MOBILE ON-SITE RECYCLING OF METALWORKING FLUIDS

by

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FOREWORD

Today's rapidly developing and changing technologies and industrial products and practices frequently carry with them the increased generation of materials that, if improperly dealt with, can threaten both public health and the environment. The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. These laws direct the EPA to perform research to define our environmental problems, measure the impacts, and search for solutions.

The Risk Reduction Engineering Laboratory is responsible for planning, implementing, and managing research, development, and demonstration programs to provide an authoritative, defensible engineering basis in support of the policies, programs, and regulations of the EPA with respect to drinking water, wastewater, pesticides, toxic substances, solid and hazardous wastes, Superfund-related activities, and pollution prevention. This publication is one of the products of that research and provides a vital communication link between the researcher and the user community.

Passage of the Pollution Prevention Act of 1990 marked a strong change in the U.S. policies concerning the generation of hazardous and nonhazardous wastes. This bill implements the national objective of pollution prevention by establishing a source reduction program at the EPA and by assisting States in providing information and technical assistance regarding source reduction. In support of the emphasis on pollution prevention, the "Waste Reduction Innovative Technology Evaluation (WRITE) Program" has been designed to identify, evaluate, and/or demonstrate new ideas and technologies that lead to waste reduction. The WRITE Program emphasizes source reduction and on-site recycling. These methods reduce or eliminate transportation, handling, treatment, and disposal of hazardous materials in the environment. The technology evaluation project discussed in this report emphasizes the study and development of methods to reduce waste.

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ABSTRACT

This evaluation addresses the product quality, waste reduction, and economic issues involved in recycling metalworking fluids through a mobile recycling unit. The specific recycling unit evaluated is based on the technology of filtration, pasteurization, and centrifugation. Metalworking fluid recycling was found to have good potential as a means of waste reduction and cost saving. Product quality was evaluated by conducting performance tests and by chemical characterization of the spent, recycled, and virgin fluids. The performance of the recycled fluid appeared promising.

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SECTION 1
PROJECT DESCRIPTION

The objective of the Waste Reduction Innovative Technology Evaluation Program conducted by the U.S. Environmental Protection Agency (U.S. EPA) is to evaluate, in a typical workplace environment, examples of prototype or innovative commercial technologies that have potential for reducing waste. In general, for each technology to be evaluated, three issues should be addressed.

First, it must be determined whether the technology is effective. Since waste reduction technologies usually involve recycling or reusing materials, or using substitute materials or techniques, it is of primary importance to verify that the quality of the recycled product is satisfactory for the intended purpose. Second, it must be demonstrated that using the technology has a measurable positive effect on reducing waste. Third, the economics of the new technology must be quantified and compared with the economics of the existing technology. It should be clear, however, that improved economics is not the only criterion for the use of the new technology. There may be justifications other than saving money that would encourage adoption of new operating approaches. Nonetheless, information about the economic implications of any such potential change is important.

This evaluation addresses the issues involved in using a particular commercially available technology offered by a particular manufacturer for recycling metalworking fluids (machine coolants). The recycling unit used in this study is a mobile unit offered by Safety-Kleen Corp. Other recycling units and technologies (with varying capabilities) applicable to the same wastestream (metalworking fluids) are also commercially available.

1.1 PROJECT OBJECTIVES

The goal of this study was to evaluate a technology that could be used to recycle spent metalworking fluids (machine coolants) for reuse in machining operations. This study had the following critical objectives:

- Evaluate the effectiveness of the recycling unit in generating a metalworking fluid of acceptable quality
- Evaluate the waste reduction potential of this technology
- Evaluate the cost of recycling versus the cost of current practice (disposal).

1.2 DESCRIPTION OF THE TECHNOLOGY

The mobile metalworking fluid recycling unit is operated by Safety-Kleen Corp., Elgin, Illinois. Safety-Kleen provides fluid recovery services to a variety of businesses, primarily those that generate relatively small quantities of fluid hazardous waste. The mobile service performs the recycling on the generator's property, thus eliminating the need for transportation of potentially hazardous wastes. Each mobile truck-mounted unit, operating off its own power, is capable of processing fluid at a maximum rate of 300 gallons per hour. Heat for the pasteurization step is drawn from the hot antifreeze of the truck.

The recycling process, as presented in Figure 1-1, consists of filtering, pasteurizing, and centrifuging the spent fluid. The fluid is first sent through a 100-micron filter to remove any large particulates. It is then pumped through a pre-heater and then a heat exchanger to kill bacteria and fungi, as well as to reduce fluid viscosity before centrifuging. Centrifuging, where tramp oil and other debris is separated from the usable fluid, is next. After cooling to the original temperature, the fluid is tested for quality. Additives are then incorporated into the fluid to restore performance. In the final step, the fluid flows through a 1-micron filter to remove any remaining particulates. The fluid is then returned to the client's clean holding tank for reuse. Of the various classes of metalworking fluids, Safety-Kleen currently offers the process only for emulsions ("soluble oils"), synthetics, and semi-synthetics.

1.3 DESCRIPTION OF THE SITE

The above technology was evaluated at three different small- to medium-sized machine shops (sites) in the Philadelphia, Pennsylvania, vicinity. The three sites were chosen from among Safety-Kleen's customer base. Two of the sites used emulsion-type metalworking fluids. The third site used a synthetic fluid.

