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DOE/BC/10183-1
(DE82009992)

ENERGY

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EMULSIFIED INDUSTRIAL OILS RECYCLING

By
Tibor Gabris

April 1982
Date Published

Work Performed Under Contract No. AC19-80BC10183

Bartlesville Energy Technology Center
Bartlesville, Oklahoma

U. S. DEPARTMENT OF ENERGY

Division of Industrial Energy Conservation

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Price: Printed Copy A08
Microfiche A01

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DOE/BC/10183-1
(DE82009992)
Distribution Category UC-92b

EMULSIFIED INDUSTRIAL OILS RECYCLING

Tibor Gabris, *Principal Investigator*
Springborn Laboratories, Inc.
Enfield, Connecticut 06082

Dennis W. Brinkman, *Technical Project Officer*
Bartlesville Energy Technology Center
P.O. Box 1398
Bartlesville, Oklahoma 74005

Funding provided by
Alternative Materials Branch
Office of Industrial Programs
Division of Conservation and Renewable Energy
Washington, D.C. 20585

Work Performed for the Department of Energy
Under Contract No. DE-AC19-80BC10183

Date Published—April 1982

UNITED STATES DEPARTMENT OF ENERGY

FOREWORD

During most of the ten years we have been performing research related to used oil recycling, our focus has been on crankcase oils. We felt the industrial lubricant recycling situation was in much better shape, since in-house or custom reclaiming tended to involve simpler technologies. In addition, such recycling was already increasing due to economic as well as environmental pressures.

However, we uncovered one area in which huge volumes of wastes were being generated, but recycling was difficult. Oil/water emulsions are used in large quantities for a wide spectrum of applications, but the oil content after use is often only a few percent. We decided this potential resource warranted further study, requested proposals through formal advertisement, and selected Springborn Laboratories to do the work after evaluating a large number of proposals.

We hope you will find the final report from this project informative and useful. As cited in the report, adopting some of the practices outlined will actually save money. We certainly believe you will find the discussion that follows comprehensive. As always, we would be interested in hearing any comments you might have after reading this report.

Dennis W. Brinkman
Project Manager, Processing

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ABSTRACT

The industrial lubricant market has been analyzed with emphasis on current and/or developing recycling and re-refining technologies. This task has been performed for the United States and other industrialized countries, specifically France, West Germany, Italy and Japan.

Attention has been focused at emulsion-type (soluble oil) fluids regardless of the industrial application involved. It was found that emulsion-type fluids in the United States represent a much higher percentage of the total fluids used than in other industrialized countries.

While recycling is an active matter explored by the industry, re-refining is rather a result of other issues than the mere fact that oil can be regenerated from a used industrial emulsion. To extend the longevity of an emulsion is a logical step to keep expenses down by using the emulsion as long as possible. There is, however, another important factor influencing this issue: regulations governing the disposal of such fluids.

The ecological question, the respect for nature and the natural balances, is often seen now as everybody's task. Regulations forbid dumping used emulsions in the environment without prior treatment of the water phase and separation of the oil phase. This is a costly procedure, so recycling is attractive since it postpones the problem.

It is questionable whether re-refining of these emulsions - as a business - could stand on its own if these emulsions did not have to be taken apart for disposal purposes. Once the emulsion is separated into a water and an oil phase, however, re-refining of the oil does become economical.

The most commonly used method to break the emulsion is chemical treatment (chemical addition). This method is practiced in the United States. A disadvantage of this method is that large amounts of waste are produced in this process which in turn cause secondary pollution problems.

Ultrafiltration is preferred in the European countries as one of the physical methods of separation. Both European countries and Japan prefer physical methods of separation as no byproducts are generated in such processes.

Ultrafiltration, however, at the present state of the art is not efficient enough to treat such large quantities of emulsions as produced by the industries of the United States.

INTRODUCTION

STUDY OBJECTIVES

One objective of this study is to provide background information on the sales, uses, and specific application of emulsified industrial oils and lubricants.

Specific primary objectives relate to identifying and analyzing trends and technologies in subject material composition, material usages, disposal, reclamation and recycling methods, practices, economics, and suitability and applications for reclaimed products.

As part of all of the above, the effect of current and developing governmental regulations relating to use, safety, health and disposal of products are analyzed.

METHODOLOGY

Specifically our general approach has included:

1. Secondary source literature and data search.
2. Collection of product literature and price lists from suppliers, formulators or blenders, wholesalers, distributors and retailers.
3. Segmentation of markets by product classification and application.
4. Outline of current and competing technologies, as well as governmental regulatory trends pertinent to emulsified industrial oils.
5. Refinement and confirmation of secondary source data and technical data by primary research, such as personal visits and telephone contacts with suppliers, major end users, trade groups and associations, recycling equipment manufacturers, chemical waste disposal groups and state governments.
6. Definition of the dynamics of use of subject industrial lubricant fluids by application, investigation of current and potential products used. Longevity of use, use conditions, maintenance practices, specification control, reclamation, recycling and disposal practices.
7. Estimates of amounts of materials currently available for reclamation, cost and problems with collection, alternate disposal methods.
8. Technology assessments based on contacts with equipment suppliers, commercial processors of chemical and petroleum wastes and major refiners as well as end users who recycle emulsified fluids on a large scale.
9. Establish a base case and demonstrate process economics on same.

SECTION I

BRIEF SURVEY AND ANALYSIS OF THE INDUSTRIAL LUBRICANT MARKET

OVERVIEW

An analysis of the industrial fluid market has been performed for the countries which have made significant contributions in the area of emulsion-type metalworking and/or hydraulic fluids. The expression "fluid" is used in this study as a generic term.

Estimates of current and future consumption of emulsion-type fluids have been provided in order to determine the volume of waste oil which will be generated and project the demand for disposal and recycling technology.

No new technology or significant trends have been found in the United Kingdom, which explains why we have no separate section on this area. The only significant event there is that Ford is evaluating some water-miscible metalworking fluids as well as hydraulics in the hope that these fluids could function in both metalworking and hydraulic applications. These fluids are referred to as "high water-base fluids". Their composition is not known but they are believed to be similar to fluids developed in the United States.

UNITED STATES

Industrial Lubricant Sector

The total 1980 market for automotive and industrial oil was approximately 9.8 billion liters (2.6 billion gallons), with automotive sales contributing 5.3 billion liters (1.4 billion gallons) and industrial sales contributing approximately 4.5 billion liters (1.2 billion gallons) (1).

Emulsified oils (undiluted) contribute a rather small percentage (about 10%) to the 4.5 billion liter (1.2 billion gallon) figure and to the 1.4 billion liter (380 million gallon) figure of used oil generated from industrial sources. The disposition of used industrial oil has been estimated as shown in Table 1.

TABLE 1

Disposition of Used Industrial Oils

	Millions of Liters/Year	Millions of Gallons/Year
To Processors	371	98
To Re-refiners	57	15
To Road Oil	113	30
To Fuel	757	200
	1,298	343
Generated Losses	140	37
	1,438	380

Source: Used Oil Burned as Fuel, Environmental Protection Agency, SW-892, 1980

The amount of used oil generated from metalworking fluids in 1980 (including emulsified fluids) was estimated to be 204 million liters (54 million gallons) and is expected to reach 208 million liters (55 million gallons) by 1985 and 216 million liters (57 million gallons) by 1990, excluding oil which is recovered from waste water treatment processes (1).

Metalworking Fluid Market Segment

Metal working fluids are employed in several major functional areas:

- cutting
- grinding
- rolling
- drawing

The fluids are designated as: straight oils, soluble oils, semi-synthetic or synthetic. The composition, general properties and patterns of use of the different types of fluids are provided in Appendix I.

Straight oils are composed primarily of petroleum, whereas soluble oils contain approximately 70% oil and are made emulsifiable with water by the addition of an emulsifier. Rust inhibitors and bactericides are also incorporated into the soluble oils. The user of the fluid will normally dilute the fluid concentrate with water generally in a 1:20-30 (oil:water) dilution.

Semi-synthetic fluid concentrate contains approximately 10% mineral oil with the remainder of the fluid containing emulsifiers, surface active agents, and bactericides. Synthetic fluids, which contain no oil, are composed mainly of water, rust inhibitors, detergents, lubricating agents and bactericides. As with the semi-synthetic fluid, the synthetic fluid is generally diluted 1:30-40 with water. The fluid longevity may reach five years in some cases, depending on maintenance practices.

Estimated and Projected Consumption of Metal Working Fluids

Total consumption of fluids used in metalworking operations is listed in Tables 2 and 3. These estimates were compiled following a survey of over forty fluid producers. Opinions regarding the percentage of straight oil, soluble oil and synthetic fluids used in metal removal, metal forming, quenching and metal protection varied considerably. When questioned about the percentage of soluble oil, straight oil and synthetic fluids in the entire metalworking area, the fluid suppliers responded:

Soluble oil - 35% to 55% of the total market

Straight oil - 20% to 50% of the total market

Synthetics and Semi-Synthetics - 10% to 20% of the total market

In the cutting and grinding fluid segment, the responses were:

Soluble Oil	-	25% to 80%
Straight Oil	-	10% to 50%
Synthetics and Semi-Synthetics	-	10% to 50%

There was disparity in the estimates of the different respondents concerning the percentage of drawing, stamping and rolling fluids that are emulsified. It has been mentioned that soluble oils are used in operations that are less severe. It appears that only a small amount is employed in wire drawing. Of this small amount of the emulsified fluid used in wire drawing, approximately 90% is used in drawing copper wire and about 10% in drawing brass coated steel wire (2). Most sources contacted state that the bulk of the metal forming area is composed of straight oils. Respondent estimates on the percentage of drawing fluids that are emulsified ranged from 5-50%. Most people consider the stamping oil area to be predominantly straight oil with a few offering estimates as high as 50% soluble oil. Aluminum hot rolling appears to be mostly soluble oil. A large percentage of emulsified fluid is used in the rolling of steel. Respondent estimates on the use of emulsified fluids in rolling ranged from 10-90%. Most sources contacted perceive the metal forming area to be 10-50% of the total metalworking fluid market. Responses on the total usage of emulsified fluids in metal forming operations ranged from 10-60%.

Most sources estimate the present annual growth rate for synthetic fluids to be 10% and project a growth rate of 10-20% for the next 5 to 10 years. This is in comparison with annual growth rate of 1% for the total metalworking fluid market. Employing data obtained from one fluid supplier interviewed, the total metalworking fluid market is projected to be 870 million liters (230 million gallons) in 1985 and 893 million liters (236 million gallons) in 1990 (3).

TABLE 2

Estimated Total Consumption of Metalworking Fluids for 1980 by Use

	Millions of Liters	(Gallons)
Metal Removal (Cutting and Grinding)	492	(130)
Metal Forming (Drawing, Rolling and Stamping)	174	(46)
Quenching	76	(20)
Rust Preventatives	102	(27)
	844	(223)

TABLE 3

Estimated Total Consumption of Metalworking Fluids for 1980 by Type

	Millions of Liters (Gallons)	% of Total
Soluble Oil	378 (100)	45%
Straight Oil	341 (90)	40%
Synthetics and Semi-Synthetics	125 (33)	15%
	844 (223)	100%

Cutting and Grinding Fluids

	Millions of Liters (Gallons)	% of Total
Soluble Oil	310 (82)	63%
Straight Oil	68 (18)	14%
Synthetics and Semi-Synthetics	114 (30)	23%
	492 (130)	100%

Drawing, Rolling, and Stamping Fluids

	Millions of Liters (Gallons)	% of Total
Soluble Oil	57 (15)	33%
Straight Oil	106 (28)	61%
Synthetics and Semi-Synthetics	11 (3)	6%
	174 (46)	100%

Quenching Fluids for 1980

	Millions of Liters (Gallons)	% of Total
Straight Oil	72 (19)	95%
Soluble Oil	4 1	5%
	76 (20)	100%

Rust Preventatives

	Millions of Liters (Gallons)	% of Total
Soluble Oil	8 (2)	7%
Straight Oil	94 (25)	93%
	102 (27)	100%

Hydraulic Fluid Market Segment

Hydraulic fluids are generally classified as fire resistant or non-fire resistant. Fire resistant fluids are selected for use when application temperatures are high and in areas where there is a known fire hazard, i.e., foundries and steel mills (4). This general category is considered to encompass four types of fluid.

1. 40% water/60% mineral oil invert emulsion.
2. Water/glycol fluid.
3. Phosphate ester fluids.
4. High water based fluids which are 95% water and 5% synthetic, or soluble oil (oil-in-water emulsion).

A description of the fire resistant fluids and a discussion of the advantages and disadvantages of the various types are provided in Appendix I.

Table 4 provides data on the estimated and projected comsumption of industrial hydraulic fluids. The industrial hydraulic fluid market is expected to grow 1% annually. Respondent estimates of the percentage of hydraulic fluids that are emulsified ranged from 1-15% with the average being 6-8%.

Estimates of the percentage of the market which is composed of fire resistant fluid varied considerably. Although respondent estimates ranged from 2-25%, the average estimate appears to be 10%. The reason cited for the low estimates is the need for the hydraulic fluid user to redesign his equipment when adopting the fire resistant fluid. Others, who are more optimistic about the growth of fire resistant hydraulic fluid, estimate current usage to be 15-25% and project that 50% of all hydraulic fluids will be water based in 10 years. These sources anticipate that the largest growth will be realized in high water based fluid. Growth would be attributed to increased use in the automotive industry and further efforts to redesign equipment to be used with water based hydraulic fluids.

TABLE 4

Estimated and Projected Consumption of Industrial Hydraulic Fluids
Millions of Liters (Gallons)

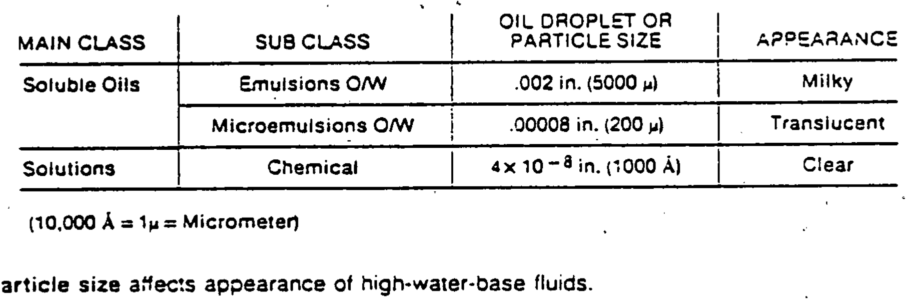
	All Types	Emulsified
1980	893 (236)	76 (20)
1985	939 (248)	87 (23)
1990	985 (260)	125 (33)

It has been suggested that the interest in high water based fluids (HWBF) may be attributed to the fact that they are considered in many instances to be more economical than petroleum products even when fire resistance properties are not essential. In addition, there are a few high water based fluids that are meant to be compatible with metal working fluids, namely the micro emulsions. Table 5 presents the major distinctions between the types of high water based fluids (5).

Projections on the future growth of the high water based fluids (HWBF) vary considerably. It has been projected that the high water based fluids will attain anywhere from 2-40% of the hydraulic fluid market in the next ten years. Despite the variation, there does appear to be a consensus that their future growth is predicated on the continued development of compatible equipment. Although a few sources anticipate that the hydraulic fluid market may be composed of 40% HWBF, most expect the percentage of HWBF to remain below 10% in the next 10 years. Most persons contacted hesitated to project what percentage of the HWBF that the soluble oil type would maintain. Originally HWBF were predominantly the 95% water/5% oil emulsified fluid. More recent developments include the synthetic type and the microemulsion which will compete with the oil-water emulsions.

TABLE 5

Types of High Water Based Fluid (HWBF)



MAIN CLASS	SUB CLASS	OIL DROPLET OR PARTICLE SIZE	APPEARANCE
Soluble Oils	Emulsions O/W	.002 in. (5000 μ)	Milky
	Microemulsions O/W	.00008 in. (200 μ)	Translucent
Solutions	Chemical	4×10^{-8} in. (1000 Å)	Clear

(10,000 Å = 1μ = Micrometer)

Particle size affects appearance of high-water-base fluids.

Source: Mezger, R., Design for High-Water Based Fluid, Sperry-Vickers

Currently more than half of the high water based fluid is emulsified but it is anticipated that the share of synthetics will increase with new developments. Current problems with synthetics include stability and disposal problems.

The bulk of the hydraulic fluid market is composed of non-fire resistant petroleum base fluids which contain antiwear, antioxidant or rust inhibitor type additives. The petroleum base fluids are generally classified as:

- rust and oxidation (R&O)
- antiwear (AW)
- combination or dual purpose

It appears that there is a major impetus toward fluid consolidation with the use of one fluid for R&O and AW applications or the use of a multifunctional fluid. It also appears that with the rising cost of petroleum, the water based fluid will continue to penetrate the market at the expense of the petroleum base fluid.

FRANCE

Production of oils in 1979 amounted to 1,490,383 metric tons. From this amount, about two-thirds were used for various industrial applications.

The distribution pattern of these oils for the years 1977 through 1979 is provided in Table 6. It is believed that the 1980 figures were close to or somewhat below those of 1979.

As can be seen from the tabulation, hydraulics represented 98,950 tons, soluble oils represented 26,965 tons and straight oils (K1) 36,312 tons of the 1979 consumption.

According to Ste. Francaise des Petroles BP (French BP), the following quantities and uses could be identified with some certitude:

- motor oils - 170,000
- hydraulic and transformer oils - 150,000
- cutting and tramp oils - 150,000

TABLE 6

Hydraulic, Soluble and Straight Oils as Used in France

(Tons)

	1975	1976	1977	1978	1979
Hydraulics	72,987	81,395	87,114	92,311	98,950
Straight Oils	29,923	33,787	35,858	36,331	36,312
Soluble Oils	13,728	15,557	21,641	26,879	26,965

Source: ANRED (Agence Nationale pour la Recuperation et l'Elimination des Dechets)

WEST GERMANY

Total Lubricant Market

The total amount of various mineral oils and other lubricating agents consumed in 1980 was 1,205,896 tons in comparison with the 1977 figure of 1,117,844 tons. The detailed consumption of these materials as consumed in 1978 and 1979 is shown in Table 7.

Metalworking Fluids

As can be seen in Table 7, metalworking fluids represented 95,763 tons or 7.9% of the total in 1979.

The German producers of soluble oils believe they are leading in Europe (and eventually in the world), and feel they have full control of the situation as far as bacteriological contamination is concerned.

Two large oil companies, BP and Shell, are the most important suppliers of metalworking fluids. However, Fuchs-Mineraloelwerke GmbH is the most advanced company to supply a broad spectrum of metalworking fluids. Fuchs is also active in the other European companies (and also in the United States).

Fuchs estimates that soluble oil metalworking fluid concentrate production in Western Germany in 1980 was 40,000 tons. Fuchs stated that the share of synthetic metalworking fluids is usually over estimated both in the United States and Germany.

Other non-oil companies quite active in this field are Oemets and Siebert. There are a number of medium sized companies in the business. These companies are characterized by more flexibility than the large ones. For example, BP offers about 10 different metalworking fluids while Oemets offers some 100 different formulations.

TABLE 7

Domestic Consumption - Lubricating Oil and Lubricating Agents - West Germany

(Tons)

		1978	1979
1	Spindle oil	148,278	183,527
2	Machine oil	179,840	208,159
3	Cylinder oil	3,421	4,777
4	Turbine oil	7,796	8,443
5	Motor oil	448,873	446,373
6	Axle and dark oils	20,027	21,695
7	White oil	44,196	51,255
8	Transmission fluid	73,035	79,071
9	Metalworking oil	95,002	95,763
10	Forming oil	15,255	16,121
11	Insulating oil (electrical)	30,334	29,339
12	Lubricating grease	25,094	29,338
13	Extracts from lubricating oil refining	50,000	32,035
Total		1,141,151	1,205,896

Source: Verband der Schmierfettindustrie

Specialized in high-pressure metalworking fluids is Becker in Hamburg while Schulke & Mayr in Hamburg is specialized in highly rust-inhibiting metalworking fluids.

Hydraulic Fluids

Hydraulic fluids used in Western Germany are straight oils. Water-based hydraulic fluids experience minimal use in this country as the Germans feel that the testing required for such fluids to establish if the pump in question and the packings can tolerate such a fluid is bothersome. Nevertheless, Ford in Europe, including Ford-Cologne, has a group which has water-miscible hydraulic fluids under evaluation.

ITALY

With the continuous industrialization and urban development, Italy has reached in 1979 a yearly consumption of 630,000 tons of lubricating oils alone. Utilization of the oils are largely in the automotive field. Table 8 shows the distribution of these oils.

TABLE 8
Domestic Market - Italy

Type of Oil	Consumption (Tons/Year)
Motor Oil	378,000
Transformers	30,000
Turbines	12,000
Hydraulic Oil	46,000
Soluble Cutting of Metals	29,000
Nonsoluble Cutting of Metals and Hardening	35,000
Spindles, Greases, Cylinders, Black Oils, Die and Mould Stripping, Various Protective Agents	100,000
TOTAL	630,000

Source: Gruppo Aziende indipendenti Lubrificanti dell'Associazione Nationale dell'Industria Chimica.

Since only 220,000 tons of the 630,000 tons of oils could be accounted for, it is assumed that the remaining 410,000 tons were discharged into the natural environment.

Of the 630,000 tons of oils used in Italy in 1979, 64,000 tons were used as metalworking fluids. In Italy, straight oils still represent a very significant portion of the metalworking fluids business. In 1979, approximately 54% of the metalworking fluids were straight oils and 46% were emulsion-type. Expressed in tons this means that 35,000 tons used in 1979 were straight oils and 29,000 tons belonged to the emulsion or soluble-oil types.

JAPAN

Production Statistics

Production statistics during the period 1975 through 1979 are shown in Table 9.

TABLE 9

Production Statistics - Japan

(Millions of Liters)

	1975	1976	1977	1978	1979
Cutting Oil	67.0	73.9	75.1	76.8	88.0
Heat Treatment Oil	15.7	18.4	18.4	19.8	21.0
Plastics Oil	28.4	33.3	35.0	36.4	35.0
Rust Prevention Oil	18.3	18.5	18.9	17.9	19.0
Washing Oil	6.0	6.4	5.5	5.0	6.0
Cement Release Oil	7.6	8.2	9.2	10.3	11.0

Source: All Japan Metalworking Oil Trade Association

Emulsified Oils

The ratio between emulsified oils and straight oils as used for metalworking fluids is about 40/60 in favor of straight oils. The share of emulsified oils, however, is increasing, and experts predict a 50/50 split in the industry will arrive not before too long.

According to industry sources, the emulsified oil portions of the industrial oils and lubricants business in recent years were as follows:

TABLE 10

Emulsified Industrial Oils and Lubricants
(Millions of Liters)

	1978	1979
Cutting Oil	19.4	30.8
Heat Treatment Oil	0.9	1.1
Rolling Oil	18.2	21.0
Rust Prevention Oil	1.6	2.0
Washing Oil	4.6	5.4
Hydraulic Fluid	9.0	10.0

Source: All Japan Metalworking Oil Trade Association

Currently, the Japan Industrial Standards (JIS) Association recognizes two types of these materials:

W-1 Type - "Emulsion Type"
The main ingredients in these are mineral oils and surface-active agent(s). When this type of product is diluted with water, the solution becomes opaque (milky). The dilution used in this case is 10 to 30 times.

W-2 Type - "Soluble Type"
The main ingredients are surface-active agents and when diluted with water, the solution becomes transparent or translucent. Dilution ratios used are 50 to 150 times.

These specifications are spelled out by JIS K2241-1980. JIS abolished the use of W-3 products, which they referred to as "chemical solutions" because of the suspected nitrosamine problem.

The general compositions of W-1 and W-2 Types products are as follows:

TABLE 11
Composition of Water-Based Industrial Fluids

	W-1 Type	W-2 Type
Mineral oil	50 - 80%	0 - 30%
Fat and fatty acid	0 - 30	5 - 30
High pressure additive	0 - 30	0 - 20
Surface-active agent	15 - 35	5 - 20
Alkanolamine and inorganic alkaline	0 - 5	10 - 40
Organic inhibitor	0 - 5	5 - 10
Inorganic inhibitor	-	0 - 10
Preservative	2 or less	2 or less
Non-farrous metal corrosion inhibitor	1 or less	1 or less
Anti-foam	1 or less	1 or less
Water	0 - 10	5 - 40

It is difficult to quantify the emulsified hydraulic fluids since hydraulic fluids are classified under medium grade lubricants and no detailed breakdown is published by the Petroleum Industry Association.

It is estimated that not more than 10% of the hydraulic fluid production represent emulsified oils. This would come to about 10 million liters (2.6 million gallons).

There are about 40 manufacturers in Japan who supply emulsified industrial oils and lubricants. The two leading suppliers are Yushiro Industry and Nikko Sangyo.

Research and development have been conducted by major lubricant manufacturers for a new emulsified fluid good for both cutting oil and hydraulic fluid. We understand that automobile industries are very keen on the development of this type of new working fluid. According to the technical staff of Nikko Sangyo Co., Ltd., a semi-commercial product has been delivered and is being tested by a certain car manufacturer. Currently about 12,000 tons of the new working fluids is produced in Japan.

SECTION II

ANALYSIS OF U.S. REGULATORY DEVELOPMENTS

REGULATION OF WASTE OIL

Selection of specific disposal, recycling and reclamation techniques is influenced greatly by environmental regulations which have been promulgated in the United States. This section of the report will examine the regulations which directly impact upon waste oil disposal along with those regulations governing the treatment of wastewater containing oily wastes and specific regulations which pertain to certain substances found in metalworking fluids either in the formulation or through contamination. Emulsified fluids may contain certain additives such as sodium nitrite, ethanolamines and phenol which are usually less than 10% of the total formulation. In addition, contamination with PCBs is a possible occurrence.

Resource Conservation and Recovery Act (RCRA)

Waste oils may become subject to regulations promulgated under the Resource Conservation and Recovery Act. Briefly, the Resource Conservation and Recovery Act provides:

1. A definition of hazardous waste.
2. Manifest system to trace hazardous waste from generation to disposal.
3. Standards for generators and transporters.
4. Permits for facilities that treat, store, or dispose of hazardous waste.
5. Requirements for state hazardous waste programs.

The major provisions of RCRA by section are as follows:(6)

Section 3001:	Generators, transporters, disposers, treaters and storers must determine if the waste is hazardous.
Section 3002:	Generators must adhere to EPA identification number requirements, DOT packaging and labeling regulations and manifest protocol. A generator who holds hazardous waste for more than 90 days must conform to regulations for storage facilities.
Section 3003:	Transporters of hazardous waste must adhere to EPA identification number requirements, DOT packaging, labeling, and transporting regulations and manifest requirements. In addition, the transporter is responsible for cleaning up a discharge, notifying authorities and preventing environmental or health damage.

Section 3004:	Treatment, storage and disposal facilities must adhere to EPA identification number requirements, facility standards, manifest system regulations, and closure and post-closure standards.
Section 3005:	Treatment, storage and disposal facilities must have filed for Part A permit applications for interim status operations by November 19, 1980.
Section 3006:	State programs.
Section 3111:	This section governs the notification process for obtaining EPA identification numbers. The filing deadline was August 19, 1980 for generators, transporters; and treatment, storage and disposal facilities. New notices must be filed 90 days after new 3001 regulations are promulgated.

According to the regulations issued May 19, 1980, a waste is considered hazardous if it is included in the list of 85 waste streams or 416 chemicals listed as hazardous under Subpart D or if it is ignitable, corrosive, reactive or toxic. The regulations specify which wastes are considered to be acutely hazardous. There are presently no process wastes classified as acutely hazardous.

The regulations include a listing entitled, Appendix VIII, which is a compilation of chemicals that have been shown to have toxic, carcinogenic, mutagenic or teratogenic effects on humans or other life forms. EPA has data on each constituent listed in Appendix VIII. In compiling the hazardous waste list, EPA utilizes Appendix VIII but also weighs such factors as:

- the toxicity of the constituents
- bioaccumulation
- persistence or degradability
- migration from waste
- the amount of waste generated
- actions taken by other regulatory agencies

It is the responsibility of EPA to determine if a constituent in Appendix VIII of Subpart D should be treated as a hazardous waste. However, it is the responsibility of the generator to determine if a waste has one of the characteristics of ignitability, corrosivity, reactivity or toxicity.

To assist in determining if a waste which may be generated in the waste treatment of oily waste, recycling of waste oil or the use of the fluids in metal finishing and other industries is hazardous, Part 261.31, 261.32 and 261.33 (f) of the regulations should be examined. The background document entitled, Listing of Hazardous Wastes (Section 3001, Part 261.31 and Part 261.32 (#1941.28), provides detailed information on the substances listed and the reasons for listing the waste under Subpart D of the RCRA regulations.

It was mandatory for anyone who transports, treats, stores or disposes of hazardous waste to have notified EPA before August 10, 1980.

The hazardous waste program became effective on November 19, 1980. It is estimated that the May 19 regulations apply to 67,000 facilities although there are most likely 750,000 facilities that produce hazardous waste. Facilities are exempted which generate or accumulate for disposal the following quantities of hazardous waste. (7)

1. Less than 1,000 kg/month of hazardous waste listed in 261.33 (f) or listed as hazardous waste from a process source.
2. Less than 1 kg/month of the acutely hazardous waste listed in 261.33 (e).
3. Less than 1 kg/month of a chemical which would have a generic name listed in 261.33 (e).
4. Any containers that have held wastes listed in 261.33 (e) that is 20 liters or less or that has been triple-rinsed. The container, that is triple-rinsed, must have been rinsed three times with a solvent capable of removing the waste. The solvent volume for each rinse must be equivalent to 10% of the volume of the container and must be later handled as a hazardous waste. Decontamination of containers is addressed in Section 261.33 (c) (2) of the regulations.
5. Less than 10 kilograms of inner liners from these containers.
6. Less than 100 kg/month of any residue or contaminated soil, water or other debris resulting from cleanup of a spill or into or on any land or water, of any commercial chemical product or manufacturing chemical intermediate having the generic name listed in 261.33 (e).

EPA is expected to phase-in rulemaking to cover small generators down to those generating more than 100 kg/month of hazardous waste within 2 to 5 years (7).

It is estimated that the current exclusions exempt 91% of the generators but exclude only 1% of the waste. Approximately 760,000 generators produce over 60 million tons of hazardous waste per year and of that total figure, 695,000 generators produce less than 1,000 kg/month equivalent to 0.23% of the total hazardous waste produced per year. (7)

The Used Oil Recycling Act of 1980 amended RCRA to encourage the use of recycled oil. The bill provided that labeling requirements be based on performance characteristics, not upon the origin of the oil. EPA was directed to evaluate whether or not to classify waste oil as a toxic waste under RCRA and to perform an economic impact analysis when developing reuse standards for oil.(8) The agency has stated its intent to regulate waste oil as a hazardous waste and is expected to publish proposed regulations in December (9). At a later date, the agency will submit the results of a used oil study discussing such considerations as energy and the environment as it is impacted by improper disposal and reuse of used oil.

Subcommittees of the House Interstate and Foreign Commerce Committee were responsible for reviewing a waste oil recycling bill to encourage the use of recycled oil. According to estimates from the Chairmen of Transportation and Energy Subcommittees, re-refining of all used lubricating oils would conserve 42,000 barrels of oil/day, equivalent to the energy from one nuclear plant (10). It is estimated that approximately 1.89 billion liters (0.5 billion gallons/year) of used oil is disposed of improperly.

The basis for listing waste oil as a hazardous waste rests on such concerns as the presence of PCBs and other toxic wastes in the oil, the possibility that the oil will enter surface and groundwater, and the release of toxic metals, i.e. lead and cadmium, when waste oil is burned.

REGULATION OF OILY WASTEWATER

Oily wastes originate primarily from operations which require coolants and lubricants. In addition, other fluids may be contaminated with these oils when residues from the fluids are removed in cleaning operations. Water used for washing filters, pumps and tanks may be contaminated with oil residues. Data from the EPA draft report on the Metal Finishing Point Source Category, including machinery and mechanical products manufacturing, reveal that in 12.4% of the plants surveyed, oily wastewater from machine sumps and process tanks is segregated from other wastewaters until treatment by an oily waste removal system. The total wastewater from the plant was on the average 6.6% oily wastes (11).

Section 304 (b) of the Federal Water Pollution Control act requres EPA to promulgate regulations providing guidelines for effluent limitations prescribing the degree of effluent reduction attainable through the application of best practicable control technology (BPT) and the best available technology (BAT). Pretreatment standards which prevent the discharge of interfering pollutants into publicly owned treatment works and pretreatment standards which would apply to new sources if they are to discharge pollutants into navigable waters are prescribed in Section 307.

The machinery and mechanical products manufacturing category was one of 21 point source categories that were addressed in the 1976 consent agreement in Natural Resources Defense Council et al v. Train. The Consent Degree expanded the Section 307 Toxic Pollutants List to include 65 priority pollutants and classes of pollutants (see Table 12). EPA was required to develop a schedule for promulgating BAT effluent limitations guidelines, pretreatment standards, and new source performance standards for the 21 point source categories for these priority pollutants. The three categories of pollutants are discussed in Table 13.

REGULATIONS AND NITROSAMINES

Introduction

Industrial fluids were initially selected for intensive study by the regulatory agencies because of the presence of diethanolnitrosamine. Contamination with diethanolnitrosamine may be attributed to the presence of diethanolamine and nitrite in the fluids. Contamination with nitrosamines may occur:

1. During the manufacturing process.
2. In the storage container, especially when the container is metal and nitrite is used as a corrosion inhibitor.
3. When amine reagents are contaminated with N-nitroso compounds (12).

TABLE 12

SECTION 307 - TOXIC POLLUTANTS

Acenaphthene

Acrolein
Acrylonitrile
Aldrin/Dieldrin
Antimony and compounds*
Arsenic and compounds
Asbestos
Benzene
Benzidine
Beryllium and compounds
Cadmium and compounds
Carbon tetrachloride
Chlordane (technical mixture and metabolites)
Chlorinated benzenes (other than dichlorobenzenes)
Chlorinated ethanes (including 1,2-dichloroethane, 1,1,1-trichloroethane, and hexachloroethane)
Chloroalkyl ethers (chloromethyl, chloroethyl, and mixed ethers)

Chlorinated naphthalene
Chlorinated phenols (other than those listed elsewhere: includes trichlorophenols and chlorinated cresols)
Chloroform
2-chlorophenol
Chromium and compounds
Copper and compounds
Cyanides
DDT and metabolites
Dichlorobenzenes (1,2-1,3- and 1,4-dichlorobenzenes)
Dichlorobenzidine
Dichloroethylenes (1,1-and 1,2-dichloroethylene)
2,4-dichlorophenol
Dichloropropane and dichloropropene
2,4-dimethylphenol
Dinitrotoluene
Diphenylhydrazine
Endosulfan and metabolites
Endrin and metabolites
Ethylbenzene
Fluoranthene
Haloethers (other than those listed elsewhere; includes chlorophenylphenyl ethers, bromophenylphenyl ether, bis (dischloroisopropyl) ether, bis-(chloroethoxy) methane and polychlorinated diphenyl ethers)
Halomethanes (other than those listed elsewhere; includes methylene chloride methylchloride, methylbromide, bromoform, dichlorobromomethane, dichlorodifluoromethane)
Heptachlor and metabolites
Hexachlorobutadiene

Hexachlorocyclohexane (all isomers)
Hexachlorocyclopentadiene
Isophorone
Lead and compounds
Mercury and compounds
Naphthalene
Nickel and compounds
Nitrobenzene
Nitrophenols (including 2,4-dinitrophenol, dinitrocresol)
Nitrosamines
Pentachlorophenol
Phenol
Phthalate esters
Polychlorinated biphenyls (PBCs)
Polynuclear aromatic hydrocarbons (including benzanthracenes, benzopyrenes, benzofluoranthene, chrysenes, dibenzanthracenes, and indenopyrenes)
Selenium and compound
Silver and compounds
2,3,7,8- Tetrachlorodibenzo-p-dioxin (TCDD)
Tetrachloroethylene
Thallium and compounds
Toluene
Toxaphene
Trichloroethylene
Vinyl chloride
Zinc and compounds

Source: Code of Federal Regulations, Title 40, Part 401

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*The term "compounds" shall include organic and inorganic compounds

TABLE 13

Federal Water Pollution Control Program

Category of Pollutant	Deadline for Achieving	Technology Required	Legal Authority
Toxic Pollutants	July 1, 1984	Best Available Technology (BAT)	Sections 301(b) (2)(A) and 301 (b)(2)(C) FWPCA
Non-Toxic Pollutants	July 1, 1984	Best Conventional Pollution Control Technology (BCT)	Section 304 (a) (4)
Non-Toxic Non-Conventional	July 1, 1984 Three years after their establishment (whichever is later but no later than July 1, 1987 under any circumstances)	Best Available Technology (BAT	Section 301 (b) (2)(A)

Source: Development Document for Effluent Limitations Guidelines and Standards for the Metal Finishing Point Source Category "Effluent Guidelines Division, EPA 440-1-80-091-A, June 1980.

