendor quotes and other engineering estimates where appropriate or necessary. The costs presented herein are comparative costs and are considered accurate to $\pm$ 50 percent. Installed capital costs were developed on a unit process basis for each alternate treatment system. Total system capital costs were obtained by summation of unit process costs and addition of appropriate non-process related and contingency costs. All capital costs are battery limit costs and do not include costs for sewers, wastewater pumping other than as specified within the treatment plant, outfall construction, and engineering above normal design work. O&M costs include operation and maintenance labor, laboratory work, electrical, chemical, and other material costs. All costs were adjusted to an ENR Construction Cost Index of 2,860 of August, 1978. All labor costs were based on a rate of $10/hr and all power costs were based on electrical costs of $0.03/kwh. Capital costs were annualized based on a 7 percent interest rate for 30 years. The resulting capital recovery factor was 0.08.

ANFLOW System Cost Basis

ANFLOW media costs were based on the use of 1-in. ceramic Raschig rings at $10/cu ft installed costs. In addition, costs were also prepared using 3-in. polypropylene plastic Raschig rings at $3.50/cu ft installed costs to indicate the sensitivity of ANFLOW costs to the selected tower, packing material. The same column volume was used for both designs although a somewhat smaller volume might be adequate with the larger packing. ANFLOW column costs were developed utilizing concrete as the material of construction with a packing medium depth of 10 ft. Provisions were made for covering both the equalization basin and the ANFLOW reaeration tank for off-gas containment. A granular media filtration system was provided for all ANFLOW design cases. It was assumed that no additional wastewater pumping would be required for the granular filtration system.

ANFLOW system O&M costs were developed on readily available information for conventional unit processes and on engineering estimates for the ANFLOW process itself. The equivalent cost of the recovered energy from the ANFLOW process was computed based on a 40 percent conversion efficiency and an electric cost of $0.03/kwh. This recovered cost was used to offset unit process power costs for the 1.0 mgd flow rate cases. The gas quantity generated at the 0.05 mgd flow rates was judged insufficient to warrant recovery. Even for the 1.0 mgd design flow cases, the off-gas quantities are quite marginal for recovery by boiler-turbine generation equipment. However, recent work by several investigators utilizing methane gas to power internal combustion engine-generator systems indicates on-site power generation as the prime electrical source is feasible (9).

Cost Basis

The unit process flow scheme for the activated sludge process is presented in Figure 5. A primary clarifier was provided for the 1.0 mgd flow case. Aeration basin sizing was based on a design F/M loading rate of 0.2 lb BOD/day-lb MLVSS. Aeration basins were considered to be steel tanks on concrete pads for the 0.05 mgd case and concrete tanks in the ground for the 1.0 mgd cases. Aeration was by diffused aeration systems. Aerobic sludge digestion was provided for all cases. Gravity sludge thickening and sand drying beds were provided for all cases.

Activated sludge system O&M costs were developed from readily available information for individual unit processes. As with the ANFLOW systems, O&M labor requirements were judged to be commensurate with effluent discharge criteria.

System Comparisons

Comparative capital cost estimates for 0.05 and 1.0 mgd treatment systems are presented in Tables 6, and 7, respectively. ANFLOW system costs are shown for use of 3-in. plastic Raschig ring packing and 1-in. ceramic Raschig ring packing. Results indicate a significant cost reduction using the 3-in. plastic rings. Although no experimental data were available at the time this evaluation was completed to indicate comparative performance of the plastic rings, it is felt that performance of the system would not be impaired using the plastic rings. Using costs for use of the 3-in. plastic ring packing for comparison, it can be seen that the ANFLOW system had an 18 percent cost advantage for the 0.05 mgd design flow, while the activated sludge process had a 30 percent cost advantage for the 1.0 mgd design flow on the capital cost basis.

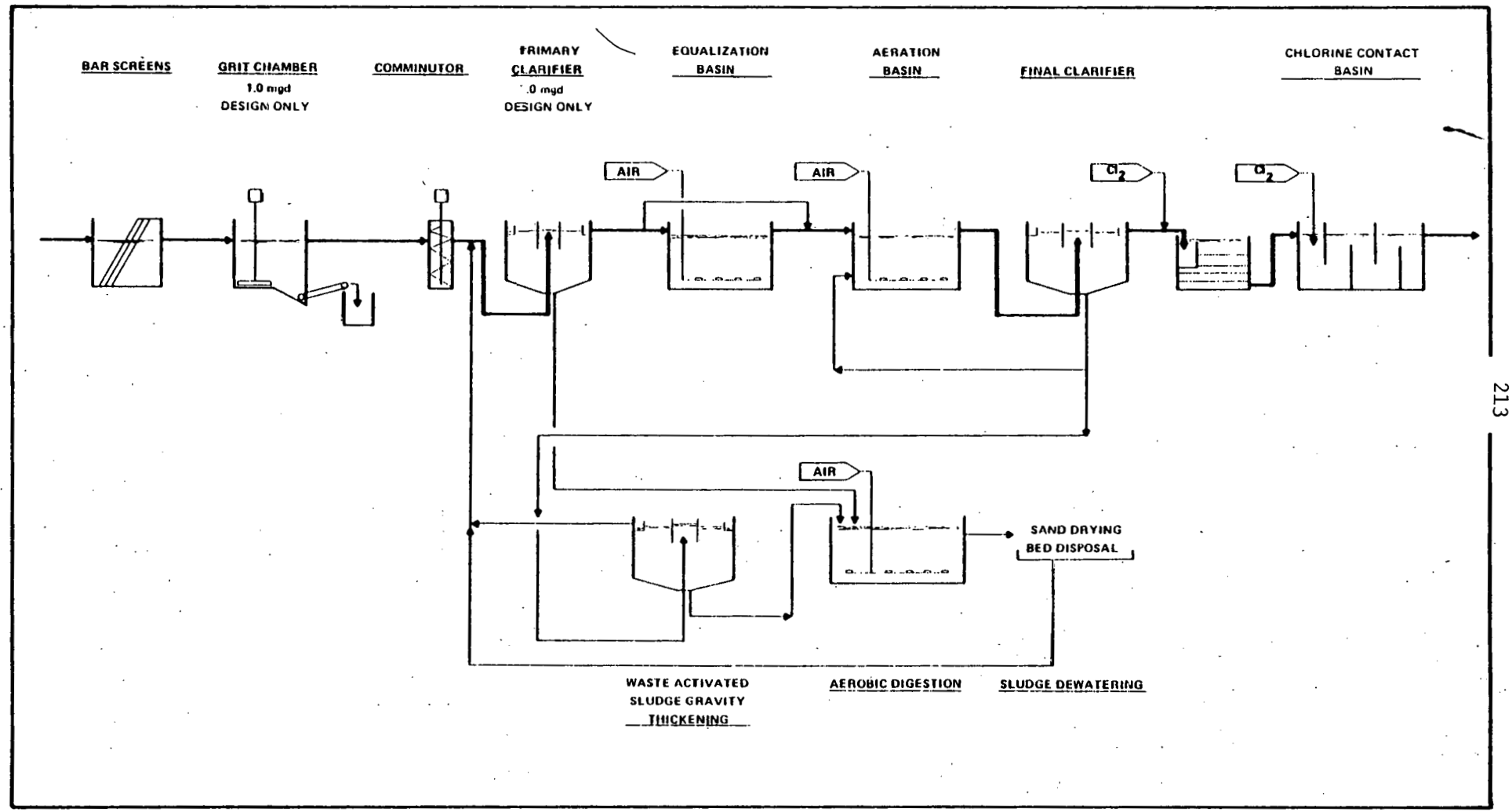


FIG. 5. ACTIVATED SLUDGE PROCESS FLOW DIAGRAM

TABLE 6

COMPARATIVE CAPITAL COSTS
FOR 0.05 mgd TREATMENT SYSTEMS

Process Area	ANFLOW		Activated Sludge
	3-in. Plastic Ring Packing	1-in. Ceramic Ring Packing	
Preliminary Treatment	$ 81,000	$ 81,000	$ 78,750
Biological Treatment	138,450	204,300	180,000
Effluent Polishing	70,750	78,750	33,750
Sludge Handling	37,500	37,500	116,259
TOTAL COSTS[a]	$335,700	$401,550	$408,750

[a]ENR Construction Cost Index of 2,860 (August, 1978).

TABLE 7

COMPARATIVE CAPITAL COSTS
FOR 1.0 mgd TREATMENT SYSTEMS

Process Area	ANFLOW		Activated Sludge
	3-in. Plastic Ring Packing	1-in. Ceramic Ring Packing	
Preliminary Treatment	$ 296,250	$ 296,250	$ 476,250
Biological Treatment	1,577,250	2,981,250	772,500
Effluent Polishing	412,500	412,500	112,500
Sludge Handling	165,000	165,500	532,500
TOTAL COSTS[a]	$2,451,000	$3,855,000	$1,893,750

[a]ENR Construction Cost Index of 2,860 (August, 1978).

Annualized costs for both systems, including amortized capital costs and estimated operation and maintenance costs are presented in Table 8. These estimates indicate that the ANFLOW system would afford an approximate 20 percent reduction in total annual costs compared to total activated sludge treatment for a design flow of 0.05 mgd, while treatment costs would be virtually identical for the 1.0 mgd design case. More recent work at ORNL has indicated that the kinetic basis for design of the anaerobic filter might be too conservative in these designs. While additional data are needed prior to making a firm conclusion regarding system kinetics, such a result would increase the advantage of the ANFLOW system relative to activated sludge treatment.

A comparison between labor requirements for ANFLOW and activated sludge systems for the two design flows are presented in Table 9. This information indicates that labor requirements for the two systems agree to within approximately 5 to 10 percent. However, electrical requirements compared in Table 10 indicate that the ANFLOW system will use approximately 45 percent of the energy required by a 0.05 mgd activated sludge system and approximately 30 percent of the energy required for a 1.0 mgd activated sludge system.

SUMMARY

Initial pilot-scale testing results of the ANFLOW process were used as the basis for developing conceptual system designs. Process designs were developed for domestic wastewaters using flows of 0.05 and 1 mgd. Comparisons were made between the ANFLOW system technology and an activated sludge system (selected as being representative of conventional and more energy-intensive secondary treatment technology).

TABLE 8

TOTAL ANNUAL TREATMENT COST COMPARISON[a]

System	Annual Cost, $ x 10^6/hr	
	0.05 mgd Design Flow	1.0 mgd Design Flow
ANFLOW[b]	0.051	0.30
Activated Sludge	0.061	0.31

[a]Costs based on construction cost index = 2,860 (August, 1978).

[b]Based on use of 3-in., plastic Raschig rings.

TABLE 9

COMPARATIVE LABOR REQUIREMENTS
FOR ANFLOW AND ACTIVATED SLUDGE

Process Area	Labor Requirement			
	0.5 mgd		1.0 mgd	
	ANFLOW	Activated Sludge	ANFLOW	Activated Sludge
Preliminary Treatment	525	500	2,100	2,500
Biological Treatment	450	275	2,000	2,750
Effluent Polishing	243	110	1,310	310
Sludge Handling	360	605	1,080	1,405
TOTAL PROCESS	1,578	1,490	6,490	6,965

TABLE 10

COMPARATIVE POWER REQUIREMENTS
FOR ANFLOW AND ACTIVATED SLUDGE

Process Area	Power Requirement (kw)			
	0.5 mgd		1.0 mgd	
	ANFLOW	Activated Sludge	ANFLOW	Activated Sludge
Preliminary Treatment	3.12	3.04	31.10	30.28
Biological Treatment	0.95	3.81	3.80	57.08
Effluent Polishing	1.14	0.38	6.66	0.95
Sludge Handling	0.0	4.19	0.0	57.45
TOTAL PROCESS	5.21[a]	11.42	41.56[b]	145.76

[a]No power recovery included.

[b]This amount will not be required since power recovery is included for this case.

In addition to developing a design for the anaerobic filter, it was necessary to select and determine a design basis for attendant processes required to provide a secondary level of treatment. Pretreatment processes selected for use ahead of the anaerobic filter included bar screening, grit removal, comminution of solids, equalization, and solids grinding. Downstream of the anaerobic filter, facilities were included for aeration, upflow filtration through a granular medium and chlorination. The upflow granular media filter was designed to function as a aerobic biological reactor to remove at least 5 mg/l of soluble BOD in addition to its function in removing suspended solids from the ANFLOW column effluent. Because of the relatively small sizes of the systems selected for analysis, sludge dewatering by application to sand drying beds was selected.

The results of this comparison are summarized as follows:

1. The ANFLOW system exhibited an 18 percent cost advantage over conventional activated sludge treatment for the 0.05 mgd design case, while the activated sludge process had an approximate 30 percent capital cost advantage for the 1.0 mgd design case.
2. Definite cost advantages were indicated for the ANFLOW system using a 3-in. plastic Raschig ring for the column fill material instead of the 1-in. ceramic Raschig ring used in the initial pilot investigations. While it is felt that the larger packing would perform at least as well as the smaller, confirmation of this hypothesis must be the subject of further investigations.
3. A comparison of total annual treatment costs (amortization and operational costs) indicated that the ANFLOW system would afford an approximate 20 percent reduction in annual costs compared to

activated sludge treatment for a flow of 0.05 mgd, while treatment costs would be virtually identical for the 1.0 mgd design case.

4. A comparison of energy usage indicated that the ANFLOW system would use approximately 45 percent of the energy required by an activated sludge system for a design flow of 0.05 mgd, while the ANFLOW system use approximately 30 percent of the energy required by a 1.0 mgd activated sludge system.

Based on this evaluation, the ANFLOW process appears to be economically competitive with conventional secondary treatment technology. This evaluation also indicated that the ANFLOW process requires significantly less energy than conventional secondary treatment systems. Initial pilot testing results indicate that the process is technically feasible. Additional aspects of system performance and confirmation of treatment levels achievable using the ANFLOW system will be investigated in a demonstration-scale plant (50,000 gpd) which is currently being designed and will be located in a City of Knoxville South Sewage Treatment Plant.

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ENERGY CONSERVATION AND PRODUCTION FROM THE ANAEROBIC DIGESTION OF THERMALLY CONDITIONED SLUDGES AND DECANT LIQUORS

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INTRODUCTION

It has long been recognized that a major drawback to the use of thermal sludge conditioning has been the solubilization of organic material during conditioning with the resulting return of high organic strength decant liquor to the plant for treatment. This return of decant liquor to the plant represents a significant increase in the organic load, resulting in a need for additional aeration and solids handling capacity. Thus, treatment of the solublized organic load adds to the capital and operating costs of the plant (both monitary and energy). Since thermal conditioning systems are not operated in a steady state manner, decant liquor recycle represents a large shock load to biological treatment systems. For this reason, it is desirable to treat the decant liquor in a separate treatment system.

Anaerobic processes offer significant advantages over aerobic processes for the separate treatment of decant liquor. Anaerobic systems are more capable of handling intermittent loads than are aerobic systems. Anaerobic systems require low energy inputs and, with the production of methane, are net energy producers. Aerobic systems have high energy requirements and sludge yields. Anaerobic processes have a sludge yield approximately 10% of the sludge yield expected from aerobic processes. Thus, anaerobic sidestream treatment will impose a lower solids recycle load on the plant that will aerobic treatment. The enclosed nature of an anaerobic system also offers an advantage over most aerobic systems in odor control.

ANAEROBIC DIGESTION PILOT STUDIES

During the summer of 1978, bench scale, pilot studies were carried out to investigate the anaerobic digestion of decant liquor from a full scale thermal sludge conditioning system. The pilot studies were designed to develop design parameters, estimate energy (methane) production, estimate performance (particularly biodegradable organic reduction), determine operating parameters, determine settleability of the sludge leaving the digesters, and investigate operational stability of the digesters, particularly the response to the intermittent loading. In order to achieve these goals, four (40, 1.5 litre anaerobic digesters were used and were fed the decant tank overflow from three (3), 9000 gph heat treatment systems.

BENCH SCALE ANAEROBIC DIGESTION

The digesters were immersed in a constant temperature water bath (96^{o}F). Feed and sample withdrawal ports allowed for the movement of liquid

through the digesters while maintaining anaerobic conditions. No mechanical mixing was provided. All gas produced by the digesters was collected for volume measurement and analysis. Analysis of feed and digester effluent operating parameters was carried out on an intensive basis throughout the study. In addition to those parameters routinely monitored, the BOD rate constants and ultimate BOD's for both feed and effluent samples were determined.

ANAEROBIC DIGESTION RESULTS

After an initial acclimation period of one (1) week, the digesters were through four (4) operating phases; Phase 1 - decant tank supernatent feed at 15 days detention time; Phase 2 - decant tank supernatent feed at 10 days detention time; Phase 3 - diluted heat treated sludge at 15 days detention time, and, Phase 4 - an intermittent feeding phase during which decant tank supernatent was fed on a three-day feed, three day rest cycle to simulate the intermittent nature of full scale operation at an average detention time of 15 days. The results of the four phases of operation are summarized in table 1.

Discussion of Results The bench scale work has clearly demonstrated that anaerobic digestion is suitable for side stream treatment of decant liquor. Stable operation was possible under all conditions tested. The intermittent feeding (three days of feed followed by three days of no feed) simulated the type of shock loading conditions that may be expected in full scale operation. It must be stressed as an overall observation of the entire laboratory bench scale study with the anaerobic digesters, that there was always an ease of operation exhibited. The digesters were never overly sensitive to any changes or shocks to which they were exposed and no chemical additions were ever required. Given food in the form of decant liquor and a proper temperature, the digesters literally "ran by themselves".

The intermittent BOD_5 analyses of the digester feed and effluent demonstrated that removal of the biodegradable portion of the organic load is significantly higher than that of the soluble COD. These removals ranged from 80 to 95 per cent. It was observed that the longer the detention time, the higher the removal rate and lower the actual BOD_5 level in the effluent.

STUDY CONCLUSIONS

The following conclusions may be drawn from the results obtained during the anaerobic digestion of the thermal conditioning decant liquors.

1). Anaerobic digestion has demonstrated that it is a stable, satisfactory method for treating decant liquors at reasonable detention times, capable of achieving approximately 80 percent soluble COD removal, and producing significant quantities of energy in the form of methane gas.

2). Digester operations were stable under all conditions tested.

3). No adjustment of pH of alkalinity was required.

4). Digester gas production was at the rate of approximately 5.5 cubic feet per pound of soluble COD destroyed.

5). Digester gas evolved was composed of 70 percent methane by volume As is normally experienced, BTU valve is anticipated to be approximately 670 BTU/SCF.

6). Solids separation in the digester effluent was observed to be good with supernatant total suspended solids averagind approcimately 200 mg/l.

7). A major portion (95%) of the organic load (COD) in the digester effluent is non-biodegradable.

DESIGN PARAMETERS

Based on the studies performed it was possible to develop design parameters for the anaerobic digestion of decant liquor from thermal sludge conditioning. The design parameters developed and presented in Table 2 are the results of a single study and while they agree with the limited information available in the literature, they should be used with care. They are suitable for preliminary design and process selection. The use of a pilot study during the design phase is highly recommended.

Table 2: RECOMMENDED DESIGN PARAMETERS FOR ANAEROBIC DIGESTION OF DECANT LIQUORS

Parameter	Range	Recommended Value*
Detention time days	10-15	12
Soluble COD removal %	75-82	78
Soluble BOD_5 removal %	80-95	88
Biodegradable Organic Removal %	80-98	95
Temperature ^0F	90-100	100
Gas Produced $\frac{ft^3}{\#\ SCOD}$	5.4-9.5	5.5
% Methane in Gas	70-73	70
Clarifier Hydraulic Loading gpd/ft^2	400-800	600

* Based on Pilot work described herein

The design parameters presented in Table 2 are based on high rate mechanically mixed mesophilic anaerobic digestion. External solids separation in a clarifier or secondary (unmixed) digester is assumed. Date were not collected on solids yield during the pilot studies. However, qualitative observations indicate very low solids yields. These observations, combined with information in the literature indicated that the use of textbook values for solids yield (in the order of 0.05 mg VSS/mg BOD_L) is appropriate.

PRELIMINARY DESIGN

The impact of the choice of solids handling methodology on the entire treatment plant unit process sizing, capital and operating costs are investigated in this paper. In order to properly assess the impact of solids handling alternatives, three different solids handling processes, shown in Figures 1 through 3, were investigated. Each flowsheet was designed and evaluated for flows of 10 and 30 MGD. The liquid phase of each flowsheet considered was identical and consisted of: preliminary treatment, primary sedimentation, conventional activated sludge, and secondary clarification.

SOLIDS HANDLING ALTERNATIVES

A preliminaty design was carried out for each of the alternatives. Power and fuel requirements for each unit process were determined, as well as the quantity of sludge cake which must be disposed of from each flowsheet. The anaerobic digestion design parameters utilized were presented in Table 2 and the influent and effluent wastewater characteristics assumed are presented in Table 3. Normal design parameters were used for the liquid flowsheet.

Table 3: WASTEWATER CHARACTERISTICS

Parameter	Influent	Effluent
BOD_5 mg/l	250	20
TSS mg/l	250	20
VSS mg/l	175	16
Summer wastewater temperature C	20	20
Winter wastewater temperature C	15	15
MLSS mg/l	3250	--
MLVSS mg/l	2600	--
Peak to average flow	1.5	1.5

In addition to the anaerobic digestion criteria presented in Table 2, it was necessary to make additional assumptions in order to properly analyze the flowsheets. Since the decant liquor and/or thermally conditioned sludge fed to the anaerobic digesters will be at approcimately 110° to 120° F, it was assumed that ten per cent of the digester gas wes used for digester heating. For digestion of the heat treated sludge and decant liquor, a primary digester retention time of 12 days and a secondary digester retention time of 6 days were selected for design/ Gas production from the digestion of thermally conditioned sludge plus decant liquor was estimated by assuming 15 standard cubic feet of digester gas per pound of volatile solids destruction and 5 standard cubic feet of gas per pound of soluble COD removed from the decant liquor. Digester gas from the digestion of heat treated sludge plus decant liquor was assumed to have a heating value of 600 BTU per standard cubic foot.

Using the assumptions presented above, the treatment units required were sized, and the fuel and power requirements estimated for each flowsheet.

The equipment and unit process sizing are presented in Table 4 and the fuel and power requirements presented in Table 5. Note that only those unit processes which are effected by the choice of solids handling flowsheets are included in Tables 4 and 5.

ECONOMIC COMPARISON

The capital and the fuel and power operating costs for each flowsheet were determined based on the preliminary designs previously presented. In order to determine the total cost of the 10 MGD plants considered, it will be necessary to add to the costs shown, the capital and operating costs for the unit processes common to all the plants. The economic parameters which were used for evaluation of alternatives are presented in Table 6. Labor was not considered in developing operating costs since it is estimated that the labor for all flowsheets, at a given flow capacity, would be similar. Parameters, the capital and operating costs for each alternative are presented in Table 8. Table 7 summarizes the costs for each alternative as well as total annual costs and as present worth.

Table 6: ECONOMIC PARAMETERS

Parameter	Value
Project life	20 years
Interest rate	6.875 %
Fuel cost	$2.50 / MMBTU
Power cost	$0.04 / KWH
Sludge disposal cost	$15.00 / wet ton

As may be seen from Table 7, digestion fo decant liquor (flowsheets B1 and B2) results in the flowsheet with the lowest capital cost. The lower capital cost is a result of a significantly lower cost for the aeration system and small savings in the cost of thickening, blending and sludge dewatering. These flowsheets which include digestion of all sludges (C1 and C2) have a slightly higher capital cost than those flowsheets whcih include only the digestion of decant liquor. Te slightly higher capital cost is due primarily to the cost of additional digestion capacity. The flowsheet which include digestion all sludges (C1 and C2) have the lowest operating costs of all flowsheets considered.

Table 7: COST COMPARISONS

Flowsheet	Capital Cost $1000's	Annual Operating Cost $ / Yr.	Total Annual Cost $ / Yr.	Present Worth $1000's
A1	3,022	382,900	655,400	7,118
B1	2,877	317,200	586,100	6,270
C1	3,129	286,800	561,300	6,005
A2	7,065	1,143,200	1,803,600	19,294
B2	6,478	942,100	1,547,600	16,556
C2	6,696	796,900	1,422,800	15,221

As may be seen from Table 7, the operating cost for flowsheet C@ is over 15 per cent less than that for flowsheet B2. The flowsheets which do not include any digestion (A1 and A2) have operating costs which are approximately 17 percent higher than the flowsheets which include anaerobic digestion of the decant liquor only (B1 and B2) and only 30 per cent higher than the flowsheets which include anaerobic digestion of all sludges (C1 and C2).

On the 10 MGD scale, digestion of all sludges results in an annual cost saving, including amortization of capital costs, or over $104,000 per year. This represents a cost savings of over 15 percent when compared to a flowsheet in which the decant liquor is returned to the liquid phase for treatment (A1 and A2). On a 30 MGD scale, the savings realized by including digestion of all sludges are over $380,000 per year, or over 20 percent. It is important to note that since savings in fuel and power costs of over 30 percent may be realized by including anaerobic digestion of all thermally conditioned sludges in the flowsheet, anaerobic digestion of thermally conditioned sludge will become increasingly attractive as fuel and power costs increase.

SUMMARY AND CONCLUSIONS

Results of the pilot study descrived demonstrated that the decant liquor is easily digested, that the anaerobic digestion is extremely stable, that over 90 percent of the biodegradable organic material is removed from the decant liquor, and that signigicant quantities of energy are produced. Design parameters developed during the pilot study combined with information available from the literature were then used to carry out preliminary design and economic comparison of the flowsheets presented in figures 1 through 3.

The inclusion of anaerobic digestion of thermally conditioned sludge resulted in operating cost savings of over 30 percent for both size plants, and overall cost savings of approximately fifteen percent for the 10 MGD scale and over 20 percent at 30 MGD. These cost savings are in addition to the advantage of more stable operation which may be expected from the flowsheets which include anaerobic digestion of the thermally conditioned sludge and decant liquor.

TABLE 1: SUMMARY OF PILOT DIGESTER RESULTS

PARAMETER	PHASE 1		PHASE 2		PHASE 3		PHASE 4	
	FEED	EFFLUENT	FEED	EFFLUENT	FEED	EFFLUENT	FEED	EFFLUENT
Soluble COD mg/L	4600	591	3895	947	4351	950	4349	888
% SCOD Removal	-	87.2	-	75.7	-	78.1	-	79.6
Total COD mg/L	4975	863	6737	1530	4934	1358	4963	1116
% TCOD removal	-	82.7	-	76.4	-	72.5	-	77.5
Soluble BOD_5 mg/L	2506	128	2127	326	1583	-	1941	96
$SCOD/BOD_5$	2.03	4.24	1.74	2.76	2.29	-	2.25	9.25
% Biodegradable organic Removal*	-	93.9	-	81.7	-	-	-	94.1
TSS mg/L	394	190	1965	278	117	223	77	94
VSS mg/L	286	148	1223	255	70	149	61	73
Gas Producer per SCOD destroyed ft 3/lb	-	5.7	-	9.2	-	5.7	-	5.5
% Methane	-	-	-	70.6	-	70.3	-	72.0

* Defined as effluent BOD_{ult} / Feed BOD_{ult} using BOD_5 - values and rate constants, K of 0.17 and 0.11 day - 1 for feed and effluent, respectively as determined during the study.

Note: All effluent values are averages of four digesters.

Table: 4 Unit Process and Equipment Sizing

Unit Process	A1	B1	C1	A2	B2	C2
Aeration basin Volume M.G.	1.31	1.05	1.05	3.99	3.26	3.26
Air Required SCFM	15,078	12371	12371	45,236	37,114	37,114
Sludge Thickener Diameter X SWD	60'X10'	55'X10	55'X10	(2) 70'X10'	(2) 70'X10'	(2) 70'X10'
Blend & Mix Tank Diameter X SWD	15'X16'	10'X16'	10'X16'	20'X16'	20'X16'	20'X16'
Heat Treatment System GPH	3750	3750	3750	8000	8000	8000
Decant Tank Diameter X SWD	25'X10'	25'X10'	---	40'X10'	40'X10'	--
Primary Anaerobic Digester Diameter X SWD	---	65'X25'	70'X25'	---	110'X25'	120'X25'
Secondary Anaerobic Digester Diameter X SWD	---	---	50'X25'	---	---	85'X25'
Vacuum Filters Diameter X Face	6'X8'	6'X5'	6'X7'	10'X14'	8'X12'	8'X14'

Table: 5 Fuel and Power Requirements

Unit Operation	A1	B1	C1	A2	B2	C2
Aeration Power KWH/year	4,729,408	3,880,008	3,880,008	14,188,225	11,640,616	11,640,616
Sludge Thickening & Blending Power - KWH/year	55,525	26,129	26,129	78,388	78,388	78,388
Heat Treatment Power KWH/year	145,964	134,888	134,888	437,320	404,040	404,040
Fuel - MMBTU/year	21,840	20,168	20,168	65,520	60,060	60,060
Decant Tanks Power - KWH/year	4,899	4,899	-----	4,899	4,899	----
Vacuum Filters Power - KWH/year	276,952	148,200	214,968	808,132	374,556	439,712
Anaerobic Digestion Power - KWH/year	----	153,510	205,115	----	453,977	600,472
Fuel - MMBTU/year	----	(7,342)	(21,115)	----	(24,237)	(63,291)
Total Power KWH/year	5,212,748	4,347,643	4,461,108	15,516,964	12,956,496	13,163,228
Total Fuel MMBTU/year	21,480	12,826	(947)	65,520	35,823	(3,231)

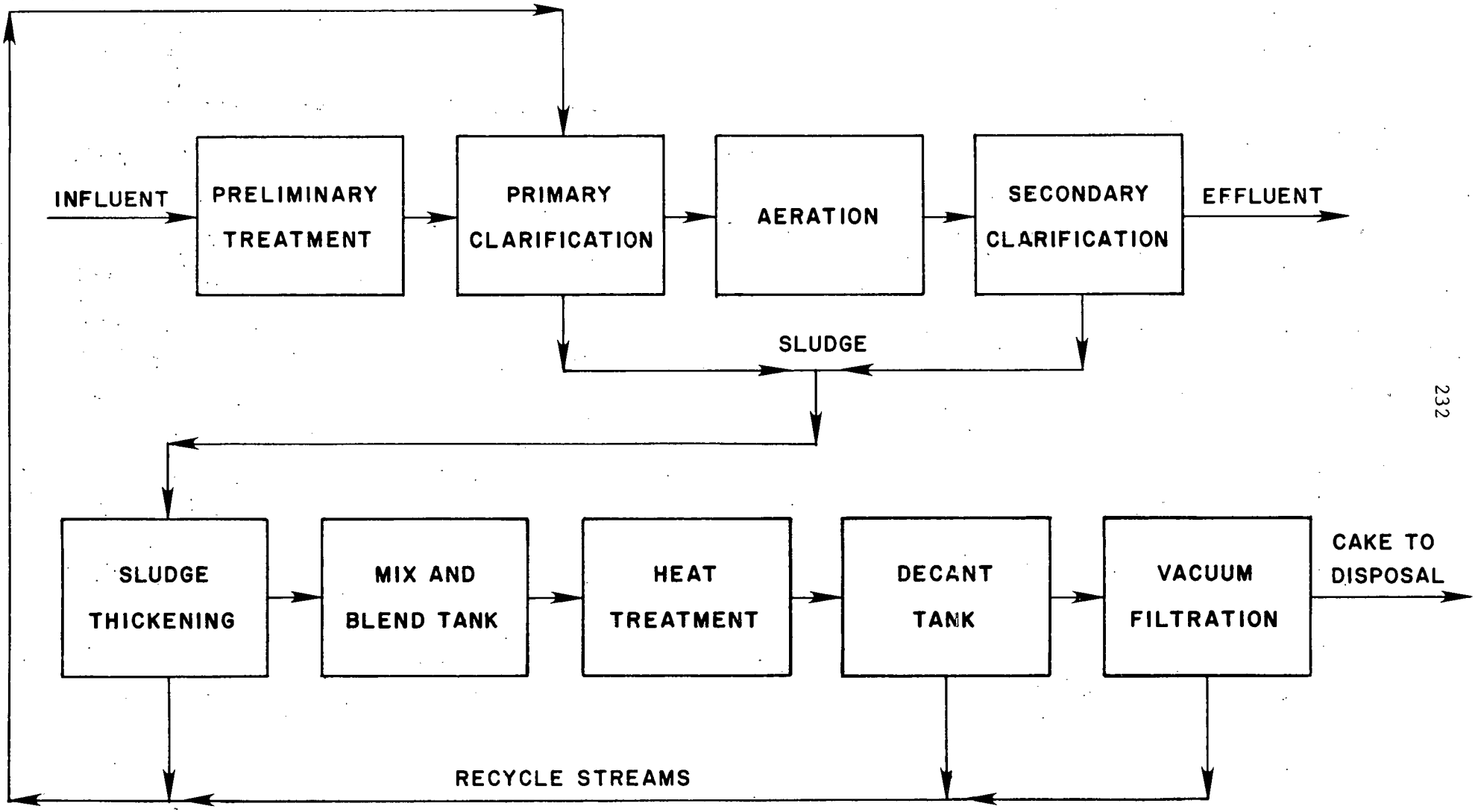


FIGURE 1 – HEAT TREATMENT, NO DIGESTION

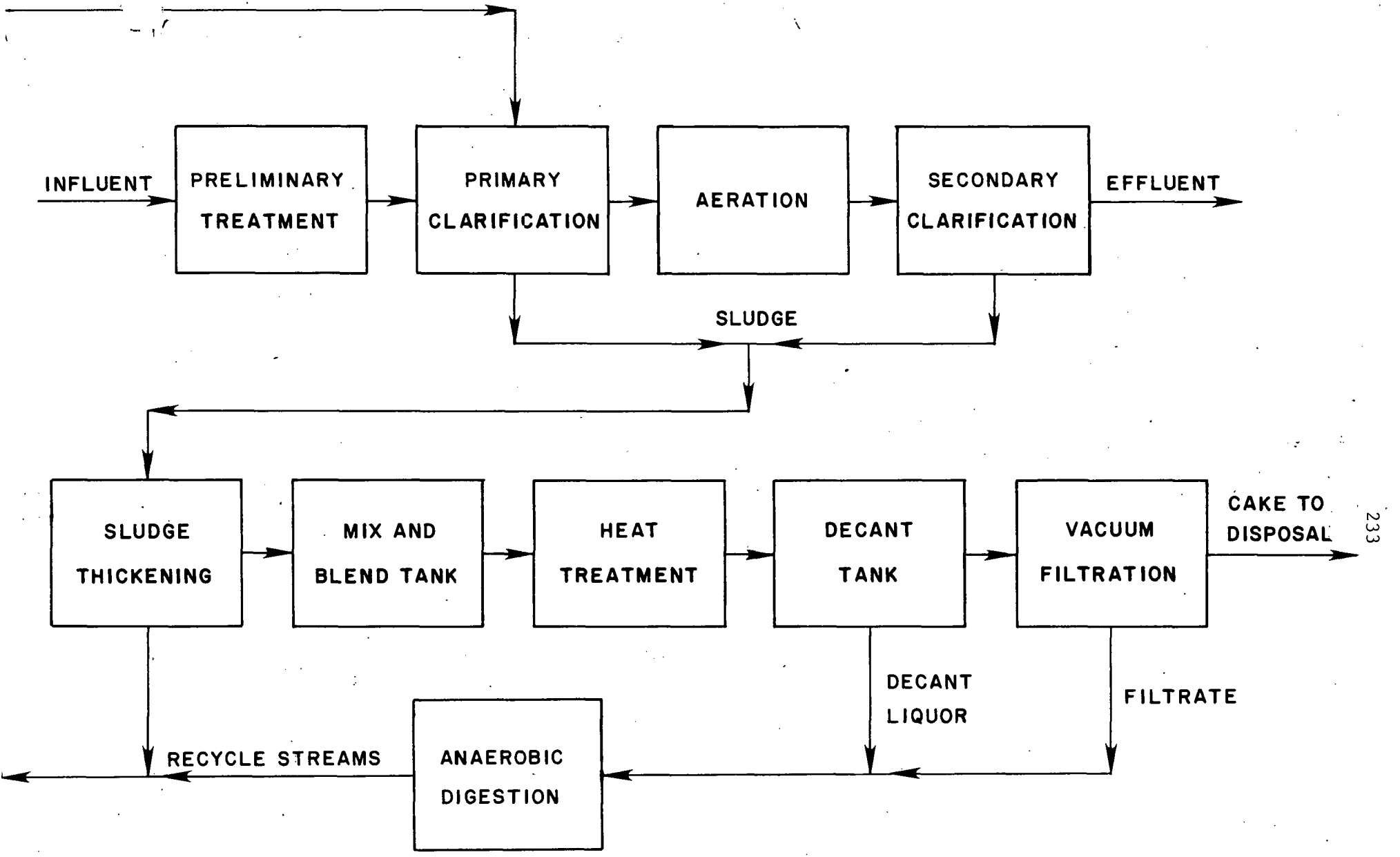


FIGURE 2 – HEAT TREATMENT, DIGESTION OF DECANT LIQUOR

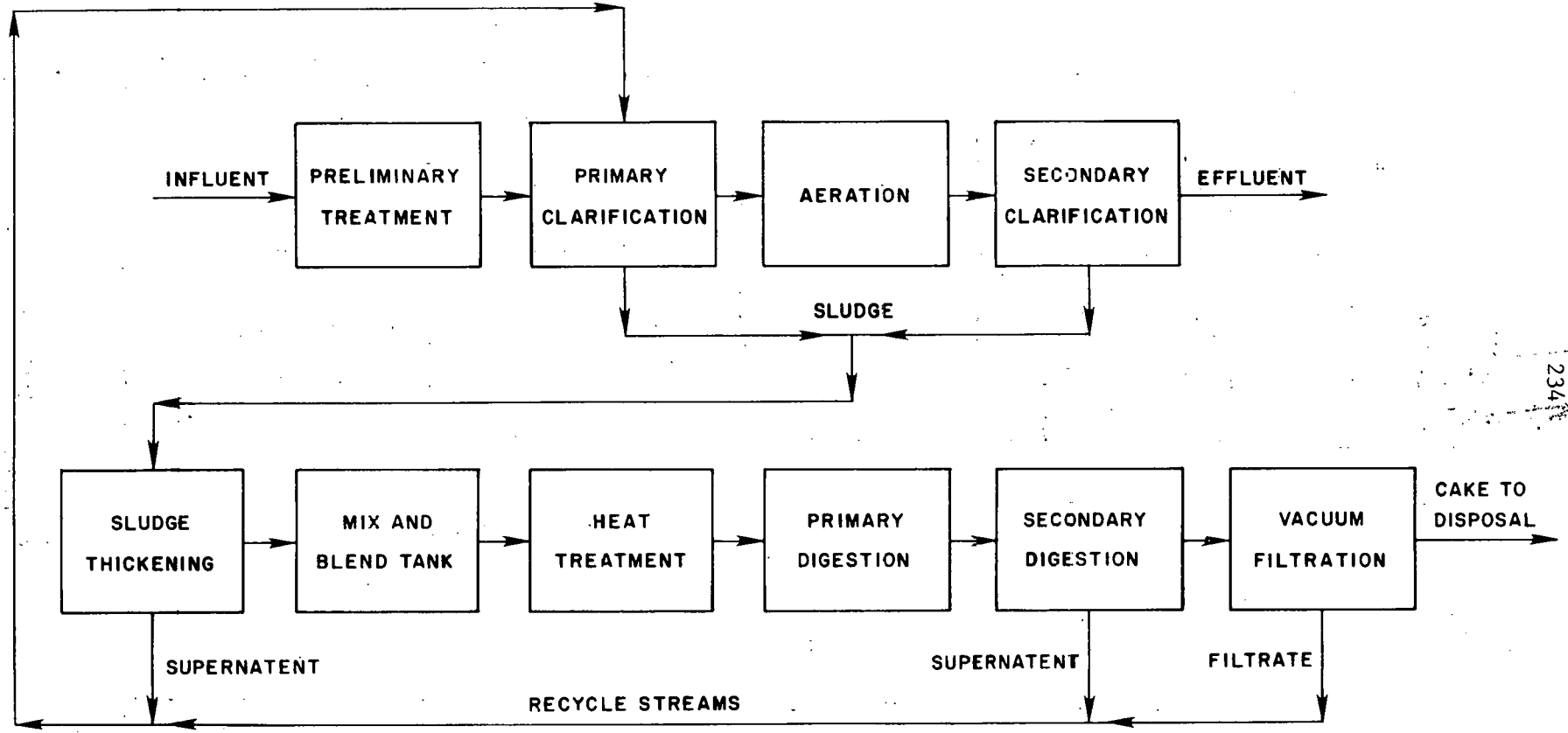


FIGURE 3 – ANAEROBIC DIGESTION OF HEAT TREATED SLUDGE

ANAEROBIC DIGESTION OF A WASTEWATER TREATMENT PLANT SIDESTREAM: POTENTIAL FOR ENERGY CONSERVATION

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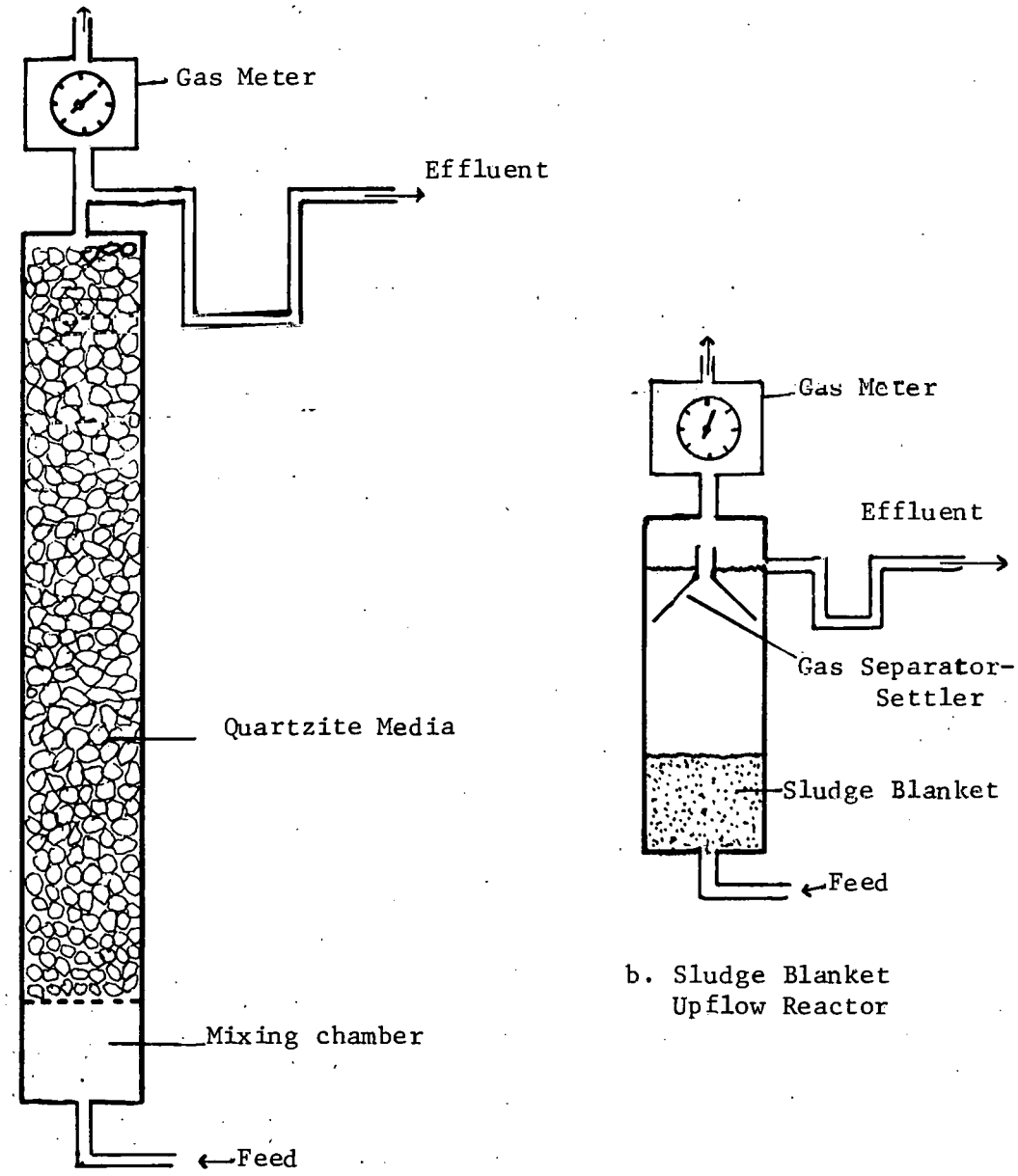
INTRODUCTION

The availability of inexpensive and abundant supplies of electricity, natural gas, and fuel oil during the 1950's and 60's led to a gradual shift from anaerobic digestion toward more energy-intensive methods of wastewater treatment especially in the area of sludge stabilization and disposal. It resulted in a statement by the FWPCA (1) that, "many utility rates are so low that it is uneconomical to install equipment to develop power from digester gas." As a consequence, many wastewater plants designed and built during the past two decades are now faced with sharply increased operating budgets as energy costs have escalated in recent years. Given the stark reality of still higher energy costs and the distinct possibility of fuel shortages it is evident that energy conservation should receive high priority for many treatment plants. Increased concern for energy conservation manifests itself in the varied studies examining anaerobic processes and lower energy-consuming aerobic methods (3, 5, 7).

Treatment alternatives which would lead to energy conservation are being examined by the Green Bay, Wisconsin Metropolitan Sewerage District which handles a combined municipal and industrial waste of 35 million gallons per day. About 65% of BOD/COD load to the plant is from paper industry sources. Its treatment plant, placed into operation in 1975, is an energy-intensive design utilizing a thermo-conditioning process (350 PSI at 375°F) for the mixed sludges from primary and secondary treatment. This method of sludge treatment increases the dewaterability of the sludges but results in a decant liquor that has BOD/COD levels as high as 12,000 mg/lt and 40,000 mg/lt respectively. The decant liquor is recycled to the head end of the treatment plant and represents about 15% of plant BOD/COD load. The nature of the thermal conditioning decantate (low solids and high soluble organic content) shows promise for energy recovery utilizing an anaerobic upflow reactor. The fixed bed upflow reactor described by Young and McCarty (9) and others (4, 8), is well suited to liquid wastes low in suspended solids since short hydraulic detention times are possible as biomass builds up on the surface of the media. The fixed bed reactor may, however, be subject to plugging or channeling as a consequence of excessive solids buildup on the media. This has lead to reactor designs without media but with gas-separator/settler devices to promote solids retention within the reactor (5, 7) in order to maintain a high rate of digestion.

EXPERIMENTAL METHODS

A fixed bed reactor was constructed using an acrylic plastic column 15 cm in diameter and 1.8 meters high (see Figure 1). It was packed with quartzite



a. Fixed Bed Upflow Reactor

b. Sludge Blanket Upflow Reactor

Figure 1. Schematic Diagram of Upflow Reactors

rock 2.5-4 cm in diameter resulting in a void volume of 12 liters. The reactor was seeded with approximately one liter of an active anaerobically digesting sewage sludge. Startup feed to the reactor consisted of a 1:1 mixture of water and decantate adjusted to pH 7 with $NaHCO_3$. It was introduced into the reactor at a rate equivalent to a three-day hydraulic detention time. Temperature was maintained at 34°C. After 30 days of satisfactory operation as evidenced by stable pH and gradually increasing gas production the feed was changed to full strength decantate and after 45 days no further pH adjustment was made to the decantate feed since considerable buffering had developed in the reactor.

Following six months of satisfactory operation with the mesophilic reactor a second reactor of the same design was placed into operation at thermophilic temperatures (50-52°C). Startup and early operation of this reactor was similar to that described for the mesophilic reactor.

The satisfactory performance of the fixed bed reactors at mesophilic and thermophilic temperatures prompted an expanded study to determine whether satisfactory digestion performance could be achieved in an upflow reactor that did not use media. This reactor was constructed of acrylic plastic with a diameter of 15 cm and height of 45 cm (see Figure 1). It has a volume of approximately 8 liters and is being operated at 34°C and hydraulic detention time of 3 days at this writing.

RESULTS AND DISCUSSION

Table 1 summarizes average reactor performance for the mesophilic reactor at 3 day and 1.5 day hydraulic detention times. Total gas production averaged approximately 0.6 liters/gram COD removed and had a methane composition of about 70%. BOD and COD removal were over 80% and 60% respectively. The 60% removal of COD is somewhat lower than some values that have been reported (2, 4) and is probably due to the presence of reclacitrant lignin derived matter in the decantate. Collection of samples from various points along the reactor also indicated that most of the COD and BOD was removed in the bottom half of the reactor, a performance characteristic also noted in other studies (2, 6).

A given hydraulic detention time does not reflect a uniform organic loading to the reactor since decantate feed was obtained on a weekly basis from the wastewater treatment plant and COD/BOD content could vary by a factor or 2 or more. Analysis data for the decantate is shown in Table 2. The reactor tolerated such organic load variations with no evidence of upset.

After six months of continuous operation the mesophilic reactor was dismantled to determine the extent of solids buildup. During the six month period the void volume of the reactor had been reduced approximately 15%. There was some channeling in the lower 30 cm of the column but no other evidence of significant channeling or plugging. The solids were rather loosely attached to the quartzite media and were easily flushed off.

The reactor was placed into operation again using as seed solids which had been saved during the dismantling operation. However, a mechanical malfunction several weeks after the second startup caused severe overheating of the

Table 1. Average Performance of the Upflow Fixed Bed Reactors

	Mesophilic (34°C)		Thermophilic (50°C)		
Hydraulic Detention Time (days)	3	1.5	1.5	1	0.5
COD (% Reduction)	62	65	56	59	50
BOD_5 (% Reduction)	80	85	62	74	69
Gas Production (lt/gram COD removed)	.55	.65	.48	.69	.52-.7
Gas Analysis (CH_4)	70%	68%	65%	67%	67%
pH (Feed = 5.0)	7.4	7.4	7.9	7.9	7.8
Ammonia (mg/lt) (Feed = 400-500 mg/lt)	1,900	1,800	1,500	900	1,100
Alkalinity (as $CaCO_3$) (titrated to pH 3.7)	---	6,300	6,400	6,600	5,200
Volatile Acids (mg/lt)	1,800	600	1,500	---	430
Volatile Acids (as % of Feed VA)	70	28	44	---	29

reactor and its biomass contents resulting in death of the organisms. A small seed digester was set up using raw sludges and following a delay of almost two months the reactor was finally placed into operation again. At this writing, it is being operated at a 1.5 day detention time and will be loaded to the equivalent of 1 day and 0.5 day detention times during the next several months.

The decantate leaves the heat exchangers of the thermal conditioning process at a temperature of approximately 50-55°C. This relatively high temperature coupled with short hydraulic detention times in an upflow reactor indicated a potential for thermophilic digestion of the decantate. A fixed bed upflow reactor similar in design to the mesophilic reactor was placed into operation six months ago. It was seeded with approximately one liter of an actively digesting sewage sludge. The seed was prepared from raw sewage sludges which were digested at thermophilic temperatures (50-52°C and 15 day detention times) for three months. The start up procedure for the thermophilic upflow reactor was similar to that described earlier for the mesophilic reactor. No problems were encountered during this period. There was a gradual buildup of microbial activity as evidenced by BOD/COD reduction and increasing gas production.

Table 2. Decantate Analysis

Parameter	Average (mg/lt)	Range (mg/lt)
BOD_5	10,000	6,000-13,000+
COD	20,000	14,000-30,000+
pH	---	4.5-5.0
Volatile acids	2,000+	1,500-3,400
Total solids	19,000	7,400-30,000
Suspended solids	Normal < 500	100-15,000
Ammonia Nitrogen	880	450-1,200
Organic Nitrogen	1,300	590-1,700
Kjeldahl Nitrogen	2,300	1,400-2,700
Phosphorus	300	110-630
Potassium	200	160-250
Calcium	160	100-280
Sodium	930	770-1,100

Average performance data for the thermophilic reactor are shown in Table 1. COD/BOD removal is somewhat lower than was obtained for the mesophilic reactor but gas production per gram COD removed is comparable. The thermophilic reactor like the mesophilic reactor seems to tolerate fluctuating loads and other upsets relatively well. Three months after start up a feed line to the digester slipped from its fitting and allowed about 75% of the contents of the digester to drain out. Following repair of the line the digester was filled by adding decantate feed to the remaining digester contents. Digester performance seemed to suffer little as gas production was back at normal levels within a week.

Most recently the thermophilic reactor has been operated at a hydraulic detention time of 0.5 days for approximately five weeks. During this period the COD content of the decantate feed to the reactor has averaged approximately 14,000 mg/liter, corresponding to a COD loading of 28 grams per liter of reactor void volume per day.

The high COD loading during this five-week period did not seriously affect the reactor's performance but COD reduction has decreased somewhat. The high loading has resulted in a considerable increase in solids development in the reactor as evidenced by increased solids concentration in the mixing chamber

(see Figure 1) of the digester and a reduction in void volume due to buildup of biomass on the surface of the quartzite media. A measurement of void volume in the digester after four weeks of operation at the 0.5 day detention time showed a void reduction of over 10%. Flushing of the digester with water reduced this solids accumulation by approximately 40%. There was more than a 20% reduction in gas production following removal of these solids but reactor performance has improved gradually after this rather drastic treatment, which included some exposure of the highly oxygen-sensitive methanogens to air.

The performance of the thermophilic reactor has been encouraging. This is in contrast to a study by Vollstedt (8) which showed a much lower level of BOD/COD removal when thermally conditioned sludge decantate was digested at thermophilic temperatures as compared with mesophilic temperatures.

Both the mesophilic and thermophilic fixed bed upflow reactors have performed well but long-term efficient performance of a fixed bed reactor may be reduced because of the inherent potential for channeling and dead space in the media. The satisfactory performance of the fixed bed reactors has prompted us to pursue the anaerobic digestion studies on the Green Bay decantate further and most recently we have placed into operation an upflow reactor that does not have media. A gas-separator/settler device patterned after that described by Lettinga (7) is being used to promote solids retention within the reactor vessel. The reactor is maintained at a temperature of 34°C and at this writing is fed decantate equivalent to a 3 day detention time. It has only been in operation for a few weeks so the solids concentration is still rather low but digestion performance based on gas production is favorable.

POTENTIAL FOR ENERGY CONSERVATION

The Green Bay Metropolitan Sewerage District treatment plant has a number of features in its design and operation which make it particularly attractive for energy conservation by anaerobically digesting the decant liquor produced in the thermoconditioning of the sludges in this plant.

1. The decantate comes out of the heat exchangers at a temperature of approximately 50°C. This high temperature coupled with the short detention times possible in an upflow reactor indicate little or no need for supplemental heating of the digester even if operated at thermophilic temperatures.

2. The plant requires extensive energy input to boilers which are presently fired with fuel oil but have dual fuel capability. Digester gas could be used to replace much of this fuel oil. There would be no need for a costly engine-generator installation for utilization of digester gas.

3. The plant has some existing basin capacity and gas storage capacity which appear promising for use in a digestion conversion. If these facilities can be utilized little capital investment would have to be made.

Table 3 describes projected energy conservation and dollar savings which may be possible by applying the anaerobic digestion process to the decantate stream. The fuel oil savings alone are calculated to be 400,000 gallons annually, an amount that represents 40% of current fuel oil consumption in the treatment plant. Smaller, but nonetheless significant, savings would accrue from a reduction in electrical energy consumption for process air as a result of reduced BOD recycle.

Table 3. Projected Energy Conservation with Anaerobic Digestion of Thermal Conditioning Decantate

Assumptions Made in the Calculation:

1. Decantate Volume: 1.3×10^6 liters/day
   BOD: 10,000 mg/lt
   COD: 20,000 mg/lt

2. Digestion Performance:

   BOD Reduction 75% (9,750 Kg/day)
   COD Reduction 50% (13,000 Kg/day)
   0.5 liters gas/gram COD removed
   Digester Gas: 65% methane
   Gas Volume: 6.5×10^6 liters per day
   Methane Volume: 4.2×10^6 liters per day

3. Energy Savings (as fuel oil):
   Methane Volume: 4.2×10^6 liters/day
   Natural Gas Equivalent: 1500 Therms
   No. 2 Fuel Oil Equivalent: 1095 gallons
   Fuel Oil value at 0.93/gallon 1018.00 per day
   Annual Savings: Fuel Oil 400,000 gallons
   with a value of 372,000.00

4. Other Savings:
   Reduced BOD recycle to aeration basins: 9,750 Kg/Day (21,450 lb.)
   Electrical Energy Savings (process air) 200.00/day
   Reduced solids to dewatering and incineration: Savings not calculated

5. Projected Annual Savings:

Fuel oil (400,000 gal.)	372,000
Electrical (3×10^6KW)	73,000
Total	445,000

Present Energy Costs: (annual basis)

Electrical:	1,265,000
Fuel Oil	1,023,000
Total	2,288,000

SUMMARY

Studies applying anaerobic treatment to the high organic-content decantate from the thermal conditioning unit of a 35 mgd wastewater treatment plant have demonstrated a potential for significant energy conservation in this energy-intensive plant. Mesophilic and thermophilic digestion of the decantate in fixed bed upflow reactors has resulted in BOD/COD reductions of over 80% and 60% under certain operational conditions, with mesophilic digestion achieving somewhat greater BOD/COD reduction than the thermophilic process. Gas production was approximately 0.6 liters/gram COD removed. Hydraulic detention times as short as 0.5 days and with COD loadings as high as 28 grams per liter of reactor volume resulted in some reduction in COD removal efficiency under thermophilic conditions. No serious loss of reactor efficiency due to clogging or other causes was encountered but remains a concern from a long-term operational point of view. A lab-scale reactor without fixed bed media has been placed into operation to determine its potential for anaerobic treatment of the decantate.

Energy conservation and economic savings have been calculated and are projected to be approximately 20% of the present energy costs experienced by this treatment plant. The plant also possesses certain unique features which may make addition of anaerobic digestion capability for the decantate feasible with a relatively low capital investment.

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ENERGY EFFICIENCY OF DEEP U-TUBE AERATION

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INTRODUCTION

Aeration is considered to be the major energy sink in the activated sludge wastewater treatment process. Approximately 800 kw-hr of electricity is consumed per ton of BOD_5 removed. This large energy consumption is related to the insoluble nature of oxygen in water, which is only 9.2 mg/l of dissolved oxygen (D.O.) in clean water at 20° C and sea level. The oxygen transfer rate is proportional to the D.O. deficit. Since standard practice is to maintain 2 mg/l of D.O. in the mixed liquor, the D.O. deficit is approximately 7 mg/l. Conventional aeration equipment therefore operates under this constraint of a relatively low D.O. deficit. Consequently the energy efficiency is relatively low and a direct economic penalty is imposed when higher mixed liquor D.O. is desired.

In 1958, the Dutch[1] introduced the concept of U-Tube aeration to oxygenate drinking water and strip carbon dioxide from it. U-Tube aeration incorporates the flow of water down a vertical shaft, underneath a baffle and back to the surface. Air is injected at the inlet and the bubbles are swept along with the water. Hydrostatic pressurization of the bubbles greatly magnifies the gas transfer rate by magnifying the D.O. deficit. The bubble-water interfacial surface is decreased by the hydrostatic pressurization, partially reducing the gas transfer rate. The net effect is such that D.O. supersaturation is easily achieved in the U-Tube discharge with superior energy efficiency and reduced cost per ton of oxygen absorbed when compared to conventional aeration systems.

A proprietary activated sludge process incorporating the entire bioreactor within the U-Tube is presently being marketed.[2] Depths up to 150 meters are specified. The intent of this paper is to present experimental results and the predictions of a computer model calibrated by these experimental results which indicate the most energy and cost efficient design for deep U-Tube aeration.

EXPERIMENTAL SYSTEM

An experimental 10 cm. U-Tube system was constructed and evaluated for the following parameter combinations:

Depth	12, 30, 60, 110m.
Velocity	0.9, 1.4, 1.8 m/s
Air	5, 15, 25 % air/water ratio

The increase in D.O., oxygen absorption efficiency and head loss were determined. Tap water was passed through the system for all of these parametric conditions. Also, 5 mg/l of anionic detergent was injected into the tap water to simulate domestic wastewater, as recommended by the British.[3]

DEVELOPMENT OF U-TUBE COMPUTER MODEL

A computer model of the gas transfer phenomena which occurs as a bubble-water mixture passes through a U-Tube was developed. The model iterates the gas transfer equation throughout the U-Tube updating the input to account for the changing:

Mass of Oxygen Transferred
Mass of Nitrogen Transferred
Oxygen Composition in the Bubbles
Nitrogen Composition in the Bubbles
Hydrostatic Head on the Bubbles
Gas-Water Ratio
D.O. in the Water
Dissolved Nitrogen in the Water

An algorithm was developed to express the reaeration coefficient, k_2, as follows:

$$k_2 = 0.1\ (\text{GAS/WATER})^{0.8}\ (1.024)^{\text{Temp.}}$$

This model was calibrated to establish the above coefficients by determining the best empirical fit to the data gathered in the experimental phase of this study.

This model was then utilized to generate the predicted operating characteristics of the U-Tube under various design conditions. The design parameters resulting in the least energy consumption and overall cost per unit weight of oxygen dissolved were identified. The sensitivity of U-Tube aeration away from the optimum conditions could also be estimated.

RESULTS AND DISCUSSION

The increase in D.O. in the U-Tube discharge is a function of the depth and gas/water ratio. A change in the nominal velocity of water through the U-Tube did not effect the discharge D.O. The effluent D.O. contours as a function of air/water ratio and depth are shown in Fig.1.

The ability of the U-Tube to readily supersaturate the discharge is due to the greatly magnified D.O. deficit resulting from hydrostatic pressurization of the bubbles. Figure 2 indicates the D.O., D.N. and D.O. deficit pattern as the water traverses the U-Tube.

It indicates the negative D.O. deficit which occurs near the discharge. Consequently some D.O. is stripped in this region as noted by the negative slope of the D.O. curve as it approaches the discharge. Figure 3 indicates the effect of air/water ratio on the D.O. traverse pattern and the increased D.O. stripping at the higher supersaturation levels of 25% air/water.

The effect of water exhibiting a reduced α factor is shown by the D.O. traverses in Figure 4. In a U-Tube, the reduced α factor reduces oxygen absorption when the D.O. deficit is positive. However, this is somewhat offset by the reduction in stripping of D.O. near the discharge when the water is supersaturated. Thus, the discharge D.O. from a less deep U-Tube would be more adversely affected by water with a reduced α factor than would be the deeper U-Tubes. Conceptually, with a U-Tube exceeding a given depth, a

reduced α factor would actually result in discharge D.O. levels equal to or exceeding that for tap water.

It has been speculated that at depths exceeding 100 m, the gas phase is entirely dissolved and then effervesces out of solution as it rises to the surface in the discharge leg.[2] Pilot field studies at 100 m. U-Tube depth indicated that even 90% absorption of very low air/water ratios of less than 5% could not be realized. Figure 5 indicates the U-Tube depths predicted by the computer model to effect 90% absorption. Potential effervescence could not be incorporated into the computer model, but this still would not affect absorption.

Energy Consumption Standard conditions for rating aerators are 20°C, inlet D.O. of 0 mg/l and sea level barometric pressure. Under these conditions Figure 6 indicates the maximum oxygen transfer in a U-Tube, having one square meter inlet and discharge legs, was 2.75 kg/kw-hr in a U-Tube of 20m. depth. The air/water ratio was 25% and the discharge D.O. was 11.5 mg/l (125% saturation). This is an exceptionally low unit energy consumption for oxygen transfer by and of itself. However, when it is coupled with the fact that the discharge D.O. is supersaturated, it underscores the exceptional potential of the U-Tube as a gas transfer device.

Costs of Oxygen Transfer Cost functions were incorporated into the computer model. It was assumed that costs for drilling and lining the U-Tube hole would be $\$1000/m^3$, because drilling contractor's estimates for holes of this diameter and depth were \$500 to $\$1000/m^3$.[4] The low head axial flow pump required to recirculate water through the U-Tube was assumed to have a capital cost of \$2/GPM, based on manufacturers estimates. The cost of electricity was assumed to be \$0.03/kw-hr. The rate of return on capital was assumed to be 7% with amortization of 30 years for the hole and 10 years for the pump. The air blower costs were negligible.

Figure 7 indicates that total operating and amortization costs of \$25/ton of oxygen dissolved could be realized for U-Tube depths of 15 to 90 meters and 15 to 25% air/water ratios. The desired discharge D.O. would be 5 to 20 mg/l depending on the depth chosen. Figure 8 is a breakdown of the cost components as a function of U-Tube cross sectional area. Power costs to operate the recirculation pump increase as the U-Tube cross-sectional area decreases due to the associated increased hydraulic friction. A 1000 kg/day oxygen transfer rate would require a 0.5 m^2 U-Tube cross-section and have \$6.80/ton for hole amortization, \$4.80/ton for pump amortization and about \$12/ton for electrical power for pump operation resulting in a total of \$23.60/ton oxygen, which compares with \$42/ton for mechanical surface aerators.[5] Figure 9 indicates that the optimal velocity increases with the size of the U-Tube facility. Larger U-Tubes, of course, are less affected by frictional losses at higher velocities.

Figure 10 is a composite graph which indicates the cost, energy and D.O. contours on a velocity-depth surface for tap water under standard conditions. The least cost optimum combination does not coincide with the least energy optimum condition. There is no rationale to indicate the cost and energy optima should coincide either. For tap water, a velocity of 2 m/sec and a U-Tube depth of 25 meters resulting in a discharge D.O. of 12 mg/l appears optimal. For polluted water having an α factor of 0.5 and inlet D.O. of 2 mg/l, the optimum depth moves to 60 to 120 meters and the cost rises to \$30/ton as shown in Figure 11. Drilling costs higher than $\$1000/m^3$ would result in the optimal depth being less than 60 meters.

SUMMARY AND CONCLUSIONS

U-Tube aeration has excellent potential as an aeration system. The discharge D.O. is not restricted to the lower saturation levels characteristic of conventional aeration systems operating near ambient pressure. Supersaturated D.O. is easily and economically produced. It must also be realized that the discharge is also supersaturated with dissolved nitrogen when air is injected. This can be a liability, particularly for surface waters maintaining trout or salmon. Potential effervescence must be considered under some circumstances with highly supersaturated discharges. Optimal operating conditions for aeration under standard conditions are 2 to 3 m/sec velocity, 30 m U-Tube depth and 15 to 25% air/water injection ratio. Under these conditions, the discharge D.O. is estimated to be 15 mg/l; 2.4 kg O_2/kw-hr is the unit energy consumption and $22/ton of oxygen dissolved is the total cost for amortization and operating costs. This compares with conventional surface aeration which produces a discharge D.O. of 2 to 4 mg/l, has a unit energy consumption of 2 kg O_2/kw-hr and costs $42/ton of oxygen dissolved. Auxiliary mixing must be provided in the aeration tank to maintain solids in suspension if a side stream is continually passed through a U-Tube for oxygen absorption and back to the aeration tank. U-Tube aeration appears to be competitive with conventional surface aeration for activated sludge oxygen absorption. For those water quality management applications where supersaturated D.O. levels are desirable, U-Tube aeration appears to be exceptionally attractive.