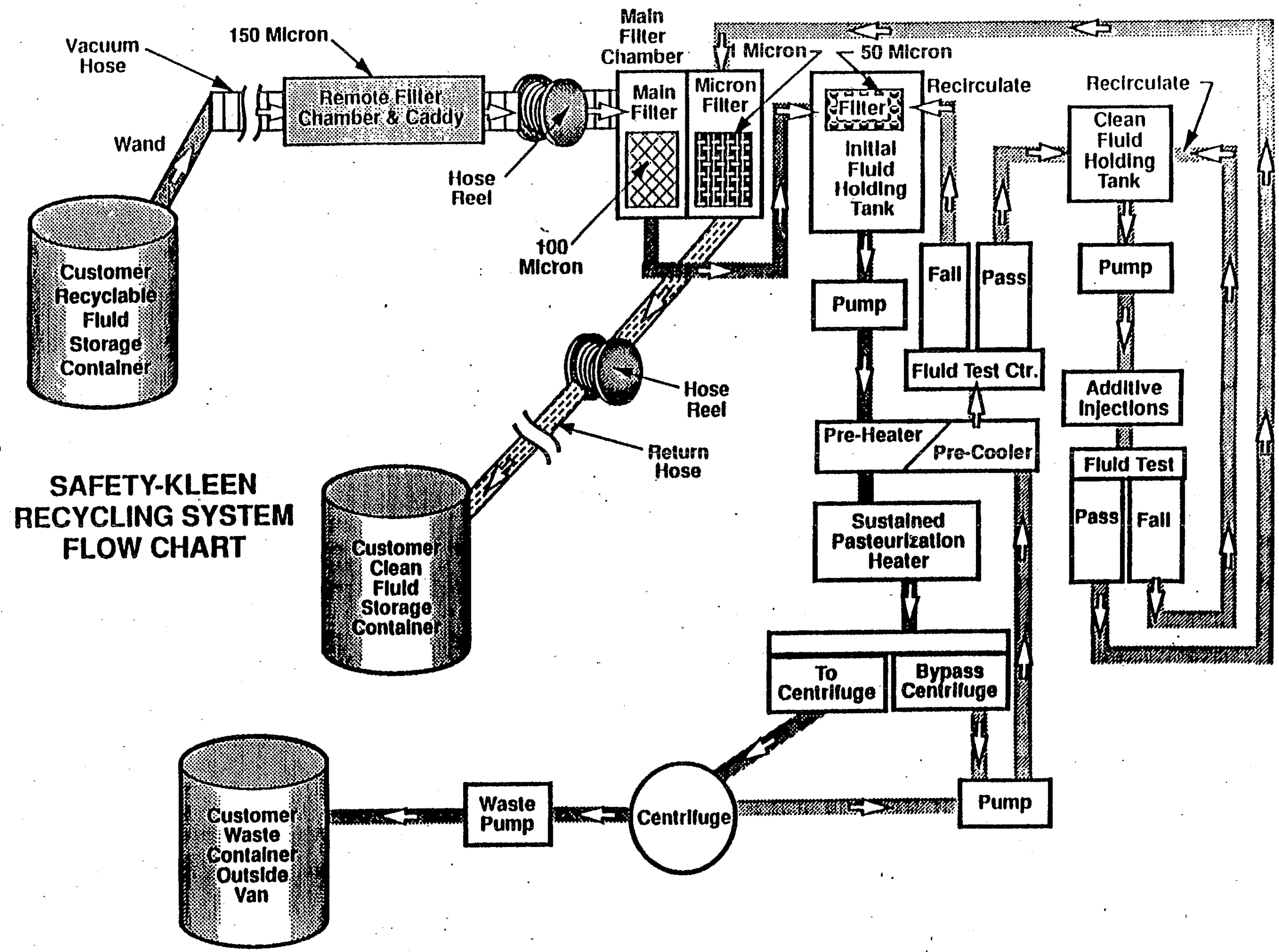

Figure 1-1. Metalworking Fluids Recycling System Flowchart
Source: Butler Corporation

1.4 SUMMARY OF APPROACH

A Quality Assurance Project Plan (QAPjP), prepared at the beginning of this study (Battelle 1991), describes the detailed approach and scientific rationale used to design the recycling unit evaluation.

1.4.1 Product Quality Evaluation

Two types of metalworking fluids were evaluated -- emulsion and synthetic. The main purpose of these fluids in machining operations is to provide lubricity and cooling.

The approach used for evaluating product quality was as follows. At each of the three sites evaluated, one sample each of the spent, recycled, and virgin fluids at their use concentrations were collected and subjected to the same series of tests. A comparison between the analyses of spent and recycled fluids indicates the improvement achieved by recycling. A comparison between the analyses of recycled and virgin fluids indicates how closely the recycled product approximates the virgin product.

The focus of this testing is to provide as broad a data base to potential were as possible. Hence, within the available resources, the objective is to take fewer samples and run several performance and characterization tests on each sample, rather than to take statistically significant number of samples and run fewer analytical tests. Thus, the evaluation provides users with an idea of the efficiency of the recycling process, and a comparison, based on a wide range of characteristics, between the performance of recycled and virgin metalworking fluids.

1.4.2 Waste Reduction Evaluation

The waste reduction potential of this technology was measured in terms of the projected reduction in the amount of spent fluid generated by typical machine shops and requiring disposal. The sidestreams from the recycling process itself are the tramp oil and filtration residue. These were also accounted for.

1.4.3 Economic Evaluation

The economic analysis includes a comparison of operating costs for the new technology (recycling) with the costs for the current practice (disposal).

SECTION 2
PRODUCT QUALITY EVALUATION

Two types of metalworking fluids were evaluated -- emulsion and synthetic. Emulsions, often called "soluble oils," consist of oil suspended in water by use of a surfactant. The oil contributes the lubricating properties, while the water provides the cooling required during machining operations such as cutting, grinding, etc. Synthetic fluids are chemicals that form true solutions in water. Both emulsions and synthetics contain additives to improve specific properties such as stability, corrosivity, foaming, and bioresistivity.

At each of the three sites evaluated, samples of the spent, recycled, and virgin fluids at their use concentrations were collected and subjected to the same series of tests. The objective was to compare the spent and recycled fluids to determine the improvement achieved by recycling. The recycled and virgin fluids were compared to determine how closely the recycled product approximates the virgin product.

2.1 ON-SITE TESTING

Table 2-1 describes the on-site testing conducted during this evaluation. Recycling was performed at two machine shops that use emulsion-type fluids and at one machine shop that uses synthetic fluids. The process for both types of fluid is the same except that different additives are used. Of the two sites where emulsions were processed, the first site was one that Safety-Kleen had serviced several times in the past. The second site was one that was being serviced for the second time only. The reason for this type of site selection was to see if the fluid quality changes over several recycles.

Samples of the spent, recycled, and virgin fluids were collected at each site. The virgin fluid samples were prepared by diluting virgin concentrate obtained from each site with tap water from the same site. At most sites that Safety-Kleen services, the concentrates are diluted to a use concentration of approximately 3 to 5% in water to obtain the desired degree of lubricity and cooling.

TABLE 2-1. ON-SITE TESTING DESCRIPTION

Site Description	Fluid Type	Site Number	Volume of Fluid Recycled (gallons)	Samples Collected[a]
<u>First</u> Machine shop where fluid had been recycled several times in the past.	Emulsion	E1	175	E1-S (spent) E1-R (recycled) E1-V (virgin)
<u>Second</u> Machine shop where fluid was being recycled for the second time.	Emulsion	E2	55	E2-S (spent) E2-R (recycled) E2-V (virgin)
<u>Third</u> Machine shop where fluid had been recycled several times in the past.	Synthetic	S1	100	S1-S (spent) S1-R (recycled) S1-V (virgin)

[a] One sample each of spent, recycled and virgin metalworking fluid at the use concentration were collected at each site.

One sample at each site was obtained from the spent fluid storage tanks by means of a bailer to ensure representative samples from all depths. Samples were shipped to the analytical laboratory in coolers packed with ice to prevent microbial growth and degradation of the fluid. All samples were refrigerated until the time of analysis.

2.2 ANALYTICAL RESULTS

The samples collected during the on-site testing were analyzed in the laboratory for various characteristics. The tests and results are described below. The two spent emulsion samples (E1-S and E2-S) had a floating tramp oil phase. This floating phase was separated in a separatory funnel and the lower bulk liquid was analyzed because most of the following tests cannot handle two phases. The performance of these spent fluid samples in the following tests is therefore somewhat better than would be normally expected if the tramp oil phase were included. No noticeable quantity of tramp oil was observed in the spent synthetic fluid samples.

2.2.1 Particulates

During machining, metallic and organic particles from various sources accumulate in the metalworking fluid. High concentrations of these particulates adversely affect tool life, surface finish, and chemical breakdown. Particles also provide substrates for microbial growth. Degree of removal of particulates during recycling is shown in Table 2-2. Particulate concentrations were measured by ASTM D 2276-89. This method measures the change in weight of an 8-micron filter membrane (relative to a control filter) after filtration of the fluid. The filter is washed with petroleum ether to remove any oily matter from the residue before weighing. The results are listed as "total" particulates in Table 2-2. At all three sites, the results showed considerably lower concentrations of particulates in the recycled fluids as compared with the spent fluids. The virgin fluids had the lowest concentrations of particulates.

Although the ether wash of the filter removes most oily matter, there may still be some organic residue (e.g., biomass) on the filter. Combusting the residue gets rid of this organic residue. When the filtration residues were combusted, the resulting combustion residues are shown in the column marked "inorganic" particulates in Table 2-2. In all samples, the "inorganic"

TABLE 2-2. ANALYSIS OF NON-DISSOLVED AND DISSOLVED SOLIDS

Sample No.	Non-Dissolved Particulate Concentration[a] (mg/100 mL)		Dissolved Solids (Conductivity)
	Total	Inorganic	(umhos/cm^2)
E1-S[b]	79.10	27.25	2,400
E1-R	22.55	1.45	1,810
E1-V	3.55	2.50	700
E2-S[b]	12.55	0.50[c]	1,820
E2-R	5.60	3.00	1,750
E2-V	4.50	2.00	810
S1-S	33.80	14.50	1,450
S1-R	17.00	1.95	1,460
S1-V	5.18	0.78	1,930

[a] By ASTM D 2276. Particulates smaller than 8 microns.

