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Project Summary

Mobile Onsite Recycling of Metalworking Fluids

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Product quality, waste reduction, and economic issues were evaluated for a technology designed to recycle metalworking fluids. Emulsion-type fluids were tested at two sites and a synthetic fluid was tested at a third site. The specific recycling unit being evaluated is based on the technology of filtration, pasteurization, and centrifugation. This recycling unit is mounted on a truck that goes from site to site, performing the recycling at each customer's location. The customer is charged a fixed fee for the service. Metalworking fluid recycling was found to have good potential as a way to reduce waste and save money. The product quality achieved by this unit was acceptable for the applications studied. Product quality was evaluated by conducting performance tests and by chemical characterization of the spent, recycled, and virgin fluids. Performance tests included tests for corrosion resistance, emulsion stability, foaming resistance, lubricity, and biological resistance.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The objective of the Waste Reduction Innovative Technology Evaluation (WRITE) Program conducted by the U.S. Environmental Protection Agency (EPA) is to evaluate, in a typical workplace environment, examples of prototype or innovative commercial technologies that have potential for reducing wastes. The goal of the metalworking fluid recycling study was to evaluate (a) the quality of the recycled coolant, (b) the waste reduction potential of the technology, and (c) the economic feasibility of the technology.

The mobile metalworking fluid recycling unit is operated by Safety-Kleen Corp.* Elgin, IL. Safety-Kleen provides fluid recovery services to a variety of businesses, primarily those that generate relatively small quantities of fluid waste. The mobile service performs the recycling on the generator's property, thus eliminating the need to transport potentially hazardous wastes. Each mobile truck-mounted unit, operating off its own power, is capable of processing fluid at a maximum rate of 300 gal/hr.

The recycling process (Figure 1) consists of filtering, pasteurizing, and centrifuging the spent fluid. The fluid is first sent through a 100-μ filter to remove any large particulates. It is then pumped through a preheater and then a heat exchanger to kill bacteria and fungi, as well as to reduce fluid viscosity. Centrifuging, where tramp oil and other debris are separated from the usable fluid, is next. Additives are then incorporated into the fluid to restore performance. In the final step, the fluid flows through a 1-μ filter to remove any remaining particulates. The fluid is

* Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

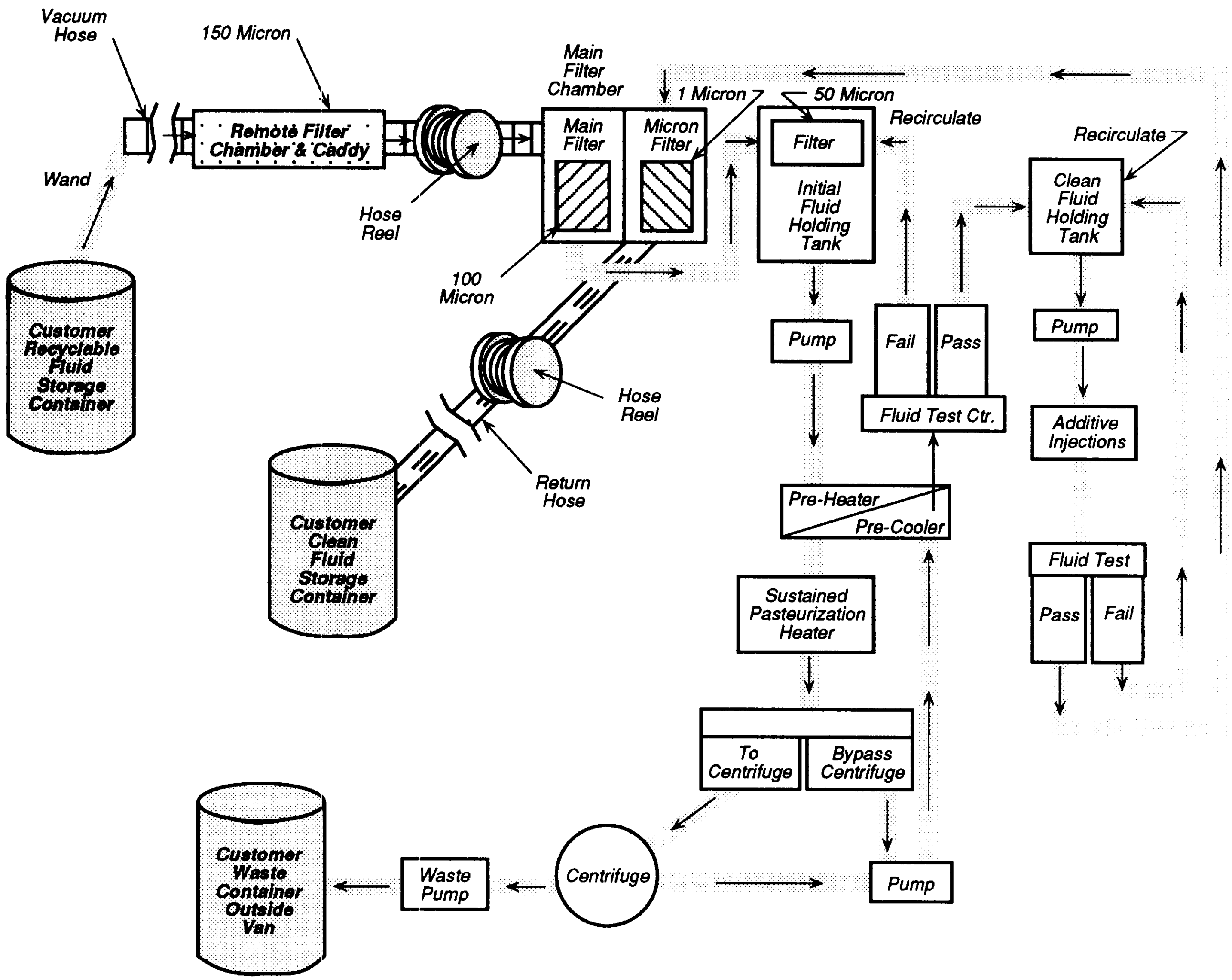

***Figure 1.** Metalworking fluids recycling system flowchart.*

then returned to the client's clean holding tank for reuse.

The technology was evaluated at three different small- to medium-sized machine shops (sites) in the Philadelphia, PA, vicinity. The three sites were chosen from among Safety-Kleen's customer base. Two of the sites (called E1 and E2) used emulsion-type metalworking fluids. The third site (called S1) used a synthetic fluid. At each site, one sample each of the spent, recycled, and virgin fluids (at their use concentrations) was collected and subjected to the same series of tests. The comparison between the spent and recycled fluids indicates the improvement achieved by recycling, and a comparison between the recycled and virgin fluids indicates how closely the recycled product approximates the virgin product. A limited number of samples was taken at each site because the objective was to conduct a broad spectrum of analytical tests on a few samples, rather than a statistical comparison based on a large number of samples.

Product Quality Evaluation

The main purpose of metalworking fluids in machining operations is to provide lubricity and cooling without causing corrosion or other problems. Through use, the fluids lose some measure of these functions because of the accumulation of contaminants and microbes. The recycling process attempts to restore these functions.

Degree of removal of nondissolved and dissolved particulates during recycling is shown in Table 1. High concentrations of these particulates affect tool life, surface finish, and chemical breakdown. Particles also provide substrates for microbial growth. At all three sites, the results showed considerably lower concentrations of nondissolved particulates in the recycled fluids (E1-R, E2-R, and S1-R) as compared with concentrations in the spent flu-

Table 1. *Analysis of Non-Dissolved and Dissolved Solids*

Sample No.	Non-Dissolved Solids Concentration[a] (mg/100 mL) Total	Inorganic	Dissolved Solids (Conductivity) (umhos/cm²)
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. E1-S = spent emulsion, site 1; E1-R = recycled emulsion, site 1; E1-V = virgin emulsion, site 1; etc.*
[c] *Possible inhomogeneity giving a low value.*

ids (E1-S, E2-S, S1-S). The accumulation of very small particulates over time and use could limit the number of times a given batch of fluid could be recycled. Conductivity of the samples was measured as an indicator of the dissolved solids levels in the fluids. Dissolved solids levels remained approximately the same after recycling, which indicated the effect of contaminant precipitation and fresh additive introduction.

Users of metalworking fluid often monitor the pH 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. This alkaline pH improves emulsion stability and corrosion resistance characteristics of the fluid. At the three sites tested, the pH of the recycled fluids was returned to this range.

Corrosion characteristics (Table 2) are important parameters for water-based metalworking fluids because of their effect on workpiece quality and tool life. The results of the iron chip corrosion test (ASTM D 4627) 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). In this test, the lower the concentration of the fluid in water at which there is no rust, the better the corrosion resistance. 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. 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. All of the collected samples (Table 2) fared virtually the same in the copper corrosion test (ASTM D 130) with a high rating of 1A or 1B, indicating that none of the samples have much effect on copper.

Tramp oil is the nonemulsified 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. Table 3 shows the results of the tramp oil analysis. 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 showed some phase separation, but this was attributed to some unemulsified concentrate in the fluid.

The results of emulsion stability testing at elevated temperature (Table 3) 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 hr, indicating that emulsion stability had been restored during recycling.

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. Foam volume in the recycled samples (E1-R, E2-R, and S1-R) was significantly higher than that in the spent or virgin samples. This can be attributed to introducing fresh emulsifier (surfactant) during recycling. A correction can be made for this effect by adding an antifoam agent during recycling. Safety-Kleen, however, does not typically add an antifoam agent unless the user specifically reports a foaming problem.