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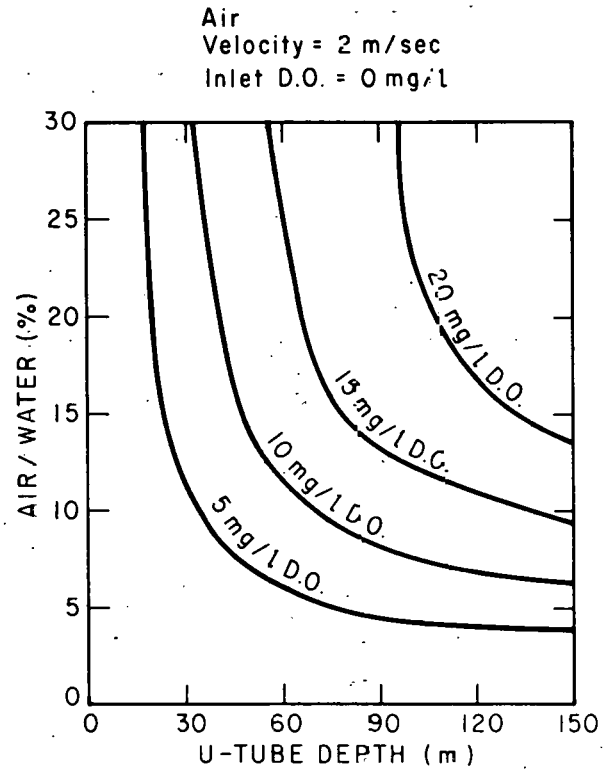


Fig. 1 Effluent D.O. Contours for Combinations of Air/Water Ratios and Depths

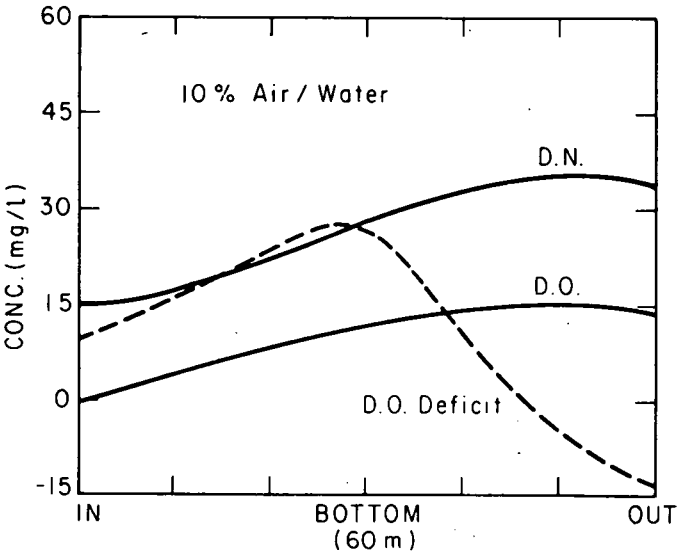


Fig. 2 Profile of D.O., D.N. and D.O. Deficit

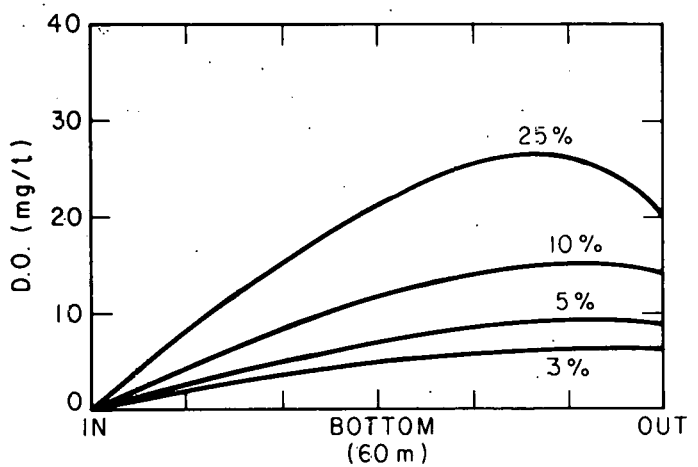


Fig. 3 D.O. Profiles - Air (60 m)

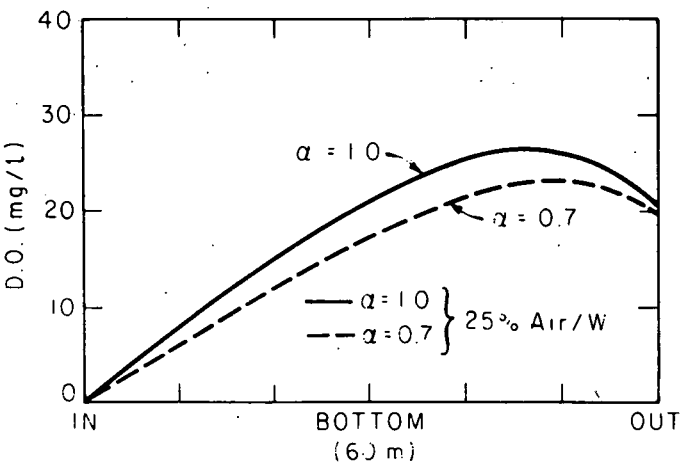


Fig. 4 Effect of Alpha Factor U-Tube Profile - Air (60m)

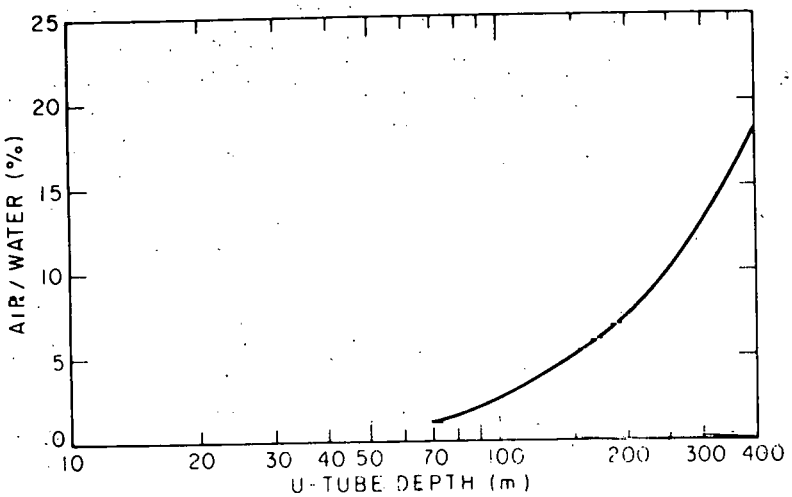


Fig. 5 U-Tube Depth Required to 90% Absorb All Air (Subsequent Effervescence May Occur)

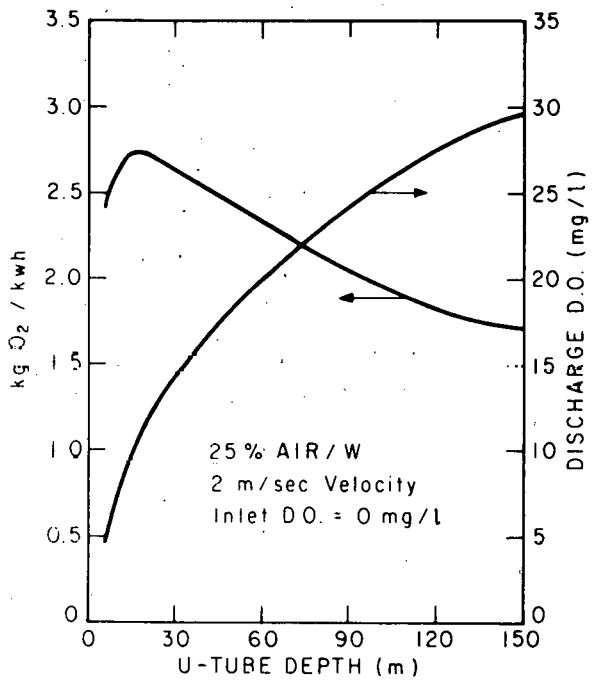


Fig. 6 Oxygen Transfer Energy Consumption and Discharge D.O. vs Depth

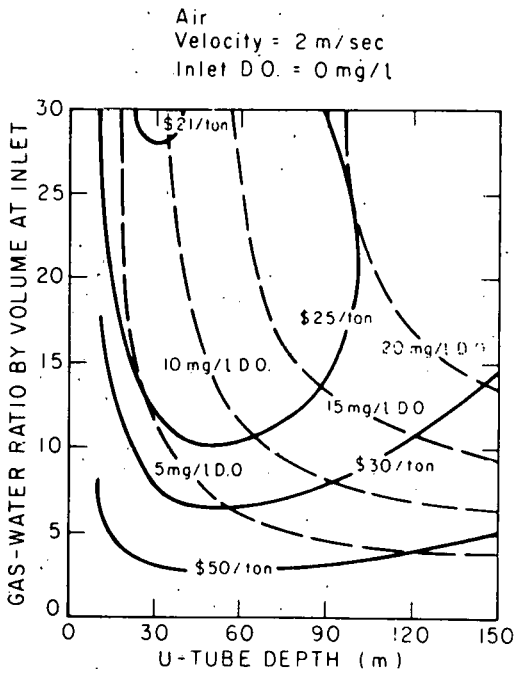


Fig. 7 Cost and Concentration Contours

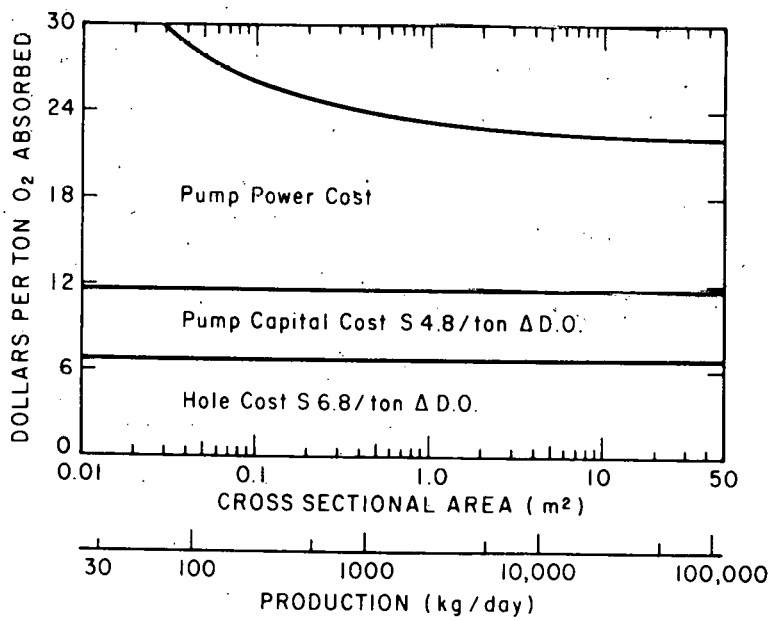


Fig. 8 Cost Breakdown Near Optimum

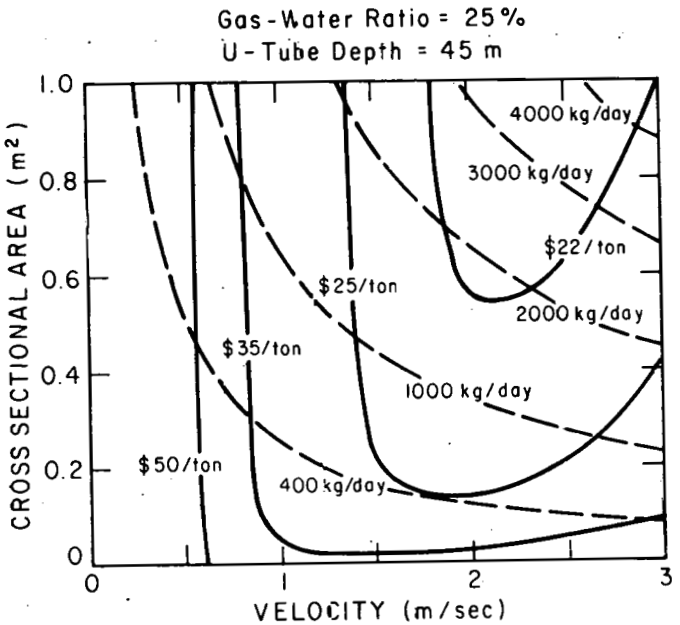


Fig. 9 Optimal Decision Plot

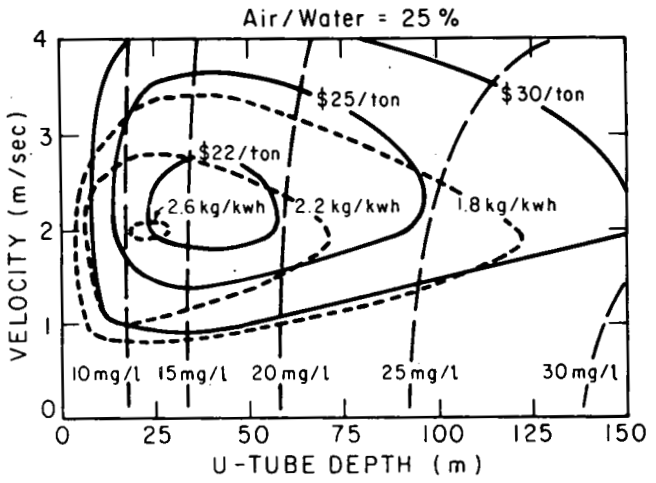


Fig. 10. Cost and Energy Efficiency of U-Tube Aerators

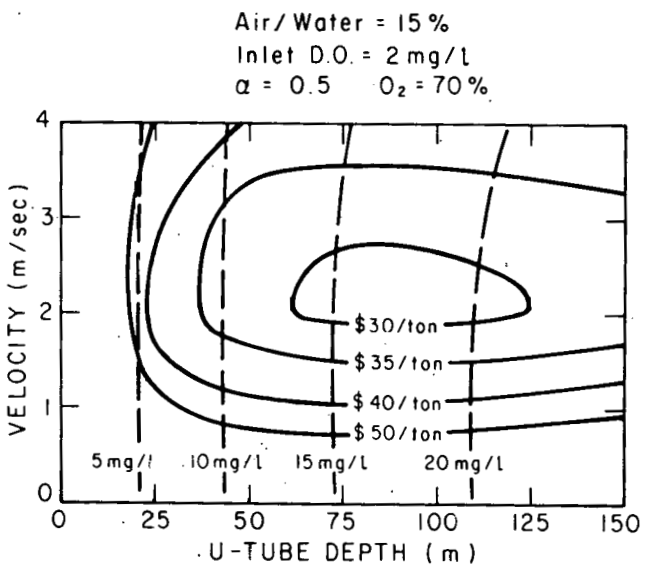


Fig.11 Contours of Cost per Ton O_2 Absorbed and Outlet D.O. Concentration for Air Injection (W/Recycle)

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ACTIVATED BIO-FILTRATION: AN ENERGY EFFICIENT SECONDARY TREATMENT PROCESS

Bill Vineyard
ABF Product Manager
Neptune Microfloc, Inc.
Corvallis, Oregon

INTRODUCTION

Rapidly escalating energy costs have forced wastewater treatment plant designers to place more emphasis on the selection of energy-efficient processes which can achieve a high quality effluent. The combined fixed and suspended growth ABF process offers the designer such a system.

Energy consumption can be reduced by optimizing the design of each unit operation and utilizing the flexibility of the process.

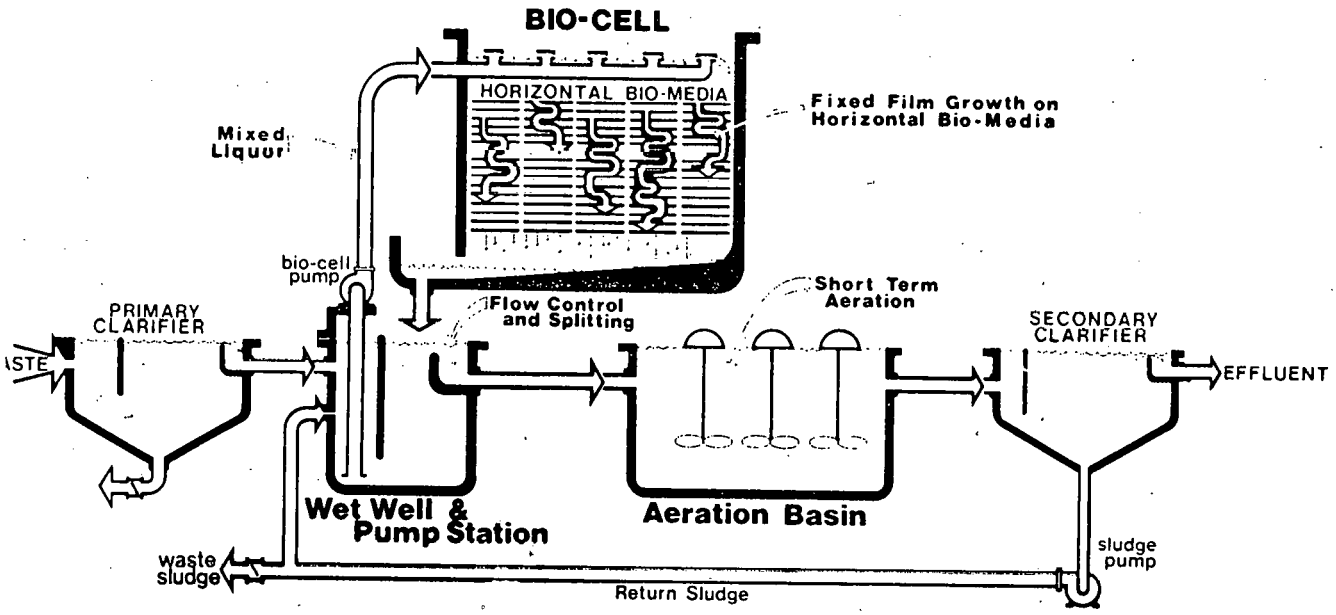
ABF PROCESS DESIGN

The ABF process is a unique combination of fixed and suspended growth biological systems. A general flow schematic is illustrated in Figure 1. ABF system components include: primary clarifier or fine screen, wetwell/Bio-Cell pump station, ABF Bio-Cell, flow control and splitting, short-term aeration, secondary clarifier and return sludge facilities. After primary treatment, the ABF process flow begins in the wetwell where a mixed liquor is formed of primary effluent, biological solids from the secondary clarifier and Bio-Cell recycle. This mixed liquor is pumped to the top of the Bio-Cell filled with ABF horizontal Bio-Media, which contains both fixed and suspended growth microorganisms. The ABF Bio-Media plays a major role in process performance since its open, horizontal configuration allows free flow of air and liquid in all directions and provides optimum oxygen transfer into the mixed liquor throughout the Bio-Cell. The Bio-Cell underflow is split, with the major portion passing to the short-term aeration basin and the remainder being returned to the wetwell. The short-term aeraton basin is a completely mixed activated sludge unit which further oxidizes biodegradable organics and provides a flocculent mixed liquor prior to final clarification. Biological solids are settled in the final clarifier and recycled to the wetwell or to the waste sludge handling facilities.

Recirculation of activated sludge to the Bio-Cell is important since it serves to: (1) substantially increase the effective BOD removal in the Bio-Cell, by adding to the quantity of organisms in contact with the wastewater as it passes through; and (2) contribute to the health and viability of the mixed liquor, and therefore, to overall process stability. Pilot studies have demonstrated the superior stability of the ABF process over the similar roughing filter/activated sludge process.[1]

FIGURE 1

ABF FLOW SCHEMATIC



The ABF process design is based on the results of various pilot and full scale plant evaluations. Slechta and Mattli[2] found that the ABF process could provide a high quality effluent and a settleable sludge at very high process loadings. Their analysis led them to define the organic loading to the process in terms of a SYSTEM F/M expressed as:

$$\text{SYSTEM F/M} = \frac{\text{Primary Effluent lbs. BOD/day to Bio-Cell}}{\text{lbs. MLVSS in Aeration Basin Only}}$$

This expression does not account for the mass of fixed growth microorganisms in the Bio-Cell which cannot be quantified. The SYSTEM F/M is, therefore, several times greater than that used in activated sludge design. Slechta and Mattli determined that the limiting design constraint for the process was the aeration basin oxygen demand and not SYSTEM organic loading in which:

$$\text{Aeration Basin Oxygen Demand} = \frac{\text{lb. } O_2 \text{ to Aeration Basin}}{\text{lb. } BOD_R \text{ in SYSTEM}}$$

For most domestic wastes, the Bio-Cell is typically designed at a loading of 200 lb BOD/day/1,000 ft^3 which falls well within demonstrated operating ranges and allows for widely varying load fluctuations. Research by Owen and Slechta[3] and design models for fixed film reactors predict an approximate BOD removal of 65% at this loading. The Bio-Cell is therefore designed as an efficient roughing unit which reduces the loading on the downstream aeration basin. Its effect on the overall process is to reduce the aeration basin oxygen demand to about 0.37 lb/O_2 per lb BOD removed in the process. This demand is approximately 30 to 40% of that which would be required by an activated sludge plant.

Slechta and Mattli[2] reported that there is no correlation between ABF process performance and Bio-Cell height over a range of 7 to 22 ft. CH2M-Hill[4] found that the performance of a fixed film reactor is related to organic volumetric loading and independent of Bio-Cell height above 8 ft. Cook[5] concluded that at a given organic volumetric loading, there is very little increased COD removal above 4 ft height. These studies indicate that the height of the Bio-Cell can vary substantially without affecting ABF process performance.

Typical ABF design parameters for carbonaceous and nitrification plants are shown in Table 1.

Table 1.

TYPICAL ABF DESIGN PARAMETERS

Criteria and Parameters	Units	Value	Typical Range
Effluent Criteria			
BOD_5	mg/L	20	10-30
Suspended Solids	mg/L	20	10-30
NH_3-N (Nitrification Design Only)	mg/L	1.0	0.5-2.5
Bio-Cell Parameters			
Organic Load	(lb BOD/day/ 1,000 ft^3)	200	100-350
Media Depth	ft	14	7-22
Hydraulic Parameters			
Sludge Recycle	fraction of raw flow rate	0.50	0.3-1.00
Bio-Cell Hydraulic Load (minimum)	gpm/ft^2	1.0/1.5[1]	1.0-5.5
Bio-Cell Recycle--as required to maintain media wetting rates or as dictated by diurnal flows			
Aeration Parameters			
System F/M[2]			
Carbonaceous Design	lb BOD/day/lb VSS	1.4	0.8-3.5
Nitrification	lb BOD/day/lb VSS	0.3	0.2-0.6
Oxygen Utilization			
Carbonaceous Design	lb O_2/lb BOD rem.	0.37	0.2-0.8
Nitrification[3]	lb O_2/lb BOD rem.	0.65	--
MLVSS Concentration	mg/L	3,000	1,500-4,000
MLSS Concentration	mg/L	4,000	2,000-5,000
Clarifier Parameters			
Overflow Rate	gpd/ft^2	600	300-1,200
Solids Loading	lb/hr/ft^2	1.25	0.5-2.0

[1]1.0 gpm/ft^2 for rotary distributors.
1.5 gpm/ft^2 for fixed nozzle distributors.

[2]Based on primary effluent BOD_5 (process influent) loading to MLVSS in aeration basin.

[3]Total O_2 required = Carbonaceous + 4.6 lb O_2/lb NH_3-N removed.

ENERGY OPTIMIZATION

The main energy consumers in the ABF process are the Bio-Cell lift pumps and the aerators. Energy demand can be reduced by (1) selecting the optimum Bio-Cell height to reduce pump head; (2) selecting efficient pumps; (3) selecting efficient aerators; and (4) utilizing the operational flexibility of the ABF process.

As previously discussed, the performance of the Bio-Cell is related to organic volumetric loading and is independent of height above approximately 7 ft. The optimum media height to achieve minimum pumping energy is a function of the interrelationship between wastewater BOD strength and minimum allowable wetting rates. The minimum recommended wetting rates (based on average daily flow) for ABF Bio-Cells are given in Table 1. Diurnal variations above and below these levels are acceptable.

Since pumping energy is a direct function of the total dynamic head, lower media height can mean lower energy usage. However, for a given media volume, the Bio-Cell plan area increases proportionally as the height decreases until a critical point is reached where the minimum wetting rate is no longer achieved unless tower recycle is increased. At this point, energy demand will begin to increase since more water must be pumped. The optimum media height for energy efficiency is achieved when the design average pumping rate is just able to provide the minimum required wetting rate. It must be pointed out that this optimum height may not provide the most cost-effective design since underdrain and distribution costs will increase with increased tower area.

The optimum media height for energy efficiency can be calculated over the general range of 7 ft $\leq H_m \leq$ 22 ft using the equation:

$$H_m = 12 \times \frac{W_m \times l_o}{L \times (Q_{BC}/Q_A)}$$

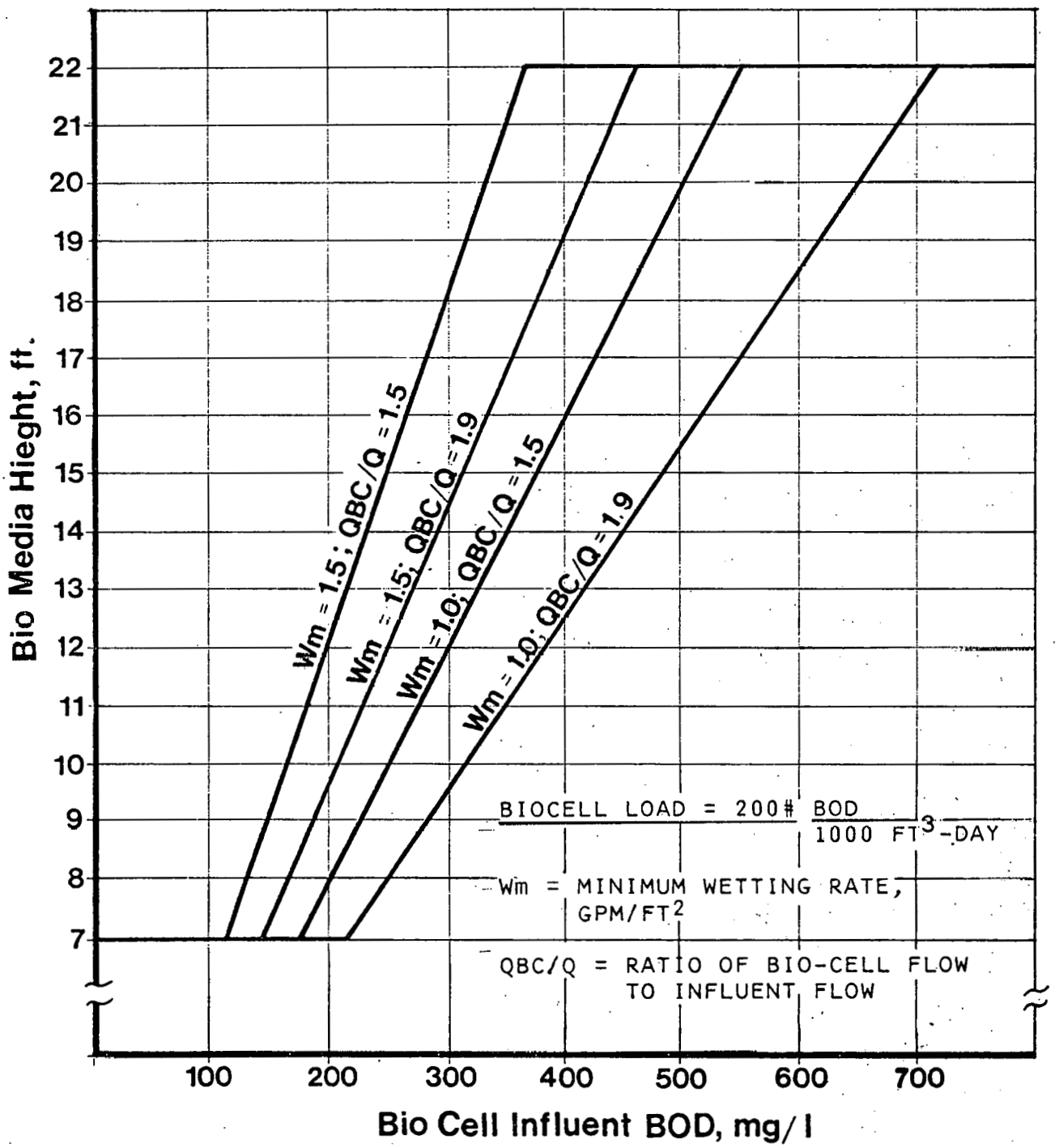
Where:
- H_m = optimum media height, ft
- W_m = min. wetting rate, gpm/ft^2
- l_o = influent BOD, mg/L
- L = organic loading, lb BOD/day/1,000 ft^3
- Q_{BC} = flow to Bio-Cell, gpm
- Q_A = average design flow, gpm

The flow to the Bio-Cell, (Q_{BC}), is the sum of the primary effluent flow, (Q_A), return sludge flow, (Q_{RAS}), and tower recycle, (Q_{TR}), as shown in Figure 1. Q_{RAS} is typically taken as 50% of Q_A for design calculations. Therefore, the minimum average daily flow to the Bio-Cell, (Q_{BC}), will be 1.5 Q_A if variable speed or screw pumps are used. If constant speed pumps are used, there will be some tower recycle, (Q_{TR}), which will average about 40% of Q_A. The average daily Bio-Cell flow, (Q_{BC}), will then equal 1.9 Q_A.

The optimum height for Bio-Cells loaded at 200 lb BOD/day/1,000 ft^3 with constant or variable speed lift pumps is shown in Figure 2.

FIGURE 2

BIO CELL INFLUENT BOD vs. OPTIMUM MEDIA HEIGHT



A discussion of aerator efficiency and selection is beyond the scope of this paper. Obviously, the aeration system with the greatest oxygen transfer efficiency will use the least energy but may not prove to be the most cost-effective design for a particular plant. In the ABF process, the Bio-Cell satisfies a major portion of the system oxygen demand and BOD reduction. The impact of the aeration system on the overall process energy demand is reduced since it acts only as a second stage polishing unit.

Process energy requirements for ABF and activated sludge versus influent BOD concentration are plotted in Figure 3. Curve B describes the energy required for an ABF plant in which the Bio-Cell height has been selected for energy optimization. Average ABF process energy demand ranges from 13 to 18 horsepower per MGD for typical domestic wastewaters having a primary effluent BOD concentration of 110 to 150 mg/L.

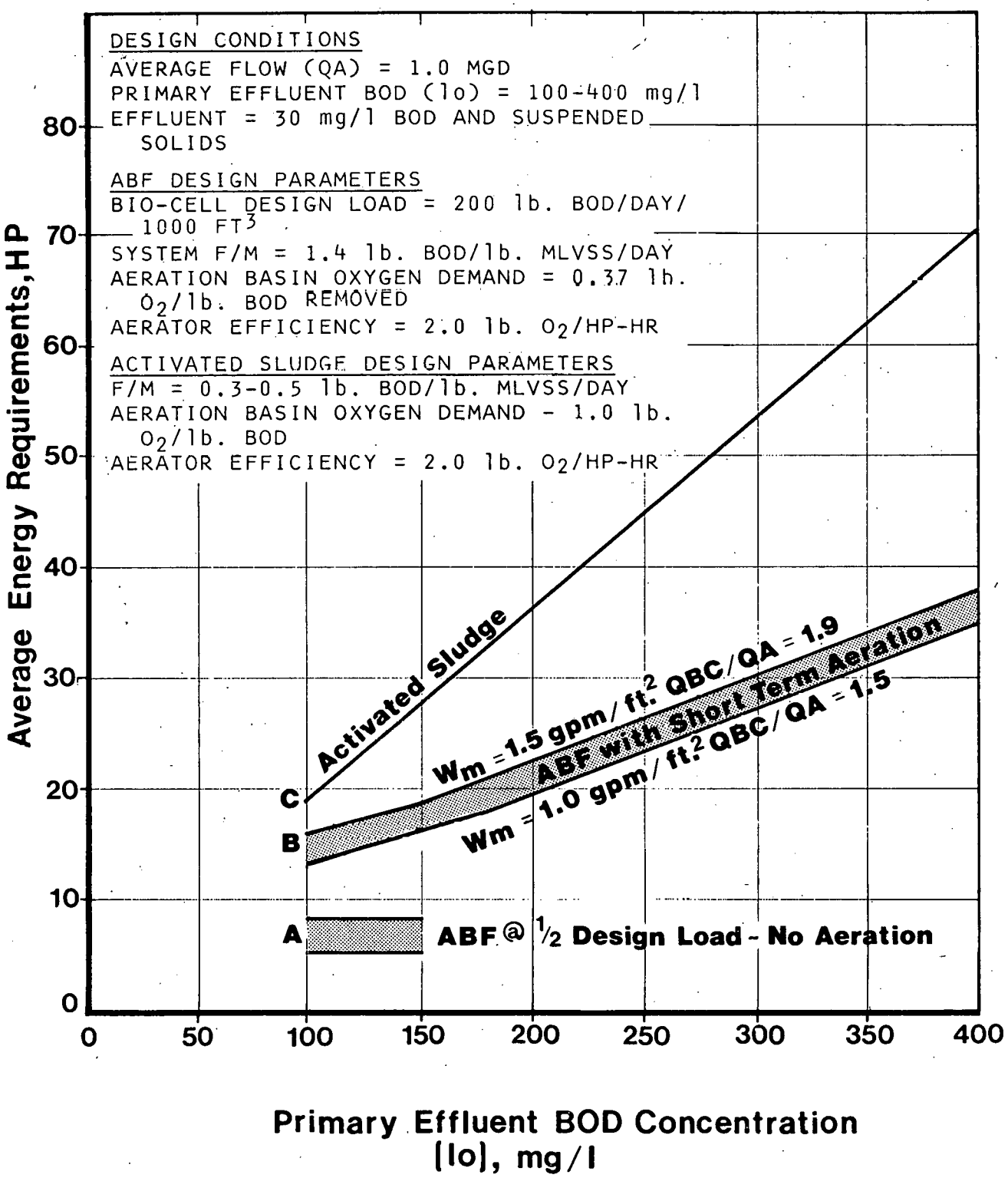
Energy consumption is based on Bio-Cell lift pump, aerator, and return sludge pump requirements. The range of energy demand shown in Curve B represents the "best" and "worst" cases as a function of the Bio-Cell and lift pump design. An aerator field transfer efficiency of 2.0 lb O_2 per horsepower-hour is used for these calculations.

The "best" design in terms of energy efficiency is based on using a rotary distributor to minimize the required wetting rate and variable speed or screw pumps to minimize tower recycle. A pump efficiency of 80% was used for these calculations which is close to the maximum achievable with these pumps. Pumping TDH is calculated by adding 8 ft head to the optimum Bio-Media height. The "worst" case design is more conservative and represents the highest energy consumption anticipated when the Bio-Cell is designed for energy optimization. In this case, a fixed nozzle distributor is used, which increases the required wetting rate. Constant speed pumps are used which increases the Bio-Cell recycle due to diurnal flows. A pump efficiency of only 70% is assumed which is low for properly sized and staged constant speed pumps.

The ABF process is flexible since it incorporates two distinct biological systems. There are many plants which operate without a subsequent aeration basin or which only use the aeration basin on a seasonal basis. In this mode, the fixed film biomass which sloughs from the Bio-Cell settles in the final clarifier and is recycled to the wetwell. A mixed liquor similar to activated sludge is formed which is pumped to the Bio-Cell where it is aerated and converts BOD to cellular material, thus increasing the efficiency of the Bio-Cell. This mode of operation can be used to decrease energy consumption substantially on plants which are not up to design organic load without sacrificing effluent quality. It is also used to treat high strength industrial wastes in roughing applications.

FIGURE 3

EFFECT OF BOD CONCENTRATION ON ENERGY REQUIREMENT



Curve A in Figure 3 presents the energy demand calculated for the lift and return sludge pumps at a plant designed for the conditions in Curve B, but which has only reached one-half of design organic load. At a Bio-Cell load of 100 lb BOD/day/1,000 ft^3, the ABF process (without aeration) can remove about 80% of the influent BOD at water temperatures above approximately 15°C. The plant can achieve the required effluent of 30 mg/L at influent strengths up to about 150 mg/L without using the aeration basin. Using the previous "worst" and "best" Bio-Cell designs, the energy requirements are calculated to be 5 to 8 hp per MGD for typical domestic waste strengths.

Estimated energy requirements for the conventional activated sludge process are presented in Curve C, Figure 3, to show that the ABF process uses considerably less energy, especially at higher wastewater strengths.

CONCLUSIONS

The ABF process can be designed to conserve energy by optimizing the Bio-Cell, lift pump, and aerator design and by using the operational flexibility of the process.

The design Bio-Cell height can vary over an approximate range of 7 to 22 feet without affecting process performance.

The ABF process energy consumption for typical domestic wastewaters can be reduced to 13 to 18 hp per MGD by designing for energy efficiency. This may not be the most cost-effective design.

The flexibility of the combined ABF process offers the potential for reduced energy consumption when the plant has not yet reached design load. The process can achieve effluent quality without aeration at Bio-Cell loads up to approximately 100 lb BOD/day/1,000 ft^3 and wastewater strengths of 150 mg/L BOD. Energy consumption is only 5 to 8 hp per MGD.

ABF energy consumption is lower than that of activated sludge at typical domestic wastewater BOD concentrations. The difference in energy consumption increases with increasing wastewater strength.

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CONCEPTUAL DESIGN FOR SUPPLEMENTAL AERATION OF THE TRINITY RIVER USING SOLAR POWER

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I. INTRODUCTION

OBJECTIVE

To investigate an innovative technique for supplemental river aeration.

SCOPE

The investigation which this paper summarizes was conducted in 1978 by the North Central Texas Council of Governments for possible application to the Trinity River at Dallas, specifically Segment 0805. Because solar power supplemental aeration has not been attempted, this investigation is preliminary and conceptual by necessity. Previous supplemental aeration studies done for the Trinity River were accepted without reevaluation and built upon. Preliminary designs and the associated costs, for both a full scale operation and for a pilot operation were developed.

BACKGROUND

The Trinity River is small and its discharge varies greatly in response to local precipitation events. The Texas Department of Water Resources bases permit evaluations on the seven-day, two-year low flow which is only 4.4cfs in Segment 0805. Two municipal sewage treatment plants discharge into Segment 0805 and their total flow is 159 MGD. Urban storm water from the Dallas metropolitan area is also discharged into the Trinity. The combination of low river flow and significant organic loading creates circumstances in which dissolved oxygen (DO) values in the Trinity sometimes violate stream standards.

The stream standards applicable to the Trinity are currently under debate, but past standards, and the standards in effect when this study was conducted, were 2.0 mg/l DO under effluent dominated conditions and 5.0 mg/l DO normally. Segment 0805

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1974 TAMU report were studied. Pressurized side-stream oxygenation was recommended.

In a report prepared for the Corps of Engineers, numerous methods for improving Trinity River dissolved oxygen are briefly discussed (Qasim and Armstrong, 1978). The investigators found side-stream pressurization the most cost-effective supplemental aeration system for existing conditions.

II. DESIGN CONCEPT

Two aspects of in-stream aeration are presented. First, the selection of the equipment capable of putting the needed amount of oxygen into the stream. And second, the method of producing the oxygen and the required power. Both are innovative. Neither has undergone a pilot scale study.

OXYGENATION EQUIPMENT

The 1977 Working Memorandum recommends that the pressurized side-stream oxygenation system be selected for pilot plant construction. This system has the lowest overall cost for short term operation and offers the fewest adverse environmental impacts.

Side-stream oxygenation is, in itself, an innovative technique. Developed by Union Carbide for sewage treatment plants, it has not come into use because other pure oxygen systems are more efficient for "in plant" application, notably Union Carbide's UNOX system. It has, however, some distinct advantages in supplemental aeration applications:

1. It does not impede navigation.
2. The capacity is easily variable.
3. The relatively small discharge system is not as susceptible to damage from bed load shifts as other systems.
4. It provides O_2 transfer during periods of low water depth (does not depend on O_2 transfer during gas rise to surface).
5. It is amenable to solar power.

The last advantage, amenability to solar power, is significant because innovative designs are being considered. Solar energy is receiving a great deal of attention, and if it can be used to improve stream quality, aesthic as well as environmental benefits are to be gained.

SOLAR POWER

Some researchers expect atomic and solar power to come into wide use by 2050 (Bockris, 1975). The world situation dictates that alternative sources of energy be investigated at every opportunity and Dallas is in a relatively high insolation area. The critical oxygen sag points of the Trinity River occur downstream of the metropolitan area where land is available for construction of solar collectors. Therefore, solar oxygen production was investigated.

CONCEPTUAL DESIGN

Figure 1 illustrates the design concept. A bank of photovoltaic cells converts insolation directly into 2 volt DC current for use in the electrolytic plant. Deionized water

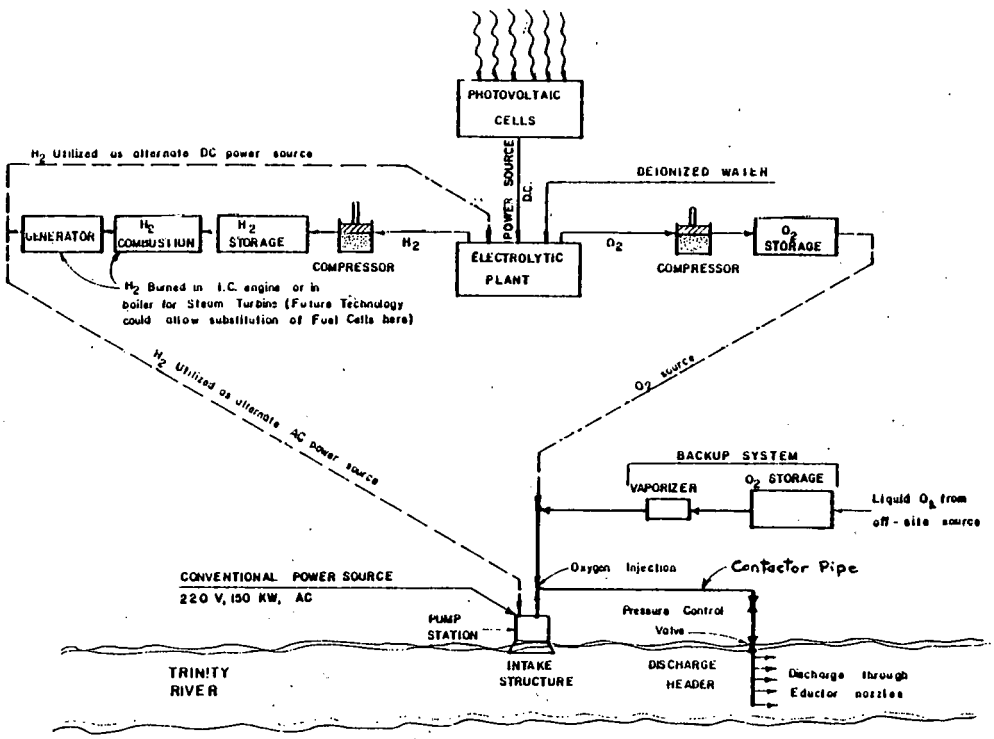


FIGURE 1, DESIGN CONCEPT

(approximately 70 gallons per day) is electrolized into hydrogen and oxygen, and the oxygen is introduced into the contactor pipe during operation of the oxygenation system.

All of the basic units proposed in this conceptual design are commercially available, but they have never been assembled in the proposed configuration. To estimate the cost of building and operating such a system and to begin to identify the interfacing problems, a preliminary design was developed and is summarized herein.

III. PRELIMINARY DESIGN

OXYGEN TRANSFER CAPACITY

The oxygen required to maintain 2 mg/l DO at the point of critical DO concentration varies with climatic, hydrologic, and pollution loading conditions. Using results of mathematical modeling and water quality sampling data it was estimated that, for a four site aeration system, the average oxygen demand to be satisfied by each plant is 1,420 pounds per day (PPD) and that the annual quantity of oxygen to be transferred to the river is 518,350 pounds per plant.

PLANT DESIGN

Figure 2 illustrates the plant layout and the following paragraphs discuss the unit sizes.

Oxygen Transfer Equipment

The pump station capacity is 1,400 gpm; the contactor pipe is 508 ft. long, 10 inches in diameter, and operates at 100 psig; the four distributor laterals are 20 ft. long, 8 inches in diameter, and are equipped with 20 eductor nozzels.

Solar Oxygen Production Equipment

Oxygen is to be produced by the electrolysis of water using photovoltaic generated electricity.

Photovoltaic power conversion utilizes the energy of the sun to generate electricity directly from sunlight. Ionizing radiation is absorbed by solar cells constructed from "doped" (structurally imperfect) semiconductor crystals; electrons are freed and induced to flow out of the cell to do useful work, to power an electrolyser in this case.

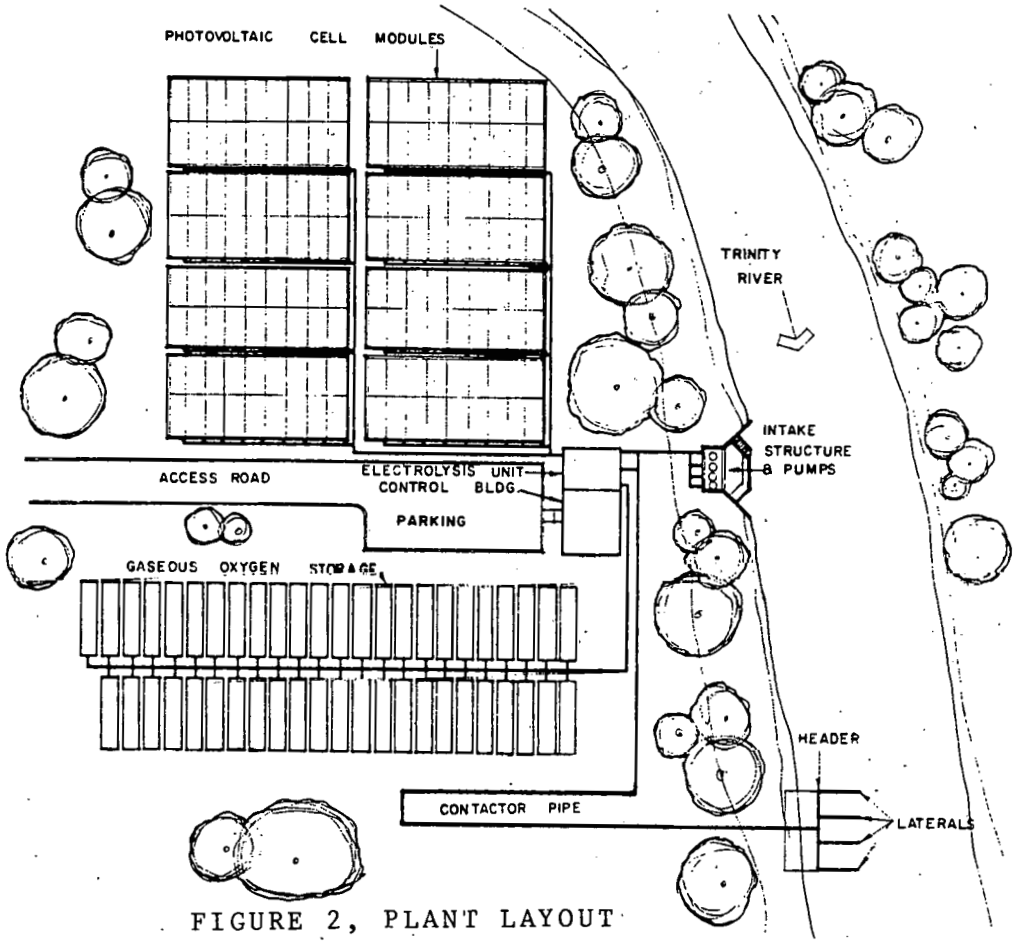


FIGURE 2, PLANT LAYOUT

An electrolytic oxygen plant is a simple system. It produces a reasonably pure stream of oxygen and a valuable by-product, hydrogen, from a small amount of water. The electrolysis process requires a low-voltage DC power source and, therefore, is well-suited for coupling with a solar power supply.

The hourly average solar insolation at the site is expected to be 244.6 watts per square meter. The estimated annual power requirement, based on an average daily oxygen output of 1,420 PPD and a requirement of 0.768 kilowatt hours (KWH) per pound, is 398,054 KWH. The anticipated conversion efficiency of the photovoltaic cells is 14%. Therefore, the required insolation is 2,843,245 KWH, and the required cell area is 1,327 m^2. Using a 50% packing factor, the required module area is 2,654 m^2. The area of the site covered by the photovoltaic cell

modules is approximately 28,560 ft^2, or a square 169 feet on a side.

Oxygen Storage Equipment

Using two models, one to calculate monthly oxygen requirements of the river and another to calculate anticipated monthly oxygen production, the required storage volume was determined. Figure 3 illustrates the results.

The maximum storage capacity required is 200,000 pounds of oxygen and the most desirable form of storage is tube cylinders on skids. A typical system consists of 6 tubes per skid with each skid containing approximately 52,500 scf (4,300 pounds) of oxygen at a storage pressure of 2,400 psig. Typical dimensions of each skid are 34 ft. long, 7.5 ft. wide, and 6 ft. high. Total weight of a skid, including appurtenances is 40,000 pounds. The maximum storage volume requires 47 such skids.

COSTS

The capital, and operation and maintenance costs of the equipment described above were estimated and compared to

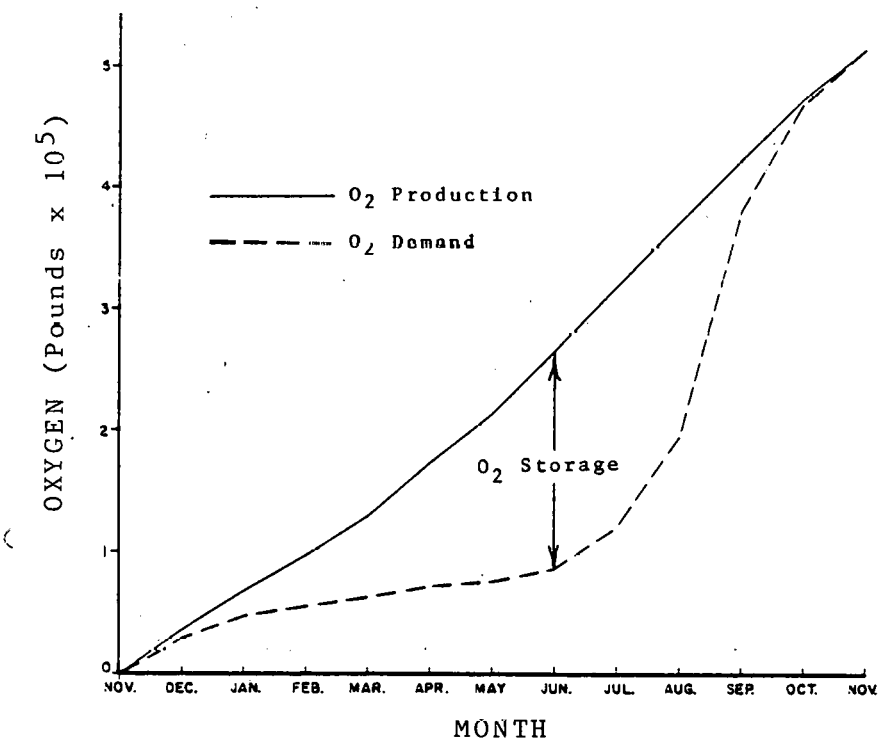


FIGURE 3, OXYGEN PRODUCTION AND DEMAND BY MONTH

estimates for other supplemental aeration equipment as reported in the 1977 Working Memorandum. The annual costs are compared on Figure 4. The cost of solar supplemental aeration in 1978 ranged from $3.4 million to $3.6 million depending on the number of weeks of operation. This was higher than other methods of supplemental aeration as shown on Figure 4. However, by optimizing the oxygen storage system and allowing for the decreasing cost of photovoltaic cells, it was projected that a solar sidestream system might become competative in the early 1980s (also illustrated on Figure 4).

A pilot scale, one site system capable of producing a peak of 2,500 pounds of oxygen per day and with an average annual transfer capacity of 129,600 pounds of oxygen, was also designed and costed. Estimated annual cost of this plant is $305,640.

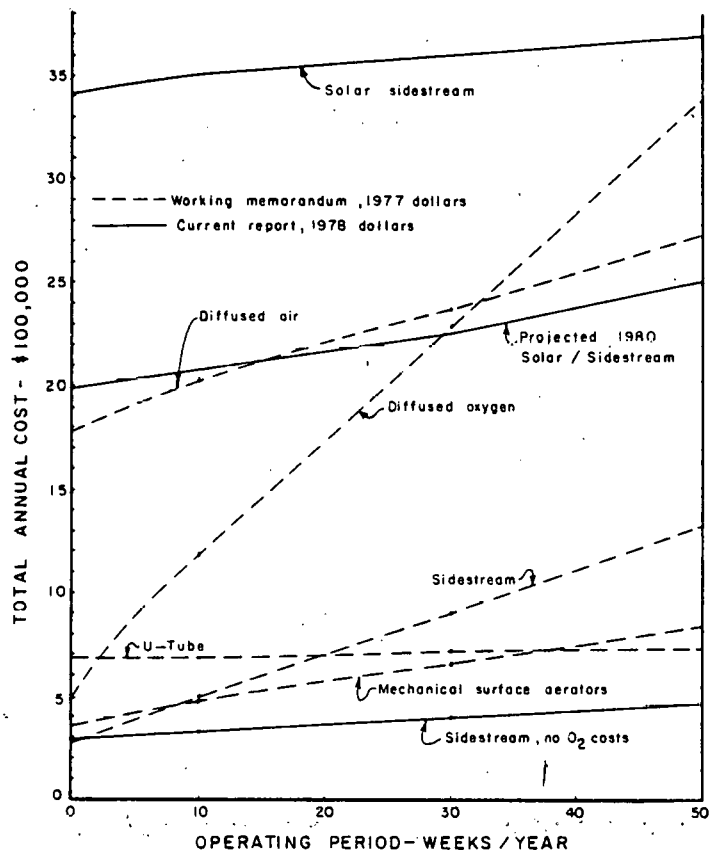


FIGURE 4, TOTAL ANNUAL COST
FOR VARIOUS AERATION SYSTEMS BY OPERATING PERIOD

Preliminary comparison of the cost of the four site system to cost of advanced wastewater treatment are favorable. If the existing Dallas municipal treatment plants were required to produce an effluent of 5 mg/l BOD_5, 5 mg/l TSS, and 3 mg/l NH_3-N (as has been discussed), the improvements would have a capital cost five times greater than solar supplemental aeration (Promise, Tate, and Naecker, 1979).

IV. CONCLUSIONS

Conclusions of the 1978 NCTCOG Working Memorandum from which this paper is abstracted include:

1. The equipment necessary to build a solar/side-stream oxygenation system is currently available. Components are presently designed for other uses and interfacing problems must be surmounted.
2. Several areas need more detailed preliminary study and a pilot plant evaluation must be done before a full scale plant can be built.
3. Preliminary costs indicate solar sidestream supplemental aeration may be competative with other methods of supplemental in the early 1980s.

A conclusion reached in subsequent, yet still preliminary investigations (Promise, Tate, and Naecker, 1979) is:

4. Solar sidestream supplemental aeration would require one-fifth the capital cost of advanced wastewater treatment units capable of improving the Dallas municipal sewage discharges to 5 mg/l BOD_5, 5 mg/l TSS, and 3 mg/l NH_3-N.

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POTENTIAL FOR BREWERY WASTES AS AN ALTERNATIVE TO METHANOL FOR DENITRIFICATION IN HONG KONG

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HONG KONG WATER RESOURCES

The water resources of Hong Kong are derived from two sources: rainwater catchments (including reservoir sites on land and two impounding sites reclaimed from the sea) and importation from mainland China. In 1977, flash distillation of seawater was initiated and proceeded for nearly one year. This facility was energy intensive and recently was taken out of commission because available natural yield is sufficient to meet existing demand. Past shortages of water resources have necessitated the restriction of water usage during the dry years of 1963, 1967 and 1976 to reduce the draw-off from the system. Water resources including catchments and present imported supplies from China will be fully utilized by 1984. Beyond that time a substantial quantity of new resources will be required to meet the growth in demand.

The potential reclamation of available degraded stream water and treated wastewater effluent is being analyzed as a possible source of municipal and industrial supply for Hong Kong. PRC Toups is conducting an advanced wastewater treatment feasibility study through pilot plant operations and testing. This program will establish optimum treatment processes, reclaimed water quality and costs of future water production from these sources.

ADVANCED WASTEWATER TREATMENT PILOT PLANT

The pilot plant consists of three test treatment trains. Treatment of secondary effluent in the pilot program involves chemical flocculation and clarification with lime, alum and ferric chloride for phosphorus removal. The clarified supernatant is treated in one of two ways. A nitrogen stripping tower provides physical removal of ammonia under high pH with subsequent recarbonation to reduce pH and dual media filtration to remove suspended solids. The other process train involves biological nitrification using a rotating biological contactor system (RBC) followed by fixed growth denitrification in submerged filters. The third process train for testing primary effluent and grossly polluted river water utilizes a modified activated sludge process with chemical addition for phosphorus removal followed by denitrification in submerged filters. This train will be modified later in the test program to evaluate an alternating contact process for nitrification and denitrification. Effluent from all three treatment schemes proceeds through a polishing system in which the water can be chlorinated, ozonated and treated through granular activated carbon adsorption.

BIOLOGICAL PROCESS TRAINS

Biological nitrogen removal, in addition to oxidation, involves the oxidation of nitrogenous materials and the reduction of nitrates. Nitrification/denitrification in this pilot study is accomplished by both suspended growth system and attached growth system nitrification and by attached growth system denitrification.

The pilot plant RBC train contains 4 separate stages of media which operate as independent reactors in which the rate of biomass growth and stripping are at equilibrium. The treated wastewater and stripped biomass pass from stage to stage undergoing a progressively increasing level of treatment by specific biological

cultures on the media in each stage which adapt to the changing wastewater. The initial stages develop cultures that will remove mostly organic matter. As the organic matter in the wastewater decrease in subsequent stages, the culture contains increasing amounts of microorganisms that will oxidize ammonia nitrogen (NH_4^+) to nitrite (NO_2^-) and then nitrate nitrogen (NO_3^-). Depending on the operating mode of the RBC and the influent pH and alkalinity, the addition of an alkalinity buffer or acid may be required to achieve the best performance.

Denitrification is accomplished with the use of submerged filters packed with fine media sand and operated in the downflow mode. Denitrification is achieved by contacting nitrified wastewater with biomass in the absence of oxygen. The reduction of nitrate in this type of system proceeds too slowly to be practical without the addition of a supplemental carbon source.

With a nominal internal diameter of 12 inches, the attached growth denitrification filters are designed to accommodate a hydraulic flow of 1.36 l/sec/sqm (2 gpm/ft^2). RBC effluent is pumped to a static mixer (where the carbon source is added) and then to the denitrification filters. Flow control valves are employed to set flows for different operating conditions. Valves are provided for sampling purposes to characterize the influent to the denitrification filters. Valves are also provided for purposes of sampling the effluent from the filters. Flow that is not drained or sampled is then conveyed to the effluent polishing processes.

Another treatment train consists of an aeration basin, clarifier and denitrifying filters, treating primary effluent. The aeration basin is initially structured in an activated sludge nitrification process mode. Denitrification is accomplished in submerged filters during the initial process mode. Subsequent to pilot plant testing of the activated sludge system, the aeration basin provides treatment utilizing an alternating contact process.

The alternating contact process utilizes an operational sequence to control biological stress thereby reducing nutrients within the wastewater. A sequence of phases differentiated by anoxic and aerobic stages provides denitrification/nitrification. In this type of system, wastewater is the carbon source.

CARBON SOURCES

The denitrification process proceeds by contacting nitrified wastewater with biomass in the absence of oxygen. In the anoxic environment, heterotrophic organisms convert the nitrates to nitrogen gas by utilizing nitrate as an oxidizing agent in the absence of dissolved oxygen. The addition of biologically degradable organic matter accelerates the rate of denitrification.

In the process of denitrification, carbon is oxidized with nitrate or nitrite serving as the electron acceptor. Methanol, wastewater and brewery wastes are three carbon sources being evaluated at the Hong Kong pilot plant. Methanol has been the prevalent carbon source of choice in the U.S., however, costs and relative unavailability of methanol in Hong Kong necessitate the testing of alternate carbon sources.

METHANOL

Methanol has been predominantly utilized as a carbon source for denitrification processes. The design methanol requirement for nitrate reduction is approximately 3 milligrams (mg) of methanol per mg of nitrate. High NH_3-N concentrations, projected full scale plant operation methanol requirements and spiraling costs are some of the factors considered in the determination to evaluate alternative carbon sources for denitrification in Hong Kong.

Methanol [CH_3OH] may be produced by natural or synthetic means. Natural methods of production involve separation or extraction from

a variety of natural plants. Methanol from the destructive distillation of wood was the only commercial source until the introduction of the synthetic process in the 1920's. [1] Most methanol commercially manufactured today is made by passing a synthesis gas containing hydrogen and carbon monoxide or carbon dioxide over a catalyst under pressure at elevated temperatures. [1]

The transformation of nitrates to nitrogen gas utilizing methanol is described by the following reaction: [2]

$$NO_3^- + 0.833\ CH_3OH = 0.5\ N_2 + 0.833\ CO_2 + 1.167\ H_2O$$

WASTEWATER

Wastewater carbon and endogenous carbon may be utilized as a carbon source in an alternating contact process. An initial anoxic zone combining return sludge and raw wastewater results in denitrification. Rates for this carbon source require a larger denitrification reactor than those utilizing methanol.

BREWERY WASTES

An alternate carbon source for the denitrification process may be procurred from industrial sources including volatile acids, molasses and brewery wastes.

The utilization of brewery wastes as a substitute for methanol was investigated in studies conducted for the City of Tampa, Florida. In bench scale tests on suspended growth systems, brewery wastes exhibited comparable denitrification rates with methanol. Pilot plant studies in Tampa, using deep bed filters, indicated that brewery wastes had high suspended solids content and associated

growth. Dosages of three to four parts of brewery waste COD per part of nitrate and nitrite were considered adequate. Higher dosages tend to result in high effluent BOD concentrations. [3]

COMPARISON OF CARBON SOURCE OPTIONS

Alternative carbon sources contain contaminants. Monitoring and analysis of brewery wastes to maintain optimum operating conditions and consistent quality are required. Methanol is free of nitrogen and other substances; however, high monetary costs necessitate the economic comparison with brewery wastes. Pilot plant studies in Hong Kong include the evaluation of individual brewery waste streams, as well as the determination of optimum dosages for denitrification, and unit process operating criteria. Operation of the advanced wastewater treatment pilot plant began in October 1979.

DENITRIFICATION IN HONG KONG

In Hong Kong, sources of methanol are limited. Projected full scale plant needs and shipping costs from other countries are substantial. Local production is inadequate to meet projected demand. Preliminary analysis and projected treatment capacity indicate an extemely high volume of methanol will be necessary in the future. Table 1 presents projected demands for methanol in the full scale plant, assuming various nitrate concentrations.

TABLE 1. METHANOL REQUIREMENTS - HONG KONG AWT

Flow mgd	Methanol gallons/day NO_3 = 10mg/l	NO_3 = 50 mg/l	NO_3 = 60 mg/l	NO_3 = 100mg
20	800	3,800	4,500	7,600
50	1,900	9,500	11,400	19,000

The current methanol price not including shipment and other costs is approximately 70 cents/gallon. It is significant to note that these costs reflect current prices. Therefore, considering the historic trends and the present economic situation these costs will significantly escalate in the coming years. The projected costs for the utilization of methanol in Hong Kong will be in the range of one million to five million dollars per year.

As a volatile alcohol, methanol has numerous environmental, physical and chemical hazards. Transportation and storage of the substance, therefore, requires special handling and associated high costs. Additional costs for these items may increase the actual cost of this carbon source by as much as six cents per gallon. To obtain the projected volumes necessary for utilization at a full scale plant in Hong Kong, methanol may have to be shipped from ports as far away as Japan or the United States.

The San Miguel Brewery in Hong Kong is located approximately 15 miles from the project site. Waste streams in this facility vary in relative constituent concentrations. Stream segregation and water quality analysis are vital in the determination of an optimum carbon source. Brewery waste stream characteristics should include high COD and low nitrogen concentrations for incorporation into wastewater treatment plant operations.

Brewery waste loading rates are being analyzed in pilot studies for wastewater influent loading of 1.36 l/sec/sq m (2.0 gpm/ft^2). Influent loading rates of 50 mg/l NO_3 are projected for the Hong Kong pilot plant. Brewery waste streams are assumed to have average COD concentrations in the range of 75,000 mg/l for testing conditions. Brewery waste may be combined with methanol as a supplement or diluted if it retains the soluble COD levels necessary for denitrification. High COD levels in wastes produce rapid denitrification rates but also achieve higher levels of solids production.

Factors considered in testing for brewery waste applicability include solids content effects on pumping and backwash. Short backwashes (bumping) between full backwash operations releases entrapped nitrogen and solids in the filter beds and lowers the frequency of necessary full backwashes. Brewery wastes are biologically active and must be handled accordingly. Preservation techniques (cooling) may be necessary to reduce degradation process.

ENERGY CONSERVATION UTILIZING BREWERY WASTES

Utilization of brewery wastes is expected to result in primary energy savings from reuse of existing material and secondary energy savings through decreased demand for methanol production.

The utilization of brewery wastes is expected to achieve energy savings. These savings are directly associated with decreased transportation (hauling and shipping) requirements. Significant energy savings as well as conservation are involved in the utilization of brewery wastes. Fundamentally, the waste streams from the brewery system are recycled or reused as an important component of another system, namely wastewater treatment.

Production of methanol began with the destructive distillation of wood. Synthesis from carbon oxides and hydrogen by gasification of our nonrenewable fossil fuel resources has become a well established synthetic production method of methanol. [1] Projected methanol requirements for a full scale wastewater treatment plant in Hong Kong would increase the consumption demands for methanol. The production of methanol requires energy consumption and the transport of methanol will increase the total actual energy consumed. Secondary energy savings are involved in the utilization of brewery wastes due to the reduction in industrial chemical production.

The results and findings of the pilot plant studies will be utilized in determining the optimum carbon source for wastewater denitrification in Hong Kong full scale plant operations. These results may find application in other areas of the world where economics and availability are significant parameters in the utilization of an alternative to methanol.

ACKNOWLEDGMENT

The authors wish to express thanks to Mr. W.D.A. Tucker, M.A., F.I.C.E., F.I.W.E.S., J.P., the Director of Water Supplies, and to Mr. To-Hin Lau, Government Water Engineer/Development and Planning, both of the Water Supplies Department -P.W.D.- Government of Hong Kong, for their review and permission of the presentation and publication of this paper.

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SESSION 3

ENERGY IN DESIGN CONSIDERATIONS

Chairpersons: Robert Southworth

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ENERGY CONSIDERATIONS IN THE DESIGN OF A PUBLICALLY OWNED TREATMENT WORKS

William F. Barry, P.E. and James W. Heine, P.E.
OWEN AYRES AND ASSOCIATES INC
Consulting Engineers
Eau Claire, Wisconsin

1. GENERAL

Eau Claire, Wisconsin is located approximately 100 miles east of the Twin Cities of Minneapolis-St. Paul, Minnesota. Eau Claire is one of the fastest growing metropolitan areas in the State of Wisconsin. The estimated 1979 population for the City is 49,600.

In 1969 the City took the initial steps to upgrade an overloaded primary treatment facility to provide secondary treatment of its wastewater prior to discharge to the Chippewa River. OWEN AYRES & ASSOCIATES INC was hired as consulting engineer for the project. By mid 1972 a facility design utilizing activated sludge treatment with solids incineration was approximately 60% complete. With the passage of Public Law 92-500 in October, 1972 funding of the project became uncertain and design work was ceased for 2 years. By late 1974 new funding regulations were being developed and the City applied for funding to conduct a '201' facilities plan. The application was approved and work began in early summer 1975.

Projections for the service area through the year 2000 showed a design population of 101,716 persons. Anticipated wastewater characteristics to be received at the facility are a flow of 16.3 MGD with a BOD_5 and suspended solids loading of 33,735 lbs/day each. Required effluent quality is for a monthly BOD_5 and suspended solids average of 30 mg/l.

2. PROCESS DESIGN

Major areas for energy savings for the process alternatives were in the wastewater pumping area, secondary treatment process and solids handling options.

Two methods of lifting the wastewater into the plant were investigated in detail. One option of utilizing a centrifugal pumping system was compared to a helical pump system. The required lift into the treatment plant is 27 feet. A centrifugal pumping system would require four pumps capable of pumping 32 MGD with the largest pump out of service. A helical pump station required 3 units each capable of pumping 16 MGD. The installation of the helical pump system would cost an additional $25,000 initially or about 4%. This additional first cost will be more than offset by an annual operation and maintenance savings of $11,600. Over the 20 year design period a savings in present worth dollars was projected to be $33,700.

Three secondary wastewater treatment processes were analyzed in detail. These were an activated sludge process, rotating biological contactor and activated biological filter. Based on existing performance at the City treatment plant it was estimated that 35% of the incoming BOD_5 would be removed in the primary treatment portion of the facility leaving an organic loading to the secondary process of 21,900 lbs/day. The estimated construction of the secondary treatment system (including clarifiers and return sludge pumping equipment) are summarized below in Table 1.

TABLE 1 - SECONDARY TREATMENT COST ESTIMATES

Process	Construction Costs (Secondary Units Only)	Annual Energy Cost	Present Worth Plant (Liquid Handling)
Activated Sludge	$3,024,300	$202,300	$12,981,250
Rotating Biological Contactor	$3,137,200	$ 97,300	$12,072,450
Activated Biofilter	$2,445,200	$156,600	$12,083,150

Based on the accuracy of the estimates all treatment systems proved to be cost competitive. To verify the assumptions made to arrive at the above estimates, pilot plants were run on all three secondary systems. The rotating biological contactor proved to be the most cost effective solution upon completion of the pilot studies.

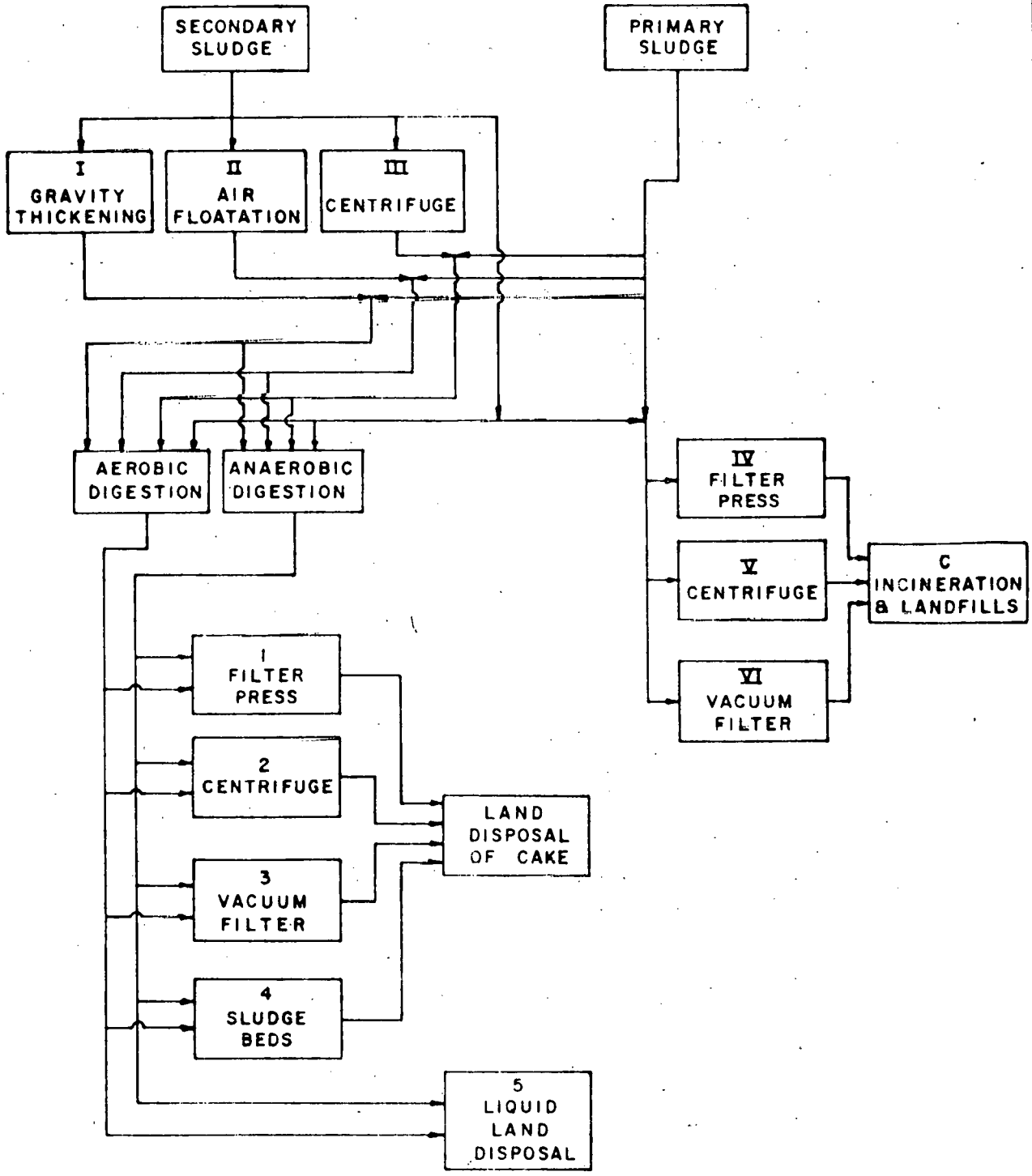
Various solids handling alternatives were analyzed in detail for the Eau Claire Treatment Plant. A flow schematic of the various processes considered is shown on Figure 1. The most economical combination of systems is to provide gravity thickening of the secondary sludge, anaerobic digestion of the combined primary and thickened secondary sludge, and finally liquid land disposal of the digested sludge.

Digested sludge will be removed from the plant site in a 6000 gallon semi-tractor trailer rig. This unit serves as a nurse vehicle to a flotation type field spreading unit of 3500 gallon capacity. During the summer months the sludge is injected directly to the soil by the vehicle. During winter when the ground is frozen the sludge is surface applied. When the soil thaws in the spring the sludge is worked into the soil.

Preliminary indications from the local power company indicated that time of day power rates would likely be implemented in the Eau Claire area in the near future. This rate sets up a user cost per KWH of approximately 5 times the off-peak rates for 60 hours during a week. These hours coincide with the expected maximum flow rates into the treatment plant. To reduce the expenditures for power, gas storage volume was provided within the anaerobic digesters. An engine-generator set will be utilized during peak power rates to minimize the purchased electrical power and also reduce the maximum demand charge for the facility. Approximately one-third of the available digester gas energy can be converted to electricity in this manner. An additional one-third of the energy will be recovered in the form of heat reclaimed from the engine cooling system and silencers. The reclaimed heat will be stored in a 60,000 gallon hot water storage tank and will be used to supply heat to the anaerobic digesters as needed to maintain the temperature at operating levels.

3. BUILDING DESIGN

A schematic site layout is shown on Figure 2. Four new buildings were constructed to meet the needs of the plant. These buildings are an administration center, headworks building, sludge thickener building and digestion building.



EAU CLAIRE URBAN AREA
FACILITIES PLAN
FLOW SCHEME
SOLIDS HANDLING ALTERNATIVES

FIGURE 1

OWEN AYRES & ASSOCIATES

EAU CLAIRE URBAN AREA
FACILITIES PLAN
WASTEWATER TREATMENT FACILITIES

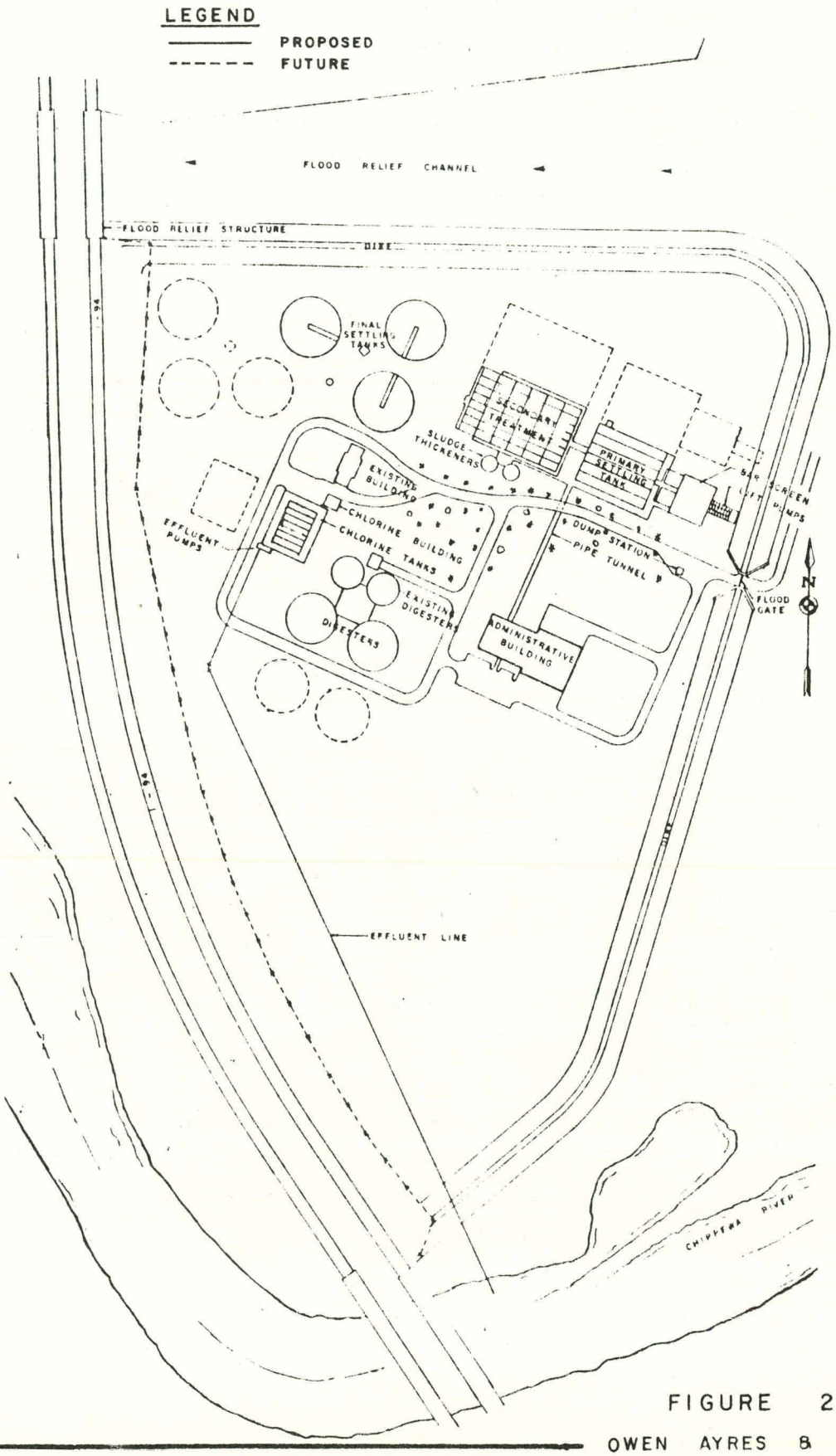


FIGURE 2

OWEN AYRES & ASSOCIATES

All buildings are designed to minimize heat loss. The wall construction consists of a standard 8" masonry block unit, three inches of rigid insulation covered by a 4-inch face brick. All roofs contain 4" of rigid insulation beneath the built-up roofing system.

It was determined during the design phase that adequate heat for the buildings could be obtained from the plant effluent. Normal winter plant effluent temperature is approximately 48^{o} F. Heat is removed from the clorinated effluent via a two stage heat pump system. A closed loop hydronic heating system is supplied with 160^{o} F water and circulated to the various buildings. It is estimated that $520,000 will be saved on a present worth basis over the design life of the project when compared to electric resistance heating.

The sludge thickener building provides another area for heat reclamation. Housed in this building are air compressors which will supply air necessary to rotate the biological contactors. The large amount of heat generated by the air compression will be ventilated into the other building areas on the plant site reducing the amount of additional heat required.

4. SUMMARY

During the design work on the City of Eau Claire Wastewater Treatment Plant effort was made to reduce the purchased energy consumption at the facility. Those areas which showed the most feasible areas for energy savings included process design and building design.

In the process design area savings were realized in the initial wastewater pumping system, secondary treatment alternative and solids handling operation.

Building design minimized heat loss thru the case of a cavity wall construction and roofing insulation. Heat for the buildings will be removed from the plant effluent and distributed throughout the plant site via a hydronic heating system.

Considerable energy savings are possible in a publically owned treatment works through the economical selection and use of available technology.

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MPI DESIGN RECOVERS HEAT AND ENERGY FOR CLEVELAND'S SOUTHERLY WASTEWATER TREATMENT CENTER

By R. F. Bonner, Jr.
Vice President
Malcolm Pirnie, Inc.
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In many large wastewater treatment plants, the disposal of skimmings (floating greases, oils, and debris) collected on the surface of settling and thickening tanks can be as difficult as treating waste. At the Southerly Wastewater Treatment Center in Metropolitan Cleveland, instead of presenting a disposal problem, the skimmings will be burned and will yield valuable process steam for heat conditioning of sewage sludge.

This system is part of an energy conservation scheme that will save the Northeast Ohio Regional Sewer District (NEO) more than $650,000 and 4.2 million gallons of fuel oil annually in operating the Southerly plant over conventional energy systems. In fact, in recognition of the effective use of energy recycling techniques at Southerly, MPI was cited last year with the prestigious Owens-Corning Fiberglas Corporation's Energy Award.