[b] Analyzed after skimming off and discarding the floating tramp oil.

[c] Possible inhomogeneity giving a low value.

values were lower than the corresponding "total" values. The "non-combustible" particulates represent the inorganic fraction of the "total" particulates and provide some indication of suspended metal particulates.

Conductivity measurements are a measure of the dissolved solids (metallic impurities and salts) content. Conductivity is tracked by metalworking fluid users as an indicator of the variation in fluid quality over time (and use). A conductivity reading was taken on all samples collected. For the emulsion-type fluids (Sites E1 and E2), the virgin samples showed much lower conductivity as compared with the spent samples, indicating that the dissolved solids content of the fluids increased over use. Recycling did not reduce the conductivity of the spent fluid noticeably. This is because the smallest filter used in the recycling process is 1-micron. Dissolved solids would pass through this filter.

This accumulation of dissolved solids over time and use can limit the number of times a given batch of fluid could be recycled. When the dissolved solids content of the fluid becomes approximately 2,600 ppm, the emulsion may start to break and water may separate out. This study did not correlate the conductivity measurements (in umhos/cm^2) to actual dissolved solids concentrations (in ppm). Only the trends were observed. Addition of fresh inhibitors during normal use or recycling could also raise dissolved solids levels.

In the synthetic fluid (Site S1), a conductivity trend was not so obvious. The virgin sample showed a higher conductivity reading than the spent or recycled samples; this may mean that the virgin fluid itself contains several dissolved additives that raise the conductivity reading. Also, the virgin sample had been prepared with tap water, which would itself contribute in some measure to the conductivity. One explanation for the results at Site S1 could be that the spent coolant had originally been prepared with deionized water, whereas the virgin sample was prepared with tap water.

2.2.2 Metallic Contaminants

Metallic contaminants enter the metalworking fluid during normal machining operations. In fact, one of the functions of spraying the fluid is to carry away metal chips from the work piece as they are formed. The metals accumulate in the spent fluid in suspended or dissolved form. In suspended form they provide a substrate for microbial growth. In dissolved form they contribute to increased levels of dissolved solids and hence emulsion instability.

No really large metal chips or turnings (coils) were visually observed in the spent samples collected, indicating that large pieces had settled out in the bottom of the spent fluid storage tank, and were not drawn into the sample. A total (suspended and dissolved) metals measurements of the fluids was conducted by ICP analysis of the samples (Table 2-3). Aluminum and zinc levels were somewhat reduced after recycling. Copper levels increased in the emulsion samples after recycling; this is attributed to the fact that copper is an ingredient in one of the additives introduced during recycling of emulsions. Lead levels remained fairly constant in the spent and recycled samples; this is attributed to the fact that lead is often present in a solubilized form and hence difficult to remove. Note that the virgin samples too had lead levels comparable to those in the spent and recycled samples. Iron levels at all three sites showed a slight increase after recycling. A possible reason for this could be that the spent fluid solubilizes some iron encountered in the recycling system (e.g., from the residue on the filters).

In general, metal levels in all the collected samples (spent, recycled, and virgin) were too low to be of concern from a product quality point of view. Many of the larger metal particles could have settled out in the spent fluid storage tank itself. Larger metal particles drawn into the recycling unit would be expected to be removed by the filters as shown in Section 2.2.1.

Calcium and magnesium levels were also measured because these metals contribute to water hardness and emulsion instability. Calcium and magnesium were not removed from the fluid during recycling, indicating that these metals are mostly in the soluble form. High levels in virgin samples indicate that calcium and magnesium enter the fluids through the make-up water (tap water) used. Emulsion stability and bioresistance tests described in Sections 2.2.7 and 2.2.10, respectively, indicated that the levels of metallic contaminants in the recycled fluids do not significantly affect their performance.

2.2.3 Viscosity

Viscosity (resistance to flow) is an important parameter for a lubricant. It determines a fluid's flow and penetration characteristics, as well as the oil film thickness. Kinematic viscosity of all samples collected was measured by ASTM D 445-71. Kinematic viscosity, measured in centiStokes (cS), is a measure of the resistive flow of a fluid in relation to its density. The recycled and virgin samples from all three sites had matching viscosities (Table 2-4) indicating that the recycling process had restored this parameter. Spent sample E2-S was the only spent sample that

TABLE 2-3. TOTAL METALS CONTENT OF METALWORKING FLUIDS

Sample No.	Iron[a] (ppm)	Copper[a] (ppm)	Aluminum[a] (ppm)	Lead[a] (ppm)	Zinc[a] (ppm)	Calcium[a] (ppm)	Magnesium[a] (ppm)
E1-S[b]	10.4	1.4	1.1	0.21	1.7	37	42
E1-R	11.1	2.3	0.7	0.19	0.6	20	35
E1-V	1.0	0.6	0.2	0.17	0.1	20	15
E2-S[b]	2.4	0.1	0.3	0.21	0.1	53	14
E2-R	5.2	2.7	0.4	0.19	0.3	40	21
E2-V	0.3	0.0	0.2	0.17	0.0	140	21
S1-S	3.1	9.2	4.9	0.41	1.6	70	40
S1-R	4.5	7.2	3.3	0.37	1.0	14	40
S1-V	0.3	0.0	0.2	0.33	0.2	50	23

[a] Analyzed by EPA 6010 (ICP).

[b] Analyzed after skimming off and discarding the floating tramp oil.

TABLE 2-4. ANALYSIS OF VISCOSITY

Sample No.	Viscosity[a] (cS)
E1-S[b]	0.77
E1-R	0.85
E1-V	0.81
E2-S[b]	0.69
E2-R	0.81
E2-V	0.77
S1-S	0.77
S1-R	0.75
S1-V	0.75

[a] By ASTM D 445.

[b] Analyzed after skimming off and discarding the floating tramp oil.

appeared to be noticeably out of range to start with; the viscosity of this fluid was restored during recycling. The viscosity measurements also indicate that the recycling process succeeded in returning the fluids to the required use concentration (concentrate:water ratio). The concentration of the recycled fluid is adjusted during the recycling process by taking refractometer readings. Small amounts of virgin concentrate is added to the recycled batch if necessary to restore the use concentration.

2.2.4 pH

The pH of a metalworking fluid is often monitored by users as an easily measured indicator of fluid quality. A change in pH may indicate chemical degradation or degradation due to microbial growth. The recycling process seeks to restore pH to a range of 8.5 to 9.5 using appropriate additives. This alkaline pH improves emulsion stability and corrosion resistance characteristics of the fluid. At the three sites tested, the pH of the recycled fluids (measured by EPA Method 150.1) was returned to this range (Table 2-5) by the alkaline component of the fresh additive. Note that at Sites E1 and E2, the spent fluid pH had degenerated to below 7. The lowered pH indicates microbial growth (acids generated by microbial metabolism) and depletion of alkalinity-building chemicals in the fluids.

2.2.5 Extreme Pressure Additives

Because many metalworking fluids contain what are known as extreme pressure (EP) additives, the collected samples were analyzed for these compounds. EP additives are organic molecules with sulfur and chlorine. They serve as solid lubricants with low binding energy. None of the samples collected (Table 2-5) showed any elevated levels of either sulfur (ASTM D 129) or chlorine (ASTM D 808), indicating that these additives were not present in the fluids used at the three sites. Some sulfur was present, but was attributed mainly to the sulfonate emulsifier used.

