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REFUSE CONVERSION TO METHANE (RefCOM):
A PROOF-OF-CONCEPT ANAEROBIC DIGESTION FACILITY

by

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DISCLAIMER

REFUSE CONVERSION TO METHANE (RefCOM):
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Abstract - The U.S. Department of Energy (DOE) is developing a process for the anaerobic digestion of solid waste and sewage sludge into methane. Known as RefCOM -- Refuse Conversion to Methane -- the DOE experimental facility in Florida can process 100 tons of raw refuse per day with an output as high as 700,000 cubic feet of gas (CH_4 and CO_2) per day. Based on an average home gas consumption of one million cubic feet per year, a 1,000 tons-per-day plant has the potential to meet the gas needs of over 7,000 homes. The objectives of the RefCOM experiment are to:

- establish information on the quality and quantity of gas produced;
- ascertain optimum operating parameters for both mesophilic and thermophilic modes; and
- evaluate the reliability of the techniques.

INTRODUCTION

As fossil fuel resources are depleted and become more expensive, alternative energy sources become more economic. Unfortunately, the public is largely unaware that one of the most practical methods of producing energy is to literally recycle urban waste -- trash, garbage, sewage sludge and industrial waste -- into methane. Simply stated, the process starts by feeding waste material through a series of trommel screens, air classifiers and separators, and is completed by the biological degradation of organics which produce methane-rich gas. Since the gas can easily be upgraded to pipeline quality, this experiment holds promise for a clean, convenient fuel for the long term.

Bench-scale studies indicated that 4.5 to 5.5 cubic feet of methane can be produced per pound of volatile solids added at mesophilic temperatures (100°F) with from 10 to 30 days retention time. In order to test the conclusions of these studies, a large-scale facility for converting municipal solid waste (MSW) to methane was funded by the U.S. Department of Energy. The design was developed from laboratory scale to a proof-of-concept size plant with enough flexibility to allow operating parameters to be varied and the overall plant feasibility to be thoroughly evaluated.

Objectives considered when designing the project included: (1) evaluating the quantity and quality of methane produced per unit of organic solids fed; (2) reduction of solids remaining for disposal; (3) dewatering characteristics of the digester sludge; and (4) the process requirements and the overall technological and economic basis for commercial utilization of this process.

History of Concept and Project

Anaerobic digestion of organic material to form methane is not a new concept. Since the dawn of time anaerobic organisms have decomposed organic material into more simple components. The principal products of this process have been methane and carbon dioxide. This gas appears naturally as swamp gas in marshy areas. Anaerobic digestion was an early sewage treatment method to stabilize and reduce the volume of sludge. It is also the normal product of decomposition in sanitary landfills where municipal solid waste and/or sewage sludge is buried.

The process is complex and not totally understood. It is essentially a three-stage process. In the first stage, cellulose and other complex organic compounds are broken down to simple sugars. In the second stage, a group of organisms convert the simple sugars to organic acids, such as amino and propionic acid. In the third stage, the organic acids are further degraded by a different group of bacteria to methane and carbon dioxide. Some nitrogen and traces of hydrogen sulfide are also produced (Table I).

Table I. Biological Process of Anaerobic Digestion

	Anaerobic Degradation of Organic Matter to Methane (CH_4) and Carbon Dioxide (CO_2)
First Group[(a)]	Mixture of species that hydrolyzes carbohydrates (e.g., cellulose and starch), lipids and proteins, and ferment these to acetic acid, other organic acids, H_2, CO_2, NH_3 and sulfide.
Second Group	Oxidizes other organic acids to produce more acetate and H_2.
Third Group	Various methanogenic bacteria which utilize CO_2, H_2, and acetate for growth with the production of CO_2 and CH_4.

(a) Although these appear to be three autonomous groups, the interactions necessitate that all three function within the same vessel. For example, an organism in group two may produce H_2. If the H_2 is not removed, the organism will be product inhibited and fail to function optimally. The H_2 removal is accomplished by a methanogenic bacteria forming CH_4.