Modifications Reshape Facility

Energy considerations were a high priority for MPI in designing the Southerly plant expansion/renovation. At this complex of more than 30 treatment units plus administration buildings, scheduled for completion in 1983, secondary treatment capacity will be increased from its present 115 mgd to 200 mgd, with full tertiary treatment for all flows up to 400 mgd; primary treatment with disinfection will be provided for stormwater flows up to 735 mgd. The facility also handles 120,000 lb/day of dry sludge solids pumped to Southerly from NEO's Easterly treatment facility.

Sludges from the Easterly plant and Southerly's primary sludges are degritted, thickened and stored if required, together with the thickened biological sludges. All thickened

sludges then go through thermal conditioning, vacuum filter dewatering and incineration, with on-site ash disposal.

The four energy recovery techniques employed by MPI in the Southerly design yield two commodities: process steam and building heat. Annualy some 400 million pounds of steam for the sludge thermal conditioning process units, along with 100 million pounds of building heating and boiler auxiliary steam, will be generated by skimmings-fueled boilers and waste heat boilers. In addition, heat pumps will remove and recycle heat from the treated plant effluent, while energy wheels recover heat from building air before it is exhausted.

Process Steam Generated from Skimmings, Wate Heat

In the plant's settling tanks and thickeners, floating components of raw sewage - spent grease from soaps and detergents, along with small twigs, rags and other debris that pass into the plant through the coarse influent screens - are drawn off the liquid surfaces by mechanical devices. Although their characteristics vary, the average heating value of these "skimmings" is substantial - over 16,000 Btu when dry.

At the 200 mgd design flow, Southerly will generate some 2700 dry lb/hr of skimmings; these, when fired at 50% moisture, along with 25% fuel oil to assure ignition, will yield a saturated steam capacity of 45,000 lb/hr at 425 psig. On an annual basis, the skimmings-fired boiler alone will provide about 290 million pounds, or 58%, of the thermal conditioning system's steam requirements - at a savings of 2.75 million gallons of No. 2 fuel oil annually.

Besides making conventional oil-fired steam generators unnecessary, this system will eliminate the need for disposing of skimmings, and will result in capital cost savings that can be credited against the cost of the skimmings burning steam generating facility.

The system, shown in Figure 1, incorporates the latest available designs in combustion control and complies with all federal, state and municipal emission requirements for air

pollution control. It also includes an oil-fired package boiler for standby use during inspection and maintenance or for emergency operation.

As a second technique for using recycled energy for the thermal conditioning process, each of Southerly's four multiple-hearth sludge incinerators is being equipped with a waste heat boiler, shown in Figure 2, that will generate saturated process steam at 425 psig. Although the technology for waste heat recovery has been available for some time, it was the rapidly escalating price of fuel oil, exacerbated by the threat of future oil shortages, that made this approach economically feasible. These boilers will save approximately 1.2 million gallons of fuel oil annually and will also reduce the exit temperature of incinerator gases before they enter the scrubber.

Heat Pumps, Energy Wheels Recover Building Heat

These two devices will save NEO more than 350,000 gallons of fuel oil each year at Southerly, by heating over 395,000 sq ft of area in 13 buildings. Ten heat pumps, employing treated wastewater as a heat source, will supply the buildings' various heating units; a typical heat cycle is shown in Figure 3. Since effluent temperature is considerably higher than ambient air temperature during winter, and a large volume of effluent is available at the plant, the heat pumps should be able to extract enough heat to satisfy building heating requirements without additional heating equipment. It is also an economically attractive method, costing $1.86 per million Btu of building heat, as opposed to $3.60 for providing the same heat with an oil-fired boiler system (assuming fuel oil @ 40¢/gal and electric power @ 3¢/kwh).

Finally, six energy wheels - rotary air-to-air heat exchangers consisting of revolving cylinders packed with coarse knit metal mesh - will recover heat from building exhaust air by transferring it to incoming ventilating air (Figure 4). In addition to reducing fuel and energy consumption and annual

heating costs, the energy wheels will reduce the size of required heating equipment.

Rising Oil Prices Increase Anuual Savings

Including these energy conservation and heat recovery units in the expanded Southerly plant cost NEO a premium of about $7.8 million, as shown in Table 1. However, based on projected annual savings of over $650,000, this increase in capital costs will be repaid in less than 12 years. And, since this estimate is based on assumed fuel oil and electric power prices which have already been exceeded and are likely to continue to rise, the payback period will be substantially less.

Perhaps more crucial, however, is the projected annual savings in fuel oil - more than 4.2 million gallons - a factor that may be of paramount importance in the all-too-likely event of future fuel shortages.

TABLE 1. Summary of Capital and Operating Cost Savings at Southerly

	Capital Cost Over Conventional Energy Systems	ANNUAL COSTS		PROJECTED ANNUAL SAVINGS	
		With Energy Conservation	Conventional Energy	$1,000	Gallons Fuel Oil
PROCESS STEAM					
Skimmings Burning	$6,100,000	$1,221,000	$1,664,000	$ 443.0	2,750,000
Waste Heat Boiler	1,386,000	320,000	472,000	152.0	1,180,000
BUILDING HEAT					
Heat Pumps	324,300	108,660	151,375	42.6	265,000
Energy Wheels	51,520	26,435	52,040	25.6	93,000
TOTALS	$7,861,820	$1,676,085	$2,339,315	$663.2	4,288,000

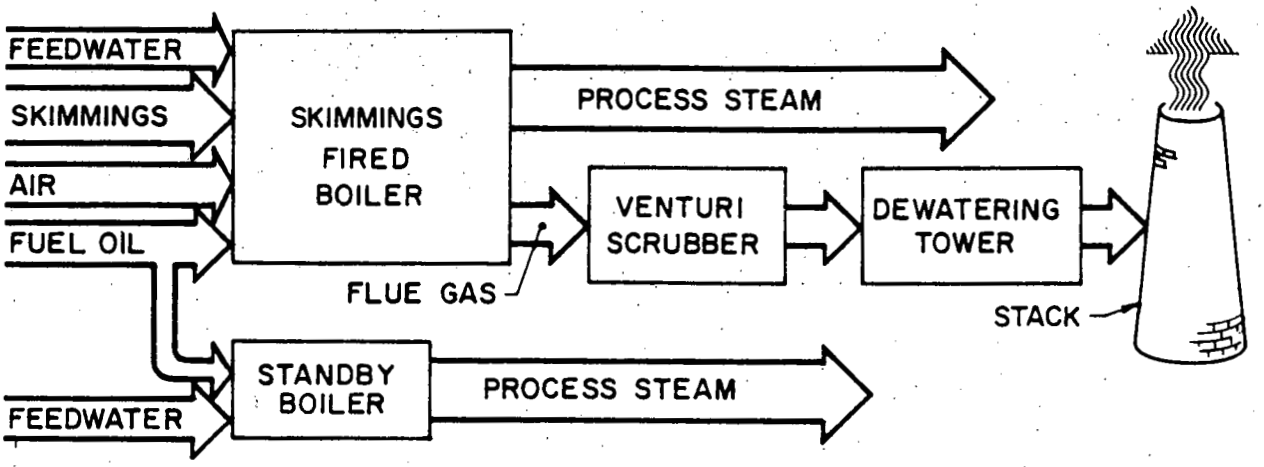


FIGURE 1. Skimmings-fired boiler generates process steam.

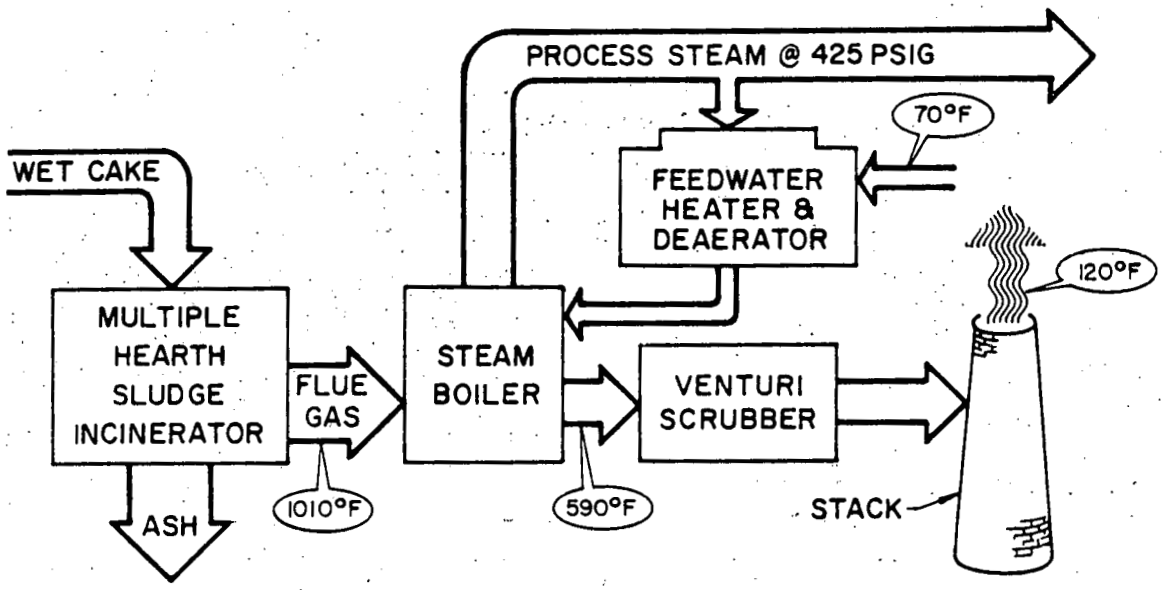


FIGURE 2. Waste heat boiler generates process steam.

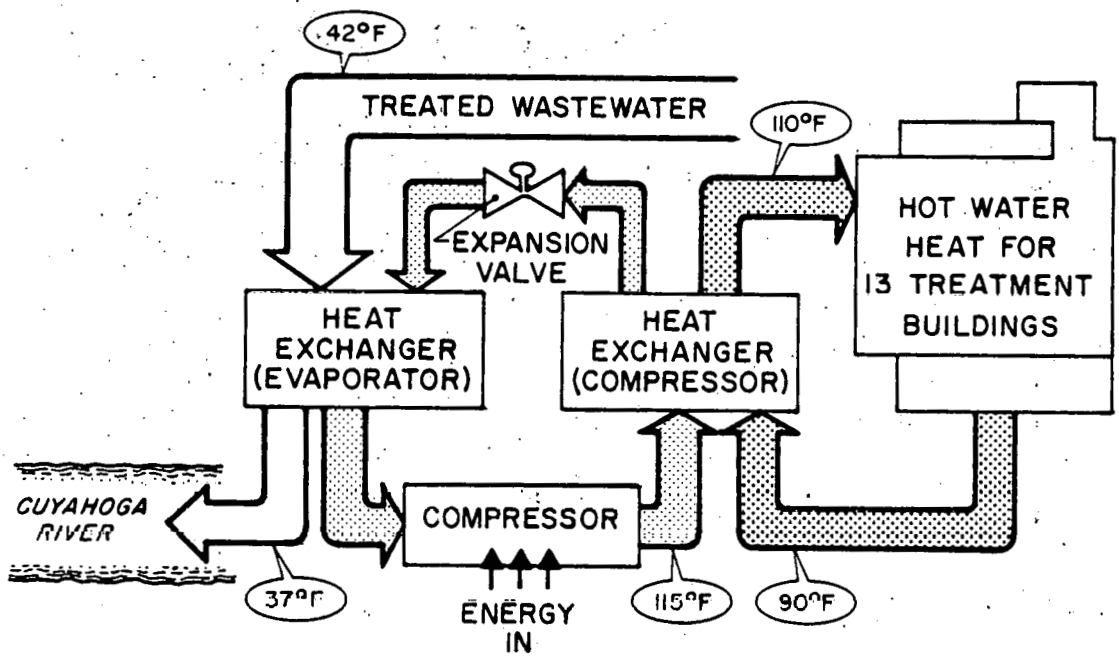


FIGURE 3. Heat pumps recover building heat from treated wastewater.

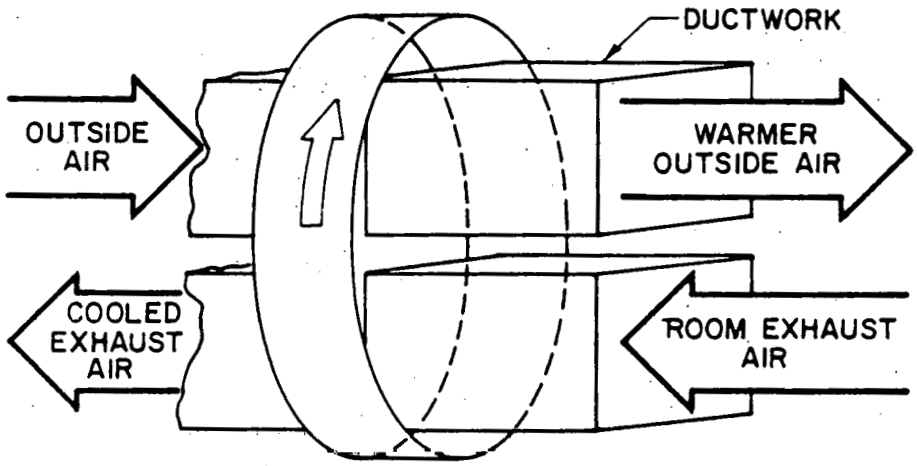


FIGURE 4. Energy wheel recovers heat from exhaust building air.

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EVOLVING ENERGY EFFICIENCY IN WASTEWATER TREATMENT FOR SMALL COMMUNITIES IN MICHIGAN

Sudarshan K. Malhotra
and
Albert R. Posthuma, P.E.
Williams & Works, Inc.
Grand Rapids, Michigan

INTRODUCTION

Every surface discharge in the State of Michigan eventually flows into the Great Lakes. Many communities are located on cold water streams with trout and salmon spawning areas. These communities are required to achieve a very high degree of treatment, and in some cases no surface discharge is permitted. All communities in Michigan must remove phosphorous.

The treatment systems tend to become more sophisticated and energy intensive as effluent standards improve. This presents a real challenge to designers to come up with new and innovative treatment schemes that will meet the effluent limits and still conserve energy.

Williams & Works believes that treatment systems can be energy efficient and still achieve a high degree of treatment. The key to an energy efficient design of a wastewater treatment system for a small community is to design systems that are specific to the community, make use of the natural resources that are available in the area and are simple to operate and maintain. This has led to the design of many small systems that were the first of their kind in the State of Michigan.

For this paper, we have selected six different treatment systems for energy comparisons—three land disposal systems and three systems with a discharge. All were designed by Williams & Works and have been in operation for at least five years. A brief summary of the treatment processes used at each of these systems is presented in Table I.

ENERGY USE

The 1978 energy use for each of the six plants studied is summarized in

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ENERGY USE

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Table I

SUMMARY OF TREATMENT SYSTEMS

Community	Design Flow (mgd)	1978 Flow (mgd)	Type of Systems	Major Unit Processes
1. Vermontville	0.100	0.067	Land Application: Flood Irrigation	10 acres of stabilization ponds and 12 acres of Flood Irrigation (4.4 inches/week)
2. Middleville	0.220	0.213	Land Application: Spray Irrigation	22 acres of stabilization ponds, 27 acres of spray irrigation (2.5 inches/week) and a chlorination system.
3. Leoni Township Jackson Co.	0.900	0.862	Land Application: Spray Irrigation	6.4 acres aerated lagoons, 28 acres storage lagoons, 140 acres of spray irrigation (3 inches/week) and a chlorination system
4. Ludington	2.5	2.010	Aerated lagoons and chemical precipitation	27 acres aerated lagoons, 2 upflow clarifiers, sludge lagoon, lime and alum systems for phosphorus removal and a chlorination system
5. Alma	2.5	2.350	Extended aeration with chlorination of sludge	Preliminary treatment units, 24 hours detention extended aeration system with Carter Aeration, BIF Purifaxing unit for chemical stabilization of sludge, sludge lagoon and sludge drying beds, ferric chloride system for phosphorus removal, a chlorination system and a polishing pond for dechlorination and enhanced secondary treatment
6. Gladstone	1.0	0.612	Biodisc with anaerobic sludge digestion	Preliminary and primary treatment units, 6 biodisc units, 2 groups of three in series with approximately 2 gal/ft^2/day loading rate, final clarifiers, primary and secondary anaerobic digesters, alum and polymer systems for phosphorus removal, drying beds and a chlorination system.

Table II. The energy use is itemized according to the type of energy used for each treatment process.

Three types of energy use were identified for each plant: electricity, fuel and chemicals. Chemicals are not a pure energy use; however, much of the cost of chemicals is from the energy used for manufacturing and transportation. Chemicals represent the third largest operating cost at half of the plants studied (after labor and electricity) because of the phosphorus removal requirements in Michigan.

The energy use is given in terms of the number of units required per million gallons (MG) treated. The pounds of chemicals could not be broken down into energy units. Therefore, the total energy use for chemicals is expressed as $/MG rather than BTU/MG. The electrical use could be converted to BTU by the conversion factor of 1 KWH = 3414 BTU.

The total cost per million gallons shown in Table II is the actual cost each community pays for its energy. A wide variation in the unit costs paid for electricity and chemicals was found between communities. It appears that many small communities are paying a premium for the electrical demand charge because they are the largest user in the area. The unit costs of chemicals reflect the higher cost of transporting small quantities to the small communities.

All of the plants do not provide the same degree of treatment. The three land disposal systems and the Alma plant would be classified as Advanced Waste Treatment (AWT), while the Ludington and Gladstone plants are secondary treatment systems. All of the systems remove at least 80% of the total phosphorus, 85% of BOD-5 and 85% of suspended solids.

Table II

SUMMARY OF 1978 ENERGY USE

Wastewater Treatment System	Unit Process	Electricity KWH/MG	Total	Fuel (1000 BTU/MG)	Chemical (lbs/MG)		Cost ($/MG)	Total Cost ($/MG)
					Phosphorus Removal	Chlorination		
1. Vermontville	Raw Sewage Pumping	811	811	-	-	-	40.57	40.57
2. Middleville	Raw Sewage Pumping	876		-	-	-	48.12	
	Spray Irrigation	907	1783	-	-	14.2	55.14	103.26
3. Leoni Township	Raw Sewage Pumping	398		-	-	-	16.72	
	Aerated Lagoons	623		-	-	-	26.17	
	Spray Irrigation	468	1489	-	-	5.1	20.26	63.15
4. Ludington	Raw Sewage Pumping	548		-	-	-	22.91	
	Aerated Lagoons	601		-	-	15.0	27.07	
	Upflow Clarifiers & Building Heat	156		1105	-	-	9.11	
	Alum + Lime	-	1305	-	(450 + 1000)	-	78.76	137.85
5. Alma	Raw Sewage Pumping	213		-	-	-	7.30	
	Extended Aeration System	1209		-	-	-	41.44	
	Purifax System and Building Heat	40		1400		106	13.12	
	Phosphorus Removal ($FeCl_3$) and Disinfection	-	1462	-	240	6	18.02	79.88
6. Gladstone	Raw Sewage Pumping	263		-	-	-	11.12	
	RBS System	1105		-	-	-	46.74	
	Anaerobic Digesters	40		3173	-	-	8.26	
	Building Heat & Truck	-		2028	-	-	4.52	
	Phosphorus Removal (Alum + Polymer) and Chlorination		1408	-	(596 + 2.4)	20	34.96	105.60

COMPARISONS OF ENERGY USE

Basis of Comparisons:

Because of the difficulty of computing energy units for chemical use, many of the comparisons are based on the cost of energy rather than energy units.

To compensate for the wide variations in the unit costs between the treatment systems studied, all costs are adjusted to the same unit costs and presented in Table III. Median 1978 costs for the communities selected were as follows:

Electricity	$0.042 per KWH
Fuel	
Natural Gas	0.210 per 100 cu.ft.
Gasoline	0.70 per gallon
Chemicals	
Chlorine - Effluent	0.120 per pound
- Alma Purifax	0.097 per pound
Lime	0.036 per pound
Alum	0.050 per pound
Ferric Chloride	0.073 per pound
Polymer	1.880 per pound

A lower cost is used for the Alma Purifax chlorine because of the savings in energy for transportation when purchasing large quantities.

The 1978 performance data for each of the systems studied is given in Table IV along with the design criteria. All three treatment and discharge systems performed better than their design limits. This is especially true for Alma and Gladstone. The treatment efficiency for the Gladstone plant will probably decrease somewhat as the plant flows approach the design capacity.

Raw Sewage Pumping:

All of the raw sewage pumping energy use is electricity. The amount of

TABLE III

COMPARISON OF 1978 ENERGY COST *
FOR DIFFERENT TYPES OF TREATMENT

	Raw Sewage Pumping Cost $/mg	Secondary Treatment Cost $/mg	Phosphorus Removal Cost $/mg	AWT Cost $/mg	Sludge Treatment Cost $/mg	Total Cost $/mg
Vermontville (0.067 mgd) -Oxidation Lagoons -Flood Irrigation	34.06	0	0	0	0	34.06
Middleville (0.213 mgd) -Oxidation Lagoons -Spray Irrigation	36.79	0	0	39.79	0	76.58
Jackson Co. Leoni (0.862 mgd) -Aerated Lagoons -Spray Irrigation	16.72	26.17	0	20.26	0	63.15
Ludington (2.01 mgd) -Aerated Lagoons -Chemical Precipitation	23.20	29.36	65.06	NA	+	117.44
Alma (2.35 mgd) -Extended Aeration -Polishing Pond -Purifax	8.95	54.44	17.47	0	12.02	92.88
Gladstone (0.612 mgd) -RBS System -Anaerobic Digestion	11.04	52.87	34.27	NA	8.86	107.04

NA - Not Applicable to This System

* The costs for all treatment systems are adjusted for the same unit costs.

\+ Lime addition for phosphorus removal aids sludge stabilization.

TABLE IV

PERFORMANCE DATA
DESIGN VERSUS 1978 AVERAGE

	Vermontville -Oxidation Lagoons -Flood Irrigation	Middleville -Oxidation Lagoons -Spray Irrigation	Jackson Co. Leoni -Aerated Lagoons -Spray Irrigation	Ludington -Aerated Lagoons -Chemical Precipitation	Alma -Extended Aeration -Polishing Pond	Gladstone -RBS System
FLOW						
Design, MGD	0.100	0.150	0.900	2.50	2.50	1.000
1978 Avg. MGD	0.067	0.213	0.862	2.01	2.35	0.612
1978 % of Design	67	142	95	80	94	61
BOD5 IN EFFLUENT						
Design Limit, mg/l	ND	ND	ND	20	7	30
1978 Avg., mg/l				12	2	7
1978 Removal, %				83	98	95
SUSP. SOLIDS IN EFFLUENT						
Design Limit, mg/l	ND	ND	ND	20	25	30
1978 Avg., mg/l				16	3	17
1978 Removal				81	97	88
PHOSPHORUS IN EFFLUENT						
Design Limit, %	ND	ND	ND	20	20	20
1978 Avg., mg/l				0.8	0.3	0.9
1978 Removal, %				81	93	81
NH_3-NITROGEN IN EFFLUENT						
Design Limit, mg/l	ND	ND	ND	NONE	NONE	NONE
1978 Avg., mg/l				NM	0.3	2.1
1978 Removal, %				NM	97	88

ND - No Discharge
NM - Not Measured

electricity used for each system varies with the topography of the area, the type of treatment system, and the size of the system.

Land disposal systems tend to have high pumping costs because suitable sites are generally located in agricultural areas outside of the service area. The size of the system is a factor because of the efficiency of pumps available. All wastewater pumps must be capable of passing 2-1/2 inch solids, whether it is a 100 gpm pump or a 5,000 gpm pump. Efficiencies are often less than 50% for the small pumps versus 70% to 80% for the larger pumps. Also, all of the larger pumps have variable speed drives to take advantage of the lower friction head loss in the force mains at lower flow rates.

Secondary Treatment:

The energy use for secondary treatment varies greatly with the type of system. Most of the energy use is electricity for supplying oxygen to the wastewater to support the aerobic biological treatment process.

The lowest energy use is for the oxidation lagoons at Vermontville and Middleville which have enough storage capacity to store the entire flow during the winter months. The aerated lagoons at Jackson County - Leoni and Ludington are equipped with Hinde aeration systems and are designed to provide a minimum of 30-days detention. These are followed by non-aerated lagoons for storing the total flow during the winter months.

The highest energy use is for the treatment plants at Alma and Gladstone. At Alma, approximately three-fourths of the energy use is electricity for the blowers, with the remainder used to operate the return activated sludge pumps, clarifiers and accessory equipment. The design at Alma has proven to be very energy efficient because of the low energy requirement for mixing by aeration guns.

In the RBS system at Gladstone, energy is required to rotate the discs. Approximately three-fourths of the total electrical use is for the bio disc units.

With the Hinde aeration system, the volume of air added can be reduced to match the oxygen demand without affecting the treatment process. Therefore, the energy use per million gallons treated will remain relatively constant for the Jackson County - Leoni and Ludington systems.

The energy use for both the Alma extended aeration system and the Gladstone RBS system per million gallons will vary with the flow.

Referring to Tables II and IV, the adjusted electrical use for secondary treatment at the Alma and Gladstone plants at the design flows would be as follows:

	1978 Flow % of Design	1978 Electrical Use, KWH/MG	Adjusted Electrical Use at Design Flow, KWH/MG
Alma	94	1,209	1,136
Gladstone	61	1,105	674

Phosphorus Removal:

Much of the impetus toward land disposal systems in Michigan has come from the high cost of chemicals for phosphorus removal. This can be readily seen from the chemical costs shown in Table III for the three plants with a discharge versus chemical costs for the land disposal systems. At two of the systems (Middleville and Jackson County - Leoni) where a crop is grown on the irrigation area, the phosphorus in the water supplements part of the normal fertilizer requirements and thus becomes an asset rather than a liability.

Advanced Waste Treatment (AWT):

Four of the six plants (the three land disposal systems and the Alma treatment plant) would be classified as advanced waste treatment systems. The Vermontville system, with flood irrigation, has no energy use. The Middleville and Jackson County - Leoni systems lease the land to a local farmer for cropping.

The Alma wastewater treatment system uses a polishing pond which uses no energy but which provides a chance for additional solids to settle out. The

chemicals added for phosphorus removal also aid in the capture and settling of fine particles. Most of the time, the flow going into the polishing pond contains less than 10 mg/l of BOD_5 and suspended solids and less than 0.5 mg/l of phosphorus.

Sludge Treatment:

The sludge treatment systems for all of the plants are very energy efficient, especially when compared to mechanical dewatering and incineration systems. The three land disposal systems, plus the Ludington system, store the sludge in the lagoons. Enough extra capacity is provided in the oxidation ponds to store the sludge for approximately twenty years. At the end of this time, the sludge would have to be removed and spread over land.

The Alma plant uses a relatively new chemical oxidation process (Purifax) which uses both electrical energy and chemicals. However, the overall energy use (and operating cost) has been very low. Part of this is due to the extended aeration process, which produces a highly oxidized sludge. The sand drying beds are also very energy efficient.

At the Gladstone plant the digester gas is used to heat both the digesters and the plant building. Extra natural gas is required in the winter months, while waste gas is burned during the summer months. All of the digested sludge is dewatered on sand drying beds.

APPLICATION TO OTHER SYSTEMS

All of the wastewater treatment systems described have energy saving features which are suitable for application to small communities. The two most important factors in determining which system to use are:

1. Land availability
2. Degree of treatment required

The most energy efficient system for secondary treatment is a lagoon system. If land area is limited, then a combination of aerated lagoons and oxidation lagoons can be utilized. A lagoon system is also very labor efficient.

A land treatment system will provide the most economical form of advanced

waste treatment where suitable land is available. The total operating cost of a land treatment system will generally be less than, or equal to, that of conventional secondary treatment when combined with a lagoon system for pretreatment and storage. Since most small communities in Michigan are located in rural areas, suitable land can often be found within a reasonable distance. Soil and groundwater conditions must also be evaluated when selecting a site.

The recent changes in the EPA grant regulations favoring land treatment systems are a step in the right direction. Often a land treatment alternative is determined to be not cost-effective because of the high initial cost of the land. However, almost all of the resources used to construct a land treatment system are recoverable at the end of the service period, while a conventional treatment system must be replaced with new resources. Also, the land treatment can often be combined with an agricultural use that converts the nutrients in the water into an asset rather than a liability.

Where suitable land is not available, either the extended aeration system or the RBS system can provide energy efficient treatment. For secondary treatment, the RBS system will provide the lowest energy use when combined with anaerobic digestion and drying beds.

The extended aeration system with a polishing pond can provide an energy efficient alternative to a conventional activated sludge system for systems with effluent limits of less than 20 mg/l for BOD_5 and suspended solids and/or nitrification requirements.

The conventional form of sludge treatment for an extended aeration system is aerobic digestion, but the electricity used for aerobic digestion can equal 50% of the electricity required for secondary treatment. A Purifax system can provide an effective treatment at a cost less than that for aerobic digestion at the current unit prices. It also produces a sterile sludge which can be stockpiled or used as a soil conditioner without fear of pathogenic organisms or odor nuisances. Early testing showed no evidence of chlorinated hydrocarbons in the sludge.

Ultimate disposal of dewatered sludge either by land application or by landfill is the most cost effective for small communities.

To tap the resources in wastewater, one must approach treatment with a fresh outlook, looking for new ways to utilize the natural forces. For example, two years ago Williams & Works designed the first wetland irrigation system in Michigan. Instead of destroying a natural resource, we, through the research of the University of Michigan, were able to show that the nutrients in the wastewater benefited the marsh, and at the same time saved the community many thousands of dollars in capital and operating costs.

I am sure there are other "wetlands" waiting to be used.

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HYDROGRAPH CONTROLLED RELEASE

Drs. Donald O. Hill, Adnan Shindala, Victor L. Zitta
Mississippi State University

INTRODUCTION

Historically, little attention was given to municipal and industrial discharges in many parts of our country. There was no central authority and local regulations were not consistent. However, due to increases in industrial output and substantial growth in our cities, the general public became increasingly aware of the deleterious effects of man's activities to the environment. The mood of the nation changed and the desire to preserve the natural values of streams for fish, wildlife, recreation, water supply and for general aesthetic beauty became prominent. This desire resulted in the passage of the Federal Water Pollution Control Act Amendments of 1972 which are well known as PL 92-500. Section 303 of the law provides for area wide basin plans whereby point sources for an entire basin will be addressed. Section 208 gives consideration to non-point sources. The new law requires a minimum level of treatment for both municipalities and industries. If the receiving stream can not assimilate the waste load resulting from minimum specified treatment, more stringent treatment is required. For municipalities, 201 Facility Plans translate these requirements to treatment works that will satisfy the specified waste load allocation.

Typically for municipalities faced with stringent effluent standards, the practice has been to abandon energy efficient systems such as lagoons and trickling filters in order to achieve higher levels of treatment. Activated sludge treatment systems seem to be most popular and have been adopted throughout the country. However, this has been at the expense of energy considerations.

The nation's energy appetite has exploded during the past decade and has resulted in the so-called Energy Crisis. It is unfortunate this development has come during a time when massive plans and expenditures are being made to upgrade the environment. Engineers are left in a dilemma that requires them to specify systems that have high rates of energy consumption. The only alternative that remains is to develop new technology and provide

new and innovative systems that would minimize energy consumption. This latter consideration is the subject of the present discussion.

SYSTEM DESCRIPTION

The innovative system under study at Mississippi State University has been called Hydrograph Controlled Release. A conceptual model of the system is shown in Figure 1. It can be noted that a facultative lagoon has been provided to achieve the minimum level of treatment required by law. It is important to note that a lagoon system is simplistic in nature, requires little operating expertise and has no energy requirement.

Two problems arise in using lagoons for wastewater treatment. First of all, many of our streams are water-quality-limited and lagoons cannot be depended upon to achieve the higher level of treatment necessary. Secondly, lagoon effluents contain large quantities of algae that will present aesthetic problems during summertime low flow periods. Both points must be addressed in order to achieve broad application of the concept.

It can be noted in Figure 1 that a typical hydrograph for small intermittant streams will have a multitude of flood events through the course of a water year. During these flood events, flows will be several orders of magnitude greater than the 10 year/7 day low flow, $Q_{10/7}$. This consideration is most important due to the fact that waste load allocations are based on $Q_{10/7}$ flow. For example, it would be common for a stream with a $Q_{10/7}$ flow from 0 to 5 cfs to have a flow of 20 to 100 cfs or more during many of these flood events.

Hydrograph Control Release utilizes these flood events to:

(1) translate a stream from the water-quality-limited category to the effluent limited category.

(2) make intermittant discharges of wastes that have been treated to the level specified by law.

During periods of warm dry weather when a stream is typically stressed, treated waste is stored and is not discharged to the stream. During periods of high flow, travel times are extremely fast, reaeration is at a maximum and consequently assimilative capacity is maximum. Discharges of treated waste during these events minimize environmental impacts while preserving the integrity and aesthetics of the receiving stream.

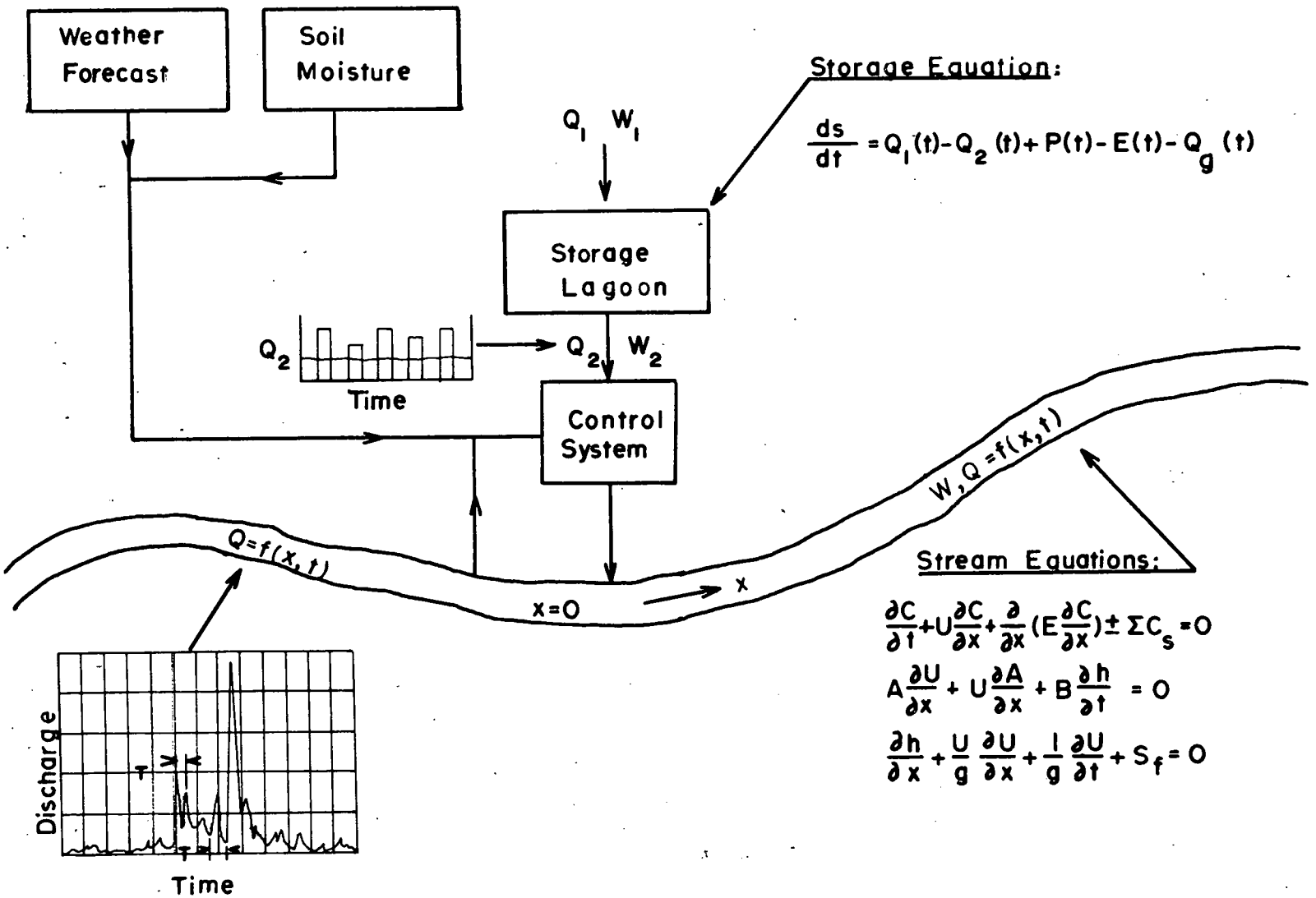


Fig. 1. Receiving Stream System

An automatic release system is pertinent to the proper operation of a Hydrograph Control Release treatment system. It is most important that the system be simplistic, easily operated and maintained. With these considerations in mind, a system has been devised with on-the-shelf components that is viewed as a bare-bones, first cut system. A schematic of the system is shown in Figure 2. The control loop consists of the following:

(1) The measuring element is a sonic stage detector. This unit has a built-in, adjustable, high level detector that produces a signal to open and close the valve.

(2) The control valve is a pneumatic on-off type with a fail-safe return. A small air compressor has been provided with a tank of suitable capacity to actuate the valve in the event of power failure.

(3) Under normal circumstances, 120 volt AC power will operate the system. Back-up or emergency battery power is also provided to operate the instrumentation.

This system is expected to be easily calibrated, operated and maintained.

BACKGROUND

A study has been carried out on a small intermittant stream in the Starkville, Mississippi area to determine the impact of lagoon effluents. The study site was selected by the Bureau of Pollution Control of Mississippi and Mississippi State University and is shown in Figure 3. It should be noted that two modest lagoons are located adjacent to each other and at the head waters of a small intermittent stream (Sand Creek). The study area includes approximately 19 miles of Sand and Caltalpa Creeks in which there is no major discharge other than the two subject lagoons.

The philosophy of controlled release suggests the release of the contents of the lagoons during the rainy season when typically flows are high, temperatures are low and flushing, transport and assimilative capacity is at a maximum. However, in order to delineate potential problems areas, the decision was made to make at least one release at minimum flow when temperatures were high and assimilative capacity at a minimum. Approximately 15 million gallons of lagoon water and 5500 pounds of BOD were discharged to Sand Creek in 2.3 days. Base stream flow was less than 1 cfs and the water temperature averaged 26°C. Stream conditions were monitored every six hours

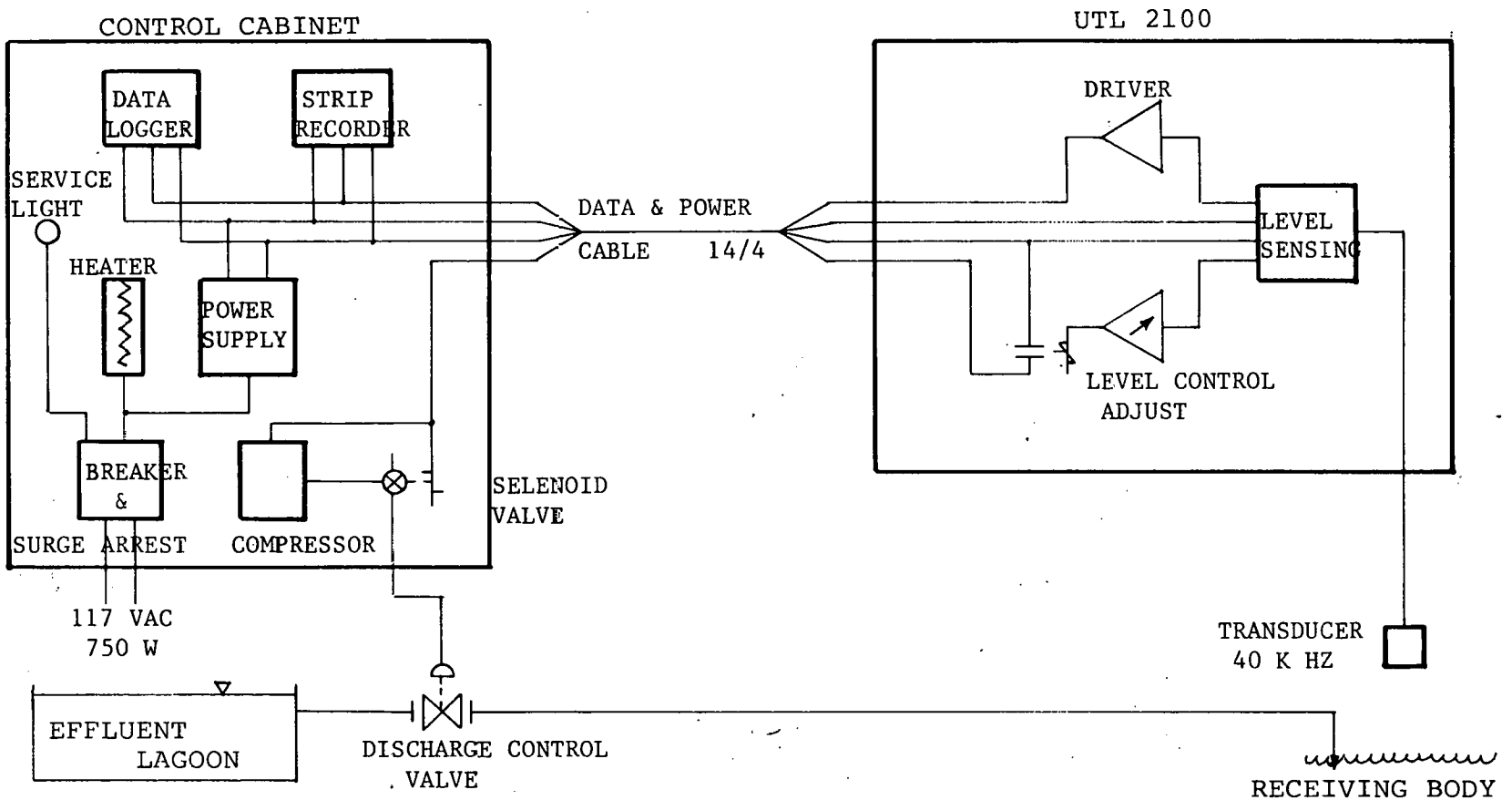
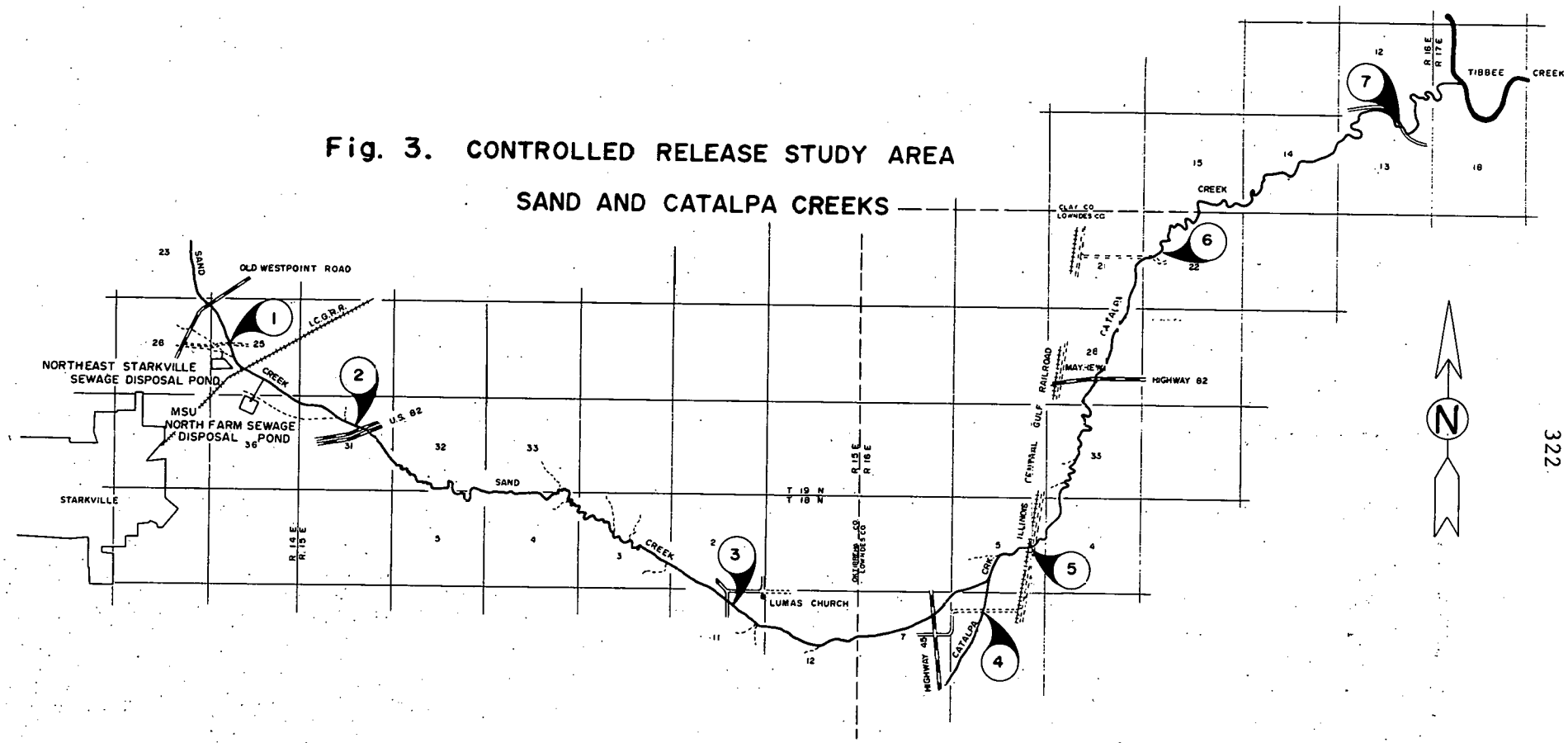


FIGURE 2. Schematic for Automatic Release System

Fig. 3. CONTROLLED RELEASE STUDY AREA

SAND AND CATALPA CREEKS



and included nighttime as well as daylight hours such that diurnal variations could be observed. Following the release there was essentially no flow at the head waters.

Dissolved oxygen data for the seven monitoring stations are shown in Figure 4. Results are surprising in that the average DO was higher than normal and the minimum points rarely violated stream standards. Had this been secondary effluent there is no doubt that anaerobic conditions would have prevailed for extended periods and fish life would have perished.

Results obtained for discharges at these very low flows are not all positive as several problems were observed. First of all, poor stream aesthetics persisted for an extended period. Secondly, there was a regrowth of several species of algae, some floating and some attached and continued to produce wide diurnal variations in dissolved oxygen content. In addition, there were some violations of stream DO requirements during the nighttime hours. Therefore, some minimum flow is required to gain the maximum potential from this technique.

A subsequent release was initiated on the rising portion of a natural flow hydrograph but persisted through the back side and into the base flow area. Figure 5 presents dissolved oxygen data for this release and it should be noted that not only did no violations occur, but very high oxygen contents were maintained. In addition, no regrowth of algae occurred and subsequent stream aesthetics were outstanding.

As a result of these impressive observations, it was concluded that:

(1) Intermittent discharges of treated waste could be made during a natural stream hydrograph such as to produce essentially zero impact on the receiving stream.

(2) Natural stream conditions could be maintained essentially 100% of the time.

In order to implement, expedite and extend the use of the Hydrograph Controlled Release method, additional work will be required to provide engineers with design information. At present, systems are being designed on a limited basis using the best available technology. As new information becomes available, these systems are expected to expand rapidly.

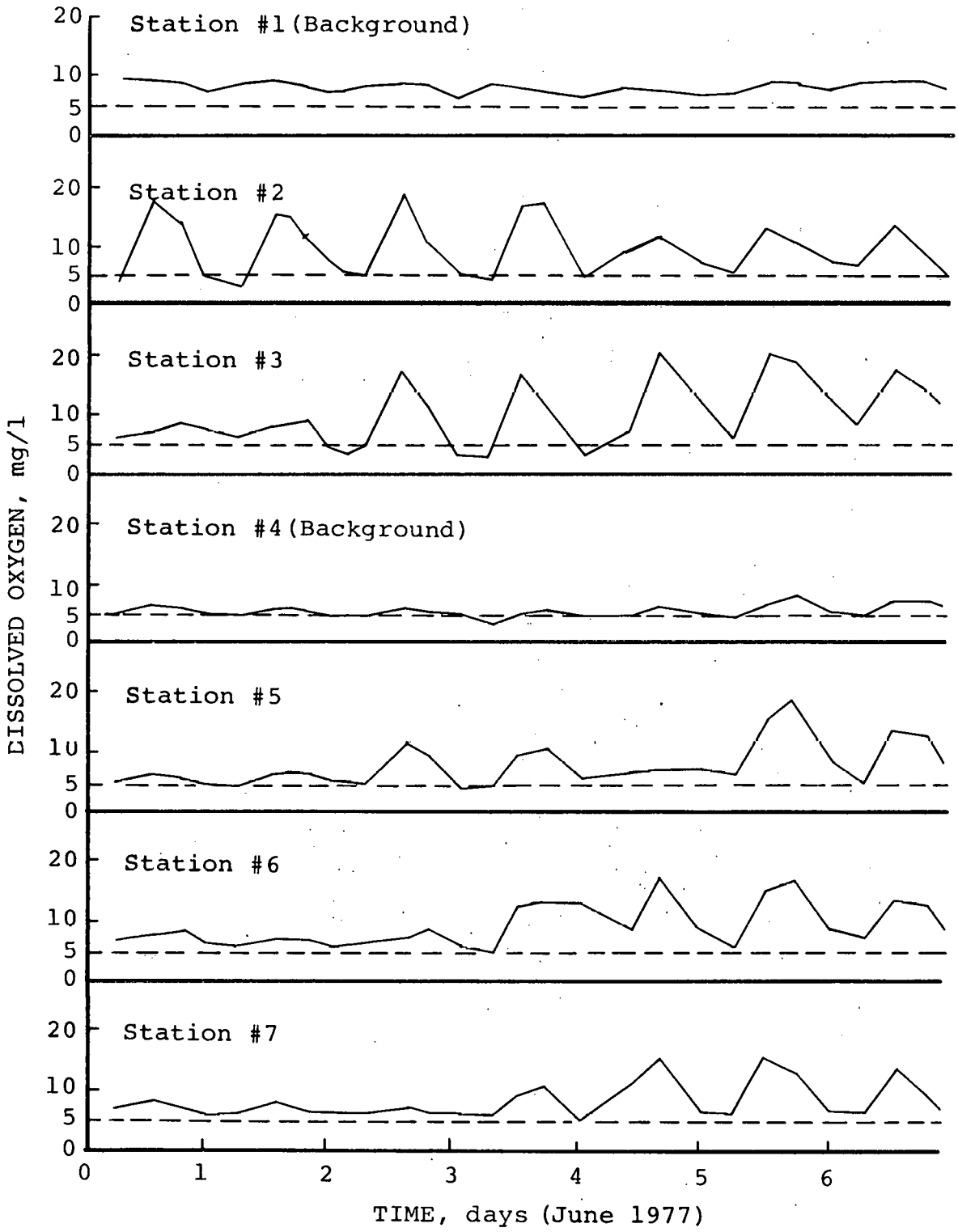


FIGURE 4. Dissolved Oxygen Profiles

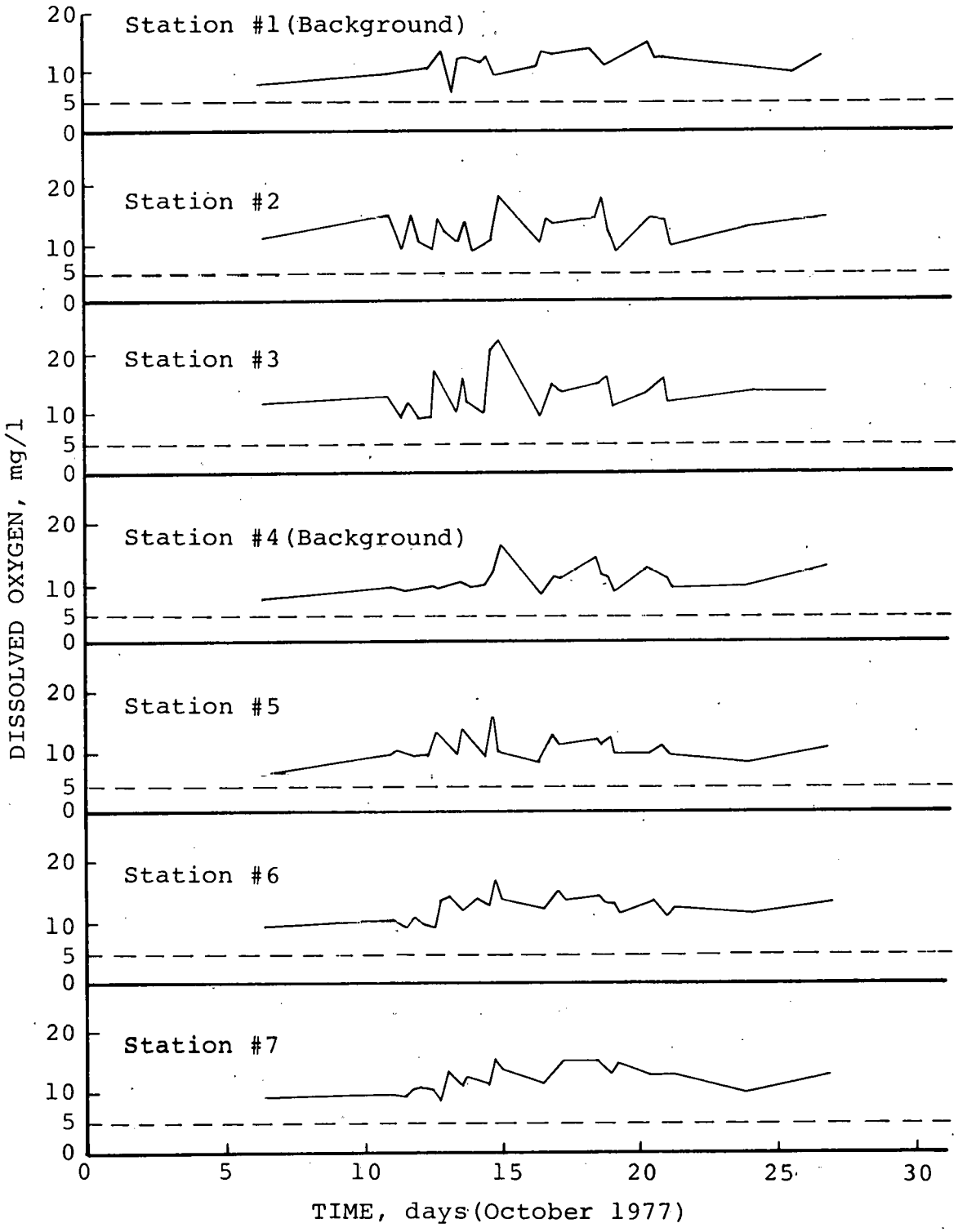


FIGURE 5. Dissolved Oxygen Profiles

APPLICATION

A recent survey showed that 10 innovative wastewater treatment facilities have been approved nationwide. Two of these systems are in the State of Mississippi and both involve the Hydrograph Controlled Release technique. One of these systems was developed for the town of Heidelberg, Mississippi, by C. B. Holder and Associates, Consulting Engineers, Bay Spring, Mississippi, which is located on a water-quality limited stream segment (Bogue Homo Creek). Step 1 of the 201 Facility Plan has been completed and approved by EPA. A brief description of the system will follow.

Heidelberg is a small town in south east Mississippi that has a design wastewater flow of 215,000 gallons per day. Waste load allocations were obtained from the Bureau of Pollution Control for stream flows of 10, 15, and 20 cfs. These data were used to determine the size of the storage facility. Stream flow records were not available for the Bogue Homo Creek at Heidelberg and it was necessary to extrapolate flow from an adjacent stream, the Tallahala at Laurel, Mississippi. The drainage area for the Bogue Homo to the point of proposed discharge was determined on a U.S.G.S. map and ratioed to flows at the Laurel gage. From an examination of the stream records it was found that the water year 1972 was most severe and, therefore, was used as the basis of design. A mass balance was established for the storage facility which would accept the municipal flow daily and discharge a predetermined quantity of treated waste at a specified stream flow. This analysis indicated a storage period of 118 days for dry weather flow and 139 days for design flow. This design is considered to be very conservative because:

(1) waste load allocations do not consider photosynthesis or transient stream conditions,

(2) the driest year on record is used for design.

It seems pertinent and proper that design be conservative until additional research can delineate the necessary transient models with appropriate coefficients. Also, stream records are deficient on many small streams and work is needed to project stream flows from other streams.

The concept of Hydrograph Controlled Release is not limited to municipal waste. It may also be used for industrial waste. A variation of the concept presented here will be used by a large industrial facility that is locating in the State of Mississippi. Plans are to provide a large storage facility

that will discharge continuously and at a rate that will maintain stream integrity as well as water quality standards.

Hydrograph Controlled Release is expected to minimize energy requirements, reduce overall costs, and maintain stream aesthetics and water quality parameters.

SUMMARY AND CONCLUSIONS

Historically, energy requirements have not been high on the priority list in specifying wastewater treatment systems. Even in light of the nation's present energy problems, it seems there is little impact on plant design.

It has been estimated that in 1977 only 0.17% of our total energy usage was consumed for sewage treatment and this is expected to climb only to 0.23% in 1990. If this is an accurate assessment, why worry about waste treatment when it has such a small impact on total energy consumption? This would be particularly true for Hydrograph Controlled Release that is presently directed toward small communities. First of all, on a national level, it seems to be analogous to the old saying, "If we watch our pennies the dollars will take care of themselves." It is not likely that large energy consumers will be eliminated or drastically reduced in the near future. Energy conservation must be practiced in all areas, particularly when there is little or no sacrifice in quality of output.

Secondly, the cost of energy for wastewater treatment along with the associated operation and maintenance costs can be devastating economically to many communities. Hydrograph Controlled Release requires essentially no energy for operation and minimizes operating requirements. This concept can relieve the financial burden for waste treatment in many communities.

Hydrograph Controlled Release is presently limited to wastewater flows that are 2 MGD or less. Much additional research is needed to delineate reasonable design criteria for the technique to enjoy broad application. In addition, work is needed to extend the concept to flows greater than 2 MGD. It would seem desirable for these larger systems to combine Hydrograph Controlled Release with Land Application Techniques.

Monetary savings resulting from the application of Hydrograph Controlled Release can be dramatic. Potential savings of $100,000,000. have been predicted for the State of Mississippi alone. Realization of these savings will depend on ability to develop pertinent design criteria and to place

this information in the hands of design engineers.

ACKNOWLEDGEMENTS

Appreciation is extended to the U. S. Environmental Protection Agency and the Mississippi Department of Natural Resources, Bureau of Pollution Control for the funds that supported this work.

DESIGNING FOR OPTIMIZATION OF DIGESTER METHANE UTILIZATION

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Sewage plants across the United States utilize methane gas generated by anaerobic digestion for digester heating. In the past, the gas was seen as a free fuel source and, because of this, little effort was made to reduce the energy required for digester heating. The small amount of gas available after meeting the digester heat requirements wasn't worth the expense of exploitation and, therefore, was burned to the atmosphere. The expense of exploitation of the gas can be justified if heat requirements are reduced, freeing the gas for exploitation.

Optimization of digester gas utilization depends on sound planning in the early phase of the design. This paper presents those design considerations critical to a successful design.

AVAILABLE ENERGY

The amount of gas produced depends upon the volume of volatile solids destroyed through digestion. Of the total volatile solids entering the digester, approximately 50-55% will be destroyed. For every pound of volatile solids destroyed, between 12-18 cu. ft. of digester gas is generated. The Btu value of the generated digester gas ranges between 500-650 Btu/cu. ft.

The volume of total volatile solids entering the digester can be related directly to the total sewage plant flow since every million gallons of flow yeilds approximately 2,000# of solids (1). Volatile solids make up between 70-80% of this 2,000#.

Based upon these criteria, the available energy from one million gallons of plant flow can be determined as follows:

2,000#/MG x 70% volatile solids = 1,400# VS/MG 1

1,400# VS/MG x 50% destruction = 700# VS destroyed/MG 2

700# VS destroyed/MG x 15 cu. ft./#VS destroyed = 10,500 cu.ft./MG 3

10,500 cu. ft./MG x 600 Btu/cu. ft. = 6.3 MBtu/MG 4

UTILIZATION OF GAS

The generated digester gas can be used in many ways. Engines which drive process blowers, pumps, or electric generators, boilers which provide heat to digester sludge and plant buildings, and fuel for incinerator operation are a few of the possible uses for this derived gas. The gas might also be sold to the natural gas utility.

Treatment of the digester gas presents a key consideration in any utilization scheme. Digester gas contains moisture, particulate matter, hydrogen sulfide, and carbon dioxide in addition to methane. Removal of moisture and particulates is easily accomplished through condensing and sediment methods. This is considered the minimum gas treatment, and is accepted as satisfactory treatment prior to engine or boiler firing, as long as hydrogen sulfide levels aren't excessive. Many plants throughout

the country successfully operate engines, boilers, and incinerators on gas with a hydrogen sulfide content in the 1,000 to 3,000 ppm range (2).

Purification beyond moisture removal adds to the cost of handling the gas, therefore utilization schemes requiring further purification should be avoided. Sale to a natural gas utility is particularly undesirable as it demands that the digester gas be purified to natural gas quality, requiring carbon dioxide removal.

ELECTRIC POWER GENERATION

Even though digester gas fueled engines can power either process blowers, pumps, or generator sets, the engine/generator combination is favored as the power generated can be used throughout the plant rather than being tied to one specific use.

Engine/generators are approximately 32% efficient in their conversion to electrical power. Based on the conversion factor of 3,409 Btu/Kw. Hr., the available electrical energy derivable from one million gallons of plant flow is:

$$6.3 \text{ MBtu/MG} \times 32\% \text{ efficient} \times \frac{1 \text{ Kw. Hr.}}{3{,}409 \text{ Btu}} = 591 \text{ Kw. Hr./MG} \qquad 5$$

ENGINE HEAT RECOVERY

Note that the above 591 Kw. Hr./MG figure is based on utilizing the entire 6.3 MBtu of digester gas produced for electrical power generation. This assumes that the heat necessary to maintain the digester temperature will come from a source other than a digester gas fired boiler.

Heat reclaimed from engine cooling water and exhaust gases can satisfy the digester heat requirements, provided the requirements are held to a minimum. Of the energy expended to generate power, 28% can be reclaimed as heat from engine cooling water with an additional 12% available through exhaust gas reclaimation. Based on one million gallons of flow:

6.3 MBtu/MG x 40% recovery = 2.52 MBtu/MG recoverable 6

Therefore, in order to heat the digester solely on reclaimed heat, the requirements must be held below 2.52 MBtu per 2,000# of solids treated, remembering 1 MG contains 2,000# of solids.

DIGESTER HEAT REQUIREMENTS

Digester heat requirements can be broken down into two components: (3)

1. Heat required to raise the temperature of the incoming raw sludge flow to digester operating temperature.
2. Heat required to maintain the digester operating temperature (make up for radiant heat losses).

Heat Required for Incoming Sludge

The temperature of the incoming sludge is seldom at the operating temperature of the digester and, therefore, heat must be added. The hourly heat demand can be expressed as:

$$Qs = \frac{\text{gal. of sludge}}{\text{day}} \times \frac{8.34 \text{ lbs.}}{\text{gal.}} \times (T_2 - T_1) \times \frac{1 \text{ day}}{\text{hrs.}} \qquad 7$$

Where:

Qs = Btu/hr. required to raise the incoming sludge stream from temperature T_1 to T_2

T_1 = Temperature of incoming sludge stream

T_2 = Temperature desired within the digestion tank

hrs. = Length of time raw sludge is pumped to the digester

Presumably, the digester temperature (T_2) is locked into around 95° F. Little can be done to control the incoming sludge temperature which ranges between 40-55° F., therefore the volume of incoming sludge becomes the crucial factor in reducing the incoming sludge heat requirement.

The length of time in which raw sludge is pumped to the digester presents another point which bears examination. Since the engine supplies reclaimed heat at a constant amount per hour, the digester heat demand should be held as constant as possible. If the hourly heat demand exceeds the hourly supply, the potential of thermal shock to occur in the digester exists, even though the daily demand doesn't exceed the daily supply.

REDUCING SLUDGE VOLUME

As previously stated, a reduction in sludge volume directly reduces the amount of heat required to raise the incoming sludge to the digester operating temperature. Indirectly, a reduction in sludge volume reduces radiant heat loss which occur through the digester vessel, since the vessel size itself is reduces.

The number of pounds of solids to be digested is a direct function of the plant flow (2,000#/MG) and, therefore, the sludge volume (number of gallons) depends upon the concentration of the sludge. The higher the solids concentration, the lower the volume of sludge which must be heated and digested.

Sludge volume (in gallons) can be expressed as:

$$Vs = \frac{\text{\# of solids}}{(8.34\ \text{\#/gal.})(\text{percent solids})} \qquad 8$$

Figure 1 shows the effect higher solids has on sludge volume and required heat. For example, 2,000# at 2% concentration means 12,000 gallons of sludge which requires 5.5 MBtu to raise its temperature from 40° F to the operating temperature of 95°. Note from Equation 6, that only 2.52 MBtu is available through heat reclaiming. In fact, 2,000# of solids only produces 6.3 MBtu (from Equation 4) of heat. Considering the radiant heat loss, very little gas will remain for electric power generation. Comparatively, 2,000# of solids thickened to 6% concentration yield 4,000 gallons of sludge which requires 1.8 MBtu to reach digester temperature. This 66% reduction in volume will also reduce the digester vessel size. Six percent solids concentration should be the minimum concentration sent to the digester if reclaimed engine heat is to satisfy the total demand.

Since the concentration of solids entering the digester is such a critical factor, the type of thickening equipment selected should provide demendable performance. The thickened sludge must alsc, as previously stated, be delivered at a constant rate to reduce the chance of thermal shock. The two most common methods of thickening sludge prior to digestion are by gravity or flotation.

Gravity thickening achieves satisfactory concentration with

straight primary sludge in the range of 5-10% solids. In combination with waste activated sludge, the expected concentration drops to a 4-6% range. (5) Gravity thickener performance is undependable, as the yield concentration depends upon diligent observation throughout withdrawal periods. Sludge withdrawals are performed on a less than continuous bases (in some cases only once or twice a day) and, therefore, cause the hourly heat requirement to exceed the hourly heat supplied, causing the digester to go into thermal shock.

Flotation thickening of the combination of primary and waste activated sludge is particularly well suited prior to digestion. Solids are withdrawn for approximately 15 minutes per hour at a consistant, predictable, concentration. Design concentrations range from 5 to 8 percent with concentrations approaching as high as 10% not uncommon.

Flotation thickening has an added advantage in that it provides for removal of grit from the sludge stream (4). Grit accumulation in the digester reduces the effective volume of the digester, reducing the detention time. In order to restore the original volume, the digester must be dewatered and cleaned, a time consuming and expensive procedure.

RADIANT HEAT LOSSES

Radiant heat loss occurs across the surface of the digester cover, walls, and floor. The heat flow through these surfaces

can be expressed as:

$$Q = A \times (T_2 - T_3) \times U \quad 9$$

Where:

Q = heat loss in Btu/hr.

A = area of material normal to direction of heat flow in sq. ft.

T_2 = temperature desired within the digestion tank

T_3 = temperature outside the surface

U = material heat transfer factor expressed in Btu/hr./sq.ft./°F.

Various values of U for different digester covers, walls and floor construction are given in Table 1.

In making material and construction selections, the durability of the selected arrangement must be considered. The sealed attic space of a steel roof Downes type floating cover provides excellent protection for insulating material such as lightweight concrete. The sealed attic space prevents moisture or freezing from damaging the lightweight concrete. Lightweight concrete has an added advantage in that it increases the static weight of the cover. Polystyrene applied in the attic space also effectively reduces heat losses. However, precautions should be taken to prevent ignition of the material by welding sparks during construction.

Application of insulating materials to surfaces exposed directly to the atmosphere is generally not advisable. Polystyrene applied to roof and protected by built-up roofing material often has its effectiveness reduced when the roofing membrane

is ruptured by foot traffic. Lightweight concrete has experienced cracking problems due to the difference in coefficients of thermo expansion between steel and concrete.

In considering tank wall construction, both brick facing and earthen embankments provide adequate heat retention and should be examined case by case on a cost comparison basis.

GAS STORAGE

Gas production fluctuates hour to hour where the demand for gas (by the engine/generator) remains, in most cases, constant throughout the day. Partially, fluctuations in gas production can be attributed to irregular sludge feeding. However, even with uniform feed rates some fluctuation does exist. Therefore, it is suggested that any engine/generator installation have provisions for gas storage to prevent the wasting of gas during peak production and shortages during low production.

Gas holder covers in most small and medium sized plants provide the most cost effective means of gas storage. The suggested storage capacity of these holders ranges between 6-8 hrs. of average gas production at pressures between 6 and 9" w.c.

In designing gas holder covers, it should be considered that they are less stable than conventional floating covers because they are supported entirely by a cushion of compressible gas rather than incompressible liquid. Additionally, they expose a large side area to lateral wind loads. To prevent tipping or binding, ballast at the bottom of the extended skirt and spiral guides must be provided (5).

High pressure gas storage should be considered when multiple gas holder covers would be required to meet the storage requirement. A typical high pressure system will include a pressurization compressor, a displacement gas holder to control compressor cycling, and a storage vessel, generally a sphere or a horizontal cylinder. Systems operate at pressures from 50 to 200 psi.

GAS SAFETY EQUIPMENT

The successful operation of the engine/generator depends upon safe and dependable delivery of the digester gas. During conveyance, moisture and sediment should be removed. With this in mind, the following design notes are presented:

- All gas lines must be tight, sloped (1/4"/ft.) towards condensate traps or accumulators, have ample capacity, and be protected against freezing.
- Lines leading to gas burners or gas engines must be protected against flashbacks by flame traps. Flame traps should be located near the point of combustion with a maximum allowable distance of 30 from the point of gas combustion.
- Bypasses around devices such as sediment traps, and meters permit access for service and repair. Flame traps should never be bypassed.
- Gas piping should be sized such that flows don't exceed 12 fps which is recommended for successful condensate drainage.

STANDBY HEATING

Digestion systems utilizing reclaimed heat should provide standby heating capabilities for operation during digester start-up or periods in which the engines are down for servicing or repairs. Heating water piping in multiple engine installations should remain segregate to allow quick detection of engine oil leakage to the water. Therefore, individual smaller boilers for each digester are preferred over a single large boiler tied to a manifold line.

Combination boiler and sludge heat exchanger units are provided as a package with the boiler section of the unit supplying heat when required. Controls of the unit detect when the engine water drops below the predetermined temperature, at this point valves close diverting the engine water and the boiler fires as necessary. Figure 2 shows this arrangement in conjunction with the engine heat reclaiming system. The combination boiler and heat exchanger units are preferred over separate units because of the interconnection of these controls and their proven performance operating on digester gas.

ENGINE SELECTION

Spark ignited and dual fuel engines are the most commonly accepted designs for use with digester gas. The spark ignited engine can operate on digester, natural, or liquid propane gas. Special carburetors blend air to the natural or liquid propane gas to lower the Btu value to match that of the digester gas.

A standby fuel supply insures continuous engine operation during periods in which the digester gas fails to meet the

demand. Interruption of engine operation allows the surfaces of the engine to cool below the dew point, resulting in condensation which damages the engine surfaces. With spark ignited engines, natural gas should not be considered as an uninterruptable fuel supply and, therefore, designs should include on-sight storage provisions for liquid propane.

Dual fuel engines operate on digester gas or diesel oil. Dual fuel engines must continuously burn a percentage of diesel oil as a pilot fuel even during digester gas firing, making operation more expensive than with a comparable spark ignited engine.

Selection of the engine should include consideration of the required inlet gas pressure. The digester gas is available at pressures ranging from 5 to 8" w.c. Naturally aspirated feed systems operate successfully at these pressures. Turbo charged feed systems require higher pressures than provided by the digester so the gas is compressed ahead of the turbo charger. Compression causes moisture and oils suspended in the gas to condense in turbo charger, often clogging fuel openings. Because of this condensation problem, engine requiring higher pressures should be avoided.

DESIGN EXAMPLE

Consider a 5 MGD plant.

Assume:

10,000#/day primary and WAS (2,000#/MG)

70% volatile solids

50% volatile solids destruction

15 cu. ft. of gas per pound VS destroyed

17 day detention time

Minimum ambient air temperature 0° F

Minimum ground temperature 40° F

Minimum incoming sludge temperature 40° F

Digester operating temperature 95° F

A comparison will be made between designs using flotation and gravity thickening with mid range values of 6% and 4% respectfully used.

Tank designs incorporating Downes type floating covers with a 1/4" steel roof and 3" lightweight concrete placed in the attic space. Walls will be 12" thick concrete with a 1" air space and 4" brick facing.

SLUDGE VOLUME

Flotation thickening:

$$V = \frac{10{,}000\#/\text{day}}{6\%\ 8.34\#/\text{gal.}}$$

$$= 19{,}984 \text{ gal./day}$$

Gravity thickening:

$$V = \frac{10{,}000\#/\text{day}}{4\%\ 8.34\#/\text{gal.}}$$

$$= 29{,}976 \text{ gal./day}$$

DIGESTER CAPACITY

Flotation thickening:

19,984 gal./day x 17 days detention

= 339,728 gal. (45,418 cu. ft.)

Select a 50' dia. x 23' SWD tank.

Gravity thickening:

29,976 gal./day x 17 days detention

= 509,592 gal. (68,127 cu. ft.)

Select a 60' dia. x 24' SWD tank.

ENERGY AVAILABLE (BOTH CASES)

10,000#/day x 70% VS x 50% destruction x 15 cu. ft./# VS destroyed x 600 Btu/cu. ft.

= 31.5 MBtu/day

= 1.3 MDtu/hr.

ELECTRICAL POWER AVAILABLE (BOTH CASES)

1.3 MBtu/hr. x 32% efficiency x $\frac{1 \text{ kw. hr.}}{3{,}409 \text{ Btu}}$ = 122 Kw. hr./hr.

RECLAIMED HEAT AVAILABLE (BOTH CASES)

1.3 MBtu/hr. x 40% recovery - 520,000 Btu/hr.

HEAT REQUIRED (FLOTATION THICKENING)

Incoming sludge:

19,984 gal./day x $\frac{8.34\#}{\text{gal.}}$ x (95°-40°) x $\frac{1 \text{ day}}{24 \text{ hrs.}}$ = 382,000 Btu/hr.

Cover:

$\frac{(50 \text{ ft.})^2 \pi}{4}$ x (95°-0°) x 0.17 = 31,700 Btu/hr.