2.2.6 Corrosion Properties

Corrosion characteristics are important parameters for water-based metalworking fluids because of their effect on workpiece quality and tool life. Corrosivity of the fluids to ferrous

TABLE 2-5. CHEMICAL CHARACTERISTICS OF THE METALWORKING FLUIDS

Sample No.	pH	Sulfur Concentration[a] (%)	Chlorine Concentration[b] (%)
E1-S[c]	6.71	< .003	< .007
E1-R	9.58	0.021	< .007
E1-V	8.60	0.011	< .007
E2-S[c]	6.57	< .003	< .007
E2-R	9.32	0.014	0.070
E2-V	8.44	0.011	0.115
S1-S	8.52	0.009	<0.007
S1-R	8.52	0.008	0.069
S1-V	8.39	< .003	< .007

[a] By ASTM D 129. Sulfur in extreme-pressure additives.

[b] By ASTM D 808. Chlorine in extreme-pressure additives.

[c] Analyzed after skimming off and discarding the floating tramp oil.

metals was measured by the iron chip corrosion test (ASTM D 4627-86). A copper corrosion test (ASTM D 130-88) was also performed.

In the iron chip test, cast iron chips are placed in a petri dish containing a filter paper soaked with the metalworking fluid. The filter paper is examined the next day for rust stains. For each fluid sample, the test was repeated for the use concentration (as-received), as well as 90%, 70%, 50%, 30%, and 10% of the use concentration (if necessary). A break-point can be determined as the weakest concentration that left no rust stains on the filter paper. It provides a relative measure of the corrosion inhibition strength of the fluid. In addition, a number of blank runs (same procedure without any iron chips) were conducted to make sure that the fluids themselves were not leaving any stains on the filter paper.

The results (Table 2-6) of the iron chip test on the virgin samples (E1-V, E2-V, and S1-V) showed that E1-V and S1-V generated no rust at the use concentration (approximately 5% solution of the concentrate in tap water). S1-V showed stronger corrosion inhibition since there were no rust stains even at 30% of the use concentration. E2-V showed rust stains at the use concentration itself, indicating that this virgin fluid had lower strength corrosion inhibition properties compared with the other two.

All three spent samples showed rusting at the use concentration, which was expected given their low pH values and high contaminant levels. Recycled sample E1-R showed considerable improvement over the spent sample (E1-S), indicating that its corrosion inhibition properties had been restored. E2-R and S1-R showed some rust at the use concentration, indicating that stronger iron corrosion resistance properties need to be imparted to these fluids.

In the copper corrosion test (ASTM D 130-88), a polished copper strip is immersed in the fluid and heated at 100°C for 3 hours. Then, the test strip is removed, washed, and compared with the ASTM Copper Strip Corrosion Standards. The test strip is then given a single rating of 1A, 1B, 2A, 2B, 2C, 2D, 2E, 3A, 3B, 4A, 4B, or 4C. The 1A rating is the best, indicating almost no tarnish on the strip, and the 4C rating is the worst, indicating heavy tarnish. All the collected samples (Table 2-6) fared virtually the same with a high rating of 1A or 1B, indicating that none of the samples had much effect on copper.

TABLE 2-6. CORROSION TEST RESULTS OF THE METALWORKING FLUIDS

Sample No.	Iron Chip Corrosion Breakpoint[a]	Copper Corrosion[b]
E1-S[c]	Rust stains at use concentration	1A
E1-R	No rust stains at 50% of use concentration	1A
E1-V	No rust stains at use concentration	1A
E2-S[c]	Rust stains at use concentration	1B
E2-R	Rust stains at use concentration	1B
E2-V	Rust stains at use concentration	1A
S1-S	Rust stains at use concentration	1A
S1-R	Rust stains at use concentration	1A
S1-V	No rust stains at 30% of use concentration	1B

[a] Analyzed by ASTM D 4627. Breakpoint is the lowest concentration tested that left no rust stains on filter paper.

[b] Analyzed by ASTM D 130. The rating scale is from 1 to 4, where 1 indicates slight tarnish and 4 indicates corrosion. 1A indicates a light orange color (almost the same as the freshly polished strip) and 1B indicates a dark orange color.

[c] Analyzed after skimming off and discarding the floating tramp oil.

2.2.7 Tramp Oil Content and Emulsion Stability

Tramp oil is the non-emulsified floating oil that builds up in metalworking fluid sumps from sources such as leaking equipment seals (hydraulic oils, gear oils) or from the workpiece itself. These oils can contaminate the workpiece or generate smoke from the heat of machining. Tramp oils are also the biggest contributors to fluid rancidity and odor. Rancid fluid promotes corrosion and may cause skin irritation. Tramp oil is removed during the recycling process by the centrifuge.

Tramp oil in the samples was measured by allowing a known volume of fluid to sit for 4 hours at room temperature in a graduated cylinder. The top layer that separated out was measured (Table 2-7). Spent samples E1-S and E2-S contained approximately 6% and 2% (by volume) respectively of tramp oil. No phase separation was noticed in any of the recycled samples, indicating the tramp oil had been removed. Virgin sample E1-V also showed some phase separation, but this was attributed to some unemulsified concentrate in the fluid. No noticeable quantity of tramp oil was noticed in any of the synthetic samples.

Often, excessive temperatures during operation, contamination, or formulation deficiencies can affect the stability of emulsions. Emulsion stability was measured by ASTM D 3707-89. In this test, a fluid sample contained in a 100-mL graduated cylinder is placed in an oven set at 85°C. The sample is examined after 48 and 96 hours for phase separation. This test was conducted on the fluid samples after any tramp oil that separated out at room temperature was discarded. The results (Table 2-7) showed small amounts of phase separation in spent samples E1-S and E2-S. The recycled samples remained as a single phase even after 96 hours, indicating that emulsion stability had been restored during recycling.

2.2.8 Foaming Tendency

Foam can be generated by agitation of the metalworking fluid caused by the machining operation or by fluid transfer. Foaming can reduce effective film strength, reduce heat transfer, and interfere with the settling of metal fines. Tendency of the fluids to foam was tested by ASTM D 892-89. In this method, a fluid sample, maintained at a temperature of 75°F, is blown with air at a constant rate for 5 minutes, then allowed to settle for a maximum of 10 minutes. The test is repeated on fresh fluid at 200°F, and then, after collapsing of the foam, at 75°F.

TABLE 2-7. TRAMP OIL SEPARATION AND EMULSION STABILITY

Sample No.	Tramp Oil Separation (Room Temperature)		Emulsion Stability[a] (Temperature = 85°C)		
				Upper Layer Volume (mL)	
	Total Initial Volume (mL)	Upper Layer Volume (mL) After 4 Hours	Total Initial Volume (mL)[b]	After 48 Hours	After 96 Hours
E1-S	898	51	100	1	1
E1-R	850	0	100	0	0
E1-V	882	22[c]	100	0	0
E2-S	846	13	100	1.5	1[d]
E2-R	850	0	100	0	0
E2-V	850	0	100	0.7	0[d]
S1-S	850	0	NA	NA	NA
S1-R	850	0	NA	NA	NA
S1-V	850	0	NA	NA	NA

[a] By ASTM D 3707. An "NA" indicates not analyzed.

[b] After discarding the upper layer formed at room temperature.

[c] Unemulsified constituents.

[d] Upper layer that formed after 48 hours reduced or disappeared after 96 hours.