Data confirming the carcinogenicity of diethanolnitrosamine initiated concern over the possible contamination of drinking water with the substance.

Concern has arisen that many of the toxic components of industrial fluids found in oily waste may cause adverse effects to health and the environment. For example, the toxicity to the marine environment is a result of PCBs and phosphates from wastewater (13). The presence of chromates, copper, nickel, lead, zinc, PCBs, and phenols may result in their contamination of drinking water or soil used for agricultural purposes (13).

Current and Proposed Regulations

The Interagency Regulatory Liaison Group (IRLG) represents the Consumer Product Safety Commission (CPSC), the Environmental Protection Agency (EPA), the Food and Drug Administration (FDA), Food Safety and Quality Service (FSQS), and the Occupational Safety and Health Administration (OSHA). According to the 1980 IRLG report, nitrosamines were one of twenty-seven substances which were of concern to two or more of the IRLG agencies. Nitrosamines are being examined by a special task group to ensure that agency regulatory development plans are coordinated (14).

FDA is currently attempting to eliminate nitrosamines in food by means of a monitoring program. Monitoring efforts have included beer, whiskey, bacon and cosmetics (15).

FDA Decision on Nitrites

On August 19, 1980, FDA and the Department of Agriculture announced that a ban on nitrite preservatives would not be initiated at the present time. The decision was based on a report from a review of the 1978 study which originally found nitrites to be carcinogenic. It was the consensus of the pathologists reviewing the study that this was not the case (15).

The National Institute for Occupational Safety and Health (NIOSH) commissioned Borriston Labs of Temple Hills, MD to do a mouse skin painting to determine the carcinogenic effects of nitrosamines in synthetic water soluble cutting fluids. The study was contracted as an 18 month study but was extended because of good animal survival (16). The study is in its final stages and a final report is expected in 4-6 months. A previous study of nitrosamines in hydraulic fluid by Union Carbide at Carnegie-Mellon Institute showed an increase in liver tumors in laboratory animals.

REGULATIONS AFFECTING PHENOLIC COMPOUNDS

Phenol and phenolic compounds are classified as Section 307 Toxic Pollutants under the Federal Water Pollution Control Act. Under a 1976 Consent Decree, EPA must promulgate regulations prescribing effluent guideline limitations for 21 point source categories.

In 40 CFR 116-117, the hazardous substances under Section 311 (b) (2) (A) of the Federal Water Pollution Control Act are listed. Phenol and a few phenolic compounds are included in the list (17).

RCRA regulations promulgated on May 19, 1980 list phenol and other phenolic compounds as hazardous wastes. Appendix III of RCRA regulations specifies the appropriate analytical procedures for determining the presence of several of the phenolic compounds.

The Occupational Safety and Health Administration (OSHA) has promulgated the following permissible exposure limit for phenol (18):

Phenol - skin	5 ppm (19 mg/m^3)

REGULATIONS AFFECTING POLYCHLORINATED BIPHENYLS (PCBs)

Introduction

PCBs are recognized as being highly toxic and persistent in nature. PCBs are known to cause health disorders such as skin, digestive and respiratory disorders and have been implicated in reproductive failures in animals.

Environmental Protection Agency (EPA)

Dielectric fluid, hydraulic fluids, paints, sludges, and other materials contaminated as a result of spills often contain PCBs.

Section 6 (e) 1 of the Toxic Substances Control Act (TSCA) enjoins any person from manufacturing, distributing or using PCBs except in an enclosed manner (19). The regulations govern the manufacturing, storage, disposal and marking of PCBs. Decontamination of PCB containers is addressed in Annex IV of the regulations. In addition, the regulations describe the requirements which storage facilities must maintain (19).

Disposal of PCBs by incineration must be in compliance with Annex I of the regulations. Approval to operate an incinerator must be granted by the Regional Administrator. If the Regional Administrator determines the need for a trial burn, a plan must be submitted which details:

- quantity and type of PCBs to be burned.
- date of planned burn.
- methods and schedule of sample analysis.
- location of sampling points and monitoring parameters.
- experts will review the results (19).

Destruction of PCBs in dielectric fluid may be accomplished with a high efficiency boiler according to the prescribed regulations. Chemical waste landfills used for the disposal of PCBs must meet specifications described in Annex II of the regulations (19). To date, there are nine facilities that have been approved by EPA for the disposal of PCBs (19).

The U.S. Court of Appeals for the District of Columbia Circuit upheld the challenge brought by the Environmental Defense Fund against certain parts of the EPA regulations of PCBs, such as the exclusion of PCBs in concentrations below 50 ppm. On February 20, 1981, a joint motion with the court was filed by EPA and EDF which requested an 18 month stay of the court's mandate. During this time, EPA would seek comments and information relating to the risk involved in the manufacture, processing, distribution in commerce and use of PCBs in low concentrations and the possible exclusion of closed manufacturing processes and processes from which PCBs are released only as waste products. EPA will later advise the court of its plans for regulatory action. (20)

PCBs are listed under EPA toxic pollutant effluent standards under the authority of Section 311 (b) (2) (A) (21).

1. All discharges of process wastes.
2. All discharges from the manufacturing incineration areas, loading, storage areas and other areas subject to contamination by PCBs and including stormwater and cleanup water.

PCBs are prohibited in any discharge from any PCB manufacturer, electrical transformer manufacturer, or electrical capacitor manufacturer. Whenever the PCBs in the effluent are a result of PCBs in its intake waters form the same body of water into which the effluent is discharged, the facility may apply for special consideration to the Regional Administrator.

EPA intends to incorporate the PCB regulations issued under TSCA into the regulations promulgated under RCRA. PCBs will remain under TSCA regulations until EPA has completed the integration of the two programs.

REGULATIONS COVERING BACTERICIDES

EPA is responsible for issuing registration numbers for bactericides used in particular applications including metalworking fluids. Biocides in cutting fluids are regulated under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) of 1972 (22). Manufacturers are required to register the product with EPA, in accordance with regulations promulgated under FIFRA. Registration of a preservative is based largely on the substance's oral LD50 in rats. The manufacturer is required to submit chemical information on the product, labeling information, microbiological data supporting the product's effectiveness and toxicological data supporting the product's safety. Toxicological testing requirements usually include oral toxicity in rats and rabbit skin and eye irritation. In addition, greater emphasis is being placed on fish toxicity and bio-accumulaton studies along with toxicological testing, such as acute and subacute dermal toxicity testing in rabbits, determatological testing in humans and inhalation toxicity studies in guinea pigs (22).

SECTION III

REGULATORY DEVELOPMENTS OF FOREIGN COUNTRIES

FRANCE

The collection and regeneration (re-refining) of used oils in France is regulated by a law dated from 1979 and is a result of a decree issued on November 21, 1979. According to this decree the disposal of used oils must be done by one of two methods:

- through collection by an authorized collecting agency, or
- proper chemical treatment.

The government released a list of authorized companies (May 21, 1980) who are approved to collect used oils. The minimum quantity of oil which is collected is 200 liters.

The French government is encouraging the reuse of oils and has a program to support this. As a result, the petroleum companies are obliged to pay a special tax to the government to support this program. This tax in 1979 was 40 French francs (approximately $10) per ton of virgin oil, but was reduced in 1980 to FF 20. The tax is paid to ANRED, the government agency involved in conservation.

The French authorities view metalworking fluids in emulsion form as a serious pollution problem and estimate that a used emulsion (at the usual working concentration) represents an approximate chemical oxygen demand (COD) value of 400,000 mg/liter (compared to a treated sewer water of 100 mg. maximum). For this reason, used metalworking emulsions must be treated before disposal. The used emulsions as they come from the plants contain about 30 to 60 grams of oil per liter, in addition to other pollutants. For these reasons, the emulsions must be treated before disposal to reach a hydrocarbon content not higher than 20 mg/liter. This is clearly spelled out by a government notice of June 6, 1953.

WEST GERMANY

Metalworking fluids in Western Germany are used mainly in the automotive and machine building industries. Many of these manufacturing plants are located in Baden-Wurttemberg where local government regulations impose a control ("Eigen-kont- roll-Verordnung") on the user of the metalworking fluids.

In Western Germany, there are a number of federal government regulations which deal with the collection and recycling of oils. According to the law, "used oils" are fluid or semifluid materials which consist fully or partially of mineral oils. Soluble oils (emulsions) are also covered by this classification.

A fund was established in 1979 by the government ("Ruckstellungsfonds") with the purpose of supporting programs which deal with the collection of oils to reduce environmental pollution. The government has the right to determine the amount of foreign materials in the used oil and weigh the amounts of used oils to be collected. The minimum amount of oil collected is 200 liters, while amounts less than 200 liters must be kept for future collection. The collection of the oil is at no expense to the person or company which generated it.

Oil containing muds originating from certain processes (like metalworking) are under the control of disposal regulations. By disclosing the composition and eventual pretreatment of these materials, permission can be obtained to dispose of these materials or to incinerate. In many cases (depending on the state regulations in question), the material must be hauled to special disposal places.

As to the disposal of water originated from emulsions, a sample of the waste water must be submitted to the authorities for tests. The waste water can be disposed of only after testing and provided the authorities permit the disposal of the water after testing.

ITALY

In Italy, a law in existence since 1940 makes the collection of used oils compulsory. This law is still in force and establishes the compulsory collection of used oils by the civil and military administrations, public bodies, industrial organizations, transport undertakings, workshops, garages, and service stations, all of whom are obliged to relinquish the product to the re-refining industry. In accordance with a law passed in 1962 which favors the re-refining industry, a tax benefit is granted on the base oils produced.

There are twelve re-refining organizations at present operating in Italy. Nine plants are located in the north (six in Lombardy alone), two in the center and one in the south.

The processing licenses issued amount in aggregate to 212,400 tons per year, of which 164,400 are thus distributed among the companies belonging to the "Group of Independent Lubricants Firms" of the National Association of the Chemical Industry. See Table 14.

TABLE 14

Re-Refining Organizations - Italy

COMPANY (NORTH ITALY		TONS
Clipper Oil Italiana -	Ceccano (FR)	35,000
ICEP -	Dresani (MI)	20,000
OMA -	Rivalta di Torino (TO)	7,000
RA.M. Oil -	Casalnuovo di Napoli (NA)	15,000
RIVOL -	Spessa Po (PV)	15,000
RONDINE -	Pero (MI)	12,000
R.O.M.A. -	Milano	21,400
S.I.R.O. -	Corbetta (MI)	9,000
VISCOLUBE -	Pieve Fissiraga (MI)	30,000

JAPAN

Water Pollution Prevention Act is the very act which governs the disposed emulsified and soluble metalworking fluids. Effluent standards for disposal are shown in Table 15.

TABLE 15
Japanese Effluent Standards

A. Noxious Materials

Noxious Materials	Allowable Limit
- Cadmium and its compounds	0.1mg of Cd per liter
- Cyanogen compounds	1 mg of CN per liter
- Organophosphorus compounds, but limiting to parathion, methyl parathion, methyl dimethon and EPN	1 mg per liter
- Lead and its compounds	1 mg of lead per liter
- Hexavalent chromium compounds	0.5mg per liter
- Arsenic and compounds	0.5mg of arsenic per liter
- Mercury, alkyl mercury and other mercury compounds	0.005mg of mercury per liter
- Alkyl mercury compounds	not detected
- PCB	0.003mg per liter

Table 15 (continued -2)

b. Conditions of Polluted Effluent

Polluted Effluent	Allowable Limit
- pH	5.8-8.6 or less for that damped out to public water other than ocean. 5.0-9.0 or less for that damped out to ocean.
- Biochemical Oxygen demand (BOD)	160mg/liter (daily average 120mg/liter)
- Chemical Oxygen demand	160mg/liter (daily average 120 mg/liter)
- Suspended matter	200 mg/liter
- N-hexane extraction content	mineral oil - 5mg/liter vegetable oil - 30mg/liter
- Phenolic content	5mg/liter
- Copper content	3mg/liter
- Zinc content	5mg/liter
- Dissolved iron content	10 mg/liter
- Dissolved manganese content	10 mg/liter
- Chromium content	2 mg/liter
- Fluorine content	15 mg/liter
- No of Colony - colon bacteria	daily average 3,000/1 cm^3

SECTION IV

DISPOSAL AND RECLAMATION OF EMULSIFIED INDUSTRIAL OILS IN THE UNITED STATES

Review Of Disposal Techniques

The disposal, recycling and reclamation of emulsified industrial oils should not be approached as three isolated issues, since all three are heavily influenced by environmental regulations. The current practice of separating water from oil and other contaminants is performed in order to meet regulations governing the discharge of water into the environment. Wastewater discharge criteria limit the concentration of oil discharged to a surface stream to 5 - 15 mg/l providing that the oil is not floating or visible.

Since emulsified industrial oils used in metalworking typically contain less than 10% oil, it is not economical to separate the oil from the water and other additives in metalworking fluids in order to reuse the oil. For this reason, many machining operations extend the life of the metalworking fluid for as long as possible. Although extension of the life of emulsified metalworking fluids through maintenance procedures will save on costs of fluid, these costs are relatively small compared to the costs associated with disposal of the fluid.

Consequently, when the metalworking fluid becomes spent and is no longer useable, owners of machining operations must pay a contractor to have the spent fluid hauled away. In some cases, where the volume of spent fluids generated is small, the cost to have a contractor haul away metalworking fluid as it becomes spent is exorbitant. In these cases, typically small machining operations, the spent fluids are temporarily stored in tanks or lagoons. The spent fluids are then hauled away on an intermittent basis, with storage costs adding to disposal costs. Less scrupulous firms simply dump the spent fluids down the drain.

In many operations, the spent emulsified fluid becomes incorporated into oily wastewater, either intentionally or unintentionally. When the volume of oily wastewater generated exceeds about 200 gallons per day, it becomes economical for the machining operation to maintain its own wastewater treatment plant rather than pay a contractor to haul away the oily wastewater.

In a wastewater treatment plant the following techniques are employed:(11)

- skimming
- coalescing
- emulsion breaking
- flotation
- centrifugation
- ultrafiltration
- reverse osmosis
- carbon adsorption
- aerobic decomposition

The discussion of these techniques will be further elaborated upon in this section. An overview of the different oil removal processes is shown in Table 16. The separation rate of oil from water is dependent on such factors as dispersed droplet size, viscosity, and the presence of surface-active agents. For example, minute droplets resist settling and require a longer settling time. This may be remedied by the process of coalescence. The presence of surface-active agents will interfere with the coalescing process in one of three ways.(23)

1) The surfactant adsorbs at the oil-water interface and its lipophilic portion prevents oil coalescence.
2) An ionic surfactant will form a negatively charged surface around the droplet causing an electrostatic repulsive force.
3) The surfactant forms a coalescence barrier due to the dense packing at the interface.

Treatment may consist of a chemical means to either overcome the effects of the surfactant and allowing coalescence or by a chemical means to cause droplet flocculation. When an ionic surfactant is responsible, an oppositely charged ion will neutralize its charge.(23)

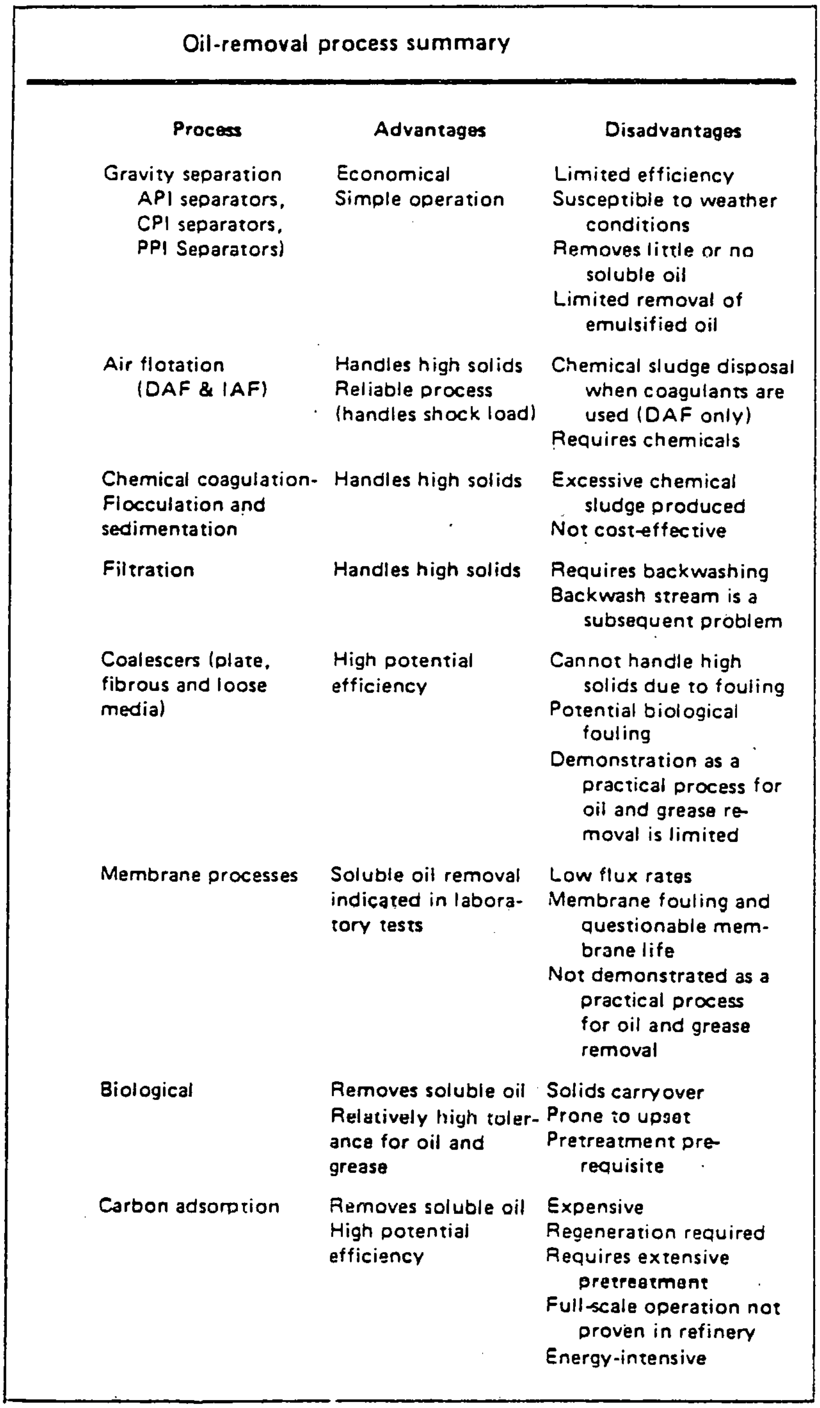
Initially, the collective use of these treatment techniques will be explored, followed by an individual discussion of each of the methods employed. Treatment generally consists of separation and skimming to remove free floating oil, followed by chemical emulsion breaking and dissolved air flotation.

In Figure 1, a process flow diagram of a waste treatment plant using the acid alum procedure is shown. As the diagram indicates, the oily waste is first placed in a holding tank where free oil that floats to the top is skimmed off. In most plants, sulfuric acid is introduced to lower the pH into the 2-4 range in order to facilitate in breaking out free oil. The skimmed free oil can be hauled away, incinerated as boiler fuel, or rerefined. The price reclaimers will pay for the oil varies depending on its quality.

After the free oil has been skimmed, the oily waste is put into a mix tank where alum (aluminum sulfate) is added as primary coagulant. Next, lime or caustic soda is added, raising the pH into the 6-8 range in order to form insoluble aluminum hydroxide. The aluminum hydroxide adsorbs the destabilized oil droplets onto the floc surface. Finally, the mixture is entered into a dissolved - air flotation unit (DAF unit), where the oil that is tied up in a floc is readily floated and separated from the wastewater. The wastewater from the DAF unit need only be clarified before being able to be discharged and the skimmed oil sludge from the DAF unit and the skimmed free oil from the holding tank can be further treated or disposed of in several ways.

Table 16

Oil Removal Processes



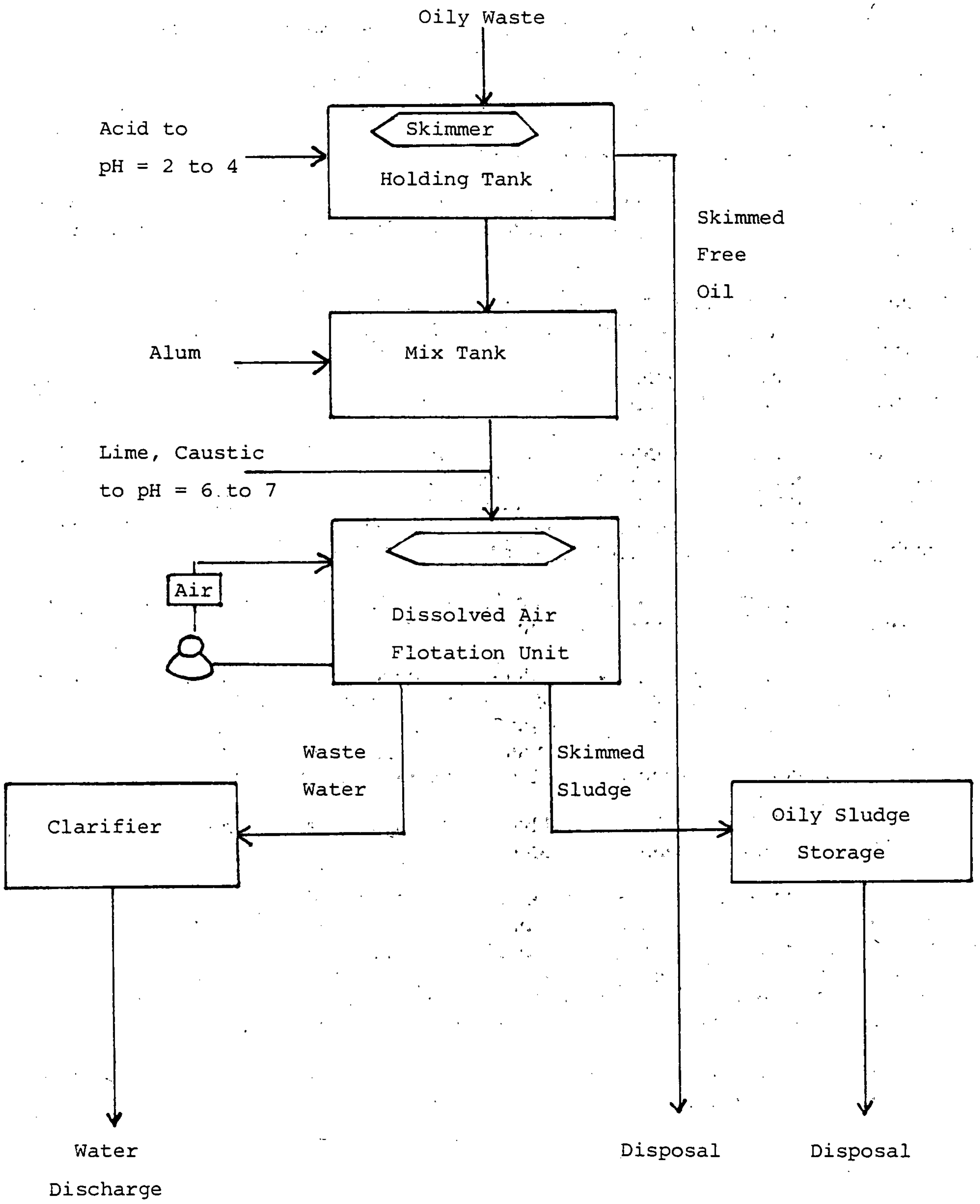
Oil-removal process summary

Process	Advantages	Disadvantages
Gravity separation API separators, CPI separators, PPI Separators)	Economical Simple operation	Limited efficiency Susceptible to weather conditions Removes little or no soluble oil Limited removal of emulsified oil
Air flotation (DAF & IAF)	Handles high solids Reliable process (handles shock load)	Chemical sludge disposal when coagulants are used (DAF only) Requires chemicals
Chemical coagulation-Flocculation and sedimentation	Handles high solids	Excessive chemical sludge produced Not cost-effective
Filtration	Handles high solids	Requires backwashing Backwash stream is a subsequent problem
Coalescers (plate, fibrous and loose media)	High potential efficiency	Cannot handle high solids due to fouling Potential biological fouling Demonstration as a practical process for oil and grease removal is limited
Membrane processes	Soluble oil removal indicated in laboratory tests	Low flux rates Membrane fouling and questionable membrane life Not demonstrated as a practical process for oil and grease removal
Biological	Removes soluble oil Relatively high tolerance for oil and grease	Solids carryover Prone to upset Pretreatment prerequisite
Carbon adsorption	Removes soluble oil High potential efficiency	Expensive Regeneration required Requires extensive pretreatment Full-scale operation not proven in refinery Energy-intensive

Source: Ford, D., and Elton, R., Removal of Oil and Grease from Industrial Wastewaters, Chemical Engineering, October 12, 1977

Figure 1

Acid - Alum Procedure



The acid - alum approach works quite well but has several disadvantages:

1) Oily wastewater is normally alkaline so that reducing the pH to the 2-4 range requires large quantities of acid.
2) Acid corrosion and handling problems are quite prevalent.
3) The pH must be adjusted upward with lime or caustic soda to form a floc which increases costs and generates sludge.
4) High alum feedrates create large volumes of sludge for disposal.

In order to combat these disadvantages, a polymer - alum approach is often used. Figure 2 depicts a flow diagram of this procedure, which is similar to the acid -alum procedure.

Cationic polymers are much more efficient than alum for charge neutralization due to their high charge density along the molecule. Furthermore, polymers function much more effectively over a wider pH range, decreasing the need for pH adjustment. At a neutral pH, cationic polymers perform the same function as alum in neutralizing the repulsive charges which stabilize the oil droplets.

Alum is usually required to supplement the cationic polymer because of its adsorptive properties. Again, the alum adsorbs the oil broken out by polymers onto the floc surface, but most of the alum is now replaced by polymers. In some cases, a coagulant aid can improve floc size and particle entrapment prior to flotation, thus increasing the overall oil and suspended solids removal efficiency.

The polymer - alum approach, therefore, offers the following advantages compared to the more traditional acid - alum approach:

1) The use of acid can be greatly reduced and even eliminated since polymers function in the neutral pH range. This reduces costs as well as corrosion problems. Alum itself may depress the pH into the neutral range.
2) There are additional cost savings as well as sludge reduction since there is no need to neutralize with lime or caustic soda to raise the pH back into the neutral range.
3) The bulk of the alum is replaced by polymer, greatly reducing sludge volume. This cuts both treatment and disposal costs.

The flow diagrams of the acid - alum and the polymer - alum procedures shown in Figures 1 and 2 schematically depict the process flow for treating an oily wastewater stream in order to obtain wastewater that is acceptable for discharge. The skimmed free oil and the skimmed oily sludge, which essentially are byproducts of this wastewater treatment process, are often treated on site at the treatment plant. Figure 3 depicts a flow diagram of the procedure usually employed.

As the diagram indicates, free oil and flocculated oily sludge are treated in separate cookers, but some plants combine them in a single cook. Because flocculated oil is

Figure 2

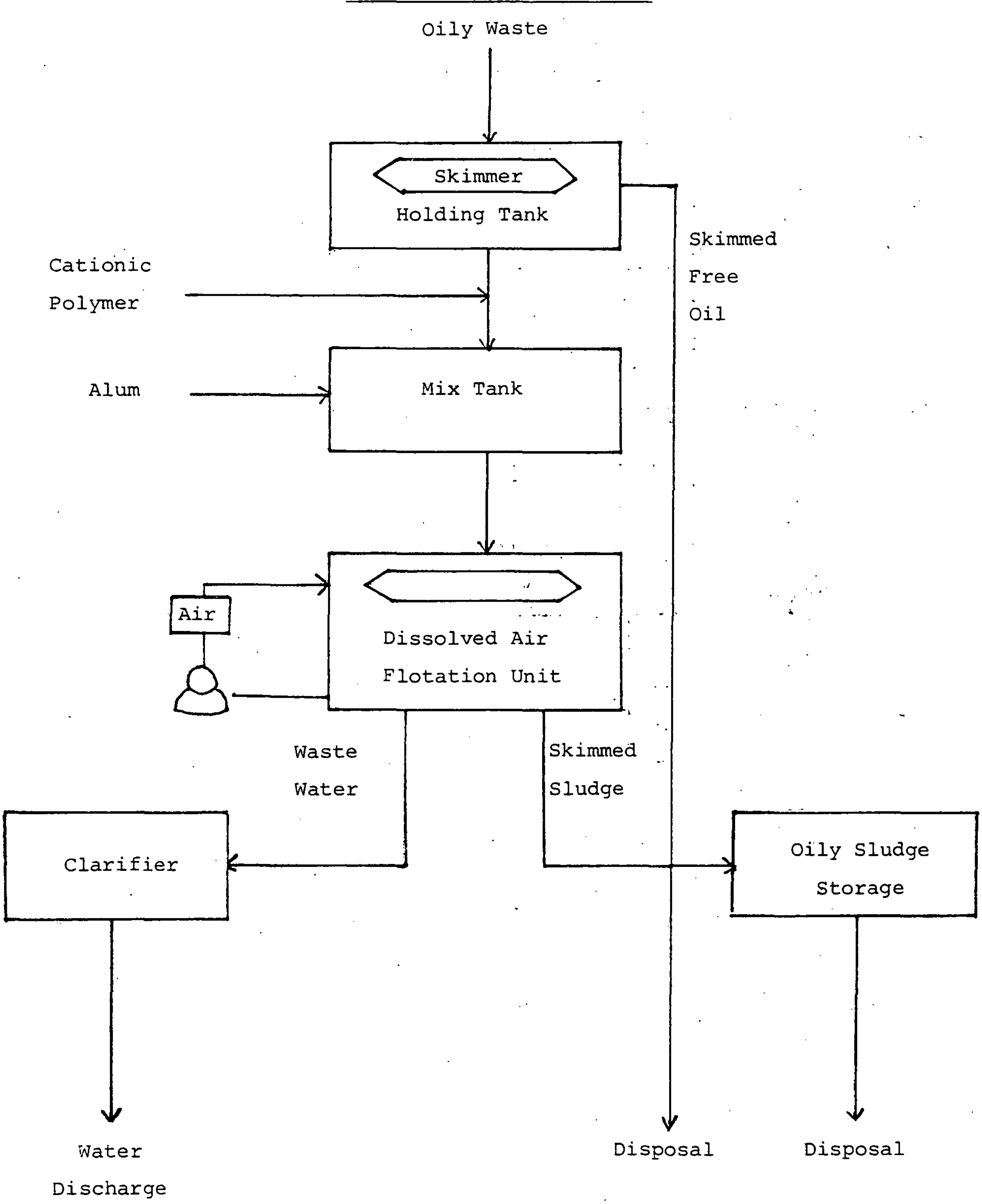
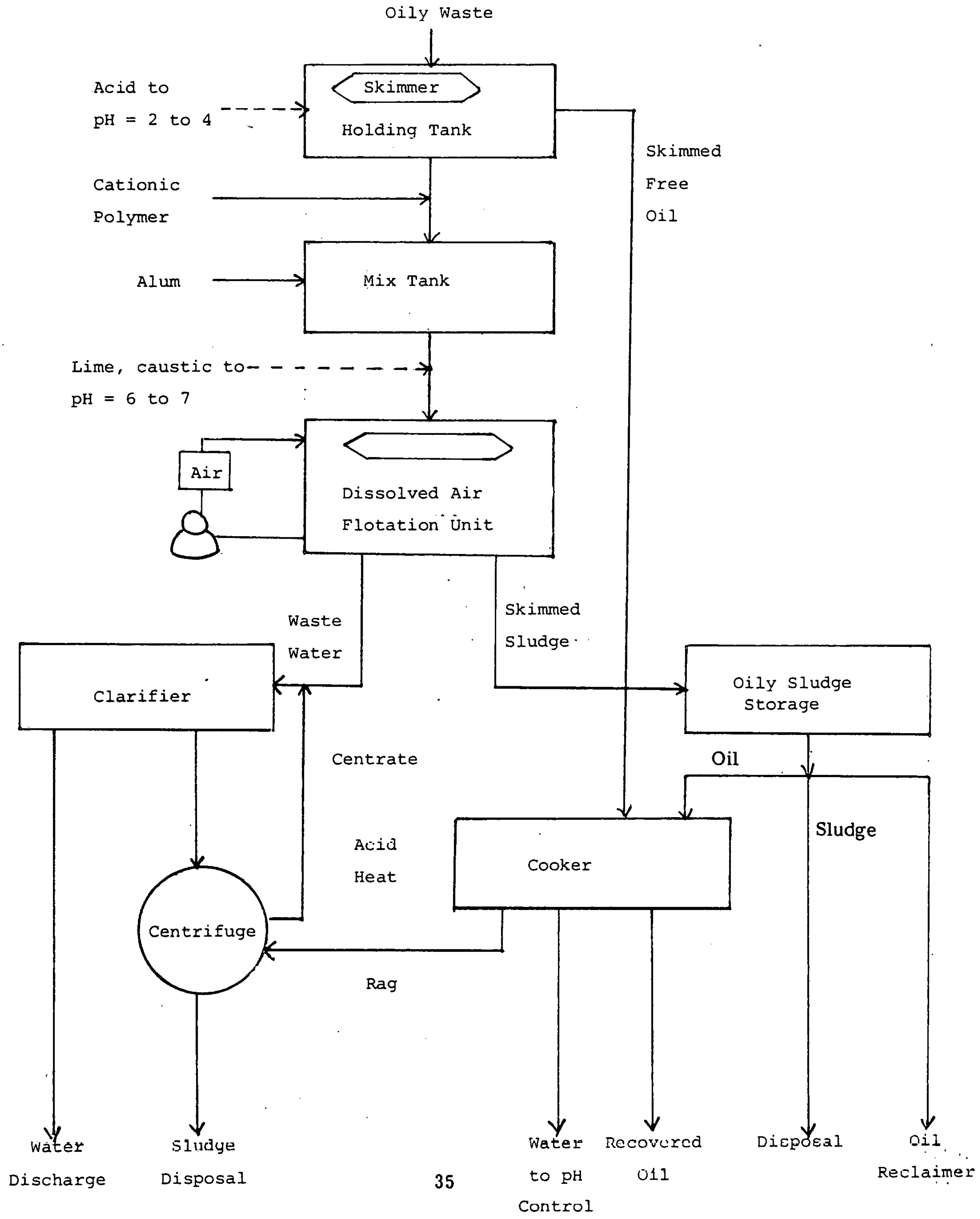

Polymer - Alum Procedure
Oily Waste
Skimmer
Holding Tank
Skimmed
Free
Oil
Cationic
Polymer
Alum
Mix Tank
Air
Dissolved Air
Flotation Unit
Waste
Water
Skimmed
Sludge
Clarifier
Oily Sludge
Storage
Water
Discharge
Disposal
Disposal

Figure 3

Onsite Treatment Procedure



normally tightly bound in a polymer - alum or alum floc, it is more difficult to break out the oil. Plants which do not want to treat onsite to recover this oil will:

1) sell the sludge to an independent reclaimer
2) incinerate the sludge
3) dispose of the sludge by landfilling

In many cases, however, environmental disposal restrictions and increased oil costs have provided the incentive for plants to recover oil in house. Oils theoretically can be reprocessed as cutting oils, but are then typically used in less critical milling operations or as supplemental boiler fuel. Recovered oils can also be sold to an independent re-refiner for further processing.

Skimmed free oil contains some solids and water which must be further removed before it can be used. The water and solids levels present in skimmed free oil can vary considerably. Oil designated as free oil may actually be an emulsion.

The traditional approach in further processing free oil is to add acid concentrations up to several percent in a heated cooker. The cookers utilize steam coils or live steam to heat the oil to a rolling boil. Once the oil is sufficiently heated, the steam is turned off and the cooking vessel is allowed to sit. Three layers are typically formed:

1) a clean oil phase on top
2) an interface or "rag" layer in the middle
3) an acid-water layer on the bottom

The treatment of oily sludges differs from the treatment of free oil. In either an acid - alum procedure or a polymer - alum procedure, the oil is tied up in sludge. This sludge contains water, solids, emulsifiers, oil, polymer and alum. This flocculated oil is normally recovered in a heated cooker using up to several percent acid. Recently, cooking chemicals (surfactants) have greatly decreased the acid required per cook while producing higher yields and a better quality oil.

After the oily sludge has been heated, a settling period allows the separation of oil-rag-water. Acid water is drawn off the bottom and recycled into the plant for pH reduction. Next, the interface or rag layer is either disposed of after centrifuging or recycled into another cook batch. Some plants collect several rag layers for recooking in a separate cooker. Finally, the clean oil phase is removed from the cooker for further processing or storage.

High molecular weight anionic and cationic polymers can be applied in cooking operations to decrease the volume of rag layer and allow a cleaner separation of the oil and water phases. A better oil yield may result, and the use of polymers may also decrease the dosage of cooking chemical required.

The sequence of chemical addition is very important. Normally acid is added first, followed by the cooking chemical. It is usually best to add acid to a heated cooker. With polymer addition to the cooker, the best order of addition is generally acid - polymer - cooking chemical.