Walls:

(50 ft.)π (23 ft.) x (95°-0°) x 0.27 = 92,700 Btu/hr.

Floor:

$\frac{(50 \text{ ft.})^2 \pi}{4}$ x (95°-40°) x 0.06 = 6,500 Btu/hr.

Total:

382,000 + 31,700 + 92,700 + 6,500 = 512,900 Btu/hr.

The total digester heat requirement can be satisfied by the reclaimed engine heat. Note that had the solids concentration been below 6%, the demand would have exceeded the available heat.

HEAT REQUIRED (GRAVITY THICKENING)

Incoming sludge:

$$29{,}976 \text{ gal./day} \times \frac{8.34\#}{\text{gal.}} \times (95°-40°) \times \frac{1 \text{ day}}{24 \text{ hr.}^*} = 573{,}000 \text{ Btu/hr.}$$

*Presuming sludge sent to the digester once an hour.

Cover:

$$\frac{(60 \text{ ft.})^2 \pi}{4} \times (95°-0°) \times 0.17 = 45{,}700 \text{ Btu/hr.}$$

Walls:

$$(60 \text{ ft.}) \pi \ (24 \text{ ft.}) \times (95°-0°) \times 0.27 = 116{,}000 \text{ Btu/hr.}$$

Floor:

$$\frac{(60 \text{ ft.})^2 \pi}{4} \times (95°-40°) \times 0.06 = 37{,}300 \text{ Btu/hr.}$$

Total:

573,000 + 45,700 + 116,000 + 37,300 = 772,000 Btu/hr.

The heat required exceeds the amount provided through heat reclaiming by approximately 50%. The amount of gas sent to the engine must be reduced such that the digester heat demand is met.

CONCLUSION

Incorporation of the presented considerations takes anaerobic digestion from a energy self-sufficient process to net energy producing process. These considerations extend ahead of the digestion phase to the thickening area. The success of an electric power generating design depends upon consistantly high solids concentration delivered to the digester at a uniform rate. Other key factors including engine heat reclaimation, gas storage, and digester tank design play an important role in the success of the design.

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TABLE 1 - "U" FACTORS FOR VARIOUS DIGESTER COVERS, WALLS, AND FLOORS

MATERIAL	U
Fixed Steel Cover (1/4" plate)	0.91
Fixed Concrete Cover (9" thick)	0.58
Floating Cover, Downes type (wood composition roof)	0.33
Floating Cover, Downes type (1/4" steel roof)	0.48
Floating Cover, Downes type (1/4" steel roof with 2" insulating concrete)	0.22
Floating Cover, Downes type (1/4" steel roof with 3" insulating concrete)	0.17
Floating Cover, Downes type (corrugated steel/concrete)	0.32
Concrete Wall (12" thick) exposed to air	0.86
Concrete Wall (12" thick) 1" air space and 4" brick	0.27
Concrete Wall or Floor (12" thick) exposed to wet earth (10' thick)	0.11
Concrete Wall or Floor (12" thick) exposed to dry earth (10' thick)	0.06

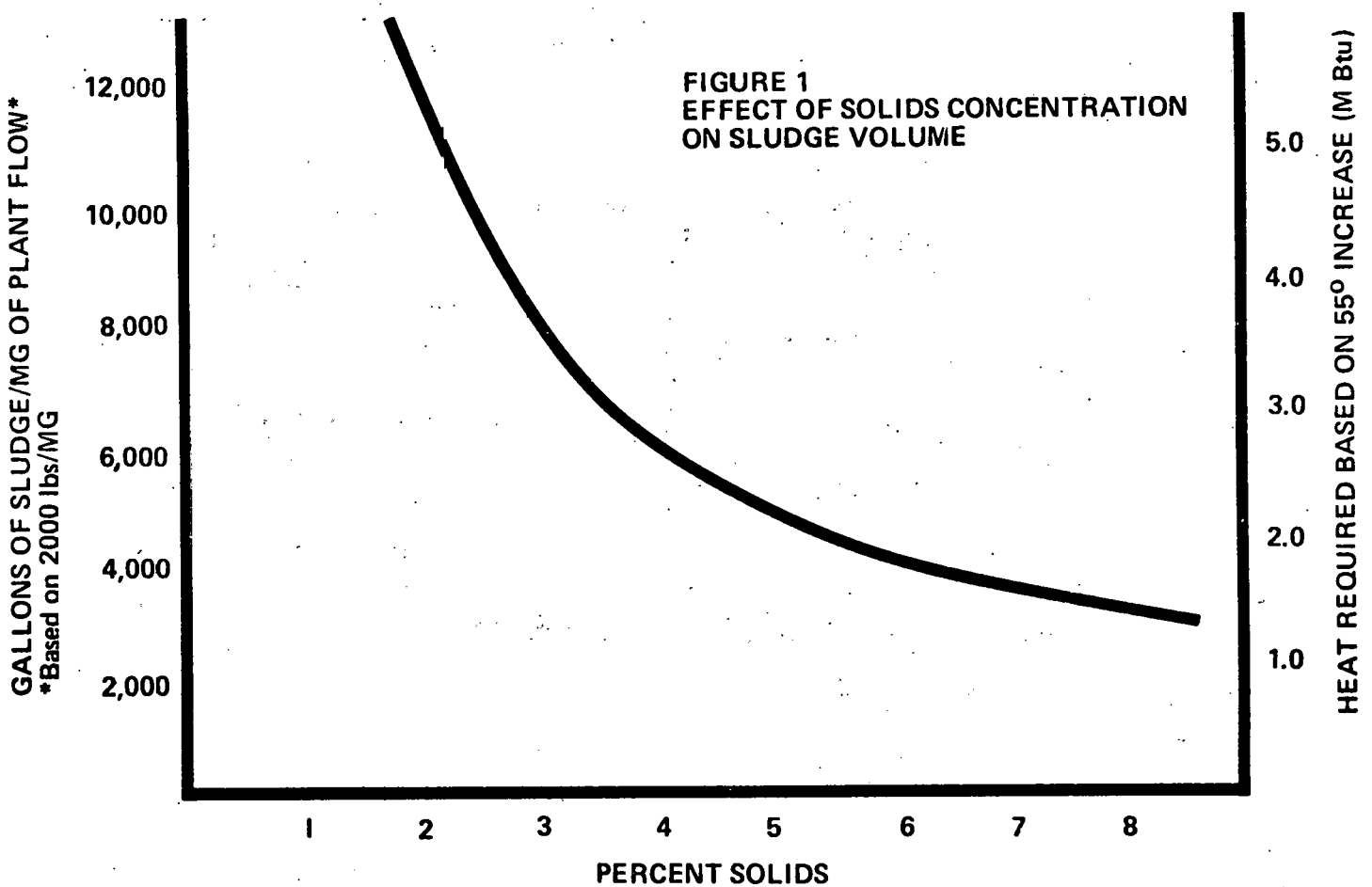
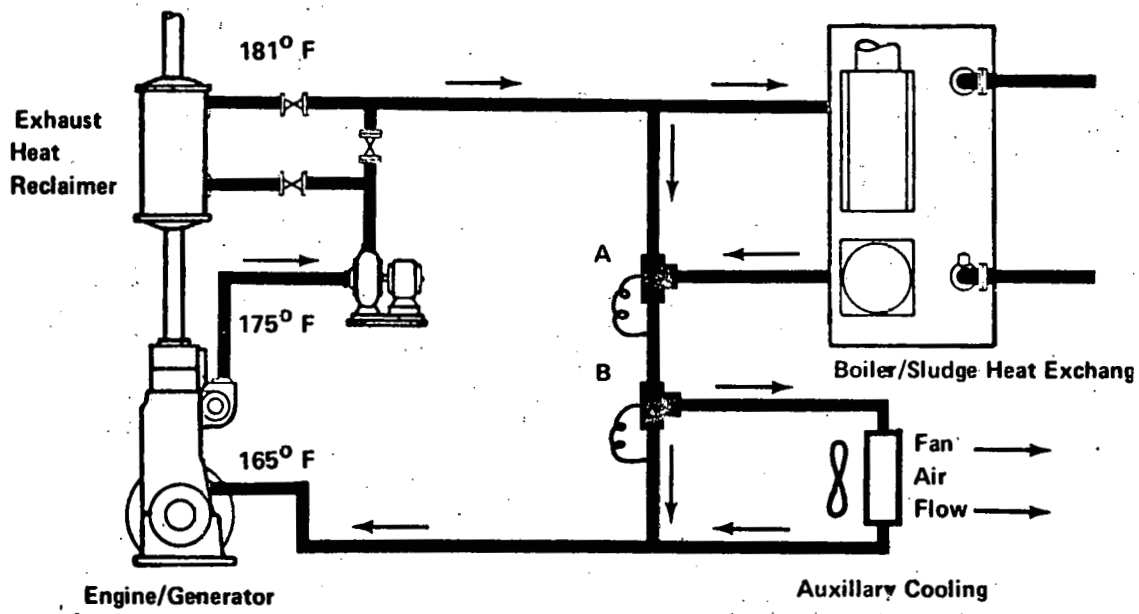


FIGURE 1
EFFECT OF SOLIDS CONCENTRATION
ON SLUDGE VOLUME



FLOW DIAGRAM OF HEAT RECOVERY

Valve A - Three way temperature regulating valve diverts engine water away from the boiler/sludge heat exchanger if temperature drops below set point.

Valve B - Three way temperature regulating valve diverts engine water to auxillary cool if above temperature set point.

SOLAR DRYING OF SLUDGE

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This paper is intended to suggest to the reader that solar energy can play an important part of the design of wastewater treatment facilities as an energy saving strategy and as mitigation of air pollution environmental impacts.

An existing 2 million gallons per day (MGD) activated sludge wastewater treatment facility in the greater Denver Metro Area needs upgrading to provide for an additional 1 MGD of capacity and to nitrify wastewater prior to discharge. The municipality currently hauls wet sludge to a temporary metropolitan landfill. The facilities exist within a populated area having the closest residence about 200 feet away.

The Denver Metropolitan area has been experiencing rapid growth and there are no sludge disposal sites that are politically feasible without being economically prohibitive. Accordingly, disposal of sludge from wastewater treatment facilities needs serious environmental planning.

The facilities recommended by the consulting engineer for the project were on-site incineration of aerobically digested sludge.[1] As is commonly known, Denver's air pollution problem is among the worst in the nation. Accordingly, a process of sludge handling which would not contribute to the existing air problem is needed.

Denver's low humidity and high number of hours of sunlight per year (3,000, tied for fourth in the nation)[2] makes it an attractive candidate for solar sludge drying.

This paper will evaluate a method of sludge handling which would provide a beneficial use of the sludge as well as conserve energy.

In order to provide for a beneficial use of the sludge as a soil conditioner, it is necessary to reduce the moisture content to no greater than 10% by weight. Heat drying has been used as a successful process for preparation of sludges for reuse programs in several facilities throughout the nation. It is therefore the selected drying process for this paper.

Conventional heat drying using fossil fuel will be compared with heat drying using solar energy during the remainder of this paper.

The heat drying process would be integrated with the solar panel drying process such as the one in Decatur, Alabama.

> Gold Kist's huge soy plant at Decatur, AL, processes 2500 tons of soybeans/day for oil production, and consumes about 1.3 million gallons of fuel oil annually, most of it for drying beans. The beans are dried in two steps. First, when they come in from the fields, the moisture content is reduced from about 15% to 12% moisture, which is suitable for storage up to one year. Then the beans are dried to about 9% moisture just before pressing. Three huge dryers heat incoming air to 180 F for drying. Because energy costs are such a major cost of operating the plant, a savings of even a few percent is significant.
>
> Practically, early in the morning the sun energy being collected reaches temperatures about 10 degrees above the ambient air. Since electric energy to the blower is a major factor of operating cost, this is the point of beginning profitable operation. The 3,000 cfm capacity fans are turned on, a positive-pressure system prevents in-leakage to the collectors, and all the hot air in the system moves through to the dryer building.

> Air is heated in the collector in 3 air channels underneath the porcelain enamal-coated steel absorber plates. The air, which can reach 180 F is transferred by a thermal manifolding in the collectors to the hot air ducts supplying heated air to the bean dryers. In order to balance the airflow, the duct dimensions range from 48" x 48" down to 24" x 24".
>
> All collector modules are airtight because silicon gaskets on the collector manifold ports prevent air leaks from collector to collector. Insulation of 2" fiberglass protects the hot-side duct work of 26-ga sheet metal from heat loss. All heated air is blown into the dryer house, where it is entrained with sufficient ambient air to fire the total dryer system--each dryer of which operates at 150,000 cfm.
>
> While this demonstration installation produces about 10,400,000 BTUs per day (each panel produces 800 BTU/sq. ft/day)--the scale is large enough to be a realistic plant-sized study. The solar collection system replaces the use of 28,000 gallons of fuel oil per year.[3]

The heat energy is to be generated by solar panels having a hot air flow rate of 1 cfm within the panel collector.

Based upon existing operation data, the proposed 3 MGD facility is expected to generate about 3,026 lbs/day of sludge at 1.5% solids. This translated into 552.2 tons/year solids. A filter press will provide for an increase to 30% solids. The sludge then needs to be dried to at least 90% solids to be marketable.

The amount of solar drying facilities must be determined. This is accomplished by the solving of two independent problems. The first is the amount of moisture which needs to be removed and the second is the amount of solar facilities needed to provide the heat required.

In order to determine the amount of moisture which needs to be removed the relative hunidity (effective evaporation rate) needs to be considered. The sludge effective evaporation rate can be considered a linear relationship of effective evaporation up to about 50% solids.[4] Higher rates of moisture removal in sludges is not linear. In fact, the rate is anticipated to become asymptotic.

The amount of energy needed to dry sludge for the 30% to the 90% dry state can be estimated from existing data generated from heat drying equipment in Maryland.[5]

An adjustment was made for effective evaporation rate and a linear relationship was assumed (please note that as per above this is an extremely liberal assumption). The data gained for the heat treatment facility was adjusted by 25%.[6] Using the adjusted data for a graph which is highest to a 90% dry solids product indicates that a minimum of about 4.4 billion BTUs/year are required.

A computer model was used to provide the amount of energy available by sunlight in the Denver area. Denver averages 1969 BTUs/ft^2/day. This would provide 716,000 BTU/ft^2/year at 100% efficiency. Solar facilities are less efficient as a function of their surface area requirement.[7] For a facility of this size an estimated 50% efficiency (incidental heat loss) rating is used. 14,400 ft^2 of surface area would generate a maximum of 5.1 billion BTUs/year.

This is 0.7 billion BTUs/day greater than the energy required to adequately dry the sludge.

The cost-effective analysis is shown below:

Project period = 20 years

INCINERATION

Capital	$ 690,000
PW of O&M	$ 738,100
Total percent worth (PW)	$1,428,100[8]

CONVENTIONAL HEAR DRYING (Fossil Fuel)

Capital	$430,000[9]
PW of O&M	$153,184[10]
Total PW	$583,184

SOLAR DRYING

Capital	$597,000[11]
PW O&M	$ 74,900[12]
Total PW	$671,900

PW EXPANSION OF $3,838,490[13]

Heat Drying		Solar Drying
$3,818,490		$3,818,490
$ 583,154		$ 671,900
$4,401,644	(Total of PW's)	$4,490,390

$4,401,644 x 115% = $5,061,890

If solar is within 115% of the least cost project, according to EPA regulations on innovative and alternative technology, it can be considered cost-effective. Therefore, in this case, solar drying can be considered cost-effective by EPA.

An energy savings criteria is used to determine if a process would qualify for a 10% bonus in grant funding as "innovative" technology. Again, according to EPA regulations, the process must save at least 20% of the total energy requirement when evaluated over the life of the project.

PW of energy requirement for activated sludge with solar drying	$130,500[14,15]
PW of energy requirement for activated sludge with heat drying using fossil fuel	$22,000[14,15]

As shown, the solar may realize a 59% savings of overall energy costs. Since the project is innovative by EPA regulations it is considered cost-effective. Since it qualifies for the extra 10% the capital costs will be funded at the 85% level instead of the 75% level as in the conventional process. It should be noted that operaton and maintenance costs are funded solely by the treatment works owner.

As one can readily see, solar sources of energy can be made use of in the design of wastewater treatment facilities and in the case of Denver, Colorado, when EPA funds are used, it is extremely attractive.

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THE DESIGN OF AERATION SYSTEMS IN AN ENERGY EFFICIENT MANNER

E.L. Barnhart
W.W. Chiang

Environmental Engineering and the design of waste treatment facilities has evolved from Civil Engineering and, as such, has inherited the conservative manner of design. This conservativism is viewed as being protective of public expehditures by employing proven technology rather than becoming involved in experimental or questionable projects at public expense. Historically, this approach has been successful in such areas as bridge building, road construction, public building erection and the like in protecting public investment to the highest degree possible. There are areas, however, where such conservative approaches tend to work to the disadvantage of the public rather than its advantage. The choice of aeration equipment in sewage treatment is a perfect example of this case.

Historically, treatment plants have been designed with considerations of capital costs and ease of maintenance as the principle objectives. The operating costs, particularly of energy, have been considered to be a minor factor in the overall expense. In the last few years the increasing cost of energy has changed this situation dramatically. Future energy costs are likely to distort historic thinking even more. It is necessary then that the field rapidly evolve to the new realities rather than moving in the slow manner that the conservativism would indicate.

This paper will not delve in any depth into the theory of oxygen transfer. However, for explanatory purposes consider Equation 1.

$$K_L a = K_L \frac{A}{V} \qquad (1)$$

In this equation, $K_L a$ is the mass transfer coefficient; that is, a comparison of the overall transfer efficiency of the system, K_L is the liquid film coefficient generally described as a function of the chemical composition of the fluid, A is the surface area available for transfer and V is the volume of the liquid being aerated.

Diffused Aeration Systems

The majority of oxygen transfer systems involve the diffusion of air bubbles into the liquid to be aerated. "A" expressed in Equation 1 is therefore equal to the total area of bubble surface available in the tank plus the surface of the tank (which is small by comparison) and V is the total volume of the system. Figure 1 shows a typical aeration tank. Considering the physical situation, it is obvious that more efficient oxygen transfer can be achieved either by having more small bubbles, or having a longer time of contact or by having a deeper tank.

Examining historic practice, we find that the typical water depth is approximately 15 feet and relatively coarse bubbles are diffused into the tank. The overall transfer efficiency of an operating bubble system usually ranges between six and ten percent; that is, less than ten percent of the oxygen put into the tank is actually made available for the treatment process. By comparison, if a deeper tank with smaller bubbles were employed, oxygen transfer as high as 25 to 30 percent could be achieved. Why then is the lower efficiency tolerated? First, because practice has used rotary-type or centrifugal-type blowers which have their optimum delivery efficiency at 8-9 psi. If one then considers losses in transmitting the air to be in the order of 1 psi and diffusal losses in the order of 0.5 psi, the remaining 6.5 to 7.5 psi indicate a water depth not to exceed 16 feet. This thinking viewed the ease of operation and maintenance as of prime importance. This type of blower required minimum air cleaning and was a highly mechanically stable system. As a result, aeration tanks have generally been standardized with approximately 16 feet of side water depth and equipment designed for diffused air systems are most available for this particular depth.

Considerations of the size of bubbles are also of major importance. Clearly, the finer the media through which the air is diffused into the tank the finer the bubbles. However, fine media requires air of high quality to avoid plugging. It is important to note that contrary to certain indications virtually all plugging of air diffusers occurs from the inside out and is a function of the air quality not the quality of the liquid being treated. There are exceptions to this, but they generally occur in corrosive or chemically-complex industrial wastes. The use of small pore diameter diffusers has been continuously debated in the field. The use of such

systems presents an ongoing maintenance problem. By and large, designers have chosen to use large orifice diffusion systems that require less maintenance rather than attempting to capitalize on improved oxygen transfer efficiency with smaller bubbles.

The combination of these ideas has become inculcated in design standards to the point where people have lost sight of the design alternatives.

A wide variety of industrial applications clearly demonstrate that depth of tank is not a major design consideration. Air compression systems to provide high volumes of clean air can be easily devised with the mechanical equipment available today. Tank depths up to 40 feet have been used successfully in the pharmaceutical and other industries with oxygen transfer efficiencies approaching 50 and 60 percent being realized. Further, certain downdraft systems such as "deep shaft" process accomplished similar transfer efficiencies by providing extremely long route of bubble contact. The possibility for enhanced efficiency through depth or geometry variations are as open as the designer's imagination will permit.

A similar statement can be made with regard to diffusion devices. The problem of plugging first can be overcome by air filtration and electro-precipitation. This art has improved dramatically in recent years, but even more open are the possibilities for improved diffusion systems. Simple devices such as nylon sacks, covering coarse diffusers dramatically increase oxygen transfer efficiency. Static mixers or sheer devices have similar effects.

Mechanical Aeration Systems

A typical mechanical aerator is pictured in Figure 2. In a mechanical system, the water surface is exposed to the atmosphere by a mechanical pumping action. The rotor may either be a slow speed device which essentially induces a wave action, an intermediate speed device which combines wave action and sheer forces or a high speed device where sheer and actual droplet formation takes place. These devices as currently applied are more energy efficient than popular diffused aeration systems. By comparison, diffused aeration systems normally deliver one to two pounds of oxygen per Hp-hour where mechanical aeration systems are in the range of 2 to 3.5 pounds of oxygen per Hp-hour.

Mechanical aeration devices are, however, quite sensitive to the geometry in which they are installed. The use of traditional 16 feet deep, 32 feet wide, plug flow-type tanks severely restricts the types of mechanical aeration devices which may be satisfactorily applied.

The further limitation of mechanical devices occurs in their use as mixers as well as aerators. It must be recognized that in a typical aeration tank, the aerator is needed not only to oxygenate the liquid but also to provide the mixing that is essential for good biological activity. When a single device must meet both these demands, it is often truely optimum for neither condition. An aerator cannot be turned off during periods when oxygen demand is minimal if turning the device off results in sedimentation. Equally, if a high level of oxygenation is required, the mixing and consequently the sheer may have to be beyond that range which promotes the best sludge characteristics. Simplicity of design and minimization of maintenance has strongly encouraged the use of devices that are subject to this limitation. However, the upcoming higher energy cost will provide the incentive to consider the design of mixing and oxygenation devices separately in order to minimize the total treatment cost.

Turbine Aeration

Turbine aeration systems that combine both diffused air injection and mechanical agitation have been widely used in the process industries to obtain higher degrees of oxygen transfer and better overall efficiency. Such units have had only limited application in Environmental Engineering, however, since the geometry limitation discussed above limit their applicability.

In a turbine system, the problems associated with bubble size are overcome by introducing the air from large orifices under a rotary blade. The blade sheers the bubbles into small size so that the effect of a high surface area is achieved without the inherent potential of clogging. The top blade in a turbine system such as that pictured in Figure 3 tends both to agitate the surface and to create a circulating motion within the tank. The net effect is to prolong the time of contact between the bubbles and the liquid while also inducing surface aeration. If the system is properly designed, it can be utilized in three operating phases.

If both the air and the turbine system are used simultaneously, the highest degree of oxygenation and mixing can be obtained. The diffuser can be used alone in certain minimum situations with intermittent operations of the turbine to prevent sedimentation or, in extended cases of low oxygen demand, the turbine can be used without the air system. Design to allow this flexibility includes the use of variable speed motor on the turbine assembly and specific design of the diffuser system to function under a variety of conditions.

Discussion of Aeration Systems

The information presented above interpreted in view of today's changing economics suggests a complete rethinking of the design basis particularly with respect to tank geometry. Increasing the tank depth by perhaps 25 percent should allow for almost a doubling of oxygen transfer efficiency. Tailoring the shape of the tank to induce flow patterns that will effect longer content between the bubble and the liquid would also be highly productive in terms of increasing oxygen transfer.

Air delivery systems and air cleaning devices that allow the use of air under higher pressures have been perfected to the point where delivery of clean air to small orifice diffusers is quite practical.

The major concern, however, still must be the overall economics of the system. Figure 1 presents an approximation of the annual energy costs for aeration at various plant sites. Note that at the 10 MGD only $60,000 a year of costs are associated with aeration. Although this is up three times in the last ten years, this still does not provide a substantial amount of money when converted to a justifiable capital investment. If conventional economics are used, a four-to-five year pay of such investment would appear appropriate -- allowing $300,000 for investment. In the larger plant, clearly at the 50 or 100 MGD level, the capital that can be invested is sufficient to make major changes in the aeration system to achieve the economy. As in all cases, a detailed engineering study should be conducted on a case-by-case basis to determine the degree of improved efficiency that is justified based on particular capital outlays.

OTHER POSSIBLE APPROACHES TO THE PROBLEM

An alternate to improving the absolute efficiency of aeration is to change the method of aeration itself or to change the demand pattern of the waste to enhance efficiency aeration. Either or both approaches may be appropriate in particular situations.

DRIVING FORCE

Examination of the theory of oxygen transfer clearly indicates that the total pounds of oxygen transfer per hour are proportional to the $K_L a$ multiplied by the driving force, that is (Cs - Ct) where Cs is the oxygen saturation at a given temperature and Ct is the oxygen concentration in the tank. For a liquid at about 25°C, the driving force is 50 percent greater if oxygen is transferred against a dissolved oxygen level 2 mg/l rather than 4 mg/l. A design that keeps the dissolved oxygen level low during the majority of the treatment time is substantially more efficient than where the oxygen is allowed to rise to higher levels. The practice of over-aeration has gradually crept into practice because of the design of "total oxidation" systems. These systems were designed to totally oxidize to the highest degree possible the sludge produced as a byproduct of biological reaction. Here again, an evaluation of the efficacy of such design need be introduced. In today's technology it is likely that we are moving toward incineration or other sophisticated disposal of solids. The energy consumed for "total oxidation" is therefore quite questionable. In fact, it can be shown that in many cases over oxidation of solids leads to a decrease in sludge dewatering characteristics. This relationship is shown schematically in Figure 5. Design of systems to accomplish only that oxygenation which is required for biological activity and the transfer oxygen at the maximum driving force can conserve up to 50 percent of the oxygen horsepower employed in a small plant. Results are usually less dramatic in larger systems.

OTHER CONSIDERATIONS

In specialized cases, such design variations as including equalization before the aeration basin recirculation, step feeding of waste and the like are also helpful to the designer in minimizing oxygen requirements. Also in special cases, such devices as rotary contactors may cut down on oxygen

horsepower requirements. These cases, however, are not in the norm and would usually not be economical even in view of today's changing energy picture.

SUMMARY

In summary then, if one sets aside the historic myths associated with oxygen transfer, systems can be developed which will greatly reduce the overall horsepower requirements while providing necessary aeration in biological treatment. The changing energy costs provide both the designer and the equipment manufacturer with a good reason to re-examine historic trends and to utilize these more energy efficient systems.

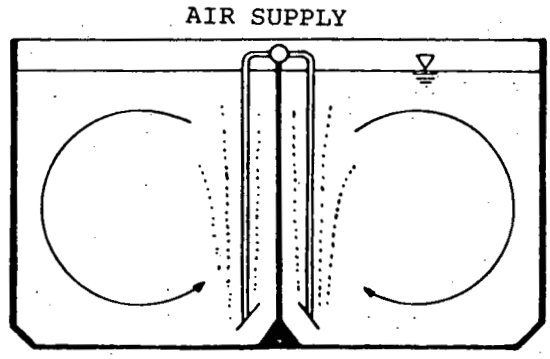


FIGURE 1 DIFFUSED AIR SYSTEM

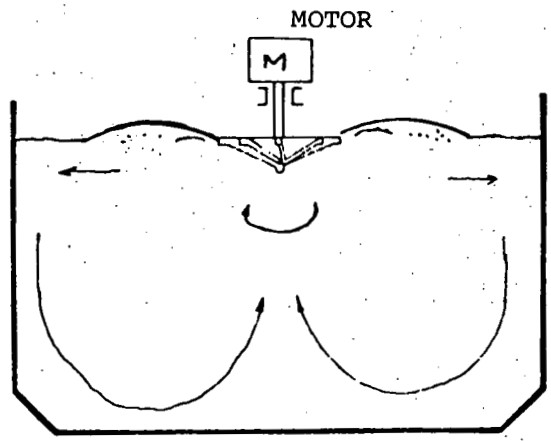


FIGURE 2 MECHANICAL AERATION SYSTEM

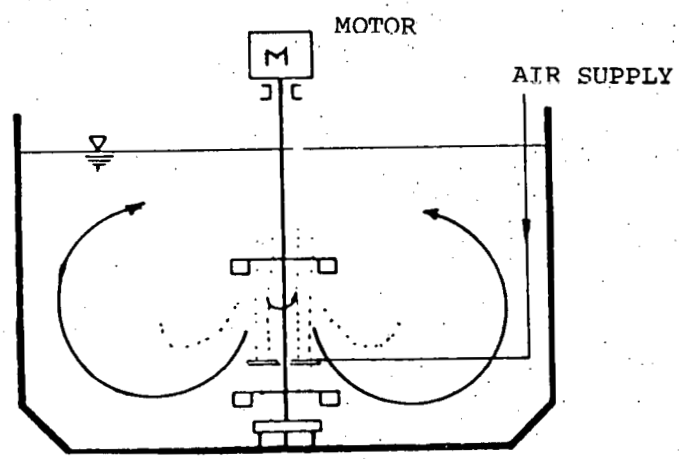


FIGURE 3 TURBINE AERATION SYSTEM

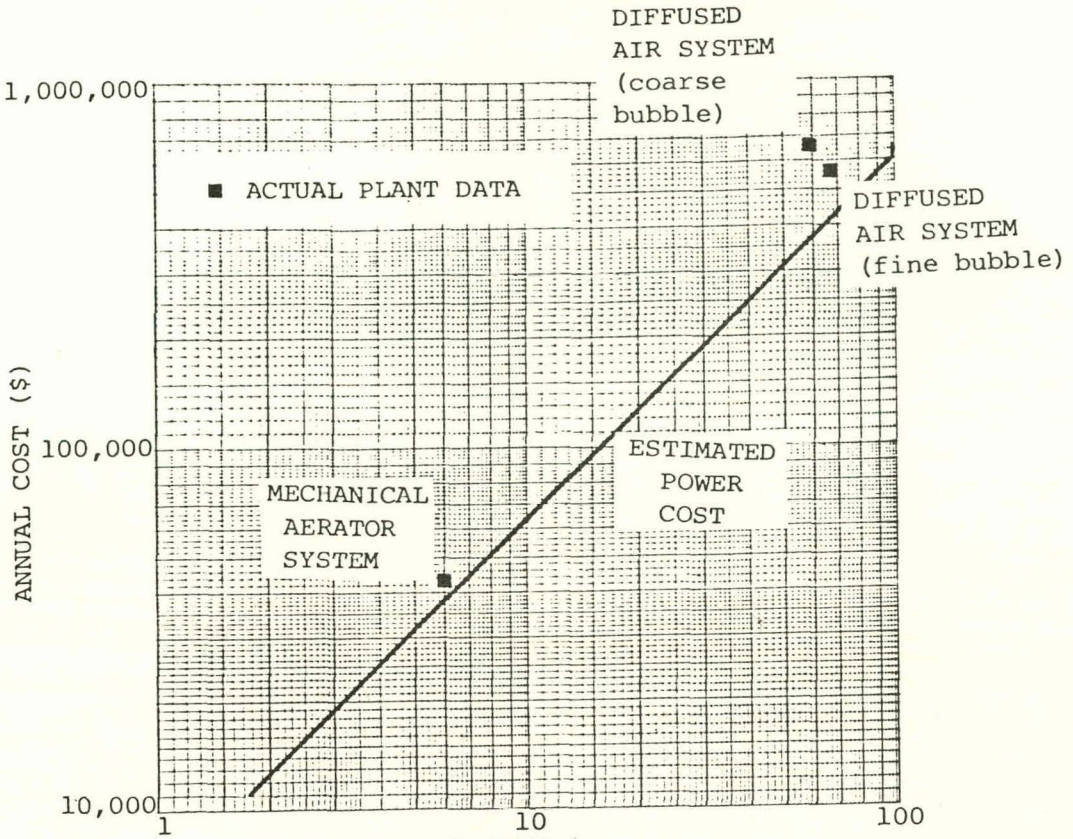


FIGURE 4
ANNUAL ENERGY COST OF AERATION

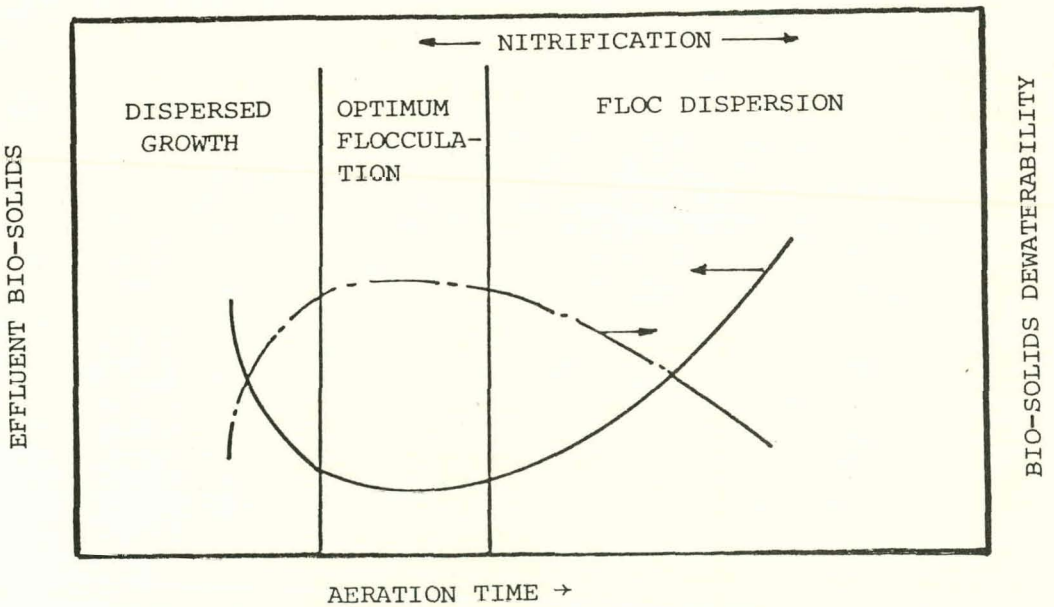


FIGURE 5 AERATION TIME VS DEWATER CHARACTERISTICS

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COST AND ENERGY EFFECTIVENESS OF WASTEWATER FILTERS

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INTRODUCTION

One criterion used in selecting a wastewater filtration process is the relative cost effectiveness of the various alternatives available. Cost effectiveness is defined by the U.S. Environmental Protection Agency (EPA) as the life-cycle costs including costs of equipment, construction, maintenance and repairs and operation. For consistency, EPA requires a comparison for a 20-yr operating life at a 6-7/8% discount rate (1). A critical factor affecting cost-effectiveness, and one that is becoming of considerable importance, is the energy consumption, both for construction and for operation. The purpose of this paper is to assess factors contributing to the life-cycle cost and energy consumption of wastewater filters and to identify design and operating changes that will reduce both costs and energy consumption.

TYPES OF WASTEWATER FILTERS

Granular media filters generally are characterized by their bed depth, their bed configuration, their mode of operation, and their backwash method. Filters with bed depths less than about 18 inches usually are considered to be shallow-bed filters. The media used in shallow-bed filters usually consists of sand alone having an effective size (E.S.) of 0.5 to 0.6 mm. Such small grain sizes are necessary to prevent rapid breakthrough of solids and to permit backwash at nominal rates of 10 to 20 gallons per minute per square foot (gpm/sq ft).

Conventional filters contain bed depths ranging from about 18 to 36 inches. Filters with greater bed-depth generally are labeled as deep-bed filters. Multi-media filter beds consist of 2 to 4 layers of media of different specific gravities. Dual-media filters usually contain anthracite coal (specific gravity=1.6 to 1.7) no larger than about 1.0 to 1.2 mm E.S. overlying a layer of 0.5 to 0.6 mm E.S. sand (S.G.=2.65). Tri-media filters use about the same size coal and sand as in dual-media filters but contain a third layer of high density illmenite or garnet sand (S.G.=4.0-4.6) beneath the silica sand. Some multiple-media filters may contain a fourth upper layer of low-density coal (S.G.=1.3 to 1.4).

Most conventional filters in the U.S. can be considered to be stratified-bed filters. This includes both shallow-bed and deep-bed configurations. Backwash of stratified-bed filters involves washing at water rates sufficient to fluidize and expand the media. The backwash rate needed to fluidize and restratify depends on the media type and grain size. Use of anthracite coal media larger than about 1.2 mm E.S. or silica sand larger than about 0.8 mm E.S. requires such high backwash rates that expansion becomes impractical. Chlorination of the influent wastewater or frequent super-chlorination of the backwash water usually is required to prevent biological growths from fouling the media (2).

Another design coming into common use is the unstratified-bed, single-media filter (3). These filters are backwashed by passing air and water simultaneously through the bed. The air causes vigorous scouring thereby loosening entrapped solids from the media grains, and the water flushes these solids from the filter. Backwash rates are below fluidization; consequently, larger media grain sizes can be used than in conventional multiple-media filters. This produces longer filter run lengths, and backwashing is needed less frequently. The vigorous scouring action produced during backwash is sufficient to clean the filter bed without the need for chlorination (2).

COSTS AND ENERGY CONSUMPTION

Factors affecting costs and energy consumption of filtration systems generally can be broken into four major categories: 1) construction, 2) repairs and replacement, 3) labor and 4) operation. These categories will be examined separately to determine their contribution to overall cost and energy effectiveness.

Construction Costs

Construction costs include items such as design and administration, equipment purchased from suppliers, installation including concrete and steel used for erection, mechanized facilities such as piping, pumps, air blowers, electrical facilities including monitoring and control equipment and start-up costs. In general, unit construction costs reported for filtration systems show considerable variation (4). However, on a given job, construction bids usually show no major favoritism for a particular filtration process. Therefore, it seems reasonable to assume that, for a given installation, the total construction cost per square foot of filter area will be equal for all reason-

able alternative processes. This assumes that requisite subsystems, such as chemical feeders, chlorination facilities, etc. are included with each alternative.

Recent reports by EPA give the following equation for wastewater filter process construction costs (4):

$$C = (2.3 \times 10^5)\, Q^{0.84}, \text{ mill. } \$ \qquad (1)$$

where Q equals the average design flow rate in million gallons per day (MGD). [Note: This equation and all subsequent cost items are adjusted to a second-quarter 1979 cost base using EPA and ENR cost indices (4,5)].

A multiplier of $(5/q_p)^{0.84}$ is recommended by the author to adjust costs for filters having different design filtration rates. This adjustment becomes necessary because some alternatives, particularly some of the shallow-bed filters, are limited in peak filtration rate capacity to 3 to 4 gpm/sq ft whereas conventional and deep-bed filters, with their larger filter media, can be operated at much higher peak rates. The numeral 5 represents the peak filtration rate commonly permitted with one unit out of serve for repairs, service or backwash; q_p is the peak filtration rate in gpm/sq ft.

This capital cost can be expressed in energy terms by using a method suggested by Mills and Tchobanoglous (6) in which a primary energy intensity of 21,800 BTU/$ of construction costs was reported for water supply, sewerage and public utilities. The primary energy equivalent reported for electrical energy production was 13,200 BTU/KWH so that

$$PE = 1.65 \text{ KWH/\$ construction costs} \qquad (2)$$

and at \$0.05/KWH delivered electrical energy cost, this suggests that 1.65 KWH/\$ x 0.05 \$/KWH, or 8.25% of the construction cost of a facility is for primary energy (in electrical energy cost equivalent).

Repairs and Replacements

Costs for repairs and replacements are impossible to predict accurately, but a present value equivalent expressed as a percentage of the present value of the construction cost often is used. For this paper a repair and replacement cost of 5% of the construction cost will be used.

Labor for Operation

Generally labor should be fairly constant for each alternative considered

for a given filter installation. For this paper, labor costs will be estimated at 3% of the annualized construction costs. This represents about 0.25 man years at $15,000 per year for a 10 MGD filtration system.

Operating Costs

Non-labor operating costs for items such as power and chemicals represent a major source of differences between filter alternatives. Individual cost and energy items include

- Influent and backwash water pumping
- Air pumping (if air wash is used)
- Chemicals
- Return and treatment of backwash water.

Pumping Energy and Costs

Pumping energy can be calculated as follows:

$$E_p = 4.51\ Q\ H\ T_p,\ \text{KWH/day} \qquad (3)$$

where: Q = pumping rate, MGD

H = pumping head, ft

T_p = fractional time that pumps are operated.

The coefficient (4.51) includes an overall pump efficiency (wire to water) of 60%, and the term, T_p, permits adjustment for non-continuous pumping activities, such as for backwashing. The primary energy factor for electrical power is 3.87 KWH P.E./KWH of consumption (6).

Air Pumping (For Backwash)

Energy consumption for air pumping during backwash can be calculated using the following equation:

$$E_a = (4.1 \times 10^{-4})\ q_a\ A\ T_a\ N_B,\ \text{KWH/day} \qquad (4)$$

where: q_a = backwash air rate, scfm/sq ft

A = total filter area, sq ft

T_a = duration of air wash per filter cell

N_B = number of backwashes per day per cell

The coefficient 4.1×10^{-4} is based on an average blower capacity of 30 scfm/HP. This coefficient will vary somewhat with different filter systems because of the different input pressures, temperatures, and blower efficiencies.

Chlorine

Chlorine costs, C_c, can be expressed as follows:

$$C_c = 8.33\ Q\ C\ P_c,\ \$/day \quad (5)$$

where: C = chemical dose , mg/l

P_c = price of chemical, \$/lb

Energy consumption for operating chlorinators can be expressed as:

$$E_c = 8.33\ Q\ C\ O_c,\ KWH/day \quad (6)$$

where O_c is the unit energy demand for operating chlorination equipment and is reported to average 0.0396 KWH/lb (6).

The primary energy equivalent of chlorination, PE_c, depends on the amount of energy needed to produce and transport the chemical and can be calculated using the following equation:

$$PE_c = 8.33\ Q\ C\ f_c,\ KWH/day \quad (7)$$

where: f_c = the primary electrical energy equivalent for chlorine, KWH/lb. A value of 2.65 KWH/lb has been reported for f_c for gaseous chlorine and will be used for calculations presented in this paper (6).

Backwash Water Return

When a filter is backwashed, the dirty water usually is returned to the upstream treatment plant. This water must be repumped and retreated and will require increased chemical dosages as well as reducing hydraulic capacity of the upstream unit treatment processes by the amount of backwash water returned. The cost of this return and retreatment, C_{BT}, is difficult to assess accurately; but for the purposes of this paper, the following equation will be used.

$$C_{BT} = (1 \times 10^{-3})\ q_b\ A\ T_b\ N_b\ P_w,\ \$/day \quad (8)$$

where: q_b = backwash rate, gpm/sq ft

A = total filter area, sq ft

T_b = duration of water wash filter cell, min

N_b = number of backwashes per day per filter cell

P_w = cost of backwash water retreatment, \$/1000 gal.

The primary energy value of this retreatment will be calculated by assuming that 25% of the cost is for power as is typical of activated sludge plants (7). This gives no allowance for increased overall plant size to accomodate

this retreatment or for additional operating costs of the treatment processes upstream of the filters. Knowledge of the construction and operating costs of the upstream process would be required in order to more accurately calculate the primary energy for retreatment.

EXAMPLE CALCULATION

Typical conventional filter designs will be used to illustrate the relative significance of each of the above cost and energy demand items. Design and operating criteria for three commonly used filter systems--multiple media, stratified-bed filters, single-media unstratified-bed filters and shallow-bed filters--are listed in Table 1 for a design wastewater flow rate of 10 MGD. Specific costs and energy demands were calculated for the multiple-media stratified-bed filter using Equations 1 through 8. Results of these calculations are presented in Table 2.

Table 1. Design and operating parameters for three commonly used wastewater filter alternatives.

Design & Operating Parameter	Filter Process Alternative		
	Single-media Unstratified-bed	Multiple-media Stratified-bed	Shallow-bed
1. Design flow rate; Q, MGD	10	10	10
2. Filter area; A, sq ft	3500	3500	4670
3. Average filtration rate; q, gpm/sq ft	2	2	1.5
4. Peak filtration rate; q_p, gpm/sq ft	5	5	3.75
5. Backwash rate; q_p, gpm/sq ft	10	20	10
6. Airwash rate; q_a, scfm/sq ft	4 (8 min)	4 (3 min)	-
7. Number of cells; N	16	16	16
8. Total backwash rate; Q_b, MGD	3.15	6.3	4.2
9. Backwash duration; T_b, min	10	7	4
10. Number of backwashes per cell per day; N_B	1	1.5	3
11. Chlorine dose; C, mg/l	0	4	4
12. Chlorine cost; P_c, $/lb	0.20	0.20	0.20
13. Influent pumping head; H_i, ft	10	10	10
14. Backwash pumping head; H_b, ft	20	20	20
15. Backwash return; %	3.5	7.35	5.6
16. Cost of backwash water retreatment; $/MG	250	250	250

Table 2. Cost and energy analysis for the 10 MGD multiple-media, stratified-bed filter described in Table 1.

Cost or Energy Item	Present Value,[a] $	Daily Cost $/day	Daily Cost % of Total	Operating Energy KWH/day	Operating Energy % of Total	Primary Energy KWH/day	Primary Energy % of Total
Construction	1,591,211	407.27	56.3	-	-	360[c]	5.0
Repairs & Replacement	79,560	20.36	2.8	-	-	18[c]	0.3
Labor for Operation	47,736	12.22	1.7	-	-	-	-
Operation:							
Influent Pumping[b]	94,662	24.23	3.35	484.2	32.1	1874	26.1
Backwash Pumping	12,952	3.32	0.5	66.3	4.4	257	3.6
Air Pumping[b]	5,046	1.29	0.2	25.8	1.7	100	1.4
Chlorination	279,499	71.54	9.9	14.2	0.9	1003	14.0
Backwash water retreatment	717,911	183.75	25.4	918.8[d]	60.9	3556	49.6
TOTALS	2,828,577	723.98	-	1509	-	7168	-

[a]Present value factor=3907 at 6-7/8% discount rate, 20 yr. life.
[b]Includes 7.35% backwash water return.
[c]Primary energy for construction only averaged over 20 years, all others using 3.87 KWH/KWH.
[d]This assumes that 25% of retreatment costs is for energy.

DISCUSSION AND CONCLUSIONS

The analysis of filter costs and energy consumption presented in Table 2 reveals some significant aspects of filter design and operation. The major cost item is construction. The most likely method of reducing construction costs is to reduce filter size, and this can best be accomplished by increasing net filtration rates. For example, increasing peak design rates to 10 gpm/sq ft can reduce construction costs as much as 44%. The use of increased filtration rates to take advantage of cost and energy savings will require a change in design practices permitted by most state pollution control agencies and used by engineers because present practice normally limits peak filtration rates to about 5 gpm/sq ft.

The second most costly item is backwash water retreatment, and the most effective method of reducing this cost is to use filter designs providing long filter runs and low backwash water return ratios. For example, the single-media unstratified-bed filter described in Table 1 reduces backwash water return from 7.35% to 3.5%. This reduces costs associated with backwash water retreatment from $184/day to $88/day or a factor of 2.1. Shallow-bed filters also show reduced backwash water use but usually only when operated at relatively low filtration rates. As with increased filtration rates, the overall

advantages of using lower backwash rates--such as reduced pump, piping, valve and gallery sizes, as well as reduced backwash water recirculation--will require state pollution control agencies and engineers to change traditional practices that are occassionally applied rigidly. For example, many states require that filters have the capability of being backwashed at 20 to 25 gpm/sq ft. This causes sizes of filter appurtenances--and the associated costs--to be greater than necessary for satisfactory operation.

The third most costly item is chlorination to prevent fouling of the filter media by biological growth. Chlorine use for such purposes can only be reduced by using filter systems that effectively clean the filter bed without chlorination. Each mg/l reduction in chlorine use will reduce total costs by about 2.5% and primary energy use by about 3.5%.

Energy consumption for filter operation can be reduced most effectively by reducing influent and backwash pumping. Influent pumping usually is fixed by design hydraulics and will be essentially the same for all filter alternatives. Gravity filter systems can be expected to use less energy because of the lower pumping head than would be used in pressure filters. Backwash water pumping can be reduced by using designs having gravity backwash.

The greatest primary energy use items are backwash water retreatment influent pumping and chlorination. Using filter designs capable of operating at 10 gpm/sq ft peak rates, without chlorination and with a backwash water return ratio of 3.5% can reduce total cost by about 47% and primary energy use by more than 44% over the design life of the filtration plant as calculated in Table 2.

The overall cost and energy effective wastewater filter will then be the alternative that can operate at high filtration rates, that will eliminate the need for chlorination to control biological growths in the filter bed and will reduce backwash water production to a minimum. Minor design differences such as different influent pumping head, use of gravity versus pumped backwash and the use of air or water wash auxiliary scouring methods will not greatly affect the relative cost or energy effectiveness of filter process alternatives.

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SESSION 4

ENERGY-INDUSTRIAL APPLICATIONS

Chairpersons: Jerome Collins

Rafael Bustamonte

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STATUS OF SYNFUEL WASTEWATER TREATABILITY OPTIONS

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"Synfuels" implies organic based fuel derived from coal, oil shale, bitumen or biomass. A major U.S. Government effort is underway to develop these national resources as an alternative to foreign petroleum. The conversion process typically fractures the basic "molecular structure" of the feedstock (coal, shale, biomass, etc.) and reforms it into a desirable end product, namely a gaseous or liquid fuel. In these conversion processes, water is invariably present and comes in contact with a wide range of organic and inorganic species. The water may be contacted with a product stream to cool it down and clean the stream to prelude subsequent tar condensation in the case of a gas or to extract polar compounds in the case of a liquid. It might even be contained with the feedstock, present as an excess reactant introduced for temperature control or as a byproduct of reaction. In every case the resultant wastewater is highly contaminated with soluble organics and, for those feedstocks containing interdispersed mineral matter (coal and oil shale), contains inorganics and trace elements.

A number of options exist for dealing with and treating the various wastewaters. While activated sludge appears to be a universal process for adequately treating synfuel wastewaters to effluent qualities reflective of current regulations, the nature of the wastewater, i.e., high organic loading, toxicity of certain compounds, presence of refractory organics, heavy metals and trace elements, causes concern with respect to the evolving Federal regulations resulting from the Toxic Substance Control Act (TSCA) and the Resource Conservation Recovery Act (RCRA). While the technical feasibility of add-on polishing steps to the conventional activated sludge train for controlling effluents to more stringent standards has been demonstrated, it remains to be seen what role a more elaborate treatment train will have in wastewater processing. As biological based treatment processes become more complicated and costly under the uncertainty as to where the evolving standards may lead, process designers will naturally choose "zero discharge" alternatives. Coal conversion wastewaters generally contain the most biologically resistant materials and highest inorganic content--they are the most difficult to treat. The trend for coal conversion is to perform some partial treatment on the wastewater stream (solvent extraction, activated sludge) and use cooling towers to concentrate the stream to a point where a reasonably sized blow-down stream can be fed to evaporation ponds or multiple effect evaporators. It is likely that future plant designs will adopt water conservation measures and desalting technology to preserve the water balance within the plant so that a concentrated, highly contaminated, low volume waste stream will be produced. Thermal oxidation techniques, e.g., gasification (recycle to the conversion process), wet-air oxidation and even incineration, are expected to become viable treatment practice for the concentrate. Biomass wastewaters, while both high in organic loading and volume of wastewater per unit product, are readily treatable with current biotechnology (activated sludge and trickling filters).

This presentation will overview the similarities and differences between the wastewater treatment/reuse schemes that are evolving for the different synfuel processes. Areas of environmental concern will be highlighted. The direction that future wastewater treatment technology is expected to take will be outlined.

STATUS OF SYNFUEL WASTEWATER TREATABILITY OPTIONS

INTRODUCTION

The U.S. has vast amounts of coal, oil shale, tar sand and biomass which can serve as a source of feedstock for the production of "synthetic" fuels. A growing reliance on foreign sources of supply has created the impetus for the conversion of these domestic materials into substitutes for petroleum- and gas-based "natural" fuels. In the longer term, the driving force is not just one of circumventing the uncertainty of a foreign-based resource and the drain on the U.S. economy from foreign purchases, but the fact that the world petroleum resources will be significantly diminished. Implicit in the quest for synthetic fuels is the continued technical desirability of "conventional" carbon-based fuel as convenient, cost-effective and environmentally acceptable means of storing, transporting and ultimately utilizing energy. At a bare minimum, synfuels can be expected to supplement natural petroleum as its supply and availability decrease, thus easing the burden of transition to other energy forms and fuels. The abundance and high energy density of carbon-based fuels would seem to dictate that they will be employed in mobile power applications, transportation in particular, for a long time.

The point is often raised that synfuels are not economically competitive with their natural counterparts at present, and that when free-market petroleum and gas prices get high enough the incentive will exist for private industry to produce abundant synfuels. In my judgment, it is time that we stop deluding ourselves with the idealized concept of synfuels economically competing with natural petroleum and gas. By their very nature (mining and handling of solids, more intensive processing, inherent process inefficiencies, solids disposal, etc.) "synthetic" fuels are going to be more expensive. The possibility of an arbitrary or artificial decrease of petroleum prices makes a synfuel industry highly vulnerable to manipulation. Therefore, one must ascribe a national need and make a national commitment if a synfuels effort is to come to pass in a measured and prudent manner, as opposed to the near panic situation that likely will exist "when the well runs dry." A number of alternatives, involving the conversion of coal, shale and biomass, are serious candidates for this demonstration activity.

As will be discussed, the nature of the feedstock strongly dictates the end product preferences, process configuration, and operating conditions. In nearly all the processes, water is present and comes in direct contact with the myriad of organic molecular species produced within the process and/or as byproducts. This water is highly contaminated and requires substantial treatment if it is to be dischargeable as a plant effluent. Typically, a somewhat lesser degree of treatment is required if the wastewater is to be recycled within the process.

SYNFUEL FEEDSTOCKS AND SOURCE OF WASTEWATER

The basic chemical composition and molecular structure of the major synfuels feedstocks coal, oil shale and biomass differ.

Coal

Coal has been formed by the "coalification" of plant matter, which collected in prehistoric lake bottoms and river deltas, by subjecting the organic material to intense pressure in a reducing atmosphere. Mineral matter, of course, was simultaneously lain down and is interdispersed (in some instances actually chemically bound) with organic structure; thus the mineral content of coal is highly variable. The coalification process appears to be a slow dehydration process where water, i.e., hydrogen and oxygen, are slowly expelled from the organic structure. The older the coal is, geologically speaking, the more graphitic its structure and the denser it is. The geologically younger the coal, the more free moisture it contains and the closer its structure comes to cellulose; peat represents the extreme case. (Figures 1 and 2.)

During coalification the oxygen-linked ring structures condense into complex configurations of aromatic poly ring structures and heterocyclic structures. The overall coal structure, sometimes represented as $CH_{0.6}O_{0.1}$, is too deficient in hydrogen to be a liquid or gas at room temperature. (Aliphatic compounds have the general composition $-CH_2-$.) Hence the main function of the coal conversion process is to simply add hydrogen to coal structure. As coal contains some hydrogen, one is able to directly pyrolyze the coal and fraction off the more volatile hydrogen-containing components, mainly methane, along with some oils and tars, thereby further depleting the remaining char of hydrogen.

The major coal liquefaction and gasification processes use hydrogen addition to obtain reasonable conversion of the feedstock. The hydrogen is produced from the well-known steam-carbon reaction ($H_2O + C \rightarrow H_2 + CO$) and water gas shift reaction ($CO + H_2O \rightarrow H_2 + CO_2$). These reactions are typically conducted in series within the gasifier (1200 - 2000°F) and over an iron oxide catalyst (700 - 900°F), respectively. The overall reaction is $C + 2H_2O \rightarrow 2H_2 + CO_2$. Acid-gas scrubbing removes the CO_2.

The hydrogen may be reacted directly with the coal to form liquid products. Normally the coal is suspended as a fine particulate in a coal derived liquid which assists in the transfer of hydrogen to the coal structure and the subsequent solubilization of the hydrogenated species. The reaction proceeds best at hydrogen pressures of 1000-3000 psi and temperatures of 800-900°F. Catalysts may or may not be present. A broad boiling range of liquids are produced, with the intensity of hydrogenation generally dictating the proportion of "light" material. This family of processes is referred to as direct liquefaction.

Another technique can be used to produce liquid fuels. The shifted gas produced from the steam carbon reaction, syngas ($2H_2 + CO$), can be catalytically converted to a wide spectrum of aliphatic liquid products. This is the familiar Fischer-Tropsch reaction, occurring at ~400°F in the vapor phase over an iron or cobalt catalyst. A recent variation of this approach, directed exclusively at gasoline production, is to use a two-stage process, selectively producing methanol as an intermediary and then catalytically converting the methanol to an aromatic based gasoline using Mobil's M-Gasoline process. Methanol is recognized as a potential motor and turbine fuel in its own right. Liquefaction processes which are based on initially gasifying the coal and effecting catalytic reformation are referred to as indirect liquefaction.

For these processes the source of the syngas is immaterial, and carbonaceous feed stock other than coal may be utilized. The high temperature employed for the steam-carbon reaction, especially in entrained gasifiers, makes the raw syngas practically devoid of heavy hydrocarbons. As a consequence, gas quench water contains very little organic residue; what is present is adsorbed on the ash carryover.

Coal gasification processes normally take advantage of limited pyrolysis phenomena and methane production (hydrogenation) within the gasifier proper to improve the thermal efficiency of the process. As a consequence, the raw product gas contains a wide range of aromatic oils and tars. Volatile inorganics that originate from high temperature reducing conditions are present as well. The major portion of sulfur compounds, especially ash pyrites, and fuel nitrogen are given off as gaseous H_2S and NH_3, respectively. A large quantity of the gas produced in the gasification step results from the exothermic carbon-oxygen reactions ($2C + O_2 \rightarrow 2CO$ and $C + O_2 \rightarrow CO_2$) which drive the strongly endothermic steam-carbon reaction. Since excess carbon is generally present, only a limited amount of CO_2 is produced.

Shale

Chemically, shale oil is quite different from coal. The organic material referred to as kerogen is weakly bound in a siliceous mineral matrix. The origin of the kerogen is somewhat open to conjecture. It is hypothesized that the material originated from the co-sedimentation of simple plant and animal life with mineral matter in primeval lakes. A representative chemical composition for kerogen is $CH_{1.4}O_{0.5}N_{0.02}$. Obviously it is closer to a "liquid" than coal. In fact, the technique for obtaining a crude product from the shale is simple retorting at approximately 600°F to fracture the kerogen and distill off decomposition products. At the same time, the mineral structure is transformed into a powdery calcium-aluminium silicate material which occupies somewhat more volume than the original shale.

Several different approaches are vying for producing shale oil. The most straightforward one is to mine the shale, crush it and heat it above ground in a closed vessel. The off-gases containing the organic vapors and water vapor are passed through a condenser where the oil and water are condensed. The heat to retort the shale may be provided by combusting a part of the residual kerogen, or it may be supplied indirectly in mixing the shale with a hot solid whose sensible heat is used to effect the decomposition. In surface operations, the quantity of water produced is limited and any excess water may be used to moisturize the spent shale to facilitate compacting and disposal.

Another approach, being pursued for thick and deep shale deposits, is to fracture the deposit within the ground and perform the retorting in situ. Some below surface mining is required to provide for growth of spent shale in the "retort chamber" and to create appropriate air distribution and off-gas channels to encourage full utilization of the resource. In situ operations are expected to produce approximately the same volume of retort water as oil, e.g., a 50,000 bbl facility will produce 2Mgpd of wastewater. Some of the wastewater may be disposed of with the spent shale resulting from surface retorting of the mined shale.

The kerogen contains a fair quantity of nitrogen heterocompounds which contribute to ammonia production during retorting; in addition, a number of volatile salts and toxic elements may be released from the mineral matrix. The fact that the raw shale oil is similar to a light petroleum crude means that only limited upgrading is required to produce a light distillate fuel. This is in contrast to coal liquids which require considerable more upgrading to produce high yields of light distillate fuels.

Biomass

Conversion of biomass to conventional fuel (e.g., methane, fuel oils and alcohols) requires different processes than conversion of coal. Normally the biomass feedstock is waste product of low caloric value due to its high moisture content. For purposes of discussion, it may be characterized as cellulose $C_6H_{10}O_5$. As a waste product, low unit feedstock costs may be assigned and relatively inefficient conversion processes may be employed. For gasification and liquefaction processes similar to those applicable to coal, i.e., pyrolysis and syngas production, a relatively dry feed stock must be employed. The use of high quality heat for drying is precluded as it defeats the advantage of low feedstock costs. Normally air and/or solar drying is used. The molecular structure of the biomass material is less cyclic than coal and the organic wastewater contaminants are less refractory. Agricultural feedstock contains very little inorganic material and is exceptionally low in ash. Obviously this is not the case for feedstocks containing urban waste which contain plastics, metals and chemicals.

The biomass may be processed by fermentation to alcohols or anaerobic digestion to methane without drying. Normally these biological processes are performed in "aqueous soups" that are heavily loaded with organic byproducts and that require intensive biological treatment prior to discharge. While activated sludge is an effective physical sorbent for most of the suspended material, the disposal of such contaminated sludges is a universal concern.

WASTEWATER SOURCE CHARACTERIZATION AND DIFFERENCES

As can be seen, there is wide variation in the feedstock and process conditions that lead to the production of synfuels. The wastewater normally represents the aqueous phase condensate that comes off the initial conversion process. Many times, in the case of coal, it is diluted with quench water used to cool and clean the raw off-gas. As a natural consequence of these differences, there is difference in the composition of the wastewaters. All waters contain a high BOD relative to municipal sewage, which may be several 100 ppm. The major constituents differ sufficiently to suggest different treatment practice. (Figures 2 and 3.)

Coal

With coal, phenolic compounds contribute to the bulk of BOD (5,000-10,000 ppm) and pose a severe stress on sludge microorganisms. One typically resorts to solvent stripping and/or dilution to bring the levels down to 1000-2000 ppm, at which level acclimated organisms can do a reasonable job. Coal wastewaters

also contain some ring structures, polynuclear aromatics (PNA's) and heterocyclics (1-10 ppm), some of which are biorefractory. The more refractory compounds are adsorbed on the sludge, with effluent concentrations running in the range of 10-50 ppb. Laboratory bench testing has indicated that a significant reduction of PNA type materials can be achieved if the effluent is subjected to partial ozonation followed by activated carbon adsorption. It appears important that the ozonation precede the sorption step, lest the large ring-structure compounds be too large for the pores of the carbon.

Oil Shale

In the case of oil shale, carboxylic acids are a major contributor to the BOD loading and are susceptible to biological treatment. With steam stripped shale retort water, the addition of powdered carbon appears to be beneficial to control "toxic effects" which appear to limit the effectiveness of sludge bacteria. No similar toxic effect has been observed with coal condensate waters, once ammonia is stripped and phenolic levels are reduced. A large portion of shale water COD is represented by thiosulfate, which is biologically digestible, but not readily absorbed on carbon.

Biomass

For agricultural biomass condensate waters and biodigestion liquors, the organic loading is sometimes so high as to be toxic; dilution and recycle are used to eliminate BOD and reduce COD significantly.

In effect, it appears that conventional activated sludge is sufficient for coal and biomass wastewaters to meet existing discharge standards, while shale wastewaters will require a combination of biological and activated carbon sorption. There are important differences with respect to inorganic composition of the coal and shale wastewaters; with respect to the biomass condensate waters this is a moot point, although for biodigestion liquors the control of nutrient additives may be considered. Both coal and oil shale condensate waters contain dissolved ammonia, up to 2%. This NH_3 is usually neutralized by dissolved CO_2 that is produced in driving the conversion process or retorting operation. Thus the condensate waters are strongly buffered and to change the pH via the addition of chemical reagents is quite expensive. With oil shale waters, particularly in situ oil shale retort waters, large amounts of non-volatile ions are present. Frequently high concentrations of sodium exist. As a consequence, the amount of CO_2 exceeds NH_3 and the NH_3 is relatively easy to steam strip. However, substantial amounts of sodium carbonate remain in solution, posing an effluent salt release problem in water basins such as the Colorado which are sensitive to "salt" inputs. In contrast, some coals contain high chloride which enters the condensate water and provides a strongly acidic anion to retain the NH_3 as NH_4Cl. In such instances it is necessary to add a strong base (CaO) to enhance NH_3 strippability. Normally such coals occur in the East and the additional salt loading due to reagent addition presents no critical problem with effluent discharges.

Other environmentally important constituents of coal and oil shale wastewaters include boron, thiocyanate and cyanide. Sulfur compounds originally present in the feed can take the form of mercaptan, cyclic compounds and thiosulfates as well as H_2S. An odor problem can be associated with the carboxylic acids and organic bases. For coal wastewater effluents, a color problem has been associated with the aging of trace polyhydric phenols. This difficulty may be overcome with a carbon polishing step.

WASTEWATER PROCESSING

In considering the inventory of unit operations available to handle the multiple treatment problems imposed by synfuel wastewaters, one should be mindful of process and site imposed boundary conditions. Is the process a water producer or a water consumer? For net water consumers (gasification and liquefaction of low moisture coals and surface retorting of oil shale) there is incentive to recycle water to the limits imposed by the build-up of a particular "problem" species, e.g., $CaCO_3$, $CaSO_4$, and CaF_2. This may lead to a small amount of effluents or "zero" if the solids are taken to dryness, where high unit treatment costs can be tolerated due to small impact on product costs. A different situation exists for net water producers (biomass, peat and lignite, in situ oil shale below the water table) where it is necessary to treat and ultimately release substantial amounts of water to the environmental.

In considering the water treatability and reuse scheme for a process, attention must be given to overriding site considerations such as water availability, acceptability of effluent, the facility and means of effecting solids disposal (wastewater sludges and salts) and the local regulatory climate. Western sites pose a special concern due to competition for water and the potential for salts to be released to water basins that are already taxed with salinity. This problem of salt control can also discourage the use of brackish groundwaters. In areas of limited water availability, within-process water reuse and conservation measures are employed to the maximum extent. Water recycle options include, but are not limited to, process feed slurrying, gasifier steam production, quench water, cooling-tower make-up, boiler-feedwaters and solid waste compaction and dust control.

As the construction of a substantial number of synfuel plants is in the distant future, the applicable standards are yet to be determined. However, one can expect the more stringent standards will be formulated to deal with the Priority Pollutant and consent-decree Toxic Pollutant lists of the EPA. Acceptable control practice for the disposal of wastewater treatment sludges, e.g., calcination, fixation, etc., will probably be established under the Resource Conservation and Recovery Act (RCRA). (Figure 4.)

TREATMENT

A number of unit operations are available to meet existing and/or future discharge standards. In summarizing these process options it must be appreciated that many factors affect the performance and limitations of the operation, paramount of which are the specific process application and siting considerations.

Gravity Separation - (Settling ponds with skimmers, API separations, centrifuges.) As pretreatment to remove suspended oil, tar, grease and solids; not effective against emulsions, small particles and substances which possess densities close to that of the aqueous phase.

Steam Stripping - Employed to remove volatile material, most notably dissolved gases, i,e., NH_3, CO_2, H_2S, HCN and COS. Light, low boiling organics, e.g., phenol, may also be removed. Steam requirements may vary from 0.05 to 0.2 pound steam/pound wastewater. Vacuum stripping can be used to reduce steam requirements which are excessive in stripping of heavy organics.

Solvent Extraction - Useful as a roughing operation for coal condensate waters to remove gross quantities of phenols and polyhydric aromatics. Methyl isobuty: ketone (MIBK) and diisopropyl ether (DIPE) are preferred solvents. Solvent extraction must be accompanied by a solvent recovery step, typically stripping. Some residual solvent inevitably remains in the water and must not interfere with subsequent treatment and/or use. The potential for solvent extraction in synfuel wastewater applications does not appear to be fully developed. With appropriate solvents, it appears adaptable to removing organic sulfur compounds, organic gases and carboxylic acids which typically plague shale oil wastewaters. When used in conjunction with biological systems, it tends to dampen fluctuations in organic loading which create difficulty for a stressed activated sludge system.

Biological Treatment - Applicable where effluent discharge is contemplated. Activated sludge treatment has a long history of success on industrial wastewater (coking and petroleum refining) similar in many respects to synfuel wastewaters. It is capable of removing all the BOD (by definition) and approximately 75% of the COD in coal waste waters. The effective removal of polyhydric phenols is open to conjecture; along with polynuclear aromatics they appear to be refractory. Heavy metal removal may be effective as 50% or more of these materials are bound-up with the sludge. Several disadvantages exist for biological treatment - its sensitivity to toxic materials and variations in feed concentration (in some instances large dilutions are required to damp out these effects) and sludge disposal concerns. (Figure 5.)

Carbon Adsorption - Employed as a polishing step to remove low level refractory organics and color bodies. Prefiltration is normally required to preclude irreversible fouling of the carbon bed. As it normally follows a biotreatment step, it may serve as an additional, although costly, safeguard during bioprocess upsets. Salt content of the wastewater may cause fouling of the carbon during regeneration, e.g., steam stripping. In some instances, pollutants are leached out of the carbon immediately after regeneration and effluent recycle is required.

Other Approaches -

Ozonation. While expensive, ozone has been shown to render large organic molecules susceptible to adsorption by activated carbon. Used as a posttreatment it can destroy color bodies.

Precipitation with Iron. $Fe(OH)_3$ floc has the capacity to adsorb heavy metal ions and may be combined with floculation, settling and/or prefiltration for enhanced heavy metal control.

Wet-Air Oxidation. Wet air oxidation has the potential of removing all organics and NH_3; however, actual effectiveness and effluent qualities are uncertain.

Ion-Exchange. Resins which have a special affinity for boron are available and may have application to effluents to be used for irrigation.

Concentration Processes. Reverse osmosis, freezing and distillation processes may be used to concentrate salts.

Incineration. This may be considered for organic-containing concentrates resulting from biosludge, extraction, etc.

Deep-well Injection. This may be considered, if concentrates are environmentally compatible with local strata.

There are several ways this inventory of wastewater treatment processes can be characterized. One way is to consider effectiveness for treating organic and inorganic contaminants. Another in-group comparison, for those processes which treat organics, would be the ability to grossly destroy the potential pollutants, polish the effluent or recover byproducts. As is appreciated, wastewater treatment economics for the individual processes depend on a number of factors, e.g., concentration of pollutant and volumetric throughout (scale-up) independence and dependence. These individual treatment operations are compared in Figure 6.

These unit operations can be arranged in a wastewater treatment train that would produce almost drinking quality water from the various synfuel wastewaters. However, the relatively high treatment costs are likely to bar such intensive treatment (Figure 7). It should be noted, depending on the gallons of effluent produced per unit energy, that these high costs relative to municipal waste treatment may not pose a severe economic burden on a given synfuel process. For example, 10-20 gallons of effluent are produced per MBtu in a coal gasification process. This translates into a total cost of 20 to 80 cents/MBtu to meet the more stringent future standards which does not seem to be an insurmountable bar to a product which is projected to sell in the range of $5-10/MBtu. It should be further noted that for coal conversion the cost impact under current standards is considerably less.

REUSE

A number of water reuse options which avoid release to a surface acceptor are apparently evolving in commercial design. As previously indicated, many processes are net water consumers; thus there is incentive for closing the "loop." The more prominent reuse options and their advantages and disadvantages are compared in Figure 8. Ideally it is economically desirable to use as poor a quality of water as the reuse application will permit. Many of the recycle systems are merely paper designs and it is not clear that special precaution has been taken to preclude the build-up of trace extractables and corrosion products which may inadvertently react with or precipitate from the recycle loop, thereby impairing the operation and reliability of the system. Many times such difficulties are hard to anticipate.

With coal, special attention has been given to reducing the quantity of wastewater associated with the quench operation by instituting a two stage quench - the initial stage is a low volume recycled highly contaminated water while the second stage consists of a much larger volume of relatively clean water, the strong acid gases condensing out in the first stage. The incentive for such a system has been shown to reside with coals having a halide content greater than 0.15% Cl, i.e., generally Eastern coals.

Some uncertainties concerning secondary environmental effects of water "reuse" options need further resolution:

- o Water quality requirements for cooling tower make-up and evaporation pond feeds,
- o Effects of disposal of blow-down and sluice water with ash and spent solids,
- o Effects of disposal of waste sludges, and
- o Fate of ultimate residuals resulting from evaporation ponding and dust wetdown.

CONCLUSION

It is critically important to consider water use and treatment as an integral part of the specific synfuel process rather than a series of end-of-the-pipe treatments. Reuse options are rapidly gaining attention as process developers become increasingly aware of the expense (in absolute terms) of meeting more stringent effluent standards in the future. Water reuse, recycle and injection directly back into the conversion process are steps that must be closely coupled to the inventory of existing treatment processes. These treatment processes should be deployed primarily to recover byproduct and/or remove substances which will materially interfere with the recycle process. The control and disposal of secondary pollutants must not be overlooked in any wastewater treatment/reuse scheme. The problem of salts is a continually nagging problem and requires special and timely attention.

ACKNOWLEDGEMENT

This presentation resulted from the technical contribution of a large number of individuals and their respective organizations which have worked under contract to the Environmental Control Technology Division, Office of Environmental Compliance and Overview, Assistant Secretary for Environment, U.S. Department of Energy. If one is interested in further details of these activities, a report entitled "Processing Needs and Methodology for Wastewater From Coal, Oil Shale and Biomass Synfuel Processes" will be made available upon request to the Division.