From the results (Table 2-8), it can be seen that foam volume in the recycled samples (E1-R, E2-R, and S1-R) was significantly higher than in the spent or virgin samples. This can be attributed to the introduction of fresh emulsifier (surfactant) during recycling. A correction can be made for this effect by adding an anti-foam agent during recycling. However, Safety-Kleen does not typically add an anti-foam agent, unless the customer specifically reports a foaming problem.

2.2.9 Lubricity and Wear Preventive Characteristics

Lubricity and wear preventive characteristics of a metalworking fluid affect workpiece quality and tool life. When a high degree of lubrication is needed, straight oils are used instead of emulsions, with a concomitant loss in cooling characteristics. Emulsions have moderate lubricity and cooling characteristics for most general applications. Synthetic fluids contain special additives to impart lubricity.

Lubricity and wear characteristics were measured by ASTM D 4172-88. In this test, three 0.5-inch diameter steel balls are clamped together and covered with the metalworking fluid (maintained at 167 F). A fourth ball (called top ball) is pressed with a force of 40 kgf into the cavity formed by the three clamped balls for three point contact. The top ball is rotated at 1200 rpm for 60 minutes. The average size of the scar diameters worn on the three lower clamped balls is measured and can be used as a parameter for comparing various fluids. The results are reported in Table 2-9.

For Site E1, the recycled sample had a much lower average scar diameter than the spent sample, but not as low as the virgin sample. This indicated that the recycled and virgin samples had better lubricity and wear characteristics than the spent fluid, and the virgin sample was slightly better than the recycled. The Site E2 samples showed no noticeable differences in performance, although the recycled and virgin samples performed about the same. The presence of some emulsified tramp oil could have improved the lubricity results of the spent sample E2-S.

2.2.10 Bioresistance

A major factor in metalworking fluid spoilage (rancidity) is microbial growth. Microbial growth is caused by the wide variety of nutrients and substrates present in the metalworking fluid and by aeration during machining and transfer. Examples of metalworking fluid components that act as nutrients are mineral oils, fatty acids, emulsifiers, etc. Waste metal chips and grinding swarf

TABLE 2-8. FOAMING TENDENCY OF METALWORKING FLUIDS

Sample No.	Temperature °F	Foam Volume (mL) at End of 5-Minutes[a]	Foam Volume (mL) at End of Settling[a]
E1-S[b]	75 (I)	10	0 after 26 seconds
	200 (II)	10	0 after 6 seconds
	75 (III)	< 10	0 after 18 seconds
E1-R	75 (I)	170	0 after 298 seconds
	200 (II)	250	0 after 161 seconds
	75 (III)	450	60 after 10 minutes
E1-V	75 (I)	20	0 after 56 seconds
	200 (II)	80	0 after 45 seconds
	75 (III)	100	0 after 535 seconds
E2-S[b]	75 (I)	10	0 after 29 seconds
	200 (II)	10	0 after 5 seconds
	75 (III)	< 10	0 after 16 seconds
E2-R	75 (I)	520	370 after 10 minutes
	200 (II)	710	0 after 328 seconds
	75 (III)	430	280 after 10 minutes
E2-V	75 (I)	< 10	0 after 7 seconds
	200 (II)	20	0 after 5 seconds
	75 (III)	< 10	0 after 6 seconds
S1-S	75 (I)	420	60 after 10 seconds
	200 (II)	10	0 after 4 seconds
	75 (III)	390	210 after 10 minutes
S1-R	75 (I)	490	190 after 10 minutes
	200 (II)	120	0 after 87 seconds
	75 (III)	510	330 after 10 minutes
S1-V	75 (I)	180	10 after 10 minutes
	200 (II)	310	0 after 135 seconds
	75 (III)	190	10 after 10 minutes

[a] By ASTM D 892.

[b] Analyzed after skimming off and discarding the floating tramp oil.

TABLE 2-9. LUBRICITY AND WEAR CHARACTERISTICS OF THE METALWORKING FLUIDS

Sample No.	Average Wear Scar Diameter[a] (mm)
E1-S[b]	1.26
E1-R	0.83
E1-V	0.64
E2-S[b]	0.97
E2-R	1.18
E2-V	1.17

[a] By ASTM D 4172.

[b] Analyzed after skimming off and discarding the floating tramp oil.

provide a substrate for microbial growth. The problem is exacerbated by poor housekeeping that leads to the presence of tramp oil, food, cigarettes, and other debris in the fluid. Rancid fluid lowers pH, destabilizes emulsions, promotes rusting, and could cause skin irritation. Controlling microbial growth is an important factor in extending the life of the fluid.

One way of controlling microbial growth is by the addition of measured amounts of biocide. It is important, however, that the biocide used does not inactivate the other fluid components and inhibitors and is not itself inactivated by the other fluid components. In the recycling process, existing microbes are killed during the pasteurization step, the dead biomass is removed during the centrifugation step, and a measured quantity of biocide is added to control future microbial growth. ASTM E 686-85 evaluates the effectiveness of biocides at use concentrations. In this test, the fluid at the use concentration and fortified with the biocide is inoculated with a mixed population of bacteria and fungi. For this study, the inoculum was prepared by culturing a sample of spent (spoilt) fluid. Iron filings are also added to the test fluid to simulate the substrate. The fluid is aerated for 5 days, left unaerated for 2 days, and evaluated for bacterial and fungal counts. The process is repeated over a six-week period. This simulates plant conditions whereby the fluid is in use (aeration) during a five-day work week, and allowed to sit (non-aeration) over the weekend. Aerobic microorganisms grow during the aeration phase and start decaying during the non-aeration phase, especially if a floating layer of tramp oil cuts off ambient air; this decaying biomass causes what is commonly called "Monday morning odor."

Recycled and virgin fluids from sites E2 (emulsion-type) and S1 (synthetic) were subjected to this test. No additional biocide was added to the virgin fluids, which were prepared simply by diluting the virgin concentrate with tap water. Results are presented in Table 2-10. Week 0 represents the microbial concentrations immediately after inoculation. Week 1 results show that both bacterial and fungal populations were completely wiped out by the biocide in the recycled samples. In the virgin samples, most of the microbial populations declined but were not wiped out in Week 1. Fungal counts in Sample E2-V increased several orders of magnitude in Week 1. This indicates that the virgin fluids needed to be fortified with supplemental biocides (a normal practice in industry). No microbial growth was observed in the recycled samples even after six weeks. None of the samples, recycled or virgin, showed any noticeable changes such as change in appearance, emulsion break-up, or pH decline.

The ASTM method suggests using 10^7 bacteria CFU/mL as a reliable cutoff point when evaluating biocide failure. By this criterion, both virgin samples demonstrated biocide failure in the first week. Other sources have suggested 10^4 bacteria CFU/mL and 10^3 fungi CFU/mL as

TABLE 2-10. RESULTS OF MICROBIOLOGICAL TESTING

Week No.	Sample No.	pH	Bacteria[a] (CFU/mL)	Fungi[a] (CFU/mL)
0[b]	E2-V	8.00	1.0×10^9	4.1×10^4
	E2-R	8.90	3.0×10^8	< 10
	S1-V	8.13	1.3×10^8	1.0×10^8
	S1-R	8.30	1.6×10^8	6.5×10^5
1	E2-V	8.12	5.9×10^7	1.8×10^8
	E2-R	8.83	< 10	< 10
	S1-V	8.10	$>1.0 \times 10^7$est	2.6×10^5
	S1-R	8.35	< 10	< 10
2	E2-V	8.20	2.8×10^7	2.3×10^5
	E2-R	8.83	< 10	< 10
	S1-V	8.10	6.1×10^8	1.4×10^6est
	S1-R	8.40	< 10	< 10
3	E2-V	8.41	1.8×10^7	2.0×10^5
	E2-R	8.78	< 10	< 10
	S1-V	8.08	5.8×10^8	2.9×10^6
	S1-R	8.41	< 10	< 10
4	E2-V	8.45	1.5×10^7	6.3×10^6
	E2-R	8.78	< 10	< 10
	S1-V	8.02	1.2×10^9	1.1×10^7
	S1-R	8.41	< 10	< 10
5	E2-V	8.40	1.6×10^7	8.0×10^6
	E2-R	8.70	< 10	< 10
	S1-V	7.92	8.7×10^8	3.6×10^6
	S1-R	8.36	< 10	< 10
6	E2-V	8.38	1.3×10^7	7.1×10^6
	E2-R	8.75	< 10	< 10
	S1-V	8.00	7.5×10^8	5.9×10^8
	S1-R	8.40	< 10	< 10

[a] Analyzed by ASTM E 686.