Cooking chemicals break oil out of either polymer-generated sludges or sludges formed by inorganic coagulants. Using cooking chemicals on polymer-generated sludges has several advantages over acid cooking of an acid - alum generated sludge. These include:

1) A higher yield of oils is realized
2) Less sludge is produced, resulting in fewer batches to cook and less rag layer to be disposed of or recooked
3) Less acid is required in cooking
4) A higher quality of oil may result

The acid - alum and polymer - alum wastewater treatment procedures described above are currently the program most often used to provide clean, oil-free effluent water, acceptable for discharge. However, as pointed out earlier, these are not the only methods for treating oily wastewater streams. Another procedure that is believed to offer great potential is the ultrafiltration method.

Figure 4 depicts a general flow diagram of the ultrafiltration procedure. As this diagram indicates, oil waste is first introduced into a holding tank where pretreatment using a skimmer and/or gravity separator is performed to remove free floating oil and large solids. Free unemulsified oil will tend to form an oil on the membrane, reduce the operating permeation rate and thereby increase the required membrane surface area. Large solids will have a tendency to puncture the membranes and also damage the feed and circulation pumps.

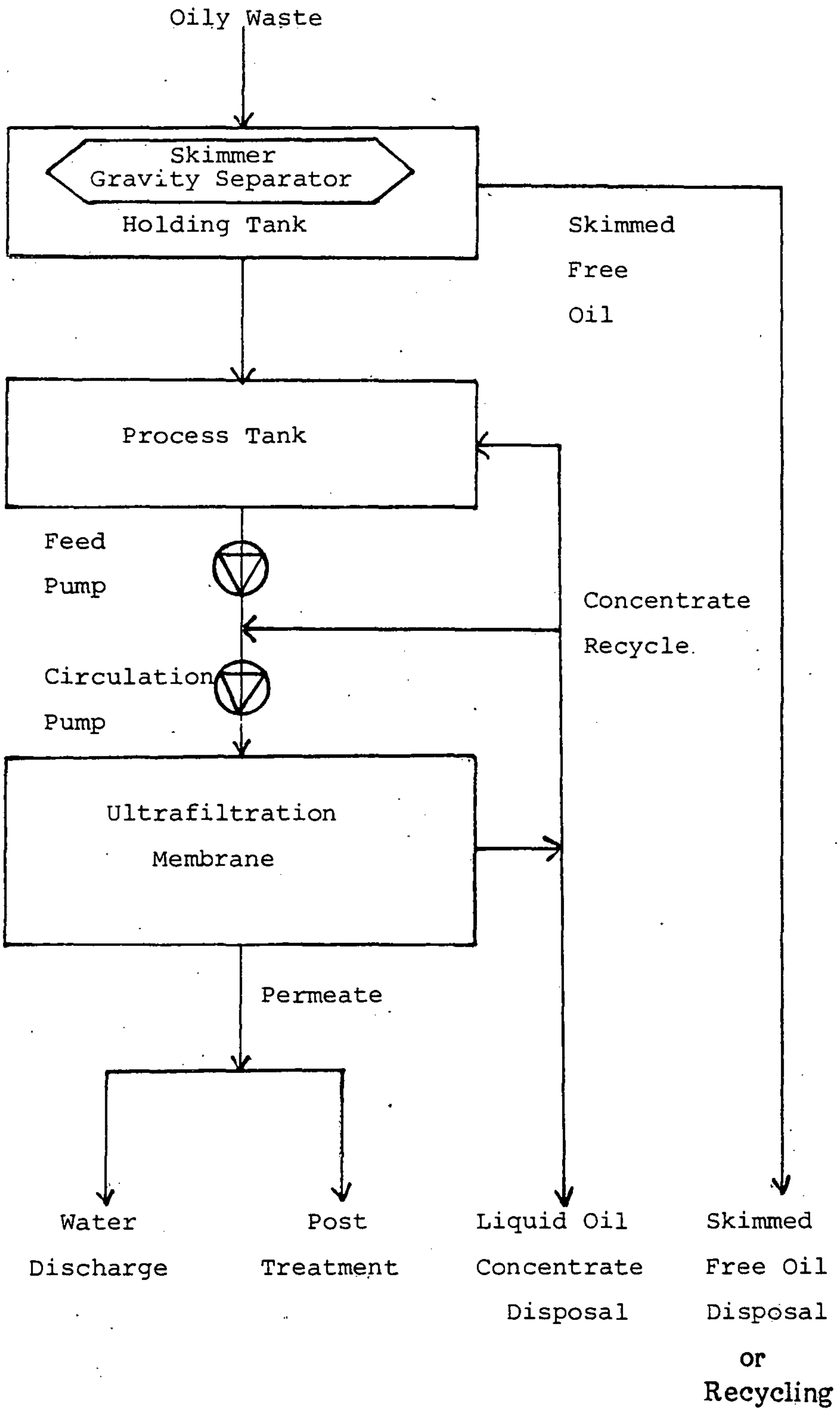
After pretreatment, the oil wastewater stream is introduced into a process tank where it is then pumped through the ultrafiltration membranes. The waste stream is continually recycled through the ultrafiltration membranes as shown in the diagram.

In contrast to a conventional filter, an ultrafilter separates the water from the emulsified oil mixture rather than the oil from the oil/water emulsion. The oil remains in solution and is retained by the ultrafiltration membrane. The high velocity of the solution over the membrane prevents buildup on the membrane surface itself. Thus, the rate and amount of oil collection on the membrane surface is very small compared to conventional filtration.

The permeate from the ultrafiltration process is usually of a quality that can be discharged directly to a sanitary sewer. In the ultrafiltration system, the only means of water removal is by passage through the ultrafiltration membranes. Since this provides for complete removal of oil particles and solids, the effluent water will always have a low oil and solids content. Operator error cannot cause poor quality of the discharge water as in other processes in which the oil and water are in direct contact. In ultrafiltration, the oil and water products are always separated by a mechanical barrier — the membrane.

Figure 4

Ultrafiltration



However, in the event that the ultrafiltered permeate is not of sufficient quality for discharge due to stringent local effluent guidelines, further treatment of the permeate can be done. Possible post treatment methods include biological degradation, carbon adsorption, and reverse osmosis.

Ultrafiltered permeate can contain high levels of biodegradable material which are measured as oils of BOD, but may not contain any other regulated substances. Thus, it may be possible to discharge the ultrafiltered permeate to the plant sewer to be biodegraded by such methods as activated sludge treatment or trickling filters.

Promoters of the ultrafiltration method claim it has significant advantages over an acid - alum or polymer - alum method. The chemical treatment methods require the use of a variety of chemicals including sulfuric acid, waste pickle acid, alum, lime, caustic soda and proprietary chemicals which include polymers.

The chemical treatment methods also produce a sludge in which the dirt, floc and trapped water remain in the oil phase. The water phase from chemical treatment of emulsions may need additional treatment to meet the quality standards for discharge to a sewer system. The sludge phase almost always requires further treatment before it can be disposed of.

On the other hand, promoters of the ultrafiltration system point out that ultrafiltration produces a water phase that can usually be discharged to a sewer without post treatment, and an oil phase that can generally support combustion. Thus, they claim, the hauling of oily wastes will not be necessary since the oil phase can be incinerated. Furthermore, if the oil concentrate cannot be burned, then only 3-5% of the original waste volume need be hauled.

Emulsion Breaking

In the case of emulsified oily wastes, the oil is separated from the water by means of emulsion breaking or an alternative technique followed by a skimming process. In emulsion breaking, coagulation and flocculation of the oily wastes occurs upon the addition of chemicals such as acids, salts or polymers. In most instances, iron or aluminum salts are used as opposed to acids, which are very expensive.

A traditional method of emulsion breaking uses alum (aluminum sulfate) at a pH of 2 to 4 to neutralize the negative electrical charges in the emulsion and destabilize the emulsion by breaking the interfacial film between the oil and water, allowing the oil to coalesce. Aluminum sulfate is recommended, because a trivalent ion is more effective than divalent, e.g. calcium chloride. Initially, unemulsified tramp oil is removed by allowing the waste to stand for 24 hours and then proceeding with a centrifuging or skimming process. The tramp oil may be disposed of or re-refined. Approximately 2-3 gallons of sulfuric acid should be added to 1,000 gallons of waste to lower the pH to 3.5. The addition of 1.5 gallons of 17% alum should follow the acidification process. After the addition of the alum, the mixture must be allowed to separate for 24-48 hours. The oil, which floats to the top of the tank must be removed. Two to three gallons of 50% caustic soda (sodium hydroxide) is added to attain a pH of 6.5-7.0. The mixture is allowed to stand for 24 hours. The aluminum is hydrolyzed to form aluminum hydroxide floc which settles to the bottom of the tank. The floc may be floated to the top by introducing air and the floc may be skimmed. Another alternative is to collect the aluminum hydroxide floc.(24) As previously mentioned, the method becomes expensive when the addition of acids are required to lower the pH. This process generates large volumes of sludge for disposal.(25) The typical emulsion breaking process is depicted in Figure 5.

A popular means of emulsion breaking employs cationic polymers to neutralize the charges which stabilize the oil droplets. Some alum may be added to enhance the polymer's adsorptive properties. Polymers, such as polyamines and polyacrylates, are often selected because they produce less sludge than the metal salts and reduce cost and corrosion. It has been estimated that the process is capable of reducing an emulsion of 5% to 10% oil to 0.01% emulsified oil. Separation of the oil and water mixture will occur in 2 hours but may be accelerated by the addition of heat.One source describes the use of a polyurea reacting with an alkylating agent to break an emulsion.(26)

A less frequently employed method involves the addition of a cation such as Fe^{2+} Fe^{3+}, Al^{3+}, Cu^{1+}, or Cu^{2+}, added in a volume of at least 1 ppm to the oil in water emulsion. The pH is adjusted to the range of 6 to 10. The emulsion is then treated with a dissolvable iron electrode. An electric current is transmitted to dissolve the electrode resulting in a ferrous ion/oil weight ratio of at least 0.02. The optimum efficiency of the process is obtained when 3 to 5 ppm of the cation is added to the emulsion at a pH range of 6 to 8. The addition of the cation reduces the time required to break the emulsion from 24 hours to 40 minutes or less.(27)

Demulsifiers of oxyalkylated alkylphenol formaldehyde resin are offered to treat oil skimmings. Another series of cationic polyelectrolytes is composed of polymers such as polyamines and acrylamide.(28)

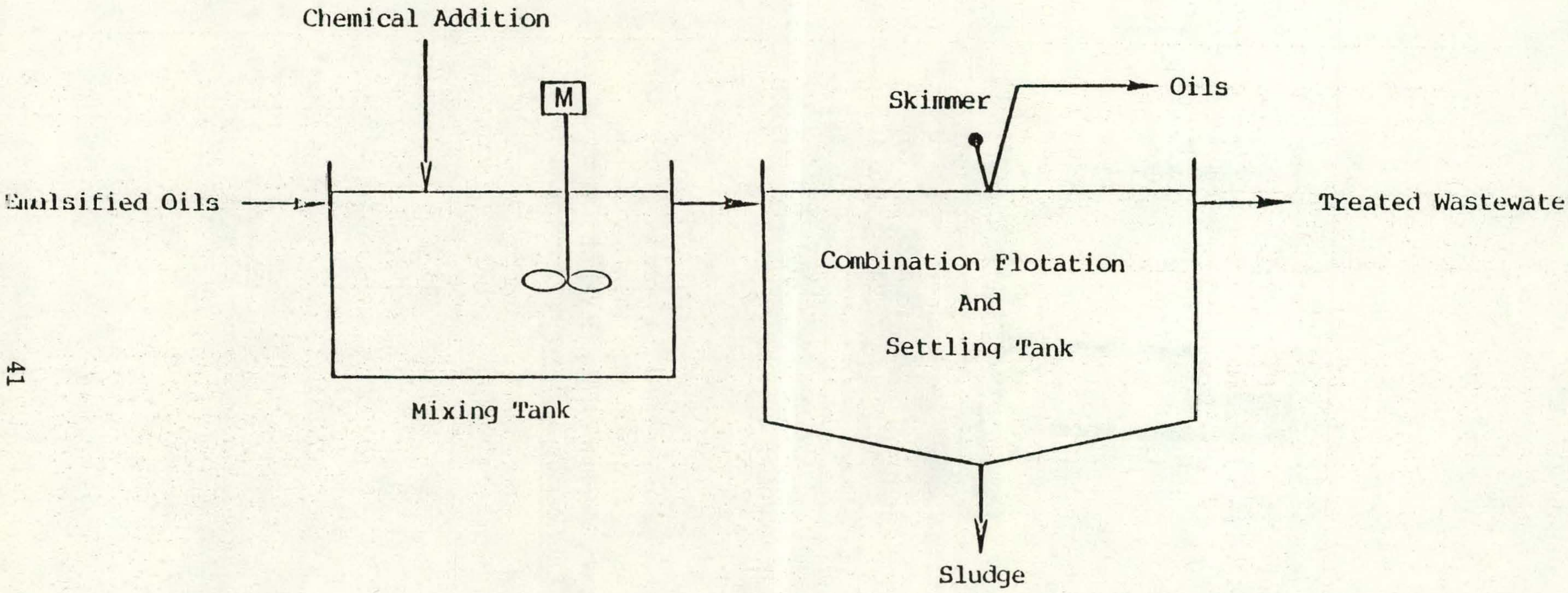
Skimming Mechanisms and Gravity Separators

Another means of oil and water separation involves the use of decantation tanks. The efficiency of the separation is enhanced by the addition of heat or chemicals. Further separation of the mixture occurs in the separator tanks with the use of skimmers.

Skimmers were first constructed as a skimming baffle plate in a weir box. The unit is not constructed to handle large flows and should be examined to ensure that manual oil removal is not required. More elaborate units contain belts or drums which attract the oil and are scraped of the oil in a skimming chamber. Some units incorporate pipes that contain slotted openings for oil removal. Another version includes a telescoping pipe that lowers to allow oil to enter.(29). The skimmers are depicted in Figures 6 and 7.

It has been estimated that roll and belt skimmers will recover floating oil with a water content of less than 5%. Multiple belt skimmers remove 64-160 gallons of oil waste per hour.(30) One method for removing oil consists of a flexible plastic, closed loop tube. The tube will remove 240 gallons per day of light oils, 600 gallons per day of medium oils and 1440 gallons per day of heavy oils.(31) (See Figure 8).

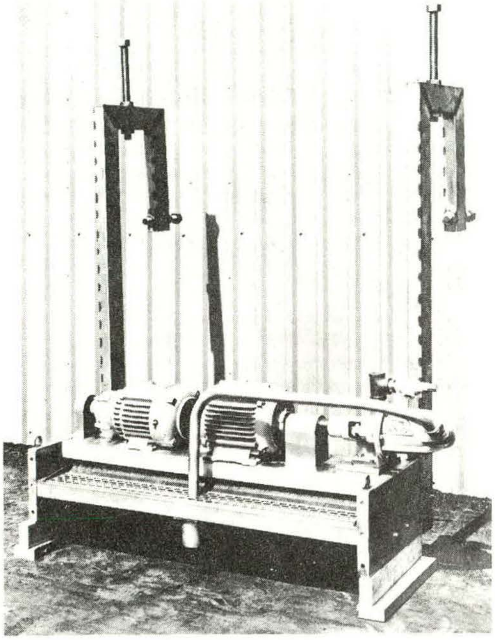
Typical Emulsion Breaking/Skimming System



Source:; Development Document for Effluent Limitations
Guidelines and Standards for the Metal Finishing
Point Source Category, Effluent Guidelines Division,
EPA 440-1-80-011-A, June 1980

Figure 5

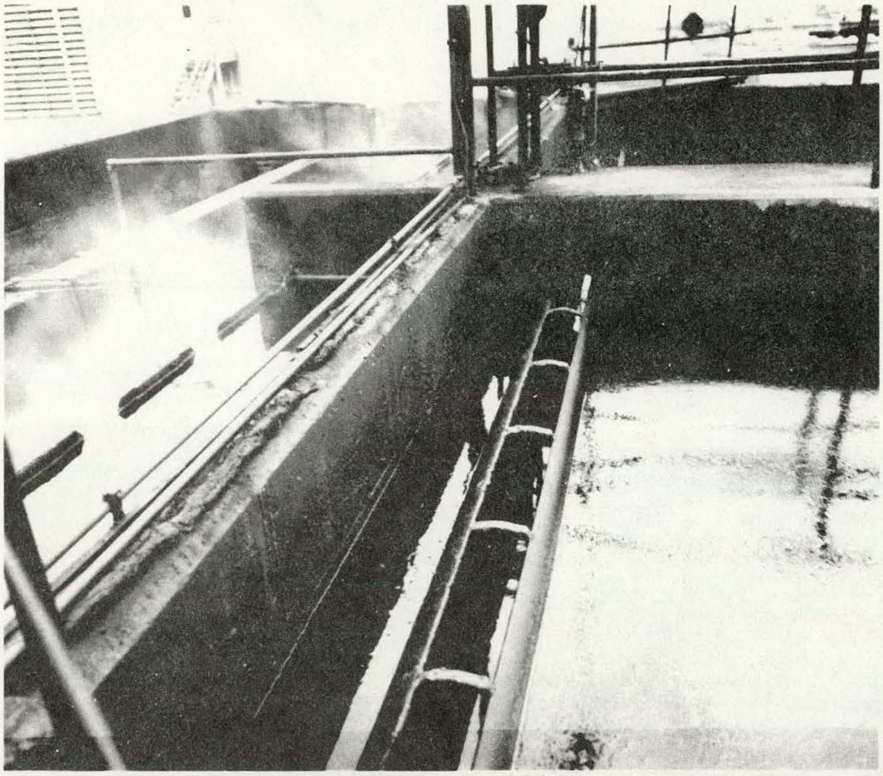
Figure 6



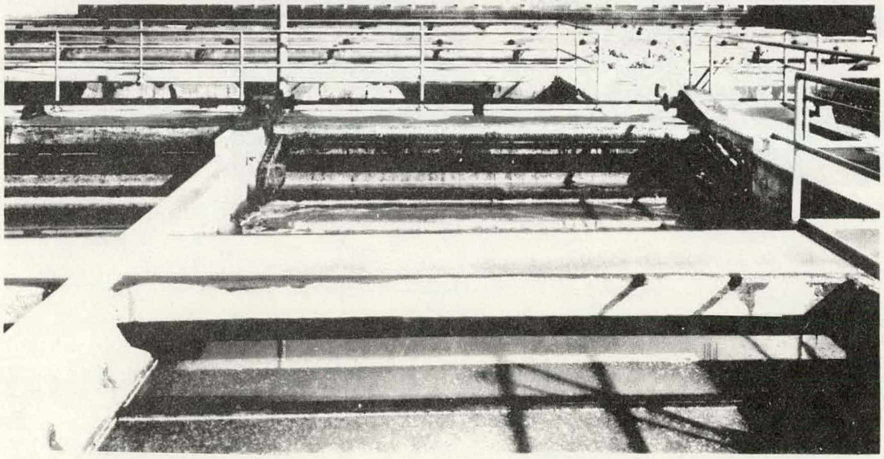
Fixed Oil Skimmer.

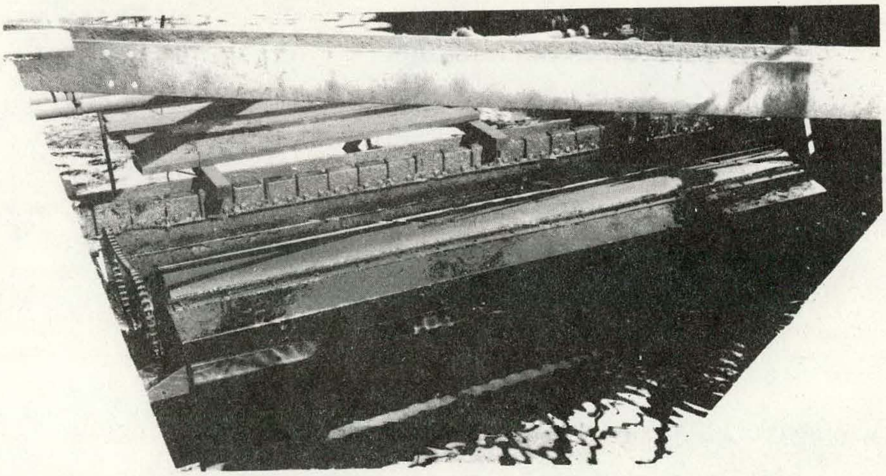
Source: Clyne, R. W., Mechanical Retrieval of Waste Oils and Solids from Water, Lubrication Engineering, November 1968

Figure 7



Auxiliary power skimmers



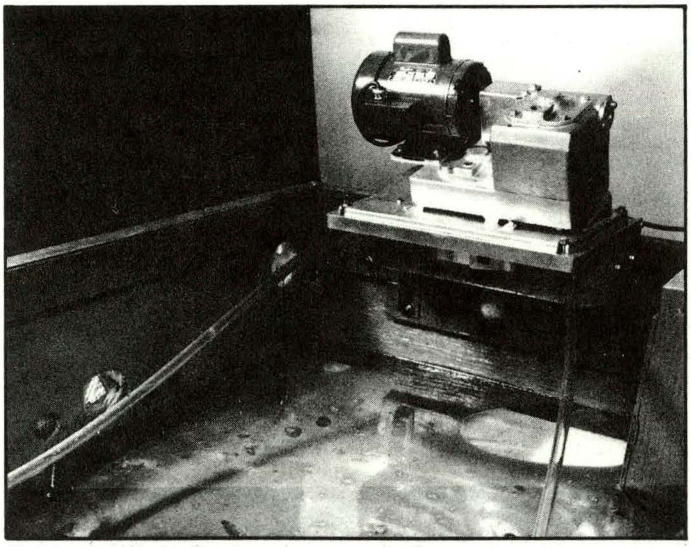


Roll and belt skimmers

Source: Rexnord Company, Envirex

Figure 8

Plastic Closed Loop Tube



Source: Oil Skimmers, Inc.

Use of a decanter is recommended if the skimmed oil is frothy. This allows the oil to separate from the water because of the difference in specific gravity. It is also recommended that an oil skimmer be employed to remove leaking lubricant and hydraulic oils from rolling mills to prevent damage to pumps and pipes.

A decanting process may be substituted when all the oils may be classified as free oils, gravity oil separation equipment used in the skimming process will remove free oil and some emulsified oil but does not always efficiently handle most soluble oil fractions and emulsions.

The coalescing gravity separator, viewed in Figure 9, operates on the principle that oil droplets will deposit on a coalescing plate and rise to the surface where they are removed by skimmers.

It is essential that skimming be performed initially. Coalescing will remove oil droplets that are too finely dispersed to be effectively treated with conventional gravity separation and skimming. Heavy solids that are not deposited on the coalescing medium must be treated as solid waste.(11)

The most frequently used separator appears to be the API separator, which contains a basin from which free oil droplets rise due to buoyancy forces. (See Figure 10).

Less frequently mentioned coalescers include the corrugated plate interceptor (CPI) and the parallel plate interceptor. (PPI)

The corrugated plate interceptor is composed of groups of 0.05 inch thick plates parallel to each other. Each group of plates numbers 12 to 48 with a separation distance of 1.9 - 3.8 cm.. Oil floats into the corrugations and coalesces on the plates (32) (See Figure 11). An additional advantage of CPI and PPI systems is that 20% less installation area is needed. Additional disadvantages of the API include construction cost, fire hazard, evaporation losses and high steam consumption.(32)

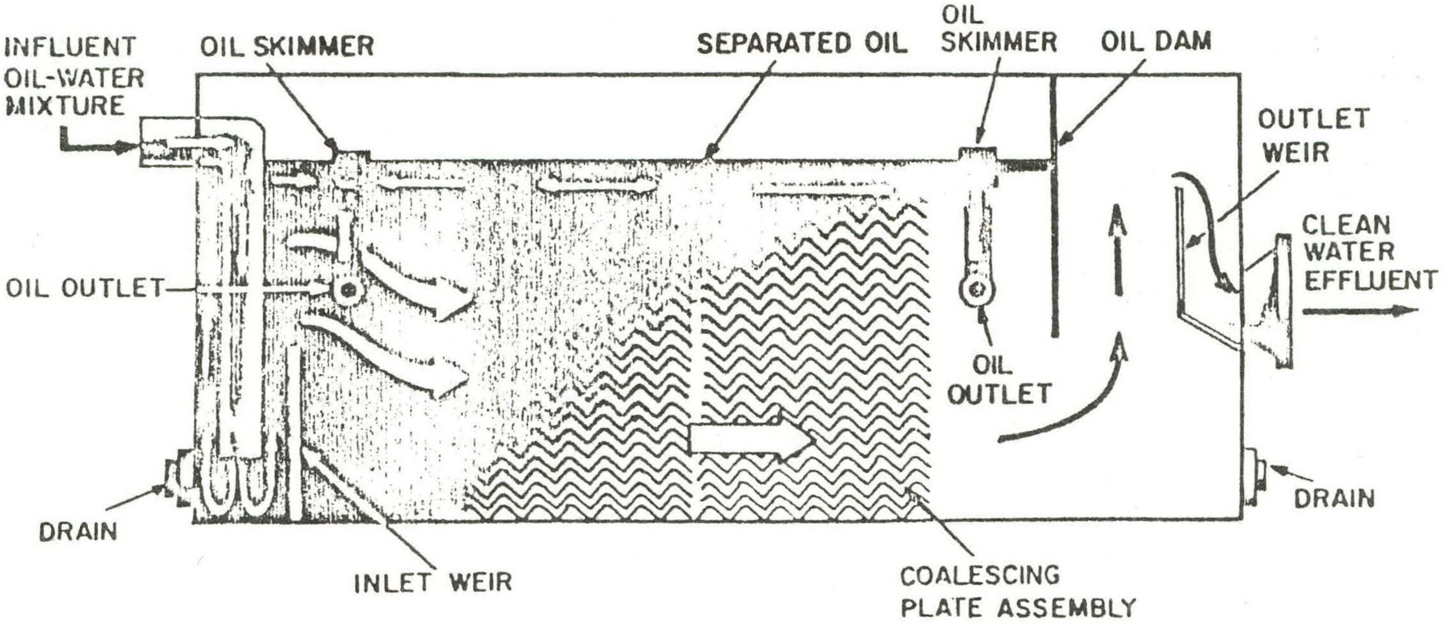
The PPI reduces the path that the oil must travel as oil coagulates on the undersurface of the plates and moves upward. Solid particles, on the other hand, collect on top of the plate and slide down to the bottom. One pump and two weirs are used in place of skimmers to accomplish the oil recovery operation.(33)

One waste treatment plant employs a modified API separator. The separator consists of two parallel channels to allow either channel to be removed for maintenance while the other is functioning. The separators, built of reinforced concrete, will remove 99% of the oil of specific gravity 0.91 and droplet diameter of 0.013 cm or larger. The separator includes five chain-type collectors acting independently: 1) a bottom collector, 2) a collector in the cross-collecting trough, 3) a collector in an inclined ramp, 4) a skimming collector, 5) a cross-collector in the skimming trough.(34)

An oil-water separator that reduces the oil content in wastewater to less than 10 ppm consists of an oleophilic fibrous coalescer. This compares with the API and parallel-plate separators that reduce oil content to 25 ppm. The coalescer, which is shown in Figure 12 is said to handle free dispersed and emulsified oil, whereas the API and parallel plate separators do not remove emulsified oil.(35)

Figure 9

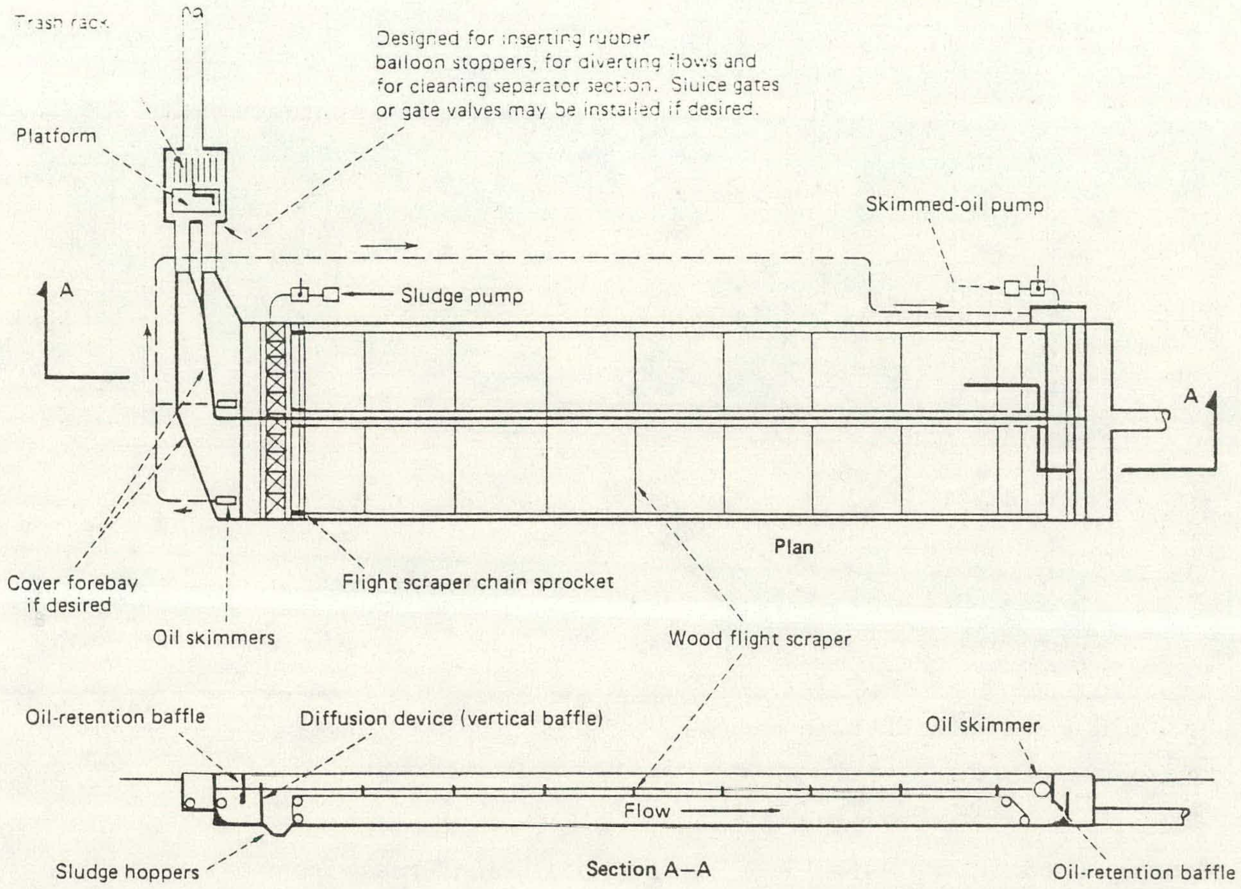
Coalescing Gravity Separator



Source: Development Document for Effluent Limitations Guidelines and Standards for the Metal Finishing Point Source Categories Effluent Guidelines Division EPA 440-1-80-091-A, June 1980

Figure 10

API Oil-Water Separator

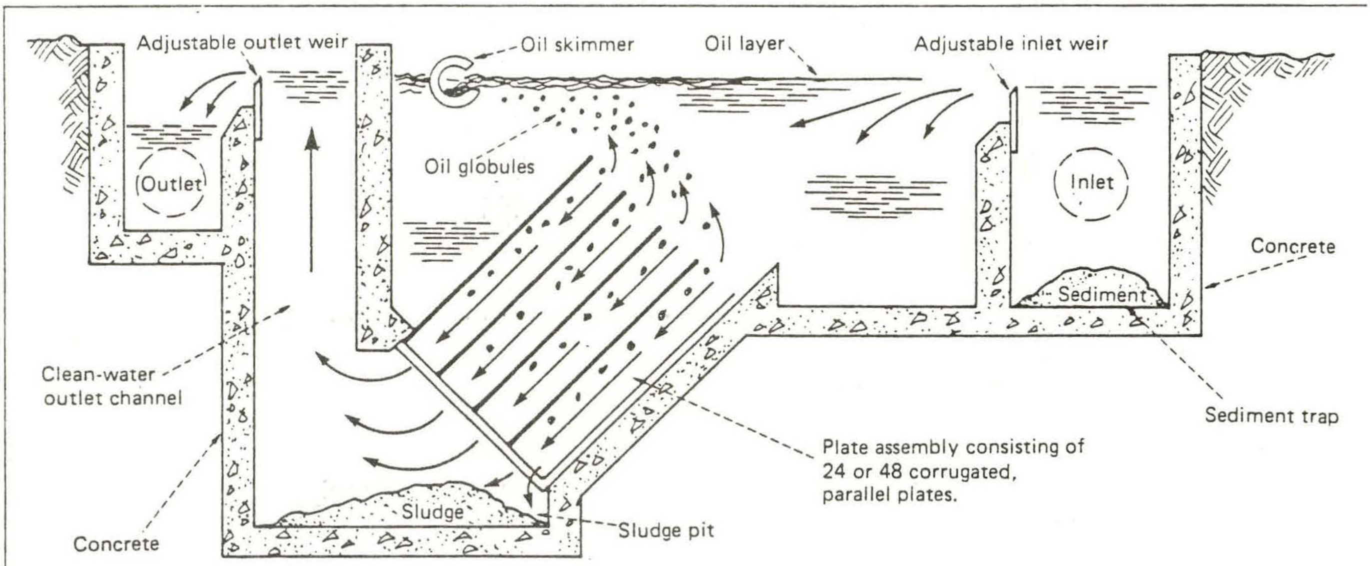


API oil-water separator

Source: Ford, D and Elton, R., Removal of Oil and Grease from Industrial Wastewaters , Chemical Engineering, October 17, 1977

Figure 11

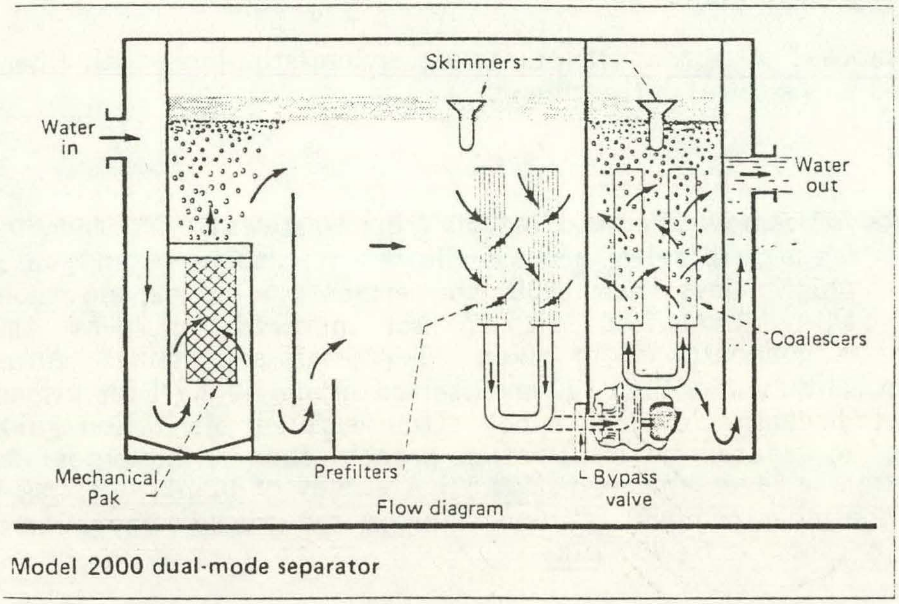
OIL AND GREASE REMOVAL



Corrugated-plate interceptor or CPI-oil separator

Source: Ford, D., and Elton, R., Removal of Oil and Grease from Industrial Wastewaters, Chemical Engineering, October 17, 1977

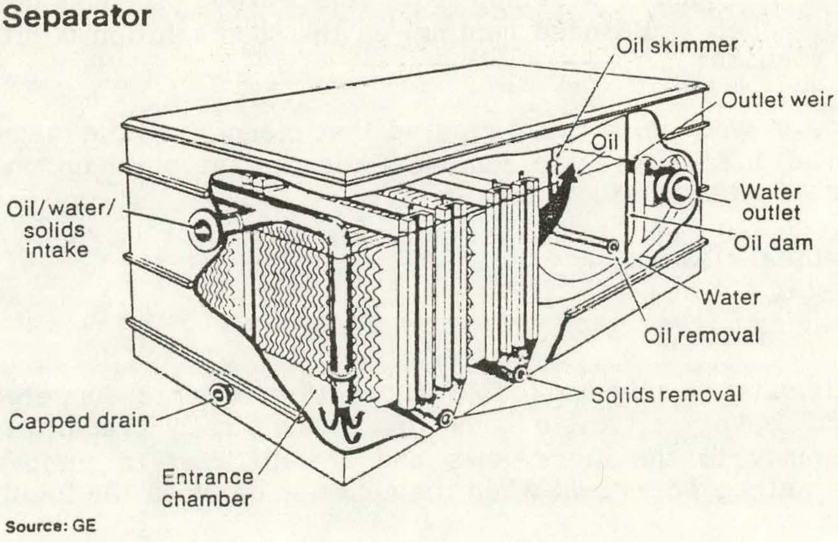
Figure 12



Model 2000 dual-mode separator

Source: Oil/Water Spills Snags Emulsified Oil , Chemical Engineering, July 18, 1977

Figure 13


Separator

Source: GE

Source: Environmental Science and Technology, July 1979

A vertical plate solids/oil/water separator has been developed which operates under the principle of gravity and coalescing. Solids settle to the bottom and oil rises to the surface. The separator has the capability of removing oil droplets as small as 5M and the effluent may contain 15 ppm or less of oil. The device may handle a capacity of 10,000 gpm.(36) (See Figure 13)

Coalescers composed of fibrous structures e.g. nylon, stainless steel, fiberglass, have been mentioned in wastewater treatment.