FIGURE 1. GENERALIZATIONS CONCERNING COAL RANK

COAL TYPE	AGE, DEPTH, HARDNESS	HEATING VALUE BTU/LB	CARBON w/o	MOISTURE w/o	SULFUR w/o
ANTHRACITE		13,500	80	1–2	0.5
BITUMINOUS		13,000	75	3–10	0.6–4
SUB-BITUMINOUS		9,500	55	16–25	0.4–2
LIGNITE		7,200	42	25–35	0.7
PEAT		6,000		HIGH	
WOOD		5,000			LOW

FIGURE 2. MAJOR SYNFUEL FEEDSTOCKS AND CONVERSION PROCESSES

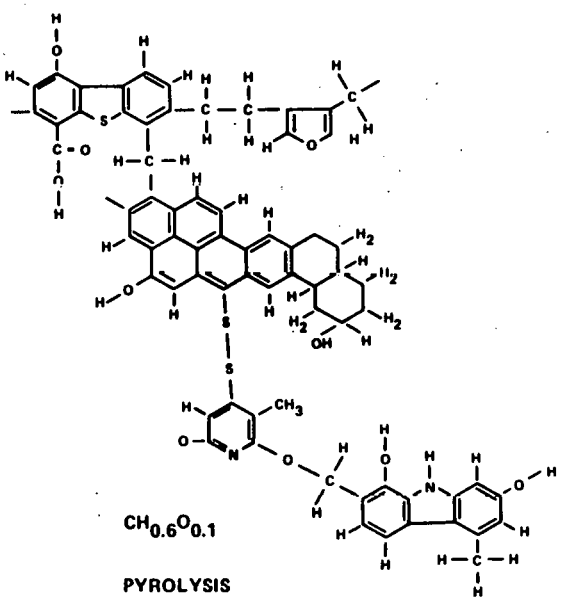
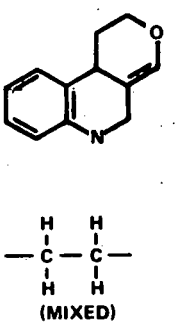
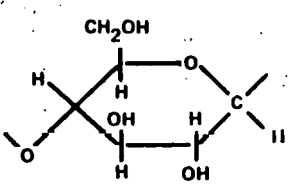
	COAL	SHALE OIL	BIOMASS
MODEL STRUCTURE		 (MIXED)	
REPRESENTATIVE ELEMENTAL RATIOS	$CH_{0.6}O_{0.1}$	$CH_{1.4}O_{0.5}N_{0.02}$	$CH_{0.6}O_{0.8}$
MAJOR CONVERSION PROCESSES	PYROLYSIS DIRECT LIQUEFACTION INDIRECT LIQUEFACTION GASIFICATION UNDERGROUND GASIFICATION	SURFACE RETORTING IN SITU RETORTING	PYROLYSIS FERMENTATION ANAEROBIC DIGESTION GASIFICATION INDIRECT LIQUEFACTION

FIGURE 3. COMPOSITION RANGE OF TYPICAL RAW WASTEWATERS (PPM)

CONSTITUENT	COAL LIQUEFACTION/GASIFICATION[1]	SHALE OIL SURFACE RETORT	BIOMASS PYROLYSIS	BIOMASS ANAEROBIC DIGESTION
ORGANICS				
BOD_5	10,000–20,000	20,000–40,000	20,000–50,000	4,000
COD	5,000–30,000	50,000–150,000	40,000–77,000	7,000–8,000
PHENOL	200–6,000	LOW	600–1,000	–
CARBOXYLIC ACIDS	50–200	500–2,000	8,000–13,000	–
POLYNUCLEAR AROMATICS	0.1–1	–	–	–
INORGANICS[2]				
AMMONIA (N)	2,000–15,000	2,000–20,000	1,200	30
SULFIDE ($S^=$)	500–3,000	–	–	–
CARBONATE (CO_2)	5,000–20,000	10,000–30,000	–	–
CYANIDE (CN^-)	1–20	–	–	–
SELENIUM (Se)	0.1–5	NIL	0.9	–
BORON (B)	NIL	50	–	–
ARSENIC (As)	NIL	1–8	0.13	–

[1]EXCLUDES ENTRAINED GASIFICATION

[2]( ) INDICATES REPORTED AS

FIGURE 4. REPRESENTATIVE EFFLUENT DISCHARGE REGULATIONS FOR COAL CONVERSION PILOT-PLANT ACTIVITIES

PARAMETER[1]	PILOT-PLANT DISCHARGE PERMIT LEVELS SRC FT. LEWIS	SRC WILSONVILLE	H-COAL	TYPICAL OUTPUT FROM LABORATORY WASTEWATER TREATABILITY PROCESS TRAINS[2]	ANTICIPATED LIMITS
TSS	(50)	60	176	ND[3]	3–15
PHENOL	1 (0.5)	1	8	0.010	0.3
OIL & GREASE	15 (10)	15	15	NIL	16
CN^-	–	–	–	0.05	0.1
NH_3	–	–	–	5–10	5
$S^=$	–	–	–	0.1	0.2
BOD	(40)	60	130	NIL	30
COD	(160)	–	–	NIL	350
PNA	NA[4]	NA	NA	0.005	?
pH	6–9 (6–8.5)	6–9	6–9	ND	6–9

[1]ppm, EXCEPT pH

[2]FIELD DEMONSTRATION PLANNED; TREATMENT TRAINS INCLUDED VARIOUS COMBINATIONS OF STEAM STRIPPING, SOLVENT STRIPPING, BIOLOGICAL DIGESTION, CARBON ABSORPTION, AND CHEMICAL OXIDATION (OZONATION)

[3]ND: NOT DETERMINED

[4]NA: NOT APPLICABLE

( )DENOTES FIELD DATE

FIGURE 5. REMOVAL OF ORGANIC COMPOUNDS IN PETROLEUM REFINERY WASTEWATERS BY ACTIVATED SLUDGE UNIT

COMPOUND CLASS	CONCENTRATION RANGE IN DAF EFFLUENT (PPB)	AVERAGE PERCENT REMOVAL BY ACTIVATED-SLUDGE UNIT
ALKANES	11–683	99.65
N-ALKANES	11–683	99.58
BRANCHED ALKANES	67–246	99.88
CYCLOALKANES	21–71	99.81
ALKYLATED BENZENES	5–187	99.97
TOLUENE	101	99.87
C_2-BENZENES	35–187	99.96
C_3-BENZENES	5–176	99.97
C_4-BENZENES	8–64	99.98
ALKYLATED INDANS TETRALINS	11–104	99.98
ALKYLATED NAPHTHALENES	21–448	99.93
NAPHTHALENE	197	99.99
METHYL NAPHTHALENES	259–448	99.99
C_2-NAPHTHALENES	45–267	99.98
C_3-NAPHTHALENES	21–160	99.89
ALKYLATED BENZOTHIOPHENES & DIBENZOTHIOPHENES	8–32	99.88
ALKYLATED PNAS	3–168	99.86

FIGURE 6. COMPARISON OF TREATMENT OPTIONS

UNIT OPERATION	CONSTITUENT TREATED: ORGANIC	CONSTITUENT TREATED: INORGANIC	APPLICABILITY: GROSS REMOVAL	APPLICABILITY: POLISHING	APPLICABILITY: BY-PRODUCT RECOVERY	TREATMENT COST: RANGE $/1000 GAL	TREATMENT COST DEPENDENCE ON: EFFLUENT QUALITY	TREATMENT COST DEPENDENCE ON: EFFLUENT QUANTITY	BASIS FOR RANGE
GRAVITY SEPARATION	✔	–	✔	–	–	0.10–0.20		✔	
STEAM STRIPPING	✔	✔	✔	–	✔	∿10		✔	
SOLVENT EXTRACTION	✔	–	✔	–	✔	∿5		✔	
BIOLOGICAL	✔	–	✔	–	–	10–20	✔		10,000ppm BOD
CARBON ADSORPTION	✔	–	–	✔	–	6–12	✔		2,000ppm COD CARBON REGEN
OZONATION	✔	–	–	✔	–	5	✔		600ppm TOC
PRECIPITATION W/IRON	✔	✔	–	✔	–		✔		
WET-AIR OXIDATION	✔	–	✔	–	–	∿25	✔	✔	
ION EXCHANGE	–	✔	–	✔	✔	0.5–2	✔	✔	
DESALINATION PROCESSES	–	✔	✔	–	✔	5–10		✔	
INCINERATION/GASIFICATION	✔	✔	✔	✔	–		✔	✔	
DEEP-WELL INJECTION	✔	✔	–	–	–			✔	

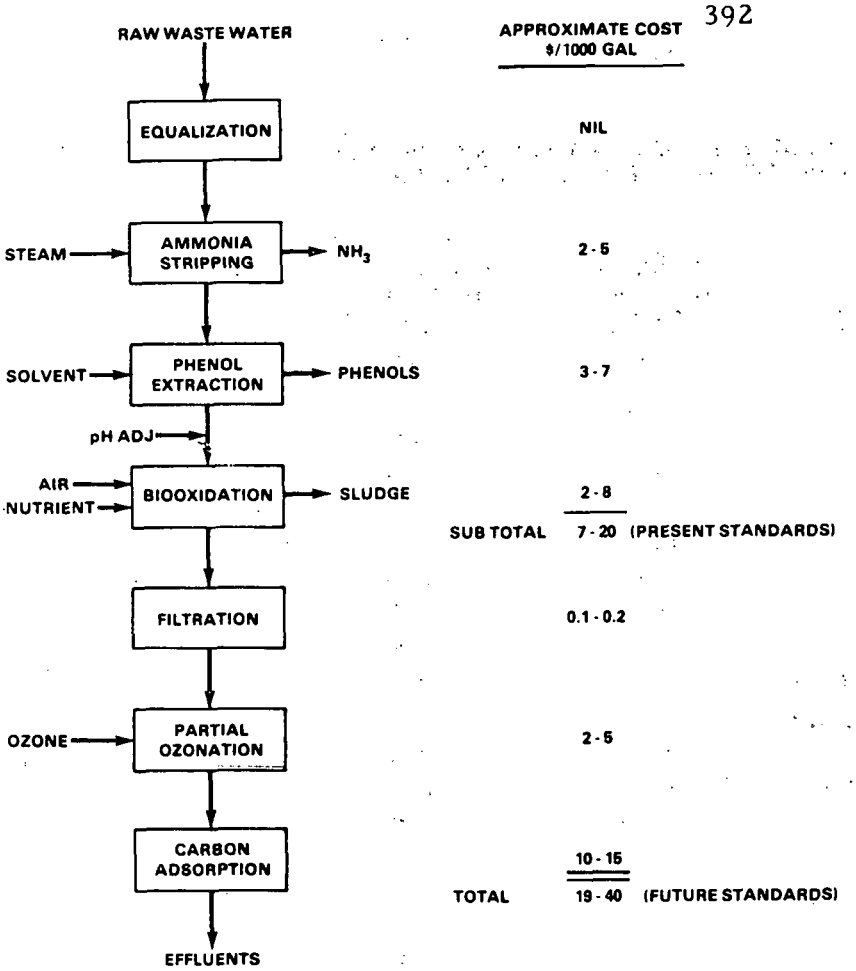
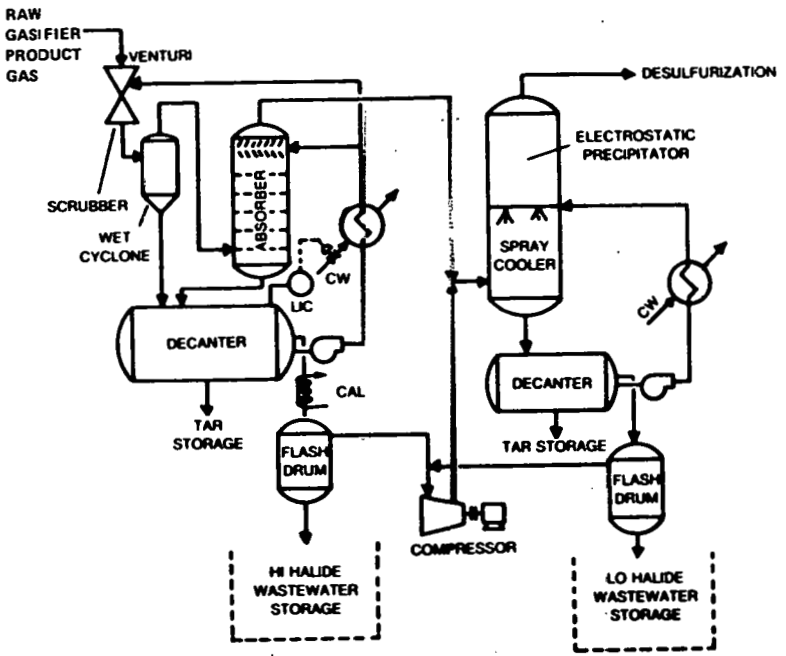


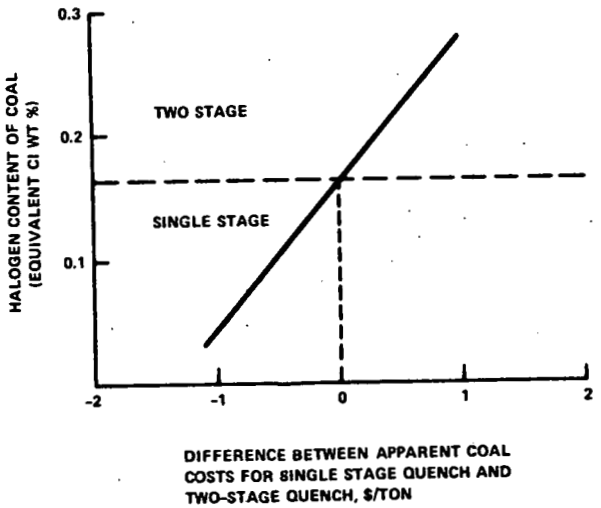
FIGURE 7. REPRESENTATIVE WASTE WATER TREATMENT PLAN FOR COAL CONVERSION EFFLUENTS

FIGURE 8. PROMINENT WASTEWATER "REUSE" OPTIONS

OPTION	POTENTIAL ADVANTAGES	POTENTIAL DISADVANTAGES	UNCERTAINTIES
REINJECTION INTO CONVERSION PROCESS	• "ZERO" DISCHARGE • DECREASES WATER USE • CAN CONSERVE SENSIBLE HEAT • LITTLE TREATMENT REQUIRED	• CONCENTRATION STEP MAY BE REQUIRED TO PRESERVE WATER BALANCE • PROCESS CHANGES MAY BE REQUIRED TO ACCOMODATE	• RELIABILITY AND COST • SOME MATERIALS MAY FAVOR RECYCLE LOOP, MAKING PURGE NECESSARY • NATURE OF SOLID WASTES MAY BE MODIFIED
MAKE-UP FOR COOLING TOWERS	• "ZERO" DISCHARGE • DECREASES WATER USE	• SIGNIFICANT PRETREATMENT MAY BE REQUIRED • MAY NOT BE APPLICABLE ON YEAR-ROUND BASIS	• RELIABILITY AND COST • CONTAMINANTS IN DRAFT MAY PRESENT PROBLEM • CORROSIVE NATURE AND SPARINGLY SOLUBLE CONSTITUENTS MAY PRESENT DIFFICULTY
WET-DOWN FOR DUST CONTROL AND IRRIGATION	• "ZERO" DISCHARGE • ASSISTS IN CONTROL OF FUGITIVE EMISSIONS • ABETS REVEGETATION EFFORT	• SIGNIFICANT PRE-TREATMENT REQUIRED • INTRUSION OF TRACE ELEMENTS AND REFRACTORY ORGANICS INTO ECOSYSTEM AND AQUIFERS	• EXTENT OF NATURAL "DETOXIFICATION" OF CONTAMINATED WASTES
BOILER FEEDWATER	• "ZERO" DISCHARGE	• SIGNIFICANT TREATMENT AND DEMINERALIZATION REQUIRED	• COST
FEED FOR SANITARY SYSTEM	• SAVE POTABLE WATER	• TREATMENT REQUIRED TO CONTROL COLOR AND ODOR, ADDITIVES MAY WORK	• COST BENEFIT • COLOR AND ODOR MAY CAUSE OBJECTIONS • EFFECT ON BIOTREATMENT PLANT

FIGURE 9. TWO STAGE QUENCH OPTION





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Peregrine White, Jr., Argonne National Laboratory

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A SURVEY OF INDUSTRIES CONCERNS ON ENERGY AND WASTEWATER TREATMENT

1. INTRODUCTION

A small but significant amount of energy is used in industrial wastewater treatment. As "Best Available Technology" regulations become effective,[1] and as energy prices increase, the energy costs associated with wastewater control in the industrial sector will increase, as will pressure to relax the controls. Therefore, more attention should now be given to reducing the energy usage in this area. The present review of regulations and survey of industries was undertaken in order to assess industries' viewpoints on these issues, and hence to assess the climate for energy-conserving innovations in industrial wastewater treatment.

1.1 GRAPHICAL REPRESENTATION OF THE ENERGY ASSOCIATED WITH WASTEWATER TREATMENT

Fig. 1 illustrates the importance of considering the energy usage of wastewater treatment (as well as that of environmental protection in general). The environment is on the vertical axis with positive values being associated with preventing environmental degradation as a result of human activity (e.g., wastewater treatment), and with negative values being associated with not preventing such environmental degradation.

Curve A illustrates the fact that there is a diminishing marginal environmental return as energy used for environmental protection increases (e.g., great amounts of energy for tertiary treatment resulting in small increases in water quality). Curve B illustrates a linear relationship between increased energy usage and environmental degradation (e.g., the more coal that is mined, the more acid mine drainage that will occur). When these curves are added, one obtains curve C which shows a maximum value of environmental protection past which the environmental degradation from energy usage more than negates the marginal environmental benefit achieved from higher levels of treatment. In the context of this diagram, the goal of energy conservation in wastewater treatment should be to reach this maximum or alter technologies such that the maximum is as far to the left on the abscissa as possible, while also being as far up the ordinate as possible.

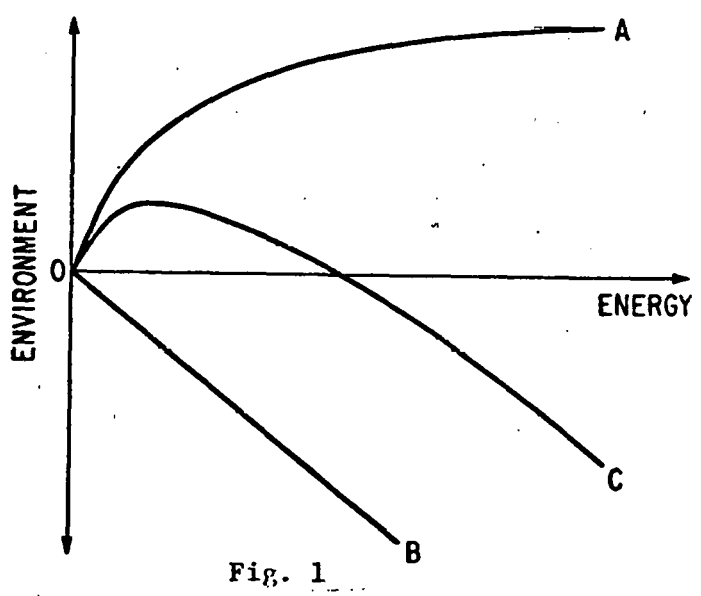


Fig. 1

[1] Goldstein, *Energy Conservation in the Treatment of Industrial Wastewaters*, 12th IECEC Conference Proceedings.

1.2 BACKGROUND INFORMATION

1.2.1 Innovation in Wastewater Treatment

It is no secret that there is a good deal of inertia in the sanitary engineering field. Especially in municipal sewage treatment, engineers entrusted with public funds are unlikely to risk their reputations by suggesting that their clients employ new, unproven technologies whose risks may exceed benefits. While this phenomenon does assure a certain level of consistency in the operation of wastewater treatment plants, it also precludes the introduction of treatment methods which avoid conventional system drawbacks.

The major government measure taken to try to ameliorate this situation is the innovative and alternative technology program of the Environmental Protection Agency. This program is attempting to implement the congressional intent of increasing the extent of wastewater reclamation and reuse, materials recycling and energy conservation. Within this program, municipalities have 85%, instead of 75%, of the costs of their facilities provided by the federal government if they employ an innovative or alternative technology.

1.2.2 Current Energy Usage

Energy conservation in wastewater treatment must be examined in the context of the total energy consumption in municipal wastewater treatment, the total energy consumption in industrial processes, and the energy load of industrial wastewater treatment. These are outlined in the table below.

Table 1. Energy for Industrial Process and Wastewater Treatment

	Amount/Yr.	Percent of Total U.S. Annual Energy Use
Industrial Processes	12 QUAD	-[2]
Industrial Wastewater Treatment	0.35 QUAD/Yr.	0.53[3]
Municipal Wastewater Treatment	0.143 QUAD/Yr.	0.17[4]
TOTAL	0.493 QUAD	

1 QUAD = 10^{15} Btu

[2]U.S. Dept. of Commerce, *1975 Annual Survey of Manufacturers*, p. 1.

[3]S.B. Ahlstrom, et. al., *Assessment of Energy Conserving Industrial Waste Treatment Technology*, p. 1.

[4]U.S. Environmental Protection Agency, *Energy Conservation in Municipal Wastwater Treatment*, p. 2-2/

These numbers are small, and the amount of government involvement in trying to reduce these amounts should reflect that fact. It should be noted that, whereas most of the attention on energy in wastewater treatment has been in the municipal sector, a larger amount of energy is consumed in treating industrial wastes; therefore more attention should be devoted to this subject than is at present. It is evident that given all these considerations, now is a good time to assess the industrial climate for innovation in wastewater treatment. Therefore, the following survey and regulatory analysis have been performed.

2 REGULATORY REVIEW

Innovation in industrial wastewater treatment is directly affected by several sections of the federal Clean Water Act, P.L. 95-217. The pertinent sections are listed in Table 2.

Table 2. Pertinent Laws and Regulations

P.L. 95-217	
Section L 101(a)(6)	National Research and demonstration effort for improvement of water pollution control technology
104(a)(1)	Promotion by EPA, with other federal, state, and local agencies, of research and other studies for pollution abatement.
201(i)	Encourage energy conservation in wastewater management.
202(a)(3)	EPA replaces, bearing 100% of the cost, the failing municipal innovative or alternative technology.
301(k)	Industries' changing production process, or innovating with a wastewater treatment process may result in that change or innovation being mandated on an industry-wide basis.
REGULATIONS[5]	
35.908 35.915(a)(1) 35.915(e) 35.917-1(d)(8)(a) 35.915-1(b) 35.930-5(b) 35.935.20 35.936-13	All pertain to municipal innovative and alternative technologies.

[5] U.S. E.P.A., *Innovative and Alternative Technology Assessment Manual*, P.Bii.

None of the above-cited sections of P.L. 95-217 and regulations encourage industrial innovation in wastewater treatment: most of the federal research effort has been in the municipal area. Nowhere in the law is there any commitment to reducing the amount of energy used in industrial wastewater treatment. Furthermore, if a firm were to try an innovative energy-conservation approach to wastewater treatment it would face two alternatives: if the approach were to fail to meet the effluent standards, the industry would probably be fined in the interim required to return to a more conventional technology; (This is in sharp contrast to the allowances made for municipalities in Section 202(a)(3) of P.L. 95-217.) If the approach were to have great success from an energy and environmental standpoint, it would stand the chance of being labelled "Best Available Technology," and being mandated industrywide. Thus, if the second alternative were to transpire, the particular industry would be saddling itself (in its other plants) and its fellow producers with a technology which, though feasible in one situation, would not necessarily be applicable industry wide. In conclusion, while the law and regulations actively encourage innovation in the municipal arena, they, in many respects, discourage such innovation in the industrial area.

3. SURVEY OF INDUSTRIES' ATTITUDES AND ACTIONS

If there is to be government support for more innovation for energy conservation in industrial wastewater treatment, one must first have a sense for the attitudes of industry with regards to this question. Therefore the following survey was performed.

3.1 METHODOLOGY

In order to obtain an insight into industries' concerns in wastewater treatment, several industries were first interviewed. The results of these interviews were used to compile a questionnaire, which was then sent to 80 firms. Of these, the distribution by standard industrial classification is shown below in Table 3. This effort was limited to larger corporations, with the assumption that they would have an officer who would be able to complete the questionnaire. Also, in general larger companies will have greater potential for energy conservation, both in general and specifically in their wastewater treatment. The companies surveyed had facilities nationwide, and the persons surveyed were in the central environmental engineering offices of those companies; therefore a good geographical distribution was obtained.

The survey form consisted of 25 statements concerning energy usage in industrial wastewater treatment, innovation as affected by environmental regulations, resource recovery issues, general attitudes on environmental issues, and the tradeoffs involved in industrial wastewater treatment decisions. A simple scoring system was employed for expressing the strength of agreement or disagreement with the statements. About half the statements dealt with attitudes, and the other half dealt with actions actually taken by the industries. In addition, the respondents were asked to list any companies they knew of which had either done energy analyses of their wastewater treatment systems, or which had developed wastewater treatment technologies as offshoots of their own waste treatment programs. The repre-

Table 3. Industries Surveyed

	Received	Sent
Chemical	4	14
Manufacturing equipment	3	6
Electroplating	1	5
Steel	2	6
Rubber	4	8
Textiles	1	6
Coal-mining	1	4
Ink manufacturing	1	1
Oil	4	9
Pulp and paper	3	8
Electric products	0	1
Dyeing and finishing	0	2
Soaps and detergents	3	6
Mineral wool	1	2
Photographic	0	2
TOTALS	28	80

sentatives were also asked to comment on how they thought the current water pollution control regulations affected the attractiveness of the option of innovating with wastewater treatment technologies.

The attitudes and actions surveyed fall into three categories: Energy and its relation to industrial wastewater treatment; industrial innovation in wastewater treatment; and industrial resource recovery. Since the primary purpose of this paper is to discern the thinking of industry on energy in wastewater treatment, the statements on this issue will be considered first.

3.2 ENERGY

The five statements concerning wastewater treatment energy consumption are listed in Table 4, in order of decreasing agreement.

3.2.1 Discussion and Comments

Statement 1: One can see that by almost a two to one margin, the industries responding did not consider the energy expenditure in their wastewater treatment to be significant. Of those who perceived energy to be a problem in wastewater treatment, two firms singled out aerovic biological treatment, and one noted that it had investigated, but not pursued, the use of solar energy to enhance such processes.

Table 4. Energy in Industrial Wastewater Treatment: Response to Statements

Statement	% Agree	% Disagree	% Unsure
1. The energy expended for wastewater treatment is insignificant when compared to the energy consumed in other manufacturing operations.	56	30	15
2. We keep data on the energy requirements of our wastewater treatment.	54	35	12
3. We have recently done a detailed energy analysis of our manufacturing operations, inclusive of our wastewater treatment.	50	31	19
4. When deciding whether to pretreat wastewater, or directly discharge into a water body, energy weighs heavily in our calculations.	16	56	28
5. This company has experimented with new, unconventional wastewater treatment alternatives which were chosen due to their energy-saving characteristics.	11	70	19

Statements 2 and 3: The response to those statements indicates greater action to assess the energy use of wastewater treatment than one might expect from looking at the response to Statement 1. However, the comments on this statement are helpful in resolving this seeming contradiction. Among these were indications that in some firms' recent energy audits of manufacturing facilities, wastewater treatment was excluded because it was not perceived to be energy intensive if wastewater treatment was included, only limited data were taken and sketchy estimates made. Also, a few firms noted that they had at one point in time taken data, but that it was not an ongoing activity.

Statement 4: The response to this is a further indication of the low level of concern for energy usage in industrial wastewater treatment. Comments on this statement included note of the fact that energy, together with regulatory, economic (e.g., user charges) and environmental factors were all considered in the process selection and design of industrial wastewater treatment systems.

Statement 5: The data on this statement, plus the comments made, show conclusively that in most innovation in industrial wastewater treatment, energy conservation is not an influential factor.

General Comments: There were two other significant comments on the energy/wastewater treatment question. One was that, "The main inputs to industrial wastewater treatment was capital, labor, and chemicals...therefore, energy is not significant." This brings up the point that in industrial wastewater treatment, as in municipal, a significant amount of net primary energy may be used in the production and transport of such chemicals.[6] The other comment was that the real potential for energy conservation in industrial wastewater lies in process water use and reuse, and not in end-of-pipe wastewater treatment. This will be discussed further in the section on resource recovery.

3.3 INNOVATION

The Department of Energy and the EPA are looking for new technologies which save energy in wastewater treatment. Since new technologies involve innovation, the industrial climate for innovation was assessed by soliciting responses to the statements in Table 5.

Table 5. Innovation in Industrial Wastewater Treatment: Response to Statements

Statement	% Agree	% Disagree	% Unsure
1. The federal government should provide tax incentives for innovation in industrial wastewater treatment.	73	8	19
2. Environmental regulations discourage innovation.	62	15	23
3. Apprehensions about an innovative wastewater treatment process being labelled "Best Available Technology," and being mandated on an industry-wide basis constitute the major disincentive to experimenting with an unconventional, potentially energy-conserving wastewater treatment technology.	52	26	22
4. If my company were to try an unconventional process for wastewater treatment, and that technology were to fail to meet EPA effluent standards, we would be fined by the EPA during the interim period necessary to return to a more conventional proven process.	44	16	40
5. This company has received federal grants for research in wastewater treatment.	15	78	7

[6] George Wesner, *Energy for Production of Consumable Materials*, ASCE, Journal of the Environmental Engineering Division, V. 104, No. EE3.

3.3.1 Discussion and Comments

Statement 1: The response to this statement is predictably overwhelmingly affirmative. However, one must be cautious in deciding whether such a tax incentive would actually stimulate such innovation, or whether the response was affirmative solely because any tax incentive can work to a company's benefit.

Statements 2 and 3: Again the response was predictably in the affirmative. When asked to comment on how environmental regulations affected the attractiveness of developing new wastewater treatment technologies, most firms responded that these regulations have a negative effect. The specific concerns are listed below:

- Uncertainty about what final removal requirements will be
- Tight timetables precluding orderly R&D effort
- Fines imposed if technology fails
- Fear of development being labeled "Best Available Technology" and being required "Regardless of Environmental Need"
- High risk, low return investments requiring scarce venture capital

Therefore the general industrial trend is to "go with the flow" and stick with proven systems which will meet the requirements.

Statement 4: The greatest amount of comment was on this statement. Two companies commented on their uncertainty as to this issue; one noted that if handled properly from the beginning of the project, that problem could be avoided; and one firm stated that the issue was subject to legal interpretation and probably site-dependent. Another company commented "That's the way the laws are written," and one stated that it was currently in litigation over that very issue. There is evidently a good deal of uncertainty over this issue, and if successful innovation for energy conservation is to be achieved in wastewater treatment, the question should be resolved.

Statement 5: The low number of research grants for industries is due to the fact that the major thrust of the federal research effort is in municipal wastewater treatment. The philosophy is that, while municipalities do not have the resources to develop means of treatment, industries do have such facilities, and they will pass the costs incurred for such efforts on to the consumer. Therefore innovation in industrial wastewater treatment would be achieved through market forces.

General Comments: Despite these expressed reservations, there has been a good deal of innovation by industries which were traditionally not in the wastewater treatment business. The companies listed in Table 6 and 7 are examples of firms which have recently entered into the environmental field.

Table 6. Firms Cited by Respondents as Having Developed Wastewater Technologies as Offshoots of Their Own Environmental Programs

Air Products & Chemicals, Inc.	B. F. Goodrich
Sun Oil	Amoco
British Petroleum	Chevron
DuPont	Monsanto
DOW	Campbell's Soup
U.S. Steel	Union Carbide
National Steel	FMC
Inland Steel	

Table 7. Firms Listed as Exhibitors at the 1979 Water Pollution Control Federation Conference

Allied Chemical	3M
ARCO Environmental	Owens Corning
Arm and Hammer	Polaroid
General Electric	

Many of these companies have approached the environmental arena as a new market for their traditional products. In that respect, the products and services may or may not be energy-intensive; energy conservation is rarely a consideration in the development or marketing of the product. In fact, of over 300 exhibitors listed in the SPCF conference directory, only nine cited energy efficiency as an advantage of their products.

One can see that although many firms perceive environmental regulations as a barrier to innovation, a substantial number of firms have entered the market with new environmental products and services. However, there is little impetus for energy conserving technologies in this area, and so from that perspective reduction in the energy usage for wastewater treatment is unlikely to occur.

3.4 RESOURCE RECOVERY

From the preliminary interviewing and background reading which were done in this study, it became apparent that there is a greater potential for energy conservation in industrial wastewater treatment through recovering wasted materials than through attempting to reduce the energy consumption of the present conventional treatment processes.

The statements in Table 8 relate to industrial resource recovery. Some of the statements were derived from statements made in a lecture by M. G. Royston[7] based on his book Pollution Prevention Pays. The purpose of including these eight statements was to determine the extent of agreement

[7] M. G. Royston, *Responsibility of Industry Towards the Environment*, the CONOCO Lecture, presented May 21, 1979.

Table 8. Resource Recovery: Response to Statements

Attitude	% Agree	% Disagree	% Unsure
1. Environment, industry, and energy constitute a single system.	68	20	12
2. Responsibility of industry towards the environment is indistinguishable from the responsibility of industry towards itself and towards its shareholders.	62	27	12
3. New constraints from environmental regulation have caused this company to totally rethink many of its productive processes.	48	26	26
4. Energy conservation and pollution prevention can be achieved simultaneously.	33	29	38
Action			
5. Just as my company has a system for taking inventory in its raw materials, intermediate goods and final products, we keep an inventory of material flows in in-plant waste streams.	59	22	19
6. We have instituted a program whereby we solicit input from all levels of the company as to how we might recover wasted materials.	54	15	31
7. The company I represent has found a market for materials which are recovered from waste streams.	35	50	15
8. We achieve short payaback periods for wastewater treatment equipment, by virtue of resources recovered which previously went down the sewer.	7	82	11

or disagreement with the theses presented in Pollution Prevention Pays, and to determine the status of industrial resource recovery operations in the United States. The assumption is that a firm which believes that "Pollution Prevention Pays" would respond to all eight statements affirmatively.

3.4.1 Discussion and Comments

Statements 1 and 2: These statements were entered into the questionnaire in order to determine whether the industries responding took a systematic view towards their own profits, energy conservation, and nonwaste resource recovering technologies. The affirmative responses to these statements would tend to indicate that that systematic view is commonly held. However, it is also possible that the statements were construed to be good ones with which to express agreement, from a public relations standpoint. This, in relation to actions actually taken, will be discussed in the general discussion below.

Statement 3: The affirmative response to this statement may indicate either of two situations. One is that the rethinking of production processes has led to changes which produce both higher profits and a cleaner environment. The other is that some thought has been given to the changes, but no action was taken.

Statement 4: The data for this statement show the widest divergence of opinion of all the statements. As in statements 1 and 2, an affirmative response would indicate a systems approach to the problem of energy and environment; the 67 percent unsure or disagreeing with the statement probably do not see the problem as one big picture.

Statements 5 to 8: The level of agreement with Statements 5 and 6 is an indication of good process engineering and management which have been practiced since well before environmental protection and energy conservation were salient issues. However, the response to statements 7 and 8, which are indications of whether an aggressive program to make "Pollution Prevention Pay," was alarmingly negative. Evidently most American companies are involved in fighting or barely complying with the regulations rather than looking for profitable ways to meet requirements.

General Discussion: One can see from Table 8 that there is a greater level of agreement with the more general, attitudinal statements than with the statements concerning actions taken by the firm. To test attitude as versus action, the following scoring method was used: for agreement, a value of +1 was assigned; for disagreement, a value of -1, and for uncertainty, a value of zero. These values were added up, both for the attudinal statements and for the statements relating to actions taken by the companies. While the number of companies with a net "score" greater than zero was 19 for the broad attitudinal questions, only 11 firms had a positive net score on the four statements of actions taken. Only one of the 28 respondents indicated agreement with as many as 7 of the 8 statements. This company's representative noted that

> "The primary focus at our company is reduction, if not elimination of the need for wastewater treatment. This is achieved through process change (such as process water use and reuse). We believe this is an environmentally sound approach, in addition to being the least expensive and most cost effective. Also, our experience indicates that major potential for energy savings lies in this area, not that of wastewater treatment."

If more industries were to adopt this approach, the energy, environmental, and economic situation would be ameliorated.

4 CONCLUSIONS

The following conclusions can be made from the survey results:

1. Most industries do not consider the energy usage for their wastewater treatment to be a major problem.

2. The greatest potential for net primary energy conservation relating to wastewater is in nonwaste, resource-recovering technologies rather than in end-of-pipe treatment systems.

3. Though some firms have been practicing certain nonwaste measures for many years, the data indicate that resource recovery is not nearly as widespread as it could be.

4. Federal Public Law 95-217 and its accompanying regulations provide little or no incentive for energy conservation in industrial wastewater treatment.

5 RECOMMENDATIONS

1. The Federal Government, through cooperative efforts involving industries, the Environmental Protection Agency, and the Department of Energy's industrial energy conservation and wastewater treatment energy conservation programs, can act as a catalyst for industrial resource recovery.

2. Further study should include estimates of how much primary energy could be conserved by nonwaste technologies in various industries. This would include a ranking of the best candidates for such energy conservation. One problem in doing such analyses, however, that the the data required are often propriet involving company secrets.

3. The progress in the industrial resource recovery area is most likely to occur independently, firm by firm. Government measure should be designed to encourage, not force, such actions.

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ACCLIMATION OF ANAEROBIC DIGESTERS TO INDUSTRIAL WASTES WITH THE ADDITION OF METALS WITHOUT LOSS OF METHANE PRODUCTION

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INTRODUCTION

The process of anaerobic digestion was studied as an energy source in relation to the treatment of a liquid industrial waste. This work shows the decisive role the digester feed plays in manipulating the composition and amount of gas resulting from digestion.

DIGESTER DESIGN AND OPERATION

Four, unmixed, bench-scale digesters were designed using three liter pyrex flasks containing 800 ml of sludge. These mesophilic digesters were maintained at a constant temperature of $35 \pm 0.5^{\circ}C$. For 89 days these units operated on a 15 day solids retention time where 53 ml were drawn off and 53 ml of feed added daily.

The feed used in this study, as was the seed to start the digesters, was obtained from a combined domestic and industrial wastewater treatment plant of the Metropolitan Sewer District (MSD) at Cincinnati, Ohio. Secondary return activated sludge and gravity thickened sludge were combined to form a mixture of approximately 4 percent total solids for the feed.

After the units had stabilized, an industrial waste was incorporated into the feed of 3 of the units. The industrial feed was obtained from a local drum recycling center where 210 liter drums were cleaned and restored for further use. The wastewater from this center consisted of a caustic soda cleaning solution, iron fillings from a blasting operation and industrial detergents which were all factors in the drum cleaning operation. This wastewater also consisted of residues found in the drums which averaged about 2 kg/drum. This residue could contain any or all of the following: oils, hydraulic fluids, paint, varnishes, solvents, dyes, coating materials, detergents, waxes or foodstuffs.(1) Through the incorporation of the industrial feed to the

MSD feed, the total solids in 3 were increased by 10 percent, 4 by 30 percent and in 5 by 50 percent in the daily feed. Digester 6 was used as a control being fed only the MSD feed.

Gas volumes were recorded daily and routine anaerobic digestion parameters tested were: gas composition, total and volatile solids, alkalinity, pH, chemical oxygen demand, ammonia and organic nitrogen and the supernatant and mixed liquor content of Cr, Cd, Pb, Cu, Ni and Zn.

RESULTS AND DISCUSSION

Of the various parameters required in evaluating the quality of digestion, gas volume, volatile acids, supernatant lead and methane composition are the most relevant here to the discussion of energy derived from the process. These are also the most important parameters dictating the properties of good digestion in this study.

Gas volume is the primary indicator of good digestion. A severe reduction in gas volume is the first sign of process instability.

Initially all digesters performances were comparable but by day 51, five's gas volume dropped off markedly as did digester 4 by day 58. Three, with the 10 percent industrial loading was still operating as well as the control. Five reached a low on day 58 and started the incline to normal gas production. Four did not reach its minimal production until day 77. The gas volume recovery in 5 occurred at a much faster rate than in 4 as shown in figure 1. Also shown here is that no significant deviation was demonstrated between digester 3 and the control.

In comparing 5 and 6, between 12 days of preliminary data (i.e. before any industrial waste was added to 5) and the last week of data collected, an increase in gas production by 9 percent was observed in 5 over 6. The industrial loadings had contributed to this increase.

The quantity and quality of gas produced in digestion is dependent upon the digester feed. A feed high in protein or fats will increase gas production and methane content. A carbohydrate feed will produce the opposite results, low gas volume and methane.(2) Digestion also particularly destroys materials with a high fuel value.(3)

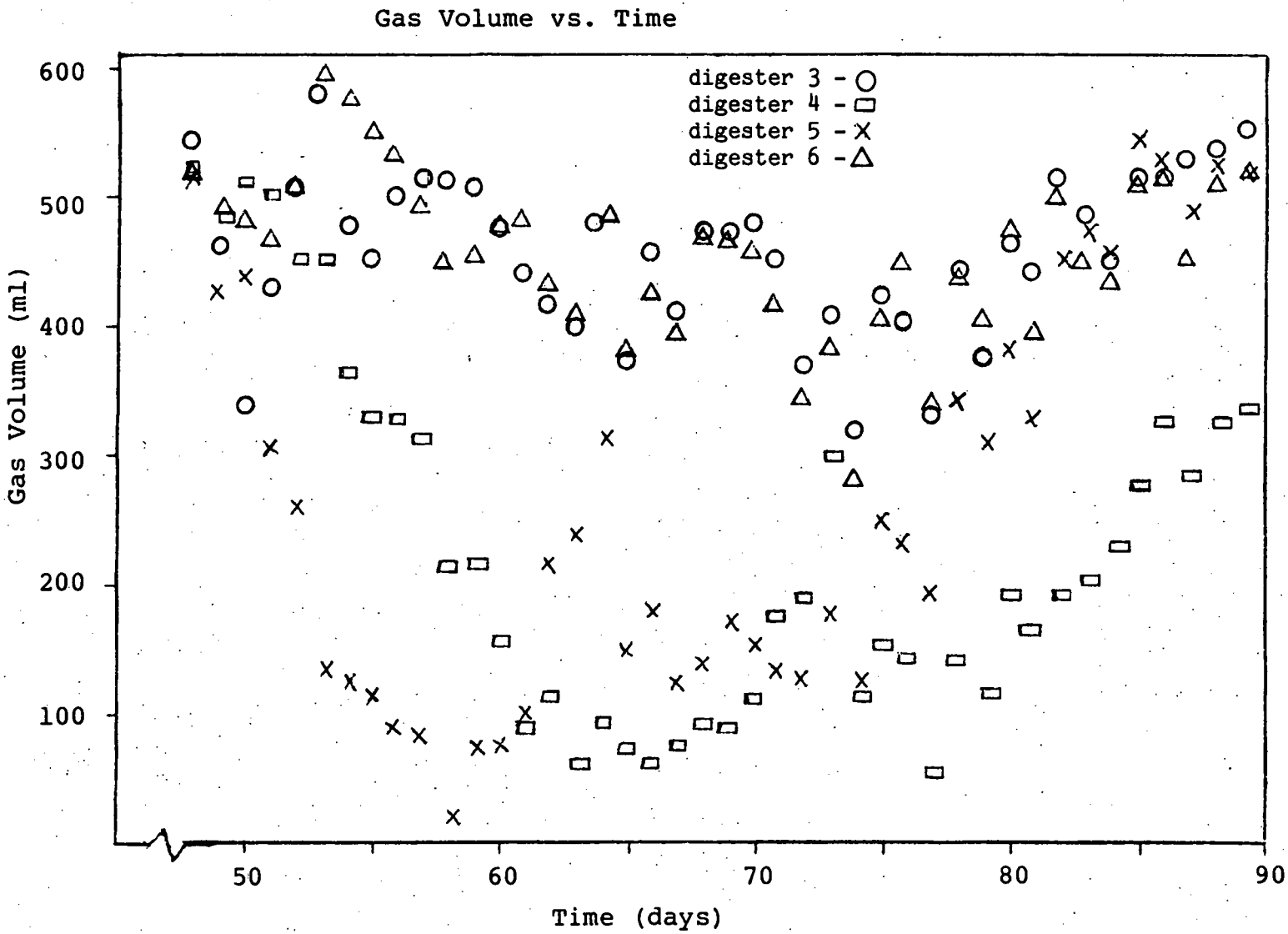

Gas Volume vs. Time
digester 3 - O
digester 4 - □
digester 5 - X
digester 6 - Δ
Gas Volume (ml)
600
500
400
300
200
100
50
60
70
80
90
Time (days)

Figure 1

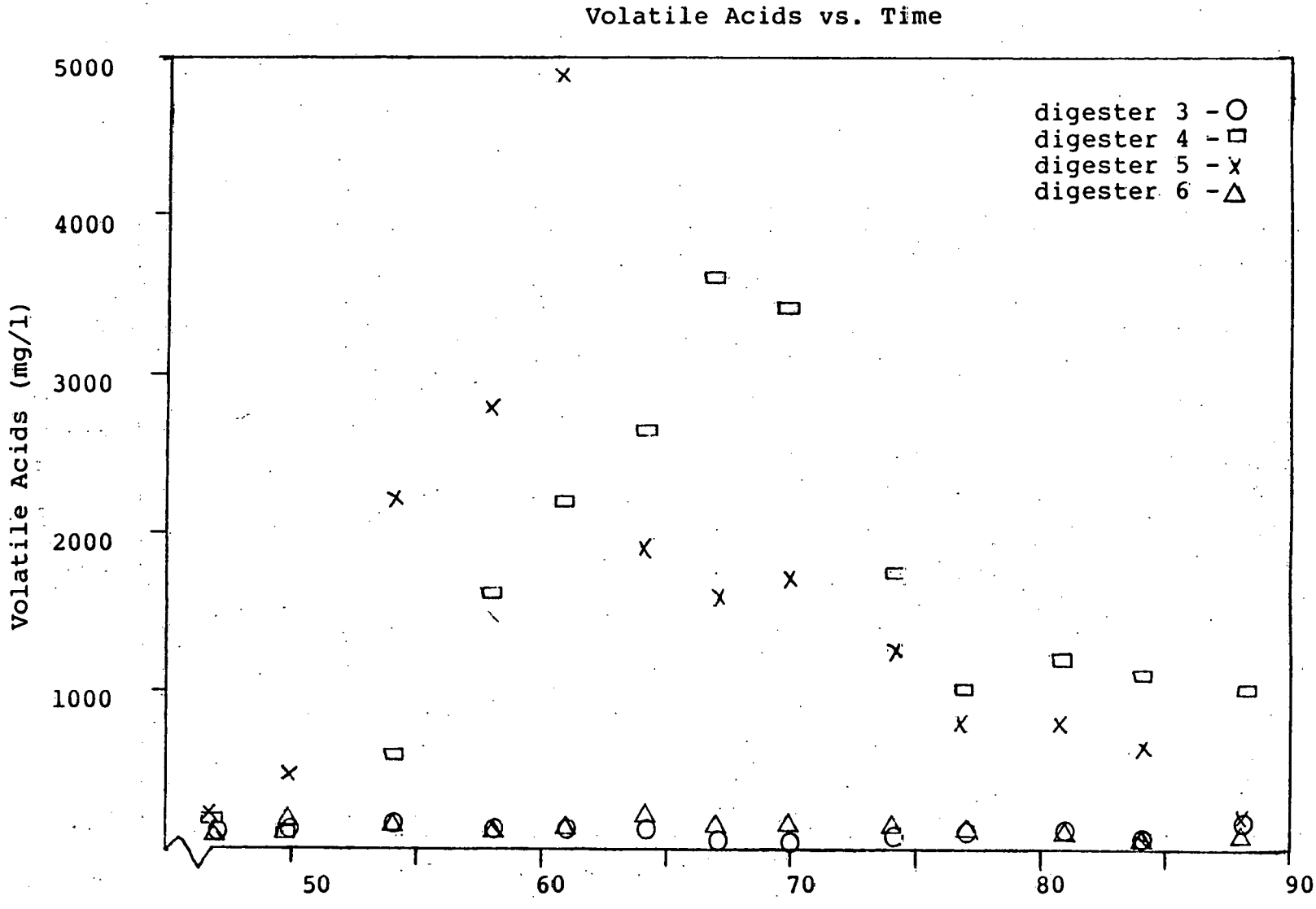

Volatile Acids vs. Time
digester 3 - O
digester 4 - □
digester 5 - X
digester 6 - △
Volatile Acids (mg/l)
5000
4000
3000
2000
1000
50
60
70
80
90
Time (days)

Figure 2

In addition to the greases and fats contained in the industrial feed, the soaps are another important element in gas production and quality. Soaps, which are comprised of sodium salts and fatty acids, are easily degraded by digestion. Since the fatty acids are the precursors of methane formation, a good quality of gas can be derived from soaps.

Soon after the gas volume in 4 and 5 dropped off, the volatile acids rose sharply. As expected, no difference in volatile acids was detected in unit 3 versus the control throughout the study (figure 2). The peak acid production coincides with the supernatant lead concentrations bordering the toxic limit of 1 mg/l in 4 and 5 (figures 3 and 4). The concentration of Pb in the industrial feed alone, was 1500 mg/l.

The methanogenic bacteria are easily inhibited or destroyed by the toxic effects exerted by the ionic species of the metals. Lead is one of the most toxic to digestion. The acid-forming bacteria, on the other hand, are more resistant to toxic conditions than the methane-forming bacteria. Additionally, acid-producers can double in minutes to hours whereas methane-producers have a doubling time of four to six days.(4) Under toxic conditions, acid-producers can quickly predominate.

As stated before, greases, fats and soaps contribute to the quantity as well as the quality of gas. Prior to toxic conditions in digester 5, the methane content had reached 75 percent (table 1). At its lowest performance, under toxic conditions, it was producing only 53 percent methane. As the unit recovered, so did the methane content. Probably, if the study had been extended, the percent of methane would have increased beyond the final 63 percent obtained.

Outside of the time period where 4 and 5 were experiencing toxic conditions, 3, 4 and 5 consistently produced more methane than the control. The process of anaerobic digestion lends itself to a minimum production of 50 percent methane gas. This is accomplished through the simple conversion of acetic acid to methane and carbon dioxide. As higher acids are degraded, the ratio of CH_4/CO_2 increases.

Gas Volume, Volatile Acids and Supernatant Pb vs. Time

Digester 4

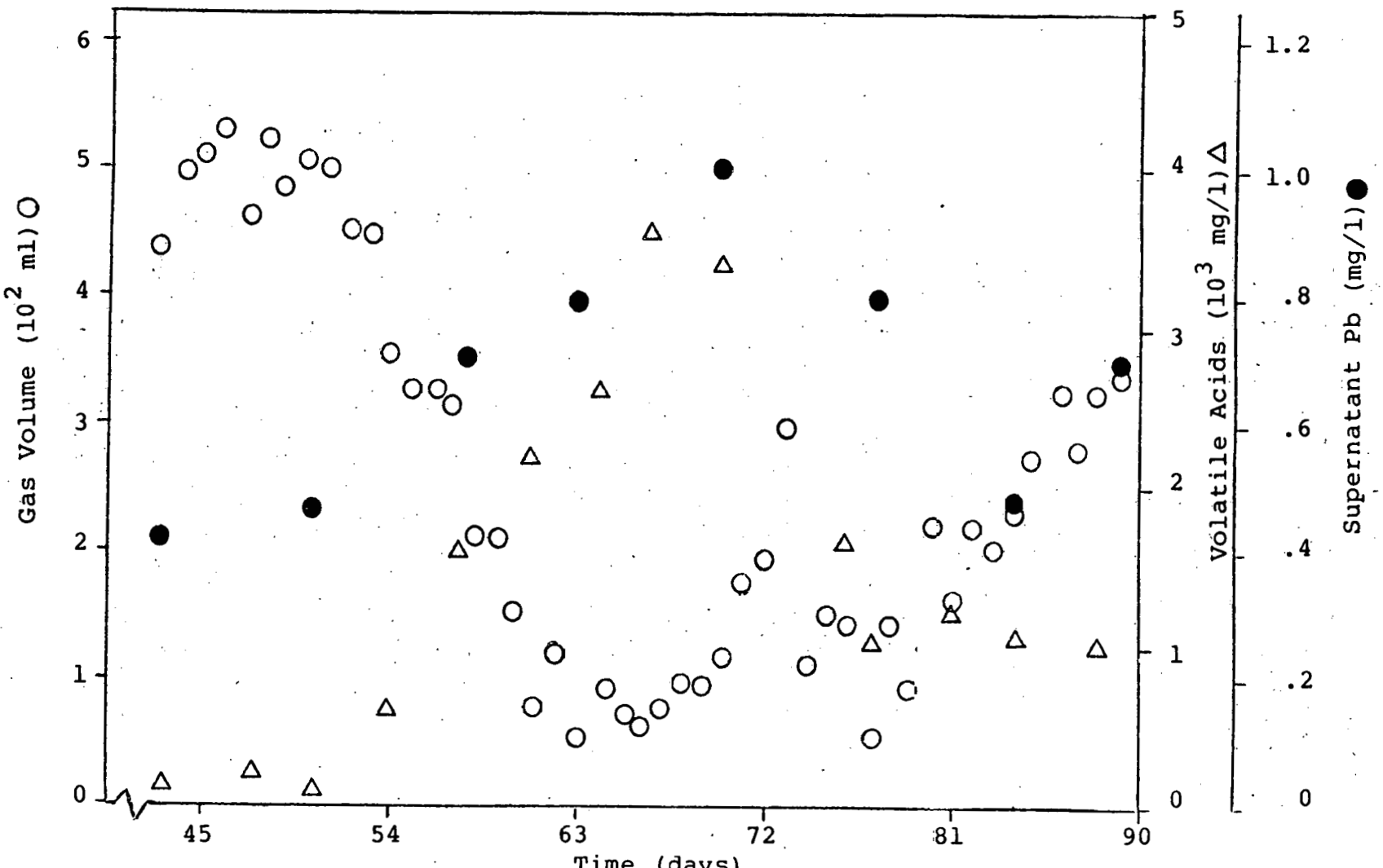


Figure 3

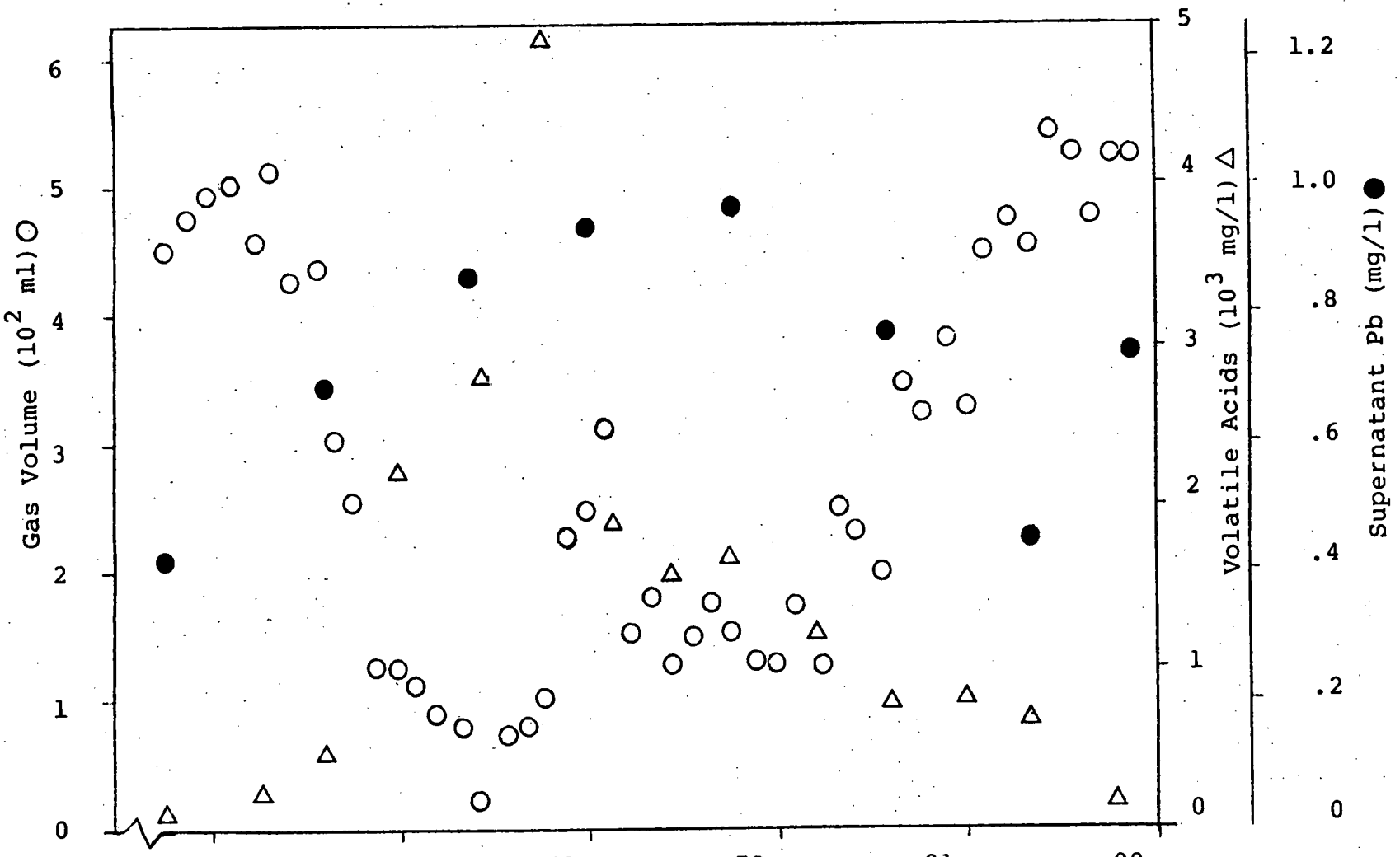

Gas Volume, Volatile Acids and Supernatant Pb vs. Time
Digester 5
Gas Volume (10^2 ml) ○
Volatile Acids (10^3 mg/l) △
Supernatant Pb (mg/l) ●
0
1
2
3
4
5
6
0
.2
.4
.6
.8
1.0
1.2
45
54
63
72
81
90
Time (days)

Figure 4

TABLE 1. METHANE GAS PRODUCTION

(Percent)

DAYS	UNIT 3	UNIT 4	UNIT 5	UNIT 6
45	64	63	65	62
48	62	60	75	56
53	65	63	66	63
55	60	60	60	58
59	62	60	59	60
62	62	58	53	60
66	64	58	59	61
69	61	57	60	59
73	62	53	60	60
77	64	55	62	61
80	64	59	63	62
83	64	59	63	61
87	62	56	63	60

CONCLUSIONS

Through the degradation of soaps, fats and greases, longer chain fatty acids are produced thereby improving the gas quality and production. The acclimation of the methanogenic bacteria to the higher concentrations of supernatant lead raised the level of toxicity.

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METHANE GENERATION FROM WHEY FOR ENERGY PRODUCTION AND POLLUTION CONTROL

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INTRODUCTION

Whey is the most visible pollutant in dairy food plant wastewaters. It is a green-yellow liquid and a by-product of all cheese production. Each pound of cheese produced results in five to ten pounds of fluid whey. In the United States, approximately 37×10^9 pounds of whey (1) are produced each year.

The high organic content of whey leads to a severe disposal problem. The biochemical oxygen demand (BOD) of whey ranges from 32,000 to 60,000 mg/l (2). Every 1000 gallons per day of raw whey discharged into a sewage treatment plant can impose a load equal to that from 1800 people. Thus, whey is produced in large volumes with a high organic content.

Whey can be thought of as a resource awaiting discovery. It has a high content of lactose and protein. Over the recent past, several investigations have developed new schemes of whey treatment with the emphasis on product recovery and new product development. Among these efforts have been fermentation of whey for alcoholic beverage production (1); drying of whey into powder which may be used as animal feed or as a supplement in human foods (3); separation of whey components by membrane technology (2); and fermentation of whey for protein production (4). Many of these schemes, however, are limited to larger dairy producers due to economic constraints. At this point whey is still a significant waste problem necessitating proper treatment.

The types of waste treatment methods used in the dairy food industry are primarily activated sludge, trickling filter, aerated lagoons, irrigation and a combination of these processes. Another waste treatment alternative which has only been used sparsely is the anaerobic process. Anaerobic processes were at one time used in the septic tank treatment of the waste from very small dairies. As these dairies grew, most turned to aeration, then conventional activated sludge units. However, the few reports of anaerobic

treatment of dairy waste have shown that the process can obtain good treatment efficiencies using conventional, contact, and fixed film processes. (5)(6)(7)(8)(9)

Anaerobic treatment offers several advantages over aerobic processes (10), such as 1) a higher degree of waste stabilization, 2) a lower microbial yield, 3) a lower nutrient requirement, 4) no oxygen requirement and 5) methane gas production. With regard to anaerobic treatment of whey, these advantages are pronounced since whey constitutes a high organic loading which is often deficient in nutrients. In addition, the methane produced, a high quality automatically separated form of energy, can be used at the cheese production plant for heating and cooking (i.e. a ready market demand at its source of production). It represents a significant resource recovery.

Thus anaerobic fermentation offers a dual benefit to cheese manufacturers — energy production and pollution control. Yet, it is used only sparsely for the treatment of whey. This most likely is a result of the general feeling of unreliability anaerobic processes receive due to several limitations commonly associated with the process. Foremost are the temperature requirements of 35°C for efficient treatment and lack of stability following changes in loading rates or temperatures. Recently, research on a new type of fixed film process shows promise of overcoming these limitations. (11)(12)

The process is called the anaerobic attached film expanded bed (AAFEB). The AAFEB process consists of a column packed with inert sand sized-particles which expand with the upward flow of waste through the column. The particles act as a support surface for the growth of microbial films and provide a large surface area-to-mass ratio. The nature of the bioreactor insures a high degree of contact between the biomass and substrate, and is capable of high biomass concentrations. The AAFEB is similar to fluidized bed reactors commonly used in chemical engineering processes. Fluidized beds have been used for the aerobic treatment of wastes for BOD, nitrogen and phenol removal (13)(14) and for denitrification (15).

The AAFEB has been demonstrated to be a reliable process for the treatment of domestic sewage and a dilute synthetic waste anaerobically, with greater than 80% removal at high organic loading rates (up to 0.5 lbs/ft^3/day), at low detention times (several hours) and at reduced temperatures

(10°C, 20°C) (11)(12). This paper will report on a preliminary study involving the use of the AAFEB for the treatment of a more concentrated waste, whey, for waste treatment and energy production. This paper will also report on a survey conducted by the New York State Energy Research and Development Authority among cheese manufacturers in New York State. This survey helps to define energy consumption at cheese plants and the potential utilization of substitute natural gas from whey for energy at the plants.

SURVEY

New York State is a large dairy state, generally ranking near the top of the United States in terms of total dairy production. In 1977, 400 million pounds of cheese were produced in New York State resulting in the generation of 2.3 billion pounds of whey. According to the New York State Department of Agriculture and Markets, cheese production is increasing as the demand for cheese is growing in New York. Consequently, whey production is increasing.

In order to ascertain the potential for recovery of methane from whey and its subsequent utilization at the dairy plants and to examine other questions such as 1) current whey treatment/utilization practices and associated costs in New York State; and 2) interest in anaerobic fermentation as a whey treatment alternative, a survey was conducted. This survey was conducted in the form of a questionnaire by the New York State Energy Research and Development Authority. Questionnaires were mailed to 47 cheese manufacturers in the state. Responses were received from 24 of the manufacturers. Some additional data were obtained from two more plants from the New York State Department of Agriculture and Markets. It was felt that most of the major cheese manufacturers in the state were then represented in the tally even though only slightly more than half responded.

The 24 plants in the survey together produced 2.1×10^9 pounds of whey annually (1.079×10^9 pounds acid whey, 1.043×10^9 pound sweet whey), with a range of from 1×10^6 to 250×10^6 pounds per year. The present treatment/utilization practices are shown in Table 1.

The costs of implementing these various practices varied from zero to $3.60 per thousand pounds of whey. The price depends upon the method used, the location of the plant, the value of the product produced (e.g. dry whey powder) and the opportunity for utilization. For example, some producers

Table 1. Present Treatment/Utilization Practices

Method	Number
Sewer discharge	5
Dried or condensed	12
Land application	3
Given away	3
Membrane technology	1

were able to give away their whey to farmers and thus the producer paid nothing for whey processing. Others who were located near agricultural land were able to apply whey to the land by irrigation and paid only a minimal cost for disposal. The producers who dried or condensed their whey were able to recover some of the costs associated with processing by selling the whey as either a human or animal food supplement — but most all of these manufacturers stated that this was not a profit making practice. In fact, only one of the respondents considered whey an asset; the others considered whey a definite liability. All but one of the respondents expressed interest in anaerobic fermentation as a treatment process if it were economically practical.

The major point of the survey concerned the potential for implementation of methane recovery from whey at the cheese manufacturing plants. The results for the survey plants of this inquiry are shown in Table 2.

Table 2 was constructed as follows. First, from the questionnaires, the oil and gas needs of the cheese plants were noted. Where quantities were reported, these were indexed to current prices (October 1979) for natural gas and number 6 fuel oil (the oil most commonly used at dairy plants). Where only prices were given, they were used as such.

Next the energy value of the whey was calculated. The quantity of whey produced was first converted to mass of BOD and then to cubic feet of methane (5.63 ft^3/pound BOD) and assuming a conversion efficiency of 80%. The quantity of gas was then translated into its natural gas equivalent at current prices and to its BTU equivalent as number 6 fuel oil, also at current prices.

Finally, the energy demands and energy value of the whey were compared on a total basis, that is, the total amount of gas (or oil equivalent) able

Table 2. Potential For Implementation For Methane Recovery of Whey

Energy Usage at Plants (1978)

Oil	:	$\$3.37 \times 10^6$/year[1]
Gas	:	$\$1.59 \times 10^6$/year[2]
Oil or gas	:	$\$0.73 \times 10^6$/year
Total	:	$\$5.69 \times 10^6$/year

Whey Energy Value (1978)

Natural gas equivalent: 5.72×10^8 ft^3 = $\$1.83 \times 10^6$/year[1]

#6 Fuel oil equivalent: 3.82×10^6 gallons = $\$2.06 \times 10^6$/year[2,3]

Potential Recovery

Total basis: 32.2 - 36.2

Average at all plants: 35.8%

Average at plants with drying/condensation: 19.0%

Average at plants without drying/condensation: 46.2%

[1]Assume as #6 Fuel Oil at cost of $0.54/gallon

[2]Assume cost of $0.32/100 cubic feet

[3]Assume one gallon #6 fuel oil = 150,000 BTU or 150 cubic feet of gas

to be generated from whey compared to the total amounts needed at the manufacturing plants. A potential recovery of 32.1 - 35.6% (depending on which basis, oil or gas) was found. Averaging each individual plant, a mean value of 35.8% was calculated.

It should be noted that the most often used whey processing scheme among the plants in our survey was drying and condensation of the whey. This practice is quite energy intensive and several of the respondents listed it as a major energy demand. If we divide the plants into those with drying or condensation and those without this practice, we are able to see a more realistic value of the potential for energy recovery from whey by anaerobic fermentation. This is so because if a given plant were to practice anaerobic fermentation (methane production and waste stabilization), whey would not be dried, thus lowering the energy demand at the plant. In this context, a

potential recovery of 46.2% (plants without drying) can be achieved. Thus, it can be seen that the energy produced from the whey represents a significant recoverable energy resource.

PRELIMINARY WHEY TREATMENT STUDY

The AAFEB has been shown to be effective for the removal of domestic sewage (12) and a synthetic dilute waste (11) anaerobically at retention times on the order of several hours; at high organic loading rates (up to 0.5 lbs/ft^3/day) and at reduced temperatures. In addition, the process was found to be able to acclimate well to changes in temperature and/or organic loading rates (12). The good performance at low temperatures and the stability exhibited by the process are two important advantages in that these are usually considered major problems with anaerobic treatment.

As the AAFEB had been developed for the treatment of dilute wastes, rather than for more concentrated industrial wastes such as whey, a preliminary feasibility evaluation of whey treatment was conducted. A prototype AAFEB reactor, used in the previous studies (11)(12) was used. The reactor was constructed from plexiglass, 5.08 cm inner diameter and 49.36 cm in length. It contained 400 ml of aluminum oxide particles which had an apparent diameter of approximately 500 microns. During operation of the reactor, the particles which were coated with a biological film, were expanded by a recycle pump to a volume of 500 ml (i.e. an expansion of 25%). Thus the expanded bed occupied a total volume of 500 ml. All subsequent loading values will be based on this 500 ml volume.

The substrate used for this study consisted of sweet whey powder, ammonium phosphate as a supplemental nutrient source and sodium bicarbonate as a buffer. The exact components of the feed are shown in Table 3.

Table 3. Component of Feed Solution

10 grams sweet whey powder
10 ml 1M $(NH_4)_2HPO_4$
5 grams $NaHCO_3$
Tapwater
Total volume = 1 liter

The feed was kept in a refrigerator to prevent excessive degradation and pumped into the expanded bed.

The experimental conditions of this preliminary study are summarized in Table 4.

Table 4. Experimental Conditions

Influent substrate concentration:	TCOD = 10,000 mg/l SCOD = 8263 mg/l
Hydraulic retention time:	24 hours - 4 hours
Organic volumetric loading rate:	10-60 kg COD/m^3/day
Temperature:	25-31°C

The organic strength of the waste was kept constant throughout the study, and the temperature was the ambient room temperature usually around 26°C. However, it did vary throughout the study. The only variable was the hydraulic retention time and subsequent organic loading rate. Six different retention times were investigated ranging from 24 hours to 4 hours.

The AAFEB has been used for the previous studies, and thus had already developed a sufficient biomass when this study commenced at an initial HRT of 24 hours. After 30 days of operation, data were taken on three successive days for the 24 hour retention time. The retention time was then decreased to 18 hours. For all subsequent changes in loading, 20 HRT's were allowed to pass before the next set of three day consecutive data were taken. The following parameters were measured: total and soluble chemical oxygen demand (TCOD, SCOD); suspended and volatile suspended solids (SS, VSS); pH; and organic acids.

Effluent data for TCOD, SCOD, pH and organic acids are shown in Figures 1, 2, and 3. Each point in these and subsequent figures are means of the three data points collected at each loading condition. The performance of the process can be evaluated in terms of removal of soluble COD. Figures 4 and 5 show organic removal efficiency as a function of the hydraulic loading and organic loading respectively. Gas was neither collected nor measured during this preliminary study. However, based on the theoretical relationship of 350 ml methane produced per gram of COD removed, the production rate of methane can be predicted. This is shown in Figure 6.

In examination of the data several promising trends can be noted. The process was able to achieve high organic removal efficiencies (87% and greater) at relatively low retention times (12 hours and greater) and at high organic loading rates (up to 20 Kg COD/m^3/day = 1248 lbs COD/1000 ft^3/day). In addition to high removal efficiencies, large quantities of methane can be generated (5-6 volumes of gas per volume of reactor, based on 500 ml reactor volume).

It should also be noted that although high organic removal efficiencies were achieved, the effluent was still high in COD because of the high influent concentration, and thus might require further treatment. Also, despite the addition of 5 grams of $NaHCO_3$ to the whey feed, the pH of the reactor did decrease at the higher loading conditions, and thus better pH control might be necessary for operation at these conditions.

It was concluded from this preliminary feasibility study that the AAFEB shows significant potential for the treatment of whey. High removal efficiencies can be achieved at low retention times operating at an ambient temperature range. This high rate performance can be more clearly recognized by comparing the results of this study to one conducted with an anaerobic filter treating whey (9). With an anaerobic filter, Hakannsson (9) was able to achieve a high organic removal efficiency (97% COD removal) with an influent COD concentration of 8100 mg/l but at a much lower organic loading rate (1.9 Kg COD/m^3/day, as compared to 20 Kg COD/m^3/day in this study).

It must be pointed out, however, that while these results are encouraging, they are highly preliminary in nature and only demonstrate that the process is potentially feasible for methane generation from whey. More work will be needed to further define the efficiency and the effect of environmental conditions on the process. At the present time, further work is being conducted in laboratory of the principal author.

SUMMARY AND CONCLUSIONS

Anaerobic treatment of whey offers the dual advantage of energy production and pollution control. The energy produced is in the form of methane which is a valuable form of energy in that it is easily separated from the liquid digesting whey, has a high caloric value and can be used for

heating and cooking at the cheese plants where it is produced. Based on the data of a survey conducted by the New York State Energy Research and Development Authority, it was shown that a significant portion (up to 46%) of the energy needs (in natural gas and oil) at cheese production plants in New York State could be recovered by methane generated from whey produced as a by-product of cheese manufacturing at the plants.

Finally, the results of a preliminary feasibility study of a new type of innovative, compact, high rate, anaerobic fixed film process show that efficient treatment of whey is possible at low retention times, at ambient temperatures and at high organic loading rates.