[b] Immediately after inoculation.

pass/fail criteria. Yet others have suggested 99.9% (three-log reduction) after 60 days as the cutoff. By all these criteria, the recycled samples performed well. It is common practice for users to supplement virgin fluids with sump-side biocide additions.

In addition to the above test, ASTM recommended practices for safe handling of metalworking fluids include recommendations and tests for acute toxicity, skin sensitization, and eye irritation. These tests address the complete metalworking fluid constitution, including the biocide. These tests were beyond the scope in this evaluation, but would be good adjuncts to the above test.

2.3 PRODUCT QUALITY ASSESSMENT

The product quality of the recycled fluids can be considered as a function of (a) the level of contaminants and (b) the concentrations and efficacies of the various components of the fluid (the base oil or chemicals, corrosion inhibitors, biocides, and other additives). The performance tests conducted in this evaluation (namely, lubricity and wear, iron corrosion, copper corrosion, bioresistance, foaming tendency, and emulsion stability) are a measure of the integral effect of both the contaminant levels as well as the fluid components. The levels of particular contaminants that can be tolerated in the recycled fluids are difficult to judge in isolation, and are often affected by the properties of other fluid components. Hence, a combination of chemical characterization and performance testing is used in this evaluation.

The recycling process brings about considerable improvement in fluid quality, making recycling a technically feasible option. The above testing showed good results for recycled fluid characteristics such as viscosity, lubricity, wear resistance, pH, particulate removal, and bioresistance. The recycled fluid showed some tendency toward foaming and iron corrosion as compared to the virgin fluid; these could possibly be adjusted by appropriate additives. One limitation of this recycling process is that dissolved components of the spent fluid are not removed before adding fresh additive. There is, therefore, some potential for old and new additives clashing.

Some solubilized contaminants (such as calcium, magnesium, etc.) remain in the recycled fluid because the smallest filter (1 micron) in the recycling unit does not remove them. However, the levels of these contaminants in the fluids at the three sites evaluated did not appear to affect their performance. Dissolved solid levels in the fluids need to be monitored periodically by the user to determine when a given batch of fluid (after several recycles) is to be discarded. Dissolved solids level (as conductivity) is a fairly simple measurement on the shop floor.

Some accumulation of contaminants is noticeable between fluids at Site E1 (which had been recycled several times) and Site E2 (which had been recycled only twice). For example, particulate and dissolved solids levels (Table 2-2) were higher in the spent and recycled fluids at Site E1 than at Site E2. Metallic contaminants (e.g., iron, aluminum, zinc, and magnesium) appeared to be higher at Site E1 than at Site E2 (Table 2-5). On the other hand, calcium levels appeared to be higher at Site E2 than at Site E1. Thus, other factors such as tap water, type of machining operations, use patterns, etc. may also affect contaminant accumulation.

Further testing could include observation of the recycled fluids during use. Parameters such as workpiece quality and tool life could be evaluated over an extended period of time to evaluate the long-term performance of recycled fluids, especially because the recycled fluid showed a slight tendency towards ferrous metal corrosion. Tests for acute toxicity, skin sensitization, and eye irritation could be done to ensure that the biocide and other additives introduced during recycling do not present an occupational hazard.

Currently, there are no published standards for recycled fluids. Each user has to evaluate his/her own requirement based on the same factors used in selecting a virgin fluid brand. At the three test sites evaluated in this study, recycled fluids appeared to satisfy the functional requirements of the users.

SECTION 3
WASTE REDUCTION POTENTIAL

Waste reduction potential was measured in terms of (a) volume reduction and (b) pollutant reduction. Volume reduction addresses the gross wastestream (such as metalworking fluid and tramp oil). Pollutant reduction involves individual pollutants (such as surfactants and heavy metals) in the gross wastestream. Volume reduction affects environmental resources (e.g., landfill space) expended during disposal. Pollutant reduction addresses the specific hazards of individual pollutants.

3.1 WASTE VOLUME REDUCTION

The waste volume reduction potential of this technology involves the amount of spent metalworking fluid prevented from being disposed of into the environment (e.g., landfilling). Table 3-1 lists the various wastestreams and waste volumes measured at the three sites evaluated in this study. On an average, Safety-Kleen visits each customer once every 10 weeks and recycles an average of 250 gallons of spent fluid per visit. Thus, there is potential for an annual reduction of 1,250 gallons from these typical customers.

Approximately 4 gallons of tramp oil per visit, on average, are generated during recycling. This tramp oil can either be disposed of by the customer or is hauled away for a nominal charge by Safety-Kleen for use as supplemental fuel. Sludge residue generated on the filters is carried away by Safety-Kleen at no charge and later reclaimed for its metal value. Metal chips on the filters are placed in the customer's metal recycling bin (personal communication with Wally Dankmyer, Safety-Kleen, Inc.).

3.2 POLLUTANT REDUCTION

Metalworking fluids may contain several components that could be detrimental to the environment. Emulsion-type fluids are made up of an oil of mineral, vegetable, or synthetic origin

TABLE 3-1. WASTE VOLUME GENERATION

Waste Type	Site	Amount Generated Per Visit[a] (gallons)
Current Practice: (Disposal)		
Spent Metalworking Fluid	E1	175
	E2	55
	S1	100
	Average[b]	250
Recycling:		
Spent Metalworking Fluid	E1, E2, S1	0
	Average[b]	0
Tramp Oil	E1	10
	E2	2
	S1	4
	Average[b]	4
Residue on Filters	Average[a]	Variable

[a] On an average, Safety-Kleen visits each customer once every 10 weeks.

[b] Average per customer based on all Safety-Kleen customers.

dispersed in water by means of a surfactant. Synthetic fluids are solutions that use synthesized hydrocarbons (e.g. polyalphaolefins) or long-chain alcohols instead of mineral oils. In addition to these basic components, all fluids contain additives that impart specific properties. Typical additives include surfactants (e.g. sulfonates), anti-foam agents (e.g., siloxane), corrosion inhibitors (e.g. amines), odor suppressants (e.g. pine oil), and extreme pressure additives (e.g. sulfur, chlorine, phosphorus compounds).

In rare cases, metalworking fluids may be discharged to natural waters under a National Pollutant Discharge Elimination System (NPDES) permit. Discharges to natural waters could also result from leaks or spills. Typically, metalworking fluids are treated in an on-site industrial wastewater treatment system or a Publicly Owned Treatment Works (POTW) prior to discharge. Waste disposal is a growing concern because of increasing costs and environmental concerns.

Of the two types of metalworking fluids, the emulsion type fluids are generally easier to treat. The emulsion type fluids are treated by adding acid to reduce the pH to the range of 2 to 5. Inorganic salts such as calcium chloride, alum, or ferric chloride are then added to help coagulation. The pH is then raised into the range of 8 to 9 by addition of caustic, lime or soda ash. Sometimes cationic and anionic polymers are used to help the emulsifying and coagulation process. Emulsion breaking and coagulation results in an oily sludge, which, depending on economics, may be disposed of or recycled.