Ultrafiltration

Another method of removing emulsified oil from wastewater incorporates an ultrafiltration unit. The ultrafiltration process allows water, solvents, and material with a low molecular weight (less than 1000) to permeate a membrane under pressure (see Figure 14). Emulsified oil is not allowed to pass through the membrane and is concentrated to about 30-60% oil and solids. A permeate is obtained which contains less than 100 mg/liter of oil and 10 mg/liter suspended solids. If this effluent discharge level does not attain effluent limitation guidelines, the permeate may be treated by a filtration process such as biological degradation, carbon adsorption or reverse osmosis.(11)(37) A survey of plants utilizing ultrafiltration revealed the mean removal efficiency for oil and grease removal to be 92% and for total toxic organics to be 88%.(11)

Since the pores of the ultrafiltration membranes are much smaller than the particles rejected, the particles cannot enter the membrane structure and plug the pores. The pore structure and small size (less than 0.005 microns) of the membrane are quite different from those of ordinary filters. With an ordinary filter, pore plugging results in drastically reduced filtration rates and requires frequent backflushing, which may produce extra solid or liquid wastes.

In an ideal ultrafiltration operation, there would be no buildup of oil on the membrane surface necessitating periodic cleaning of the membrane. Cleaning consists of washing the ultrafiltration system with a soap solution, which is displaced back to the feed tank after the cleaning is completed. This method produces no additional solid or liquid wastes that would need hauling, as the soap solution is ultrafiltered along with the feed solution.

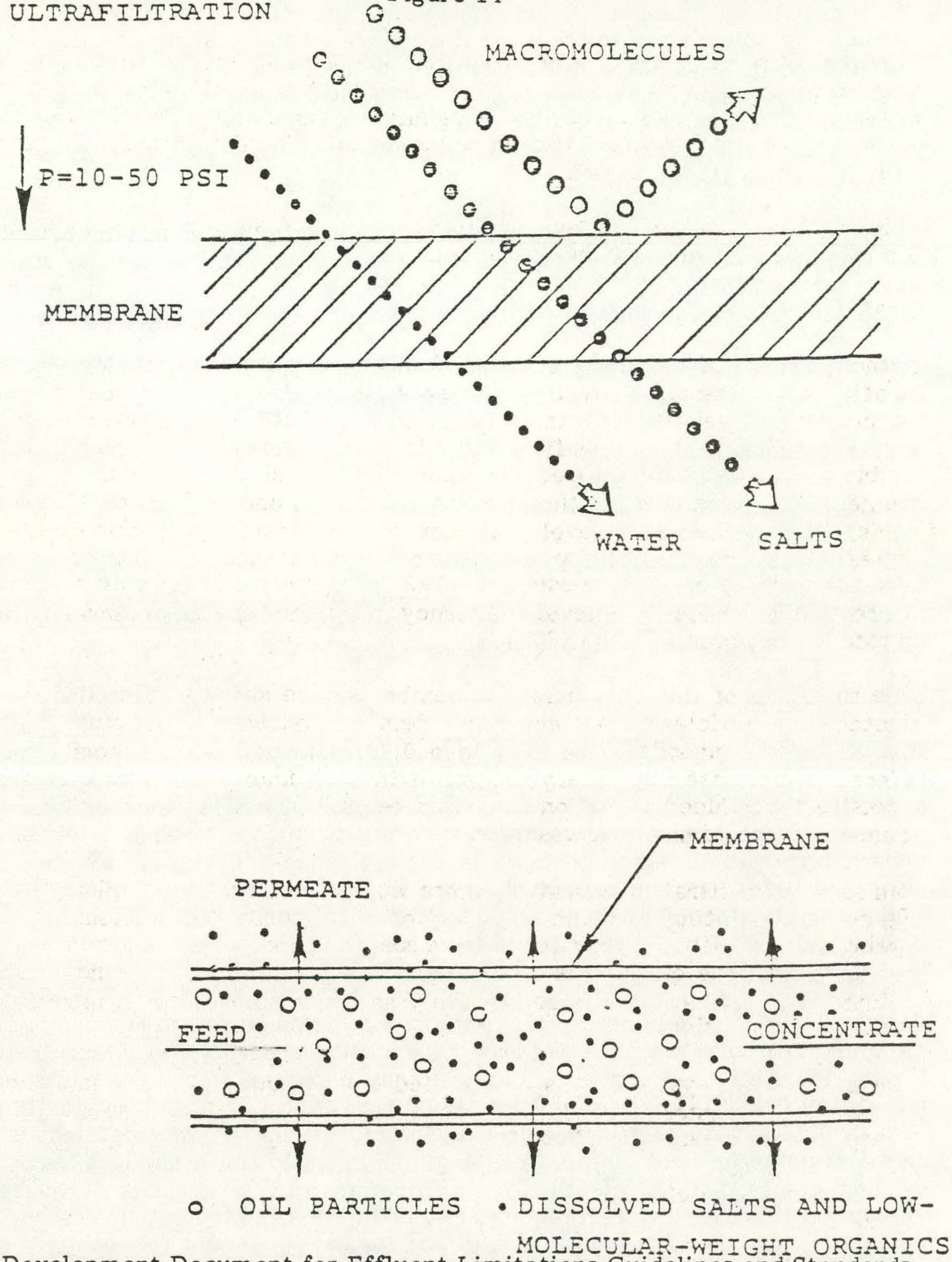
In large oil-water systems, it is anticipated that cleaning of the membranes normally will be required once a week to remove foulants that build up on the membrane surface. These cleaning methods are:

1) mechanical cleaning
2) dispersing
3) solubilizing

Mechanical cleaning is only applicable in practice to large diameter ultrafiltration membranes and is very effective in removing chemically precipitated species that adhere tenaciously to the membranes and are difficult to remove by any other method. This method works best when the adhesion between the fouling layer and the membrane is weak.

Dispersing methods of cleaning function by breaking up deposits in the membrane and dispersing them into colloidal sized particles. The most commonly used dispersants are detergents.

Figure 14



Source: Development Document for Effluent Limitations Guidelines and Standards for the Metal finishing Point Source Category", Effluent Guidelines Division - EPA 440-1-80-091-A, June 1980

SIMPLIFIED ULTRAFILTRATION FLOW SCHEMATIC

Cleaning by solubilizing consists of dissolving, by physical or chemical means, the fouling deposit. This is the most effective of the three cleaning methods. It is most often used to clean the membranes of metal hydroxide or other chemical deposits. Solutions of acids and chelating agents are usually used for this purpose. The filtering membrane used for emulsified industrial oils should be resistant to acidic, alkaline and caustic cleaners.

With the ultrafiltration process, solid waste is practically nonexistent because there is no addition of the chemicals required for demulsification such as sulfuric acid, waste pickle acid, alum, iron sulfate and proprietary polymers. The emulsified oil, which does not pass through the filter, may be incinerated or sold to a reclaimer.

Ultrafiltration is recommended by metal working fluid manufacturers as a disposal method for oil wastewater for the following reasons:(38)

1) reducing sludge disposal
2) less expensive than incineration
3) less expensive than contract hauling
4) costs less per gallon for treatment
5) requires less skill for operation

In addition to the skimming and ultrafiltration processes,additional treatment may include the use of a reverse osmosis system or a carbon adsorption system.(11)

Reverse Osmosis

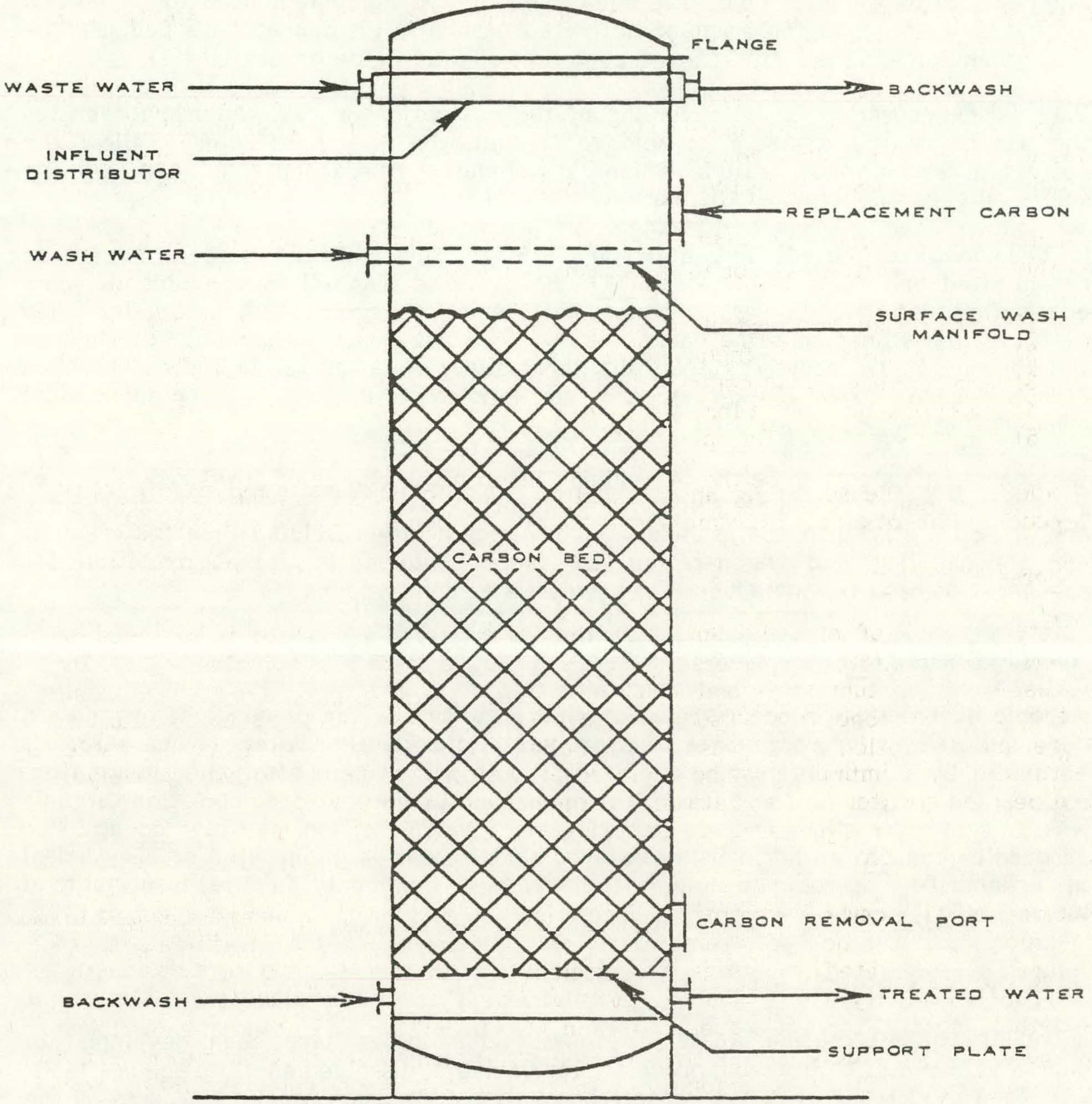
Ninety percent of oils and solids in the ultrafiltered permeate is removed with reverse osmosis.(37)The reverse osmosis modules may be selected from three available types: tubular, spiral-wound, or hollow fiber.(11) In the reverse osmosis process, a more concentrated solution is forced to diffuse through a membrane into a more dilute solution when pressure is applied. The concentrate which is unable to permeate the membrane may be reserved for further treatment or may be recycled. The permeate water may be returned to the operation for reuse.

Carbon Adsorption

Alternatively, a carbon adsorption process may be employed to remove oils and toxic organics that have not been removed by emulsion breaking and ultrafiltration. (See Figure 15) Activated carbon is an efficient means of removing organics with an adsorption capacity of 500-1500 square meters/gram. It is limited to treatment of less than 18,925 liters/day, due to column saturation.(37) Pretreatment is desirable to maintain an influent of less than 50 ppm suspended solids and less than 10 ppm for oil and grease.(11) In addition to a filtration unit, a granular activated carbon adsorption treatment system requires two or three activated carbon adsorption columns, a holding tank, liquid transfer pumps, and equipment for reactivation, i.e.,a furnace, quench tank, spent carbon tank and reactivated carbon tank.(11)

Figure 15

Activated Carbon Adsorption Column



Source: <u>Development Document for Effluent Limitations Guidelines and Standards for the Metal Finishing Point Source Category,</u> Effluent Guidelines Division, EPA 440-1-80-091-A June 1980

The two-stage powdered carbon unit incorporates "four flash mixers, two sedimentation units, two surge tanks, one polyelectrolyte feed tank, one dual media filter, one filter for dewatering spent carbon, a carbon wetting tank, and a furnace for regeneration of spent carbon. The comparison of the equipment used for powdered activated carbon and for granular activated carbon is introduced here because the process equipment used will affect the amount of solid waste generated.(11)

Thermal regeneration is the reversing of the adsorption process which incorporates the use of heat and steam to remove the adsorbates and therefore allow the activated carbon to be reused. Chemical regeneration is acceptable when only one solute must be dissolved off the carbon

It has been estimated that between 4-9% of the adsorbed carbon cannot be regenerated and must be disposed.(11) Solid waste disposal is unavoidable when contaminated activated carbon cannot be thermally regenerated, especially when regeneration is deemed to be dangerous due to a hazardous component adsorbed on the carbon. It has been suggested that thermal regeneration be employed only when carbon usage is above 454 kg/day and that solid waste disposal is more economical when carbon usage is below that figure.(11)

Regeneration appears to be the overriding factor in the choice of powdered carbon or granular carbon. In comparison, powdered carbon has a higher adsorption capacity and is less costly than the granular, but requires a larger volume than the granular and its handling and regeneration are more problematic.(11) Wet oxidation for regeneration has been introduced for powdered carbon systems.

Aerobic Decomposition

Aerobic decomposition occurs when organic materials in the presence of oxygen are decomposed by micro-organisms to form carbon dioxide and water. When sludge is activated by micro-organisms, a clear effluent will remain after the sludge flocculates and settles. In the trickling filter method of aerobic decomposition, organic wastes flow over slime and are decomposed. Decomposition may also occur in an aerated lagoon. In all methods, dewatered sludge must be incinerated or disposed of in a landfill. Aerobic decomposition is used commonly in the treatment of lubricants.(11)

Dissolved Air Flotation

A variety of alternative waste treatment technologies have been developed to improve the emulsion breaking process. For example, dissolved air flotation is (DAF) a method used to improve the effectiveness of the emulsion breaking process by the inclusion of bubbles of dissolved air to increase the buoyancy of the oil droplets, raising them to the surface where they will float. (11) Coagulants, i.e., lime, alum ferric salts or polyelectrolytes are added to enhance floc formation.(32) In addition, air will oxidize sulfides, which will release adsorbed oil.

The success of the dissolved air flotation process depends on the ratio of air to solids. Air is dissolved in water at elevated pressures and bubble formation will occur when the pressure is reduced to atmospheric. The amount of air that can be dissolved is contingent on the temperature, dissolving pressure, time and saturation characteristics of the waste. (34) Equipment required for the process includes the flotation tank, recycle pumps, dissolving tank, and the air supply and controls. (34) (See Figure 16)

A dissolved air flotation unit may be incorporated in a treatment system utilizing an oil-water separator. Wastewater passes through an API oil-water separator and following the skimming off of free oil is passed to a dissolved air flotation unit. Oil is again skimmed off and the water is processed through the clarifiers in a biological oxidation system. This system may not effectively separate the oil and water if the volume of oil is too great. The concentration of oil in the effluent from the dissolved air flotation unit may be 100-150 ppm, which exceeds the capability of the bio-oxidation process.(11) When low molecular weight organic polymers was added to the inlet of the dissolved air flotation unit, the concentration of oil in the effluent was reduced to 15-30 ppm.(39) (See Table 17)

TABLE 17

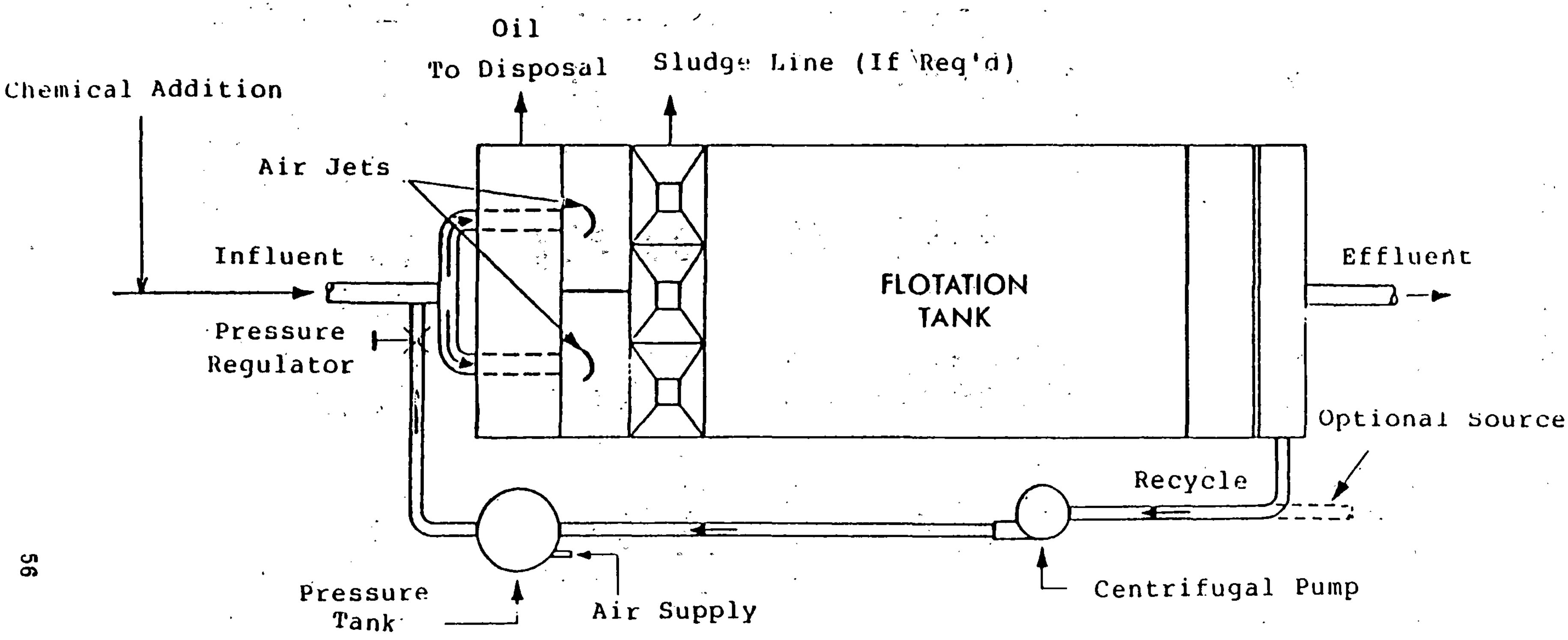
Results Of Emulsion Breaker Application
In The API-DAF System
Oil and Grease

	API Infl.	API Effl.	Percent Removal	DAF Effl.	Percent Removal
No Treatment	1500	200-300	83	100-150	50
Emulsion Breaker Treatment	1500	100-125	93	15-30	79

Determination by freon extraction, values expressed in parts per million (volume basis).

Source: Gruette, J., "Primary Wastewater Treatment and Oil Recovery in the Refining Industry", National Petroleum Refiners Association Meeting, March 19-21, 1978

Figure 16



TYPICAL DISOLVED AIR FLOTATION SYSTEM

Source: Development Document for Effluent Limitations Guidelines and Standards for the Metal Finishing Point Source Category, Effluent Guidelines Division, EPA 440-1-80-091-A, June 1980

Studies have compared the effectiveness of flotation versus gravity separation. It was concluded that: (40)

1) flotation requires less space
2) gravity settling yields a superior effluent compared to flotation
3) flotation requires higher operating costs
4) flotation yields a thicker sludge
5) a solids-contact unit as opposed to flotation should be employed when the slurry contact is enhancing the adsorption of material being coagulated, density of the precipitates or completeness of the chemical reaction

Induced Air Flotation or Dispersed Air Flotation

Dispersed air flotation is an available means of removing oil and suspended solids from waste waters. Dispersed air flotation would not be selected in instances where turbulence would be undesirable since it would disturb flocculation. It is considered by some to be a simpler and less expensive method than dissolved air flotation, although its present usage is about 1/5 that of DAF. Dispersed air flotation requires less floor space (100 sq. ft. or greater, depending on the machine), and a shorter retention time (4 minutes).(41) The method of producing air and introducing it into the liquid differs from the dissolved air flotation system.

The apparatus has been identified as the dispersed air flotation machine because it contains air dispersing mechanisms that produce dispersed air in the form of finely divided bubbles.

The bubbles rise to the top carrying oil droplets and are removed by a revolving froth skimmer. The individual dispersed air flotation mechanism is composed of a vertical shaft with an attached impeller surrounded by a diffuser and circulation hood attached to a vertical pipe. The impeller displaces liquid which results in the flow of air down the standpipe. Liquid mixes with the air flowing from the standpipe resulting in the formation of air bubbles. The amount of aeration is produced by adjusting the speed of the impeller and the rate of fluid circulation through the impeller.(41)

Electrolytic Flotation

An electrolytic flotation method requires electrocoagulation cells, flotation basins and a chemical treatment and sludge system. The advantages of the system lie mainly in the need for less chemicals and the creation of less turbulence in removing of suspended and emulsified materials. The electrocoagulation cell functions by destabilizing suspensions and promoting flocculation through surface charge attraction. This unit operates by passing electrical current through water between a series of electrodes. The electroflotation basin concentrates the floc and separates it from other floatables. Material is floated to the top by means of bubbles created by an electrical current.(11)

Centrifugation

Centrifugation accelerates the separation of materials by applying centrifugal force. The oily wastes collect nearest the centrifuge head, the solids in the outermost part of the centrifuge, and water in between the two layers.Centrifugation may be accomplished at a batch process or continuously.

Batch centrifugation is employed when there is a low rate of accumulation of impurities or when a considerable amount of accumulation may be withstood. The oil may be transported to the centrifuge or a portable oil purifier may be acceptable. In this system, the centrifuged fluid is emptied into the transfer tank to allow the machine sump to be cleaned. The cleaned oil is returned to the sump after the addition of additives.

Continuous centrifugation allows for the removal of contaminants before reuse of the lubricant.

Vacuum Distillation

Recycling and disposal techniques were discussed with several recycling and treatment equipment manufacturers. Several manufacturers of vacuum distillation equipment were questioned in order to determine the capability of their equipment to handle soluble oils. The reason for this approach was the reported testing of vacuum distillation by one automotive manufacturer on an emulsified fluid that was 60% oil. It was hypothesized that vacuum distillation may be used to further treat soluble oil following the ultrafiltration process, considering secondary source data that states that oil may be concentrated to 60% using ultrafiltration.

Vacuum distillation processes have been used to remove water from hydraulic fluids, transformer oils, quenching oils, stamping oils and turbine oils. The notion of using vacuum distillation on soluble oils was inconceivable to most manufacturers contacted since the soluble oils are viewed as only containing approximately 5% oil, and the amount of soluble oils containing 60-80% oil is minimal, i.e. hydraulic fluid and fluid used in heavy duty machining, metal and gear rubbing and some stamping and forming operations.

It appears that the capabilities of the vacuum distillation units vary. One manufacturer contacted claimed that their system is only capable of handling 1-3% water. Another manufacturer estimates that it is not feasible to treat a soluble oil or any fluid that is less than 50% oil. Still another claims that its vacuum still is capable of handling all soluble oils, regardless of the percentage of oil.

The question arises as to whether emulsified metal working fluids may be handled by using ultrafiltration in tandem with vacuum distillation. One ultrafiltration manufacturer viewed the 60% figure as dubious. It was estimated that their ultrafiltration process was capable of concentrating about 10 times; therefore, a fluid, which was 1-5% would be concentrated to roughly 30%.

Reclaimer Practices

Figure 17 provides a diagram of the steps involved in fluid reclaiming. Reclaimers and re-refiners charge on a sliding scale for oil waste pick-up. The scale depends upon: (1) percent oil, (2) percent bottom sediment and water (BS+W), (3) the distance the waste must be hauled, (4) the size of the generator, (5) how the generator has been doing business with a reclaimer or rerefiner, (6) how well the personalities involved get along, (7) how much does the generator want to get rid of the waste (most reclaimers will not handle over the legal limit for PCBs), and (8) how much does the reclaimer or rerefiner want that particular batch of oil. Many large cases are handled on a bid only basis.

Reclaimers' feedstocks are generally fairly constant from source to source over time; however, the everyday input of feedstock waste oils varies from 2-98% oil. Reclaimers find most of their feedstocks falling between 25-70% oil. It is preferred that the waste oils be pretreated and concentrated first by the generator. This is to the generators' benefit also as they can then get paid for their waste rather than pay to have it hauled away. This pretreatment varies from a simple gravity settling tank to sophisticated in-plant waste treatment facilities (installed for water clean-up; getting money for the oil or reprocessing it themselves is just a byproduct of complying with federal and state clean water standards).

A categorical description of the sources of the emulsified waste oil has been adopted by some reclaimers as follows:

small users - produce 18,900 liters/yr.
medium users - produce between 18,900 and 7,570,000 liters/yr.
large users - produce more than 7,570,000 liters/yr.

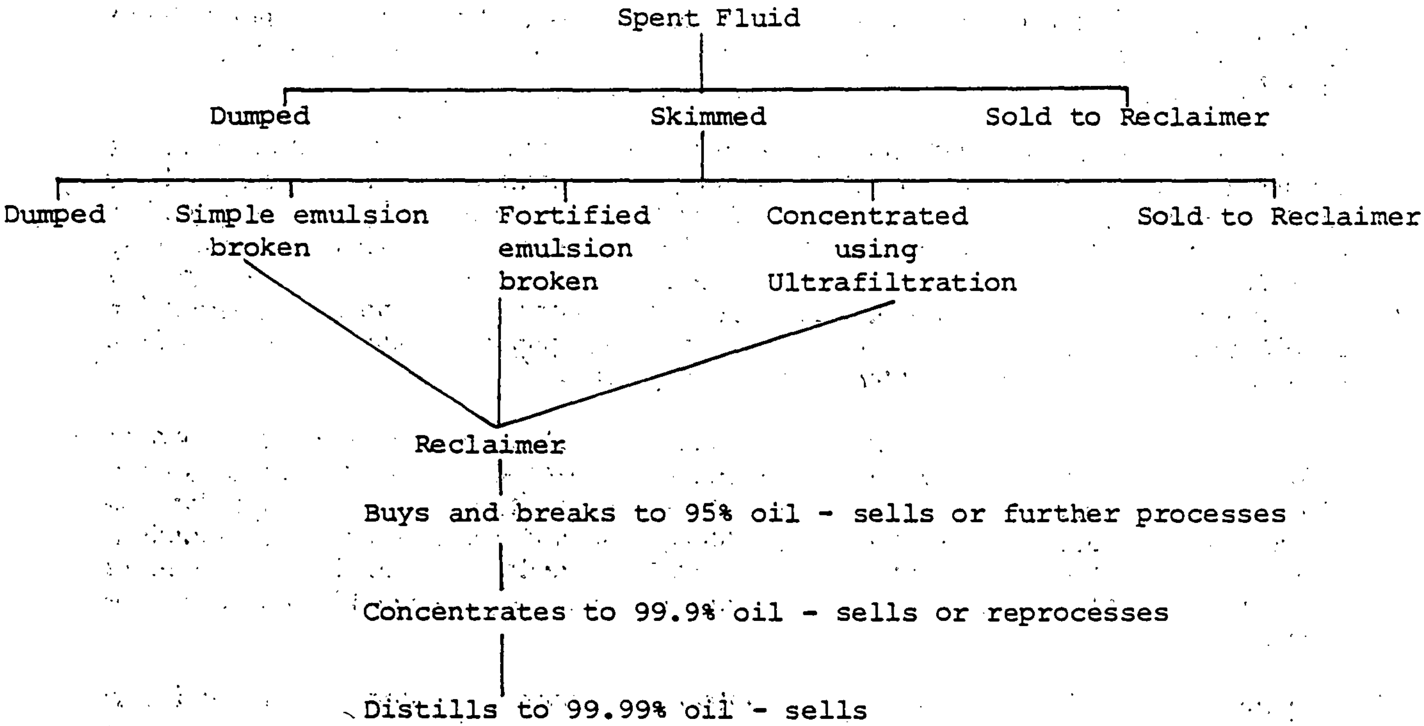
Spent Fluid Sources

Those manufacturers producing less than 50,000 gallons per year are most prone to dump the spent emulsions illegally into the municipal sewer system or arrange to have the waste picked up by local "reclaimers" who may actually reclaim it or even sell it as dust abatement fluid. The latter service costs from 5¢-30¢/gallon although 10-15¢/gallon is believed to be more common.

Some small manufacturers (15%) do store their waste in a tank and pay a reclaimer about 8-15¢/gallon to remove it. However, this procedure can be very expensive for small manufacturers. Typically a sliding scale is used which is dependent upon oil content. A sliding scale used by one reclaimer/rerefiner charges manufacturers 12¢/gallon for any waste below 40% oil or for small orders and from 40-45% oil there is no charge. Above 45% oil, the reclaimer pays the manufacturer as follows:-65% (5-20¢/gallon), 65-75% (30¢/gallon), 89-90% (45¢/gallon), and 90-100% (up to 70¢/gallon).

Figure 17

Fluid Reclaiming



Overall (large, medium or small manufacturers), it is estimated that a least 20% of fluid consumption (70-90 million gallons) is annually dumped without any treatment. This can only be alleviated by providing an economic incentive for manufacturers (mainly the small and medium-sized companies) to save and at least minimally treat their spent fluids. This would allow them to receive money instead of paying out for fluid disposal.

The second category involves medium and large size manufacturers who do break the emulsion to some extent but do not reuse any of the component parts (water, oil for fuel). Generally, the tramp oil is skimmed off then burned or sold (for 25-60¢/gallon to a refiner) and then the emulsion broken. The broken emulsion usually contains up to 50% oil which a reclaimer hauls away. Although there may be a fee for hauling away 30-60% oil emulsions, the manufacturer often does pay for the freight costs (up to 20¢/gallon). Those who do not break the emulsion pay the reclaimer a 10¢/gallon haul-away fee plus as much as 20¢/gallon freight costs.

The third category contains those manufacturers that break the emulsion down to 95% oil. They reuse whatever water they can and whatever oil can be burned as fuel. The 95% oil is sold to reclaimers for 30-70¢/gallon (the reclaimer pays for the freight) which more than offsets the 20-30¢/gallon cost for breaking the emulsion. The more fluid used, the faster the initial capital investment is paid off. One large company spent $1.75 million on a reclaimation system and saved $1.25 million the first year.

A typical system involves as a large central tank used to collect all waste fluids which include spent hydraulic fluids, cutting and grinding fluids, tramp oil, etc. The floating oil is skimmed off and a heated tank with acid, alum and a polymer are used to aid further separation. Solids are separated and sold (metal), water is drawn out of the bottom and reused, the light oily layers are reprocessed with the next batch, and the heavy oily concentration (95% oil) are drawn off and sold. (42)

SECTION V

DISPOSAL AND RECLAMATION COSTS IN THE UNITED STATES

INTRODUCTION

Some manufacturers indicate that some form of emulsion treatment is done only to fulfill environmental regulations and local sanitary sewer ordinances, and some reclaimers handle only certain concentrations of emulsions. These circumstances may indicate that there is no significant economic incentive to handle the emulsions. However, this would be an erroneous conclusion.

In fact, for those end users/reclaimers/re-refiners who know the costs and the technology involved (and it is not complicated), great benefits accrue from emulsion treatment. Sophisticated end-users can save significant amounts, and knowledgeable reclaimers/re-refiners have lucrative businesses treating these materials.

IN-PLANT METHODS AND COSTS

Reclaiming can be either a batch or continuous operation. A batch system drains the spent fluid from the pump into the dirty oil tank. A pre-filter removes the large dirt particles, then a centrifuge with heat is used, followed by ultrafiltration (as a "polishing" filter), then back to the clean oil tank.

A continuous or on-line system does the same thing as a batch system but there are no dirty and clean oil tanks. The operation continuously processes small amounts, operating on the premise of maintaining an acceptable level of contaminants at all times.

ALTERNATIVES AND THEIR COSTS

The use of one system or another depends entirely upon factory logistics.

(a) The spent fluid can be either skimmed and further processed, dumped, or a reclaimer may be paid to remove it.

  (1) dumping charges average 10¢/gallon but range from 8-25¢/gallon
  (2) reclaimer is paid 10¢/gallon to remove plus up to 20¢/gallon freight charges
  (3) tramp oil removal costs (skimmed or centrifuged) are about 2¢/gallon for labor and equipment. It may be sold to a reclaimer for 15-30¢/gallon or burned as fuel. Most tramp oil is burned, as #4 fuel oil costs about$1.02/gallon.

(b) Emulsion minus tramp oil is either broken, concentrated, hauled away by a reclaimer, or dumped

(1) same as a1
(2) same as a2
(3) breaking the emulsion depends upon the type of emulsion, whether it is simple or fortified

- Simple emulsions only contain oil, water and emulsifier (no additives) and are used in some cutting and grinding applications.

  The water phase may be dumped in the local sewer system or further clarified by dissolved air flotation (DAF). If necessary, the water phase may be "polished" by ultrafiltration or carbon filters.

  The water is often recycled back into the plant for non-potable uses since it may contain acid, dissolved sodium sulfate, etc. It may be pumped back to the main waste oil collecting tank, used for non-contact cooling, toilets, etc.

  If the 58% (oil) sludge is not taken by a reclaimer, the plant may further process it themselves using heat and acid. This can produce a 95% oil concentrate that costs about 5-35¢/gallon to make. The plant can now be paid (20-70¢/gallon) instead of paying for someone to haul it away.

  If the concentrate is not sold, the plant would be able to burn it as fuel saving $1.30/gallon. These fluids are easily broken by acid/alum additions. Sulfuric acid lowers the pH to 2.5, thereby destroying the emulsion. This process is aided by adding alum, which, as a strong cationic material, further helps to destroy the anionic emulsion by coalescing the oil droplets.

  Sodium hydroxide is then added until pH 5.5 is reached. This induces the formation of an aluminum hydroxide floc which absorbs the oil. This sludge floats on the now clear water and contains about 58% oil, water, and aluminum hydroxide. The oil is con tained in an invert (water in oil) emulsion.

  Costs could run 2¢ for the chemicals and 3¢ for labor and depreciation or a total of 5¢/gallon.

Many unsophisticated reclaimers do not want this sludge, but knowledgeable ones do, since with proper treatment it is very valuable. Reclaimers are paid about 20¢/gallon for freight and after further processing, produce a product containing oil. Blend ing must be done with new fuel oil if it is to be burned. The solids which are separated out are mostly metal fines which may be used as landfill (if EPA approved) or sold as scrap (brass and bronze can get 90¢ per pound).

Fortified emulsions are similar to simple ones plus they contain additives such as rust inhibitors, sulfur, chlorine, extreme pressure (EP) additives, etc. Two other types are the synthetic (no oil, just chemicals) and semi-synthetic (both oil and chemicals) fluids. The regular oil and water types are difficult to break, but the semi-synthetic and synthetic types are particularly difficult. Some recyclers claim no feasible technology is currently available.(43)Others say that it is possible but only after extensive work with arm-twisting of the fluid manufacturer. As these products gain a greater market share, technology will have to be developed and their disposal will become less secret.

Many large companies currently will not use synththetics if the manufacturer does not offer a method of breakdown and disposal. Synthetics will commonly last a year but longevity depends upon how effectively the in-plant recycling system operates. For example,one elaborate system includes a large waterfall aeration section. (42) This has allowed the company to keep the fluids very clean and along with adding in new water and concentrate, they are still using some fluid that was put into the system 15 years ago. Those with less elaborate systems are often forced to pour them down the drain if the manufacturer will not be of assistance or if no method really exists for breaking the emulsion. Ultrafiltration can be used to concentrate the spent fluids for further processing and it will not destabilize synthetic fluids.