ACKNOWLEDGMENTS

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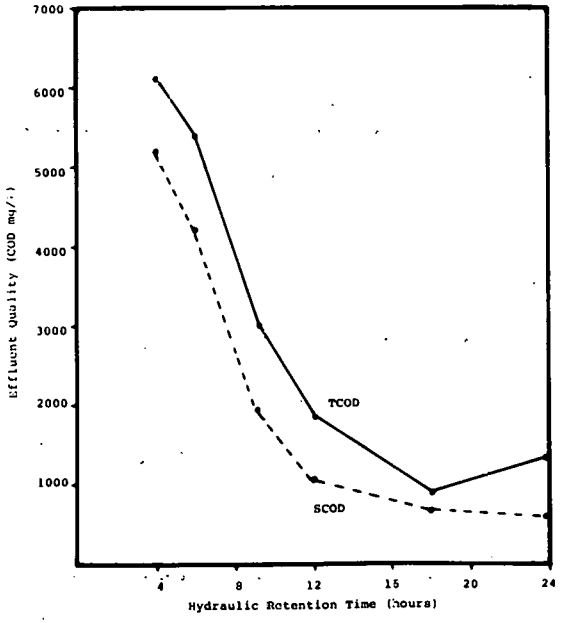
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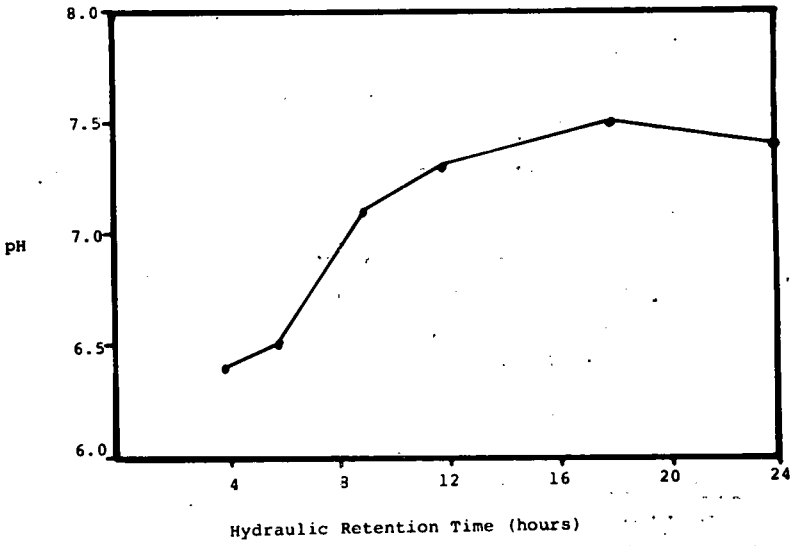
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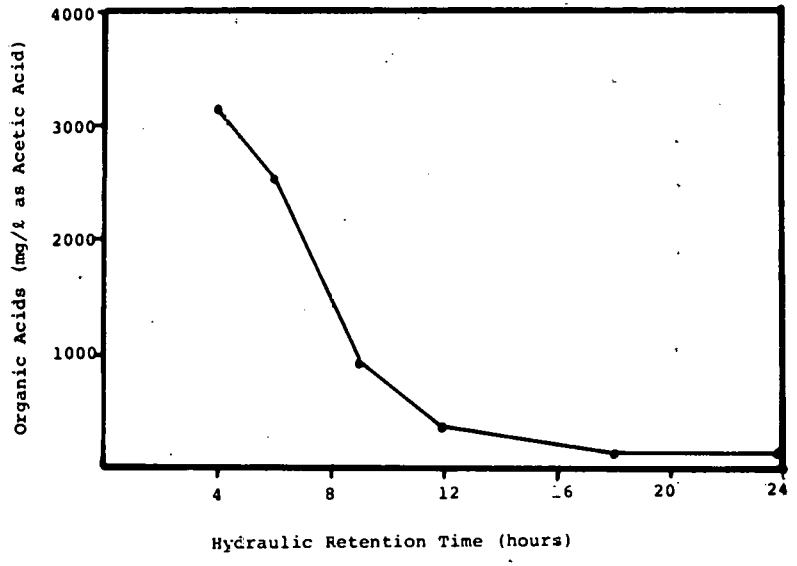
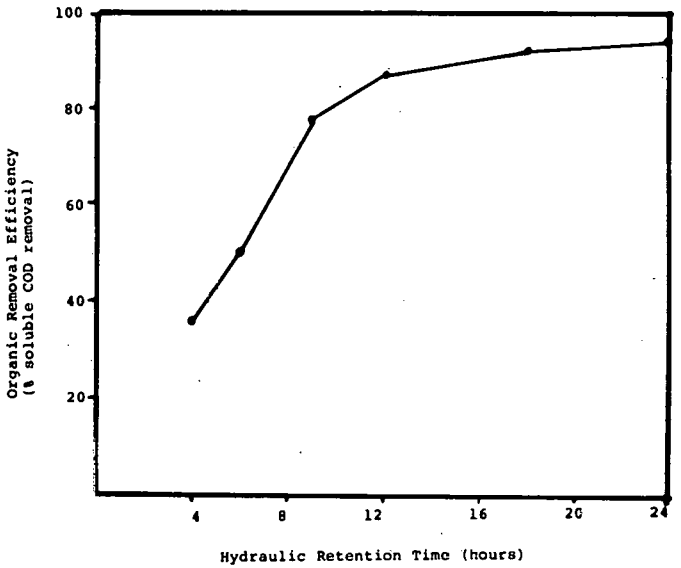
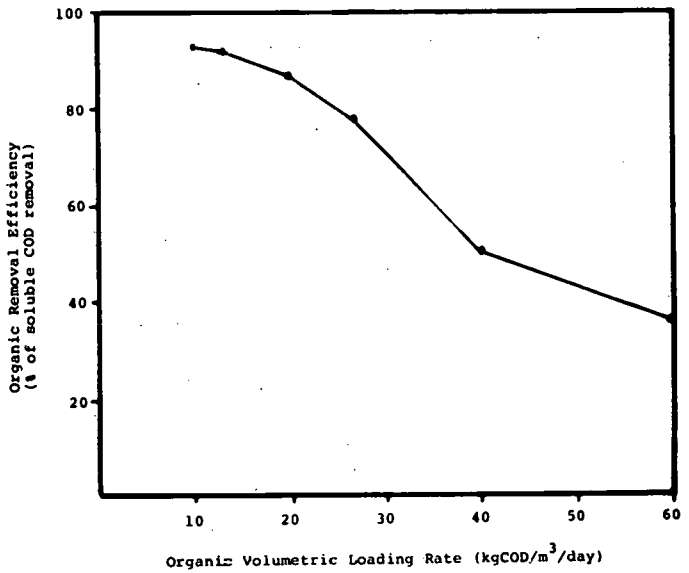


Figure 1 (Top, left) - Influence of hydraulic retention time on effluent quality as chemical oxygen demand.

Figure 2 (Top, right) - Influence of hydraulic retention time on pH.

Figure 3 (Bottom) - Influence of hydraulic retention time on organic acids concentration.





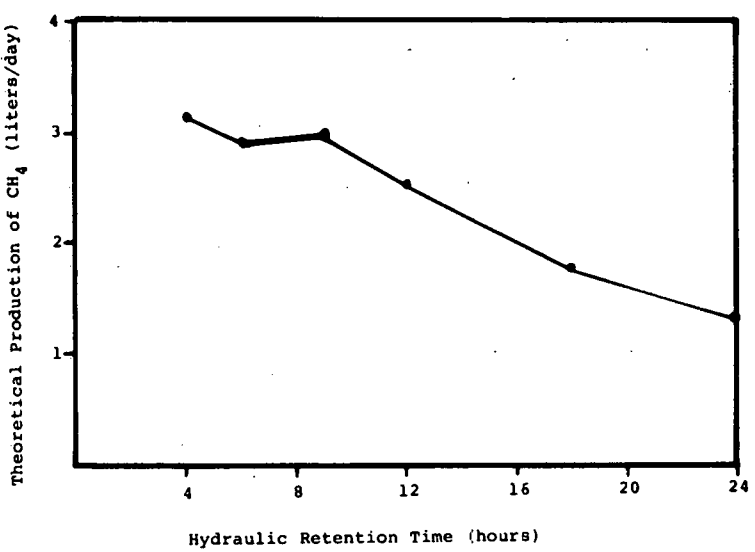


Figure 4 (Top, left) - Influence of hydraulic retention time on the organic removal efficiency of the AAFEB treating whey.

Figure 5 (Top, right) - Influence of organic volumetric loading rate on the organic removal efficiency of the AAFEB treating whey.

Figure 6 (Bottom) - Theoretical production of methane for the AAFEB treating whey.

LAND APPLICATION AND RECYCLING OF INDUSTRIAL WASTE THROUGH FORAGES

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Under the Federal Water Pollution Control Amendments of 1972, land application is recognized as an alternative method for effecting stages of wastewater treatment and for ultimate disposal of solid wastes. Both the U. S. Environmental Protection Agency (EPA) and the Washington State Department of Ecology (DOE) are currently promoting land application of municipal and industrial wastes.

Several basic points relating to land application of wastes have been developed (3).

1. Land is a valuable natural resource and the viability and productivity must not be endangered during application of wastes.
2. The system must be managed so that normal agricultural production can be maintained without sacrificing crop quality or yield.
3. A balanced system must be established so that the finite limits of the regeneration processes of the soil are not exceeded.
4. Primary emphasis is upon utilization of the usable resources in the waste constituents rather than providing a disposal site.

The capacity of soils to receive wastewater and sludges and to inactivate contaminants varies greatly, depending upon a variety of soil, plant, and climatic factors. Most well-aerated soils are generally quite efficient in organic matter conversion so that BOD loading is not a direct problem. Certain nutrients, such as nitrate-N, which are produced by organic matter break down, may become a problem at high loading rates. Soils with high water infiltration capacity, which would allow large water loading rates, may be ineffective in trapping nutrients even though BOD elimination is rapid. The soil selected for waste application on land must therefore be chosen on the basis of waste characteristics, site operation and management

aspects, cropping systems, and other factors which make each decision an individual undertaking. The best soil for receiving waste application is usually dictated by a necessary balance between potential soil loading rates and potential environmental contamination.

STANDARD BRANDS WASTE DISPOSAL PROJECT

Standard Brands, Inc., is located in the northwest portion of Sumner, Washington near the confluence of the Stuck and Puyallup Rivers. The company has operated a commercial yeast propagation facility at that location since 1913. Waste effluent from the plant was initially discharged into the Stuck River, but with the emergence of environmental concerns, particularly as related to water quality, the wastewater discharge was diverted to the Sumner sewage treatment plant. As Sumner and its surrounding area are experiencing rapid growth the sewage treatment plant soon became overloaded. The company then turned to land disposal using nutrient recycling through forage crops as a solution to the problem.

WASTE EFFLUENT COMPOSITION

The effluent consists of two sources: second separation beer and molasses-yeast condensed solubles (MYCS) condensate resulting from evaporation of first separation beer. The two materials have a relatively constant ratio of 1:1. Chemical analyses of the wastes are presented in Table 1.

Table 1. Composition of first separation beer condensate and second separation beer (2).

Material	Total N	Nitrate	Potassium	Phosphate	BOD
	ppm				
MYCS condensate	3.7	0.14	0.7	0.10	1670
Second beer	17.0	0.10	560	12	2060

SOIL AND CLIMATE CHARACTERISTICS

Standard Brands Inc., owns two tracts of land near their yeast producing facility that are available for a land application waste disposal system. Field I consists of 4.4 acres whereas Field II has 7.8 acres.

Soils within Field I consist of Sultan silt loam and Puyallup fine sandy loam (1). Both of these soils are within zero to 3% slope, generally well drained and are considered to be good agricultural soils. They closely fit the desription of the ideal waste disposal soil (3) except that the Sultan series is somewhat prone to soil compaction under certain conditions.

All soils in Field II are Sultan silt loam.

Western Washington has a marine climate characterized by moist mild winters. Spring time weather is usually moist; the period from June through September is usually the driest part of the year. Annual precipitation at at Sumner is approximately 40 inches.

Analyses for NO_3-N in soil samples taken from Field 1 May 1978 and Field II May 1979 prior to waste application are given in Table 2.

Table 2. Initial NO_3-N concentrations in soil layers of the two waste effluent disposal areas.

Soil depth	Field I	Field II
feet	NO_3-N, ppm	
1	5.4	5.9
2	6.4	4.3
3	5.6	4.1
4	5.8	4.0

NUTRIENT RECYCLING CROP

Soil and crop management are the key to success with any waste disposal system of this nature. Field I was plowed and a clean seed bed established in the fall of 1977. A forage seeding mixutre of red clover (Trifolium pratense), white clover (Trifolium repens), rye grass (Lolium perenne) and orchard grass (Dactylis glomerata) was seeded October 11, 1977. Seedling emergence was good for all materials, but because the seeding was rather late and was followed by cool weather, the ryegrass quickly dominated the stand. By the spring of 1978 when waste application commenced, the stand was primarily ryegrass.

Field II contained a thick, pure stand of established orchardgrass at the time it was converted to a wastewater disposal site.

EFFLUENT APPLICATION

Wastewater applications were made to Field I starting June 3, 1978 after the spring growth was harvested as green chop forage and were continued throughout the year. Treatments to Field II did not start until May 1979. Wastewater was applied to both fields throughout the growing season of 1979, but the loading rate was less than that applied to Field I in 1978 when it was the only operational site. Wastewater application to Field I totaled 19.9 acre-inches in 1978 and 16.2 acre-inches in 1979; Field II received 14.1 acre-inches in 1979.

All wastewater was applied by means of a self-propelled side-roll irrigation system. Application to Field I from June 1 through September 30, 1978 was 1.16 acre-inches/week and 1.01 acre-inches/week for the same period in 1979. Field II received 0.92 acre-inches/week in 1979.

Quantity of nutrients applied to the land through the waste disposal system are given in Table 3.

Table 3. Nutrient loading of Field I and Field II in 1978 and 1979.

Field	Year	N	P	K
		------- lb/acre -------		
I	1978	223	157	1360
I	1979	180	127	1096
II	1979	155	109	995

FORAGE HARVEST AND NUTRIENT REMOVAL

Above normal precipitation during August and September of 1978 required a reduction in waste application below the anticipated quantity. During the latter part of the summer soil compaction, lowered infiltration rates and puddling began to occur. These problems appeared to be the result of the high rate of waste loading and precipitation associated with intense traffic from harvesting equipment required to remove the forage. Plant growth was vigorous and frequent harvest schedules were required. Forage was removed by means of a tractor operated pull-type forage harvester and a feed truck. The small area to be harvested at any given time required many sharp turns and the resulting traffic pattern imposed upon saturated soils caused some stand damage. The forage harvester was old and well-worn which caused it to lose chopped forage back to the soil surface. The accumulation of chopped forage tended to seal the soil surface and further decrease the infiltration of waste water.

During the June 1 to September 30, 1978 period when forage production was monitored, large quantities of forage and nutrients were removed from the site. Average crude protein concentration was 21% in 1978 and 14% in 1979. The larger area available for waste disposal in 1979 allowed longer periods between harvesting, hence the grasses were more mature and the percentage of crude protein was lower. The forage was analyzed in 1978 to determine the possibility of livestock poisoning from nitrates, but was found to contain only 0.09% NO_3-N, which is well below the toxicity threshold.

Forage yields and quantities of nutrients removed by cropping are presented in Table 4.

Table 4. Total yield and nutrient removal from spray field effluent disposal site by forage harvesting.

Field	Year	N	P	K	Forage yield (3% moisture)
		------ lb/acre ------			tons/acre
I	1978	364	33	484	5.5
I	1979	171	23	334	3.8
II	1979	317	43	422	7.1

INFLUENCE OF WASTE LOADING ON SOIL ANALYSES

Soils were sampled at approximately thirty-day intervals by one-foot increments to a depth of four feet and analyzed for NO_3-N during both years. The NO_3-N data is presented in Table 5.

Table 5. Nitrate-N concentrations from soils in spray irrigation disposal areas during periods of heavy waste loading.

Field I 1978

Soil depth	Date sampled 6/30	7/26	9/5	10/6
feet	---------- NO_3-N, ppm ----------			
1	8.1	7.4	9.9	13.0
2	3.9	3.2	8.6	6.7
3	2.3	2.4	5.6	2.9
4	6.2	3.9	3.0	1.5

Field I 1979

	5/9	6/13	7/25	8/28	10/2
feet	---------- NO_3-N, ppm ----------				
1	11.3	16.7	19.7	18.3	26.8
2	12.0	16.0	18.3	13.0	20.5
3	9.3	11.4	14.6	19.1	17.0
4	4.8	7.8	15.0	13.1	14.6

Field II 1979

	5/9	6/13	7/25	8/28	10/2
feet	---------- NO_3-N, ppm ----------				
1	6.2	6.6	3.4	7.3	7.6
2	4.3	6.3	3.1	0.7	3.9
3	4.1	7.1	3.3	0.6	2.8
4	4.0	7.5	3.4	1.2	2.1

The NO_3-N data from Field I indicate the grass system worked well by intercepting and utilizing the applied nitrogen and that NO_3-N loss to the ground water aquifer was minimal in 1978. This is further substantiated by NO_3-N analyses of water drawn from peiziometer tube test wells installed in and around the location. Nitrate-N concentrations remained low (2 to 4 mg/l) in these aquifer samples and were comparable to the background values obtained from the wells prior to waste application.

The 1979 NO_3-N data from Field I show the effect of the reduced efficiency of nitrogen removal by the damaged grass stand. Nitrates increased throughout the soil profile as the season progressed. The stand density was much reduced in 1979 as compared to 1978, not only because of harvesting impacts already discussed, but also as a result of an unusual and extremely long, cold period during the winter when the field had no snow cover. The increase in soil nitrates corresponds with the reduced removal of nitrogen by the crop and the much lower forage yields obtained from Field I in 1979 as compared to 1978 (Table 4).

Data obtained from Field II in 1979 show that soil nitrates remained low and forage yields were exceptionally high. Peiziometer tube test wells in and around Field II were sampled for NO_3-N and the water was found to have only the background concentrations of nitrates.

General soil test data from Fields I and II are presented in Table 6.

Table 6. Soil analyses data for three sampling periods from two effluent disposal areas.

Location	pH	Organic matter	P	K	B	Ca	Mg	CEC	Base saturation
		%	----	ppm	----	mg/100 g soil			%
Field I									
Spring 1978	5.8	3.7	1.3	427	0.57	6.40	2.05	15	66.3
Fall 1978	6.4	3.6	1.6	557	0.48	6.70	1.84	16	70.7
Fall 1979	6.5	4.1	1.3	905	0.36	7.05	2.04	18	71.0
Field II									
Spring 1979	5.7	2.9	7.2	398	0.26	6.89	1.27	19	53.5
Fall 1979	5.8	3.0	6.1	465	0.31	7.49	1.40	20	56.5

The most notable changes that have occurred are increased pH and K, particularly for Field I which has been in operation a year longer than Field II. There is also an indication that organic matter, Ca, CEC, and

percentage base saturation are increasing. Boron appears to be declining in Field I which may be the result of the leaching effect of the large quantities of water that have been applied. The decline in B is greater in the Puyallup fine sandy loam portion of the field than it is in the area of Puget silt loam. The soil nitrate movement is also greater in the sandy soil.

In view of the large quantity of K that is present in this effluent and the associated accumulation of soil K, close attention should be given to future soil test values for K and Mg as grass tetany may become a problem with livestock utilizing this forage.

CONCLUSIONS

Land application of wastewater from the yeast manufacturing plant and the nutrient removal by forage crops has been succesful. During the four-month period in 1978 for which the system was monitored, the 4.4 acre tract provided the forage requirements for 28 head of Angus beef cattle. The overload at the sewage treatment plant was corrected by a reduction of 400 lb BOD/day entering the plant. Energy conservation achieved during the period June 1 to September 30 as a result of using the land disposal system rather than an evaporation system is estimated to be 605,000 KwH valued at nearly $19,000 at prevailing power costs. The biological filter of ryegrass successfully intercepted the NO_3-N and no degradation of groundwater quality was noted.

On the negative side, the test area was too small to provide for continuous effluent disposal. Heavy traffic of farm equipment imposed on moist soils reduced the waste acceptance capability of the site. Failure of worn-out forage harvesting machinery to effectively cut and blow the forage crop for removal from the site contributed to stand damage as did failure of the operator to leave adequate stubble length of 3 to 4 inches. Close cutting of grass swards reduces plant vigor and retards growth.

When Field II was brought into service the quantity of waste water discharged was doubled. The increased capacity for waste discharge brought a corresponding increase in energy saving and BOD removal from the sewage treatment plant. Forage production increased from 24.2 tons of oven-dry forage in 1978 to 60.4 tons in 1979 thus providing an increased feed base for the beef cattle herd.

A new forage harvester with a wider cut was placed in service and this resulted in less traffic and a cleaner cut, eliminating the chopped forage drop that reduced infiltration. The feed truck was placed backwards on a dolly that was towed behind the forage harvester to further reduce vehicle traffic and the resultant soil compaction. Direction of harvest traffic has been altered to minimize turns on the disposal site. With these operational changes it appears the two fields will be adequate to provide for continuous waste water disposal during the growing season and limited treatment during the winter period.

Field I must receive more limited loading until the vegetation is reestablished. The need for replanting of the vegetative filter should be recognized in the design process as systems of this nature should have excess land area of at least 20% above the estimated land requirement for waste application. This will allow maintenance of a vigorous plant system.

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APPLICATION OF ULTRASONICS AND ELECTROSTATICS - AN INNOVATIVE AND ENERGY SAVING APPROACH TO INDUSTRIAL WATER TREATMENT

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INTRODUCTION

With the increased demand for water, any treatment process requiring little to no chemicals is a conducive alternative for many industries. The application of ultrasonic-electrostatic water treatment has demonstrated reductions in operation and maintenance problems along with savings in energy requirements. The potential for this process has been noted in the soft drink bottling industry, boiler water treatment, and cooling tower systems. The objective of this paper is to elucidate the potential effectiveness of this process in industrial water treatment, the economic feasibility of this system with respect to other chemical water treatment approaches, and the current limitations with respect to design in water treatment.

BACKGROUND

The application of ultrasonics and electrostatics for water treatment, disinfection, wastewater treatment, and various industrial applications dates back to the Twenties (1,2), but as of 1978 there can be found no process utilizing both sonic and electromagnetic force fields in the literature or patent files. In general, past processes have used electrolytic treatment, induced electromagnetic force fields, and ultrasonics (3), yet there has been a great deal of skepticism concerning these low power water treatment processes which reduce chemical requirements (4,5,6). Recent research indicates that these low power processes indeed effect chemical requirements of water and there is a great deal of new scientific information demonstrating potential application in both water treatment and disinfection.

In 1865, the first water conditioning gadget patent in the United States was applied for and accepted. These gadget processes offer a something-for-nothing or a kind of panacea process. These gadgets were claimed to be special devices requiring no technical control and to treat water by nonchemical means to prevent scale, corrosion, and other problems encountered in the industrial use of water (4). In the late 1950's, Eliassen, et al (5) investigated various water conditioning processes utilizing induced magnetic fields and noted the following observations:

1) Water treated by magnetic fields did not inhibit scale formation.
2) The rate of corrosion was not influenced by magnetic fields over a 4-month period.
3) Conditioned waters used in accelerated laboratory corrosion experiments indicated no significant inhibition control.

A plausible reason why the magnetic conditions were not effective was because of the low magnetic fields used as compared to the high magnetic fields required (10,000-fold difference in electron densities). In 1977, a publication warned the public of devices which claim to operate on electromagnetic, electrostatic, magnetic, sonic, or any other physical principles for the prevention of scale and corrosion. Generally, they felt that these processes were in conflict with basic scientific laws, allowed far too little exposure to the field, questioned the ability of cations to adsorb electrons, and felt that this treatment would not be carried beyond the treater (6). In the recent 40th International Water Conference at Pittsburgh in October, 1979, two papers (7,8) warned industry of new gadgets or non-chemical water treatment processes. One paper (7) just restated the same concerns as the 1977 paper (6), and in fact, it just directly quoted this paper. The other paper (8) reviewed the literature concerned with problems resulting from these processes and examined the claims made by electrostatic water treatment, electrostatic,/ultrasonic processes, magnetic water conditioning devices, and SGA water treatment systems. The scepticism is due to the lack of scientific substantiation over the mechanisms by which these processes descale, disinfect, etc. In most situations, the above scepticism should be of major concern for all professionals, but recent research has brought to the forefront data that indicates the application of electrostatics and ultrasonics as a viable approach to water treatment.

In the last ten years, researchers have noted that magnetic and electrostatic fields have been beneficial in the reduction of boiler scale (especially the work of Russian researchers) (9-12). Toshi and Kamat (9) have noted substantial pH drops in distilled water (0.62 pH units) exposed to magnetic field of 1900-5700 gauss. Similar observations have been reported for naturally occurring waters (11). Measurements of magnetic effects on the physical properties of water have usually been part of an investigation of the reduction on boiler scale which results when the water supplied to a boiler is passed through a magnetic field. A variety of explanations have been proposed for this phenomena, and one such explanation involves a magnetically induced change in the pH of water (9). The reduction in pH indicates an increase in the Lewis acids (electron donors) which in turn can carry electrons to scales. Quickenden, et al (13) were not able to substantiate the above observations with distilled water, but this could be due to many other water quality factors.

In 1973, the University of Michigan (14) investigated the effectiveness of electrostatic and magnetic treatment of water to prevent scaling, to inhibit corrosion and to reduce biological activity. They noted that Koubikoua (15) found magnetic fields reduced and mitigated scale but these same fields had no control of corrosion. Also, the influence of magnetic fields tended to change the crystalline structure of calcium carbonate scale (from calcite to aragonite)(15), and the Japanese (16) have noted the reduction of scale and mitigation of corrosion. At the University of Michigan, aluminum was found to corrode and scale at a higher rate in 48 hours at 180°F when water is not passed through electromagnetic field, and Daphnia were found to be somewhat less viable in the presence of electromagnetically treated water (there is some question to these results). This same group investigated the influence of electrostatic treatment and noted the following observations:

1) Tanks heated to 200°C had soft scale in treated water but tenacious scale for non-treated waters.

2) Plants only grown in soils of high nutrient values were increased 30% with treated waters, yet in soils of poor nutrient levels, there was no difference observed.

In 1977, Duffy (17) conducted research on influence of electromagnetic systems and observed the following phenomena:

1) At 85°C, there appeared to be no influence on the precipitation nor the formation of calcium carbonate.

2) The treatment did not effect the structure of the water.

3) In the presence of 3% NaCl at 25°C, corrosion appeared to increase when a 1018 steel rod was magnetized.

4) The presence of ferric hydroxide in the feed water decreased the formation of scale and the control of scale varied directly with concentration of the ferric hydroxide and inversely with temperature; but scale was inhibited at pHs ranging from 6 to 11.

In 1979, Krajiic and Milosevic-Krajiic(18) published case histories of facilities utilizing electromagnetic water treatment devices. In this study, they noted that scaled boilers started descaling within a month. Descaling was noted in situations where calcium sulfate, magnesium carbonate, calcium carbonate, calcium hydroxide, magnesium hydroxide, and calcium magnesium carbonate were supersaturated after consideration of temperature and ionic strength. Similar results were observed for cooling towers and a lab distiller. In the case of cooling towers, the use of algicides was necessary and no mention of corrosion control was stated in this paper.

In the last fifteen years, the influence of ultrasonics on aqueous systems has been investigated by major research institutes in Russia (Institute of Ultrasound), Germany, and Austria. The application of ultrasound has been found to decrease the solubility of mineral oils in water, increase the formation of electron excited states in water, increase the filtration of fluids through filters (water and oils), accelerate chemical reactions (especially oxidation-reduction reactions), influence the effect of catalytic reactions (either way), promote strong electron ionization and polarization, and improve heat transfer (3,19,20). It is interesting to note that many chemical reactions and molecules are influenced by ultrasonics in unique ways. The oxidation of ferrous ion to ferric ion in 0.8 normal solution of sulfuric acid occurs only in the presence of ultrasonics and at an optimum frequency of 15-20 kHz (3). When investigating water treatment, the above phenomena can be of major importance. Another important factor concerning the application of ultrasonication emphasized by Murry (3) and Ouelette, et al (2) was that ultrasonication alone would not have a germicidal effect or increase reactivity, but when used with other treatment methods or catalysts, the influence of the ultrasonics can make the reactions or biocidal magnitudally more effective.

APPLICATIONS CONCERNED WITH BIOKILL ENERGY AND ECONOMICS

In April, 1978, Dairymen, Inc. of Franklinton, Louisiana, placed an Aqua Scrubber on both an old and a new boiler. The reason for the switch from chemical treatment to the electrostatic/ultrasonic process was the failure of chemical treatment to clean the old boiler. In April, 1978, they spent $13,360.00 to clean both boilers chemically. The new boiler was cleaned, but the old boiler popped off a valve and required an additional $3,255.00 for the valve. After this treatment, the boilers were fired, blown down, and opened with very little scale reduction. After this experience, an Aqua Scrubber was purchased to treat both boilers at a total cost of $8,082.00 and installed in front of the feed water tanks for both boilers. At the end of three months, the boilers were reopened and great quantities of scale was removed. As shown

in Table 1, the fuel demand has been reduced 38% for a three month period in comparison of both boiler treatment processes.

Table 1. Fuel Savings Due to Aqua Scrubber of Boiler Waters (Based on $2.70 per thousand cubic feet of gas)

Month/Year	Gas Usage (thousand cubic feet)	Production (pounds)	Thousand Cubic Feet per Million Pounds of Production	Fuel Cost per Million Pounds
		Chemical Treatment		
Sept., 1977	7,670	10,580,000	725	$1,958.00
Oct., 1977	6,020	11,020,000	547	$1,477.00
Nov., 1977	6,990	12,150,000	575	$1,553.00
		Average	616	$1,662.00
		Aqua Scrubber Treatment		
Sept., 1978	4,100	11,580,000	354	$ 956.00
Oct., 1978	4,870	12,310,000	396	$1,069.00
Nov., 1978	4,500	11,200,000	401	$1,083.00
		Average	383	$1,036.00

Along with this fuel savings, considerable savings due to continued chemical use cannot be estimated, but just for the single month, there was a savings of 51%. This was taking the capital cost for the Aqua Scrubber in comparision to chemical cost for cleaning these boilers which was noted to be ineffective. It should also be noted that deoxygenation was required to control corrosion since this electrostatic/ultrasonic process is not anticorrosive.

In a second case, Avondale Shipyards had problems with the chemical treatment of their boilers. Although all their boilers were equipped with water softening and phosphate treatment systems, they noted the following problems:

1) The stack temperatures were generally running too high, indicating maximum operating efficiency was not being obtained.

2) Chemical costs were running high and two personnel were necessary full time to pick up, mix them, and monitor treatment parameters.

3) Maintenance costs were running high with frequent retubing of boilers.

4) Automatic blow down control probes required frequent cleaning to function properly.

5) Back wash from water softeners and boiler blow down was not in compliance with our NPDES permit concerning phosphate and suspended solids.

After extensive review of their boiler water treatment program the following observations were elucidated:

1) Application of the chemical treatment program would require highly skilled personnel in boiler water treatment and that no two boilers had the same chemical treatment or maintenance problems.

2) Additional treatment equipment would be required to remove phosphate and suspended solids to comply with NPDES requirements.

3) The automatic blow down control probes would be a continuous

maintenance problem and require frequent cleaning and/or replacement.

4) In those boilers which had high stack temperatures acid cleaning was necessary to remove excessive scale formations to properly implement a new chemical treatment program.

Contact was made with several companies concerning this problem so that an alternative process could be obtained. The alternative process would hopefully meet the following necessary criteria:

1) Operate steam generators at maximum efficiency.

2) Minimize present fuel, feed water, chemical and maintenance costs.

3) Generate high quality steam for the distillers.

4) Achieve compliance with EPA discharge guidelines.

The chemical companies recommended two programs: chelants and chelant-polymers (SCA's). Both of these programs involved expensive equipment and higher chemical costs than that for the phosphate program, and were unproven for the size and type boilers in Southern Louisiana. In addition, acid cleaning prior to implementation would be required along with highly skilled personnel to supply and mix chemicals and monitor the treatment. Since additional unwanted chemicals, increased solids from blowdown and more frequent water softener back washing would be required, additional equipment would be needed to remove these impurities from this wastewater discharges.

The electrostatic/ultrasonic process on the other hand would replace all present treatment equipment. This treatment could descale the boilers at a controlled rate making acid cleaning unnecessary. As a result, this process was installed on a 150 HP and 15 psig packaged fire tube generator which was normally on-line twenty-four hours a day. When the unit was put on line, it was noticed the conductivity on the blowdown water increased immediately to 7000 umhos and depending on the frequency of blowdown, the conductivity was noted to rise above 7000 umhos. At the end of forty days the scale had began to drop off the inside walls and fire tubes. After 90 days, the inside of the boiler was 95% cleaned of scale formations. During this period, no significant shift in the blowdown water and feed water pH was observed and no signs of tube failure or oxygen pitting was found. It was apparent during the test period that the scale inside the boiler was composed of several different layers with each layer affecting the rate of scale removal differently. The thick, soft layers of scale were removed rather quickly and their thin hard layers were removed at a much slower rate.

At the end of the ninety day trial period, another electrostatic/ultrasonic unit was purchased, but this time, it was used to treat feed water supplied to two 150 HP, 150 psig packaged fire tube steam generators. Both installations were monitored during this period with the results of the new installation turning out similar to the first test case at the end of ninety days. Inspection of the original test case during the second ninety days showed that the remaining five percent scale in the boiler was removed and a protective oxide film had formed on the fire tubes. No significant change in the blowdown water and feed water was noticed and no apparent signs of tube failure or oxygen pitting had occurred. The stack temperatures of all three boilers showed a significant drop from around 450°F to about 350°F.

The success of these two test cases led Avondale to evaluate using this type unit in lieu of a chemical treatment program. The net results of this evaluation were:

1) One full-time employee who was required to administer the chemical treatment program would be free to perform preventative maintenance 100% of the time.

2) An inventory of and warehousing for chemicals would be eliminated.

3) A motor bike could be used instead of a truck for transportation from one boiler site to another since containers of chemicals would not have to be transported daily.

4) Existing feed water treatment equipment and chemical treatment equipment could be eliminated.

5) Field test equipment required to monitor treatment would be minimal and not require a person trained in water treatment to understand test results.

6) Annual maintenance costs were expected to decrease due to less tube failures and better preventative maintenance program.

7) Treatment could be applied to boilers without acid cleaning them initially.

8) Procurement and installation of nine Sonic Clean treatment units to replace chemical treatment presently installed on thirteen steam generators would have a simple payback of 0.78 years.

Even so, there were some problems which were noted by use of this process, and they are listed below:

1) Excessive scale fallout in boilers which were not acid cleaned caused hot spots to occur in the tube sheets where water circulation was stopped by accumulated loose scale resulting in tubes to fail at the rear tube sheet or hair line cracks to occur in the rear tube sheets.

2) There is no present device installed on the Electrostatic/Ultrasonic unit which indicates defective electrodes exist. Avondale has gone as long as thirty days before a visual inspection of the boiler internals indicated effective treatment has ceased. TDS and pH readings were ineffective in determining this problem in most occurrences.

3) Treatment of feed water occurs only when flow through the unit is maintained and lasts for a short period of time. To assure treatment of the boiler water, a small continuous blowdown flow is required to turn over the water in the boiler to maintain effective water treatment.

4) The life span of the electrodes used in the unit has not been established. Evidence exists that the current electrode is temperature dependent and its life decreases more rapidly at temperatures above 145°F. The life and replacement cost of this component could significantly affect the economics of using this unit in lieu of chemical treatment for certain applications.

Since applying the ultrasonic/electrostatic processes in Avondale, the following decreases in operations and maintenance cost of their boilers has been observed as follows:

Year	Annual Cost	
1977	$95,346.00	100% Chemical Treatment
1978	$57,122.00	50% Chemical Treatment 50% Sonic Clean Treatment
1979	$37,109.00 (thru Sept.)	100% Sonic Clean Treatment
	$49,600.00	(Projected Cost thru December)

In fact, a major savings is due to the considerable reduction in labor, chemicals, etc. Table 2 indicates a reduction in operation and maintenance costs of over 60% annually, and this does not consider the reduction in fuel demand as noted in the previous situation to be almost 40%.

Table 2. Operation and Maintenance Cost

Industrial Boiler Water Treatment(1) Without Chemicals

Annual Chemical Treatment Costs(2)	
a) Chemicals	$27,994.00
b) Chemical Labor & Transportation Cost	6,940.00
c) Labor for Maintenance & Monitoring of Program	36,940.00
	$71,874.00
Sonic Clean Treatment Costs(3)	
a) Annual Maintenance & Monitoring	$26,640.00

(1) Costs presented do not include energy savings. The Avondale boilers had from 1/16" to 1/4" thick scale on them.
(2) Chemical treatment costs based on 1977-1978 consumption and product and labor rates in effect at that time.
(3) Actual costs tracked from 1977 through September 1979 indicate the maintenance and monitoring costs will be less than that projected.

The reasons for this higher operation and maintenance costs as shown in Table 2 is due to the cost for burned out boiler tubes resulting from trapped scale. A significant savings in fuel consumption was gained due to the reduction of scale ranging from 1/16" to 1/4" thick. This allowance will reduce the fuel savings for these boilers by at least 20%. This savings has been reflected in lower stack temperatures and improvement in steam generation during peak demand periods.

LIMITATIONS OF THE PROCESS

These limitations have been ascertained from both laboratory and field testing. Obviously, this information is the most current. They can be classified into three categories: process limitations, proper placement of the process, and operation and maintenance problems.

Process limitations can be divided into physical factors, chemical parameters, and new solubility limitations. The physical factors are pressure,

temperature, and residue from the treatment. At present, all Aqua Scrubber units are rated for 85 psi at 145°F maximum pressure and temperature. The 85 psi is the limiting pressure for the effective treatment by the ultrasonic transducer and the 145°F is the maximum temperature at which the electrode will operate efficiently. If the process is operated above either or both limits treatment is radically reduced. It must be noted that these abiotic factors influence the treatment within the process. After this treatment, the temperature and pressures of treated water can be raised to 200 plus °F and 200 plus psi. If the water has less than a six second residence time in the scrubber, then the effective treatment can be greatly reduced. Again, there are times when treatment can be effective with a lower residence time, but this is only feasible under specific situations (i.e., water quality and scaled environments). From laboratory and field results treated water from the Aqua Scrubber retains effectiveness from 30 minutes to 60 minutes after discharge from the Scrubber. Treated water must be used within this time period to obtain possible descaling.

The Chemical Parameters are suspended solids and organic content. As the suspended solids concentration increases greater than 20 mg/l (organic, i.e., volatile suspended solids, or inorganic, i.e., inert suspended solids), the effectiveness of Scrubber treatment is significantly reduced or completely inhibited. Therefore, it is recommended that water of this quality be pre-treated (i.e., filtration, sedimentation, etc.) before passing through the Aqua Scrubber. The influence of dissolved organics on Aqua Scrubber treatment tends to vary. In some instances, the organics act as a biocide and reduce biological activity, but, in general, it has been noted that increases in disssolved organics tend to reduce the effective treatment by our system. Currently, if the dissolved organics are greater than 20 mg/l as carbon, the efficiency of the Scrubber can be greatly reduced and at 50 mg/l as carbon, it is completely inhibited. Oil and grease will react similarly (20 mg/l and 50 mg/l) but generally is limited to lower values (10 to 25 mg/l) due to possible coating of the electrode.

Finally, the solubility limit for calcium carbonate at 100°F is approximately 400 mg/l as calcium carbonate. This is a ten-fold increase in solubility (from the 40.0 mg/l as calcium carbonate) for systems without an Aqua Scrubber. Probably, this Aqua Scrubber effect on solubility is similar for other salts (coagulative salts: ferric ions, sulfides, magnesium ion, chlorides, etc.) and should be considered before utilizing this system for other descaling applications.

Proper placement of the scrubber is influenced by both the process being treated and placement before or after pump. Many failures have been a result of this very problem. Major problems have resulted when the Aqua Scrubber was installed on rinse tanks of bottle washing and rinse machines. In general, there was a build up of soluble salts (particularly alkalinity) noted and uncontrollable pH fluctuations (due to caustic residues from pre-rinse water and soak tanks). This pH fluctuation actually scaled up the Aqua Scrubber itself because the solution was near the solubility limits for effective Scrubber operation at pH 8. This pH increase (8 to 10) increased the carbonate concentration approximately 100 times (which will cause precipitation due to the common ion effect). This situation can be avoided by installing the Aqua Scrubber on the fresh water supply (final rinse line). When Aqua Scrubber is installed in this location, both the upper and lower spray heads must be supplied by the treated water. By placing the Scrubber after the pump,

pressures have been observed greater than 85 psi and the resulting treatment has been greatly reduced. Just placing the Scrubber before the pump (on its vacuum side), the resulting pressure has been found to be far less than 85 psi. Thereby, the effectiveness of this process has greatly increased.

Operations and maintenance problems have been noted due to trapped and accumulated scale. The resulting problems can be resolved depending upon the specific treatment (e.g., boiler water treatment and cooling water treatment). As a result of boiler water treatment by the Aqua Scrubber, large pieces of scale have dropped from the upper tube and tank wall surfaces and accumulated on areas of the tubes below (on top of lower bundles). If this scale is not removed soon after it collects, the resulting "hot spots" will require tube replacement and expensive down-time. Frequent inspection and, if necessary, scale deposit removal by the customer is strongly recommended. Accumulation of scale in the bottom of the boiler can also occur as cleaning progresses. This can clog blowdown openings and also cause a build up in soluble salt concentrations which could result in precipitation for particular boiler system. If careful and regular maintenance is not carried out, a renewed scaling problem is likely to occur. The high solids in cooling towers can cause two problems: (1) clogging of downstream equipment and (2) increased scaling. The clogging of the downstream equipment is a result of the flaking of a solid from the cooling tower. Also, these suspended solids can increase the soluble salt levels to above maximum solubility limits and this higher soluble salts will cause increased precipitation. The above problems can be resolved by filtering the suspended solids.

SUMMARY

From field testing, this water treatment process has decreased scaling, reduced operation and maintenance problems, and mitigated many noxious nuisances for the soft drink bottling industry and descaling operations for boilers and cooling towers. By reducing the chemical requirement for scale inhibition, there has been noticeable cost savings (30 to 60 percent) depending upon the industry, and much of this savings can be directly related to energy savings (i.e., 38% for a boiler system of Dairymen, Inc. of Franklinton, Louisiana). Important limitations of the process can be capsulated into three areas: (1) process limitations due to solubility, suspended solids, organics, pressure, and temperature, (2) logistics of placement for maximum treatment, and (3) operation and maintenance problems from trapped and accumulated scale. Even though there are many limitations concerned with this form of water treatment, the application of this innovative process in many industrial water treatment situations can be beneficial both in cost and energy savings.

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INNOVATIVE ENHANCED OIL RECOVERY SEPARATIONS METHODS

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INTRODUCTION

In enhanced oil recovery procedures, polymers are added to banks injected into oil bearing formations to raise their viscosity above that of the banks they displace, in order to prevent viscous fingering of the displacing banks into those being displaced. Microbial polysaccharides comprise one class of polymers used for this purpose. However, present costs of biopolymer at the wellhead are relatively high. Field production is under consideration, to avoid the cost of preparing the polymer in a dry form suitable for shipment over large distances as well as problems in redispersion of polymer for injection.

Whether or not the biopolymer is precipitated prior to field use, separation of biomass from the fermentation broth is a major consideration in polymer quality. During passage through a porous oil bearing formation, the final polymer solution may be required to travel through hundreds of meters of passages of micron diameter without plugging those passages. In the production of scleroglucan, a fungal biopolymer, separation of biomass from broth is generally accomplished by diatomaceous earth filtration (Rogers 1973). In the case of xanthan gum, a bacterial polysaccharide, centrifugation has been used (Rogovin, Anderson, and Cadmus 1961). Other methods of biomass-broth separation which have been investigated include centrifugation, foam fractionation, flocculation, and electrophoresis. These methods were reviewed by Freeman (1964) and Wang and Sinskey (1970). Among the difficulties encountered with conventional filtration methods are partial removal of the polymer from the solution along with the biomass and the production of large quantities of waste when filter aids are used to increase cake permeability. Elimination of diatomaceous earth filtration would not only save the purchase and disposal costs of filter aid, but would avoid contamination of biomass with material which might interfere with its beneficial use as a byproduct. Byproduct uses of fungal biomass could include supplementation of animal feeds as a replacement for current organic nitrogen sources.

On the basis of bench and pilot microscreen tests, we feel that microscreening (or microstraining) is a promising alternative. This approach has been successfully used in the field of water and wastewater treatment for the removal of fine solids since the early 1950's. The microscreening process performs a continuous separation of solids from a liquid suspension utilizing a filter media continuously regenerated by backwashing.

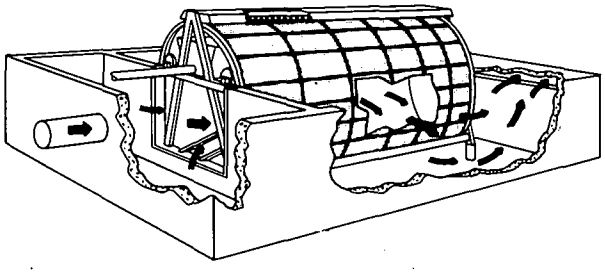


Fig. 1. Fluid flow through an operating microscreen.

Microscreens are mechanical filters consisting of a slowly rotating horizontal drum whose cylindrical surface is made of a screening medium. Fig. 1 shows fluid flow through an operating microscreen unit mounted in a concrete or metal vessel. Fluid enters the drum at one end and flows out radially through the filter fabric. Solids are retained on the inner surface of the drum as the flow passes through the drum. These solids form a layer of material which intercept even smaller size particles. During the backwash cycle the accumulated solids are removed from the medium by a pressurized spray wash system mounted over the top of the drum. Generally, screened effluent is used for this purpose.

The important process design variables are drum size, rotational speed, media selection, pore size, hydraulic head, and backwash rate. In order to assess these variables and to make possible estimates of the utility and potential cost of biomass removal by microscreening, bench and pilot unit (4 ft diameter by 2 ft long) tests were conducted using procedures developed by Envirex, Incorporated, a Rexnord Company.

MATERIALS AND METHODS

Suspended solids. With minor modifications, the method used follows *Standard methods for the examination of water and wastewater.* A 42.5 mm Whatman GF/C glass fiber filter was weighed using a 4 place Mettler balance. The filter was placed in a Millipore glass filter holder with a teflon rim, put under vacuum, and wet with filtered distilled water. The measured sample was centrifuged at 15,000 × *g* for 15 min, and the pellet resuspended in filtered distilled water, rewashed, and resuspended for filtration. The supernatants were pooled for polymer determination. The filter was washed with three 10 ml aliquots of 70 C filtered distilled water and the vacuum released. The filter was dried at 102 C for at least 1 hr or until the weight remains constant. A blank washed with three 10 ml aliquots of 70 C filtered distilled water was processed concurrently and used to correct for the small weight change generally observed with glass fiber filters during processing. After correction for the weight change in the blank, the suspended solids were computed as g/liter of total suspended solids.

The samples were then fired at 550 C for 30 min and reweighed. After correction for weight changes in blanks, the suspended solids were computed as g/liter of fixed (or fired) suspended solids. Fixed suspended solids are a measure of the inorganic ion content of the sample.

Biopolymer weight and biomass were expressed as volatile suspended solids, which is the difference between total and fixed solids. Volatile suspended solids is a measure of the organic content of a sample.

Biopolymer concentration. Two to three volumes of isopropyl alcohol were added to the pooled supernatants from suspended solids centrifugation. After precipitation of the biopolymer, it was removed to a tared aluminum moisture dish, dried under vacuum at room temperature, and weighed.

Broth production. Broth from a *Sclerotium rolfsii* culture, unless otherwise stated, was from a culture innoculated with a 1 to 5% v/v innoculum and grown at 26 to 27 C until adequate polymer production, as measured by precipitation of an aliquot, was reached. The bench experiments were conducted with strain ATCC 15203, and the pilot experiments, with a production strain which was the kind gift of Ceca, a European polymer manufacturer. The Type GF0014 Chemapec fermenter in which the broth for bench scale experiments was produced receives 1 v/v of air per min. The fermentation was allowed to proceed until polymer production was maximal. After fermentation was judged to be complete, the broth was brought to a pH 7 in the fermenter. It was then placed in 40 liter stainless kettles and heated at 90 C for 90 min. The hot fermenter broth was blended in a 4 liter Waring blender for 2 min on low speed and 1 min on high speed.

During bench microstrainer tests, post fermentation broth treatment was varied. As used in microscreening tests, *neutralization* means to bring broth pH to 7 with sodium or potassium hydroxide, *autoclaving* means to heat broth at 90 C for 90 min in a 40 liter stainless kettle, and *blending* means to blend in a 4 liter Waring blender for 2 min on low speed and 1 min on high speed.

The 360 liter fermentations were prepared in the ORNL Biology Division fermentation facility. The fermentations were conducted using the same medium, but the culture innoculum was at 3% v/v, rather than at 5%. The Ceca production culture, rather than ATCC culture, was used. A slightly lower air throughput was used, but the fermenter pressure was increased to provide adequate dissolved oxygen.

Media. Liquid cultures were grown in a medium consisting of (per liter): 50 g anhydrous glucose, 3 g $NaNO_3$, 1 ml H_3PO_4, 0.5 g $MgSO_4 \cdot 7H_2O$, 0.5 g KCl, 0.05 g $FeSO_4$, and 1 g either Amber or Difco yeast extract at a temperature of 26 to 27 C. This medium was used for both *Sclerotium rolfsii* cultures. Other carbohydrates, including starch or sucrose, may be substituted for glucose. The amount of carbohydrate may also be varied between 3 and 6% w/v.

Slants were maintained on Difco 0013-01 potato dextrose agar in 1 × 4 in. screw cap vials. After slant cultures were fully developed, they were refrigerated at 4 C. Slants may be covered with a layer of sterile mineral oil to retard evaporation.

Bench procedure. The Envirex procedures for microstrainer evaluation use a header box with adjustable headloss and a variable filtration time. The procedure, which has the following 8 steps, was developed for users. (1) Select a desired headloss for the test run and install the proper length tube into the constant head box. (2) Install the screen media sample to be tested in the proper position. (3) Fill the head box such that the liquid level is near the top of the tray and determine raw sample characteristics. (4) Select a submergence time for the test run. (5) At time zero, set a stopwatch, pull the plug, and collect the flow that passes the screen media for exactly the submergence time selected in Step 4 and then replace the plug. (6) Measure the volume collected and analyze it to determine the amount of solids removed. (7) Remove the screen holder and backwash the screen media with two passes simulating the backwashing under full scale conditions. (Note that it is not necessary to

remove the screen media from the holder to accomplish this.) The direction of backwashing must be opposite to the direction of sample flow passing through the screen media. (8) Repeat steps 1 to 7. (In a formal test program each test run should be made in triplicate.) It is important to quantitatively evaluate how well backwashing can be accomplished.

The overall objective is to select the cloth or screen which will remove the required amount of suspended solids at minimum head. Actual flow rate Q can be calculated from the volume of flow collected over the given submergence time and through the known diameter screen. With Q and headloss H known, the permeability coefficient F can be determined for each different submergence time. With the relationship between H and Q known, one can predict the screen headloss with the given sample for any hydraulic loading Q. These relationships are only useful if the desired suspended solids removal is accomplished. This treatability procedure and apparatus will not only yield the value for F, but will determine the efficiency of the screen with regard to suspended solids removal.

Pilot procedure. The pilot unit used was a 4 ft × 2 ft fully automated microscreen. In tests here, initially the polymer feed was partially diluted broth (perhaps 1:4 with filtered distilled water) in a feed tank, and the microscreen tank and drum were filled up to the effluent weir level with filtered distilled water. The 8:1 dilution of fermentation broth adopted as standard for these tests refers to the total dilution of original broth by both the water added prior to microscreening and the water in the microscreen and its tank. Because of limited broth available for the tests, effluent and backwash were recycled to the continuously mixed feed tank. In all runs except for the first 1 μm screen run, essentially complete mixing was attained. Performance of the screening was evaluated on the basis of samples taken from the influent to the microscreen and from the filtrate exiting from the microscreen weir. The first run was dropped from consideration because of incomplete mixing. In other runs, early points may not reflect complete mixing.

During operation, a record of headloss; drum submergence; backwash composition, pressure, and flow; effluent flow; and media size and type was kept. Operational data are in Table 1. The first 1 μm media run did not appear to reach a point where effluent and influent polymer concentrations were comparable; since this appeared due to insufficient mixing, the 1 μm run was repeated after the 6 μm run. The last run was the treatment of effluent from the 21 μm screen through 1 μm media to determine the efficiency of two step treatment.

MICROSCREEN BENCH TEST RESULTS

Bench tests were performed on broth from a *Sclerotium rolfsii* ATCC 15203 culture grown on 5% glucose-nitrate medium. The culture was started from a frozen innoculum, and was harvested at 3.5 days. The reducing sugar in the broth was 0.5% w/v. The media and methods for culture maintenance and growth were given in *Materials and Methods*. Before the culture broth was used it was first neutralized with KOH to a pH between 6 and 8. The neutralized broth was heated to 90 C for 30 min and blended in a Waring blender for at least 2 min.

Table 1. Microscreen pilot run conditions

Head, in	Speed, rev/min	Backwash psig	Elapsed time, hr
Run 1, batch 1, 1 μm PE cloth			
7	2.0	20W	0.0
10	3.0	20E	0.5
11	3.0	19E	1.0
14	1.5	20E	1.5
14	3.2	20E A	2.0
13	3.2	40E	2.5
12	2.0	38W A	3.0
6	2.0	40W/A	3.5
14	2.0	40E	4.0
14	2.0	30E	5.0
7	2.0	36E	6.5
Run 2, batch 1, 6 μm PE cloth			
		40E	0.0
6	2.0	30E	1.3
7	2.0	30E	2.0
12	2.0	30E	3.2
8	2.0	30E	4.0
Run 3, batch 1, 1 μm PE cloth			
13	2.0	40E	0.0
5	2.5	30E	4.0
4	3.0	24E	8.0
2	2.0	24E	12.0
9	2.0	30E	16.0
14	2.0	30E	20.0
14	2.0	30E	24.0
14	2.5	30E	28.0
10	3.0	30E	32.0
14	3.5	30E	36.0
11	4.0	30E	40.0
Run 1, batch 2, 21 μm PE cloth			
14	4.0	30E	0.0
14	3.0	30E	2.0
14	2.5	30E	5.0
14	2/5	30E	8.0
14	2.0	30E	10.0
Run 1, batch 2, 1 μm PE cloth Feed: 21 μm effluent			
14	2.0	30E	0.0
14	2.0	30E	7.0
14	2.0	30E	12.0
14	2.0	30E	17.0
14	2.0	30E	19.5

A = air, W = water, and E = effluent.

The culture broth treatment was varied during the tests using five different preprocess treatments: 1) neutralization and blending (NB); 2) neutralization, blending, and autoclaving (NBA); 3) neutralization, blending, autoclaving, and blending (NBAB); 4) neutralization, blending, autoclaving, blending, and reautoclaving (NBABA); and 5) neutralization, blending, autoclaving, blending, reautoclaving, with filtration performed on 40 C (hot) broth (NBABH). All test runs were made with a 10:1 dilution of the broth after treatment. This corresponds to a polymer concentration of 1.8 g/liter based on direct recovery from a sample of the culture broth by alcohol precipitation.

The apparatus used in the Envirex procedure is shown in Fig. 2. The bench test apparatus was designed to provide a large surface area at the top to maintain a constant head on the filter and eliminate turbulence due to refilling. Use of a close fitting plug to minimize dead space under the media before the start of the run was important when small permeate volumes were collected. In addition the filter head can be varied by changing pipe sections below the constant head box. Both stainless steel and polyester media were tested. The stainless steel media mesh sizes tested were 15, 23, and 60 μms. Polyester media mesh sizes tested were 1, 6, 17, and 21 μms. Mean filtrate volume and biomass removal efficiency for each treatment and media tested are presented in Table 2. As shown in Fig. 3, filtrate volumes collected increased with increasing broth treatment prior to screening. Little difference in filtrate volumes was observed between stainless steel and polyester media with similar aperture, although stainless-steel media were more difficult to backwash than the polyester media. The difficulty in backwashing stainless-steel media has been partially attributed to roughness of the wire surface by Cravens and Kormanik (1978). As expected, increasing the media size increased the filtrate volume collected. For neutralized, blended, autoclaved, and blended (NBAB) feed, the filtrate volumes were 7.9, 23.3, 35.3, and 41.0 ml for 1, 6, 17, and 21 μm polyester media.

Biomass removal efficiencies presented in Fig. 4 were calculated as the percentage of volatile solids removed by the media. Poorer removal efficiencies were attained with increasing broth treatment for feed treated using the 6 μm and larger screens. Broths which had been neutralized, blended, autoclaved and blended (NBAB) or neutralized, blended and autoclaved (NBA) showed poorer solids removal than did broth which had been merely neutralized, and blended (NB). However, broth treated by neutralization, blending, autoclaving, blending and reautoclaving (NBABA) responded as well as did

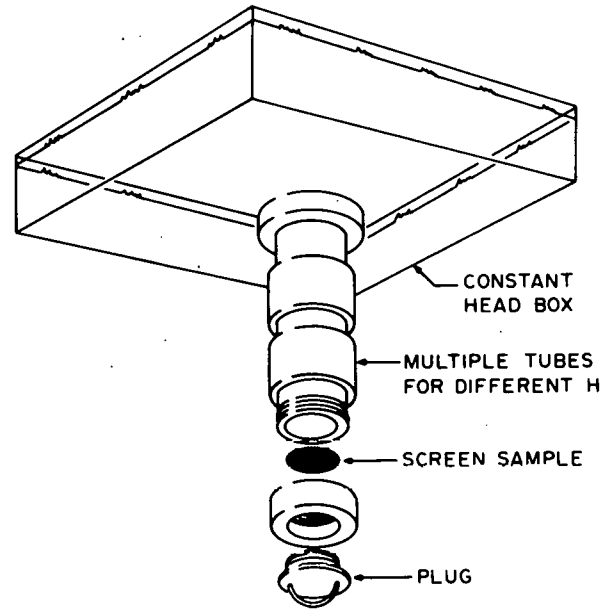


Fig. 2. Envirex bench test microscreen.

Table 2. Summary of bench run results.

Treatment	Media	Aperture, μm	Head, in.	Flow, ml	Biomass removal, %
NB	PE	6	11.0	13.8	89
NB	SS	15	11.0	9.5	
NB	PE	17	11.0	14.6	84
NB	PE	21	11.0	14.2	79
NB	SS	23	11.0	13.0	
NBA	PE	6	11.0	16.4	69
NBA	SS	15	11.0	15.0	
NBA	PE	17	11.0	23.5	62
NBA	PE	21	11.0	24.5	63
NBA	SS	23	11.0	17.0	
NBA	SS	60	11.0	60.0	51
NBAB	PE	1	11.0	7.9	56
NBAB	PE	6	11.0	23.3	37
NBAB	SS	15	11.0	19.2	38
NBAB	PE	17	11.0	35.3	33
NBAB	PE	21	11.0	41.0	32
NBAB	SS	23	11.0	27.2	46
NBAB	SS	60	11.0	129.0	8
NBABA	PE	1	11.0	9.4	69
NBABA	PE	6	11.0	29.0	47
NBABA	SS	15	11.0	12.8	
NBABA	PE	17	11.0	20.0	58
NBABA	PE	21	11.0	41.5	36
NBABA	SS	23	11.0	34.4	
NBABA	SS	60	11.0	204.0	18
NBABH	PE	1	11.0	10.8	63
NBABH	PE	6	11.0	34.5	33
NBABH	PE	17	11.0	21.8	47
NBABH	PE	21	11.0	45.0	15

PE = dacron polyester filter media, SS = woven stainless steel filter media.

broth which had been neutralized, blended, autoclaved, and blended (NBAB). Increasing treatment resulted in a slightly higher solids removal efficiency for the 1 μm screen feed which was probably due to further precipitation of metabolites or clumping of mycelial filiments. A small increase in volatile suspended solids after each autoclaving was measured as may be seen from Table 3.

Biomass removal efficiencies decreased with increasing media size; however, the 15 and 23 μm stainless steel media pair provided better biomass removals than the comparable 17 and 21 μm polyester media pair for broth treated by neutralization, blending, autoclaving, and blending (NBAB). This might have resulted from adhesion of mycelial fragments to stainless steel media, which is less smooth than comparable polyester media.

No significant loss of viscosity as a result of screening was measured for any of the shear rates employed nor was media size or type significant.

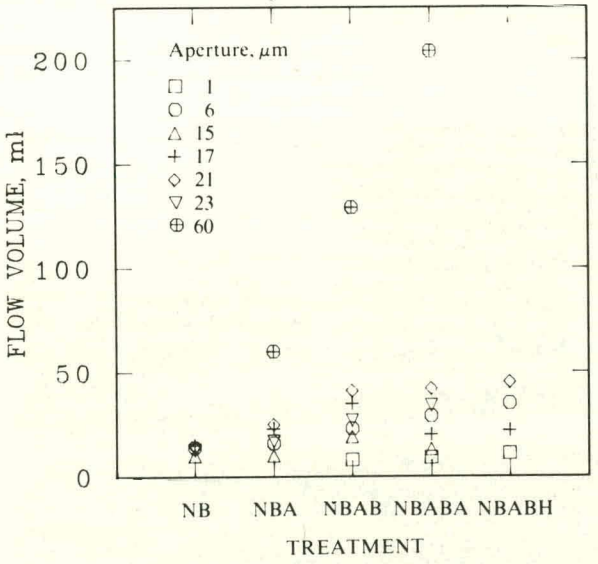


Fig. 3. Filtrate volumes as a function of culture broth treatment.

Table 3. Variation in volatile suspended solids concentration with feed preparation.

Treatment	Volatile solids, g liter
NB	0.770
NBA	0.887
NBAB	0.630
NBABA	0.683
NBABH	0.630

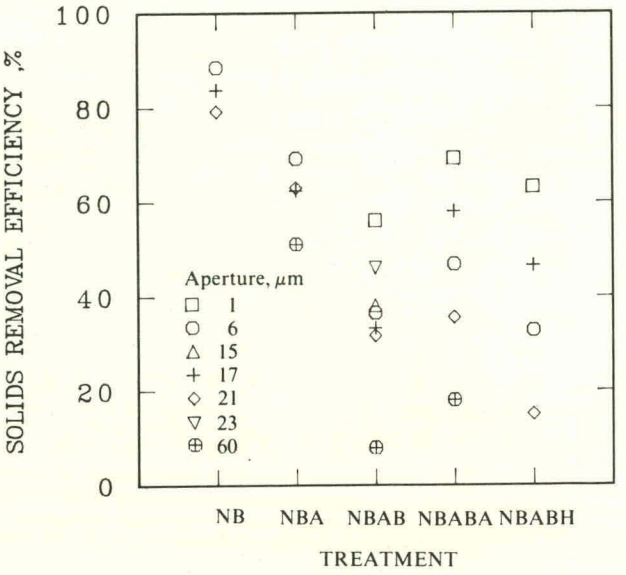


Fig. 4. Effect of media aperture on solids removal.

PILOT PLANT RESULTS

Pilot-scale microscreen results were obtained using a type PDP-52 microscreen shown in Fig. 5. On dilute feed, such as sewage effluent, this unit is capable of handling flows to 100 gal/min. Filtrate, water, or compressed air, either singly or in combination, was used to remove the filter cake from the filter medium during the backwash cycle as shown in Fig. 6. Three media apertures, 1, 6, and 21 μms, were tested. In a two stage test, sequential treatment through 21 μm and 1 μm media was performed.

In contrast to the bench scale tests, the pilot tests were conducted on fermentation broth which had merely been pasteurized in the fermenter prior to discharge. Exerted shear on the polymer broth arose from three main sources: mixing in the feed tank, pumping operations, and drum backwash spray. Although previous literature indicates that passage of a scleroglucan broth through a high shear is a major part of commercial polymer recovery from a broth, we did not find high shear necessary when a microscreen type operation, which washes the mycelium, was used (Ferguson and Westover 1969). A major reason for the relatively low use of shear in broth processing was the apparant increase in suspended solids removal with decreasing shear treatment of the broth in bench tests.

As shown in Fig. 7, the 6 μm screen was able to remove better than 4/5 of the influent volatile suspended solids in most cases. It appears that a 6 μm screen would require subsequent polishing filtration

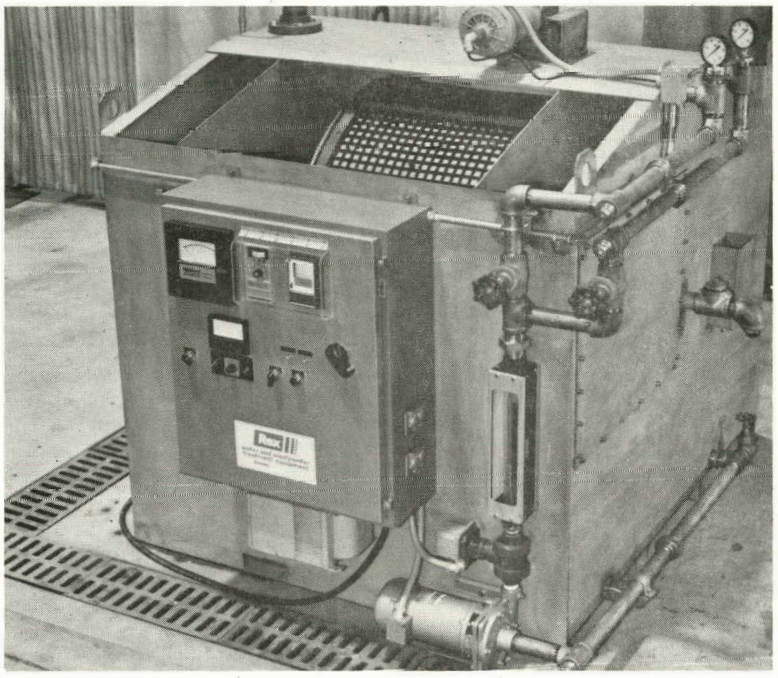


Fig. 5. Envirex PDP-52 microscreen used in pilot tests.

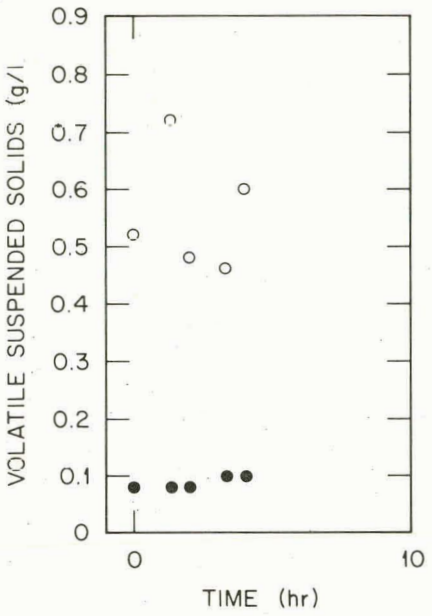


Fig. 7. Volatile suspended solids in influent (o) and effluent (•), 6μm screen.

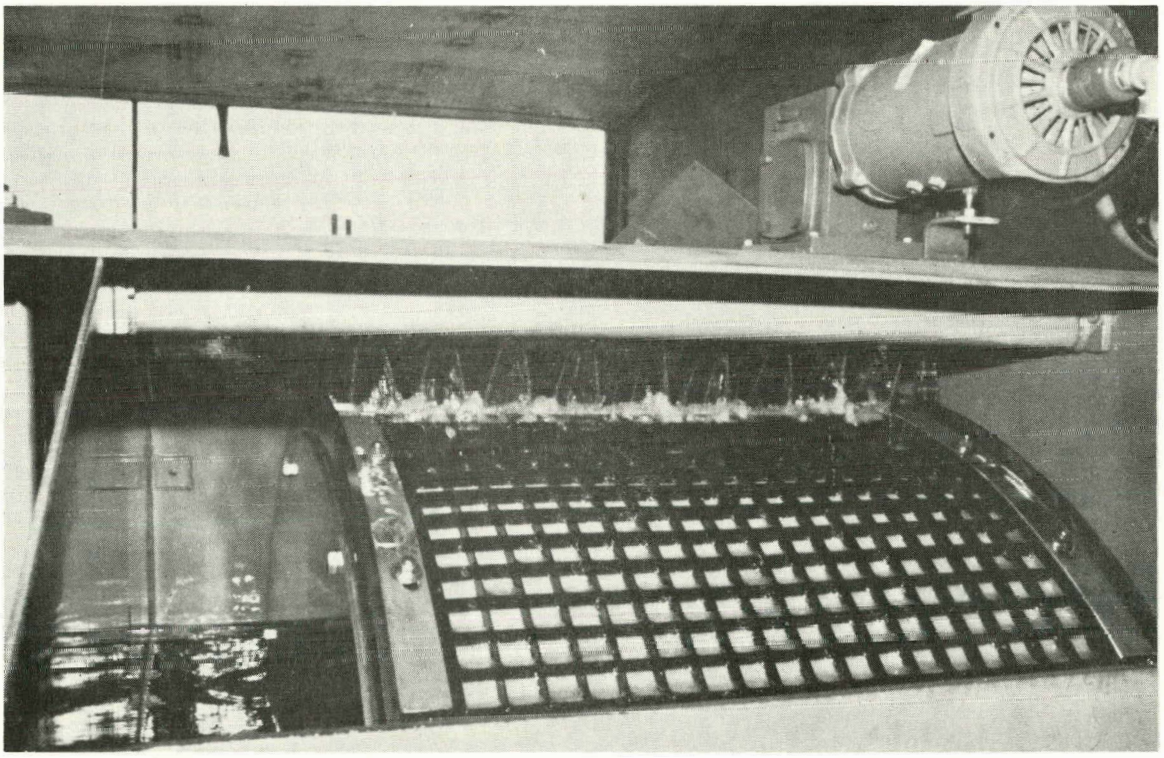


Fig. 6. Continuous filter cake removal from screen by backwash.

to remove the remaining suspended solids; however, the size of the polishing filtration equipment and the amount of filter aid or diatomaceous earth would be substantially reduced by the microscreening step. It is known that macromolecules may be partially rejected in passage through a filtration medium, *i. e.* the filtrate will be less concentrated in polymer than the feed. Although it appears that mixing was incomplete at the start of the 6 μm runs, as shown by the difference between influent and effluent polymer concentrations in Fig. 8, it appears that influent and effluent polymer concentrations tended to reach comparable values by the end of the experiment. Thus, it appears that scleroglucan biopolymer is not rejected by the 6 μm screen media to an appreciable extent.

In filtration by 1 μm media, as shown in Fig. 9, rejection of scleroglucan biopolymer was limited or absent during a 40 hr run. The variation in individual influent and effluent polymer concentration values appears to be greater than the usual difference between the two types of values. Unfortunately, as shown in Fig. 10, apparent volatile suspended solids removal values for the 1 μm medium are not as favorable as those for the 6 μm medium. Envirex experience indicates that this is probably because at the relatively low flow rate through the one micron medium, the slight leakage through the rotating drum seal at the influent entrance into the drum became important. This problem has been solved by the development of a special teflon rotating seal which is used in larger microscreens; however, the improved seal was not been installed in the small pilot test units. However, at worst volatile suspended solids removal was above half of the amount contained in the influent, and, at best, comparable to that by the 6 μm screen.

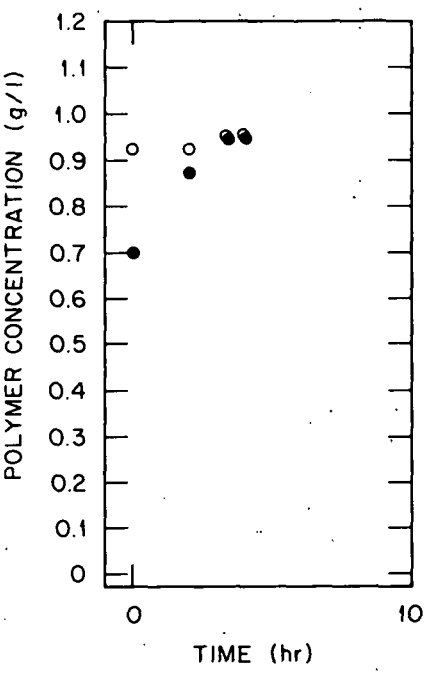


Fig. 8. Polymer concentration in influent (o) and effluent (•), 6μm screen.

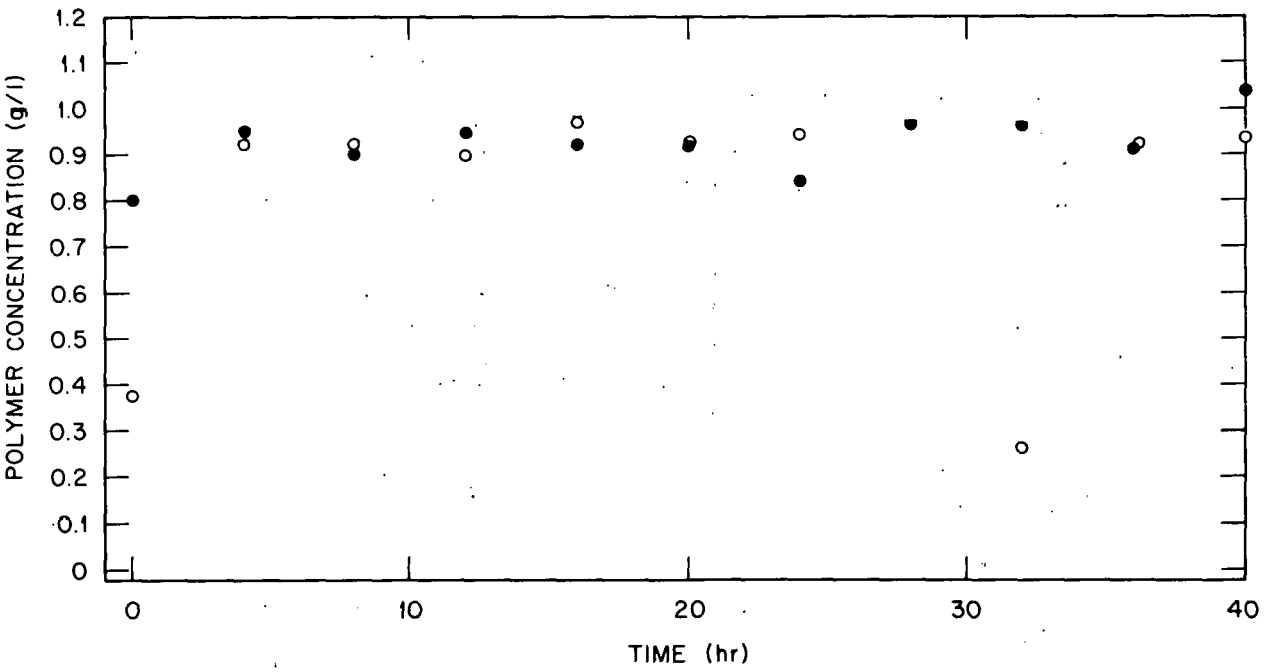


Fig. 9. Polymer concentration in influent (o) and effluent (•), 1μm screen.

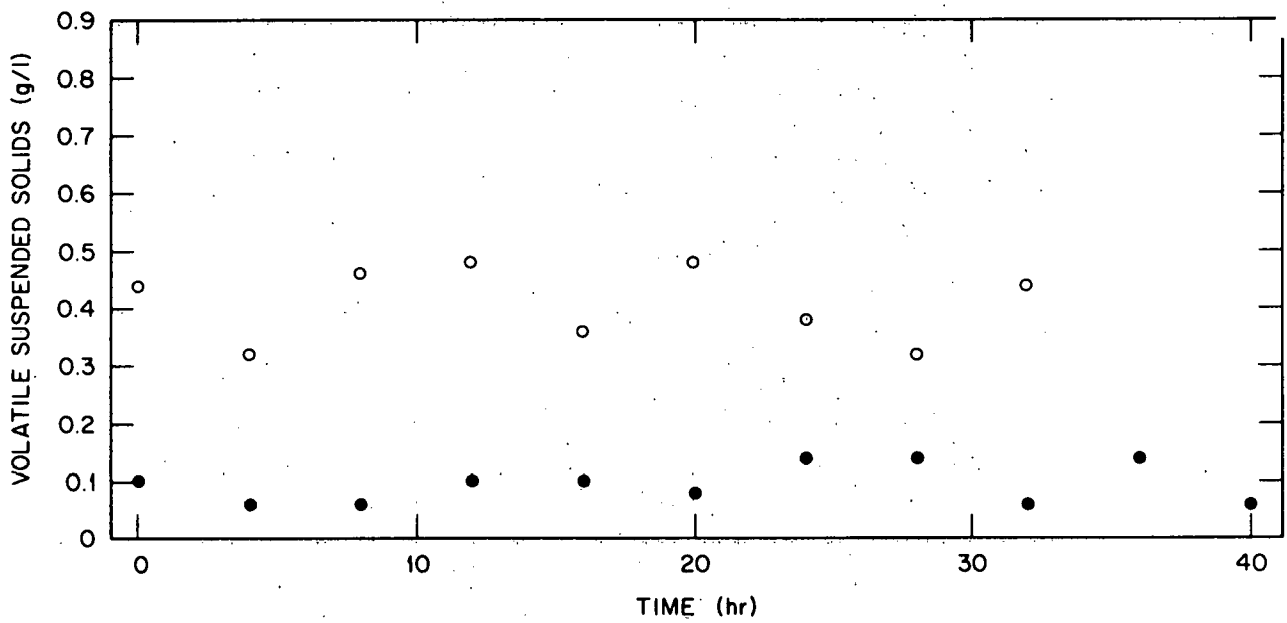


Fig. 10. Volatile suspended solids in influent (o) and effluent (•), 1 μm screen.