Since the late 19th century anaerobic digestion has been used to stabilize sewage sludges. By the 1920s some treatment plants were using the combustible gas produced by anaerobic digesters. However, the production of gas is variable even in well-operated plants. Because the gas is saturated with water and contains some hydrogen sulfide, it is corrosive and difficult to handle. In addition, while anaerobic digestion can stabilize and reduce the solids volume by 50 percent, the remaining 50 percent requires disposal. Consequently, the anaerobic digestion process fell into disfavor.

With the advent of the energy crisis, interest in the process revived. In the early part of this decade, Dr. John T. Pfeffer of the University of Illinois, Urbana Campus, initiated research in the area sponsored by the National Science Foundation (NSF) under the Research Applied to National Needs (RANN) program and the U.S. Environmental Protection Agency (EPA). Dr. Pfeffer's experiments primarily used refuse derived fuel (RDF).

Laboratory-scale studies performed to date by Dr. Pfeffer, who is also technical consultant on the RefCOM project, indicate that approximately 6,000 cubic feet of mixed methane and carbon dioxide gas are produced per input ton of raw refuse. Thus, 3,000 cubic feet of methane (equivalent to pipeline quality gas) per input ton could be produced by this process. Based on an average home gas consumption of 1,000,000 cubic feet per year, a 1,000 tons-per-day plant could serve the gas needs of over 7,000 homes.

Dr. Pfeffer's positive findings led NSF to fund the Dynatech Corporation to conduct an economic and sensitivity analysis of the process. This study developed a preliminary design and an economic model for a full-scale (1,000 tons-per-day) digestion plant.

The Dynatech economic computations indicated that urban waste methanation would prove technically feasible at a cost competitive with available sources of natural gas. Most of the equipment necessary for operational scale-up of the laboratory bench-scale experiments (upon which the preliminary designs and cost estimates were based) appeared adaptable from other industrial processes, and the investigation had reached the point where pricing of construction and operation of a practical size scale-up was necessary to determine actual production, purification and distribution prices.

Based on the favorable findings of these two reports, a request for competitive proposals to construct a 50 to 100 tons-per-day proof-of-concept plant was issued in March, 1975, by the Energy Research and Development Administration (ERDA) which had by then assumed the NSF program. Twenty bids were received. Waste Management, Inc., of Oak Brook, Ill., was selected and awarded the contract in June, 1975.

The Project

Waste Management's winning proposal called for construction of the facility at its Pompano Beach Solid Waste Reduction Center and disposal facility. There, residential and commercial waste collected from Broward County and vicinity is shredded and landfilled. Shredding prior to landfilling reduces the need for cover material since the waste has less tendency to blow, is more homogeneous, and does not provide a breeding ground for vermin and other disease vectors.

The intent of the original proposal was to use a portion of the waste from a 15 tons-per-hour (TPH) Heil vertical mill for the DOE plant. A processing train was to be built in the back of the primary shredder. A secondary shredder would permit experiments with feedstock size, and a rotary screen would remove grit and fines. The processed waste would be conveyed from the main building to a storage facility. From storage it would be mixed with nutrients and water and fed to twin digesters.

Prior to construction, Waste Management decided to expand its facility by adding a 60 TPH Heil mill. Consequently, the space for the DOE processing train was no longer available. Therefore, separate structures for the DOE plant (hereafter called RefCOM) were planned.

In retrospect, the change proved advantageous. The difficult interface between an operating facility and an experimental facility had been one of the problems with the plant. The problem may have been intensified with part of the experimental facility in the operating area.

Today the waste can be processed through either the 15 TPH or 60 TPH mill, although the 15 TPH mill provides a better feedstock to RefCOM. From the mill, the waste is conveyed past a magnet to remove ferrous metals to a diverter valve. Most of the waste goes to the landfill, with a slip stream of it going to the storage building.

Storage underwent major changes in design. Originally, an automated storage and retrieval system was planned. Subsequently, an economic and operational study indicated that a flat floor storage facility was a better solution for the relatively short life of the facility.