The regular fortified types are effectively broken using sulfuric acid and small amounts of an expensive polymer (a cation poly valent polyelectrolyte) while heating in a conical tank. (44) After several days, various layers have separated out which can be removed from each other using a valve at the bottom of the tank. Typically such a separation consists of:

5% pure oil, which is burned or sold
5% solids (mostly metal fines) which are sold as landfill
10% oil/water, which is composed of 70/30 oil/water and is reprocessed
30% water, which is reused in-plant or dumped into sewer systems
50% oil/water, which is composed of 95/5 oil/water and is burned or sold to a reclaimer for 30¢/gallon

Costs for breaking fortified emulsions from 5/95 to 95/5 oil/water range from 10-40¢/gallon. A cost breakdown could be 5¢ for chemicals, 10¢ for labor and depreciation and 2¢ for storage, for a 17¢ total.

(4) Ultrafiltration works well for concentrating emulsions from 1-5% oil to 25-50% oil. It decreases the volume of fluid to be broken in-plant or shipped out to a reclaimer. The 80-90% volume reduction entails removing much water which may be reused in-plant or piped into a sewer line (the surfactants contained within are usually biodegradable).

Often,the 25-50% concentrate is sent to a heated tank where further water is driven off forming a 70% oil concentrate.

A reclaimer pays to haul the concentrate away. This is a substantial saving versus paying the reclaimer 30¢/gallon to remove a 5% oil emulsion. The savings eventually pays for the ultrafiltration system over a period of time depending on volume.

A system would typically involve the fluid being passed over the ultrafiltration membrane (changed every two years) at about 50 psi and 110°F at a flow rate of 25 gallons per minute for 1-inch membrane tubes. A system that could recover 1000 gallons per day from 20,000 gallon emulsion feed (containing 5% oil) would cost about $50,000 versus $75,000 for a chemical treatment facility that would process 60,000 gallons/day. However, ultrafiltration only costs 3-6¢/gallon to operate compared to 11-14¢/gallon for chemical treatment.

If the concentrate is to be treated further in-house, it is sent to a heated tank where acid and polymer are added followed by dissolved air flotation. The recovered oil is burned as fuel or sold to a reclaimer. The water is further treated and reused or discarded and the solids are used as landfill or sold as metal scrap.

Ultrafiltration economics are discussed in Table 18 and Figure 18.

Table 18

ECONOMIC ANALYSIS FOR ULTRAFILTRATION

TREATMENT OF INDUSTRIAL WASTEWATER
(5 CARTRIDGE CIMCOOL UF SYSTEM)

1. Operating Parameters

250 days per year; 2 shifts per day	
Volume to be treated	1000 gallons/day
Volumetric reduction	90%
Contract hauling costs	$.25 per gallon
Sewer surcharge (assumed to be enforced)	$.045/lb. of COD

2. Capital Costs

CIMCOOL Ultrafiltration System	$56,490.00
Investment Tax Credit (10%)	$ 5,649.00
Equipment Depreciation (over 8 yrs. 50% after tax)	$ 3,630.63/year

3. Operating Costs

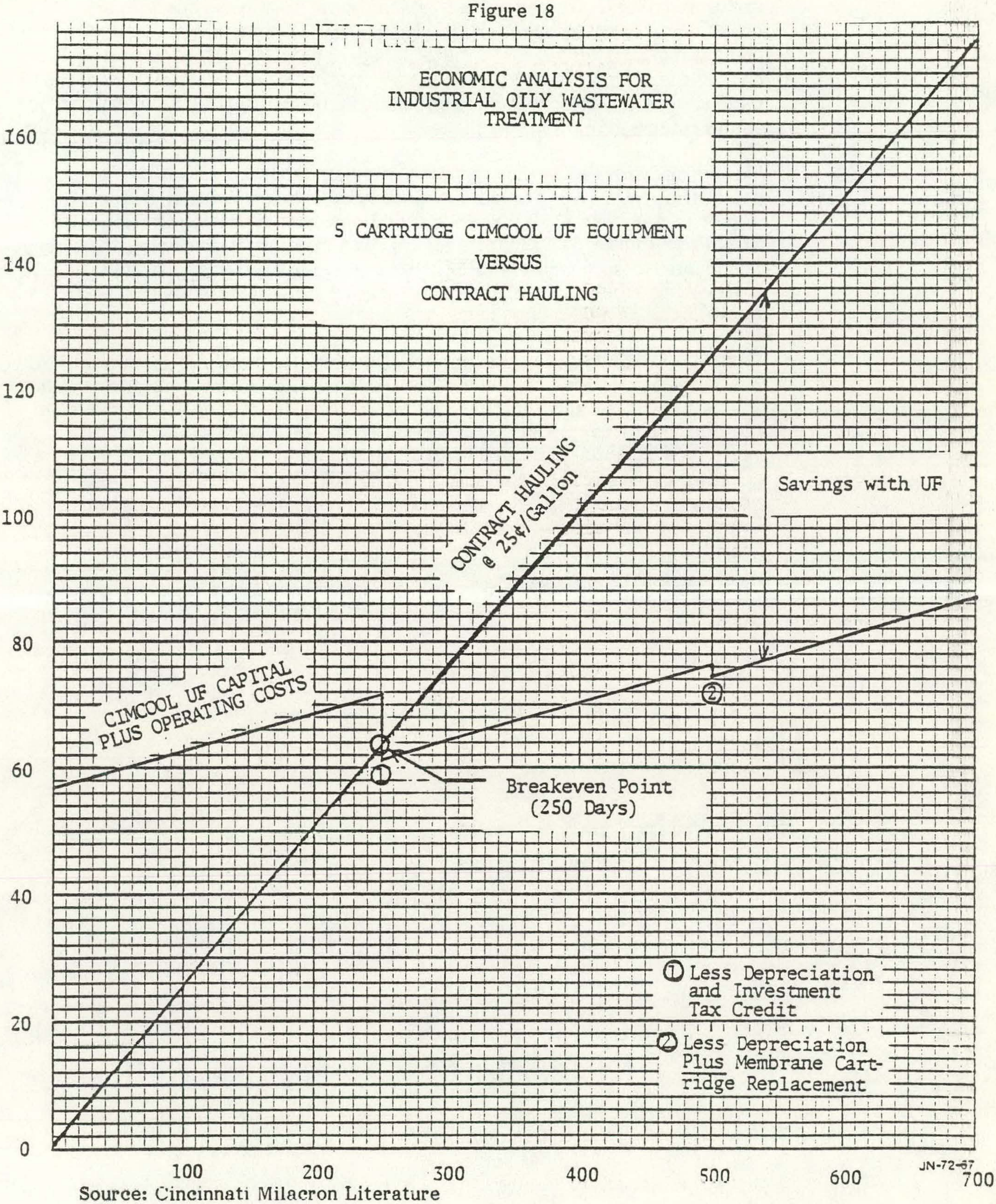
Electricity ($.045/kw hr.)	$8/day
Cleaning fluids (3 gal/cartridge/clean)	$3/day
Labor (2 hr/day @ $10/hr.)	$20/day
Concentrate disposal @ $.25/gal.)	$25/day
Sewer Surcharge (5500 ppm COD)	$1.85/day
Operating Cost/Gallon	$.0579/gal.

4. Membrane Replacement - every 2 years	$2,550.00

SUMMARY

Equipment Breakeven Point	250 days
Total Savings After Two Years	$49,720.26

Figure 18



Source: Cincinnati Milacron Literature

(5) Centrifuges are claimed by suppliers and users alike to be easier to use than filters. However, the related maintenance is the major drawback due to errosion and corrosion of the inner parts. A system processing 50-100 gallons/minute using a centrifuge would require having the pits, holes and scoring in the stainless steel patched or replaced once a month. Generally, weld patching is performed at a $400 cost rather than replace a $5,000 base plate.

Centrifuge sizes vary considerably and can range up to 200 gallons/minute. A system that could handle a few million gallons a year might cost $150,000 - $200,000 versus a filtration system cost of only $50,000 - $100,000. An effective method of removing the larger particles which can plug the centrifuge is to prefilter using a vibrating screen filter. The fluid can be passed through cold using an 80-mesh screen or hot using a 200-mesh screen.

Some systems utilize a heating coil for pasterurization purposes which can be a large added expense. The positive side is that pasteurization kills all bacteria and removes the need for large amounts of expensive biocides. However, the negative aspect is that users claim sterile systems are much more prone to fungal attack. Once a fungus starts growing in a tank it becomes very difficult to remove; many fungi are resistant to fungicides and must be hand scraped and chiseled out of the tank.

PROCESS ECONOMICS

No two companies process the same fluid compositions, have the same equipment, the same overhead and the same accounting methods. Hence there cannot be any "typical" examples. What can be done is to present the tools available for economic analysis and demonstrate their use with some general cost data.

Equipment costs vary considerably depending upon type, size and supplier. Six of the most common equipment types are continuous flow gravity settling tanks, oil separators and skimmers, pressure filters, vacuum filters, diffused air flotation, and centrifuges. Purchase costs can vary considerable by the volume to be processed. Table 19 gives approximate equipment costs at different yearly processing volumes.

Other factors besides equipment costs must also be taken into consideration when determining the cost of operation. These include variable costs (chemicals, utilities), fixed costs (labor, overhead), and, if processed and then sold by the company, corporation expenses and tax expenses. These are broken out in Table 20 for a company annually recovering 200,000 gallons of oil from 1,000,000 of waste fluid. According to this model, it would cost the company $0.88/gallon of oil reclaimed. Virgin oils will range from $0.80 - 1.90/gallon depending upon the oil grade and additive content. If the recycled oil is to be burned as fuel then $1.30/gallon would be used instead, to figure the recycling economics. The process is done in-plant, hence there will be no selling and corporate expense, nor a tax expense.

The costs were derived as shown in Table 21.

Based upon market share and percent oil content, the various metal working fluid types were averaged, and found to contain a mean 20% oil. The example therefore assumes that out of 1,000,000 gallons (3,785,000 liters) of waste fluid, 200,000 gallons (757,000 liters) of oil is recovered. It is further assumed that most of the oil is a soluble oil ($1.85/gal virgin) with some hydraulic oil contamination. The recovered oil will be reused as a soluble oil, saving $0.97/gallon ($1.85-$0.88) or $194,000 per year (200,000 x $0.97).

The reuse of an oil depends upon: (1) the original use and (2) how clean the recycled oil is. If it is not suitable for the original use, then an application is found with less critical specifications. Typically the high quality end is represented by the soluble oils and the low quality end by the cutting oils as shown below:

Metalworking Fluid Types and Prices*

Fluid	$/Gallon
Cutting oil	0.85
Lube start	1.30
Hydraulic oil	1.60
Soluble oil	1.85 (with additives may cost $7-10/gallon)

*Source: Industry Contacts

TABLE 19

Some Equipment Choices and Estimated* Costs At Different Processing Levels

Capacity**	Continuous Flow Gravity Settling Tanks	Oil Separator And Skimmer	Pressure Filter	Vacuum Filter	DAF	Centrifuge
			Purchase Cost ($, U.S., 1980)			
50,000 gal.	7,000	3,000	1,500	40,000	8,000	27,000
500,000 gal.	8,000	10,000	2,000	40,000	8,000	27,000
1,000,000 gal.	14,000	13,000	3,000	40,000	8,000	35,000
5,000,000 gal.	18,000	15,000	15,000	50,000	8,000	55,000
Installation Cost						
50,000 gal.	4,000	3,000	1,500	5,000	16,000	54,000
500,000 gal.	6,000	3,000	2,000	5,000	16,000	54,000
1,000,000 gal.	9,000	3,000	3,000	5,000	16,000	70,000
5,000,000 gal.	9,000	3,000	5,000	5,000	16,000	110,000
Yearly Maintenance Cost						
50,000 gal.	500	1,500	1,000	1,000	600	1,000
500,000 gal.	500	1,500	2,000	2,000	600	1,100
1,000,000 gal.	500	1,500	5,000	4,000	600	1,300
5,000,000 gal.	700	2,000	20,000	8,000	3,000	1,500
Depreciation Cost (avg. total costs over 10 year equipment life)						
50,000 gal.	1,600	2,100	1,300	5,500	2,000	9,100
500,000 gal.	1,900	2,800	24,000	6,600	2,700	9,200
1,000,000 gal.	2,800	3,100	4,600	8,500	2,700	11,800
5,000,000 gal.	3,400	3,800	13,000	13,500	5,400	18,000

*Based upon amount of oil finally reclaimed per year

Gallons**	Gal./Hour	Gal./Minute	
50,000	125	2	(operates one shift, 20% of time).
500,000	250	4	(one shift)
1,000,000	500	8	(one shift)
5,000,000	800	13	(three daily shifts)

** For capacity in liter: multiply by 3.785 (the resulting number will be a rather uneven meaningless capacity for the American reader).

TABLE 20

Waste Oil Recycling Process Costs

Cost Item	Recovered Oil Cents/Gallon	$/Million Gallons of Waste Fluid	
Chemicals	25.000	50,000	
Electricity	6.000	12,000	
Total Variable Costs	31.000		62,000
Direct Labor	16.000	32,000	
Supervision and Indirect Labor	16.000	32,000	
Building Maintenance	0.187	375	
Equipment Maintenance	1.460	2,920	
Insurance and Property Taxes	1.470	2,940	
Depreciation	9.9550	19,900	
Capital Interest	11.595	23,191	
Total Fixed Costs	56.662		113,386
Total Process Costs	87.662		$175,386

Table 21

Chemical Treatment Process Economics

Chemicals:	5¢/gallon x 1.0 million gallons =	50,000	
Electricity:	4¢/kw hour x 150 kw x 2000 hrs.=	12,000	
Total Variable Costs:			$62,000
Direct Labor:	2 laborers, 1 shift, $8/hour (inc. fringes), 2000 hours./year	$32,000	
Supervision and Indirect Labor	(General Plant Overhead) = 100% Direct Labor =	$32,000	
Building Maintenance	1.5% of offsite cost (1000 square feet @$25/sq.ft. = $25,000)	375	
Equipment Maintenace	= 4.0% of equipment cost ($73,000) (settling tank, separators, skimmer, pressure filter, dissolved air floatation, centrifuge)	2,920	
Insurance and Property Taxes	3.0% of equipment and building cost (73,000 plus 25,000) = 98,000)	2,940	
Depreciation (straight line)	(Equipment and installation cost)/10 years plus building cost/25 years (73,000 + 101,000)/10 + 25,000/25 17,400 + 2,500 =	19,900	
Capital Interest	$100,000 of $199,000 (building, equipment, and installation costs) borrowed @20% interest for 10 years Yearly payment =	23,191	
Total Fixed Costs:			$113,386
Total Process Costs:			$175,386 (17¢/gal.)

If a recycled fluid is to be used as a cutting oil, many would rather burn it as fuel and save $1.30/gallon instead of using it as an $0.85 cutting oil. However, once burned, the oil is gone forever. If used as a cutting fluid it has the possibility of being recycled and reused many times. Hence many consider burning a last resort only.

Whether to reprocess or recycle is dependent upon several factors but the most crucial is economic. The economic question may be evaluated using a variety of methods including Break-Even Point and Payback Time.

Break-even analysis tells how much money or how many gallons of recycled oil it will take to recoup the initial investment costs. An equation describing this may be written as follows and may be graphically presented as shown in Figure 19. The example shows that in this case 684,365 liters (180,810 gallons) of oil must be recycled to break-even.

Payback period is basically the number of years before the initial investment is paid off; hence, the more profitable the operation, the faster the payback period. A simple payback equation would be:

$$\begin{aligned}\text{Payback period (years)} &= \frac{\text{(Equipment purchase and installation costs)}}{\text{Revenue from operation or net savings*}}\\ &= \$174{,}000/\$194{,}000\\ &= 0.88/\text{years}\end{aligned}$$

A more accurate and sophisticated model would take into consideration the value of money over time. Such an equation would find

P = installed process costs
R = yearly revenue or savings from in-plant recycling
i = interest rate
n = payback period (years)

$$n \frac{-\log(1-iP/R)}{\log(2+i)}$$

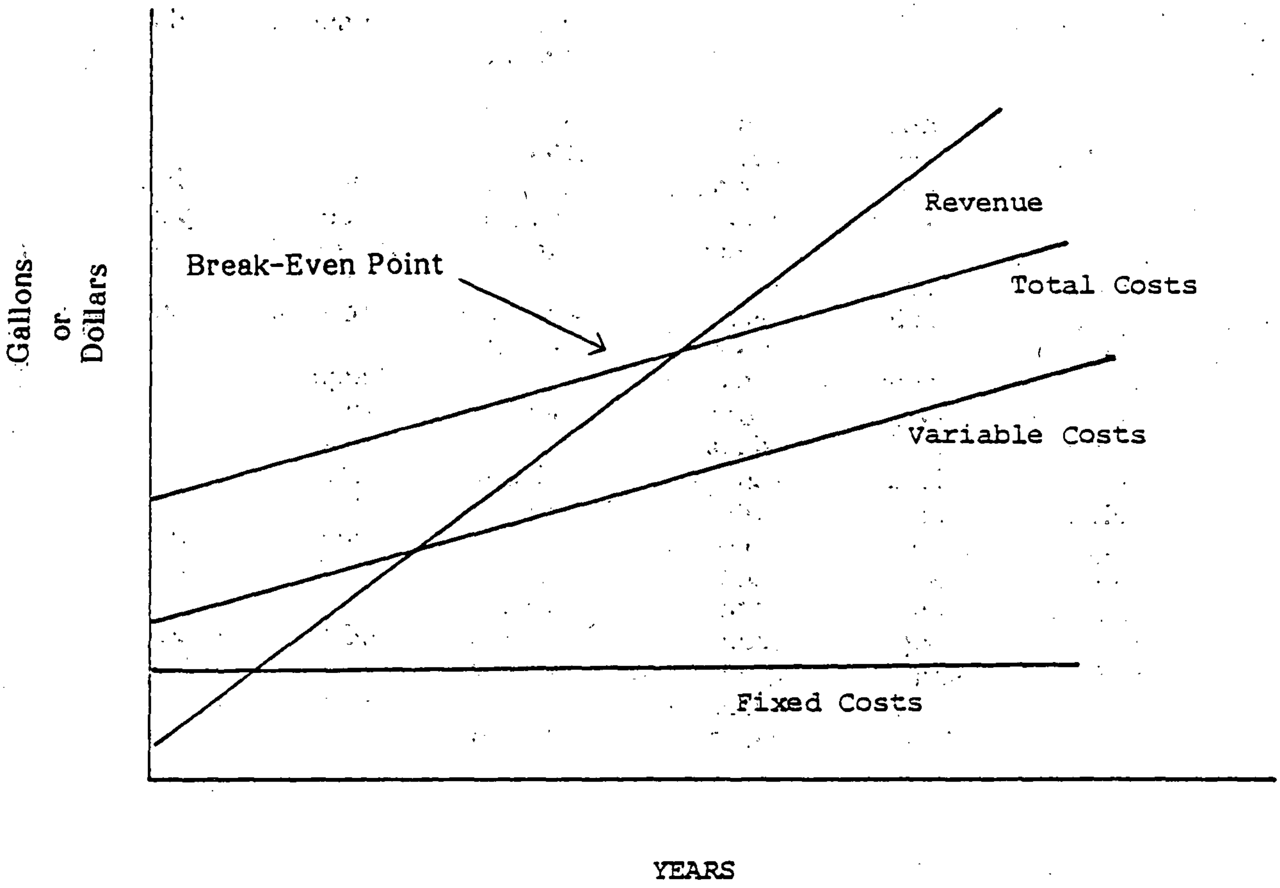
*Net savings = (Gallons oil recycled) (Savings per gallon)

Figure 19

Break-Even Analysis

Break-Even Point = Total Costs
Net savings per gallon
of acclaimed oil

= 175,386/0.97
= 180,810 gallons (684,365 liters)



OIL INVENTORY PROGRAM

The question of how much, if any, reprocessing should be in-plant will depend upon the volume of oil generated. This is best determined by good record-keeping which (1) gives accurate figures for determining economics, (2) aids control of usage and inventory which is very important in this age of rising oil prices, and (3) creates accountability for all used oil hazardous wastes which are covered in the Resource Conservation and Recovery Act of 1976. Accurate accounting will show what oils are being disposed of, how much is being disposed, how disposal is done, maintenance problems and usage rates. This can demonstrate previously unknown conditions. One report shows that most manufacturing plants can account for less than half the oils purchased. Most of the losses are through sloppy accountability methods, although some is lost down the drain or on the floor and on the final product.(45)

Actual record-keeping should be done by those engineers or department supervisors most closely related to oil usage. Analyzing the gathered data and instituting and maintaining a comprehensive oil conservation program can result in significant dollar savings and a reduction in pollution and waste-disposal headaches.

A comprehensive oil conservation program could include (45)

- checking oil for evidence of regular contamination
- minimizing the number of different oils used, to facilitate reuse/segregation
- determining average oil usage for each type of oil and each piece of equipment
- requiring the installation of oil fill-line meters and requiring record-keeping and formal notice of unusual use
- for a large plant, assigning responsibility to the production and maintenance departments to account for oil losses during their shift
- requiring routine maintenance checks and follow-up record keeping
- keeping production line foremen constantly involved in conservation
- investigating separate after-use storage for some types of special or expensive oils and oils used in large quantities. Separate storage of these oils simplifies reclamation procedures and improves reclamation economics.
- identifying those oils that have potential for being reused directly for other applications with less stringent quality requirements than the original use. For instance, quenching oils, may be used for rustproofing.
- before buying new equipment, specifications and design should be reviewed in light of overall plant oil use and recycling program
- preparing monthly or quarterly computer printout tally sheets of oil consumption by department, oil types and perhaps by production line.

The above may be aided by using the survey sheets shown in Tables 22-25. Table 26 describes the major functions of the plant survey.

RECLAIMER

The reclaimer picks up oil emulsions of varying concentrations from 5-95% oil, and at a cost of \$10-\$20/gal; heat, acid and polymer are added breaking the emulsion and forming a 95% oil concentrate.

The 95% oil concentrate from in-house processing and 95% oil concentrate purchased from outside sources is then treated with earth and clay and the solids filtered out. This costs about 5¢/gallon and produces a 99.9% oil concentrate. This concentrate is worth \$0.70 - \$1.50/gallon (av. \$1.10/gallon) and it may be sold as fuel, sold as gear cutting fluid or further processed.
The 99.9% oil concentrate is vacuum stripped (medium temperature re-refining at 550°F) producing a 99.99% oil at a cost of about 30¢/gallon. The value ranges from \$1.50-2.20/gallon (average \$1.80/gallon) and may be sold as base stock for new lubricants or fluids or also as fuel. About 20% of the volume consists of light and heavy ends; the light ends are sold as kerosene and the heavy ends sold as road tar or asphalt.

Fluid recycling flow and costs are given in Figures 20 and 21.

Re-refiner revenue is often 3-4 times the cost of purchasing and processing waste oils.

Some reclaimers/refiners also run a "laundry" type operation. The re-refiner may add additives (rejuvenate) to fluids that are to be sold back to the plant they originated from. This may cost 10-65¢/gallon for hydraulic oils and even higher for the expensive additives for rolling fluids. These rejuvenated fluids are generally sold back to the user at anywhere between \$0.70-\$1.00/gal. for hydraulics and from \$1.00-3.00/gal. for rolling oils.

Figure 20

Fluid Recycling Flow

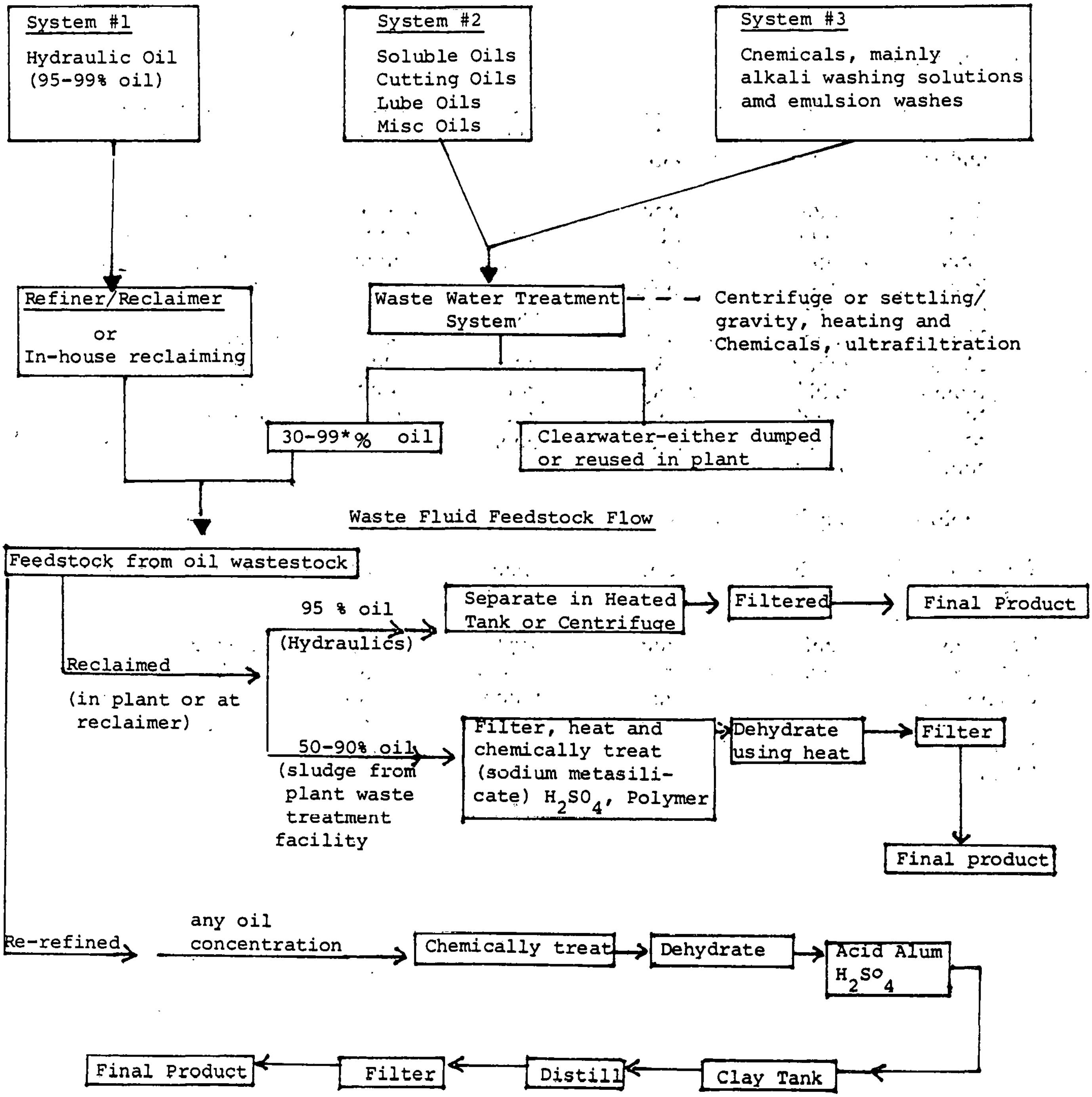


Figure 21

Fluid Recycling Costs

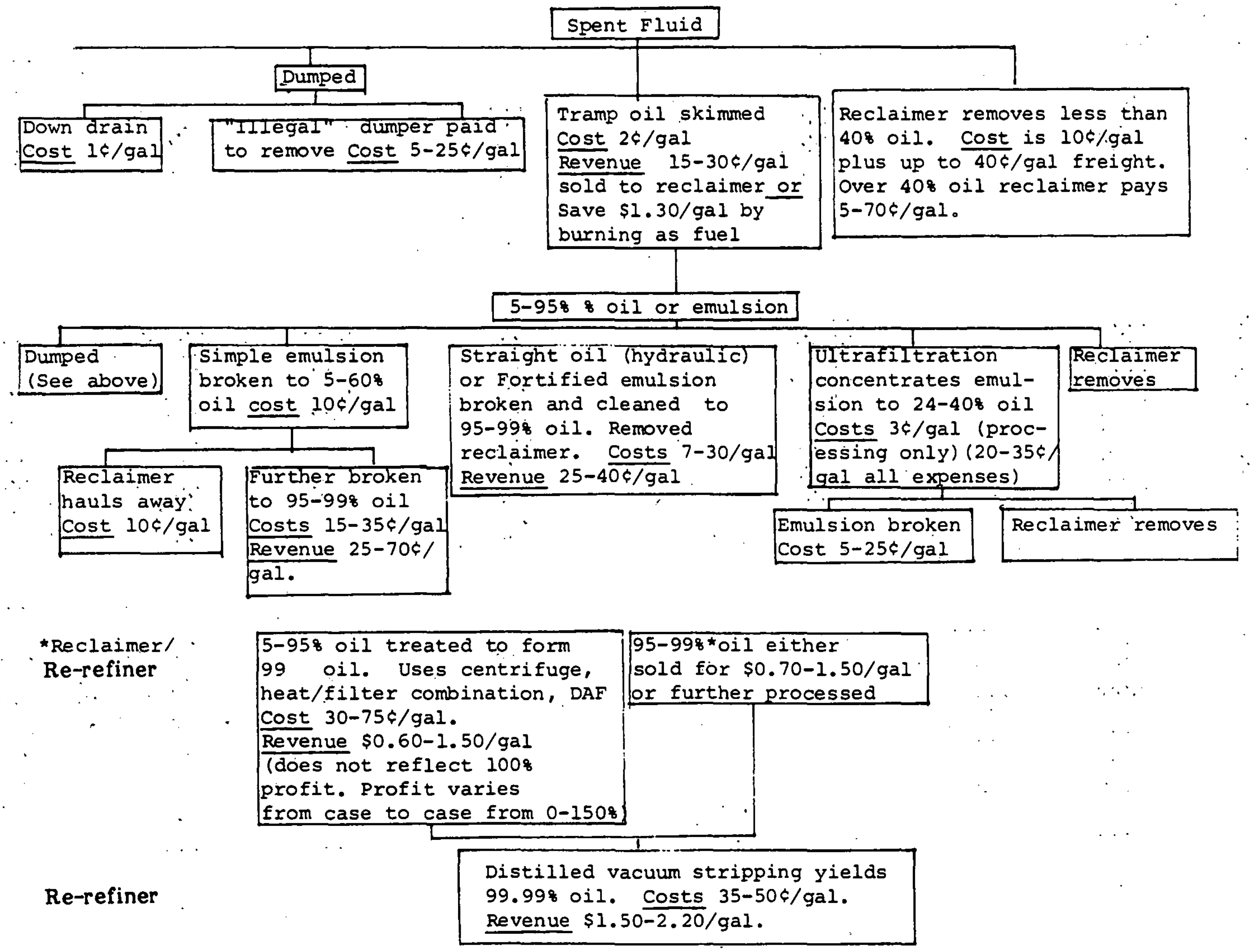


TABLE 22

OIL USE SURVEY

MONTH:[1]
DEPARTMENT:
SURVEYED BY:

Machine/Process		Production in Units $(\times 10^3)$	Oil Used As			Amount Used		Reasons for Abnormal Use, if Any[4]	REMARKS
Type[2]	No.[2]		Lubricant	Coolant	Other	This Month	Last Month		

[1] If not available on a monthly basis use most appropriate time period.

[2] Drill press, lathe, rolling mill, etc.

[3] Serial number of any other number for identification purposes.

[4] Some of the reasons for abnormal use can be oil leaks, spilling, inefficient filtering or other machine problems.

Source: Yates, J, ETA Engineering, Inc., Paper presented November 20, 1980, Alternatives to Industrial Fluid Disposal Seminar, Des Plaines, Ill.

TABLE 23

OIL REUSE AND DISPOSAL SURVEY

MONTH:
DEPARTMENT:
SURVEYED BY:

Used Oil Generated		Percentage Collection Efficiency[2]	Quantity Reused or Disposed of According to Method							REMARKS
Type[1]	Qty		In-Plant Use		Outside Re-refining	Outside Reprocessing		Waste Collectors	Others Specify	
			Fuel Oil	Reclaiming		Fuel Oil	Lubricant			

[1] Type stands for the type of new oil the use of which has resulted in that used oil.

[2] Quantity of used oil expressed as a percentage of new oil used. Quantities of new oil used can be taken from survey sheet on New Oil Inventory Accounting.

Source: Yates, J, ETA Engineering, Inc., Paper presented November 20, 1980, Alternatives to Industrial Fluid Disposal Seminar, Des Plaines, Ill.

Table 24

ECONOMICS OF OIL REUSE AND DISPOSAL

MONTH:
DEPARTMENT:
SURVEYED BY:

Used Oil Generated		Cost/Benefit Data for Recycling and Disposal Through[2]						REMARKS
					In-Plant Use[5]		Other	
Type[1]	Quantity	Waste Collectors[3]	Re-refiners[4]	Reprocessors	Fuel Oil	Lubricant		

[1] Type stands for the type of new oil the use of which has resulted in that used oil.

[2] Indicate the net saving per gallon for relevant method(s) of disposal.

[3] If collector was paid for hauling the material, use negative sign before the number to denote cost.

[4] If sale to re-refiner was made on the understanding that the material would be sent back to plant after re-refining, indicate net savings by using re-refined oil instead of new oil. Otherwise indicate the sale price.

[5] Indicate saving/gallon realized by using re-refined oil instead of new oil.

Source: Yates, J, ETA Engineering, Inc., Paper presented November 20, 1980, Alternatives to Industrial Fluid Disposal Seminar, Des Plaines, Ill.

Table 25

NEW OIL INVENTORY ACCOUNTING

MONTH:
DEPARTMENT:
SURVEYERD BY:

OIL TYPE	Quantity of Oil Used		Quantity of Oil Used During the Month			REMARKS
	This Accounting Period	Last Accounting Period	Normal	Above Normal	Below Normal	

Source: Yates, J, ETA Engineering, Inc., Paper presented November 20, 1980, Alternatives to Industrial Fluid Disposal Seminar, Des Plaines, ILL.

TABLE 26

Major Uses of Suggested Plant Surveys

Oil Use Survey	Oil Reuse and Disposal Survey	Economics of Oil Reuse and disposal	New Oil Inventory Accounting
-Identifies and compares oil use for individual machines. -Provides information on machine performance with regard to its oil consumption overtime. Any abnormality in oil usage will suggest further investigation into possible causes. -Production data, such as number of parts produced provides a base for comparing oil consumption for various machines performing similar functions.	-Identifies the quantities of used oil disposed of by various disposal methods. -Incicates the percentage of new oil being collected as used oil. -Analysis of used oil disposal data can suggest ways to improve present used oil disposal program and to reduce plant costs (waste collection costs, sewage treatment costs, etc.).	Gives a comparison of basic cost/benefit data for various used oil disposal options. -Analysis of these data can help the management in deciding on an optimum used oil recycling and disposal program.	-Provides a check on the new oil consumption over time. -Ensures that a proper inventory accounting is being carried out for new oil.

Source: Yates, J, ETA Engineering, Inc., Paper presented November 20, 1980, Alternatives to Industrial Fluid Disposal Seminar. Des Plaines, Ill.

SECTION VI

DISPOSAL AND RECLAMATION IN FOREIGN COUNTRIES

FRANCE - GENERAL SITUATION

The bulk of the metalworking fluids in France are used in high-quality metallurgy.(46) Many of the companies incinerate used oils; however, the large automobile manufacturers like Renault are working on an ultrafiltration process. Renault is already using this process in some parts of the plants to recover oils from the emulsion type metalworking fluids.

Generally, the emulsions are sent to official treating centers. Oil-regeneration capacity of France is approximately 150,000 tons.(47) Both in 1979 and 1980 approximately 90,000 tons of oil were regenerated.(48) The most commonly used method of regeneration is the acid-clay process. Regeneration of oil can be done only with government approval.(49)

FRANCE - DISPOSAL AND RECLAMATION TECHNIQUES

The processes in use and/or under investigation to treat metalworking fluid emulsions are:

- chemical to destablize the emulsion
- separation by heat
- separation by mechanical means

The various processes are discussed below.(50)

Shell Process

The Shell process is based on studies conducted by Meijs and Mitchell, who carried out a systematic study to establish the efficiency of quaternary ammonium salts.

In the Shell process, dodecylbenzylhexadecyldimethyl ammonium chloride is used together with cationic polyacrylamides. These are used at the minute concentrations of 10 and 20 ppm. The treatment is done in about a 15-minute cycle. In a natural decantation step, the oil content decreases from 1,000 to 70 ppm respectively.

Roques Process

This is a laboratory process developed by Professor Roques of France. The process is studied by some companies in France. It is a batch process which utilizes the destabilization of the emulsion with the help of synthetic polynitrogen products. For an emulsion of 5% oil, very small quantities of said compounds are effective: 1% based on the oil. This treatment yields a water phase with oil concentrations less than 2.5 grams/liter and a pH of 7. The process includes a purification with the help of activated carbon which in turn reduces the oil content to 0.2 grams/liter.

This process can be made continuous by the use of a mechanical separator. An advantage of the Roques process is that no salt is produced and the process is non polluting.