From the influent and effluent volatile suspended solids values plotted in Fig. 11, it appears that the 21 μm medium provided slightly poorer removal efficiencies than did the 6 μm screen. However, the flow rate was substantially higher. At worst, the volatile suspended solids removal efficiency was still above 0.50, indicating that a detailed economic analysis considering the trade-offs between polishing filtration and microscreening annualized costs should be performed for individual installations. Influent and effluent polymer concentrations were comparable, as shown in Fig. 12. Polymer rejection was not apparent when the 21 μm screen was used.

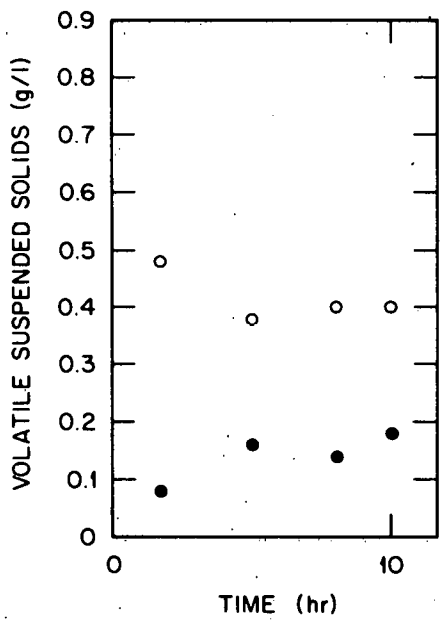


Fig. 11. Volatile suspended solids in influent (o) and effluent (•), 21 μm screen.

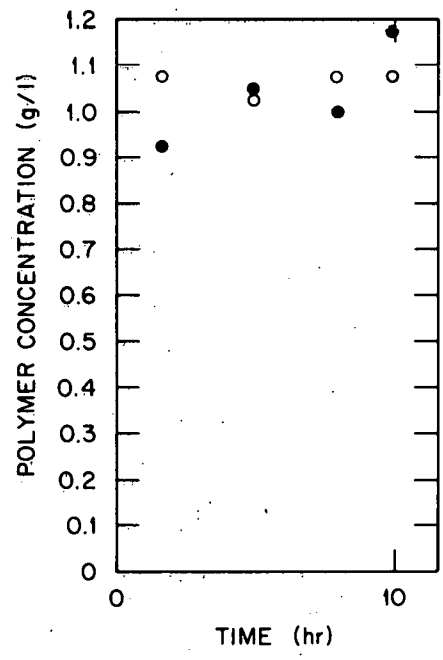


Fig. 12. Polymer concentration in influent (o) and effluent (•), 21 μm screen.

Two-stage treatment using 1 μm media to treat the 21 μm media effluent was also performed. This was done to determine whether a two stage filtration could be used to decrease capital cost while producing a high quality effluent. However, as shown by the influent and effluent volatile suspended solids in Fig. 13, this was not the case. Little volatile suspended solids removal occurred during treatment with the 1 μm screen. Fortunately, however, influent and effluent polymer concentrations as shown in Fig. 14 were similar, indicating that polymer was not removed during the filtration process. It is possible that performance of the two stage treatment process could be improved by decreasing backwash on both screens to permit the buildup of a thicker filter cake.

ENERGY COSTS OF ALTERNATIVE PROCESSES

Field *vs.* dry production. The major potential advantages of field over central production arise from avoidance of the necessity for preparing a dry product to reduce shipping costs and spoilage. The conventional method of precipitation is by isopropyl alcohol addition. Although the process involves alcohol recovery, we understand that a typical process loss is on the order of 1 gal alcohol per lb dry polymer recovered. For one metric ton of polymer per day, this would correspond to 2,200 gal. If enhanced oil recovery procedures using a lb polymer / bbl oil, a low to average figure, were implemented to produce 5% of current U.S. domestic consumption, isopropyl alcohol use would be roughly equivalent to current U.S. ethyl alcohol production. The cost and energy equivalent of lost alcohol is obviously significant.

Further problems with dry polymers arise from the necessity of redispersion in the field. A polishing step, often diatomaceous earth filtration, is thought necessary to reduce formation plugging by undissolved polymer aggregates (Smith 1975). A polishing procedure may also be necessary with a field fermented product; there are possibilities for the development of alternative continuous procedures (Griffith, Tanny and Compere 1979). In any case, redispersion is a troublesome step, avoided when the polymer is never reduced to a dry state.

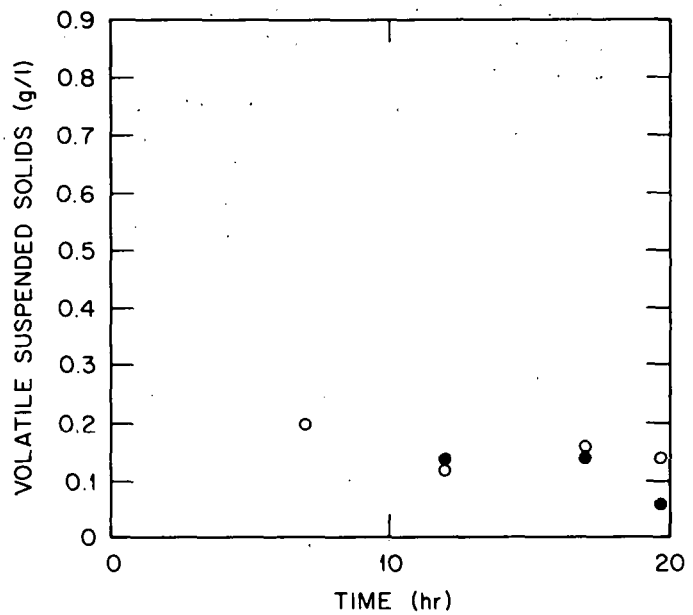


Fig. 13. Volatile suspended solids in influent (o) and effluent (•), 1 μm screen following 21 μm screen.

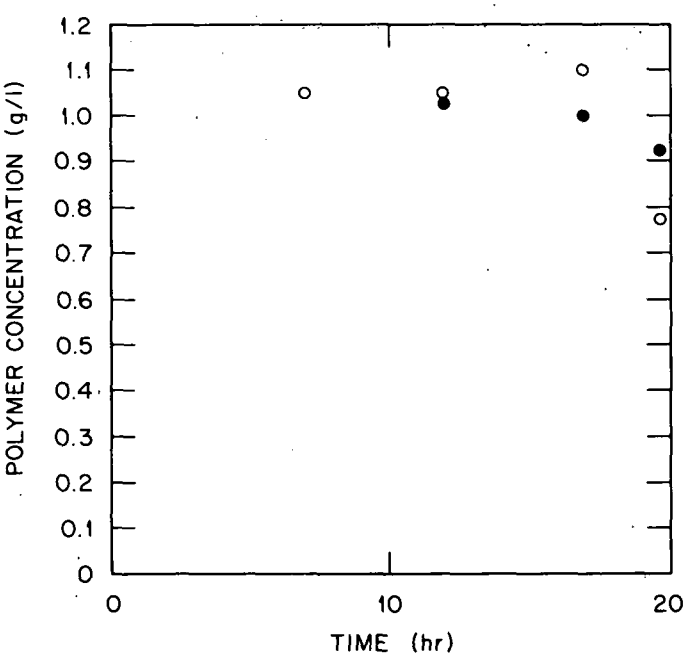


Fig. 14. Polymer concentration in influent (o) and effluent (•), 1μm screen follwing 21 μm screen.

Table 4. Cost and energy of alternative processes for a 1,000 kg/day pilot installation.

Process	Cost, 10^3 $	Power, hp	Flow, 10^3 gal/day
DE filter	155	180	264
Centrifuge[1]	107	40	264
Microscreen[2]	80	8	264

[1]Maximum power demands up to 60 hp. [2]Polishing step required.

Field separation. The literature indicates that centrifugation or diatomaceous earth filtration may provide satisfactory treatment for biopolymer solutions produced in the field. In order to compare the capital costs and energy requirement of these methods with microscreening, we obtained capital cost figures from manufacturers of these units. In the case of centrifugation and microscreening, a final polishing step may be indicated either to increase effluent quality or to provide a back up system in the event that a problem causes solids to come through the system. It is assumed that a polishing unit or back up unit would be a relatively small part of overall capital cost. Table 4 indicates that microscreening compares favorably with centrifugation and diatomaceous earth filtration for solids removal from field produced broth.

CONCLUSIONS

Bench and pilot tests with Envirex microscreen equipment indicate that it is possible to remove on the order of 4/5 of the influent biomass, as volatile suspended solids, from a high viscosity scleroglucan biopolymer feed stream. It appears that microscreening decreases or obviates the need for high-shear treatment of scleroglucan solutions prior to solids separation. A further advantage of microscreening is the elimination of the biopolymer precipitation and consequent high shear resuspension operations. Biopolymer precipitation is a major energy consuming process in biopolymer preparation since it can account for a solvent loss on the order of a gal of alcohol per lb biopolymer.

ACKNOWLEDGEMENTS

Ed Phares and Mary Long, who run the Oak Ridge National Laboratory Fermentation Facility, performed our two large scale fermentation runs. Without their expertise, experience, and facilities, we would have found it very difficult to run the pilot unit tests. We would also like to thank the Biology Division Engineering staff, especially C. R. Abercrombie, Jr., and L. E. Dew, who provided support services for the pilot installation.

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ELECTRIC GENERATING STATION WASTEWATER TREATMENT SYSTEM USING HYDRAULICALLY OPERATED HELICAL FLOW REACTOR CLARIFIERS

David K. Wyness
Emil N. Cook
Crawford, Murphy & Tilly, Inc.

The City of Springfield, Illinois owns and operates a water and electric utility. Lake Springfield is a dual purpose reservoir which supplies cooling and process water for a 460 mega watt coal-fired electric generating station, and is the water supply for the 48 million gallon per day water treatment plant.

Over 5 mega watts of electric generating production is consumed by air pollution control equipment. With this in mind, the City's Electric Division engineering staff required that the generating station's new water pollution control facility be designed to consume a minimum of energy.

In addition, the water pollution control system had to produce a high quality effluent exceeding Environmental Protection Agency regulations since, in order to conserve water, the discharge would be directed into the City's water supply reservoir, Lake Springfield.

Crawford, Murphy & Tilly, Inc., Consulting Engineers, designed a gravity-flow water pollution control system to remove grit, suspended and colloidal solids, oil and trace heavy metals from this 2-10 million gallons per day (7,571-37,854 cubic meters per day) waste stream.

The system consists of a grit and oil removal structure which is cleaned with the utility's rubber tired end loader coal pushers, a flow surge and temperature stabilization lagoon, a chemical feed station and three 36.5 foot (11.1 meters) diameter hydraulically-operated helical flow reactor clarifiers. The total system is operated by an 8.55 feet (2.6 meter) static head from the influent wastewater sewer to the normal lake level, and can be maintained in service for up to 48 hours without electricity.

The wastewater source from the electric generating station consists of slag tank overflows from the wet bottom boilers, pyrite removal system wastes, boiler blowdowns, as well as various equipment, yard and floor drains. Treating this waste stream presents special design considerations, since the water temperature fluctuates as much as 15° C within a few minutes, the solids and grit loading fluctuates and the flow varies rapidly.

The flow ranges from 2-10 million gallons per day (7,571-37,854 cubic meters per day) with a current average flow of 3.5 million gallons per day

(13,249 cubic meters per day). The primary contaminants are inorganic suspended and floating solids which range from 40 to more than 4,000 mg/l; trace heavy metals and iron, considerable quantities of oils and, on occasion, unburned carbon.

Prior to design of the waste treatment system, the City of Springfield had utilized various prototype helical flow reactor clarifier pilot plants to obtain information on treating this type of waste stream. From the pilot plant study and various laboratory simulations, a gravity flow system was designed utilizing a grit and oil removal system, a flow and temperature stabilization lagoon, and three helical flow reactor clarifiers.

Because of high concentrations of very abrasive grit entering the system, a grit chamber design was developed which could be cleaned with one of the city's rubber tired end loader coal pushers. Measuring 20 x 60 feet, (6.09 x 18.28 meters) this grit chamber was constructed perpendicular to the flow stream with underflow baffles. The flow velocity through the structure is approximately 2 feet per minute (.60 meters per minute). Retention time in the grit chamber is approximately 10 minutes. This structure is also equipped with scum, oil, and floating solids removal skimmer pipes.

Water from this grit chamber flows over a low spillway to a surge lagoon where water temperatures and flow are stabilized. This lagoon is 80 feet (24.38 meters) wide, 130 feet (39.62 meters) long and is operated with a 6 to 8 foot (1.82 to 2.43 meters) water depth.

In order to size this lagoon properly, numerous calculations were made to determine heat transfer from water surface areas, and actual temperature stabilizations were simulated in various containers of water under differing climatic conditions. The intent of this testing was to design a lagoon as small as possible so that a minimum of solids would settle requiring infrequent removal with a clam bucket or dragline. However, the lagoon needed to be large enough both to provide flow surge capacity as well as to reduce and stabilize the water temperature. The lagoon was built with 10,000 square feet (929 square meters) of surface area and was equipped with an underflow baffle which retains warm water until it cools. This lagoon is presently being operated with a two-hour retention time.

Flow from this lagoon then enters a chemical feed building which provides chemical storage and houses feeding equipment, a mixer and water quality monitors. Three liquid chemical feed pumps are provided to add

polymers or liquid coagulants, and two dry feeders were provided to add alum, lime, bentonite or various other coagulants, or pH adjusting compounds.

From this chemical feed station water is directed through a Parshall flume to a diversion structure which provides equal head to and from the 3 helical flow reactor clarifiers.

The first concept and prototype versions of this type reactor clarifier design were built and tested by the City of Springfield Water Department. The structural, hydraulic and mechanical design of the original concept was then developed by Walker Process, Division of Chicago Bridge and Iron Company. This firm presently fabricates and markets helical flow reactor clarifiers.

The three units at the Lake Springfield treatment plant are each 36.5 feet (11.1 meters) in diameter. The units have an area at the major diameter of 1,036 square feet (96.2 square meters), an overall depth of 24 feet (7.31 meters) and a surface area of 500 square feet (46.45 square meters). The flow-through retention time is 55 minutes at design flow of 1.5 million gallons per day (5,678 cubic meters per day).

The energy to operate the units, to provide the flash mix and maintain a dynamic rotating sludge blanket, is derived from the .5 foot to 2 feet (.152 to .609 meters) of head in the diversion structure. This head varies according to flow.

A cylindrical section forms the clarifier base into which raw water enters at a tangent. The rotational velocity of the raw water is maintained in the cylindrical section to provide a rapid mix of the raw water with reactant chemicals and previous precipitate. Adjustable baffles, located in the cylindrical section, perpetuate the rotation and control the tangential velocity components of helical flow. The bottom of this cylindrical reaction and flocculation zone is sloped to a drain and grit removal outlet.

Above the cylindrical section is the major conical section in which the rotating sludge blanket is formed. The conical shape of this section decreases the vertical component of the helical flow and prevents sludge from building up or settling on the sides of the unit. Within this solids contact zone is a centrally-located, adjustable, conical shaped sludge collector and concentrator. The level of this sludge concentrator is regulated from the bridge deck, controlling to an optimum both volume and

sludge density, as well as the sludge clear water interface. Because the ratio of sludge contact time versus clarification time is also determined in this manner, the unit can be adapted to various flow, and raw water conditions.

The upper portion of the major conical section is the clarification zone through which water continues to rise in a helical flow pattern until it flows over a circumferential weir.

Raw water enters the unit with an influent velocity of from 1 to 4 feet per second (.3 to 1.2 meters per second). The rise rate in the cylindrical rapid mix section is in the range of 20 gallons per minute per square foot (814 liters per minute per square meter). The horizontal component of flow at the major diameter of the conical section is decreased to 1 to 4 feet per minute (.3 to 1.2 meters per minute) and the vertical component is decreased to 1 gallon per minute per square foot (40.7 liters per minute per square meter).

The Springfield units are presently being operated at a rise rate of .9 gallons per minute per square foot (36.67 liters per minute per square meter) at the major diameter and a surface rise rate of 1.8 gallons per foot (73.26 liters per minute per square meter) with a flow-through retention time of 1 hour.

In order to evaluate the unit's potential, a flow of over 4 million gallons per day (15,142 cubic meters per day) or 2.67 times the design rate, was directed through one of the units. At this flow, the rise rate at the major diameter was 3 gallons per minute per square foot (122.1 liters per minute per square meter), the surface loading was 6 gallons per minute per square foot (244.2 liters per minute per square meter) and the flow-through retention time was 20 minutes. During this test period, an effluent turbidity of less than 1.5 neflumetric turbidity units (NTU) was maintained be feeding 2 mg/1 of cationic polymer.

Under normal operation, 1-2 mg/1 of cationic polymer are used to maintain an effluent turbidity of $\pm$ 1 NTU.

On occasion when treating relatively clear, colored, or cold wastewater, the addition of from 5 to 10 mg/1 of bentonite or alum improved the effluent water quality, and the addition of these compounds is necessary to maintain an effluent turbidity of $\pm$ 1 NTU, which the utility desired.

A flow-coordinated composite sampler is used to obtain representative

effluent samples. The turbidity, pH, temperature and flow of the final effluent is monitored and recorded by a panel within the chemical feed building.

Sludge blowdown from the three reactor clarifiers is controlled by selectively timed, motor-driven plug valves. The coagulated sludge flows by gravity to a wet well which was sized to store the sludge from 48 hours of plant operation. Since sludge disposal pumping is the only power requirement absolutely necessary for the plant operation, the system can be operated without electricity for up to two days.

During no-power operation polymer coagulant feed can be accomplished by gravity flow to the waste water stream. The polymer feed rate can be regulated by a pinch valve on the flexible polymer feed tubing.

The sludge is pumped from the sludge storage wet well to the generating station bottom ash sluice lines and is disposed of in landfills with the ash by two 30 hp. progressive cavity pumps, each of which operates approximately 15 minutes per day. These pumps are the only major energy consumers in the system.

Total yearly operating cost to treat 13 billion gallons (49.2 billion liters) of water with this system is projected to be $56,650, based on the first 10 months of operation. Of this, $32,000 is labor and maintenance, $22,800 is for chemicals and $1,850 is for electricity.

ACKNOWLEDGMENTS

Crawford, Murphy & Tilly, Inc. wishes to acknowledge Evans Construction Company, general contractor of this project; Walker Process which designed, fabricated and installed the Claricones; Illinois EPA which reviewed and approved this design which varies considerably from present standards; and Utilities Commissioner Paul Bonansinga and the staff of City Water, Light and Power whose concern for the aquatic environment of Lake Springfield made this design a reality.

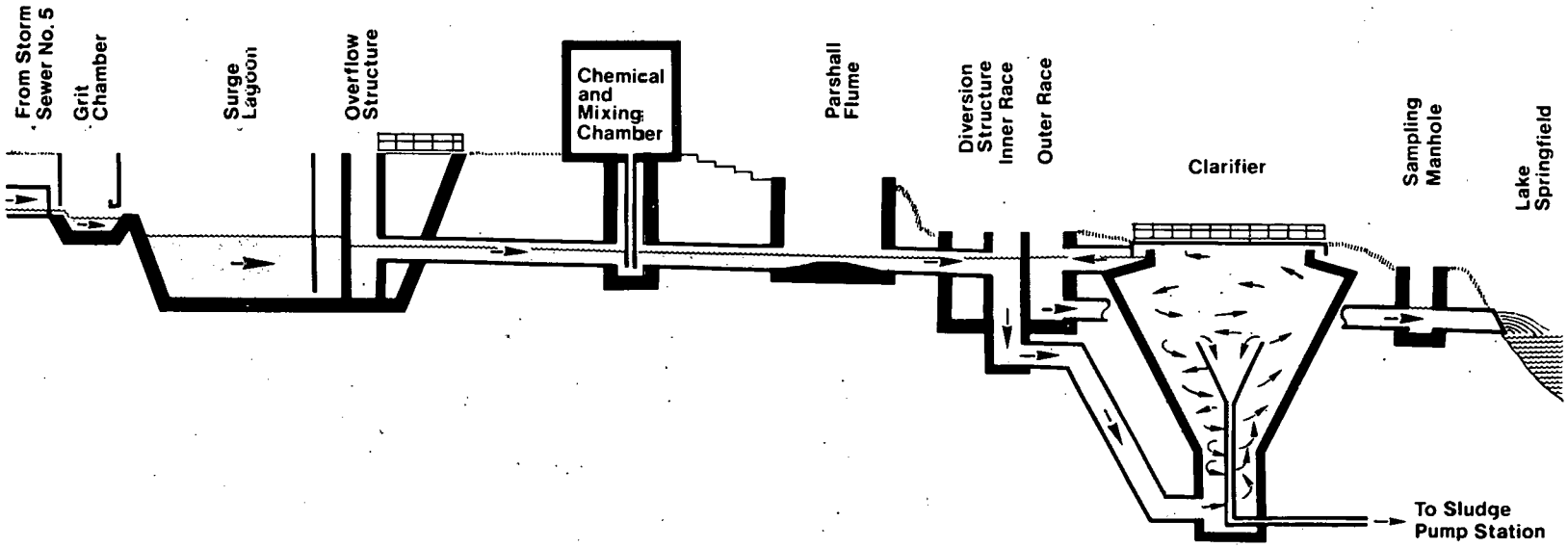
CITY WATER, LIGHT & POWER
WASTEWATER TREATMENT PLANT

OPERATIONAL DATA

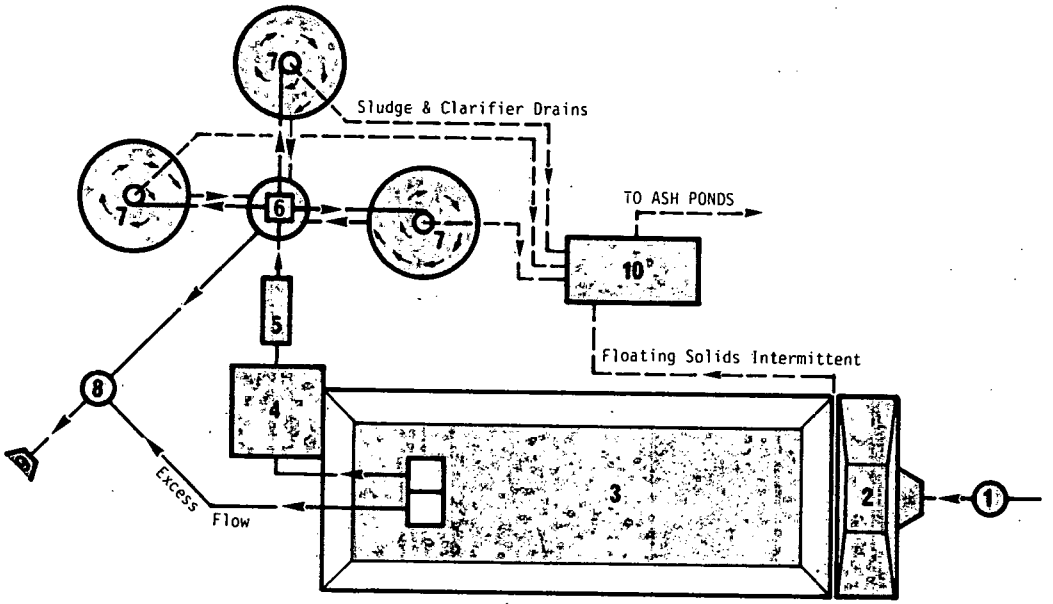
RAW WASTE			GRIT EFFLUENT		SURGE EFFLUENT			FINAL EFFLUENT			
SUSP. SOLIDS mg/1	pH	Fe mg/1	SUSP. SOLIDS mg/1	pH	SUSP. SOLIDS mg/1	TURB. (NTU)	pH	SUSP. SOLIDS mg/1	TURB. (NTU)	pH	Fe mg/1
92	6.6		90	6.6	87	95	6.8	4	1.3	7.0	
148	6.9	.58	142	7.0	143	115	7.0	0	0.76	7.4	.04
1998	6.9		1708	7.0	318	140	6.9	7	4.0	6.7	
128	6.9	1.10	116	6.9	129	130	6.9	1	1.9	7.0	.01
91	7.6		61	7.6	49	101	7.4	1	2.8	7.4	
26	6.6		26	6.6	22	9	6.7	3	1.0	7.1	
4430	6.2		1076	6.7	49	42	6.8	0	1.2	7.0	
134	7.9		156	8.0	147	69	8.2	5	3.6	8.2	
77	6.9	.92	153	6.9	149	106	6.9	3	2.8	7.2	.02
124	7.0		118	7.1	82	125	7.0	10	7.0	6.8	
35	8.2		55	8.2	55	32	8.2	1	0.82	8.2	
2875	7.0	1.05	388	7.2	41	16	7.2	1	1.20	7.2	.32
122	7.0		101	7.2	96	120	6.6	1	1.6	7.0	
4424	6.3		158	6.7	106	98	6.7	0	0.98	6.7	
121	6.9	.20	70	6.9	65	101	6.9	4	4.6	7.0	.01

AVERAGE CHEMICAL FEED 1-2 mg/1 Cat. Polymer

On occasion 5-10 mg/1 of alum or bentonite are used in addition to the polymer



HYDRAULIC PROFILE



1. STORM SEWER
   Avg.Flow 3.5 MGD
   Max.Flow 7.5 MGD
2. GRIT CHAMBER
   Velocity
   2.44 ft/min.
   *6.10 ft/min.
3. SURGE LAGOON
   Retention = 40 Hr.
   *Retention = 2.4 Hr.
4. CHEMICAL FEED & MIXING CHAMBER
5. PARSHALL FLUME
   Avg. 3.5 MGD
   Max. 7.5 MGD
6. DIVERSION STRUCTURE
   Avg. 3.5 MGD
   Max. 7.5 MGD
7. CLARIFIER - 36.5' Dia.
   UR = .66 gpm/sq.ft.
   *UR =1.0 gpm/sq.ft.
   Avg. 1.16 MGD
   Max. 2.5 MGD
8. SAMPLING MANHOLE
   Avg. 3.5 MGD
   Max. 7.5 MGD
9. DISCHARGE TO LAKE SPRINGFIELD
   Avg. 3.5 MGD
   Max. 7.5 MGD
10. WET WELL & SLUDGE PUMPS
    250 to 400 GPM intermittent

* Indicates MAXIMUM FLOW
UR Indicates UPFLOW RATE

FLOW DIAGRAM

SESSION 5

ENERGY CONSERVAVATION OPERATION AND MAINTENANCE

Chairpersons: James Smith

Richard Genung

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ENERGY CONSERVATION AND MONITORING IN WASTEWATER TREATMENT PLANTS

Earl L. Heckman
Greeley and Hansen, Engineers

Dr. John F. Andrews
University of Texas

Harold Gilman
Greeley and Hansen, Engineers

1. THE ENERGY CONSERVATION POTENTIAL

The rate of depletion and the skyrocketing prices of fossil fuels leave no doubt of the need for their conservation. Although the fuel and electrical energy used in wastewater treatment plants is estimated as only a fraction of 1 percent of the total energy use in the nation, it represents the largest single energy use in many communities.

The total operating energy budget for municipal wastewater plants has been estimated by Smith[1] to exceed 1,300 kilowatt-hours per million gallons treated, based on activated sludge plants with anaerobic digestion and sludge incineration. Donald Walter, chief of the urban waste and municipal systems branch at the Department of Energy has estimated that as much as 1/3 of this total plant energy use potentially can be saved.[2] Only the safe treatment and disposal of wastes should hold priority over energy conservation in this new era of resource management. Plants designed without adequate attention to energy use will experience potentially insupportable operating cost increases. High projected operating cost is reported to have forced one advanced waste treatment (AWT) plant to be converted during mid-construction to a secondary plant with phosphorus removal. A second AWT plant which had been completed in 1975 was changed to a 3-stage lagoon system, partly for the same reason.[2]

The largest potential savings of energy usually will lie in the areas of major energy usage. For an activated sludge plant with anaerobic digestion and sludge incineration, energy consumption typically is distributed about as follows:[1]

System	Operating Energy Consumption Percent of Total
Aeration	42
Heating: Buildings 7, Digestion 13	20
Incineration	17
Influent Pumping	10
Other Power and Lighting	11

Energy conservation in new and remodeled plants can be accomplished through design which intentionally avoids unnecessary energy use. Where multiple methods of meeting design objectives are available, a method permitting lower energy use should be proved unfeasible before proceeding to a method demanding higher energy use. Energy use avoidance is usually the most economical means of energy conservation. A variety of possibilities for reducing energy and for heat recovery can be found in many older treatment plants.

This paper will deal primarily with reduction of net heating loads. The other listed system categories warrant separate monographs, and will be covered here in broad outline only. Aspects of computer monitoring to energy management and control will be discussed, and finally a few energy reduction possibilities for future development will be listed.

2. ENERGY CONSERVATION TECHNIQUES

Within practical limits a reduction in plant influent flow will tend to reduce all costs associated with wastewater treatment. Three approaches to flow reduction include:

- Public education to use water-saving fixtures and to reduce water wasted
- Structuring sewer use fees to discourage unnecessary flow increases
- Design or repair of wastewater collection systems to minimize inflow and infiltration.

From an energy conservation standpoint, reduction in the waste of clean water correspondingly decreases the energy expended in its production.

As the largest energy user, the aeration system is likely to be the most susceptible to energy conservation techniques. The aeration energy requirement is a function of BOD level, required dissolved oxygen level, oxygen diffusion efficiency, and aeration equipment efficiency. The technique of shortening sludge retention time produces a double energy benefit. It will minimize the extent of aerobic digestion which occurs, and by passing more nutrients to the digester will increase digester gas production. Another technique is to control dissolved oxygen at the lowest level consistent with effluent quality. The manner of DO control should be accomplished in a manner which proportionally reduces the aeration equipment power consumption. Finally, aeration systems employing high efficiency small bubble diffusers may be an economical way to improve oxygen transfer efficiency. It should be emphasized that fine bubble diffusion demands high efficiency air filtering and consistent diffuser maintenance to

remain effective. Combinations of these methods have been reported as reducing aeration energy used by as much as 20 to 60 percent.

Sludge incineration, though incurring a high energy use, may necessarily be the disposal method of choice if lower energy methods are foreclosed. Improved dewatering which yields a drier sludge will reduce the incineration fuel requirement. Waste heat recovered and utilized from the incinerator off-gases by means of a waste heat boiler also will lower new energy use.

Conservation opportunities in influent pumping and in other power and lighting uses center primarily in equipment efficiency and control. Savings accrue through use of high efficiency motors and pumps, the application of capacitors for power factor improvement, and efficient control. In certain cases a useful heat source may be tapped, or extra heat removal ventilation may be avoided, through ducting of the hot air rejected by large motors to a heat exchanger or directly to outdoors. Significant percentage reductions in total energy use are difficult to achieve in these areas.

3. BUILDING HEAT ENERGY CONSERVATION

Building heat encompasses both thermal transmission loss from structures and heating of ventilation air. Transmission losses are cut by providing higher thermal resistance in the walls, roof and glass, as recommended by Standard 90 of the American Society of Heating, Refrigerating and Air Conditioning Engineers. Judgment must be used, however, in adding insulation to structures with high internal heat gain such as blower and compressor rooms. Increased annual energy consumption may result from additional mechanical outdoor air ventilation required for heat removal in warm weather. Judicious building fenestration and shading can both limit heat losses, and help offset those losses through passive solar heat gain in winter.(3)

Ventilation heating loads often can be reduced through energy recovery by means of direct heat exchangers, thermal wheels, heat pipe coils, and runaround coil systems. These devices exchange heat between exhaust air and incoming ventilation air. Heat recovery efficiencies in the order of 60 to 80 percent are obtainable, depending upon relative flow rates and the mean effective temperature difference between the air streams. These devices are effective both for heated and air conditioned spaces requiring high ventilation rates.

Building HVAC systems employ a number of electric motors in the 1-25 horsepower range. A fully loaded 10 HP motor operating continuously has an annual energy cost of $2,220 at 3 cents/kwh. A 10 HP high efficiency motor can decrease energy usage sufficiently to pay back its $60 capital cost premium in about 9 months.

In addition, such motors run cooler, and their life expectancy is lengthened.

Many HVAC loads vary with outside temperature. Their pumps and fans are designed to handle peak load conditions, but at the frequently prevalent part load conditions need not operate at full capacity. Properly designed variable air volume systems and variable speed pumping systems reflect reduced energy input in proportion to actual loading, thus conserving energy.

For nonhazardous spaces, energy can also be saved by cycling supply and exhaust fans intermittently, rather than operating them continuously. Such savings are offset in part by increased wear on belts, motors, and starters, but net savings can be achieved with scarcely noticeable variation in the environmental conditions maintained.

Energy retained in the product of one heat exchange process may serve as the heat source for a second exchange process to a lower energy level. Such a cascade effect is evident in the heat recovery devices previously mentioned. Other examples are the use of combustion gases leaving a steam boiler to preheat its boiler feed water or combustion air, and steam production by passing incinerator off-gases through a waste heat boiler.

4. DIGESTER HEAT ENERGY CONSERVATION

Sometimes the product heat content from one heat exchange process is insufficient and at too low an energy level to supply a second process. In such instances, a heat pump may sometimes be used both to amplify that heat content and raise its temperature to a useful level. The digestion process is a case in point.

The digester gas produced in northern climate secondary and advanced waste treatment plants, when burned in boilers and incinerators, may be insufficient to meet the winter heat demand.

If that heat demand cannot be reduced to match the heat available, the difference must be made up through purchased energy. As natural gas is unavailable in some areas, the practical choice of supplemental fuel in many cases has been between fuel oil and electricity. Based on fuel oil costing 50 cents per gallon and burned at 75 percent efficiency, versus electrical energy costing 3 cents per kwh, electric resistance heat will cost 1.8 times as much as heat from oil.

One nominal 200 MGD plant reviewed has a calculated shortfall of about 16×10^6 Btu/hr of heat demand not met by expected digester gas production. A preliminary study and life cycle analysis performed to EPA guidelines by Greeley and Hansen indicates that with the stated energy costs the heat deficiency can be made up more economically by electric driven heat pumps than by burning fuel oil in the boilers.

Heating of cold sludge to a point sufficiently above the 95 degrees F digester temperature to offset digester losses requires about 168 kilowatt-hours of energy per million gallons treated.(1) The digested sludge, due to its low temperature and difficult handling characteristics, has been neglected as a direct heat source for any other required heating operation. If unnecessary heat losses are minimized by design, however, the centrate or filtrate separated from the dewatered sludge retains a large proportion of the heat added at the sludge heater.

A heat pump is an ordinary refrigeration machine applied in the heating mode rather than the cooling mode. The heat pump removes heat from a source fluid, such as sludge filtrate passed through its chiller component, and discharges heat to a receiving fluid passed through its condenser. In this instance, the receiving fluid will be closed circuit heating return water from the sludge heaters. The salient feature of the heat pump is its capability of discharging much more heat to the receiving fluid than the heat equivalent of energy furnished to the heat pump compressor. The heat pump's coefficient of performance (COP) is defined as the quantity of heat discharged, divided by the heat equivalent of the energy input to the compressor. For filtrate entering the chiller at approximately 90 degrees F and sludge heating water leaving the condenser at about 140 degrees F, a COP of 3.0 is obtainable. That means that the heat equivalent of the compressor input is tripled as heat output at the condenser, and the heated water temperature is at a usable level.

The proposed heat pump system can be integrated into the sludge heating system as shown diagramatically in Figure 1. The heat pump chillers, and also the heat pump condensers, will be piped for series flow supplied continuously at a constant flow rate to maintain adequate velocity for good heat transfer. If the available supply water for either circuit drops below that circulation rate, recirculation will occur to a corresponding extent and the mean effective temperature differences for the exchangers will decrease.

The heat pumps will be sized with total heating capacity equal to the digester gas shortfall. A corresponding quantity of heating return water will be directed through the heat pump condensers, and back into the return heating main. The required quantity of boiler water at 180 degrees F will be mixed with the combined return flow to assure 140 degrees F supply water to the sludge heaters. An equal quantity of heating return water will be diverted to the boiler loop to be heated. If a heat pump is out of service, needed heat can be supplied from the boilers by burning an alternate fuel in one boiler.

The sludge heaters and associated space heating coils are selected to use 140 degrees F heating water supply, to optimize the COP of the heat pumps at only a small penalty to the sludge heaters.

The heat pump tubes cooling the warm filtrate will be cleaned at timed intervals by a proprietary automatic cleaning system. A spiral nylon brush, normally held at each tube outlet by a plastic retainer, will clean the tube inner surface when propelled to the opposite end of the tube by fluid flow reversal. There it will be caught by another retainer, and returned to its original position by a second flow reversal. A 4-way motorized valve and timer will initiate the two flow reversals at the end of each timed period. Independent tests indicate that the tube fouling factor can be held to 0.0005 over long periods of time, resulting in compressor energy saving.

Each heat pump will have full capacity control. The three heat pumps will be brought on-line and up to full capacity in sequence in response to a master condenser leaving water temperature controller set at 140 degrees F. As digester gas production begins to catch up with heating demand in milder weather, the heat pumps will operate at correspondingly reduced capacity, and be turned off in sequence. When gas production is adequate, all heat pumps will be off.

Using supply water at 140 degrees F to the sludge heating circuit reduces circuit temperature drop and proportionally increases required flow. To minimize the pumping energy required, the sludge heating pump will be provided with a variable speed drive, controlled to provide the head required to produce design flow at the most distant sludge heater. Energy will be conserved by pumping only at the rate necessary to meet the demand of sludge heaters actually in operation at a given time.

5. ENERGY CONSERVATION BY COMPUTER MONITORING

Through installed watt meters on the plant power service and feeders to major plant processes, a central computer system can process and store information, and continuously provide to the plant operator the data needed for energy use decisions. Data charts and graphs can be displayed upon call showing actual energy use distribution throughout the plant, historically based energy use expectations, energy use trends, and data relationships. The operator also can be alerted by annunciator signal to off-normal energy use by any system. Power usage can be correlated with such operating variables as process flow and total plant flow as measures of plant operating efficiency.

Plant management initially will need to establish power usage criteria from past experience, and store the proper data in the computer system data base. Through its data gathering and analysis capabilities, the computer can subsequently be used to upgrade those parameters to reflect a realistic assessment of normal plant energy use. Comparison of the various system requirements with energy usage at similar plants will indicate areas of potential improvement.

A computer also can be advantageous in determining maintenance intervals and adequacy of maintenance procedures. By monitoring temperature differentials through heat exchange equipment, the computer can be used to assess the point at which cleaning of transfer surfaces becomes energy efficient. Analogous monitoring could flag the need for cleaning of air diffusers and various types of filters. The actual performance of cleaning procedures and their effectiveness also can be monitored. This knowledge should provide maintenance personnel with added incentive to do a consistently thorough job. Running time of various pieces of equipment can also be accumulated by computer, with a warning signal provided when each should be lubricated. Performance of preventive maintenance when actually needed, rather than on a calendar basis, will result in overall energy conservation.

6. LOOKING AHEAD

A few ideas which may effect greater energy conservation in the future will be mentioned briefly. Some are proven but not widely used, and others only futuristic possibilities.

Combustion gases from boilers, incinerators and furnaces contain heat which can be reclaimed. A direct heat exchanger in the breeching connection can be used to preheat boiler feed water or combustion air. Some European practice has used a scrubber to cool these gases below their dewpoint, thus recovering increased sensible heat, plus the latent heat from water vapor in the gases. The heat is then transferred through a heat exchanger to a lower energy level heating circuit.

Through adaptations of standard equipment, digester gas fueled engines or turbines could drive screw type or centrifugal compressor heat pumps, essentially eliminating the cost burden of purchased electricity associated with electric driven heat pumps. Total heat derived from the digester gas so used, including that recovered from jacket water, exhaust gases and cooling oil, is predicted to be at least 1-1/2 times as great as if the same gas were burned in a boiler with average combustion efficiency. In effect, the gas driven heat pump can extend the available heat supply.

In 1976 H. Clyde Allen, Vice-President - Rates, Union Electric Company in St. Louis predicted[4] peak load pricing emphasis in electric rates of the future. This would take the form of demand charges based on a customer's load at the time the utility system experienced peak load, and energy charges based on the time of use in the industrial sector. If such rates were to be applied to wastewater treatment plants, equalizing basins might be used to store daytime flows to await night-time pumping. Similarly, electric heat pumps operating at night could store heated water in insulated tanks for daytime use.

One large area awaiting energy conserving solutions is that of excess digester gas production in summer and its disposal in waste gas burners.

Gas engine driven pumps, blowers and generators for summer use only, have presented some problems in application. A possible use for summer electrical generation might be electrolytic dissociation of water into hydrogen and oxygen. Hydrogen is storable in the form of hydrides for future recovery as supplemental fuel. Oxygen could be added to the aeration stream to improve transfer efficiency. Alternatively, if "waste" digester gas were cleaned of carbon dioxide and sulphur by scrubbing, the remaining methane might be sold to a gas company or to a private consumer. Or as a chemical feedstock, it might either be sold or converted on-site to such useful products as fertilizer or activated carbon. At least one waste treatment plant has converted plant vehicles to use digester gas as fuel, and others are investigating this application. Appropriate and economical uses for excess digester gas should be developed rather than wasting this renewable resource.

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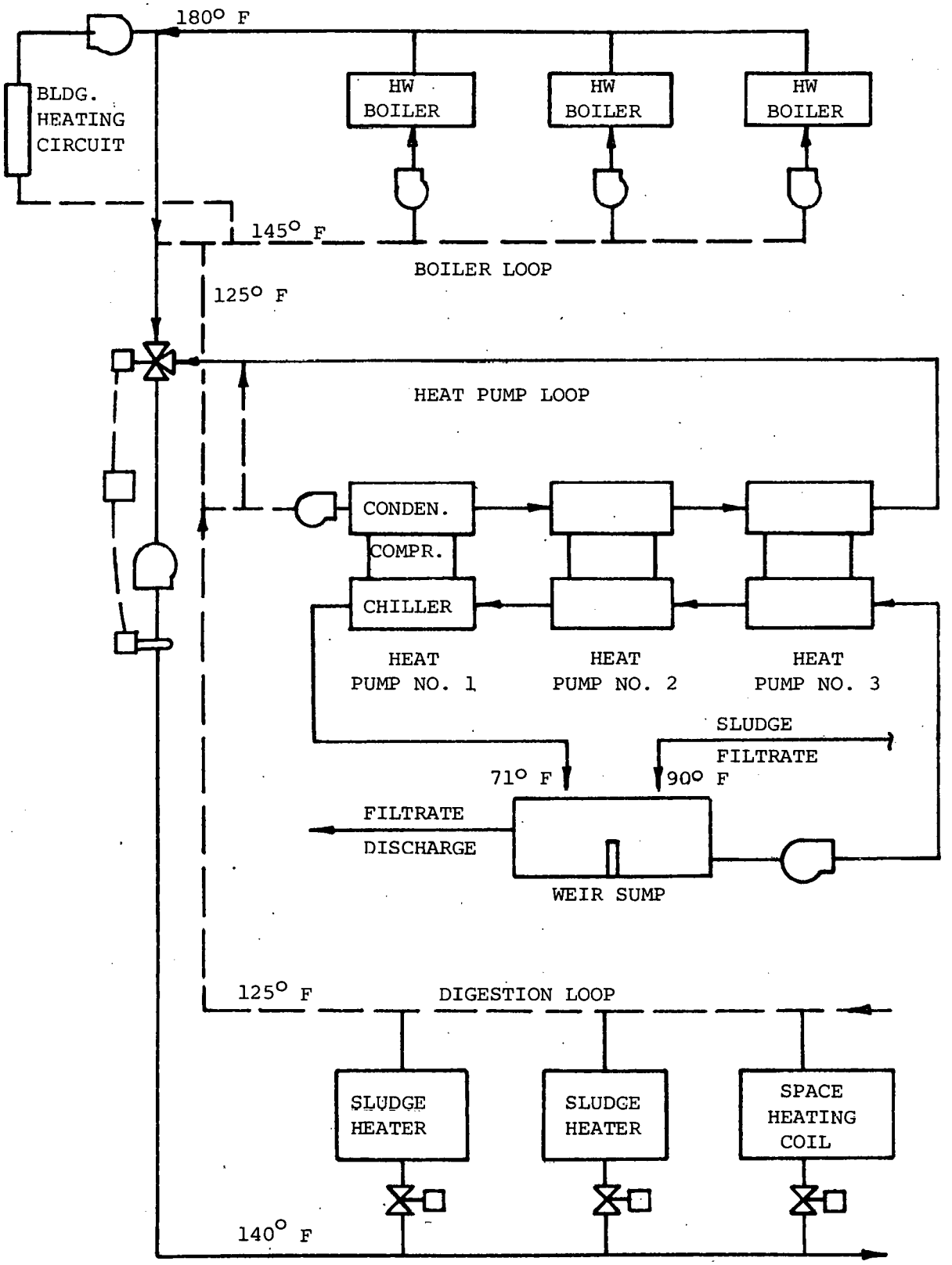
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FIGURE 1. SLUDGE HEATING WITH HEAT PUMPS AND BOILERS



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OPERATIONAL FINE-TUNING FOR ENERGY CONSERVATION IN WASTEWATER PLANTS

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INTRODUCTION

All of the wastewater treatment plants in the United States consumed only about 0.17 percent of the nation's electricity in 1977, but that amounted to approximately $300 million worth of energy! As this figure increases and energy supplies continue to dwindle, more emphasis is being directed toward energy conservation in plant design and operation.

Since most treatment facilities depend largely on electricity as their source of energy, this paper will begin by defining in general how power rate schedules are set up. Treatment plant operators need to understand the methods used to compute the plant's power bill so that they can direct their energy-saving efforts toward cost-saving as well.

Examples of energy-conservation techniques used in various plants are described using generalized case examples. The operator's role in optimizing the use of energy is the focus of these discussions, with emphasis on areas such as biological treatment, solids handling, and energy recovery. The intent of this presentation is that operators will relate these examples to situations in their own plants to aid them in devising programs for conserving energy.

POWER RATE SCHEDULES

In past years, before there was commonly thought to be an energy crisis, large users of electrical power received discounts as their consumption increased. This encouraged industrial growth and increased power generation by the utilities. Because of regulatory pressure and the increased emphasis on conservation, rate schedule structures have now been drastically revised.

A. Energy and Demand

Energy is defined as the quantity of power used per unit time, measured as kilowatt-hours (kWh). Demand is an instantaneous measurement of the power being used at any particular time. It is measured in kilowatts (kW), which can be related to the effective horsepower of the equipment in operation at the time.

An energy charge is made for each kWh used, to pay the utility's operating costs for generating the power. A demand

surcharge may also be assessed each billing period, based on the maximum demand sustained throughout a specified time interval such as 30 minutes. This surcharge pays the capital costs for having generating capacity available to meet the demand.

B. Time-of-Day Demand

In areas where the demand threatens to exceed power production capacity at certain times, a sliding scale is being used to adjust the demand surcharge to the time of day and the season. This is intended to discourage large customers from creating a high demand during peak times, such as summer afternoons when a large number of air conditioners are running.

Some manufacturing operations are probably able to adjust their production schedules to avoid peak demand periods, but doing this in a wastewater treatment plant requires a lot of ingenuity because of the lack of control over incoming flow and loadings. However, some possibilities are:

1. Flow storage prior to treatment
2. Shutting down solids processing during demand peaks and catching up later
3. Off-peak generation and storage of oxygen for activated sludge processes
4. Storing digester gas or other fuel and generating power during peak demand periods

An example of a peak-period demand surcharge schedule for a plant with a monthly demand greater than 4000 kW is shown below.

Demand charge per kW	Summer	Winter
On peak (early summer and late winter afternoons)	$4.20	$2.80
Partial peak (mornings and evenings)	0.35	0.35
Off peak (nights, Sundays, holidays)	None	None

C. Other Charges

Several other factors which affect the dollar amount of the monthly power bill are:

Customer charge--A flat rate service charge for each metered connection is assessed.

Voltage adjustment--Customers taking delivery at voltage higher than 2 kV may get a demand charge discount.

Power factor--The ratio of lagging kilovolt

ampere hours to kilowatt hours consumed increases or decreases the total bill, depending on how much it deviates from a specified ratio (usually about .85).

Facility charge--If the utility spends more constructing service facilities for a customer than they receive in revenue, an additional charge may be made as a percent of the excess.

Energy cost adjustment--A variable charge per kilowatt-hour is made to cover changes in the cost of fuel used to generate power.

ENERGY SAVING TECHNIQUES

Specific methods for trimming energy costs are outlined below, using generalized case examples based on actual operating plants. With some techniques, the cost savings result from reduction in demand peaks. In most cases, an overall reduction in energy consumption is the primary method of saving money. The most important aspect of an energy conservation program is a total system approach. For each operational change initiated to save energy, the whole facility must be considered to insure that a corresponding increase does not occur in another area.

A. Power Monitoring

Relatively inexpensive instrumentation is now available for constant monitoring of both energy use and demand. Installation of monitoring equipment at the plant's incoming substation and at individual motor control centers supplies on-line information to the operations staff, telling them how much power is being used in which areas. This information is essential, especially if time-of-day demand peaks are being shaved through operational modifications. Where digital computer systems (or even small microprocessors) are available, the data can be trended and totalized to aid in interpretation and record keeping.

B. Unit Capacity Optimization

Plant managers should carefully evaluate process operations to determine when treatment units should go in and out of service, especially in plants where the load changes seasonally. Although short-term fluctuations in loading may not dictate changes, anticipation of and response to seasonal variations can save significant amounts of energy while still maintaining effluent quality. Accurate judgements are required--for instance, cutting back on anaerobic sludge digester mixing may save only minimal amounts of energy while causing a disastrous upset. In contrast, secondary treatment units such as activated sludge aeration tanks and high-head oxidation towers are very energy intensive and should not be operated far below design capacity. Clarifiers,

on the other hand, require a very small amount of power and may enhance treatment efficiency when multiple units are operated at low overflow rates.

A municipal secondary treatment plant using high purity oxygen activated sludge was designed for 120 million gallons per day (mgd). The flow configuration uses eight biological reactor trains and twelve clarifiers. Although the nominal design flow for each reactor train is 15 mgd, the oxygen dissolution capacity is adequate for at least twice that, to handle seasonal load increases and a possible future requirement for nitrification. Since each train uses 400 hp of mixers, a significant energy savings is realized by operating only three or four trains for the actual average flow of 80 mgd. All available clarifiers are used, since they have only 1 hp drive motors.

C. Aeration Blower Control

In most conventional activated sludge plants, the largest consumers of energy are the blowers or mechanical devices used to supply air to the aeration tanks. Many plants in past years were designed with strictly manual control of the aeration system, due to the following factors:

1. Reliable on-line instruments for measuring the dissolved oxygen (DO) level of the mixed liquor in the aeration tanks were not yet available.

2. The cost of energy was much lower than now, as compared to the relative cost of instrumentation systems.

3. The state-of-the-art of activated sludge process control was less advanced.

Now that energy costs are high and DO controls systems fairly reliable, the majority of new plants are being designed with these control systems and many agencies are adding them to their existing plants. Although there have been some attempts to control mechanical aerators by DO level, most of the current systems use diffused aeration with suction-throttled centrifugal blowers. An electrical signal from the DO probes in the tanks is usually converted to a pneumatic signal which controls automatic air distribution valves on the headers to each aeration tank pass. A pressure sensor on the blower discharge manifold upstream of the distribution valves controls the inlet guide vanes on the blowers to maintain a constant pressure in the manifold. Analog or digital control loops can be used.

The energy consumption is reduced with DO control because centrifugal blowers use less power when the suction is throttled. The turndown limit (surge point) is usually about

50 percent of design capacity, so several blowers of different sizes may be used to provide a better coverage of operating ranges. The activated sludge process is subject to upset at DO levels lower than 1 milligram per litter (mg/l), so controlling the DO in the neighborhood of 2 mg/l protects the process.

Two oil refineries have activated sludge systems for treatment of their process wastewater. Even though both systems originally used single-speed mechanical aerators with no control systems, studies showed that installation of completely new aeration systems using DO control with diffused air and centrifugal blowers could save enough in power costs to pay for the new equipment in several years. Some particular considerations which contributed to this analysis were:

1. Due to the cyclic nature of refinery processes, the incoming waste load varies widely over periods of short duration.

2. The temperature of the wastewater is unusually high which cuts into aeration efficiency and makes a more efficient system more cost-effective.

D. On-Site Power Generation

The current emphasis on the environment and energy has focused attention on the production of "bio-gas" from digesting organic matter. Municipal waste treatment plants have used the anaerobic digestion process for over 50 years to stabilize sludge before utilization or disposal. The gas produced, containing about 65 percent methane, has been used in boilers to produce heat for the digesters and plant site buildings. In some larger plants, the excess gas is used to generate power.

One problem with using digester gas for power generation is the high initial capital cost and high maintenance costs for large reciprocating engines. Another problem, particularly with primary plants, has been that the greatest excess of gas is available in the summer, when heat requirements are less and power requirements lower due to decreased flows. Experience with engine-generator design and the development of gas turbines have helped to minimize maintenance costs. Some plants expanded to secondary treatment have found a drastic shift in their seasonal energy requirements, with summer peaks occurring for biological treatment of food processing wastes. The advent of co-generation, where induction generators are operated in parallel with utility power, will also contribute to the cost-effectiveness of installing on-site power generation systems.

A 55 mgd primary and secondary plant located in a largely agricultural area treats a mixture of domestic sewage and seasonal cannery wastes. Methane gas from anaerobic digesters is used to fuel three piston engines driving variable frequency generators. Two generators power the influent and effluent pumps using the variable-frequency feature to control pump motor speed. The third unit powers other plant equipment when extra gas is available. In 1978, 36 percent of the power used in the entire plant was generated on-site at a savings of $120,000. Hot water from the engines' cooling system is circulated through a reservoir loop to heat the digesters and plant buildings.

E. Heat Reclamation Systems

Heat is produced in some treatment plant processes while being required in others. Waste heat can be recovered in large quantities from incinerators, boilers and engines. It is transferred in water to heat sludge digesters and plant buildings or in steam to power turbines driving mechanical equipment. Operational control is critical because the systems are often complex, with the balance between heat requirements and availability constantly changing as changes occur in plant load, flow, and ambient air temperature.

One type of system uses a hot water reservoir loop to circulate waste heat from digester gas-powered engines to digester and building heating systems. Thermostatically controlled valves and pumps regulate the flow of water to the various units. A balance in the system is maintained by disposing of excess heat in exchangers located in the wastewater flow stream. In emergencies, heat from auxiliary boilers or resistance-type electrical heaters is added. Because no automatic system can anticipate changes in variables such as digester gas availability and ambient temperatures, the experience of the operators is relied upon for judgements as to when engines should be started or control setpoints changed.

A more recently designed system for a 60 mgd water reclamation plant is modeled after industrial systems using steam turbines. The waste heat from incinerators burning sludge is recovered as steam, which is used to drive the plant's aeration blowers.

F. Solids Handling Tradeoffs

The push for secondary treatment expansions mandated by the 1972 Water Pollution Control Act often resulted in a decrease in emphasis on solids handling and disposal. Now that many new secondary plants are on line, the full impact of increased sludge production and changes in its characteristics are being realized. Processing and disposal or

utilization of solids is rapidly becoming the most cost and energy intensive aspect of wastewater treatment, especially as urban sprawl increases the distance between treatment plants and land areas available for disposal.

The operator's success in reducing the overall amount of energy consumed in solids handling processes will depend on his recognition of the relationships between tradeoffs in which he can make choices. Some examples of these follow:

1. A vacuum filter is a very energy-efficient device for dewatering some types of sludges. Correct chemical conditioning of the sludge is critical and relates to energy use because higher production and lower moisture content mean shorter running time for equipment and lower offhaul costs.

2. The use of centrifuges for dewatering digested primary and secondary sludges is becoming more common because of the difficulty in thickening these sludges. When centrifuges are operated at a low capture, the operator may have the illusion that he is producing a lot of cake at a low chemical dosage. He should realize that the cost and energy penalty is high for this because solids recycled through the plant have to be retreated and reheated in the digesters before he gets another chance to remove them. In-plant solids recycle is also a major cause of effluent quality degradation.

3. When sludge is to be incinerated, dryness is usually of paramount importance because large amounts of supplemental fuel are required when excess water is fed to the furnaces. Most dewatering equipment will produce a drier cake at lower throughput, so it becomes the responsibility of the operations staff to operate more dewatering units on a longer schedule if the tradeoff is favorable.

4. The difference between being able to use a low-energy land disposal or composting operation or a higher technology, more energy-intensive alternative often depends on the operator. He can insure adequate sludge stabilization through efficient process operation and develop favorable public relations by taking prompt action on odor and nuisance problems.

G. Pumping and Hydraulics

Operators cannot be expected to redesign the hydraulic profile of a treatment plant, but they can often save energy by making some simple adjustments. The approach of the design engineer is usually to conserve as much pumping head as possible in equipment and structure design, since it is

estimated that each foot of head will cost about $500 per year per mgd in energy. However, the design must allow operational flexibility and leave room for possible future expansion, so pumps are sometimes oversized and head losses designed in.

Treatment units such as synthetic media oxidation towers (modern version of the "trickling filter") depend on recirculation pumping for aeration and contact between waste and micro-organisms. Using frequent loading rate calculations, the operator can adjust the recycle rate to the minimum necessary to maintain process efficiency. Excess recirculation only wastes energy and will not increase removals. This also applies to return activated sludge pumping. It may be easier to crank the pumps up to high speed and forget about them, but careful sludge blanket monitoring will result in an increase in solids concentration, which will allow lower pumping rates.

The operators of a 3 mgd oxidation tower plant noted that the primary effluent fell several feet into the tower feed pump well. The well level set point is maintained by automatic modulation of a pneumatically-controlled butterfly valve in the tower effluent recycle line. There is an overflow weir at the end of the primary effluent channel upstream of the pump well for diversion to the percolation ponds in case of a power failure. About three feet of head ($4,500 per year) was conserved by installing a plate to raise the weir level and then raising the pump well level control set point to minimize freefall into the well.

SUMMARY

1. Wastewater treatment plants in the United States depend primarily on electrical power as a source of energy, consuming over $100 million worth in 1978.

2. The size of the monthly power bill depends on the amount of energy used and the magnitude of the demand, as well as several other factors.

3. Plant operators need to understand the energy interrelationships and individual impact of variables under their control so that they can fine-tune the treatment processes to reduce energy consumption.

4. Some energy saving programs and techniques currently in use are:

   A. Shaving demand peaks by careful operations scheduling.

   B. Optimizing process units to reduce the amount of equipment in service.

   C. Aeration equipment control automation by dissolved

oxygen level.

D. Power generation using gas from sludge digesters.

E. Reclaiming excess heat from mechanical systems, such as engines and incinerators.

F. Evaluation of solids handling energy tradeoffs.

G. Conservation of hydraulic head.

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TRACER MEASUREMENT OF OXYGEN TRANSFER EFFICIENCY

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INTRODUCTION

Spiraling energy costs continue to increase the costs of operating aeration equipment for wastewater treatment. As energy resources become more valuable, aeration equipment manufacturers and process design engineers are increasingly concerned about energy-efficient aeration. A long-standing problem in aeration process design has been the lack of a reliable testing technique to accurately measure aeration equipment performance in the field under real process conditions.

The purpose of this paper is to acquaint the conference participants with an innovative tracer approach to accurately measure oxygen transfer efficiency in wastewater treatment plants. Complete technical details of the tracer method have been previously published.[1,2]

CONVENTIONAL TESTING

Presently, most oxygen transfer efficiency measurements are made using the clean water non-steady-state test. In this method, the test basin is cleaned and filled with tap water prior to the testing. The test water is then chemically deoxygenated by using excess sodium sulfite and cobalt as a catalyst while the aeration equipment is operating. Once the excess sodium sulfite is oxidized, DO levels in the test tank will steadily increase and approach the prevailing saturation limit. By measuring the rate at which DO approaches saturation during the test, it is possible to calculate the rate of oxygen transfer based on gas-transfer theory.

The clean water non-steady-state test is widely used to determine oxygen transfer efficiency despite the limitations and uncertainties associated with the test. The test is limited to applications where the test water does not react with oxygen and near complete mixing is achieved. The test water requirement precludes the use of this method in real wastewater systems, and the complete mixing requirement means that many aeration systems, quite satisfactory in treatment terms, are not suited to this testing method. There are also numerous uncertainties about how the test is conducted and how the data are analyzed.

A second approach to oxygen transfer efficiency measurement has been the respiring system indirect oxygen-uptake method. This method is used in operating treatment plants. The test requires that all sources and sinks for DO be evaluated except for oxygen transfer, which is indirectly calculated based on a theoretical model of the system. The calculated oxygen transfer is subject to considerable uncertainty because all errors of measurement are lumped into the computed oxygen transfer rate bssed on a model involving biochemical parameters that are difficult to evaluate and usually impossible to verify. At best, the respiring system approach can only provide relative performance information rather than absolute efficiency.

(A more detailed discussion of the problems and limitations of present oxygen transfer efficiency measurement is presented in the EPA/ASCE workshop proceedings on oxygen transfer.)[3]

THE TRACER METHOD

The gas tracer method for oxygen transfer performance testing was developed to overcome the limitations and problems

associated with present conventional testing methods. The gas tracer method employs simultaneous use of two radiotracers: dissolved krypton-85 gas is the inert (Noble gas) tracer for DO and tritiated water is the conservative dispersion and dilution tracer. The tracer method was originally developed at the U.S. Public Health Service by Tsivoglou and others[4,5&6] for measurement of oxygen transfer in flowing streams. Since the first field applications in 1966, the tracer method has been used in at least a dozen states and is widely considered to be the only reliable method for accurate measurement of stream reaeration. In 1971, the stream method was adopted for use in operating wastewater aeration basins and a complete series of demonstration tests were conductd in diffused-air and mechanical aeration systems at operating wastewater plants. The results of these tests have been reported previously.[1&2]

Both the krypton-85 and the tritiated water are homogeneously mixed together in a single tracer-unit bottle. The krypton-85 gas is completely dissolved in water, and the bottle is filled with the water/tracer mixture so as to exclude air space into which dissolved krypton-85 might transfer.

The tracer unit is released by quickly breaking the bottle below the water surface in the operating aeration basin. Both tracers are dispersed and diluted according to the prevailing mixing and flow conditions in the system. The tritiated water provides an accurate measure of the total dispersion and dilution taking place. The dissolved krypton-85 gas is subject to the same dispersion and dilution as the tritiated water because both tracers are released simultaneously in a homogeneous mixture. Also, the dissolved krypton-85 gas is lost from the water because of physical gas transfer but, being a noble gas, krypton-85 is not subject to other significant losses.

The rate of change in concentration of the dissolved krypton-85 gas relative to the rate of change in concentration of tritium accurately reflects the rate of dissolved krypton-85 gas transfer.

From detailed experimental work and theoretical considerations by Tsivoglou and others[4&6], the rate of krypton-85 gas transfer relative to the rate of oxygen transfer has been established as a physical constant. Namely, the observed krypton-85 gas transfer rate coefficient is 83-percent of the actual oxygen transfer rate coefficient. Therefore, it is possible to precisely measure the rate of inert krypton-85 transfer and reliably establish the oxygen transfer which cannot be measured directly due to the limitations and problems of conventional oxygen transfer measurement techniques.

SUMMARY

The principal advantages of the tracer method over more conventional testing methods are as follows:

1. Highly accurate and reliable.
2. Can be applied in test tanks or in actual operating treatment facilities without modification or upset of normal operations.
3. Can be used in any liquid from clean water to sludge.
4. Does not depend on any chemical or biological parameters.
5. Can be used in any type aeration system: mechanical, diffused, turbine, packed column, step aerators, etc.
6. Can be used in any mixing regime ranging from plug flow to complete mix because the conservative tracer (tritiated water) accurately accounts for dilution and dispersion effects.

7. The conservative tracer (tritiated water) precisely defines mixing and flow-retention characteristics as part of the overall process evaluation.

Any disadvantages of the test are those associated with the use of radiotracers. All concentrations must be within prescribed regulatory limits. It has been well demonstrated that good testing procedures coupled with the low relative hazards associated with the tracers keeps any radiation exposure to personnel conducting the tests far below regulatory limits and typically below limits of detection.

For new treatment plants, the tracer method can be used to acurately determine actual installed aeration capacity as part of the initial performance evaluation. For older plants, with insufficient aeration, the tracer method can be used to determine existing conditions before new capacity is designed and added.

With the availability of accurate and reliable field performance data in various operating plants, with different types of aeration equipment, new design specifications could be more precisely established on a rational basis. The tracer method is a high-technology tool that can be used to firmly establish oxygen transfer efficiency in any aeration system. With reliable performance data available, the goal of energy-efficient oxygen transfer is within reach.

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ENERGY CONSERVATION TECHNIQUES IN THE ACTIVATED SLUDGE PROCESS USING TWO-STAGE GAS-LIQUID DISSOLUTION

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INTRODUCTION

Gas-liquid dissolution is a process of considerable economic importance. While its applications cover many fields, gas-liquid dissolution is basic to most operations in wastewater treatment. The unit operations of wastewater processing typically concern three cases of gas-liquid dissolution.

The three cases all involve wastewater as the liquid. The gases to be dissolved distinguish the three cases. The most general case is for air, where the oxygen component is to be dissolved. The next most general application in wastewater treatment is for disinfectants. This category includes chlorine and ozone in gas mixtures. The third case is the direct oxygen process. Usually straight oxygen is applied in the activated sludge method of aerobic treatment.

System Considerations

Three performance characteristics arise in comparisons of alternative gasliquid dissolution processes. The dominant process consideration is energy. For wastewater processes, this is typically expressed as pounds of oxygen dissolved per kilowatt hour of energy expended.

The next process consideration is efficiency. It is typically expressed as the weight ratio of gas dissolved to that applied. This ratio is most important where the gas dissolved is either expensive or toxic. These conditions are present for any disinfectant and for the use of oxygen.

The third process consideration is mixing which directly affects the first two process characteristics. In gas-liquid dissolution, mixing is essential: a.) to reduce energy consumption, b.) to sustain efficiency c.) to minimize concentration gradients of gas dissolved in the gas-liquid mixture.

The fact that dissolved gas concentrations should be uniform is evident both for aerobic and for disinfecting applications. It is also clear that the mixing condition implies a momentum exchange in the liquid, as from circulation.

Typical Processes

Typical gas-liquid dissolution processes generally applied in wastewater treatment include: a.) surface aerators, b.) static mixers, c.)

submerged propellers, usually without casings, volutes or vanes and with open gas spargers, d.) submerged diffusers, and e.) two-stage systems.

Two-stage, gas-liquid dissolution systems operate upon pumped fluid recirculation. They include an extended in-line component and a gas recovery subsystem. The most suitable pump is a submerged propeller with open suction, including a casing, vanes and a discharge diffuser section. High solids-clearance centrifugal pumps also may be applied either conventionally or submerged. These provide complementary transfer capabilities.

The principal focus of following discussion is a brief technical outline of the two-stage process for gas-liquid dissolution. Its performance is compared to that of gas-liquid dissolution using submerged gas diffusers.

GAS-LIQUID DISSOLUTION

The TwoStage Process

Scope

In wastewater treatment, many applicatons of gas-liquid dissolution are appropriate. The applications include, a.) equalization, b.) aerobic units, c.) holding basins, d.) digestion, e.) stabilization of supernatant, filtrate or centrate, f.) the oxygen process for activated sludge, and g.) disinfecton.

Performance

Efficiency. Two-stage aeration system efficiency is the cumulative efficiency of two components. The first component is an in-line gas dissolution subsystem imposed upon a pumped recirculation of liquid. This component operates in a hydraulic pressure gradient, that is, at substantially constant pressure.

First-Stage. A full-scale equalization basin was examined in the Indiantown, Florida municipal wastewater treatment plant. The observed first stage aeration efficiency is shown in Figure 1. In this figure, the ordinate efficiency is expressed as the weight ratio of oxygen dissolved to oxygen fed.

The abscissae represents the weight ratio of the gas fed to that which would saturate the liquid at 100% efficiency. In each case, the gas quantities considered were the oxygen components of the air fed.

The plotted data represent performance at a liquid (wastewater) depth of five feet. In this plot, at a feed ratio of 1.15, the observed efficiency is 0.20. This means that the oxygen component in air was fed at 1.15 times the saturation feed rate at the liquid temperature and pressure.

The maximum possible efficiency for this condition would be 0.87. This means that under ideal circumstances, only ,87 of the oxygen feed could dissolve. Since 0.20 of the feed oxygen dissolved, 0.67 of the oxygen fed did not dissolve. It is on this fraction of oxygen that the gas recovery subsystem operates.

Second Stage. The second stage is the gas recovery subsystem. It operates in the liquid basin rather than in the external pumped recirculation line. There, a gravitational pressure gradient prevails. This means that the liquid pressure is not constant, except within any horizontal plane. Vertically, the pressure varies linearly, at a rate of one foot per foot.

The observed second-stage efficiency at a side water depth, SWD, of five feet appears in Figure 2. This illustration retains the coordinates of Figure 2. This illustration retains the coordinates of Figure 1. The gas recovery is of interest. Using the feed rate of 1.15, for example, the second stage efficiency is 0.24.

Two-Stage. Retaining the same coordinate system, the overall efficiency of two-stage aeration is shown in Figure 3. At the reference feed ratio of 1.15, the efficiency is 0.44 for the two-stage aeration process.

A logical question is, "How good is the efficiency of 0.44 at a SWD of five feet?" The answer lies in a comparison of two-stage aeration with aeration from submerged diffusers. To make this comparison, first it is convenient to introduce depth of submergence instead of SWD. Then, the eductor-diffuser of two-stage aeration and the submerged diffuser of conventional aeraton are compared at the same submergence. A SWD of five feet compares to a submergence depth of three and a half feet.

Submerged diffuser. The performance of submerged diffuser aeration appears in Figure 4. As before, the ordinate represents efficiency. The abscissae represents submergence depth. However, in this figure, logarithmic coordinates are used.

For submerged diffuser aeration at 3.5-feet submergence, the efficiency is 0.25. In the same figure, the second stage efficiency is 0.24, about ten times as great.

The basic reason for low aeration at 3.5-feet submergence, the efficiency is 0.025. In the same figure, the second stage efficiency is 0.24, about ten times as great.

The basic reason for low aeration efficiency with submerged diffusers is extremely high gas feed rates. High gas rates are used for two reasons. One is to induce sufficient liquid circulation, or mixing. The second is to force an adequate rate of dissolved oxygen transfer from air to liquid. This desired result is manifested by a increase in dissolved oxygen concentration in the aerated liquid.

The necessity for using high aeration rates with submerged diffusers is generally recognized. Experience confirms the practice. In consequence, most regulatory agencies stipulate minimum acceptable aeration. A representative stipulation is 1750. cubic feet of air per pound of BOD applied.

Dissolved Oxygen Increase. Next to efficiency, the liquid system increase in dissolved oxygen is a basic performance parameter. Reference 4 indicates test procedure, typical data and techniques for the reduction and analysis of aeration system performance. These apply to aeration with submerged diffusers or the two-stage process.

In either case, the direct D.O. test of tank liquid will disclose the overall increase in dissolved oxygen in the entire aerated liquid of the test tank. In two-stage aeration, the system increase in DO which occurs in the pumped, recirculated fluid can be measured directly for the first stage subsystem. The difference in the two direct measurements represents the second stage effect on increasing system D.O.

For two-stage aearation, the system increase in dissolved oxygen, D.O. is shown in Figure 5. In this figure, the ordinate represents system D.O. added. The abscissae represents the oxygen feed rate expressed as a fraction of the saturation feed rate.

Figure 5 shows that efficiency progressively decreases as the gas feed rate increases. This implies that the pumped recirculation capacity required to develop a desired DO magnitude decreases as the gas feed rate increases. Concurrently, the gas feed cpacity required increases with increasing gas feed rate.

It is therefore clear that a balance between installed pump and compressor capacity exists. This affects capital cost. Further, an optimum exists in total operating energy for pumps and compressors.

In Figure 5, note that for shallow depths, increases in gas feed rate beyond 2.0 become decreasingly productive. In addition, it is impractical to attempt system increases in D.O. greater than perhaps 0.66 of the saturation D.O. However, these observations suggest that increased submergence depth might beneficially influence the performance of the two-stage aeration system.

Overall System Efficiency. Previously, the second stage gas recovery subsystem efficiency was compared to that of submerged diffusers. Now, the overall system efficiency comparison will be considered, as shown in Figure 6.

In this figure, the ordinate represents overall system efficiency. The abscissae represents submergence depth of the diffuser. The lower line depicts conditions for conventional aeration with submerged diffusers. At 9.0- feet submergence, the system efficiency is .07.

The upper line shows that two-stage aeration efficiency at the same depth is .98. This result occurs at an air feed rate of 1.15. At high-

er feed rates, the efficiency is lower, for either aeration process. Basically, the reason why submerged diffusers are so inefficient is that they operate at air feed rates far in excess of those for saturation.

Normalized Data

As a practical consideration and to simplify design, it is desirable to consolidate four variables. These are: a.) the gas to be dissolved, usually oxygen or air, b.) the submergence depth, c.) the overall system efficiency, and d.) the system D.O. added.

Previously, the gas feed rate was normalized by representing it as a fraction of the saturation feed rate. In a similar way, the system increase in D.O. may be normalized. It may be made non-dimensional by expressing it as a fraction of the saturation D.O. Hopefully, normalized performance data would be consistent for any gas and at any depth. This result would simplify the consolidation of variables.

Figure 7 presents normalized performance data. The basic variables presented are system D.O. added and gas feed rate. The results are consistent for either air or oxygen. They are consistent throughout a broad range of SWD.