From storage, the waste is fed to a classification building. In the classification process the shredded waste passes through a rotary screen (trommel) to remove grit and fines (glass, silica, sands, ash, etc.). The material then undergoes secondary shredding to permit experimentation in particle size and air classification and to separate light and heavy fractions. The light material is pneumatically conveyed to a cyclone. From the cyclone it is conveyed on a weighfeeder to a pre-mix tank to be blended with sewage sludge, recycled filtrate, nutrients and steam for temperature control. This slurry is then metered into two mechanically agitated anaerobic digesters.

The original design of the anaerobic digesters called for a gas mixer, but a small test program at Pompano Beach and a separate DOE/EPA sponsored project indicated it would not be successfull. As a result, mechanical mixers were installed. Here the biological process converts approximately half of the organic feed solids into a product gas composed of approximately 50 percent methane and 50 percent carbon dioxide. At RefCOM, most of the gas is flared to keep experimental concentration on the digestion process. A portion of the gas is used in the steam generator that heats the digester. Future plans call for using the gas as the secondary fuel for a hospital and pharamaceutical waste incinerator, and as fuel for an internal combustion engine generator set. In a full-scale facility, the gas could be dried, scrubbed of impurities, and introduced into a pipeline as synthetic natural gas (SNG).

The effluent from the digesters passes through a vacuum filter. To date, the filtrate has been totally recycled or stored in a second digester. The filter cake, which is stable and has been as high as 25 percent solids, is sent to the landfill. Future experiments will search for productive uses of the filter cake. It has been known to air dry quickly. If a solids content of over 35 percent can be achieved, it will burn and is expected to have sufficient energy to power the process.

Experiment Objectives and Phases

Most of the project experiments will be concentrated on digester performance. Since the digesters are designed to run with fixed volume, the variables are process conditions such as residence time and solids loading.

A detailed experimental program has been developed for the facility to evaluate, in phases, several independent variables. The most significant areas to be studied are: (1) methane production per unit of organic solids fed, (2) reduction in solids remaining for ultimate disposal, (3) mixing characteristics of the urban waste/sewage sludge slurry, (4) dewatering characteristics of the reactor slurry, (5) process stability, (6) energy requirements for operation, and (7) chemical costs for nutrients and pH control.

The various phases of experimentation include determination of optimum fermentation temperatures

Table II. Advantages of Mesophilic and Thermophilic Conditions

Mesophilic	Thermophilic
• Less water vapor in gas.	• Higher rate of digestion and methane production resulting in shorter retention time and smaller digestion volume for the same trash throughout.
• Less CO_2 in gas.	
• More types of bacteria grow and produce methane.	• Decrease in net sludge.
	• Destruction of more pathogenic organisms.
• Lower heating requirements.	• Potential for increased digestion efficiency.
	• More rapid regeneration of population after partial souring.
	• Easier maintenance of anaerobic conditions.

(mesophilic and thermophilic) (Table II), evaluation of feed preparation, evaluation of feed solid concentration and residue recycle, evaluation of pH and nutrient requirements, residue dewatering, and residue disposal. Table III illustrates the range of variables to be investigated.

As of this date, the experiment has focused on the use of mesophilic temperatures using slurry feed concentrations of nine percent and temperatures of 100°F. Retention times were 30 days and 20 days with a particle size of 1.5 inches. The data obtained will be of most value as a baseline for the process, and for comparing laboratory and RefCOM results.

Start-up and Modifications

As with any complex manufacturing plant or processing facility, start-up is not a simple task. This is especially true at an experimental facility such as RefCOM. For example, the RefCOM start-up program began March 15, 1978. Minor modifications were needed on the conveyors to relieve restrictions at transition points. An electrical system check-out was completed and the belt tracking and vibration were checked. Some defective parts were located and replaced. In April, representatives from suppliers arrived to make adjustments on the installed equipment. During this period the open conveyors, open sides on the processing building and the winds of South Florida created a problem of trash dispersion that demanded an early solution. The easiest method was judged to be covering the trommel and exposed conveyors. The covers were designed and built on site. A heavy metal box with hinged lid and rubber skirts rubbing on the belt was devised. It was effective, although lack of attention to dust control has resulted in more dust than would be desirable in a commercial-scale facility.