At all three sites, the recycled and virgin fluid viscosities were very close (Table 4); this indicated that the recycling process had restored this parameter. The viscosity measurements also indicate that the recycling process succeeded in returning the fluids to the required use concentration (oil:water ratio). The concentration of the recycled fluid is adjusted during the recycling process by taking refractometer readings. More virgin fluid is added

Table 2. *Corrosion Test Results of the Metalworking Fluids*

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

Table 3. Tramp Oil Separation and Emulsion Stability

	Tramp Oil Separation (Room Temperature)		Emulsion Stability[a] (Temperature = 85°C)		
				Upper Layer Volume (mL)	
Sample No.	Total Initial Volume of The Fluid Samples (mL)	Volume (mL) of Upper Layer Separating Out After 4 Hr	Total Initial Volume (mL)[b]	After 48 Hr	After 96 Hr
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 concentrate.
[d] Upper layer that formed after 48 hr reduced or disappeared after 96 hr.

to the recycled batch if needed to restore the use concentration.

Lubricity and wear preventive characteristics of a metalworking fluid affect workpiece quality and tool life. Lubricity and wear characteristics were measured by the standard "four-ball test" (ASTM D 445) (Table 4). For Site E1, the recycled sample caused a much lower average scar diameter than did 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 that the virgin sample was slightly better than was 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.

A major factor in metalworking fluid spoilage (rancidity) is microbial growth. 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. No microbial growth was observed in the recycled samples even after 6 wk.

The performance tests conducted in this evaluation (viscosity, 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 level of additives and other 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 and additives. The recycling process brings about considerable improvement in fluid quality, to make recycling a technically feasible option. The recycled fluid showed some tendency toward foaming and iron corrosion when compared with the virgin fluid; but these could possibly be adjusted by appropriate additives. Some solubilized contaminants (such as calcium, magnesium, etc.) remain in the recycled fluid because the smallest filter (1 μ) in the recycling unit does not remove them. The levels of these contaminants in the fluids at the three sites evaluated did not, however, appear to affect their performance. Retention of solubilized constituents in recycled fluids also has the potential for old and new additives to clash if they are mismatched.

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.

Waste Reduction Potential

The waste volume reduction potential of this technology involves the amount of spent metalworking fluid kept from being disposed into the environment (either by landfilling or by onsite wastewater treatment and sewer disposal). On an average, Safety-Kleen visits each user once every 10 wk and recycles an average of 250 gal of spent fluid per visit. Thus, there is potential for an annual reduction of 1,250 gal from a typical small user. Approximately 4 gal of tramp oil per visit are generated during recycling. This tramp oil is hauled away at a competitive fee by Safety-Kleen for use as supplemental fuel. Residue generated on the filters (mostly metal chips) is transferred to the user's waste metal bin and later reclaimed for its metal value.

According to a 1991 study by the Independent Lubricant Manufacturer's Association, the volume of metalworking fluids (concentrate) manufactured in the United States, has increased steadily from 67 mil gal in 1985 to 92 mil gal in 1990. By extending the life of metalworking fluids through onsite 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

Table 4. Lubricity and Wear, and Viscosity Characteristics of the Metalworking Fluids

Sample No.	Viscosity[a] (cs)	Average Wear Scar Diameter[b] (mm)
E1-S[b]	0.77	1.26
E1-R	0.85	0.83
E1-V	0.81	0.64
E2-S[b]	0.69	0.97
E2-R	0.81	1.18
E2-V	0.77	1.17
S1-S	0.77	NA
S1-R	0.75	NA
S1-V	0.75	NA

[a] By ASTM D 445. An NA indicates not analyzed.
[b] Analyzed after skimming off and discarding the floating tramp oil.

be as much as 20 times higher than the manufacturer volumes, since many types of fluids are diluted into 3% to 5% solutions in water.

Economic Evaluation

The economic evaluation compared costs for recycling versus costs for disposal. Recycling costs included the onsite service charge for the customer and tramp oil disposal cost. Disposal costs included spent fluid disposal cost and hazard analysis costs. The annual savings for a typical small user, who recycles 1,250 gal/yr of metalworking fluid was approximately $1,600, if the spent fluid was nonhazardous, and $7,800, if the spent fluid was hazardous (by the Toxicity Characteristic Leaching Procedure).

Conclusions

This evaluation found that recycling of metalworking fluids is a good option for small- to medium-sized plants with machining operations. In the absence of published standards for recycled fluids quality and performance, the user has to evaluate the recycled product by the same criteria used to select a virgin brand. In addition to the testing performed in this evaluation, shop-floor testing of the recycled fluids over an extended period of time to determine the effect on workpiece quality and tool life would be desirable.

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