The synthetic fluids use synthesized hydrocarbons that form true solutions with water. Therefore, it is not possible to remove the organic materials by emulsion breaking. As a result, the synthetic fluids are more difficult to treat. The dissolved organics contribute significant quantities of oxygen demand which is normally removed by a biological process. The unexpected arrival of a high concentration of a waste with high oxygen demand can upset the operation of the biological digestion portion of a treatment plant.

Environmental concerns arise due to fundamental properties of metalworking fluids, whether they are released to a natural water body or to a treatment system. The major characteristics of concern are:

- Biochemical Oxygen Demand (BOD)
- Chemical Oxygen Demand (COD)
- Fats, Oils, and Grease
- Total Suspended Solids
- Toxicity and potential to induce cancer

BOD measures the dissolved oxygen consumed by biological activity to degrade the organic and inorganic contaminants. COD measures the oxygen consumed when the contaminants are oxidized in a potassium dichromate/sulfuric acid solution. The COD test involves a powerful oxidizing agent and therefore determines the oxygen demand for both biodegradable and non-biodegradable compounds. COD is not directly representative of oxygen demand in natural systems but can be measured more quickly and repeatably than BOD.

When waste containing degradable compounds enters a body of water or a biological treatment system, natural purification by biological activity begins to occur. Microbes use organic contaminants as a carbon and energy source. Dissolved oxygen in the water is consumed to sustain respiration. While exact interpretation of the significance of BOD and COD depends on the characteristics of the receiving water or treatment system, they generally indicate the oxygen consumed by the waste as it decomposes. Most water systems can tolerate some additional oxygen demand. However, an abrupt introduction of a new source of biodegradable chemicals may deplete dissolved oxygen faster than it can be replenished by dissolution from the air. Reduced dissolved oxygen concentration can cause fish kills in natural waters or failure of the biotreatment system in a water treatment plant.

Fats, Oils, and Grease in the waste stream can cause problems. Free oil and grease in natural waters can coat and foul skin, feathers, or gills of animals. Similar fouling and flow blockage can occur in equipment at water treatment plants. Most cities do not allow any floatable grease in waste water entering their treatment systems. The other oils, fats, or fatty acids are not as harmful as oil and grease but can still foul natural ecosystems. The oil and grease will increase sludge volume in a water treatment plant. Water treatment plants typically limit the inlet concentration of vegetable oils, fats, and fatty acids to 150 mg/l.

Total Suspended Solids measures the total filterable particulate matter in the fluid. High levels of suspended solids can increase the turbidity of natural waters. Suspended solids increase the amount of sludge that results from a water treatment system.

Surfactant additives emulsify oil in metalworking fluids. Different surfactants vary widely in terms of aquatic toxicity and ease of biodegradation. Surfactants accumulate within and on the surfaces of aquatic organisms (such as the gills of fish) and interfere with the function of these organs (Smith 1989). Biocide additives are used in metalworking fluids also. The main categories of these biocides include: alkane derivatives, formaldehyde condensates, isothiazolinones, morpholine compounds, oxazolidine compounds, phenols, pyridine derivatives, and quaternary ammonium compounds. Release of biocides into an aqueous or soil waste stream can cause detrimental environmental effects. For example, Dowicide 1 (0-phenylphenol) can form mutagens (Ames positive) when exposed to nitrites and nitrates in an aqueous environment irradiated by sunlight (Suzuki et al., 1990). Low levels of Dowicide 1 have also been detected in citrus (Ito et al., 1979). Disruption of plant leaf cells upon contact with Busan 77 caused by the disorganization of cellular membranes has been reported (Towne et al., 1978). The inherent toxicity or mutagenic properties of many biocides to the organisms that they would encounter, if released into the environment, preclude the disposal of many of these compounds into soil or water wastestreams.

As discussed above, metalworking fluids are typically processed in a wastewater treatment system. Under normal operations processing the fluid increases the volume of sludge from the treatment plant. The possible presence of high oxygen demand and free mineral oil and grease will increase the required complexity of the treatment system and may result in occasional operating upsets. In rare instances of direct release, the oxygen demand and free mineral oil and grease may damage aquatic life in the receiving water. Thus, there is a measurable pollution prevention accruing from recycling metalworking fluids.

3.3 WASTE REDUCTION ASSESSMENT

Although most water-based metalworking fluids are about 95% water at use concentration, there is concern about the detrimental effect of some of the fluid components listed above on the environment. Many states such as California, New Jersey, and Connecticut consider spent coolants as hazardous waste. In most other states, spent fluids are disposed in accordance with state regulations for oily wastes unless the TCLP test shows high levels of metallic contaminants, in which case the fluid is disposed of as hazardous waste. Recycling enables the recovery and reuse of most of the metalworking fluid components, thus, reducing waste.

According to a 1991 study by the Independent Lubricant Manufacturers Association (ILMA 1991), the volume of metalworking fluids (concentrate) manufactured in the U.S.A., has increased steadily from 67 million gallons in 1985 to 92 million gallons in 1990. By extending the life of metalworking fluids through on-site recovery, considerable amounts of fluid can be prevented from going to waste. The actual total volume of fluids going to waste, in some cases, may be as much as 20 times higher, since many types of fluids are diluted into 3 to 5% solutions in water.

SECTION 4
ECONOMIC EVALUATION

From the point of view of a small generator of spent metalworking fluid waste, the economic evaluation of this mobile recycling process consists only of a comparison between the operating costs for disposal versus those for recycling. There are no capital costs because the generator does not have to purchase and install any capital equipment, other than perhaps a holding tank to store the recycled fluid. Clean 55-gallon drums often suffice for this purpose.

4.1 OPERATING COSTS COMPARISON

The evaluation involved comparing the operating cost of disposal to the cost of the recycling (summarized in Table 4-1), from the point of view of a typical small generator who generates 250 gallons of spent fluid every 10 weeks (1,250 gallons/year). If the generator were to have the spent fluid hauled away by a waste disposal company (in the New Jersey/Pennsylvania area), the cost would be about $1.05/gallon if a TCLP test showed the fluid to be non-hazardous. This cost would rise to $6.00/gallon if the TCLP test showed the fluid to have hazardous levels of metals. In addition to this base disposal cost, there would be an annual analytical charge of $900 for the TCLP test and $385 for other miscellaneous analysis (such as fuel value). The typical small generator would therefore pay $2,600/year if the TCLP test was negative, or $8,785/year if the fluid was hazardous.

The charge for the recycling service is $1.25/gallon. The typical generator would therefore pay $1,565/year for five recycling visits (250 gallons/visit) to process 1,250 gallons/year. On average, 4 gallons of tramp oil is generated per visit (20 gallons/year). Because of its fuel value, tramp oil is hauled away at a charge of $0.15/gallon ($3/year). The total annual cost of recycling for the typical small generator, therefore, is approximately $1,570/year.

TABLE 4-1. OPERATING COSTS FOR DISPOSAL AND RECYCLING

Cost Element	Amount Generated Per Year (gallons)	Unit Cost ($)	Total Cost ($)
Disposal:			
Spent Fluid Disposal			
- if non-hazardous	1,250	1.05	1,315
- if hazardous	1,250	6.00	7,500
Hazardous Analysis			
- TCLP	1	900	900
- other	1	385	385
Total			2,600[a]
Recycling:			
Fluid Recycling Charge	1,250	1.25	1,565
Tramp Oil Disposal	20	0.15	3
Filtration Residue	Variable	0	0
Total			1,568

[a] If non-hazardous. The total cost of disposal would be $8,785 if TCLP testing showed it to be hazardous.