Table III. Variables in Anaerobic Digestion to be Investigated

	Range	Measure
Temperature		
Mesophilic	95-115	°F
Thermophilic	130-140	°F
Hydraulic retention time	5-30	days
Feed slurry concentration	8-20	% dry solids
Loading rate	0.2-2.5	lb volume solids/day/CF
Filtrate (centrate) recycle	50-100	%
pH	6.8-7.0	
Particle size	1.5-3.0	inches
Nitrogen	300	(mg/1)
Phosphorus	60	(mg/1)

By June, waste was being processed and a series of nagging problems solved. For example, input waste was pinched against an elevating cleated conveyor by a leveling plate. The plate was reversed to shear off the top rather than compress the waste on the belt. A vibrating feeder to the trommel frequently jammed and eventually had to be removed.

The secondary shredder has been the most persistent problem. It has a number of deficiencies for service of municipal waste. Although intended for less than three-inch material, it had a two-inch throat opening when delivered. In addition, it had no junk chute. As a result, ferrous metals passing through the magnet had no exit unless they either wore down enough to pass the grate or broke the grates. Finally, the shredder operated as a large fan, and even with the covers it blew dust RDF out of any available openings. Extensive in-house modifications opened the throat and provided a dust control system, although the latter has created some fires in the bag house. The best solution has been stationing personnel at the trommel discharge to remove bulky items.

The weigh feeder posed another problem. The actual density of the material conveyed on it was only about one-half of what was expected. Eventually, the belt speed was doubled and the load measurement system replaced and recalibrated.

The final digester problem concerned the transport of material at 10 to 15 percent solids. The original design was for a screw feeder. Initial conjecture was that material might flow in by gravity. In reality, the material frequently jammed the screw. A rotary star valve replaced the screw but it has not proven entirely satisfactory.

Strings of textile and plastic present in the feed interweave with cellulose fibers and sometimes weigh as much as 80 pounds each. These break free from the premix tank agitator and star valve. They also tend to unbalance the mixer and overload the motor. They are now controlled by frequently removing them by hand and by stationing men at the trommel. After considerable research, a wire system is being installed in the trommel so that the longer textiles can wrap around it and be removed.

Since August, 1978, the digesters have been producing gas. However, many problems with the processing equipment prevented a steady and adequate supply of feed to the digesters. Therefore, gas production has fluctuated and has not achieved expected results. However, the digesters were not heated (they stabilized at about 30°C/85°F) and the solids contents did not exceed three percent (versus an expected operation at eight percent). Incidentally, the mechanical mixers have operated at less than 10 percent of their available power and have apparently completely mixed the tank. Even when shut down they have broken up the scum layer.

During the early summer of 1979 the facility began producing refuse derived fuel at design capacity and the experimental program is commencing. Separate environmental studies of the facility sponsored by DOE's assistant secretary of the environment are ongoing. To date, tests of the effluents, the products and the processing facilities have not developed any significant problems.

CONCLUSION

The RefCOM facility at Pompano Beach is an operation utilizing the age-old process of anaerobic digestion. It is fermenting urban waste under controlled conditions to a mixture of methane and carbon dioxide. This proof-of-concept facility is providing information that makes it possible not only to dispose of urban waste, but to collect methane that can be used by homes and industries in the same way that pipeline quality gas is now used.

The facility, built from the research-oriented bench-scale model of John T. Pfeffer, incorporates state-of-the-art information. However, start-up procedures have identified engineering design shortcomings, and the initial operation of the plant provided new information relating to the handling and processing of shredded refuse.

Anaerobic digestion has a number of problems that must be resolved before it becomes a commercial source of fuel. It is a slow process and difficult to control. Problems notwithstanding, the process holds much promise. Once operational information is gathered and some problems solved, it can be applied to larger facilities with significant amounts of methane produced and used as a substitute for scarce and expensive fossil fuels.