Referring to figure 7, one point is of particular interest. It occurs at high gas feed rates. Performance shown in the plot for localized circulation is depressed compared to the improved performance of generalized circulation.

Data for the five-foot depth were measured in the Indiantown equalization basin. Comparable data at this depth were obtained at the Stafford, N.J. treatment plant. At three and eleven feet SWD, data are from the Indiantown aerobic digester. In each case, two similar eductor-diffusers were used.

In equalization, the eductors were installed vertically. Because of this positioning, the induced circulation was localized. In the aerobic digester, the eductors were inclined from the vertical to induce a generalized rotational toroidal circulation.

The generalized induced recirculation improves the system D.O. added and the efficiency. It is directed momentum which enables the development of a generalized induced circulation. For this reason, it is useful to assess the directed momentum available to the aerated liquid.

Directed Momentum

The data of Figure 7 illustrate effects of directed momentum. Substantial benefit accrues from directing momentum input in such a way as to induce a generalized circulation. Underwater observations and photographs of eductor discharge in two-stage aeration explain this result.

FIGURE 1
EFFECT OF FEED RATE ON
FIRST STAGE AERATION EFFICIENCY
DEPTH FIVE FEET

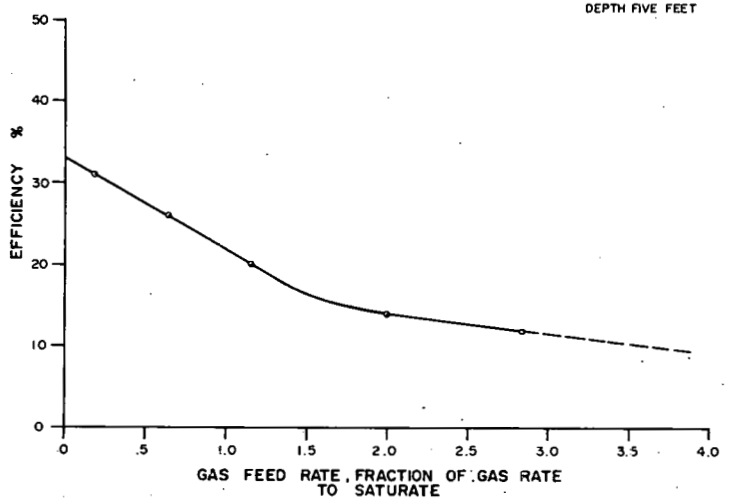


FIGURE 2
EFFECT OF FEED RATE ON
SECOND-STAGE AERATION EFFICIENCY
DEPTH FIVE FEET

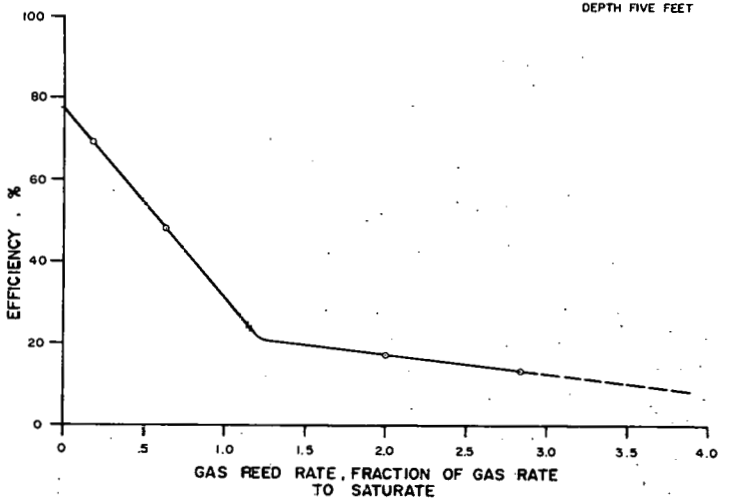


FIGURE 3
EFFECT OF FEED RATE ON
TWO-STAGE AERATION SYSTEM EFFICIENCY
DEPTH FIVE FEET

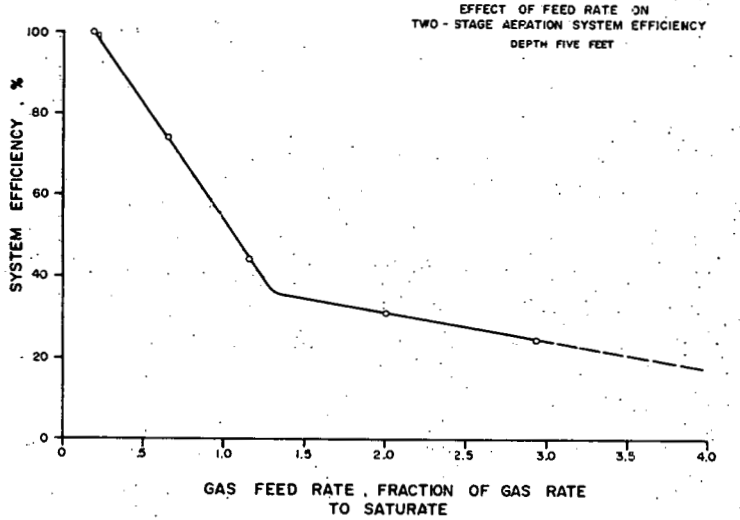


FIGURE 5
EFFECT OF FEED RATE ON
TWO-STAGE AERATION SYSTEM DO
ADDED IN PUMPED RECIRCULATION
DEPTH FIVE FEET

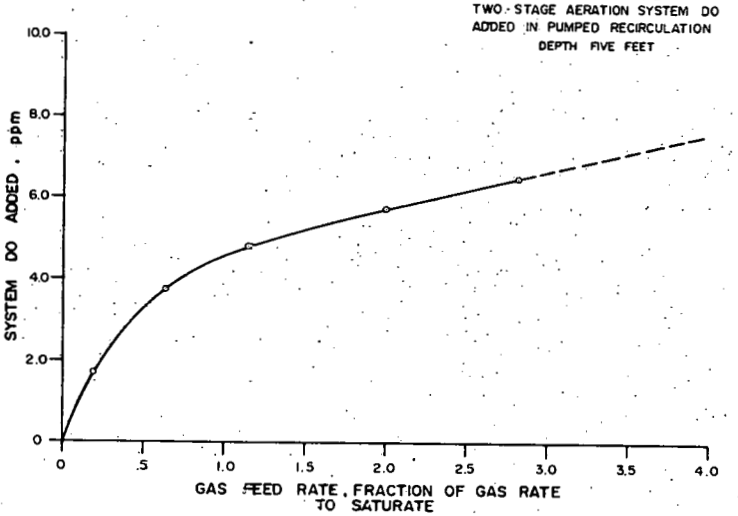
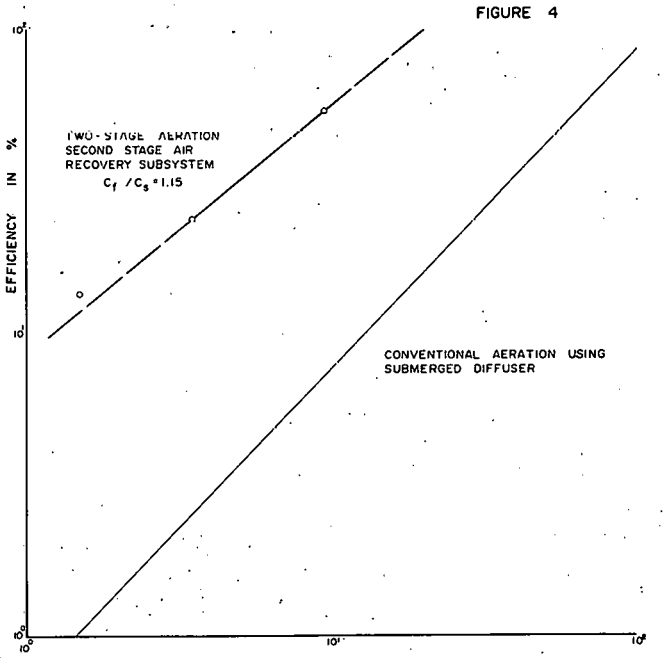


FIGURE 4



EFFECT OF DIFFUSER SUBMERGENCE ON AERATION SYSTEM EFFICIENCY

SECOND STAGE GAS RECOVERY SUBSYSTEM
COMPARED TO CONVENTIONAL SUBMERGED DIFFUSER

FIGURE 6

EFFECT OF DIFFUSER DEPTH ON AERATION SYSTEM EFFICIENCY

TWO-STAGE AERATION COMPARED TO CONVENTIONAL AERATION

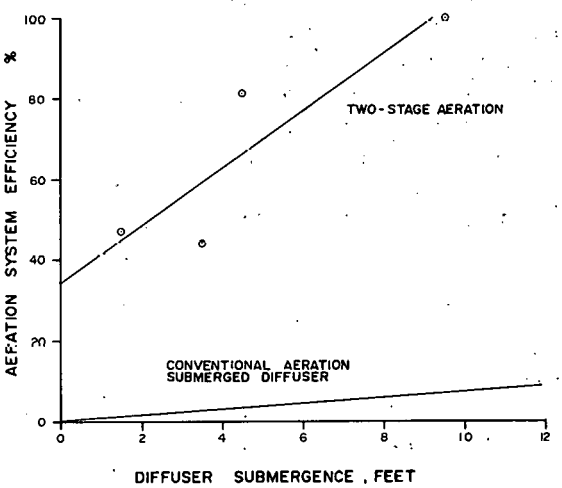
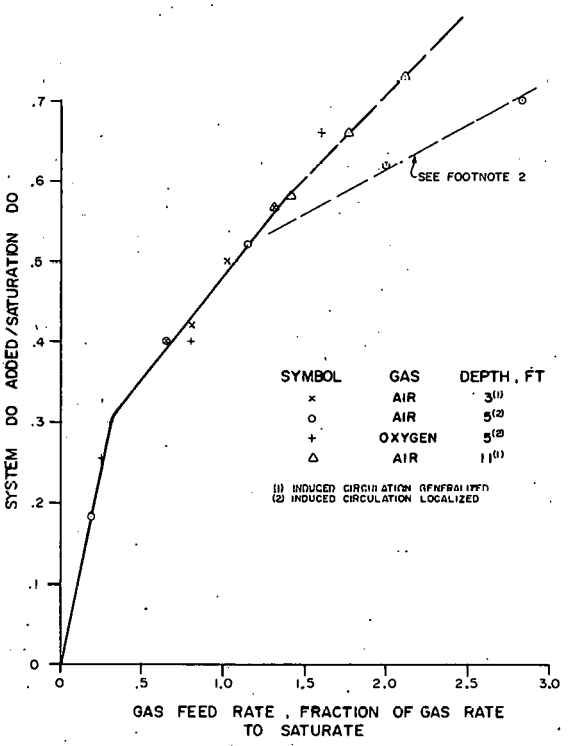


FIGURE 7

TWO-STAGE, GAS LIQUID MIXING SYSTEM PERFORMANCE



First, the eductor discharge consists primarily of pumped recirculation. In the fluid, high concentrations or air are present. This is manifested by increased capacity of the discharged jet. In addition, a uniformly dispersed fine bubble pattern is evident. This is so although the discharge fluid jet diameter is large.

Recirculation

Localized. If the recirculating fluid jet is disposed vertically beneath a fluid surface, a localized circulation is induced. The usual induced localized circulation is toroidal. It is localized in the sense that it has little interaction with similar adjacent circulations. The interaction which does occur is predominantly at stagnation surfaces. These surfaces occur between adjacent toroidal circulations. At such surfaces little change in momentum occurs. In consequence, mixing is minimal.

Generalized Recirculation. In contract, the discharge jet may be inclined from the vertical. Then, the circulation induced will be three dimensional with a superimposed overall circulation. The jet orientation may be arranged such that the fluid develops an induced overall rotational circulation. The radial components of velocity may be controlled by the degree and direction of jet inclination. Usually, velocity components are set to minimize energy dissipation.

Momentum. Momentum for a jet flow is defined by the relation:

$$M = (m = \frac{W}{g}) \cdot V ,$$

Where M is the momentum pounds
m is the mass W/g
W is the weight, pounds
g is gravitational acceleration, ft. $sec.^{-2}$
V is the change in velocity, ft. sec^{-1}

For two-stage aeration, the usual jet flow is set for a velocity head of 1.5-feet. The corresponding velocity is 9.8 feet $second^{-1}$. Under these conditions, the momentum per second may be quantized for a flow of one MGD or 1.55 $feet^3$ $second^{-1}$. It is about 30 pounds. At pumped recirculation rates required to provide DO, this magnitude of momentum input has been found to be effective in developing a generalized liquid circulation. The direct result is to reduce the magnitude of pumped recirculation required. In this way pump capacity and operating energy are reduced. With this understanding, it is useful to examine applications of normalized data to design.

Design Application

The illustrative design application is actually a comparison. Two modes of activated sludge aeration are compared. The first mode is aeration using submerged diffusers. The second mode is aeration using the two-stage process.

In each comparison, the aerobic unit configuration is the same. It is comprised of four tanks, each rectangular 10-feet wide, 12-feet long and with a side water depth of 10'-6". The design capacity for 24-hour detention in the extended aeration process is about 37,500. gallons per day. The aerobic unit loading is equivalent to 60 pounds of oxygen per day. Therefore, the BOD removal is 64 pounds per day.

Submerged Diffusers. With submerged diffusers used in extended aeration the air supply must provide 1,200. to 1,800. cubic feet per pound of BOD removed. The stipulation depends upon the regulatory agency. The Ten State Standards require an air delivery capacity of 1500. cubic feet per pound of BOD applied to aerobic units.

Air Requirement. For this case, the air requirement is about 96,000 cfd, or 67. cfm. The oxygen equivalent of this air rate is 1,670. pounds per day, or 417. pounds per day to each of the four aerobic tanks.

The same reference prescribes a minimum air supply to ensure mixing. One empirical convention for mixing is 20. cfm per 1,000. cubic feet of aeration tank volume. This case works out to be 100. cfm. An alternative approach suggests 3 cfm per foot of tank length. For this case, the mixing requirement equates to 144. cfm for each of these aerobic units.

One implication is that the 67. cfm air supply may be marginal from the standpoint of mixing. Mixing might require an additional air supply of 50% to 100%. However, the relative importance of mixing is underscored.

Air Compression Power. The power to compress air at 67. cfm has been determined. It is 2.25 kilowatts. Submerged diffuser operation would impose a daily energy use of 54. kwh. The corresponding expense at 5 cents per kwh is about $2.70 per day.

Two-Stage Aeration. With two-stage aeration, the required dissolved oxygen capacity is 64. pounds per day. In the extended aeration mode of the activated sludge process, the dissolved oxygen supply to each of the four aerobic tanks is the same, 16. pounds per day. The oxygen input is developed in a pumped recirculating flow. This flow also develops necessary levels of mixing.

Pumped Recirculation. The oxygen input is a function of the air feed rate, now assumed to be at twice the rate for saturation. Preceding Figure 7 indicates the system D.O. added is 0.685 of saturation. At a liquid depth of 10.5 feet, the saturation concentration is 12. ppm. Therefore, at a depth of 10'-6", the DO added would be 8.2 ppm. From this, the necessary pumped recirculation is determined.

$$MGD_R\ (8.34)\ (8.2) = 16.$$

$$MGD_R = 0.23$$

Where MGD_R is the pumped recirculation, MGD
8.34 converts gallons to pounds
8.2 is the system DO added, and
16 is the DO capacity, pounds per day.

All four aerobic tanks require a total recirculation of 0.92 MGD. However, this tankage is committed to operation in four different process modes. For this reason, individual recirculation is appropriate.

The recirculating pump operates at equal suction and discharge static head. Thus, the pump head accounts for friction losses in pipe, valves and fittings. For two-stage aeration, the usual system design head is three feet. Pump power and energy consumption are moderate, as discussed later.

Air Compressor capacity. The total compressed air capacity required for four aerobic tanks is determined simply. The air feed rate was assumed to be twice the saturation rate. The saturation concentration of oxygen in water at a depth of 10.5-feet at 20^0 C. is about 12 ppm. At twice saturation, 24. ppm, the air injection to a 0.92 MGD recirculation is:

$$MGD_R\ (8.34)\ (24) = 184.\ \text{pounds per day.}$$

The corresponding compressor capacity is:

$$\frac{184.}{.075\ (.232)\ (1440)} = 7.3\ \text{cfm}$$

This capacity may be contrasted with that for submerged diffusers, 7.3 and 67. respectively. Including mixing air, the comparison is 7.3 and 100. cfm, respectively. In the two-stage aeration process, mixing is provided by pumped recirculation.

Power. The power required for recirculation is:

$$kw = \frac{0.746 \cdot w \cdot Q \cdot h}{550 \cdot e}$$

Where kw is the power, kilowatts
0.746 converts horsepower to kilowatts
w is the density of water, pounds $ft.^{-3}$
Q is the flow rate, cfs
h is head, feet
550 is ft. lb. sec^{-1} per horsepower
e is pump efficiency

At 1.43 cfm (.92 MGD), a head of three feet and pump efficiency of 0.5, the power required is 0.72 kw. To this must be added air compression power.

The air compression power is proportional to flow at the same discharge pressure. The flow ratio is 7.3/67. and the kilowatt requirement for

the submerged diffuser case was 2.25 kw. so,for two stage aeration, the air power is 0.25. The total power for this case is 0.97 kw, compared to a value of 2.25 kw for submerged diffusers. This is about 43% of the power for submerged diffusers with no allowance for mixing air.

Transfer. Transfer refers to charging and discharging liquids, as in aerobic units. With submerged diffuser aeration, separate pumps are required for transfer. In two-stage aeration, the recirculating pumps can be used to pump liquid to or from aerated tanks. In such applications, the pump head on suction and discharge may not be the same. Therefore, pump duplication is avoided. However, pump power is higher for transfer than for aeration. The transfer requirement for pumps and for pump power is independent of the aeration process selected.

The transfer capability of two-stage aeration pumps is particularly useful in specific cases. These include: a.) return activated sludge (RAS) reaeration b.) RAS aerobic digestion, and c.) equalization.

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ENERGY OPTIMIZATION IN SEQUENCING BATCH TREATMENT OF WASTEWATERS

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1. SEQUENCING BATCH REACTORS

Sequencing batch reactor (SBR) technology recently made substantial advancement in water pollution control. Irvine (1) gave an overview of sequencing batch reactor systems; these systems were described and control strategies defined. Six other articles followed Irvine's (1) overview paper and described in detail laboratory investigations, mathematical models of these systems, field studies and cost comparisons.

In general, a sequencing batch reactor system, when used for biological wastewater treatment, provides for both aeration and settling in a single tank. Figure 1 shows a schematic view of a three-tank system which would provide an alternative to a conventional, continuous-flow, activated sludge system. The three tanks operate in parallel and are sequenced so that one tank is accepting the total plant influent while the other two are in other phases. Each tank is phased as follows: FILL, influent flows into the tank, aeration may or may not be provided during this phase; REACT, aeration is supplied until the biological reactions are completed; SETTLE, aeration is discontinued and the biological floc formed during the reaction phase is allowed to settle under quiescent or closely controlled mixing; DRAW, the clarified supernatent is drawn from just below the surface, reducing the liquid volume to about one-half its full volume, the settled sludge is therefore left in the tank ready for the next cycle; finally, IDLE, is a period to provide for flow variation and to assure the tank is ready to receive inflow when the other tank is full.

It is important to recognize that oxygen demanded for biological treatment can be closely matched by the supply from the aeration system. If influent wastewaters are weak, a relatively common circumstance in municipal wastewater treatment, aerators can be shut down during all or some portion of the fill period. This energy saving mode of operation, and because aeration is not needed in tanks during idle period, which may be relatively

long during night-time and other low flow periods, the total energy needed for aeration can be held to a minimum and result in substantial energy savings.

A simple sequencing batch reactor system requiring little operator skill, is shown in Figure 2. This system, an alternative to wastewater stabilization lagoon, can accomplish high quality effluent with low levels of energy input. A single reactor would be suitable for systems which have either a no-flow period or a low-flow period during the night. Aeration would be supplied only during the day as required to accomplish stabilization of the wastes or to maintain floc in suspension. The suspended floc during day-time operation, particularly during summer months, will reduce sunlight penetration and reduce algae growth. Therefore, one of the major disadvantages of lagoons, production and discharge of effluent with high algae concentration, is reduced.

This single-cell system would be operated with one-cycle per day. Settling and draw would occur during the night low-flow or no-flow period. Typically, this system would be operated with small changes in liquid level. The settled sludge would therefore be maintained for longer periods and sludge disposal becomes less frequent.

This paper reports on a project supported by the U.S. Environmental Protection Agency(2). The project provides for modification of an existing continuous flow-activated sludge plant, and will allow its operation as a sequencing batch reactor system. In addition, the relationships between energy inputs and carbon and nitrogen reduction requirements are discussed.

2. CULVER, INDIANA SBR SYSTEM

Culver, Indiana provides wastewater treatment for a boarding school and a small quantity of industrial wastewater, however it is primarily a domestic wastewater treatment plant. The system includes comminution, grit removal, primary sedimentation, activated sludge treatment (aeration and secondary settling) and chlorination. Sludge treatment includes aerobic digestion and sand bed dewatering followed by land disposal of the dewatered sludge, or liquid sludge taken directly from the digestors.

The modification to provide biological treatment using the sequencing batch reactor mode of operation, is accomplished by using the two existing

aeration tanks for the SBR reactors. These tanks are rectangular and each have a maximum liquid volume of 460 cubic meters. The wastewater average flow rate is about 200 cubic meters per day.

The modification of these two aeration tanks includes the following:

- new inlet system to allow alternating the plant flow from one tank to the other.
- a new jet aeration system to replace the existing coarse-bubble diffuser system. This modification was made both because of the inefficient oxygen transfer of coarse-bubble diffusers and to allow mixing of these tanks without aeration.
- a new effluent system to allow varying the liquid level between the high water level and the low water level.
- some internal baffling to improve the mixing patterns during aeration.

These modifications allow operating these tanks in a fill-and-draw mode with both aeration and settling accomplished in the same tank.

The major objectives of this study are as listed below:

- define operating procedures necessary to meet effluent limitations for biochemical oxygen demand (BOD) and suspended solids.
- develop steps to convert an existing continuous flow system to sequencing batch reactor operation.
- compare cold and warm weather operating conditions.
- investigate alternative sludge wasting procedures.

A microprocessor is used to provide automatically controlled operation. The recent development of this technology allows highly reliable control at very low costs. The simplest control scheme makes use of the microprocessor as an accurate timer. Tanks are sequenced based on a fixed period of filling and each phase is operated for a specified time. This scheme is not energy efficient and results in different liquid volumes at the end of each fill cycle. However, the control equipment is very inexpensive, reliable, and once set, demands little attention from the operator.

In our system, the microprocessor operating scheme is expanded to take advantage of its ability to be both a "timer" and a "thinker". For example, during the FILL period of one tank, the microprocessor can monitor the liquid level, the filling rate and the filling time. Based on this infor-

mation, decisions can be made on when to begin aeration during the FILL period, when to end FILL and when to modify or change the operation of the adjacent tank to assure it will be ready to accept the flow. Likewise, the dissolved oxygen concentration can be monitored during REACT and aeration times or rates modified to closely match oxygen demands. This would result in energy savings, because aeration, a major source of energy consumption in any biological wastewater treatment plant, would be supplied only as needed to meet effluent requirements.

These more complex, "thinking" microprocessor control systems are more difficult to construct, but once completed have been found to be highly reliable. Our system has been developed to allow easy modification as different aspects of the study are emphasized or future treatment requirements change. The microprocessor functions at extremely high rates (i.e., in fractions of seconds). Because wastewater treatment changes occur in terms of minutes and hours, it becomes easy for the microprocessor to look at each task as a series of steps. It can make appropriate control decisions, and cycle through all the tasks in such a short period of time, that for all practical purposes, it appears to continuously monitor each task. A main control program is written which simply cycles through each task. A task can be either simple or relatively complex, and can be written as a self-contained package. New tasks can be added, and existing tasks modified without changing the main control program or any of the other tasks. For example, a task to control the filling of one tank may initially be written to only provide 6 hours for FILL. Later after liquid level monitors have been installed, the task can be redefined to either fill to a fixed liquid level or stop filling after a given period of time. In the first case, the main program cycles to the task to control filling and asks the question, "Has the FILL period exceeded 6 hours?" If it has not, it does nothing and cycles to the next task. If it has, it actuates the valve necessary to switch the flow to the other tank, then it cycles to the next task. In the modified case, the question may be two parts, as follows: "Has the liquid level exceeded the maximum allowable depth or has the time exceeded 6 hours?". If either condition is true, the appropriate valves are actuated and the flow switched to the other tank.

These "thinking" microprocessor controllers will require special training for the operator, or the services of outside consultants to change the control strategy after they have been initially developed. The major advantage of these systems, is their ability to closely match treatment (i.e. energy input) to treatment requirements.

3. NITRIFICATION

As indicated above, the major objective of the study at Culver, Indiana is to demonstrate that a full-scale municipal wastewater treatment plant can effectively and efficiently meet BOD and suspended solids effluent limitations. Another objective of this study is as follows:

- determine operating procedures which result in nitrification.

During the first phase of the study, emphasis will be placed on controlling cycle times, aeration periods and rates, and other operating schemes which result in effective BOD reduction and suspended solids removals. Control of aerators can be developed with relatively reliable dissolved oxygen probes, or respirometers, in the sequencing batch reactors. During the REACT period, when dissolved oxygen concentrations begin increasing at a rate which would indicate that the carbonaceous oxygen demand has been satisfied, aeration will be discontinued and the SETTLE period begun. Energy input to the aeration system will therefore closely match the requirements of each batch or tank full of wastewater. The ordinary operating scheme automatically accomplishes this close match of energy input and wastewater treatment requirements.

When effluent ammonia limitations are imposed, treatment must be modified to assure conversion of the organic nitrogen and ammonia to nitrate plus nitrate. Organic nitrogen in excess of that needed for cell growth is typically released as ammonia during the aeration time needed to satisfy carbonaceous oxygen demands of the wastewater. Under these conditions, ammonia concentrations often develop in excess of effluent limitations. In continuous flow systems, aeration periods are typically extended, resulting in the desired oxidation of ammonia, but at a substantial increase in energy input.

Several control strategies exist which will assure that the energy input needed to accomplish ammonia oxidation is held to a minimum in the

sequencing batch reactor. One strategy would include control of the aerators to be switched from the respirometer or dissolved oxygen monitor, used to indicate that the carbonaceous oxygen demand had been satisfied, to an ammonia concentration monitor. Aeration would continue beyond the time needed for BOD reduction, until the ammonia monitor indicates that the batch of wastewater under aeration reached an ammonia concentration sufficiently low to assure each batch met effluent ammonia limitations. This control strategy, probably the most effective strategy, however is subject to the availability of a reliable ammonia monitor. If a sufficiently reliable ammonia monitor is not available, two other control strategies exist. First, assuming wastewater characteristics vary little with time, the control strategy could be based on a fixed aeration time following the oxygen monitor's indication that carbonaceous oxygen deman had been satisfied. The other strategy would require a closer monitoring of oxygen concentrations during the REACT period, and sufficient operating experience to recognize a second change in the rate of dissolved oxygen concentration increase, which would indicate ammonia oxidation also had been completed. The first control strategy (i.e., fixed ammonia aeration time), will likely result in energy input in excess of that needed to meet effluent ammonia requirements, however operation is simple. The second strategy (i.e., continuing oxygen concentration monitoring), may be limited if operating experience does not result in the ability to recognize when ammonia oxidation has been completed by the oxygen concentration monitor. However, it is highly unlikely that one of these control strategies will not result in efficient operation and a close match of energy input to effective ammonia reduction.

4. DENITRIFICATION

Another objective of the Culver, Indiana investigation is as follows:

- investigate operating procedures which result in denitrification.

This phase of the study will depend on the outcome of the other studies which will be complete in the early phases of the project. In addition, it may be limited by the available size of the two sequencing batch reactors (i.e., the existing aeration tanks) at Culver.

Laboratory studies (3) have shown that denitrification can be accomlished in the sequencing batch reactor if an anoxic period of slow mixing is provided following completion of ammonia oxidation. Because each batch of wastewater must be held for a longer period of time, to provide for the anoxic mix, the reactors must be larger, or additional reactors provided. At Culver, Indiana we are limited to the existing tanks, therefore this phase of the study can only be undertaken if plant influent flow rates are sufficiently low. However, other systems can be designed initially to provide for denitrification. In existing plants,where nitrogen removal becomes a new treatment requirement, operating procedures can be modified and additional tanks constructed. These can be conveniently added as modular units.

Control of the denitrification phase during our study, initially will be accomplished by providing a fixed period of anoxic mixing following completion of ammonia oxidation. A short period of aeration will then be provided to sweep out the gaseous end-products of the anoxic reactions, and to assure oxygen is present in the treated effluent. Anoxic mixing periods can be established during operation and can be held constant and slightly longer than needed to complete denitrification. Energy input to provide the slow mix is small, therefore the slightly excessive mixing periods result in no substantial energy consumption and treatment requirements can be met.

5. SUMMARY

Sequencing batch reactors (SBR) can be operated under many different strategies. Energy input, especially to provide aeration in biological wastewater treatment systems, can be matched closely with effluent requirements. Each batch can be treated to meet effluent requirements and both consistently high quality treatment and minimum energy consumption are assured for each batch. The use of microprocessors makes control relatively easy and reliable. When future effluent requirements become more stringent, the operating strategy can be changed to meet these requirements and modular reactors added if more tank capacity is also needed.

A single reactor can be used for biological treatment for BOD reduction, nitrification or denitrification or different combinations of these reactions,

and for settling by changing the operating strategy. Phosphorus reduction can also be optimized by providing the best conditions for luxury uptake. Another operating strategy might be to minimize sludge production. In this case, increased periods of aeration, possibly during the IDLE period when the volume is low, might be used to reduce the sludge volume.

The highly flexible operating strategies possible with sequencing batch reactor systems provide the opportunity to closely match system requirements and effluent limitations with energy inputs and other operating costs. These flexibilities also allow future changes in the operation to meet future and different requirements. The microprocessor controlled system can be readily changed as improved monitors become available or system demands change. The batch-by-batch treatment assures each batch meets effluent requirements at a minimum energy input.

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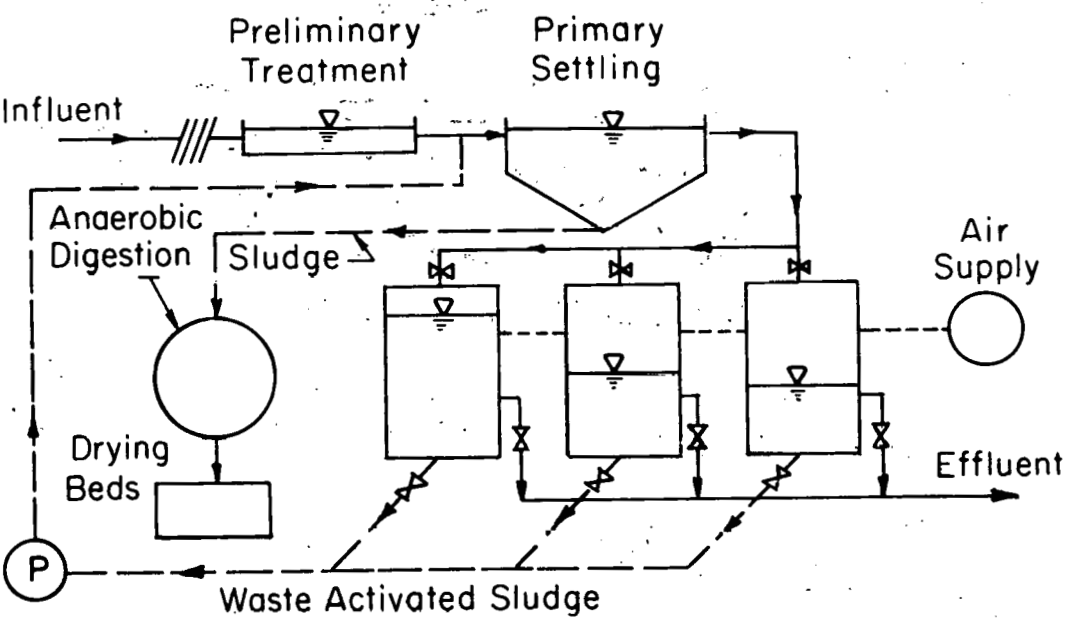


Figure 1: Schematic diagram of a three-tank sequencing batch reactor system.

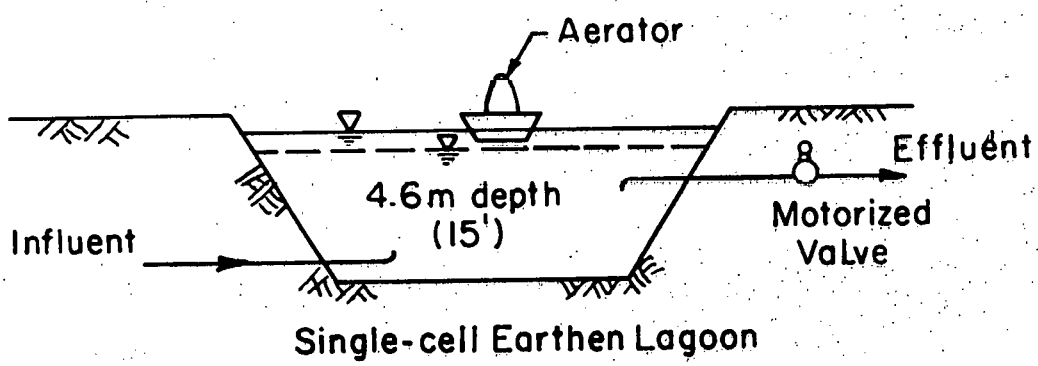


Figure 2: Schematic diagram of a single-cell earthen lagoon sequencing batch reactor system.

ANALYSIS OF THE WINSTON-SALEM ANAEROBIC DIGESTER-POWER GENERATION SYSTEM

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1. INTRODUCTION

The Archie Elledge Waste Treatment Plant, located in Winston-Salem, North Carolina, treats the combined municipal and industrial wastewater from the City of Winston-Salem. A two-stage biological process is utilized to provide secondary treatment, which consists of primary sedimentation, roughing trickling filter, and activated sludge. Excess sludge is stabilized by anaerobic digesters and dewatered on sand drying beds.

The flow to the plant averages 23 mgd. The organic loading to the plant averages 70,000 lb BOD/day, with a solids loading of 111,000 lb SS/day. Figure 1 presents a schematic illustration of the treatment facilities.

There is no outside source of power for the Elledge plant. All power comes from the plant power generation system. The generation system consists of four DeLaval-Enterprise drive units and one Worthington drive unit. There are two Ideal units rated at 1,500 KW, two Allis-Chalmers units at 750 KW, and one General Electric unit at 500 KW. Normal operation consists of one 1,500 KW unit and one 750 KW unit. The fuel sources consist of fuel oil, natural gas, and digester gas.

The digester gas comes from the anaerobic digester system. There are six primary digesters and two secondary digesters. The majority of the organic conversion and removal, solids reduction, and gas production occurs in the primary digesters. The main function of the secondary digesters is to allow settling of solids. The total primary digester capacity is 7,560,000 gallons. The total secondary digester capacity is 2,990,000 gallons. An illustration of the primary and secondary digestion unit is presented in Figure 2. A schematic of the gas collection system is presented in Figure 3.

Typically, anaerobic digesters have been operated as a solids reduction and stabilization process. There has been little attention paid to gas generation because the alternative energy sources were inexpensive. However, with the spiraling costs of energy, the City of Winston-Salem embarked in 1977 on an extensive analysis of its overall energy utilization program.

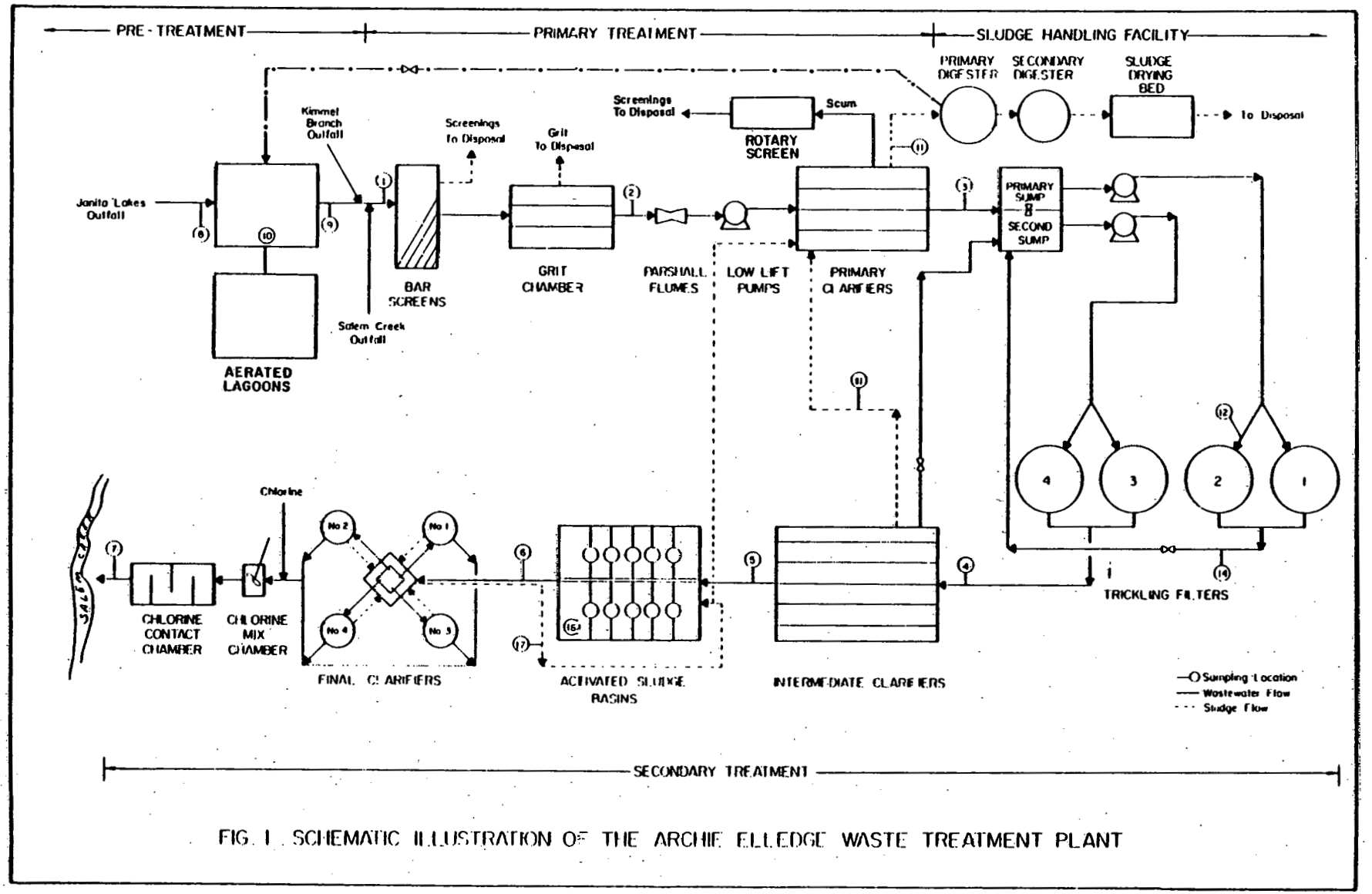


FIG. 1 SCHEMATIC ILLUSTRATION OF THE ARCHIE ELLEDGE WASTE TREATMENT PLANT

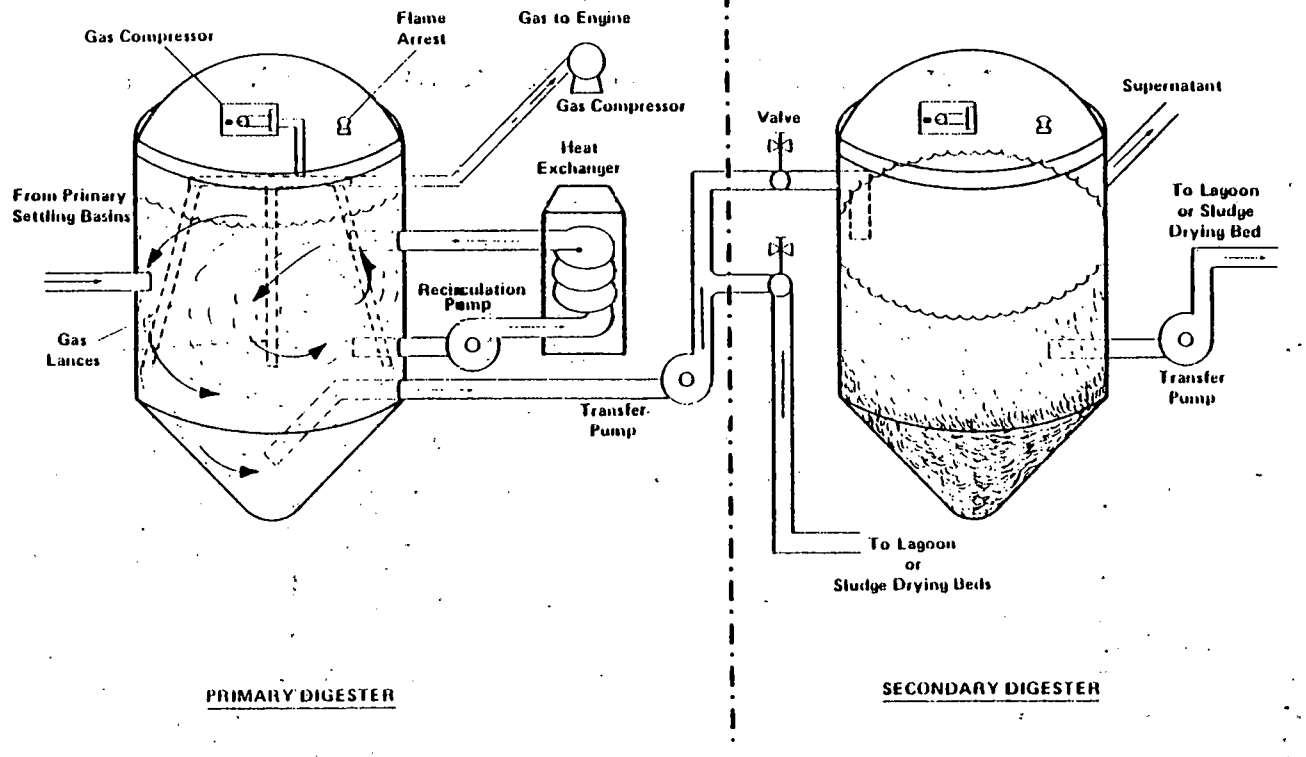


FIG. 2. SCHEMATIC OF THE ARCHIE ELLEDGE WASTE TREATMENT PLANT PRIMARY AND SECONDARY ANAEROBIC DIGESTERS.

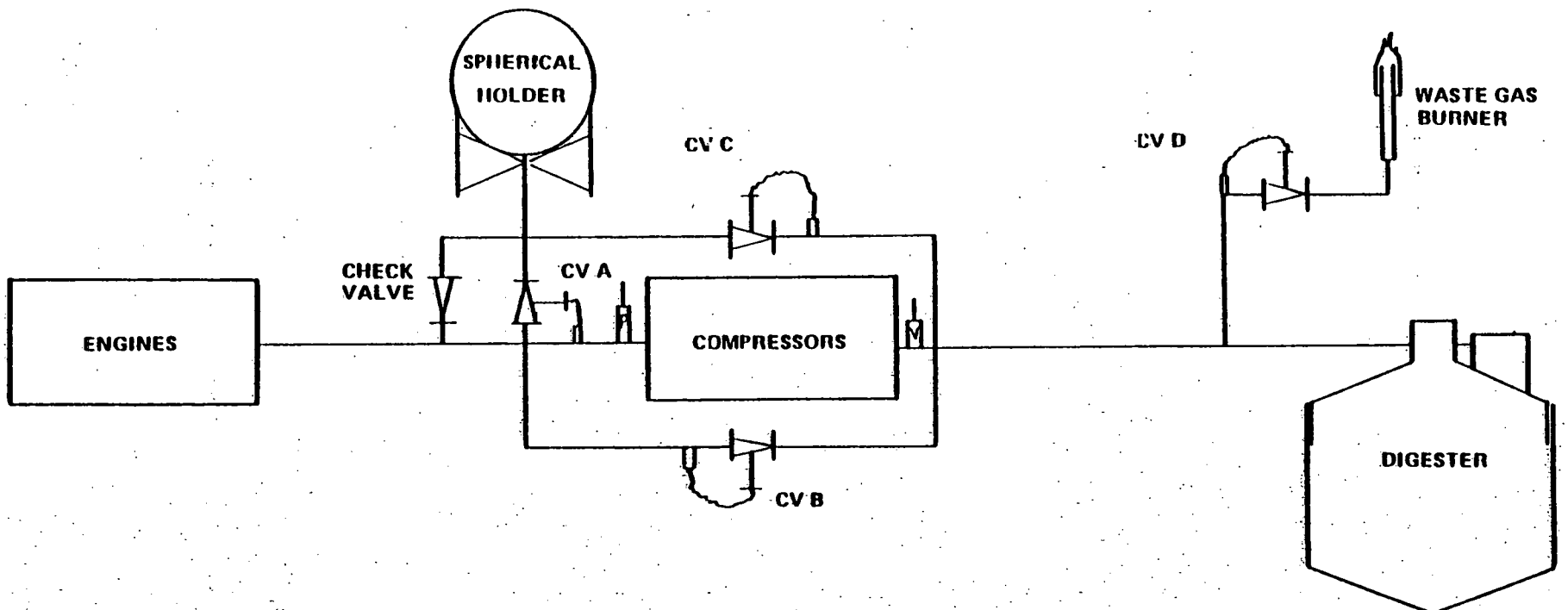


FIG. 3. SCHEMATIC OF GAS PRESSURE CONTROL EQUIPMENT

The objective of the program was to evaluate the digester performance in terms of energy generation and to determine methods of optimizing gas generation without inhibiting the solids reduction process. The overall economics of the power generation system were evaluated in order to provide a realistic analysis of power generation costs and efficiencies to compare to alternative systems. This paper summarizes the results of the study, reviews programs which can be utilized to optimize digester performance, and reviews the economics of the power generation system.

2. DIGESTER PERFORMANCE

An intensive monitoring program was conducted on the operation of the digesters. The results of this analysis are presented in Table 1. These data indicate that the performance of the system is consistent with published data on anaerobic digester operation. A summary of the solids balance around the system is presented in Figure 4.

3. SYSTEM OPTIMIZATION

In order to optimize the performance of the digesters, a number of programs were implemented. These included:

1. Digester cleaning. It was found that there is significant accumulation of scum and grit in the digesters. This results in a reduction of the effective volume of the digesters and in the mining efficiency of the digesters.

   A program was implemented to periodically clean out the digesters. The performance of the digesters prior to and following cleaning is summarized in Table 2. This indicates a significant improvement in overall digester performance.

2. Primary screening. The skimmings from the primary clarifiers consisting of grease, plastic and rubber material, and hair discharge directly to the digesters. This resulted in scum accumulation in the digesters. A rotating screen was installed on the primary clarifier skimmings line. The screen provides dewatering of these materials so that they can be hauled directly to a landfill.

3. Supernatant screens. The supernatant screens on the secondary digesters were cleaned and repaired. A weekly maintenance program has been implemented to assure proper operation. This has resulted in a reduction of supernatant solids from 1 to 1.5 percent to less than 0.5 percent.

4. Implementation of a compressor manometric switch. The operation of the gas compressor was implemented hourly during the operator's rounds. However, it was found that a significant volume of gas was lost through the relief valves. To alleviate this pro-

TABLE 1

SUMMARY OF ANAEROBIC DIGESTER
PERFORMANCE AND CHARACTERISTICS

Digester Volume	
Primary Digesters	
4 @ 90' dia, cu ft	612,000
2 @ 100' dia, cu ft	400,000
Total, cu ft	1,012,000
Secondary Digesters	
2 @ 100' dia, cu ft	400,000
Influent Flow, mgd	0.383
Detention Time	
Primary Digesters, days	11.9
Secondary Digesters, days	7.8
Influent pH	6.93
Digester pH	6.96
Digester Gas Composition	
Carbon Dioxide, percent	35.12
Oxygen, percent	0.0
Nitrogen, percent	3.92
Methane, percent	60.96
Total percent	100.0
Influent Temperature, ^{o}F	71.8
Digester Temperature, ^{o}F	93.9
Influent Solids Loading, lb/day	96,082
Influent Volatile Solids Loading, lb/day	66,024
Loading Rate, lb VS/cu ft-day	0.07
Average Percent Volatile Solids Reduction, percent	38.4
Average Gas Production Rate, scfm/day	317,000
Ratio of Gas Produced/lb VSS removed, cu ft/lb VSS-day	12.5
Volatile Acids/Alk. ratio	0.092

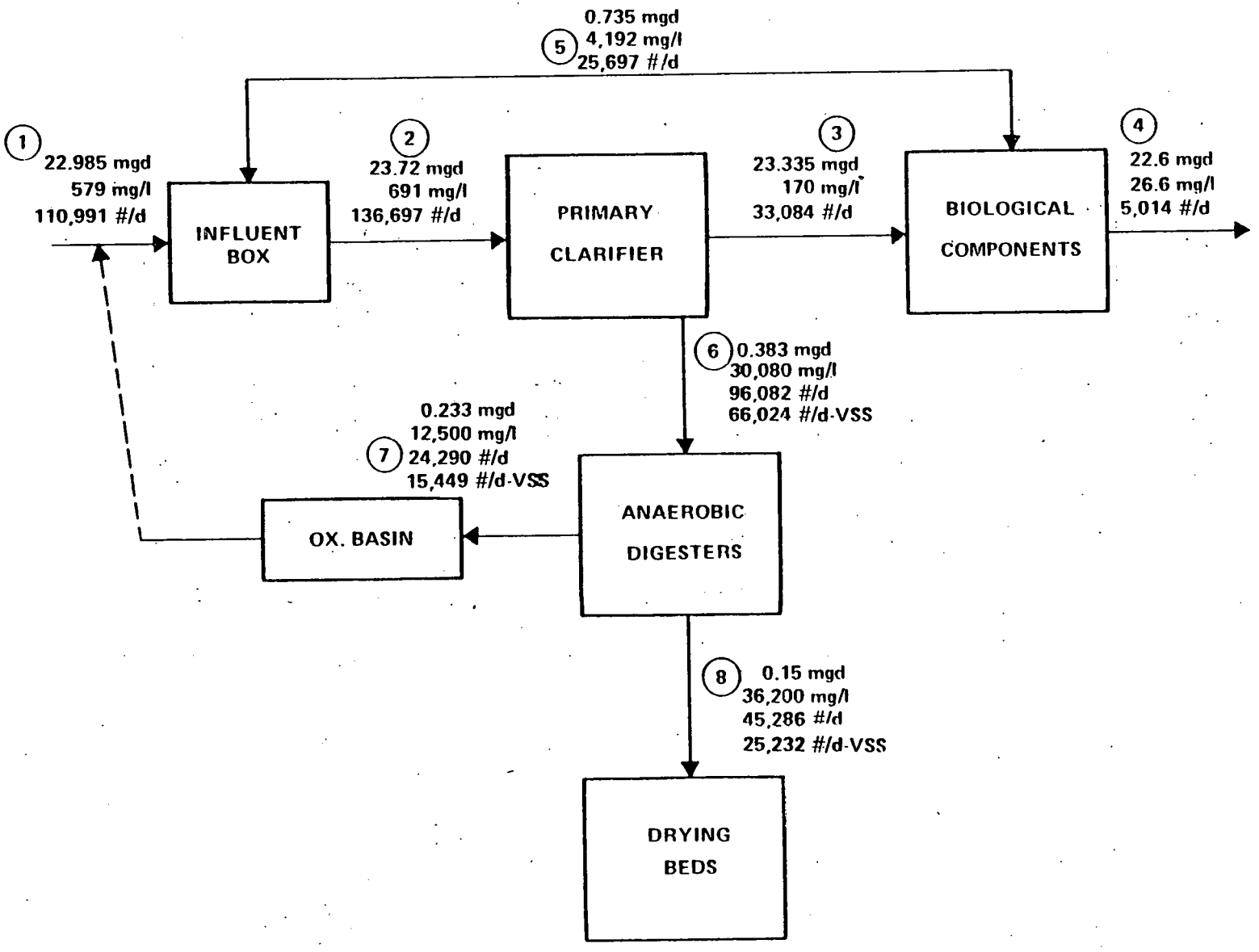


FIG. 4. SOLIDS BALANCE JULY 1978—JUNE 1979

TABLE 2

DIGESTER PERFORMANCE BEFORE AND AFTER CLEANING

Date	pH	Vol. Acids	Alk	VA/A	% TS to Beds %TS	% TS to Beds %VTS	Average Solids Conc.	Inches Fed/Mo. Total	Inches Fed/Mo. Avg.	% Methane	Avg. Temp. °F
Jun 78	7.0	101	1,876	0.05	5.5	2.9	7.2	--	--	--	--
July	6.9	362	1,826	0.20	6.8	3.4	7.9	415	14.8	64.3	94.5
Aug	6.9	222	2,420	0.09	4.4	2.5	9.2	431	14.4	65.7	98.2
Sep	6.8	362	2,416	0.15	3.6	2.0	8.1	499	14.9	64.8	96.0
Oct	7.0	214	1,970	0.11	3.1	2.0	7.7	541	17.5	65.1	92.5
Nov	6.9	149	2,090	0.07	3.7	2.4	8.2	461	12.5	63.9	98.8
Dec	7.0	101	2,260	0.04	3.7	2.3	7.7	456	12.0	63.9	94.5
Jan 79	6.9	130	1,874	0.07	2.9	1.8	8.0	421	13.6	65.4	87.0
Feb	CLEANED DIGESTER										
Mar	6.8	170	2,490	0.07	2.9	1.8	2.9	529	12.6	66.0	83.0
Apr	6.9	126	2,228	0.06	3.9	2.4	3.8	493	13.7	66.5	89.0
May	7.0	86	2,053	0.04	3.6	2.2	3.4	453	14.2	65.3	94.5
Jun	6.9	137	2,450	0.06	4.4	2.6	4.4	408	13.1	66.6	93.5
Jul	7.0	72	1,951	0.04	3.6	2.1	4.2	334	12.4	67.3	101.0
Aug	6.9	165	1,990	0.08	2.6	1.6	3.8	346	12.4	62.8	96.5
Sep	7.0	88	2,291	0.04	3.3	--	3.4	--	--	--	--

blem, operation of the compressors was automated using a compressor manometric switch. This has resulted in improved gas collection.

5. Upgrading of the overall operational program. In most treatment plants the anaerobic digesters are operated solely as solids reduction mechanisms. The program was revised to consider both the solids reduction and utilization of the digesters as an energy source. In conjunction, an intensive laboratory support program was implemented to provide a basis for proper operation. These have resulted in improved operation awareness and served as a basis of defining other problems.

4. ENERGY BALANCE

To properly evaluate the performance of the system, an energy audit was conducted. This is summarized in Figure 5. As can be seen, the plant has three sources of energy: digester gas, natural gas, and fuel oil. Fifty-six percent of the energy comes from digester gas.

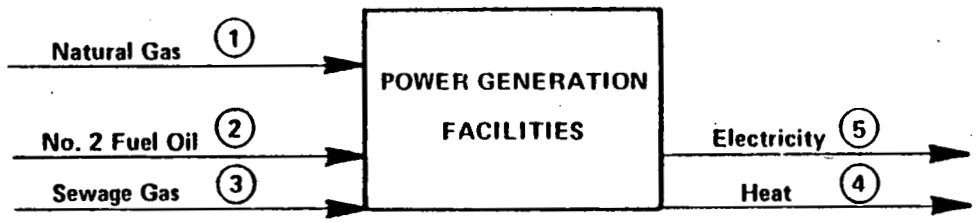
The efficiency for the input energy in terms of electric power generation is 34.6 percent. Ten percent of this is required for the operation of the equipment in the anaerobic digestion-power generation system. Therefore, 31 percent of the input energy is available for other plant uses. The performance of the plant is comparable to similar power generation systems, which indicate an effective power utilization of 21 to 36 percent.

In addition to the power generation, the system provides a significant level of heat input. This includes preheating of the raw sludge, maintaining temperature of the digesters, providing winter building heat, and providing plant hot water. By including the heat captured for sludge preheating, the plant obtains a 53.7 percent energy recovery; with the inclusion of all factors, the overall energy recovery appears to be approximately 60 percent.

5. ECONOMICS

In order to totally evaluate the feasibility of the system, an economic evaluation is required. The factors included in evaluating the system costs were energy (fuel) costs, maintenance costs, manpower costs, and operating costs. A summary of these costs is presented in Table 3. These indicate an average operation cost (not including amoritization) of 3.45¢/KWH.

The cost is 0.651¢/1,000 BTU based on total energy recovery. A summary of the energy costs for the various sources for the period July 1978 to June 1979 is presented in Table 4. The results of this study indicate that the costs of digester gas and internal power generation are comparable to alternative energy sources. However, if on-site power gen-



ENERGY INPUT

(1) Natural Gas
18,256,000 ft^3/yr = 1.8256×10^{10} BTU/yr

(2) Fuel Oil
296,731 gal/yr = 4.1542×10^{10} BTU/yr

(3) Sewage Gas
1.1534×10^8 ft/yr = 7.4971×10^{10} BTU/yr

Total = 13.4769×10^{10} BTU/yr

ENERGY RECOVERED

(4) Electricity
$1.365465 \times 10^7 \frac{KWH}{YR}$ = 4.659×10^{10} BTU/yr

(5) Heat
= 2.5766×10^{10} BTU/yr

= 7.2356×10^{10} BTU/yr

FIG. 5. SYSTEM ENERGY BALANCE

TABLE 3

SUMMARY OF OPERATION AND MAINTENANCE COSTS FOR POWER GENERATION FACILITIES AND ANAEROBIC DIGESTERS[a]

ANAEROBIC DIGESTERS	
Operation:	
½ Operator per shift	
3 shift/day, 365 day/yr = 4,380 MH/yr[b]	$ 29,597.41
½ Lab Tech, per day	
5 day/wk, 52 wk/yr = 130 MH/yr[b]	878.46
Maintenance:	
1,474 MH/yr[b]	9,960.41
Cleaning 3 Digesters	47,615.50
Parts and Materials Cost	32,534.89
TOTAL	$120,586.67
POWER GENERATION FACILITIES	
Operation:	
½ Operator per shift	
3 shift/day, 365/day/yr = 4,380 MH/yr[b]	29,597.41
Maintenance:	
2 men, 8 hr/day, 5 day/wk	
52 wk/yr = 4,160 MH/yr[b]	28,110.78
Parts and Material Cost	119,271.81
Natural Gas (182,560 cu ft)	55,133.97
Fuel Oil (296,731 gal)	107,788.61
Lubricating Oil (9,500 gal)	10,695.00
TOTAL	$350,597.58

[a]All costs are for the period of July 1978 to June 1979. The costs do not include the capital investment, buildings, etc.

[b]Cost are calculated by applying Aug cost/hr + fringe benefits ($5.98/hr x 1.13).

TABLE 4

SUMMARY OF ENERGY COSTS

Natural Gas	0.302¢/1,000 BTU
Fuel Oil[a]	0.259¢/1,000 BTU
Sewage Gas	0.161¢/1,000 BTU
Commercial Power[b]	0.768¢/1,000 BTU

[a]October 1979 fuel oil cost was 0.429¢/1,000 BTU.

[b]Actual power cost with power correction factor, approved fuel charges, and billing demands.

eration were not utilized, there would be additional costs for installing power and backup capacity, disposal of water, gas, and heating of digesters and buildings.

Many of the costs for operation of the anaerobic digesters are fixed and would appear even if there were no power generation. Based on these considerations, anaerobic digestion-power generation provides a practical method of treatment plant operation.

6. SUMMARY

The utilization of digester gas provides a valuable by-product for wastewater treatment plant operation. The utilization of this gas is neglected at many treatment plants. The results of the analysis at the Winston-Salem plant show that digester gas utilization is an economical energy source.

The anaerobic digester-power generation system is a cost-effective source of energy for the plant. The analysis indicated that more attention is required in the operation of the digesters as an energy generation system as compared to the stabilization of solids. In evaluating the economics of power generation, consideration needs to be given to the total costs of all alternatives. This would include the costs of demand charges and possible surcharges on electricity, along with costs for disposal of waste gas and heating of the digesters and buildings.

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ENERGY AND COST-EFFECTIVE WASTE TREATMENT FOR LAKESHORE AND OTHER SMALL COMMUNITIES

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1. INTRODUCTION

Never before have we known better the composition of waste, the properties and treatability of its constituents, and their effects on the environment upon discharge. This knowledge and the awareness that we must conserve energy and other resources should make it possible at least in many smaller communities to devise simple and cost-effective waste handling systems.

In the course of undertaking this study, one finds, however, that traditional thinking and a maze of well-intended rules and regulations directed at individual steps of the process or components of the system can sometimes reduce maneuvering space sufficiently to prevent the adoption of an innovative, environmentally sound, and cost- and energy-effective solution.

In this paper we shall discuss several innovative system components which taken together, can produce combined cost and energy savings even exceeding those of the individual components.

2. BLACKWATER-GREYWATER SEPARATION

Part of our argument can be summarized in the statement that water to some extent is an unnecessary component of municipal and industrial wastewater. The principle which is the most useful and the most universally valid for water conservation, for efficiency of waste treatment and reduction of waste loadings on the environment is the principle of isolation and segregation of different waste streams as closely to the sources as possible to keep volumes small and concentrations large.

Blackwater-greywater separation in residential areas is one way of applying this concept. With blackwater, we refer to the sanitary wastes which contain large amounts of

1. Biodegradable organic matter which needs to be stabilized to preserve an acceptable environment;

2. Microorganisms, including pathogens, which are to be contained and destroyed to maintain public health;

3. Nutrients which are stable in groundwater and affect adversely either human health (nitrogen converted to nitrate) or the quality of receiving surface waters (phosphates and/or nitrates).

For thorough and reliable treatment of this waste stream we continue to favor collection and treatment in centralized facilities wherever population density is high or discharge of effluents from individual treatment systems to the local groundwater or to surface waters is not desirable.

The remaining portion of the residential waste flow, the greywater, is relatively innocuous. Tub, shower, and laundry wastes contain surfactants and soap, along with soil, alkali and relatively few microorganisms. In several states of the USA, greywater by regulation is very low in phosphates and therefore not harmful to receiving surface waters. Alkali in septic tank leachate can even counteract the effects of acid precipitation on receiving waters. The biodegradability of surfactants is subject to federal regulation, and requirements are, or can be made, more stringent when local conditions require it. While the dissolved solids content of greywater may be of concern in some areas, it is less than that of treated whole sewage effluent, particularly after chemical treatment. Certain domestic waste, e.g., kitchen wastes and phosphate-rich dishwater effluent, may be classified black or greywater. Spent organic solvents should be collected separately and not discharged as greywater or blackwater. With proper regulations it is not difficult to make greywater acceptable for direct recharge.

The separation of black and greywater as defined here will reduce sewage flows from residences to 58% of the normal flow (SES Engineers, 1979). To accomplish this reduction in sewage flow, it is necessary to isolate the internal plumbing in the residence. This is very easy in one-story houses with basements or crawl spaces. Some second-story flows, when difficult to isolate, may be treated as blackwater. (The industrial case may be more involved but may result in a larger savings. Recycling of boiler and cooling water is now practiced widely.) In the case of the older subdivision being added to an existing sewer system, the use of the existing septic tank and leach field to treat the greywater offers a great advantage. Where new subdivisions are being added to an existing sewer system, the necessary addition of a dry well increases the cost, depending on soil permeability. In built-up areas, building codes may provide for the separation in all new construction for a gradual changeover.

In a lakeshore or small community, low housing density can make a conventional gravity system very expensive. Most EPA publications (Van Note et al., 1975; Dawes and Moore, 1978) do not take into account the sparsely populated communities when providing cost effective wastewater treatment systems or analysis of operation and maintenance costs for municipal wastewater treatment systems. In addition, unfavorable topographical and geological conditions might increase the cost of the collection system drastically.

Innovative collection systems are presently available and being used throughout the country. These are pressure sewers, vacuum sewers and small diameter gravity sewers. There are advantages and disadvantages to each of the systems. Under average conditions, the gravity system is the least expensive (SCS Engineers, 1979; Energy and Environmental Analysis, Inc. 1979; Wesner et al., 1978), and its cost per capita decreases with the size of the

community. Pressure sewer systems are of comparable cost in small communities (500 population). Cost decreases less with population size, as the need for grinder pumps is responsible for most of the capital cost. Piping in the pressure system, however, costs only 1/5 of that in the gravity system. Operation and maintenance costs of the pressure sewer system arise mostly from the operation of the grinder pumps, those of the gravity system depends heavily on the number of pumping stations and force mains that are to be maintained.

If blackwater separation is practiced and flows are reduced, outlying areas of a district can be served by small-diameter pressure lines. No gradient is lost and the cost of interceptor construction is reduced. In a gravity system, flow reduction may allow a larger part of the network to be constructed from minimum-diameter piping.

Generalizations of the annualized per-capita costs can be misleading. It is for this reason that one must understand fully the applicability of the innovative collection systems. Often a totally integrated system which takes advantages of the topographic conditions, can be the most cost effective. As was pointed out by Kreissl (undated), the capital costs for innovative collection systems versus conventional systems can produce savings from 30% to 80%. These savings in addition to a reduction in total treatable waste can in reality be very substantial for a small, strictly residential, low density community. Often the engineer must deal with the expansion and upgrading of existing systems. Flow segregation can help to make an existing system serve a much larger population.

3. THE TREATMENT OF CONCENTRATED WASTEWATER

Even without flow segregation, pressure sewer systems by excluding infiltration, reduced wastewater flow to 32 $gal \cdot cap^{-1} \cdot day^{-1}$ or less than 30% of the average national water consumption per capita, while it increased BOD_5 increased from 220 to 330 $mg \cdot liter^{-1}$, suspended solids from 230 to 310, and TKN from 30 to 80 $mg \cdot liter^{-1}$ (Carcich et al., 1974). Blackwater-greywater segregation would increase organic content much further, particularly if flow-reducing devices are used in toilets. In the following we shall discuss the advantages of a smaller, more concentrated waste flow.

The reduction of wastewater flow with a proportional increase in organic biodegradable contaminants has been studied in activated sludge systems to some extent. These studies essentially confirm that proportionality exists between influent and effluent concentrations at constant dilution rates as can be expected from theory (Adams et al., 1975; Grady and Williams, 1975; Bohas and Sierka, 1978; Hoepker and Schroeder, 1979). This means that a given amount of waste in a smaller volume of water can be treated in a proportionately smaller tank with effluent concentrations increased and pollutant output remaining the same, or can be treated in a tank of the original size with effluent concentrations remaining the same or slightly lowered, and pollutant output markedly reduced. In every case, an advantage is realized. In addition, the efficiency of aeration is greater in the concentrated waste.

Less commonly realized is a qualitative advantage of treating more concentrated wastes. According to bacterial growth kinetics in a completely

mixed reactor, washout of a population occurs at a critical dilution rate (D_c) which is related to its maximum growth rate (μ_m) and half-saturation concentration for a given substrate (K_s) by the concentration of the nutrient in the feed (S_o), by $D_c = \mu_m S_o/\beta(K_s + S_o)$ (Pirt and Kurowski, 1970), where $\beta = 1$ without, and $\beta < 1$ with recycle of biomass. As S_o is increased, D_c increases, and the danger of washout from the reactor of slow growing yet biochemically important species is lessened. The effect is more pronounced in mixed-substrate systems with a high apparent K_s. Incidentally, this effect of producing a more adaptable, "mature" biomass is more commonly obtained by increase mean cell residence time, i.e., by increasing tank volume.

Recycling part of the biomass as is customary in activated sludge systems also serves to maintain high biomass diversity, since under these conditions dilution rates may even be higher than μ_m without the danger of washout. The advantage of the higher feed concentrations exists also under these conditions.

The same considerations apply to an even greater degree to anaerobic digestion because it is characterized by low microbial growth rates and yields. With wastewater flows of sufficient strength (1,000 to 2,000 mg BOD/liter) direct anaerobic treatment becomes economically attractive (Cillie et al., 1969; Pretorius, 1971). The lower value can be approached by blackwater/greywater separation in combination with infiltration prevention and water conservation in toilets. Additional organic loading is available by the addition to the digestor of solid waste, e.g., garbage or cellulosic waste such as grass clippings, leaves, or waste paper.

The advantages of more concentrated waste streams also are quite apparent in physical and chemical treatment processes. Aeration and ammonia stripping are carried out more efficiently, and less chemicals are needed for pH adjustments and for the maintenance of supernatant concentrations in precipitation reactions.

Of the biological treatment alternatives, thermophilic anaerobic digestion deserves special consideration.

4. THERMOPHILIC ANAEROBIC DIGESTION

Recent studies of the thermophilic, anaerobic decomposition of wastes indicate that there are several advantages of thermophilic digestion over conventional mesophilic processes (Cooney and Wise, 1975; Pfeffer and Liebman, 1976; Varel et al, 1977; and Therkelsen and Carlson, 1978). The major advantages are: (1) more rapid digestion of volatile solids; (2) higher yields of methane; (3) improved dewatering of solids; and (4) pasteurization of digestor contents. Higher digestion rates are probably due to an increase in the rates of the biochemical activities necessary for anaerobic decomposition, with the increase in temperature. Higher yields of methane apparently result from an increase in the amount of organic matter in wastes that is subjected to microbial decomposition when digestion is carried out at high temperatures. Improved dewatering properties may in part result from the lower viscosity of the liquid phase of digester contents and the increased rate of settling of solids at high temperatures (Ohara et al., 1978). Pasteurication, or killing of potential pathogens (bacteria and viruses) is

caused by exposure of digester contents to high temperatures for long periods of time.

Higher rates of digestion permit the use of smaller digestion tanks than would be necessary at mesophilic temperatures. Higher yields of methane increase the potential for energy recovery. The decomposition of volatile solids also is increased, which reduces the amount of sludge that has to be disposed of after digestion. Pasteurization reduces the possibility of health hazards and increases the likelihood of using the liquid and solid residues of fermentation as fertilizer.

Most of the studies that indicate the advantages of thermophilic digestion of wastes have dealt with either municipal solid wastes or animal wastes. There are no contemporary studies that directly compare the effectiveness of thermophilic versus mesophilic digestion of sewage. Results of older studies are contradictory because investigators were often unaware of the fact that distinctly different microbial communities had to be established to effect digestion at mesophilic versus thermophilic temperatures. Many comparisons were made by subjecting a mesophilic digester to a rapid change to higher temperatures. This stressed the mesophilic microorganisms and did not allow sufficient time for the establishment of populations of bacteria that require higher temperatures for growth. However, it is clear from the older literature, from the contemporary operation of one thermophilic digester in the Soviet Union and one in the United States and from recent experiments in our laboratory that it is as easy to establish a thermophilic as it is to establish a mesophilic process for digestion of sewage. Recent studiesof the thermophilic digestion of an artificial facsimile of sewage showed that satisfactory digestion was achieved at loading rates of 7.8 kg VS/m^3·d and a detention time of 5.5 days (Therkelsen and Carlson, 1978). VS reduction was 57% and 0.4 m^3 methane were produced per kg VS fed.

There are no special design requirements for thermophilic digesters. It is obviously important to apply design principles that conserve heat. Our calculations show that the requirements for process heat in both mesophilic and thermophilic digestions are about the same. In the eastern New York climate, however, energy savings are available by increased insulation of the smaller thermophilic reactor and the use of a heat exchanger which transfers heat from the effluent to the influent sludge.

5. STUDY OF TREATMENT SYSTEM FOR NIVERVILLE, NEW YORK

A greywater-blackwater separation scheme was studied for a new sewer system and treatment plant for the lakeside settlement of Niverville, town of Kinderhook in east-central New York. Here the separation of flows would have reduced the total flow to the treatment plant from 190,000 to 100,000 gpd. In addition, however, the fact that the relationship of solids to the total flow was double the normal led to other more important discoveries.

At Niverville, only a small, intermittent stream is available for discharge, and the quality of the groundwater away from the lake and the village is of secondary concern. In this situation, primary treatment and land disposal of the primary effluent by infiltration/percolation was contemplated.

The reduced flow required less lagoon area and therefore less land acquisition, site preparation and pumping. This made the land disposal less costly and of course more energy-efficient than any secondary treatment alternative. The disposal of the primary sludge by anaerobic mesophilic digestion generally is not considered cost effective at flows below 5 mgd. Thermophilic digestion, however, was estimated to be cost-effective and was included in all subsequent plans. Ironically, the blackwater-greywater separation scheme which led to this layout was later abandoned when EPA ruled that the plumbing changes required in the homes were not eligible for grant support under their regulations. These costs would have to be borne directly by the homeowners who were not under a discharge permit requirement to sewer the community. The irony of the situation is that the total cost to the homeowners of the plumbing modification was less than the savings that would have been realized in the portion of the project which to a large extent is publicly funded. As a result, the design flow was back at 190,000 gpd, and the land disposal scheme favored by EPA was no longer cost-effective. Of all alternate schemes, treatment of the primary effluent with rotating disc contactors, ozonation and filtration before discharge to the stream, and thermophilic digestion of the sludge with ultimate land application is the cost-effective solution.

The decision in favor of thermophilic digestion at the Niverville plant was based mainly on reductions in costs that accrue from the smaller digesters required because of the expected rapid fermentation, and by the elimination of a secondary digester. The latter is unnecessary because of the rapid primary fermentation and the expected more rapid settling of solids. The plant is also designed with the potentiality for directly using the digester effluents as liquid manure. This use would greatly reduce the load on the secondary and tertiary portions of the plant because of the elimination of the necessity for treatment of the digester supernatant.

Thermophilic digestion is a cost effective, environmentally sound strategy for dealing with the sewage problems which are addressed in the design of the Niverville plant, and it should also be considered for use in other sewage treatment systems including conversions of existing mesophilic to thermophilic digesters.

6. SUMMARY

The combination of several innovative features in the collection and treatment of domestic wastewater leads to economies in cost and energy use which exceeds those of the features taken singly in an otherwise conventional collection and treatment scheme. The features are: (1) blackwater-greywater separation with regulation of greywater composition and disposal directly to ground of the greywater. (2) Blackwater flow reduction and treatment at a central plant with maximum utilization of thermophilic anaerobic digestion.

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