By recycling 1,250 gallons/year, the typical generator potentially reclaims and reuses approximately 1,200 gallons of valuable product; the slight difference being accounted for by systemic losses due to tramp oil removal, residual fluid in the recycling process lines, etc. Virgin fluid concentrate costs about $9/gallon (generally $7-11/gallon). This concentrate is usually diluted to a 5% use concentration in tap water. Thus, the generator realizes a recycled product worth $540/year; in other words, $540/year are saved in virgin fluid purchase costs.

4.2 ECONOMIC ASSESSMENT

The annual saving for the typical small generator is $1,572 if the spent fluid is non-hazardous. This saving reflects the difference between total disposal ($2,600) and recycling ($1,568) costs, plus recycled product value ($540). If the spent fluid is hazardous, the total disposal cost rises from $2,600 to $8,785 and the annual saving goes up to $7,757. Thus, it is economically beneficial for a small generator to recycle through mobile services rather than dispose, if it is determined that the recycled fluid quality is acceptable for the specific application.

SECTION 5
QUALITY ASSURANCE

A Quality Assurance Project Plan (QAPjP) was prepared and approved by the EPA before testing began (Battelle 1991). This QAPjP contains a detailed design for conducting this study. The experimental design, field testing procedures, and laboratory analytical procedures are covered. The QA objectives outlined in this QAPjP are discussed below.

5.1 ON-SITE TESTING

On-site testing was conducted as planned in the QAPjP.

5.2 LABORATORY ANALYSIS FOR COOLANT PERFORMANCE

All analysis was performed as planned, except that a duplicate analysis (to determine precision) for the emulsion stability test was not conducted. All samples were additionally analyzed for calcium and magnesium because high levels of these metals are associated with water hardness, and can lead to unstable emulsions.

Table 5-1 describes the QA data (based on precision) on the performance tests. All performance data was within acceptable precision. Table 5-2 describes the pecision data for the metals analysis. Precision for the metals analysis was within the accceptable range. No matrix spikes or method blanks were reported for metals because analysis was done by the standard additions method.

Water content analysis of the metalworking fluid samples was planned and results are reported in Appendix A.1. This analysis was performed by the Karl-Fischer titration method (ASTM D 1744). This method is predominantly used for determining water content (up to 0.1 %) in petroleum products. Because water content of the fluid samples was high (> 90%), this method was found to be unsuitable; and results could not be corroborated by observations made during on-site testing. However, other parameters (e.g., viscosity) can be used to indicate that water content of the samples was appropriate.

TABLE 5-1. LABORATORY QA DATA FOR PERFORMANCE TESTS

Parameter	Precision Requirement for this Study	Duplicate Results	Precision[a] Acceptable
Particulate Concentration	Relative percent deviation should be no more than 30%	86.50; 79.95	Yes (7.9%)
Conductivity	Relative percent deviation should be no more than 25%	1750; 1980	Yes (12%)
pH	Relative percent deviation should be no more than 5%	6.57; 6.62	Yes (0.8%)
Iron Chip Corrosion	Duplicates must target the same or consecutive dilution	Target same dilution	Yes

[a] $$\text{Precision} = \frac{\text{regular-duplicate}}{(\text{regular}+\text{duplicate})/2}$$

TABLE 5-2. PRECISION DATA FOR METALS ANALYSIS

Parameter	Sample No.	Regular Sample (ppm)	Duplicate (ppm)	Precision (RPD)[a]
Aluminum	SK-E1S	1.14	0.98	15.1%
Copper	SK-E1S	1.39	1.45	4.2%
Iron	SK-E1S	10.43	10.78	3.3%
Lead	SK-E1S	0.21	0.21	0.0%
Zinc	SK-E1S	1.65	1.65	0.0%

[a] Relative Percent Difference = $\frac{\text{regular-duplicate}}{(\text{regular}+\text{duplicate})/2}$

5.3 LIMITATIONS AND QUALIFICATIONS

QA objectives mentioned in the QAPjP (Battelle 1991) were met, and the results of the on-site and laboratory testing can be considered as a valid basis for drawing conclusions about product quality and waste reduction. One limitation of this evaluation is that the scope did not include shop-floor testing of recycled fluids over an extended period of time to determine workpiece quality and tool life. The shop-floor testing of the recycled (and virgin for comparison) fluids would be an essential step for all users. Also not included in the scope were tests for occupational hazards (skin irritation, etc.) from the recycled fluids. All these additional factors are also the same considerations that a user would evaluate while choosing a virgin brand.

Data for economic analysis were mostly obtained from Safety-Kleen's charges for its various services. Any assumptions made are specified so that the readers can adjust them to their own case.

SECTION 6
CONCLUSIONS AND DISCUSSION

This evaluation found that recycling of metalworking fluids is a good option for plants with machining operations. The recycled fluid quality was determined to be satisfactory for the applications at the three sites serviced. Waste generation was reduced and a valuable resource (metalworking fluid) was recovered. Mobile (on-site) recycling makes economic sense for small generators who may find purchasing and running their own recycling equipment too expensive.

There are many aspects to the process of extending the life of metalworking fluids; recycling is one of them. Many fluid users, large and small, are beginning to institute a fluid management system. This system begins with an examination of all plant operations with a view to consolidating the number of different fluids used. By testing different brands, a plant may be able to reduce the number of different fluids used without compromising workpiece quality. Consolidation of fluids enables users to focus on fewer waste types. Plants often find that consolidation makes recycling more viable.

Plants have also found that converting from a central fluid collection system, to a decentralized system facilitates better segregation of waste fluids. This makes recycling easier. Another practice that is being abandoned is that of collecting waste oil and waste metalworking fluids through a common system.

It is recognized in industry that using deionized water instead of tap water contributes to longer fluid life by avoiding contaminants that make their way into the fluid through tap water (such as calcium, magnesium, chlorides, sulfates, and bacteria). Regular fluid monitoring with parameters such as concentration, pH, conductivity, etc. also helps to improve fluid life. If monitoring indicates a problem, it can be immediately addressed (e.g., by adding more virgin fluid concentrate or biocide). Good housekeeping to prevent extraneous materials such as dirt, food, cigarettes, cleaners, and solvents from getting into the fluid is a good practice.

On-site recycling installations are often implemented progressively to improve fluid life. First a filter may be installed to separate out particulate material. Various devices to separate out tramp oil, such as coalescers or skimmers, may be the next feature. Pasteurization units accompanied by sump-side biocide addition may also be installed. The advantage of on-site installation is that the system and the additives can be tailored to the user's specific needs. For small generators who do not want to purchase and operate these pieces of equipment, the mobile recycling service is a good option. Currently, users generating as little as 55 gallons of used coolant per month to as much as 1000 gallons of used coolant per month have been using this service.

In 1990, 92 million gallons of metalworking fluid (concentrate) were manufacutured in the U.S.A. (ILMA, 1991). The total volume of fluid going to waste, in some cases, may be 20 or more times higher, because many fluid concentrates are diluted 20 or more times in water before use. Considerable amounts of this fluid can be prevented from going to waste by on-site recycling.

SECTION 7

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APPENDIX A

WATER CONTENT ANALYSIS

APPENDIX A-1. WATER CONTENT ANALYSIS

Sample Number	Water Content (%)
SK-E1S	86.4
SK-E1R	80.4
SK-E1V	88.8
SK-E2S	89.6
SK-E2R	85.7
SK-E2V	79.2
SK-S1S	85.5
SK-S1R	85.2
SK-S1V	76.1