On the following pages are illustrations of the equipment and steps in the process of converting urban waste to methane through anaerobic digestion.

GLOSSARY OF TERMS

Air classification - separation of waste particles according to weight through an air blower system.

Anaerobic digestion - fermentation or breakdown of organic material under oxygen reduced or oxygen free conditions.

Bio-mass - renewable feedstocks used to obtain fuels and chemical feedstocks.

Filtrate recycle - after some of the suspended solids have been removed from the digestion process, a certain amount of effluent can be incoming feed as makeup liquid. This procedure can accomplish conservation of limiting soluble nutrients, e.g., nitrogen and minerals, and conservation of heat. The latter is especially important at thermophilic temperatures.

Front-end or feed preparation process - acceptance of raw urban solid waste with varying composition, texture, and moisture content, and the conversion of this input to a relatively homogeneous feedstock to meet the needs of the methane-producing digestion process.

Gas production - approximately 13 cubic feet of gas will be produced per pound of volatile solids destroyed (=0.8 liter/g VS). Of this, 50 to 65 percent will be CH_4. Therefore, 6.5 to 8.5 cubic feet of CH_4/lb VS destroyed (=0.4 to 0.5 liter/g VS) will be produced, the balance being CO_2.

If 50 percent of the volatile solids fed is destroyed the amount of methane produced is 3.25 to 4.25 cubic feet/lb volatile solids fed (=0.2 to 0.25 liter/g VS).

Nutrients - in addition to organic matter that supplies energy and carbon required for bacterial growth, nutrients such as nitrogen and various minerals are required. Some substrates (e.g., manures) contain adequate amounts of these nutrients while others (e.g., urban refuse which is mainly cellulosic) have little thus requiring additions. Much nutrient addition can be alleviated by filtrate recycle.

pH - optimum pH is about 7.0. The rate of methanogenesis drops as pH drops.

Retention time (RT) - mean time, in days, that a component will remain in the digester. Optimum retention time may be from five to 30 days depending on other conditions. Theoretically, a shorter retention time will force the bacteria to grow and metabolize at a greater rate. Practically, a longer than minimum retention time is desired to achieve greater system stability. Generally, a thermophilic regime will accommodate shorter retention time than a mesophilic one.

BIBLIOGRAPHY

[1] C. Bissille, M. Kornreich, M. Scholl, P. Spewak, Urban Trash Methanation Background for a Proof-of-Concept Experiment, Mitre Corporation, p. 12, February 1975.

[2] A.S. Fox, Advanced System Experimental Facility Solid Waste to Methane Gas (RefCOM) Pompano Beach, FL - Design and Construction, Jacobs Engineering Group, Inc., May 20, 1979.

[3] D.K. Walter, C. Rines, Status of RefCOM - Pompano Beach, Florida, December 1978.

[4] P.J. Ware, RefCOM - A Project Review, presented to the 3rd Annual Biomass Energy Systems Conference, p. 6, June 7, 1979.

[5] D.L. Wise, Fuel Gas Production from Biomass Progress and Plans in Fuels from Biomass Symposium, by John T. Pfeffer and James J. Stukel, U.S. Department of Energy, April 18-19, 1977.

[6] RefCOM Engineering Report, A.S.E.F. Solid Waste to Methane Gas, Pompano Beach, Florida. Waste Management, Inc., November 1978.

[7] RefCOM - Status Report Covering the Start-up Phase, Waste Management, Inc., Oak Brook, Ill., October 18, 1978.

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Currently chief of the Urban Waste and Municipal Systems Branch of the Department of Energy, he was city engineer for the City of Annapolis, Md., for two years, a position he accepted in 1973 after retiring as lieutenant colonel with 20 years service in the U.S. Army Corps of Engineers.