Fiat-Ireo Process

The destabilization of the emulsion is established by the addition of (31° Baume) sulfuric acid. The amount of sulfuric acid used is approximately 6.5 kilograms per m^3. In this process, the pH of the emulsion reaches approximately 1.5. To complete the destabilization of the emulsion, the acidified emulsion is heated to 80°C. The oil is recovered in a separator, and the acid water is then treated with caustic and then filtered with the help of a filter press.

The treated water passes through a heat exchanger to use its heat content for the preheating of the next batch. The treated water has an oil content of 10 to 30 ppm and a pH of 8.5.

It is estimated that, in addition to the cost of the chemicals, the process requires an energy of about 60 KWH/m^3, and about 2 to 3 hours of labor per 24-hour cycle.

There are approximately 50 of these units in use in Europe. They have a low capacity: 500 to 2,000 liters per day. The currently used process is a batch process; however, 500 to 2,000 liters/hour continuous installations are now under investigation and available on a commercial scale.

"First" Degremont Process

The Degremont company developed a batch process which can be used both to treat concentration of 2 to 5% and diluted solutions of 0.7 to 1.5 g/l.

The process is a sulfuric acid process followed by an aluminum sulfate treatment, and finally neutralization at elevated temperature. This yields a water phase of a pH between 6 to 8 and an oil content of 20 ppm.

Currently installations of the following capacities exist:

300 m^3/day
30 m^3/hour
80 m^3/week

The Degremont Process:

This process is commonly referred to as the "Degremont Process" and can be used for various concentrations: 2 to 5% down to 0.7 to 1.5 grams/liter. The process involves a treatment with sulfuric acid followed with a treatment with aluminum sulfate and a neutralization at elevated temperature.

In this process a water phase of pH 6 to 8 is obtained which contains 10 to 20 ppm oil. The process is a batch process.

So far three units are available in France: one with a capacity of 300 m^3/day, another with 30 m^3/hour and still another with 80 m^3/week.

Emulseri Seri-Renault:(50)

The emulsion is passed through water to achieve a high concentration of water. After the material is treated for improving the aging, two reactive materials are added:

- calcium or magnesium chloride to reduce the solubility of the hydrophilic fraction, and
- a coagulating agent like aluminum sulfate, ferric sulfate or chloride.

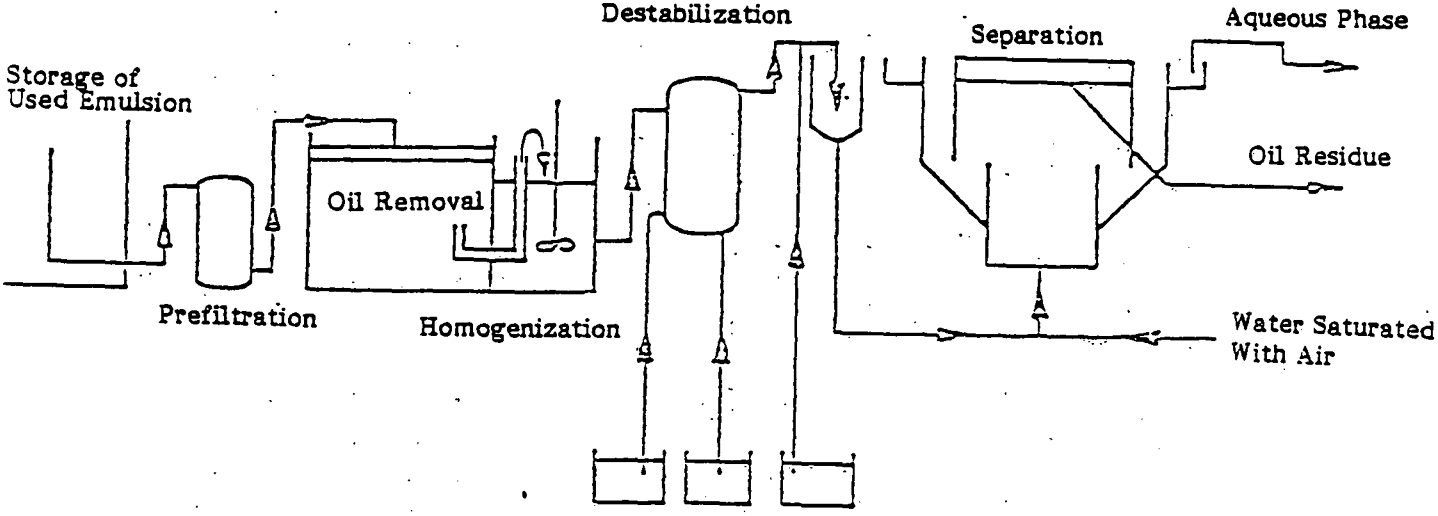
The separation of the two phases is accomplished by aeroflotation. A water phase of pH 5.5 to 8.5 is obtained with oil content less than 30 ppm. The oil phase, which represents about 4 to 5% of the total volume treated in the process, contains 30 to 40% oil and 10% other materials which stay in suspension.

Actual industrial installations exist in following capacities: (50)

100 m^3/day
310 m^3/day
20,000 m^3/year

The flow diagram of this process is shown in Figure 22.

Figure 22



Source: Deuxieme congres europeen sur le recyclage des huiles usagees, Paris, September 30 - October 2, 1980

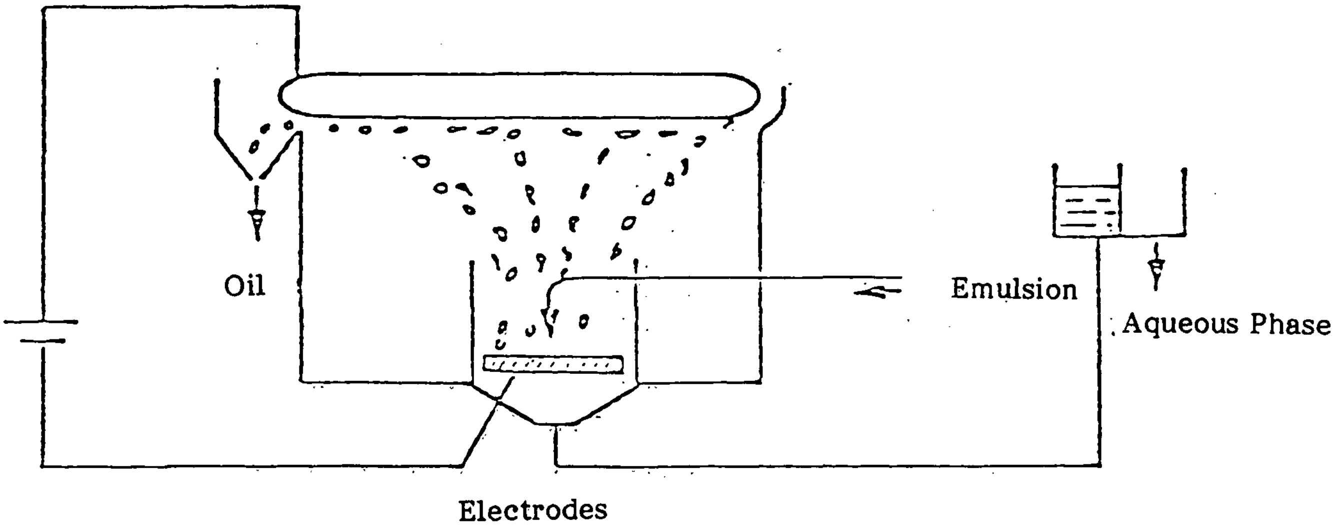
Saint-Gobain New Technique

An earlier technology of Saint-Gobain is not used anymore. This more recent method is referred to as S.G.N. (Saint-Gobain Techniques Nouvelles).

The emulsion is destabilized with the help of iron sulfate and the separation is done by airflotation at a speed of 100 m^3/hour.

The flow diagram of the S.G.N. process is shown in Figure 23.

Figure 23



Source: Deuxieme congres europeen sur le recyclage des huiles usagees, Paris, September 30 - October 2, 1980

Alfa-Laval/Westfalia

The emulsion is destroyed by the help of sulfuric acid and the separation is done by centrifuge. The water phase obtained by this method is purified by treatment with aluminum sulfate in the presence of polyelectrolytes in an alkaline media. After this, the liquid is filtered.

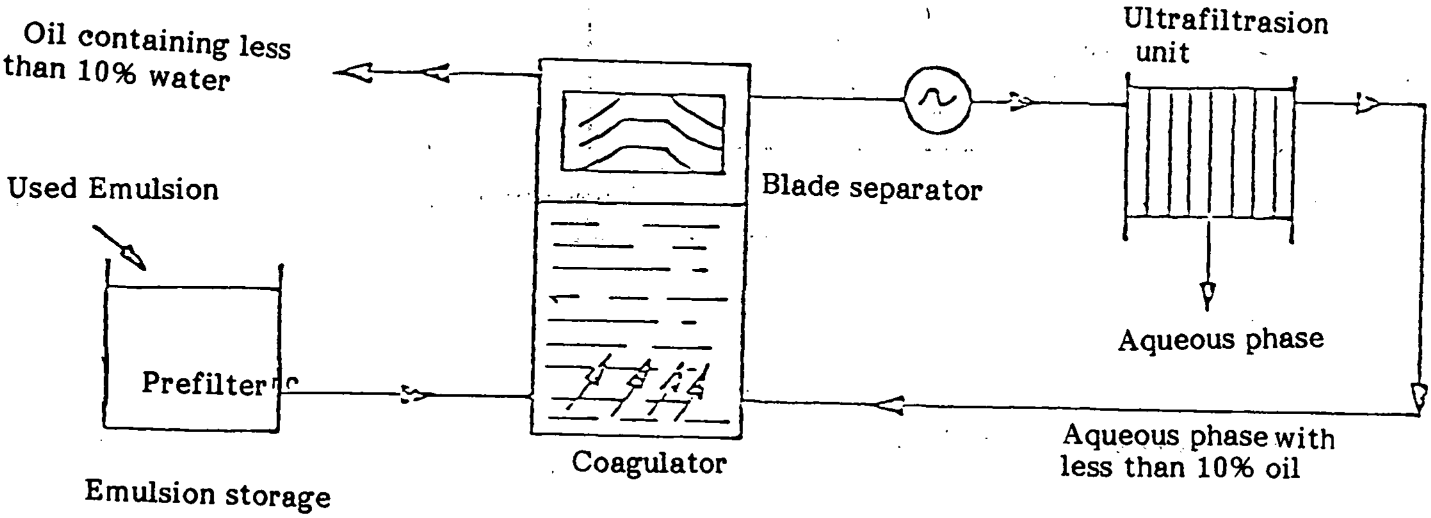
Rhone-Poulenc/Creusot-Loire

Rhone-Poulenc, a large French chemical company, developed a method based on membranes and ultrafiltration. In the commercial version of this process, the membranes have a capacity of 40 to 120 liters per square meter. A water phase is obtained which contains less than 20 ppm of oil.

The French company, Creusot-Loire, made an improvement by combining the Rhone-Poulenc process with a coagulator. The coagulator consists of ceramics on which oleophilic amines have been adsorbed. With the help of this arrangement, the oil can be extracted. This approach improves the efficiency of the original Rhone-Poulenc method and extends the life of the membranes.

The flow diagram of the Creusot-Loire process is shown in Figure 24.

Figure 24

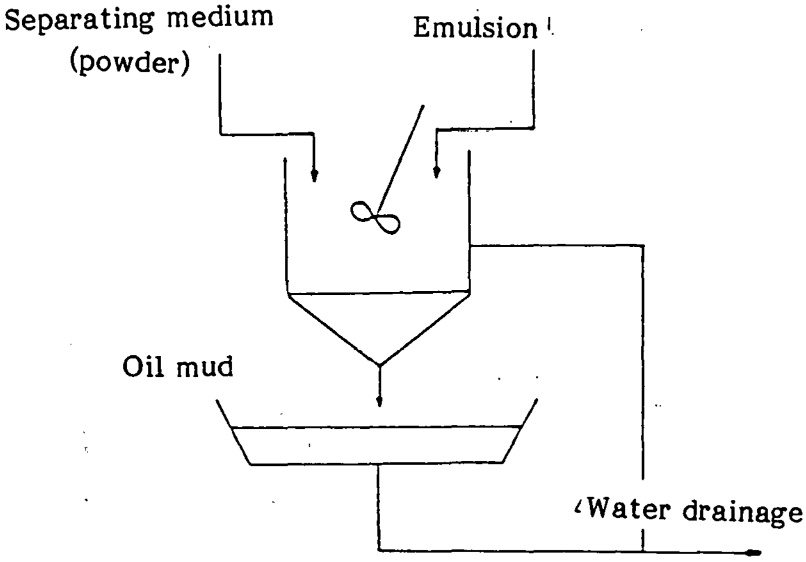


Source: Deuxieme congres europeen sur le recyclage des huiles usagees, Paris, September 30 - October 2, 1980

Separation by Adsorption:

In this process, a powder of high adsorptive capacity is added to the used emulsion as shown in Figure 25.

Figure 25



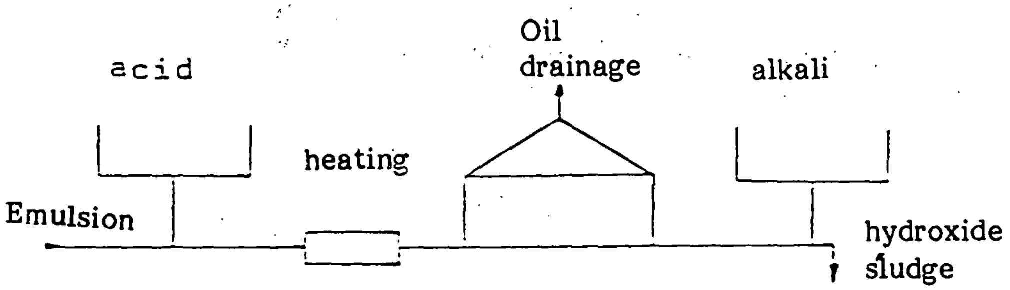
Source: VDI Richtlinie 3397/1

The best known process of this kind is the Degussa process. The destabilization of the emulsion is achieved by the addition of alkaline earth, and the separation by adsorption on hydrophobic silica. This treatment takes about 5 to 10 minutes. The sludge is filtered with the help of a filter press, and the oil cake is separated from the remaining clear liquid.

Acid Split

In this process, the emulsion is mixed with an acid which splits the emulsion.(52) The oil is separated from the water in a column, and the water is neutralized with an alkali. The small amount of hydroxide slush is removed by filtration. The simplified version of this process as used in Germany is shown in Figure 26.

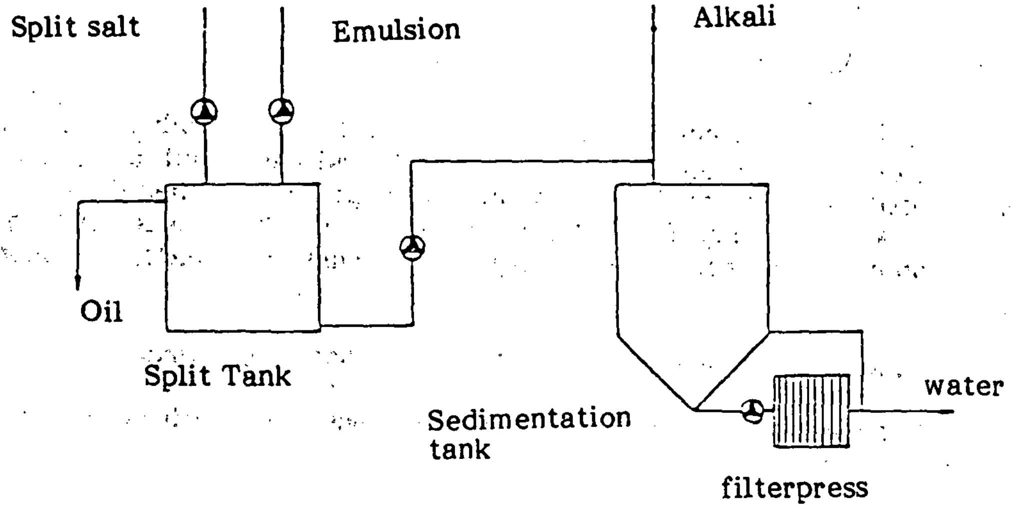
Figure 26



Source: VDI Richtlinie 3397/1

The emulsion when mixed with the acid can be heated to 90°C (approximately) and introduced into a separating column filled with silica. The silica accelerates the separation of the oil into a continuous phase, which is then removed from the top. This is actually a combination of the Degussa process. A more complex flow diagram of the salt-split process is shown in Figure 27.

Figure 27

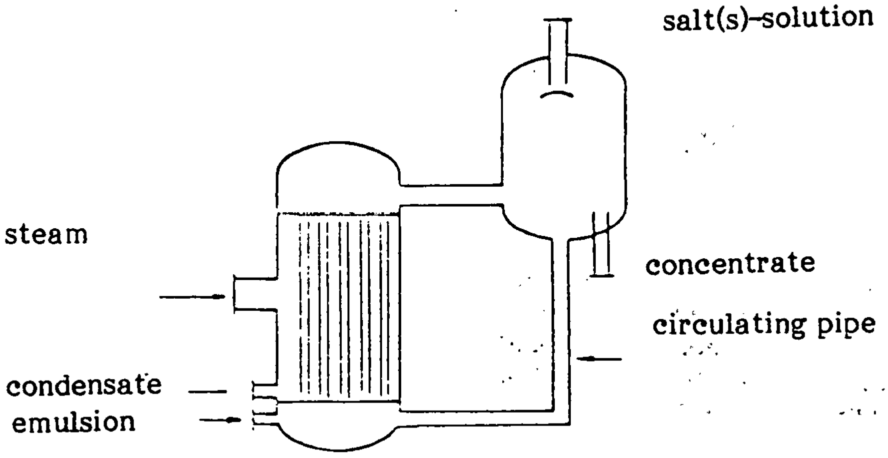


Source: VDI-Richtlinie 3397/1

Evaporating

The emulsion is heated in a circulating type unit. The concentrate is taken off by a pump and the oil is further dewatered in an evaporator. Flow diagram of the process is shown in Figure 28.

Figure 28



Source: VDI Richtlinie 3397/1

A typical example of this process is the Faudi process. The Faudi process involves the evaporation of water by an evaporator with several (different level) platforms. This gives best utilization of the energy since the oil phase furnishes the heat needed by the process. A preliminary filtration is applied to catch the oils which escaped. An active carbon bed is connected to the equipment which eliminates the odor of the water phase.

In the process a water phase of less than 20 mg. of oil per liter is produced.

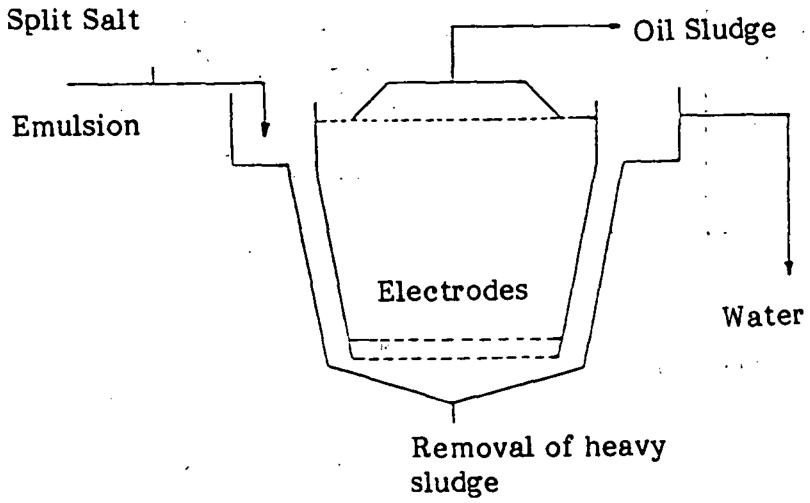
Completely automatic and continuous type installations exist with capacities of 250 to 3,000 liters per hour.

Electro-Flotation

In this process, the emulsion is mixed with salts which split the emulsion. The electrolysis intensifies the action of splitting the emulsion and also accelerates the floating of the oil to the surface. The oil sludge is continuously removed from the top. The water leaves the unit through a sludge-trap.

The simplified flow diagram of this process is shown in Figure 29.

Figure 29



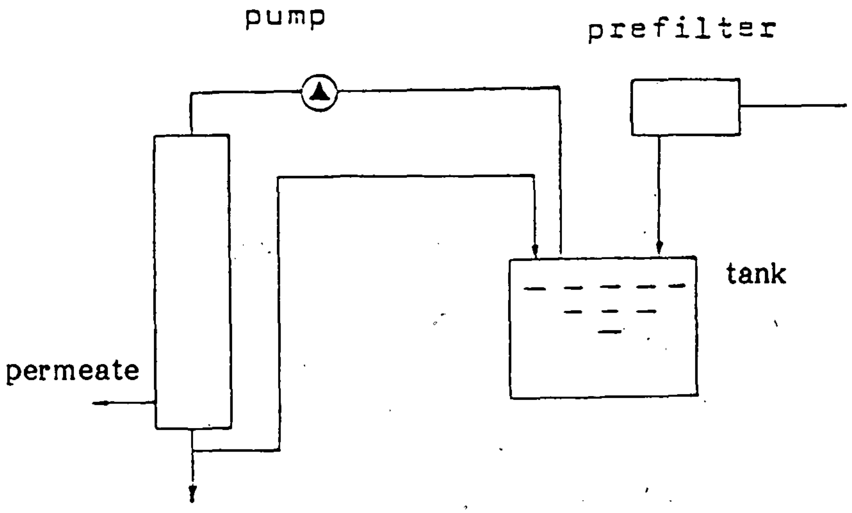
Source: VDI Richtlinie 3397/1

Ultrafiltration

Ultrafiltration is much favored in Western Germany. In this process, the emulsion is pumped through a semipermeable membrane (Modul) which retains the oil molecules and lets the water and dissolved salts pass. Through the continuous elimination of water (Permeat), the emulsion is concentrated to an oil content of 30 to 50%.

The membranes (Modul) consist of organic (cellulose acetate polyamide) or inorganic materials. They can exist in tube, capillaric or plate forms. To increase the efficiency, the filtration can be carried out at elevated temperatures; this is limited by the heat resistance of the "Moduls." The schematic flow diagram of this process is shown in Exhibit 30.

Figure 30



Source: VDI Richtlinie 3397/1

WEST GERMANY - PRACTICAL EXPERIENCE AND ECONOMY

As to waste materials, the thermo-treatment and ultrafiltration are viewed in Western Germany as the most favorable processes. The oil/water mixture produced by ultrafiltration (generally 30-50% oil) can be separated just by storing. By heating, this separation can be accelerated. The separated water phase is reused in the ultrafiltration process.

The acid and combined acid/salt split results in a hydroxide material. This is generated in modest quantities in the acid process, and in large quantities in the acid/salt process. The disposal of these is cost-intensive. This problem is quite a handicap and critical in the adsorption and electroflotation processes. In these, almost exclusively high-water content materials are produced. The high water content increases the cost of incineration as well as the disposal.

As to the recycling of the water produced in these various processes, it is economical and possible to use the water coming from thermo-processes and ultrafiltration in such applications as phosphating, galvanizing or the manufacture of metalworking fluids. This is not the case with water generated in the other processes since the salt content of such waters limits the uses. These waters can be used in such applications as degreasing baths or coagulating agents for spraying of lacquers. In the latter case, the salt content is actually an advantage. (53)

Until a few years ago in the Daimler-Benz (Mercedes) production plant combined acid/salt process and electroflotation were used exclusively.(54,55) Due to the relatively high maintenance costs of the oil slush, the company examined thermoprocesses and ultrafiltration. In considerable experiments and working together with universities, optimal processes were developed for metalworking fluids. As a result, the chemical processes have been replaced or supplemented by ultrafiltration. In one plant the evaporation process has been elected because here the metalworking fluids and rinse waters are strongly contaminated with chlorinated hydrocarbon solvents. Therefore, ultrafiltration would not be suitable since the module materials are on the market which can withstand these solvents.(56,57)

Table 27 summarizes the advantages and disadvantages of the aforementioned processes. Advantages are marked (+), disadvantages are marked (-).

Table 27

Advantages and Disadvantages of Various Processes

	1	2	3	4	5	6	7	8	10	11	12	13
									spezielle Anwendung bei Kuhlschmierstoffen A			
Kriterien	Investitionskosten	Platzbedarf (Hohe Flache)	Betriebskosten	Bedienungsaufwand	abhangig vom Kuhlschmierstoff	Reststoffentsorgung	Einhaltung Grenzwert Ol im Wasser	Wasserrecycling fur gleichen Zweck	in kleinen Mengen	und sauren oder alkalischen Wassern	mit Nitrit	mit Losungsmitteln
Verfahren												
Abfuhr	+	+	−	+	+	+	+	−	+			
Adsorption	+	+	−	−	−	−	−	−	+			
Elektroflotation	(+)	−	−	−	−	−	−	−		+		
Salzspaltung	(+)	−	−	−	−	−	−	−		+		
Saurespaltung	−	−	+	(+)	+	(+)	+	−		+	+	
Ultrafiltration	−	+	+	+	+	+	+	+				
Verdampfen	−	−	+	+	+	+	+	+			+	+

Code:

1 = cost of investment

2 = room requirement

3 = maintenance cost

4 = care needed

5 = dependence on the metalworking fluid

6 = disposal care of residues

7 = control of oil content of water

8 = water recycling for same purpose

A = special care with metalworking fluids

10 = in small quantities

11 = acid or alkaline water

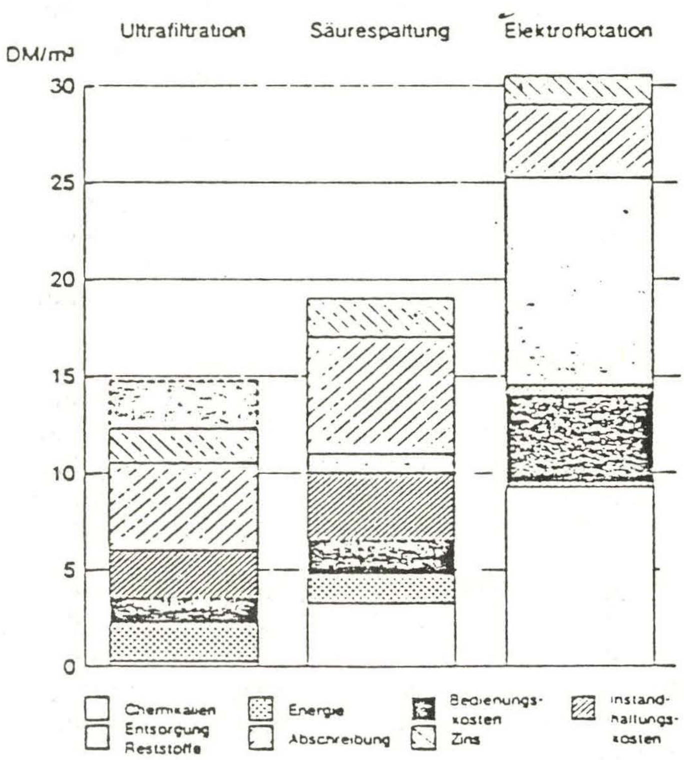
12 = with nitrite

13 = with solvents

Source: VDI-Richtlinie 3397/1

The cost balances of the three processes, ultrafiltration, acid-split and electroflotation are compared in Figure 31. The calculations refer to similar types of metalworking fluids (emulsions). To make these cost calculations comparable, all are based on an output of 2.0 - 2.5 m^3/hour.

Figure 31



Chemikalien = chemicals

Entsorgung = maintenance

Reststoff = residual materials

Abschreibung = depreciation

Bedienungskosten = operating costs

Zins = interest

Instandhaltungskosten - upkeep

Source: VDI Richtlinie 3397/1

ITALY

Since the 1960's, the re-refining industry in Italy has undergone considerable development with the erection of new plants and the expansion of those already existing.

As to the type of clay used in refining oils, Prout RF, a fast filtering clay made by Caffaro S.p.A. in Milan, is a good example. This clay has a high bleaching power and good capacity to absorb colloidal substances suspended in oils. The clay is produced in a plant located at Caffaro in Porto Marghera.

General characteristics of this clay are as follows:

Specific surface, sq.m./g.	220-290
Apparent specific weight	0.45-0.50
Humidity, %	8-10
Acidity, expressed as H_2SO_4%	0.030-0.060

The chemical people in Italy made the statement that, if the used oils are subjected to further treatment so that they lose the initial definition of "waste" and acquire that of "raw material", new base oils can be manufactured (re-refining). They further state that the base oil obtained by re-refining is today fully comparable with the base oil obtained by the direct refining of crude petroleum. Even with the most careful analysis there is no substantial difference between "new oil" and "re-refined oil."

According to Italian findings, the re-refining is highly economical. The process in fact gives about 70% yield: from 100 kilograms of used oil it is possible to obtain 65 to 72 kilograms of new base oil. According to Italian calculations (based on local conditions), the re-refining process is more economical than ordinary refining: the production of re-refined oils requires electrical energy about 1/5 as much as the production of refinery base oils.

JAPAN - PRACTICE OF DISPOSAL

After the expiration of the useful life, the emulsified and soluble metalworking fluids are changed, but old fluids are not allowed to be dumped in the environment. Effluent coming from industry sites is controlled by the central government ordinance, such as Water Pollution Prevention Act and Sewage and Drainage Act. In addition, there are local government regulations to specify respective restrictions.

Japan Industrial Standards Association (JIS) specifies the allowable chlorine and sulfur concentrations of the concentrates, which should not exceed 15% chlorine and 5% sulfur. This is to prevent disposal problems and pollution problems at disposal.

As far as hydraulic fluids and metalworking fluids are concerned, emphasis these days is on economical products and resistance to high pressure. To meet these requirements, additives are used on increased scale.

One concern that has been expressed is that additives in metalworking fluids and hydraulic fluids complicate the disposal of these fluids. This is especially important in view of the many emerging Japanese regulations.

Only water/ethylene glycol type hydraulic fluids are reclaimed. Our investigation indicates that no company is involved in the reclaiming of emulsified and/or soluble materials. All these, after they have served their purpose, are taken to two routes of disposal:

- In-house waste disposal facilities designed and built in compliance with respective local government regulations.

- Request an authorized (licensed) industrial waste disposer to take the material(s).

In disposing of the emulsified and soluble metalworking fluid the technical difficulty lies in breaking the emulsion. The common methods known to the industry to dispose of the emulsified and soluble metalworking fluids in Japan are:

- Emulsion breaking
    - Chemical treatment
        - Aluminum sulfate
        - Poly aluminum chloride
        - Ferric chloride
    - Physical treatment - osmosis

- Separated oil is brought to incinerator for burning (energy source of heating, etc.)

- The other part is precipitated with the help of caustic lime: Ca $(OH)_2$. The liquid is then processed through activated carbon by adsorption and dumped. Before dumping in the environment, the material is checked that the effluent is in compliance with government specified values.

- The precipitated slurry is brought to a vacuum filter and is taken as a cake for subsequent burning or dumping.

It is very difficult to assess the economics of the disposal of emulsified and soluble metalworking fluids in Japan, as one can get no data except for straight oil reclamation.

JAPAN - RECLAMATION OF OILS AND PROCESS FOR SAME

Reclamation of Straight Oils:

In Japan, the reclamation of industrial oil on commercial scale is performed only for straight oil. Only a limited number of oil reclaiming contractors are in existence; about 4 plants in Tokyo and its vicinity and 5 plants in Osaka area.

According to New Japan Fat and Oil Industry Co., a lubricant oil manufacturer and industrial oil reclaimer stated that they had processed the following used oils/lubricants.

Hydraulic fluid	34.3%
Compressor oil	13.8
General-purpose lubricants	9.2

Turbine oil	7.8
Metalworking fluid (non-emulsion)	5.1
Freezer oil	4.6
Hardening oil	4.6
Hydraulic fluid (water-ethylene glycol)	4.6

The same source indicated the bulk of what they had reclaimed was hydraulic and compressor fluids of the non-emulsified type. The reclaiming of the emulsified oils is considered by this source to be totally uneconomical.

The chief engineer of New Japan Fat and Oil stated that the above trend may be common to all other industrial oil reclaimers.

Reclamation Process:

a. Receipt of waste industrial oil
b. Primary inspection
c. Decision of reclaiming process
d. Elimination of sludge and foreign materials
e. Thermal treatment - dehydration
f. Sulfuric treatment
   (1) Sulfuric treatment
   (2) Neutralization
   (3) Clay absorption process
g. Emulsion breaking
h. Alkaline pretreatment
i. Absorption
j. Filtration
k. Dehydration
l. Silica-alumina adsorption
m. Deodorizing and degassing
n. Adjusting viscosity and adding additives
o. Final inspection

JAPAN - CURRENT PRACTICE AND COST CONSIDERATIONS

The current cost of reclaiming is discussed in Table 28:

Table 28

Cost of Industrial Oil Reclamation
Japanese yen per liter

Collection	3.40 - 6.90
Reclamation	13.70 - 27.50
Overhead	3.40 - 6.90
Depreciation	3.40 - 6.90
Total	23.90 - 48.20

Source: New Japan Fat and Oil Industry

The cost of new base oil is 100-110 yen per litre, so that the reclaimed oil is about one-third of that of new oil.

However, at this time the general demand of industrial oil reclamation is rather poor. A well-informed source told us that only very small quantities of waste industrial oils are brought for reclamation. This source estimates that less than 1% of the total of straight industrial oils (thus about 9,000 kilolitre) has been processed for reclamation.

Japanese users calculated that at the very dilute concentrations at which these water-systems are used, reclamation and re-refining are far from being economical; therefore, they do not bother. This is especially true with W-2 type materials in which case dilution causes such low working concentrations as 0.1 to 0.5%.

SECTION VII

FLUID MAINTENANCE AND RECYCLING IN THE UNITED STATES

GENERAL

Ideally, with proper fluid maintenance, soluble oil-water emulsions should last indefinitely. In practice, ideal conditions during cutting/grinding operations are not met, and degradation of the emulsion does occur after a time (the emulsion tends to split). If properly maintained and cleaned, there should be minimal fluid turnover.(42) Maintenance procedures are facilitated by restricting fluid use to one or two high quality fluids so that a central maintenance and treatment center can be effectively used. It has been estimated that good fluid maintenance will effectively reduce by 80% the volume of emulsion that must be broken or otherwise disposed of.(43)

Proper maintenance would include skimming or centrifuging off tramp oil, filtering out metal fines, or using liquid-liquid separators. (58). Once the emulsion has been cleaned, needed ingredients can be added, such as water, biocides, rust inhibitors and other additives. The skimmed tramp oil can be sold to reclaimers for 15¢ to 28¢ per gallon. (See Figure 32.)

However, addition of biocides, removal of tramp oil, and related methods of maintenance used in attempts to overcome the effects of coolant degradation may well be obsolete in light of newly developed, patented technology (59). Dealing with preservation and conservation of coolant rather than its disposal, it is so radical in concept that (until recently) only a small number of metalworking plants had put it to large scale use.

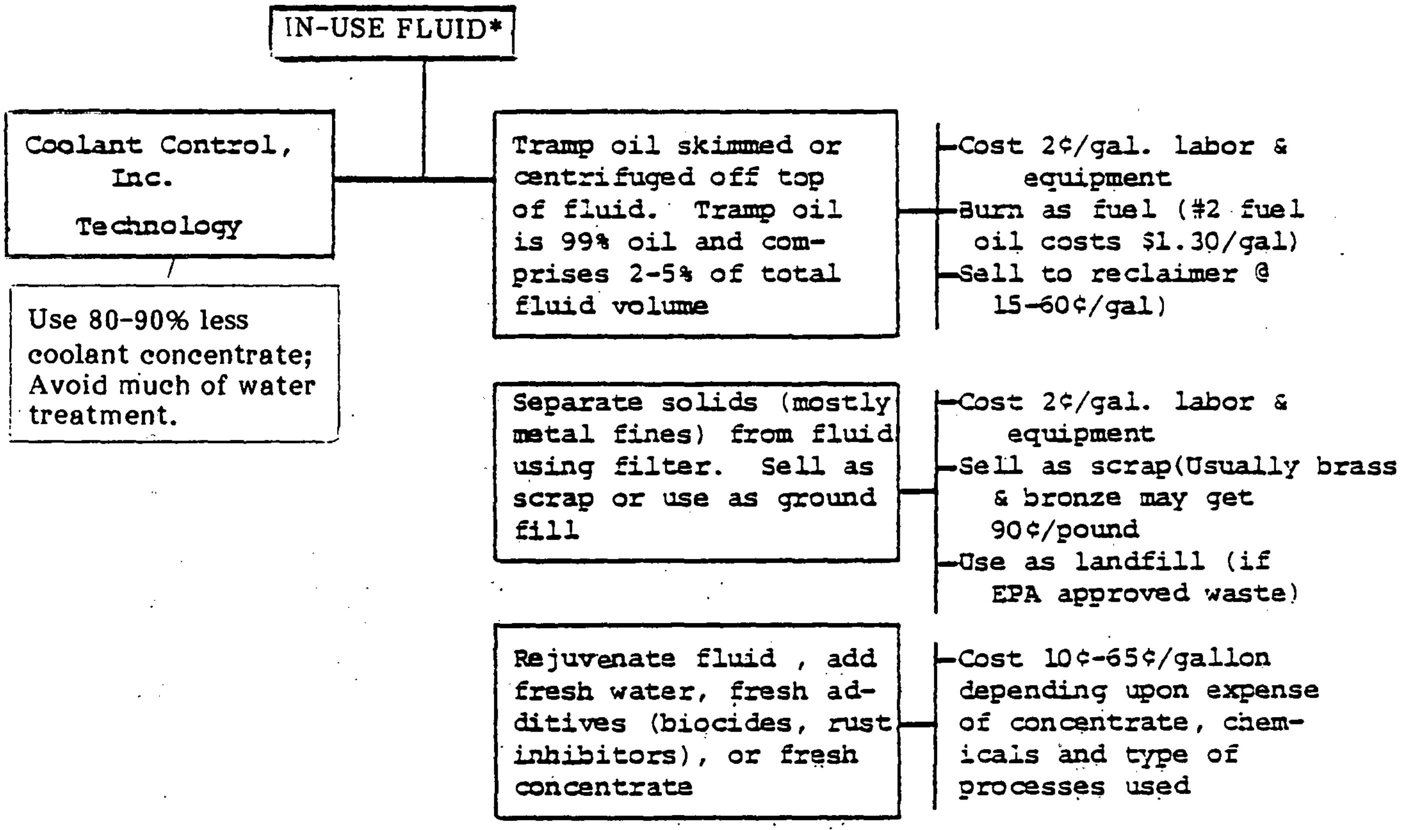
This technology, the Oxcedot Treatment System,™ involves the use of an emulsion stabilizing agent, disodiummonocopper (II) citrate, to balance the stabilizing forces and the destructive forces stressed in the coolant. Research in soluble oil coolants has demonstrated that coolant failure is a result of the destablizing of the emulsion and the weakening of the electrochemical bond between the oil and the water caused primarily by ions generated during the machining operations neutralizing the negatively charged oil and secondarily by hard water minerals, heat, and bacteria. (59, 60 61.) The mechanisms of metalworking fluid failure are depicted in Exhibit 33.