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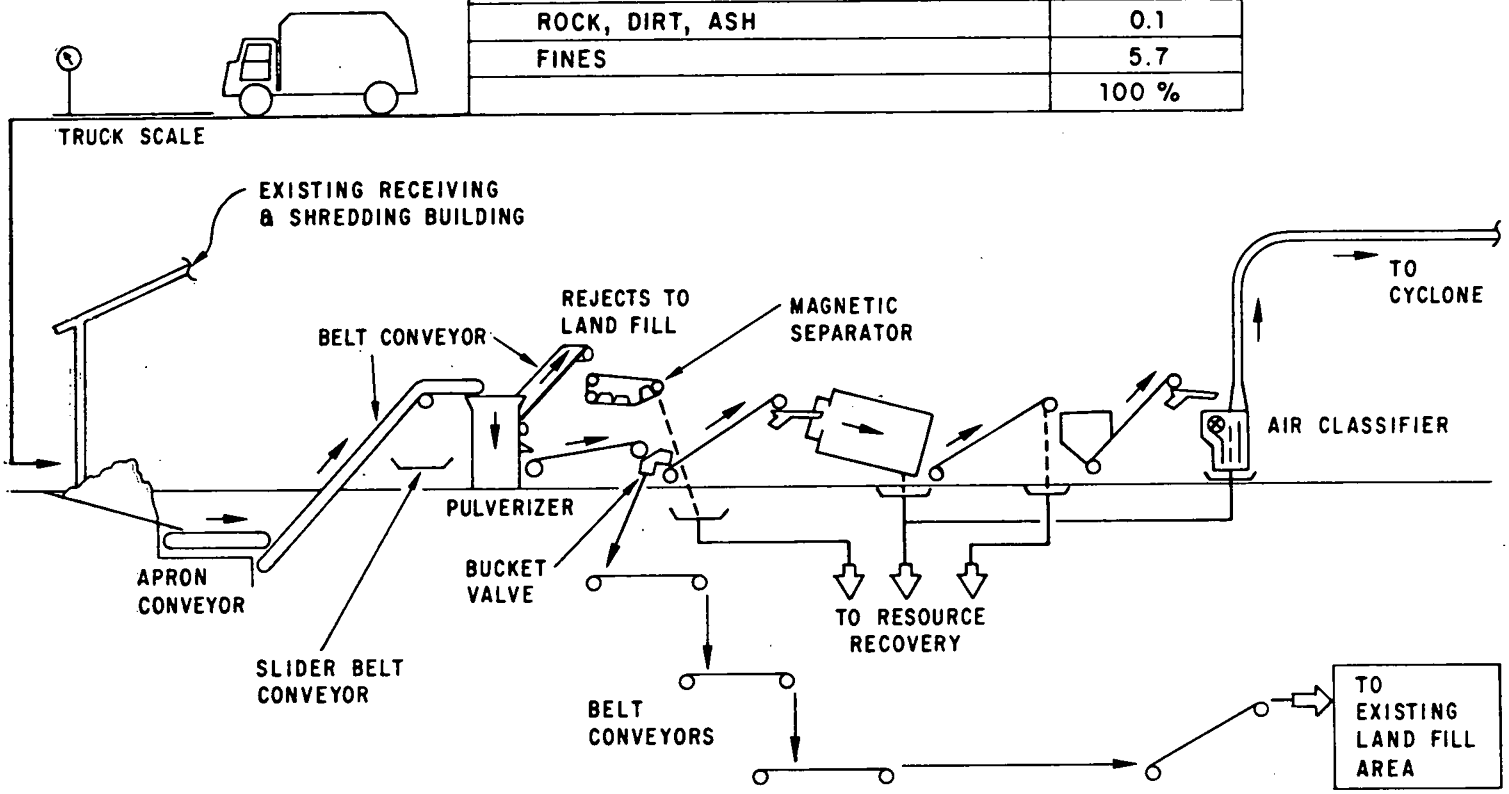
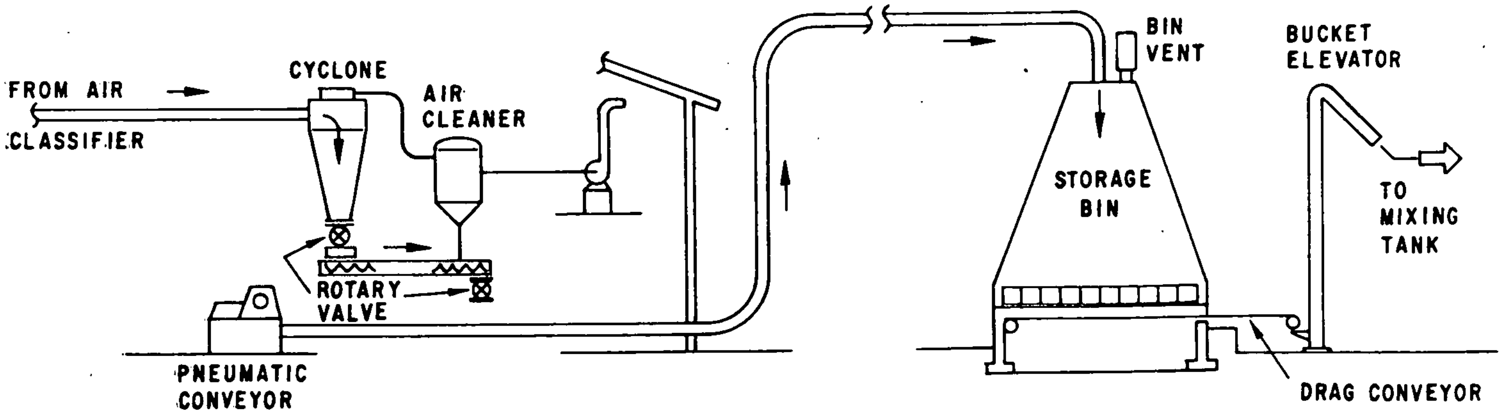
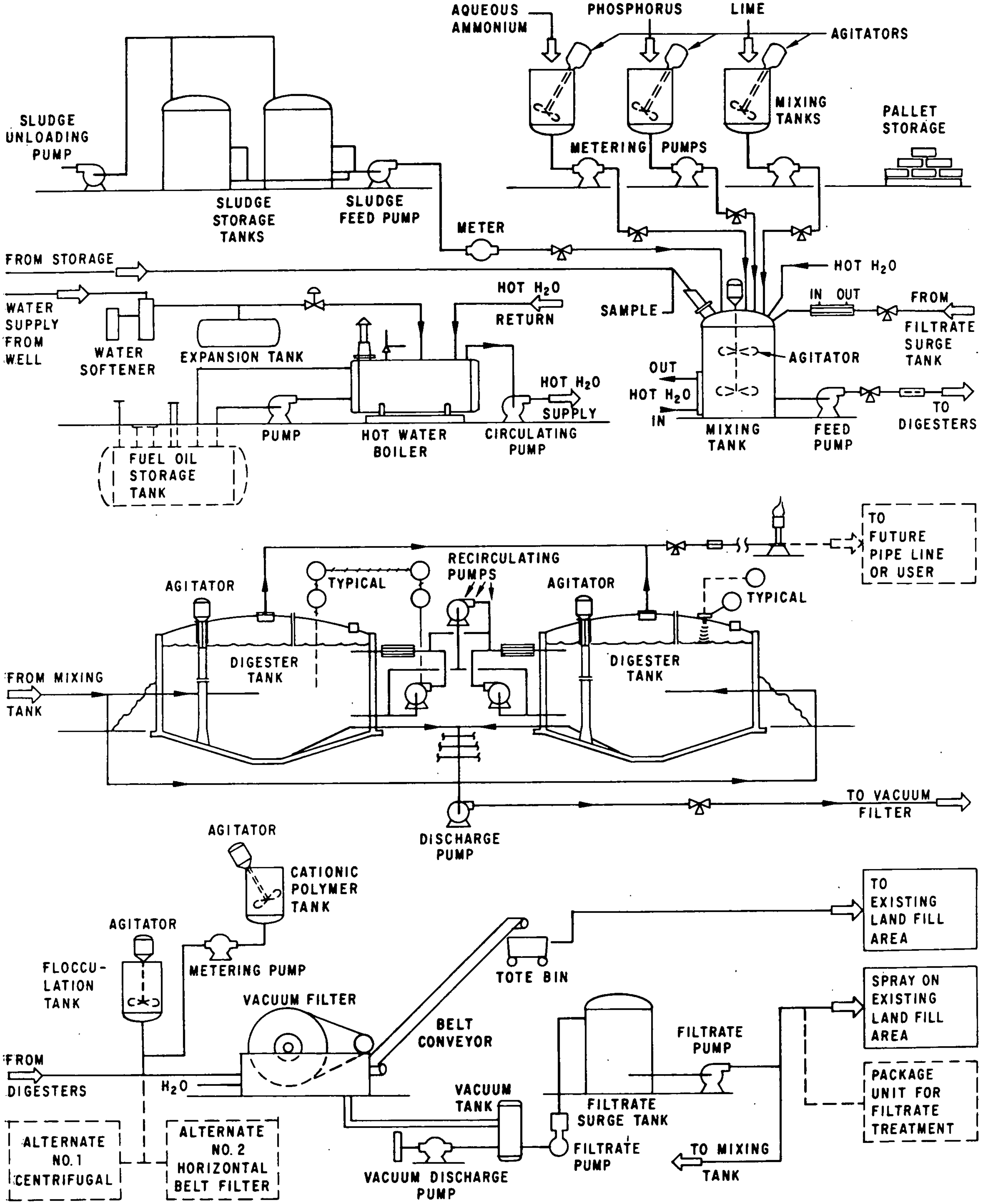
COMPOSITION OF DRY SOLID WASTE DELIVERED TO FACILITY	
TYPE	AVERAGE %
FOOD	4.2
GARDEN	5.8
PAPER	54.6
PVC, RUBBER, LEATHER	4.4
TEXTILES	2.2
WOOD	2.6
FERROUS METALS	7.2
NON-FERROUS METALS	1.1
OTHER METALS	0.1
GLASS, CERAMICS	12.0
ROCK, DIRT, ASH	0.1
FINES	5.7
	100 %







AQUEOUS AMMONIUM
PHOSPHORUS
LIME
AGITATORS
SLUDGE UNLOADING PUMP
MIXING TANKS
PALLET STORAGE
METERING PUMPS
SLUDGE STORAGE TANKS
SLUDGE FEED PUMP
METER
FROM STORAGE
HOT H_2O
WATER SUPPLY FROM WELL
HOT H_2O RETURN
SAMPLE
IN OUT
FROM FILTRATE SURGE TANK
WATER SOFTENER
EXPANSION TANK
AGITATOR
OUT HOT H_2O IN
HOT H_2O SUPPLY
TO DIGESTERS
PUMP
HOT WATER BOILER
CIRCULATING PUMP
MIXING TANK
FEED PUMP
FUEL OIL STORAGE TANK
TO FUTURE PIPE LINE OR USER
RECIRCULATING PUMPS
TYPICAL
AGITATOR
AGITATOR
TYPICAL
DIGESTER TANK
DIGESTER TANK
FROM MIXING TANK
TO VACUUM FILTER
DISCHARGE PUMP
AGITATOR
CATIONIC POLYMER TANK
TO EXISTING LAND FILL AREA
AGITATOR
FLOCCULATION TANK
METERING PUMP
TOTE BIN
VACUUM FILTER
BELT CONVEYOR
SPRAY ON EXISTING LAND FILL AREA
FILTRATE PUMP
FROM DIGESTERS
H_2O
VACUUM TANK
FILTRATE SURGE TANK
PACKAGE UNIT FOR FILTRATE TREATMENT
ALTERNATE NO. 1 CENTRIFUGAL
ALTERNATE NO. 2 HORIZONTAL BELT FILTER
VACUUM DISCHARGE PUMP
FILTRATE PUMP
TO MIXING TANK