The Oxcedot Treatment System functions in the following ways: (59, 60)

- It coats the surfaces of emulsified oil particles to provide stability, superior lubricity and cooling, and protection from bacteria and charged particles, thereby eliminating the need for biocides and reducing the likelihood of dermatitis.

- It improves particle removal operations such as settling and filtration by preventing the combination of fines and other particles with emulsified oil.

Figure 32
In-Plant Fluid Maintenance and Recycling


IN-USE FLUID*

Coolant Control, Inc. Technology

Use 80-90% less coolant concentrate; Avoid much of water treatment.

Tramp oil skimmed or centrifuged off top of fluid. Tramp oil is 99% oil and comprises 2-5% of total fluid volume

- Cost 2¢/gal. labor & equipment
- Burn as fuel (#2 fuel oil costs $1.30/gal)
- Sell to reclaimer @ 15-60¢/gal)

Separate solids (mostly metal fines) from fluid using filter. Sell as scrap or use as ground fill

- Cost 2¢/gal. labor & equipment
- Sell as scrap(Usually brass & bronze may get 90¢/pound
- Use as landfill (if EPA approved waste)

Rejuvenate fluid , add fresh water, fresh additives (biocides, rust inhibitors), or fresh concentrate

- Cost 10¢-65¢/gallon depending upon expense of concentrate, chemicals and type of processes used

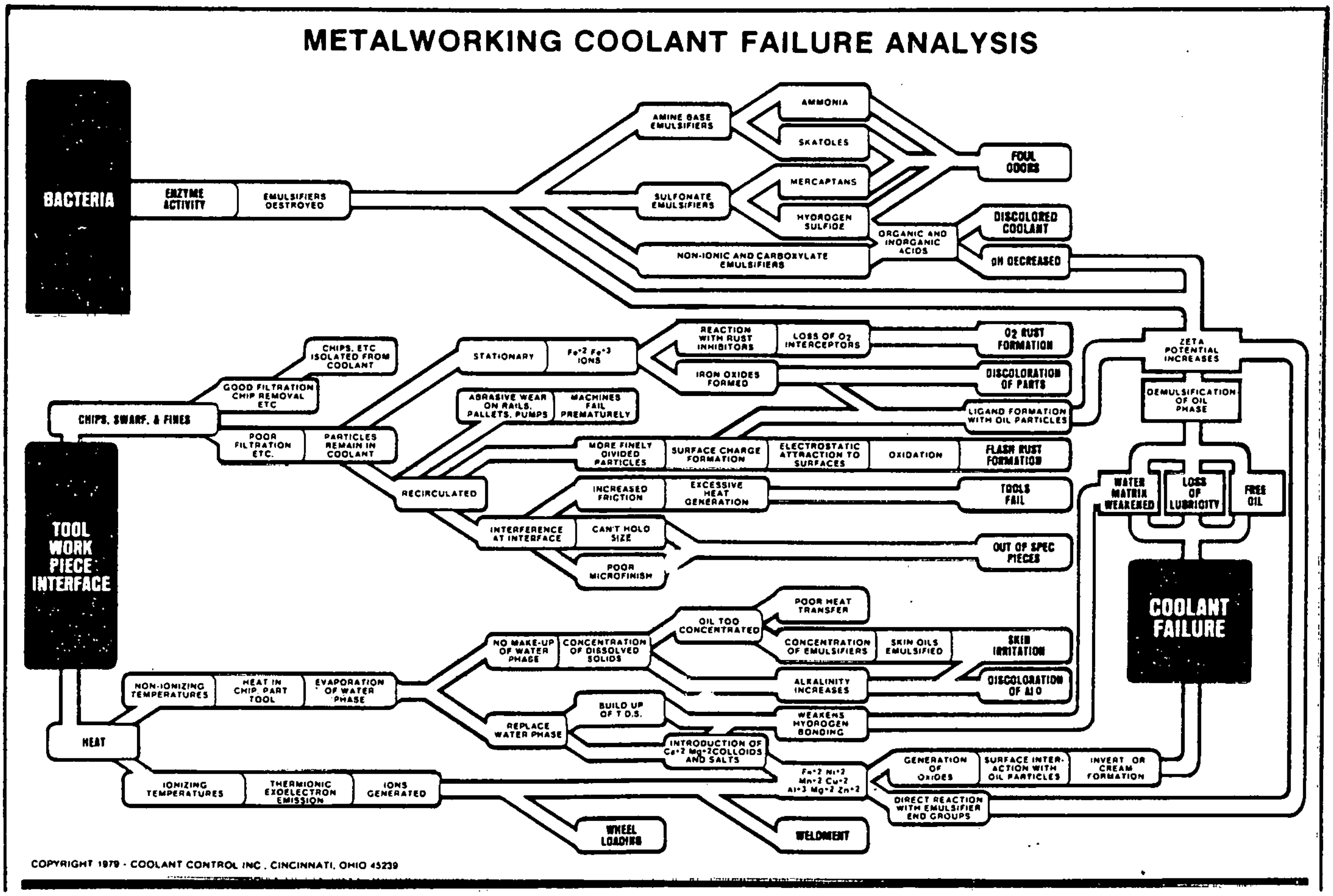
Total fluid maintenance
and recycling costs
range: 14¢-69¢/gallon

* Process	Cost (¢/gal)
Gravity settling	0.1-1.0
Cyclone centrifuge	0.1-1.5
Cartridge filtration	1.0-2.0
Flat bed paper	0.5-2.0
Diatomaceous earth	0.5-3.0
Chemicals	
Soda ash, borax	1.0-1.5
Biocides	1.0-5.0
Rust inhibitor	1.0-2.0
Other additives	2.0-10.0
Deionized water	1.0-2.0
Complete fluid concentrate	25.0-50.0

Labor & Depreciation

Add 5-25¢ per gallon

Figure 33



COPYRIGHT 1979 - COOLANT CONTROL INC., CINCINNATI, OHIO 45239

Source: Obrzut, J. J., Squeeze More From Cutting Fluids by Managing Them, Iron Age, December 17, 1980

- It eliminates the formation of odors due to the bacterial breakdown of coolants and netralizes odor-causing compounds such as hydrogen sulfide, mercaptans, and ammonia, e.g. hydrogen sulfide reacts with the cooper sulfide.
- It softens water by reacting with calcium and magnesium salts.
- It reduces soluble oil consumption up to 90% because oil does not adhere readily to chips and swarf, the split out of oil is minimized, and the need for dumping malodorous coolants is eliminated.
- It eliminates the tramp oil which is attributed to the split out of soluble oil caused by the neutralization of the emulsifiers so that in absence of hydraulic leakage there is virtually no tramp oil.
- It eliminates misting and smoking caused by partially demulsified oil.

The soluble oils can be easily broken and treated, but the new synthetics are another matter. These are chemicals, not oils, and a very sophisticated water-treatment plant is necessary. They are nonionic and hence unaffected by extreme acid or alkaline systems. Many are claimed to be biodegradable and are diluted to very low concentrations, then dumped; others are left for a period of time to degrade in ponds or tanks, but this is very expensive.

Manufacturers of synthetics say that, if properly maintained, synthetic fluids will last forever; however, end users say this is also claimed by the soluble oils. Hence, many are hard pressed to justify their purchase of synthetics. Although synthetics were first sold for light cutting and grinding applications, the major growth market today is hydraulic fluids, and since hydraulics represent the largest portion of the waste fluid market, synthetic fluid treatment will become more and more prevalent over the next several years.

EMULSIONS VS. STRAIGHT OILS

Straight oils and emulsions are treated slightly different during in-plant maintenance as outlined below.

Emulsions

1. Fluid is discharged from machine and either goes to a portable recycling system or is pumped to a central system handling several machines.

2. Large solids (dirt, metal chips, scrap) filtered out:

   (a) metallic filter (revolving magnetic drum) removes metal

   (b) cloth filters or paper filters (easiest to use, least expensive in the long run). Diatomaceous earth is used for oils, not solubles. Some prefer flat bed filtering to cartridge filtering as cartridges reportedly plug up faster. Large machine shops commonly use gravity setting or a cartridge filter and heat exchanger.

3. Tramp oil is removed if the generator produces enough fluid to warrant having a large tank for gravity settling. The process can be continuous or batch (tank contents settle at night or on weekend). A continuous system could be a 100,000 gallon tank but with only 40,000 gallons turnover, thereby allowing time for settling. A good tramp oil contains 99% plus oil and typically represents 10% (8-12%) of the dirty fluid. Tramp oil may be removed using a skimmer or belt loop or, if settling takes place in a cone tank, by bottom draining all fluid until only the tramp oil remains. Those that do not remove in-house have reclaimer remove entire fluid periodically.

4. Fluid minus filtered contaminants and tramp oil is pumped back to machine. Oftentimes biocides and rust inhibitors are not added as pH adjustment can be used to control bacterial growth and rust formation.

Straight Oils

1. Fluid discharged from machine as with "1" above.

2. Fluid is filtered or centrifuged and sent back to machine.

3. Fluid is treated further when water level exceeds some preset level (up to 10%).

   (a) sent out for water removal and cleaning.
   (b) portable service company performs removal in plant.
   (c) plant buys heated tanks and dehydrates fluid in-house.

4. Back to machine.

CLOSED LOOP SYSTEM

Increased fluid longevity may be achieved through the user's efforts to properly maintain the coolant. The user may attempt to integate components of different manufacturers into one system or may purchase a complete recycling system from one equipment manufacturer. (See Figure 34.)

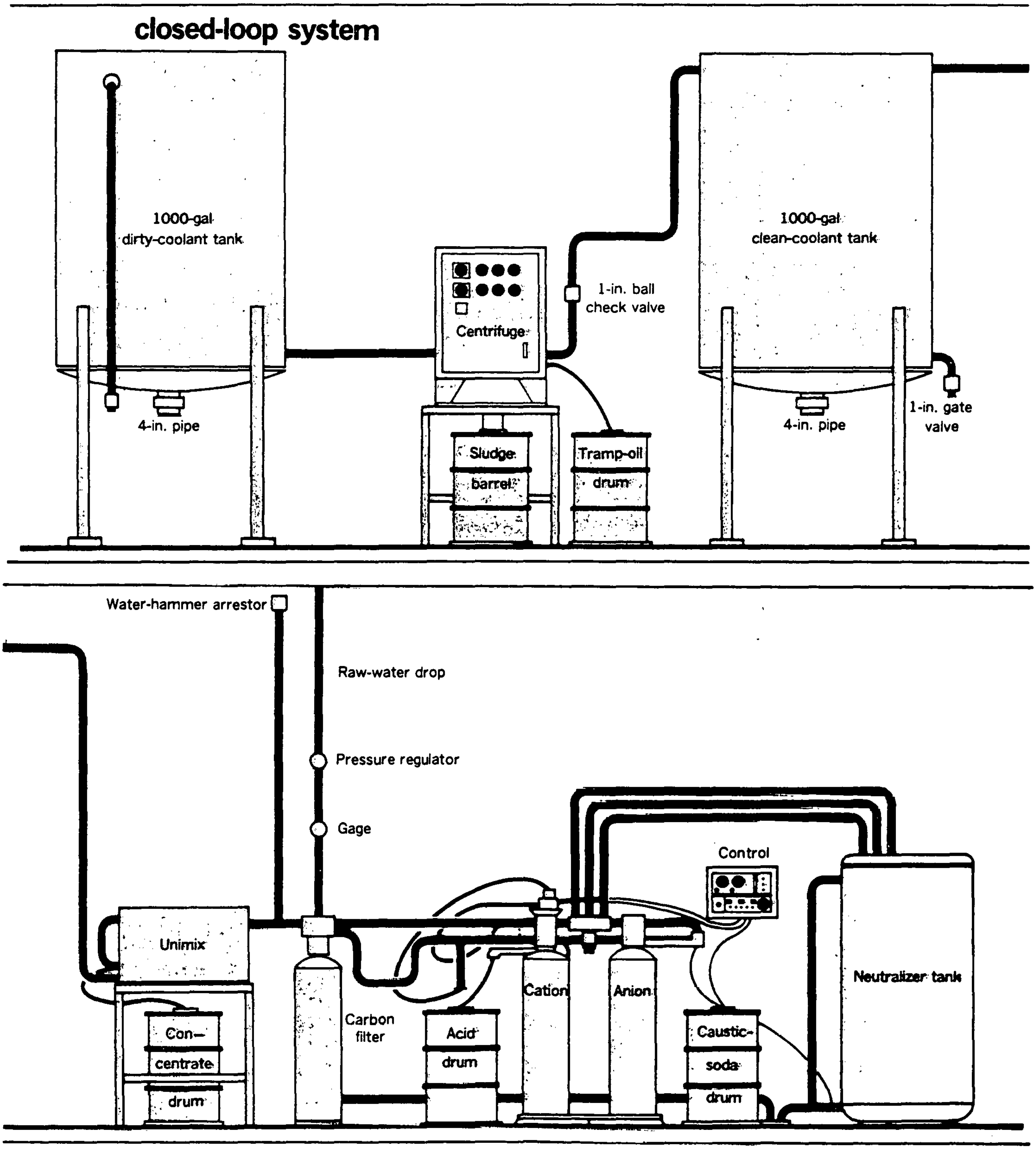
One manufacturer provides a closed-loop coolant recycling system, which operates in the following manner. (24)

1. The coolant passes through a filter and then into a dirty coolant storage tank.
2. After settling has occurred in the dirty coolant tank, the settled sludge is disposed of and tramp oil (other lubricating oil and hydraulic fluids that contaminate the metalworking fluid) is skimmed from the top of the tank. A centrifuge is employed to remove loosely emulsified tramp oil that has not settled out.
3. Cleaned coolant flows into the cleaned coolant tank and the necessary rust preservatives and bactericides are restored.
4. The equipment manufacturer encourages the use of deionized water. Cations and anions are removed by means of a filter, which contains resin particles that electrically attract oppositely charged ions. The central control unit recharges the resin particles with acid and caustic soda.
5. The neutralizer tank balances the pH of the effluents.

For plants with a total coolant pump capacity not exceeding 1,000 gallons, a smaller system is available. The system has a tank capacity of 250 gallons compared with a capacity of 1,000 gallons in the larger model.

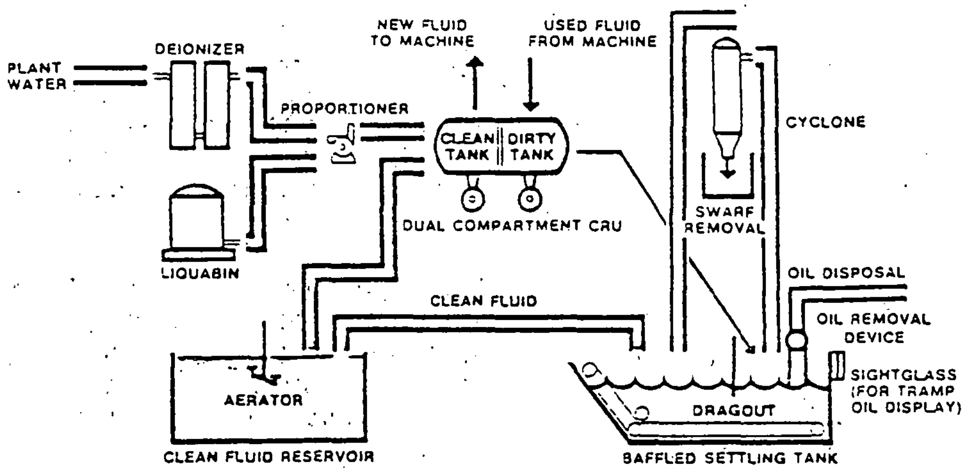
A similar system incorporating a recovery unit with other apparatus, such as a settling tank, a filtering device, skimmers and a centrifuge is depicted in Figure 35.

Figure 34

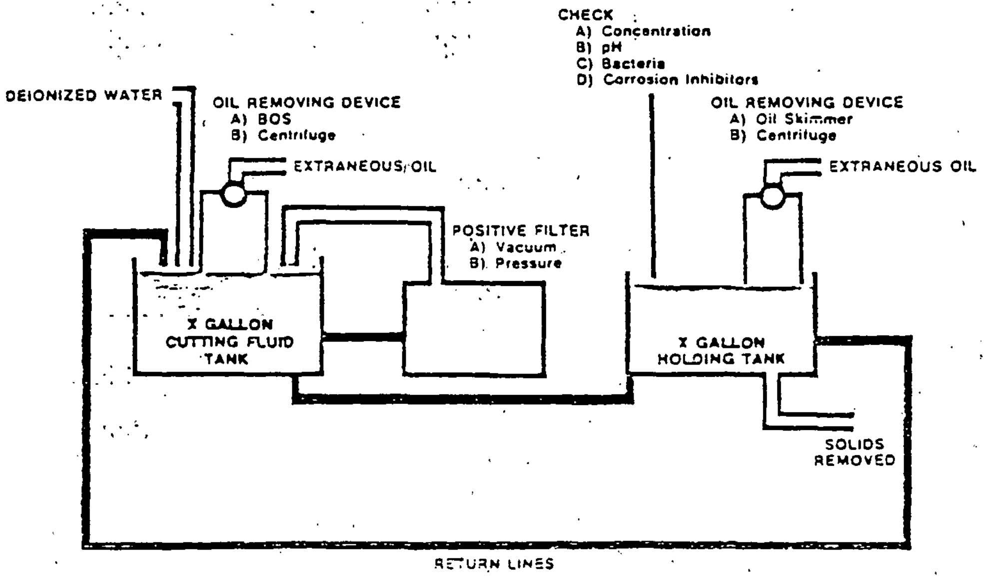


Source: Huntress, E., "Loop System Cuts Coolant Wastes", American Machinist, April, 1979

Figure 35



CUTTING FLUID RECLAMATION SYSTEM FOR INDIVIDUAL MACHINES



Source: Cincinnati Milacron Literature

USE OF PURE WATER

A key to good maintenance is the use of pure water (free of mineral salts, chloride and fluoride ions). The use of deionized, distilled or boiler condensate water will achieve this; however, defoaming agent additives should be employed, since there will be a greater chance of foaming. (62) It has been estimated that fluid usage may be reduced 30% using deionized water. Many equipment and fluid suppliers or users encourage the use of deionized water with their metalworking fluids. Others expressed the opinion that the use of deionized water was not critical and did not appear to be a factor in the selection of a fluid. It was estimated that approximately 10% of the users require deionized water.

Promoters of deionized water claim that the performance of industrial fluids is affected by the presence of dissolved minerals in untreated water. These dissolved minerals will increase the particle size of the fluid resulting in greater decomposition by bacteria, lower surface, area, lesser efficiency in the operation and greater separation from solution. In addition, minerals in water, such as chlorine, iron, and sulfates, cause corrosion and staining of metals. (63)

The hardness of water results in sticky residue deposition. Hardness of water may be attributed to the presence of calcium and magnesium ions and, on occasion, zinc, iron and aluminum may contribute to hardness. One grain of hardness is equivalent to 17 ppm of calcium carbonate per gallon of water. (See Table 29.) Deionization, which removes minerals by chemical absorption, is an effective means of eliminating hardness.

Table 29

The Degree of Water Hardness

Classification	HARDNESS ppm	 Grains per Gallon
Very soft water	less than 17	less than 1
Soft water	17 to 52	1 to 3
Medium hard water	52 to 105	3 to 6
Hard water	105 to 210	6 to 12
Very hard water	greater than 210	greater than 12

Source: Humnicky, Stephin, "Water Quality Factors on the Cost and Performance of Coolants", Society of Manufacturing Engineers

Further research has shown that water hardness plays a secondary role in destabilizing the emulsion, affecting only a small percentage of the total oil in the coolant. (61). Coolant failure is attributed primarily to particles generated during the machining operation. In addition, the technology is now available to soften water by means of the Oxcedot treatment method. (59)

TRAMP OIL REMOVAL

Tramp oil results primarily from split-out soluble oil and in some cases from hydraulic fluid leakage (62). Tramp oil will have a deleterious effect on the life of the fluid by:

1. Reducing the cooling effect
2. Impeding filtration
3. Causing loss of wetting
4. Stimulating growth of bacteria (24)

In addition, tramp oil contamination will interfere with titration methods for measuring the concentration of a fluid, yielding erroneous results.

It is the opinion of the majority that tramp oil in the range of 3-5% is acceptable; however, one manufacturer advocates reducing the level of tramp oil to less than 0.5%. (24)

Separation with a centrifuge is obtained by a force equal to 13,200 times the force of gravity. The selection of centrifuges includes both solid retaining and self-cleaning models. Manual cleaning requires a shutdown period and is facilitated by the use of a paper liner. Some models incorporate an electric heater, which is advisable when the oil does not have a low viscosity. (64)

Tramp oil may be removed by centrifugation or by means of gravity separation. It is estimated that the use of oil wheels, oil belts, and other skimming devices along with settling tanks may reduce tramp oil to 1.5 - 2.5%. Fluid is held in a tank for approximately one hour and is heated to about 160°F and floating oil is removed by skimming.

It has been estimated that the use of settling tanks and skimmers will remove a volume of 5-10 gallons/hour of tramp oil. The removal of particle entrained tramp oil will prevent damage to scale pit pumps and pipe on rolling mill operations. The skimmed material passes to a breaker tank where it separates into three layers. The top layer consists of tramp oil with fine solids, the middle layer consists of coolant and the bottom layer consists of sludge. In the breaker tank, sludge settles out at approximately 3-10 pounds/hour (65).

Centrifugation is expected to increase as a method of tramp oil removal. The centrifuge affords the benefits, which the gravity settling tank does not provide, such as conservation of floor space and rapidity of operation; however, a major disadvantage appears to be the cost of the equipment and the careful maintenance that is required.

Although several manufacturers advocate the use of centrifuges to remove solid particles which may be entrained in tramp oil, the centrifuge is employed primarily to achieve an acceptable level of tramp oil in the fluid. Centrifugation may reduce tramp oil to less than 0.05%. (24)

In emulsion the dispersed particles should be maintained at one micron or less, since as the size increases, the oil will float to the surface. (66) It has been recognized that tramp oil may clog cellulose, polypropylene or polyester filter media, making filtration difficult. Regardless of the methods employed, solid particle and tramp oil removal must go in tandem.

PARTICLE REMOVAL

Although centrifugation and settling have been discussed in relation to solid particle removal, filtration appears to be the most common means of removing solid particles. The selection of filtration method depends on cost, the type of contaminant present and personal preference.

Solid particles are composed of grinding-wheel fines and metal chips. Large chips, which originate from milling and drilling operations, are removed by settling systems. Operations requiring the machining of cast iron, aluminum, steel, brass or bronze employ settling systems. A system may incorporate tramp oil removal and solid particle removal, i.e., separator depicted in Figure 36. This particular separator may be employed when material is expected to settle out in five minutes or less; however, if longer settling time is necessary, adaptations may be made to allow greater retention time. The separator will clean coolant to 20 ppm with particle size less than 15 microns. (31)

Systems which allow the separation of solid material and removal by dragout are depicted in Figures 37 and 38. Large ferrous particles may be removed by a magnetic separator, which captures the particles. (See Figure 39). These particles, in turn, form a filter medium for removing other solid particles. The magnetic filter may be employed as a primary device for grinding, rolling, polishing and honing operations and as a secondary apparatus in drilling, hobbing, milling and broaching operations.(67)

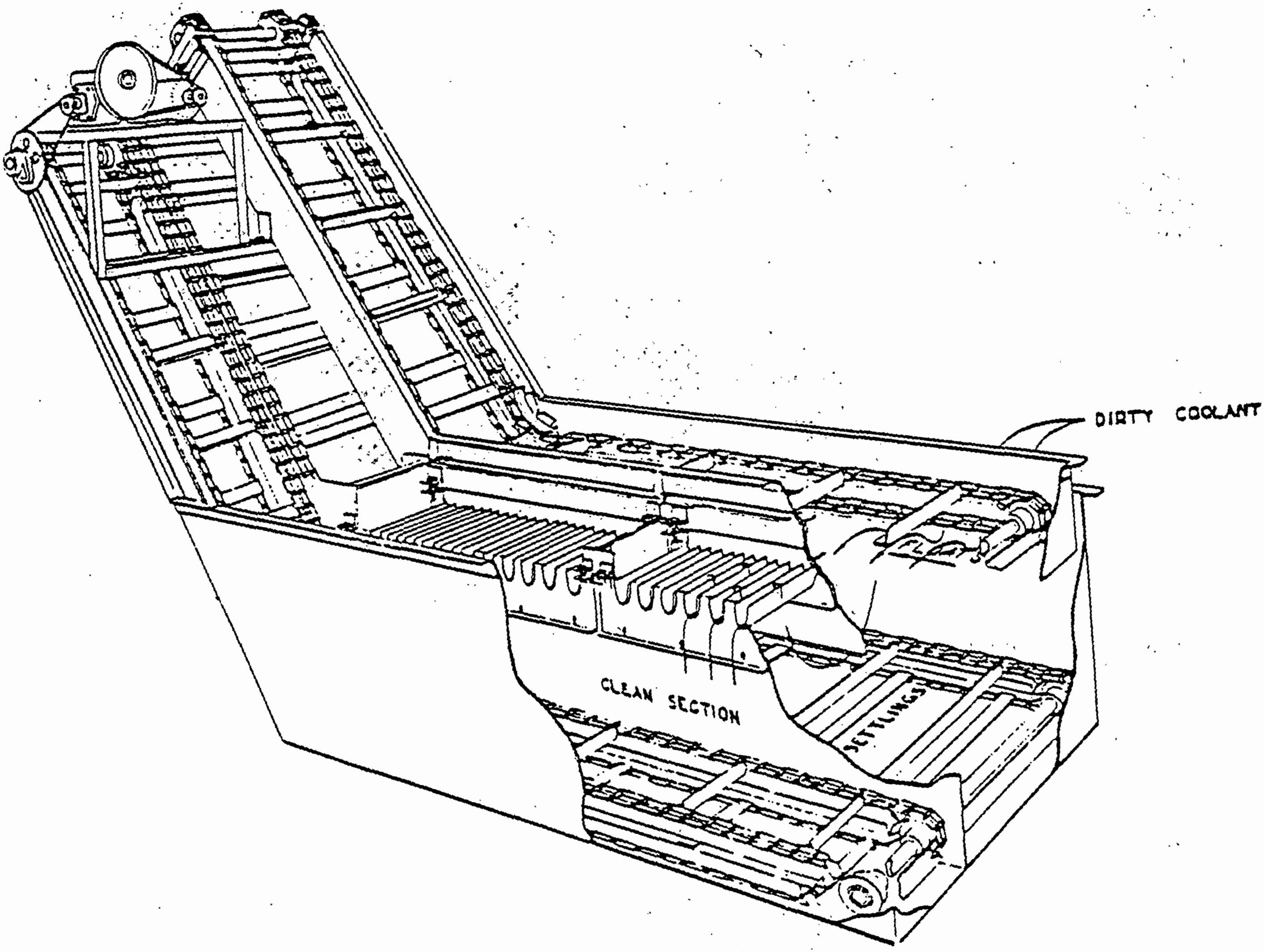
Smaller chips, which arise from grinding or surface finishing operations are usually handled by hydrocyclones or filters. The selection of a filter depends greatly on the contaminant present. A fine dust would require a medium that may be regenerated or replaced, i.e., paper or cloth. A vacuum filter of pleated polyester, which is capable of handling particles up to 10 microns, has been recommended. The use of a hydrocyclone for smaller chips has also been mentioned. It has been estimated that hydrocyclones are capable of reclaiming particles larger than 20 microns in size with a flow rate ranging from 100-600 gallons per minute.(67)

Some filters are estimated to have the capability of handling 10-10,000 gallons per minute with particle removal to 1 micron. (68) Vacuum filters operate by employing a vacuum under the media which draws the particles to the media. The pressure filters require a pump, which feeds fluid to the media. Generally, pressure, vacuum and hydrocyclone equipment are not capable of handling material smaller than 5 microns.

Cartridge-type filters are available for smaller loads of particles. "Cartridge" is a broad term for a self-contained device which has a filtering medium that may be replaced or regenerated. These filters may contain paper, fiberglass, wool, cotton,

Figure 36

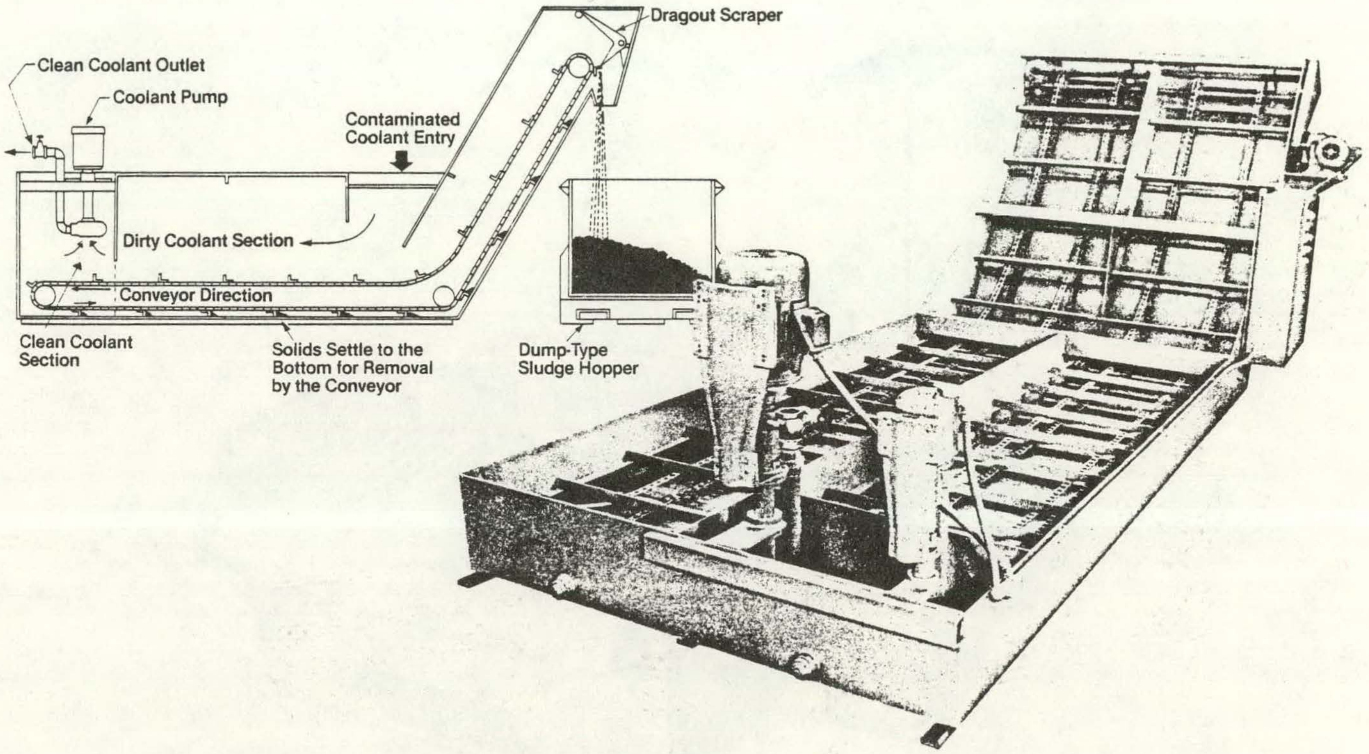
Chip and Oil Separator



Source: Henry Filters

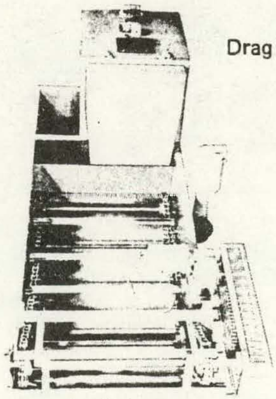
Figure 37

Settling Tanks With Dragout



Source: Polyclon, Inc.

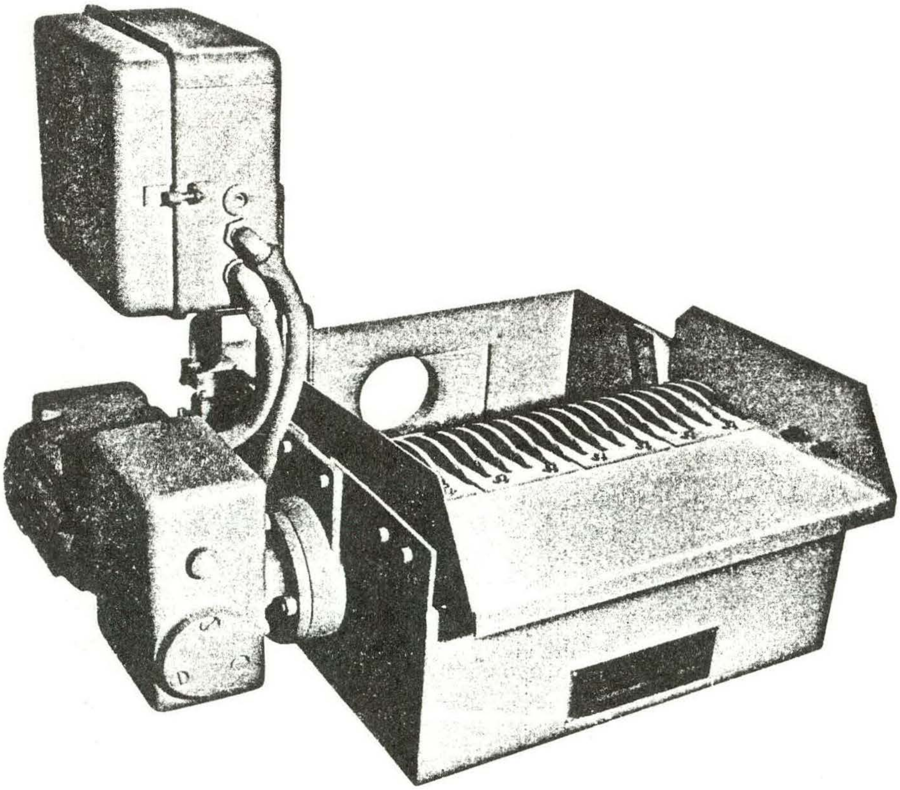
Figure 38



Source: Monlan Corporation

Figure 39

Magnetic Separator



Source: Polyclon, Inc.

etc. Paper and fiberglass have been recommended for soluble oils, fiberglass for amorphous contaminants and paper for granular and metallic contaminants. Hydrocyclones and cartridges are often used together, with the hydrocyclone removing larger particles and cartridge for finer filtration. Another type of filter, wedge wire, allows the metal chips to perform the actual filtering. The wedge wire filter is a screen of wires with triangular cross sections which support the collected chips.

Paper filters are used for soluble oils and are considered acceptable for filtering steel, aluminum and brass. However, paper is viewed by some as being too expensive.

Very fine material arises from honing or superfinishing operations. Filtering very fine material requires the use of a pre-coat filter, which is a pressure filter using diatomaceous earth. A pre-coat filter is necessary for removing particles less than 5 microns in size. Pre-coating is the application of material such as diatomaceous earth, fuller's earth, etc., on the media prior to filtration.

The various oil recycling devices are discussed in Table 30. (58)

MAINTENANCE AND HEALTH PROBLEMS

Selection and Maintenance of Fluids

Known occupational hazards associated with cutting oils include eye irritation, pneumonitis, skin sensitization, acne and folliculitis. Occupational exposure may also result in keratosis, malignant dyskeratosis and squamous cell carcinoma.

Contact dermatitis results from prolonged immersion in watery or oil solutions. Solvents, emulsifiers, soaps and detergents seem to increase the possibility of dermatitis and defat the skin. Keratolysis of the upper layers of the epidermis results from using a cutting fluid with an alkaline cutting oil, pH 9-12. Some dermatitis is a result of allergic sensitization to the germicides, rust inhibitors, nickel salts and chromates. The emulsified oils may also block hair follicles, leading to folliculitis. Studies show that following folliculitis, the skin may become hyperpigmented. If chlorinated hydrocarbons are present, chloracne may occur. (69)

In extreme cases, malignant tumors and benign papillomas may be attributed to the use of certain oils. To avoid these conditions and other occupational dermatoses, it is recommended that personal protective equipment, including gloves and barrier creams, be employed. (69)

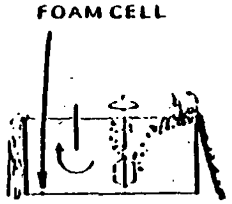
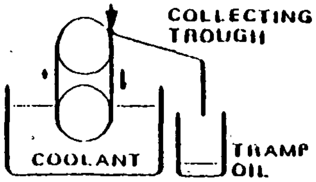
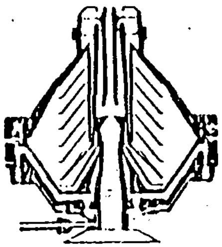
Dermatitis has been associated with a number of possible sources in cutting oils: (24, (70)

1. Cutting oils themselves, which cause irritation.
2. Improper mixing.
3. High alkalinity.
4. High acidity.
5. Solvents.
6. Metals such as chromates, zinc and cadmium.
7. Breakdown in the presence of water.
8. Improper bactericides.

Table 30

INDUSTRIAL FLUID MANAGEMENT

COMPARISONS OF PURIFYING EQUIPMENT

UNIT	ADVANTAGES	DISADVANTAGES
 Aeration Device	1. Can be combined with settling tanks for fine particle removal 2. Inexpensive	1. Cannot remove coarse particles 2. Will not remove tramp oil
Belt Skimmer 	1. Removes floating tramp oil and some solids 2. Inexpensive	1. Will not remove dispersed tramp oil 2. Will not remove fine particulate matter
 Centrifugal Purifiers	1. Removes floating and dispersed oils 2. Removes fines down to 5 micron	1. High investment cost 2. Limited dirt capacity 3. Disposal of sludge & tramp oil 4. Prescreen of feed needed to protect the centrifuge bowl from large, abrasive, contaminant particles

Source: Hyde Products, Inc.

Table 30 (continued)

INDUSTRIAL FLUID MANAGEMENT

COMPARISONS OF PURIFYING EQUIPMENT

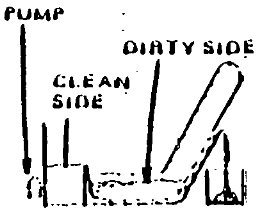
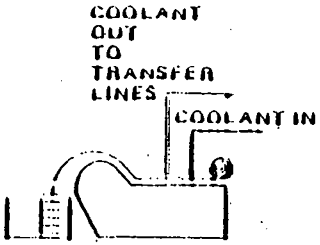
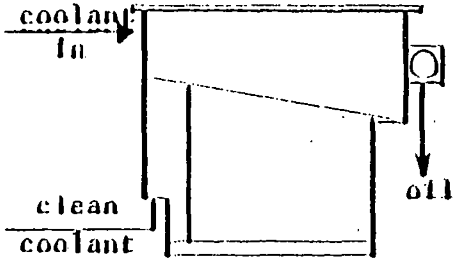
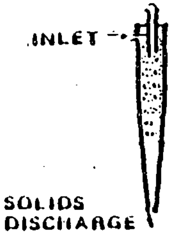
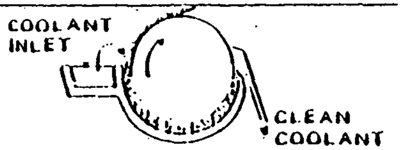
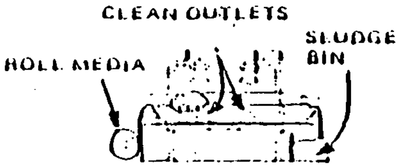
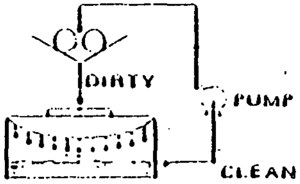
UNIT	ADVANTAGES	DISADVANTAGES
 Flight Drag Settling Tank	1. Simple 2. Inexpensive 3. Removes large particles	1. Slow 2. Large floor space 3. Small particles will not settle out 4. Entrained tramp oil will not separate
 Gravity Filter	1. Simple to operate 2. Inexpensive 3. Moderate use of floor space 4. Low investment cost	1. High filter medium cost 2. Overflow of solids into clean coolant 3. Cannot handle high tramp oil contamination
 Gravity Separator	1. Simple to operate 2. Non-mechanical 3. Removes high concentrations of floating and dispersed tramp oils 4. Low investment cost	1. Limited dirt capacity 2. Prescreen of feed needed to protect separator from large amounts of contaminants 3. Will not clarify some semi-synthetics

Table 30 (continued)

INDUSTRIAL FLUID MANAGEMENT

COMPARISONS OF PURIFYING EQUIPMENT

UNIT	ADVANTAGES	DISADVANTAGES
 Hydrocyclone	1. Automatic discharge of solids minimizes service requirements 2. Inexpensive 3. Small size. 4. Non-mechanical.	1. Will not clean oil based coolants. 2. May become clogged with large particles. 3. Will not remove tramp oil.
 Magnetic Separator	1. Does not remove coolant additives. 2. Very compact. 3. Removes ferrous particles.	1. Does not remove tramp oil. 2. Does not remove particles smaller than 35 micron. 3. Does not remove non-ferrous particles.
 Pressure Filter	1. Simple. 2. Indexes automatically. 3. Cleanable medium. 4. Moderate investment. 5. Dry sludge cake.	1. Initial pressure forces particles into filter medium. Impending permeability. 2. Possible high cost for filter paper. 3. Disposal of filter media.
 Vacuum Filter	1. Removes fine particles. 2. Efficient with low viscosity fluids. 3. Indexes automatically.	1. May require additional filtration. 2. Disposal of sludge & filter media. 3. Blinds off because of tramp oils.

If chlorinated sulfurized cutting oils contaminate a water-soluble fluid, the water which is present will break down the chlorine, resulting in the formation of hydrochloric acid. Contamination of water-soluble oils with sulfurized cutting oils may occur when a water-soluble oil is introduced into a machine which had formerly used chlorinated sulfurized cutting oil but was not thoroughly cleaned. (27, 70) Cleaning may be accomplished by use of a petroleum solvent or an alkaline cleaner. The removal of water-soluble fluid at the end of one day and again in three days or a week is essential when solvent is employed to clean the machine following the discontinuance of sulfurized cutting oils. Contamination may also occur when the worker alternates using water-soluble and straight oil during certain operations or for certain types of metal. (24, 70)

In another instance, dermatitis may result when a worker avoids using protective creams or gloves when changing from working with chlorinated sulfurized cutting oil to using water-soluble oils. It has been determined that a one to two-week time lapse is required to allow the oil to be completely removed from the skin. The opportunity of developing dermatitis is greatly enhanced when a worker who is not wearing gloves uses a solvent which removes the oil from his skin and then is exposed to the contaminated water-soluble fluid. (24, 70)

Dermatitis may also be avoided by rinsing off all plated parts before grinding to remove chromates and cadmium salts. Dermatitis may also be eliminated by using steel or plastic measuring and mixing equipment rather than galvanized metals, which produce zinc salts when in contact with specific coolants. (24, 70)

Fluids With Bactericides

Biocides or bactericides are preservatives which control biological degradation by killing, inhibiting or repelling bacterial growth. The chosen biocide should exhibit properties such as a broad spectrum of activity, low toxicity to the environment and humans but high toxicity to the biological organism, and compatibility with other chemicals. The number of biocides available is large. Approximately 100 different chemicals are manufactured by about 200 companies.

An emulsion - stabilizing treatment has been previously discussed which protects the emulsified oil from bacterial breakdown. (59). Without this treatment, bactericides are needed to prevent the growth of bacteria which decrease the lubricating effect of the oil, thereby increasing corrosion and the wearing away of the grinding wheel or cutting tool. (24) (See Table 31.) In water-soluble fluids, bacteria generate acids which result in discoloring of the machine tool. Bacteria, such as *Desulfovibrio desufuricans*, produce hydrogen sulfide gas, which rusts the machine, turns the coolant black, and produces a strong odor. The bacterium *Pseudomonas oleovorans*, the most predominate organism in fluids, grows rapidly in machines which leak hydraulic oils. *Pseudomonas aeruginosa* also grows in all miscible fluids. *Desulfovibrio desufuricans* is capable of growing only in the presence of *Pseudomonas*. It has been discovered that chemical changes in the coolant unrelated to bacterial activity can produce unpleasant odors. (59)

Table 31

A Summation of the Bacteria Found in Water Soluble Fluids

Grow Abundantly in All Products:

Pseudomonas aeruginosa
Pseudomonas oleovorans
Desulfovibrio desulfuricans

Grow Abundantly in Many Products:

Paracolabactrum species
Klebsiella pneumoniae
Proteus vulgaris
Escherichia coli

Limited Growth in a Few Products:

Salmonella typhosa
Staphylococcus aureus

Source: Master Chemical Corporation Literature

Phenolics were used as biocides when it was determined that the free hydroxyl group of the phenol molecule was "the reactive entity" in imparting bactericidal properties.(71) It has been determined that phenolics act by penetrating the cell wall of the microorganism. By coagulating the cell membrane, the phenolics allow the leakage of essential metabolites from the cell. Currently, phenolics continue to maintain a major share of the market despite their disadvantages. Some of these disadvantages include stringent water pollution regulations affecting the phenolics, the likelihood of phenolics causing dermatitis and the fact that when in low concentrations, the organisms will actually utilize the phenolics for metabolic growth.(71)

Certain biocides decompose to release formaldehyde. It has been established that formaldehyde interferes with the nuclear synthesis of the microorganism. Formaldehyde is also known to coagulate the proteinase portions of tissue. Formaldehyde releasing biocides are responsible for the accumulation of 1,3 thiazine-4-carboxylic acid in the micro-organism, which inhibits methionine formation and therefore with cytoplasmic synthesis. (71)

Formaldehyde releasing biocides that have been described as very effective against bacteria are 2-hydroxymethyl-2-nitro-3-propanediol and hexahydro-1,2,5-tris-hydroxyethyl-(s)-triazine. These substances have not achieved success against fungi and molds. (71) Hexahydro-1,3,3-trishydroxyethyl-(s)-triazine is formed by the condensation of paraformaldehyde with ethylamine. (71)

Table 32

Chemical Categories of Cutting Fluid Preservatives

Chemical Compound	Category
o-Phenylphenol	Phenolic
Sodium Salt of o-Phenyl phenol	Phenolic
2,3,4,6-Tetrachlorophenol	Phenolic
o-Benzyl-p-chlorophenol	Phenolic
Sodium Salt of o-Phenylphenol and Sodium mercurio salicylate	Phenolic/salicylate combination
2-Hydroxymethyl-2-nitro-1, 3-propanediol	Formaldehyde "donor"
Hexahydro-1,3,5-tris-2-hydroxyethyl-(s)-triazine	Formaldehyde "donor"(?)
Hexahydro-1,3,5-tri-ethyl-(s)-triazine	Formaldehyde "donor"(?)

Source: Smith, T.H. "Toxicological and Microbiological Aspects of Cutting Fluid Preservatives", Lubrication Engineering, August, 1969

The addition of a biocide to a metalworking fluid must be carefully calculated. Too much bactericide may result in an overgrowth of fungi, whereas too little bactericide will not effectively kill the bacteria will actually stimulate their growth. The effectiveness of a bactericide may vary depending on the specific metalworking fluid into which it is incorporated. (See Table 33.)

Table 33

BACTERICIDE EFFECTIVENESS

Coolant	Days of Inhibition
Max Mix coolant	49
Shell emulsion	105*
Vantrol emulsion	70
Sun emulsion	70 (mold growth)
Monroe emulsion	105*
Norton emulsion	BE
Shamrock emulsion	BE
DoAll coolant	105*
Quaker coolant	56
Texaco emulsion	56
IRMCO emulsion	56
P. C. coolant	105*
Shercool coolant	105*
Sanson emulsion	42
Lusol coolant	63
Union emulsion	105*
Tower II coolant	77
DuBois coolant	105*
Metalube 1-14	105*
Yusiro emulsion (c)	35
Master Draw B emulsion	77
Cook Cool 2020 emulsion	70
Sintolin O emulsion	105*
Conoco emulsion	105*
Gulfcut HD emulsion	42
Cimcool coolant	105*
Trim Regular coolant	105*

Conditions: 40/1 water/oil ratio, 112 ppm bactericide as supplied
Legend: *No growth when test was halted; BE = broke emulsion

Source: Rohm & Haas Company Literature

A list of biocides used in metalworking fluids is given in Table 34.

Table 34

Biocides Used In Metalworking Fluids

PRODUCT
6-Acetoxy-2,3-dimethyl-m dioxane
1,2-Benzisothiazolin-3-one
5-Chloro-2-methyl-4-isothiazolin-3-one + 2-methyl-4-isothiazolin-3-one
4-(2-Nitrobutyl) morpholine + 4,4'-(2-Ethyl-2-nitrotrimethylene dimorpholine
o-Phenylphenol
Sodium 2-pyridinethiol-1-oxide
Sodium 2,4,5-trichlorophenate
1-(3-Chloroallyl)-3,5,7-triaza-1-azoniaadamantane chloride
2,2-Dibromo-3-nitrilopropionamide
Hexahydro-1,3,5-triethyl-s-triazine
Hexahydro-1,3,5 tris(2-hydroxyethyl)-s-triazine
Hexahydro-1,3,5-tris(2-hydroxypropyl-2-triazine
2(Hydroxymethyl)-2-nitro-1,3-propanediol
Tris-hydroxymethyl) nitromethane

Of the biocides used in cutting fluids, approximately 50% are triazine derivatives and are classified as formaldehyde-releasing. Another 50% are composed of phenols. Quartenary ammonium compounds and iodine complexes are used very infrequently.

SECTION VIII

FLUID MAINTENANCE AND RECYCLING IN FOREIGN COUNTRIES

WEST GERMANY

According to several sources, West Germany is the most advanced European country in recycling technology. Special assistance is extended to the industry by the association of the lubricating grease industry: Verband Schmierfett-Industrie E.V., "VSI" (Am Reisenbrook 21, 2 Hamburg 67). Another advisory body is the association of German engineers, the Verein Deutscher Ingenieure or "VDI" (Graf-Recks Strasse 84, 4000 Dusseldorf 1).

As to the classifications of metalworking fluids by the German standards DIN (similar to ASTM designations), DIN 51385 makes a distinction between water-miscible and non-water miscible metalworking fluids.

VDI suggests three methods of recycling or maintaining the metalworking fluids. These are (1) main stream clean-up, (2) full stream clean-up, or (3) partial stream clean-up. In this clean-up process, metal chips, shavings and foreign oils are eliminated.(See Figure 40.)

For recycling (cleaning of the metalworking fluid), sedimentation trays and tanks are still used in West Germany because of the low cost of investment. However, these are labeled as old fashioned, and generally they are used only in combination with other methods. In the case of large chips and shavings, they require frequent cleaning; in the case of fines, the efficiency is poor.

The methods of filtration as illustrated by VDI 3397 are shown in Figure 41 and Table 35.

<u>Cost Considerations</u>

Table 36 provides an idea of the typical cost considerations with recycling.

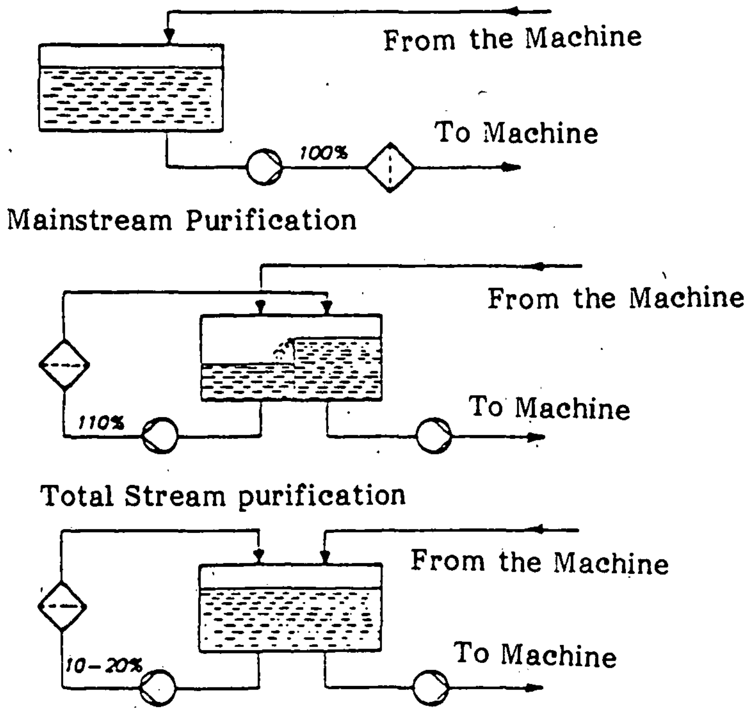
Table 36
Cost Overview

Material	Cost*
Metalworking fluids	DM 60-200/ton
Oil containing "muds"	85-300/ton
Solvents	100-300/ton
Used oil with foreign matters not exceeding 10%	No charge
Used oils with foreign matters more than 10%	According to foreign matter content
Transportation	DM 0.5-1.5/kilometer

*One D Mark at current exchange rate = $0.50 approximately
Tons are metric tons
One kilometer = 0.6 miles approximately

Figure 40

Recycling Suggested by VDI

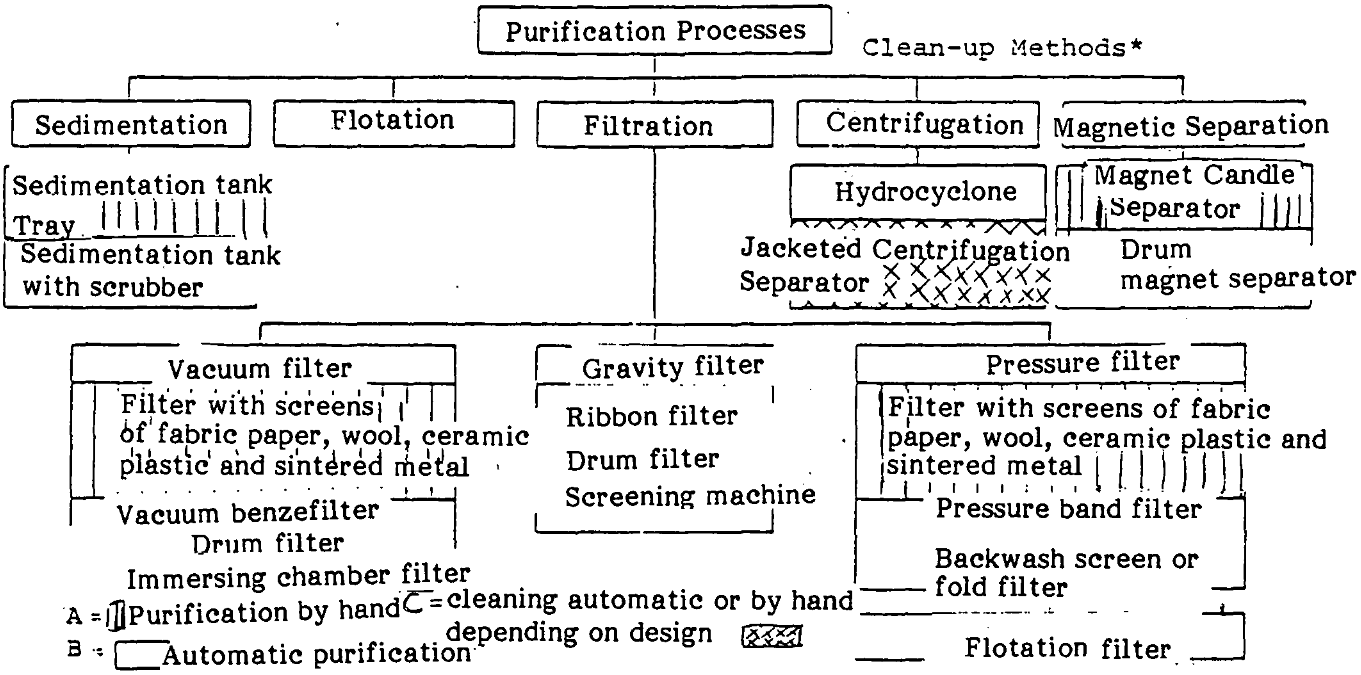

Mainstream Purification

Total Stream purification

Source: VDI-Richtlinie 3397/1

Figure 41

Clean-Up Methods



A = cleaning by hand

B = automatic cleaning

C = cleaning automatic or by hand depending on design

Source: VDI Richtlinie 3397/1

VDI 3397 rates the various methods of cleaning the metalworking fluids from chips and shavings. The rating is from 1 to 5, 1 being unfavorable, and 5 indicating favorable:

TABLE 35
Fluid Efficiency Rating

Water Containing Cooling Fluids

Method	Watery Emulsions	Water Solutions	Non-water Miscible Fluids	Degree of Cleanliness	Maintenance Cost	Space Requirement	Cost of Investment	Cost of Filter Media
1. Sedimentation tray and tank	1	2	1	1	1	2	4	5
2. as 1 with scrubber	2	3	1	2	5	3	3	5
3. Hydrocyclone	4	4	1	3	4	5	3	5
4. Centrifuge	4	4	4	3	4	4	3	5
5. Centrifugation separator	4	4	4	3	4	4	2	5
6. Discontinuous Magnetic Separator	4	4	3	4	2	4	4	5
7. Continuous Magnetic Separator	4	4	3	4	5	3	5	5
8. Gravity Filter	5	5	3	4	5	3	5	2
9. Vacuum belt filter	5	5	3	4	5	4	4	3
10. Belt Filter by pressure	5	5	3	4	5	4	3	4
11. Screen filter with backwash	5	5	5	4	5	4	4	5
12. Immersing chamber filter	5	5	5	4	5	4	3	5
13. Drum filter	5	5	5	4	5	4	4	5
14. Filter press								
14.1 Disk filter	4	4	4	5	2	4	4	3
14.2 Basket filter	3	3	3	3	2	4	4	4
14.3 Fold filter	4	4	4	5	4	3	4	2
14.4 Bag filter	4	4	1	3	3	4	4	4

JAPAN

According to Yushiro Chemical, the users of emulsified and soluble type metalworking fluids are demanding maximum longevity of the fluids. Yushiro is now offering fluids which are useable (can be recirculated) for two years. In order to extend fluid life, the suppliers put emphasis on research to find nontoxic inhibitors and preservatives to protect the fluids against action caused by bacteria.

With the increased use of soluble oils and emulsions in the metalworking industry,the problem of the cross-contamination of metalworking fluids and hydraulic fluids is emerging. The latter are still predominantly straight oils.

APPENDIX I

ADDITIONAL MARKETING INFORMATION

METALWORKING FLUIDS

There are over 300 different suppliers of emulsified oil, metalworking fluids and lubricants in the United States. They range in size from small "garage formulators" to divisions of multibillion-dollar petroleum producers. Almost every metalworking Standard Industrial Code SIC code is a user of or potential user of emulsified cutting, grinding, rolling or lubrication oils. The number of users literally runs into thousands.

Straight oils, which are composed primarily of petroleum, animal, marine or vegetable oil, are generally classified as active or inactive, depending on their chemical activity. An active oil functions as a lubricant in the lower temperature range (400-500°F), whereas an inactive oil functions best in the higher temperature range (700-900°F). Oils composed of animal, marine or vegetable oil are polar oils, which serve the function of wetting the chip/tool interface by reducing the interfacial tension between the mineral oil and the metal. In order to obtain the greatest load-carrying capacity and heat resistance properties, chlorine, sulfur or phosphorus compounds are added to the animal, marine or vegetable oils. In an inactive oil, sulfur is highly bonded within the hydrocarbon structure and serves no chemical function.

Straight mineral oils are employed in light-duty machining operations of nonferrous metals. Fatty oil mineral oil blends function well in automatic screw machine operations. Fatty oils have rather limited use, primarily in gear hobbing operations. Sulfurized mineral oils are employed in machining tough, ductile metals, whereas sulfo-chlorinated mineral oils are useful for machining tough low-carbon steels and chrome-nickel alloys. It has been estimated that about 80% of straight oil is employed in cutting operations such as milling, boring, drilling, reaming and turning, and 20% is used in grinding operations.

The soluble oils are employed approximately 50% of the time in cutting operations, i.e., turning, boring, broaching, milling, planing, drilling and reaming, and another 50% in grinding operations, such as surface, internal, centerless, cylindrical, thread, gear, crush and form grinding. Fluid longevity may range from a few weeks to one year depending on maintenance practices.

The various metalworking fluids are composed of multifarious ingredients, such as rust inhibitors, lubricating agents, emulsifiers, bactericides and inorganic chemicals. Specific ingredients of the synthetic fluids, soluble oils and straight oils are presented in Table A-1.

The properties of the various fluids are summarized in Table A-2.

TABLE A-1

(A) Synthetic cutting fluid or chemical coolant

50-90%	(1)	Water
1-10%	(2)	Rust inhibitors and detergents
		(a) sodium nitrite
		(b) di- and triethanoleamines
		(c) potassium or sodium soaps
25-50%	(3)	Lubricating agents
		(a) polyether glycols
		(b) alkyl-phenol-ethylene oxide condensation products
0-1%	(4)	Bactericides
		(a) chlorophenols
		(b) organic mercurials
		(c) iodine compounds
		(d) formaldehyde releasers
		(e) quaternary ammonium compounds
		(f) hexachlorophene

Note: Synthetic cutting fluids are diluted (20-150:1) with water prior to use.

(B) Soluble or semisynthetic cutting fluids

60-90%	(1)	Mineral oils
1-5%	(2)	Water
5-30%	(3)	Emulsifiers
		(a) sodium and amine soaps
		(b) sodium sulfonates, naphthenates, rosinates
1-20%	(4)	Coupling agents
		(a) alcohols
		(b) glycol ethers
		(c) glycols
1-10%	(5)	Rust inhibitors
		(a) amines
		(b) sodium nitrite
		(c) fatty oils
		(d) sulfurized fatty oils
0-10%	(6)	Bactericides (as above)

Note: Soluble cutting fluids are diluted with water prior to use.

(C) Insoluble or straight oils

80-100%	(1)	Mineral oils (including sulfurized mineral oils)
1-40%	(2)	Fatty oils (including sulfurized fatty oils)
0-10%	(3)	Sulfur (combined and suspended)
0-10%	(4)	Chlorine
		(a) chlorinated paraffins; rarely chlorinated aromatics
0-1%	(5)	Phosphorus
		(a) organic phosphates and phosphites

Source: Chemical Hazard Information Profiles TSCA Chemical Assessment Series EPA 560/11-80-011

TABLE A-2

Fluid Type	Advantages	Disadvantages
Straight Oils	Lubricity Price (short-term) Rust inhibition	Price (long-term) Disposal Future availability Health (oil mist in workers' lungs) Safety (slippery floors, tools) Low cooling effect Fire hazard
Soluble Oils	Heat reduction (allows higher speeds) Cleaner conditions Economics (diluted with water) Cooler, cleaner parts Improved health and safety	Disposal Future availability Price (future) Rancidity Lubricity Milky emulsion
Semi-Synthetics	Heat reduction (allows higher speeds) Less oil than soluble oils Cleaner conditions Economics (higher dilutions with water) Cooler, cleaner parts Improved health and safety Good detergent properties Excellent workpiece visibility Residual film, light and easy to remove Easy to mix Excellent rancidity resistance Very long life	Oil-containing; could have future problems with price, availability, and disposal. Lacks lubricating ability of oils Higher incidence of dermatitis due to fluid's detergent action. Less control of rust and corrosion May foam
Synthetics	Contain no oil Same advantages as the semi-synthetics (above)	Lack the lubricating ability of oils Higher incidence of dermatitis due to detergent effect. Additional additives required for rust and corrosion control May foam

Drawing, Stamping and Rolling Operations

Fluids are employed in a variety of metal-forming operations, which result in the reshaping of metals. The fluid is applied to minimize the contact and friction between the metal and the die by the formation of a film. The selection of the fluid is dependent upon the severity of the operation. Press drawing is an operation that may range in severity depending on such factors as: (72)

- the metal to be drawn
- the cleanliness of the material
- the depth of the draw

The emulsified fluid is viewed as the easiest to remove; however, it does not afford the lubrication properties necessary for most severe operations. Chlorinated or sulfo chlorinated oils appear to be the lubricants of choice in severe drawing operations (73) It has been mentioned that a soluble oil would not be used in drawing more than 50% of the diameter of the blank(74)

In 1979, there were approximately 91 million metal cans produced. Of that total, 53.5 billion were beverage containers. Table A-3 presents the numbers of 2-and 3-piece beverage cans produced in 1979.

TABLE A-3

Beverage Cans Produced in 1979

	Billions of Units
Soft Drink	
Steel	
3-piece	8.084
2-piece	5.339
Aluminum	
3-piece	0
2-piece	12.459
Beer	
Steel	
3-piece	1.707
2-piece	5.675
Aluminum	
3-piece	0
2-piece	20.192
TOTAL	53.456

Source: Current Industrial Reports, Metal Cans, 1979

An oil-in-water emulsion is frequently employed in the manufacture of the two-piece can for the purposes of cooling and lubricating (75). The formation of the two-piece can is achieved with the use of cupping and bodymaking presses. Lubricated aluminum sheet is fed from a coil into a cupping press, which consists of multiple punches that operate at a rate of 60-180 strokes/minute (76). In the draw and wall-iron method, a disk is blanked from the coiled sheet and punched or drawn into a shallow cup (75, 77). When the redrawing process is performed, the diameter of the cup is reduced as the walls are elongated.(77) The bodymaking operation consists of the passage of the can through the redraw die and a minimum of three ironing dies (76). The ironing presses run at a rate of 100-250 strokes/minute for the purposes of reducing wall thickness and extending wall length (76). The emulsified fluid is sprayed into the can prior to contact with each die in order to: (75, 76)

- control friction
- minimize wear
- combat transfer of aluminum to the dies
- cool the equipment
- protect can walls from scoring against the tungsten carbide dies

It has been determined that too low a friction will result in sidewall wrinkling whereas too high a friction will result in cup tearing. The percentage of oil in the emulsified fluid may range from 5-50%. In the cupping operation, the fluid used may contain 20-30% oil or may contain no water whatsoever (76). The fluid is applied by dipping or by means of rollers (76). In the ironing operation, the fluid is sprayed on the cup and punched from a circulating system (76). The fluid contains 4-20% oil in order to supply the needed cooling properties (76). Following the ironing operation, the can is trimmed at the top to the proper dimension (77). The can is run through a washer in order to receive a cleaning and acid wash (77).

It is estimated that the carry-off of oil on the can is great enough to require replacement of 10-30% of the oil per day (75) if recycling is not performed. Drawing and rolling fluids generally contain petroleum oils, fatty acids, emulsifiers, fatty acid soaps and esters. It has been projected by major aluminum can manufacturers that the use of synthetic drawing fluids will increase greatly in the next five to ten years. Current estimates of the use of synthetics center around the 50-70% range. It is anticipated that in the future this percentage will increase to 90-100% (78, 79)

The rolling of aluminum sheet may be accomplished through a reversing and/or multistand reduction mill with an oil-in-water emulsion which is used at a concentration of 2-10% depending on the reduction, the fluid used and the alloy rolled (80). The reversing mill is employed to slab the ingots which have been preheated at temperatures between 500° C and 600° C. Coils of reroll stock are obtained by means of the multistand mill at operating temperatures of 300° C. The shape of the rolls is determined by the cooling achieved by the use of the emulsified fluid. The emulsion is sprayed on the roll and separates out forming a film which functions as a lubricant during rolling, a process referred to as thermal separation or the rate of deposition of the oil phase onto the roll. The emulsion prevents contact of the steel rolls with the aluminum sheet preventing transfer of material. When material is transferred onto the roll, it will be reprinted on the sheet on the next revolution (81). The aluminum pick-up will appear as streaks in the metal after the cold rolling and anodizing processes (81). Aluminum pick-up has also been attributed to the formation of a rough surface known as rolling coating (81).

HYDRAULIC FLUIDS

As was previously discussed, the fire resistant hydraulic fluid classification encompasses: invert emulsions, water/glycol fluids, phosphate ester fluids, and high water based fluids.

The water-in-oil emulsion is viewed by many as a fluid, which is selected for low pressure systems, such as those found in coal mining and die casting (82). Other sources state that the invert emulsion may be used in systems up to 2250 psi depending on the equipment (83). The invert emulsion has been successfully employed in the operation of a steel slab caster at pressures up to 3000 lb./in.^{2} for 17 days with an internal crescent gear pump (84). Testing demonstrated that the emulsion did not decrease to a 50% level after 15 days at pressures of 3000 lb./in.^{2} but stability does diminish after 17 days at 93° C. A monitoring system was adopted to maintain proper fluid cleanliness and emulsion stability and to guarantee that there was a sufficient level of water for the necessary fire resistance. The filtration operation incorporates filters, such as suction, wire mesh, and pressure filters with paper media (84). It has been observed that excessive pump wear and valve malfunction may be avoided by removal of particles in the 5-15 micron range.

A monitoring program is also essential to ensure the safety of invert emulsions used in coal mine hydraulic systems. In many instances, these invert emulsions contain the minimum water content which is required to meet spray flammability test criteria, i.e. 40-45% water content in the United States (86). Water evaporation from fluid increases greatly at operating temperatures above 130° F. In addition, emulsified fluids experience viscosity problems at 40° F and below. The water glycol fluids are viewed by some as affording certain advantages over the emulsified fluids since the water glycol fluids do not separate during storage and fire resistance properties are greater (82).

High water based fluids are generally designed for use in systems at less than 1000 psi, primarily because water will not provide enough lubrication in high pressure systems due to low viscosity (82). Low viscosity also is responsible for shortened longevity of pumps.

It has been recognized that units must be redesigned in order for water-based fluids to be used at pressures greater than 1000 psi. Currently, standard in-line piston pumps function well on HWBF up to 1000 psi; however, vane and gear pumps must be redesigned for use with the high water based fluids (86). Other candidates for change include fluid motors, linear and rotary motors and filter elements (85). Servo valve hydraulic systems may not be acceptable since they require a 5 micron filter which causes breakdown of the emulsion (85).

It is anticipated that high water based hydraulic fluids will be selected in the metal working area, which requires 300-400 lb./sq. in. and in die casting, which requires 200-2000 lb./sq. in. (82) Metalworking is viewed as a large volume area, whereas die casting is a low volume use. High water based fluids are being employed in coal mining in Japan and Europe. Uses in the United States include underground mining, steel mills, roof support and in transmission plants in the automotive industry (86).

The use appears to be contingent on temperature, since the surrounding environment must not be too cold or too hot (86). The fluids should be used at temperatures under 120° F and above 32° F, which eliminates certain outdoor uses.

It was mentioned by one source that an experimental high water based fluid is being developed for use in 1000 psi systems (73). A high water based fluid is not advisable on machines which use a coolant which is a straight oil. A water based hydraulic fluid is desirable in cold rolling to avoid the staining caused by oil which leaked on the rolled strip (87).

Table A-4 summarizes the advantages and disadvantages of the various fire resistant fluids.

TABLE A-4

Fluid Type	Advantages	Disadvantages
Phosphate Ester	High fire resistance Availability of pumping equipment at high pressure, i.e., 3000 lb./in.^{2}	Expensive Compatibility problems with seals hoses and electrical insulation Disposal problems due to poor recovery from water Sensitive to temperature fluctuations
High Water Based (95% water and 5% oil)	Methods available for reclamation from water	Freezing problems Expensive reciprocating plunger-type pumps required Too low in viscosity Provide inadequate lubrication at high pressures
Water Glycol	Fluid maintenance is not a problem Low pour point	Poor recovery from water Almost as expensive as phosphate ester May not be suitable for high pressure systems Limited applications, i.e. gear pump roller bearings
Invert emulsion 60% oil/40% water	Not expensive Methods available for reclamation	Rotary high pressure pumps may not be compatible Freezing problems Stability problems at high temperatures and pressures Must be monitored since some fluids are formulated close to the minimum water content and loss of water will reduce fire resistance

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