TOXICS USE REDUCTION INSTITUTE

THE MASSACHUSETTS TOXICS USE REDUCTION INSTITUTE

Fact Sheet 7

Overview of Machining Fluids and Aqueous Cleaning with Pollution Prevention Opportunities

In the machining of metals, fluids are used as lubricants, chip removers, rust inhibitors, and coolants. A variety of machining fluids are used based on compatibility with the metal and the machining process.

After a part has been machined it often must be cleaned to ensure the success of further processing steps (such as electroplating). Historically firms have cleaned work-pieces in degreasers containing chlorinated solvents. Under the Montreal Protocol companies were required to phase-out production of 1,1,1-TCA (trichloroethane) and chlorofluorocarbons (e.g., CFC-113) by 1995. Also, taxes and disposal costs of these chlorinated solvents are increasingly prohibiting their use. Water-based cleaners will most likely be favored over the many possible replacements for chlorinated solvents.

This fact sheet presents the new challenges that companies face in reducing their reliance on chlorinated solvents. It describes types of machining fluid and suggestions for selecting and maintaining fluids. Also included is a description of aqueous cleaning technologies for firms that are considering adopting them and suggestions for firms trying to improve their existing aqueous cleaning process. The fact sheet provides insight into the relationship between machining fluids and aqueous cleaning.

Selection Processes

Large firms may employ a lubricating engineer to select the best machining fluid for a given application, however smaller firms are often less systematic. When selecting a machining fluid, it is important to consider not only how well it performs, but also the ease of removing and recycling the fluid, and the worker health and safety impacts of that fluid. By improving the method of selection and application, fluid purchase and disposal costs can be decreased while reducing the load to the cleaning system.

For aqueous cleaners there is no complete information regarding a cleaner's effectiveness at removing a specific contaminant and often product information sheets overstate the cleaner's capabilities. These factors make selecting an appropriate aqueous cleaner a challenging task. Recommendations for effective cleaning formulations for specific applications can be obtained from the Toxics Use Reduction Institute's (TURI) Surface Cleaning Lab,[1] vendors or literature case studies. Bench-scale testing may be necessary to further evaluate the recommendations.

Machining Fluids

Machining fluids can be categorized by percent mineral oil content and percent and type of additives used as lubricants, emulsifiers, rust inhibitors and biocides. General formulations of machining fluids are given on product information sheets and Material Safety Data Sheets (MSDSs). Machining fluids are often divided into three categories: cutting oils, water-soluble fluids, and paste or solid lubricants.

Cutting Oils

Cutting oils are mineral oils used alone or compounded with polar additives (such as vegetable oil) and/or chemically-active additives. The mineral oils used are typically paraffinic (straight-chain hydrocarbon base), or naphthenic (ring-structured hydrocarbon base). Naphthenic oils are more widely used because they have a much higher solubility for additives. There are two classes of cutting oils: inactive and active. Inactive cutting oils are mineral oils compounded with chemically inactive additives which provide increased lubricity. Active cutting oils are mineral oils or fatty mineral oil blends that contain sulfur, chlorine or phosphorus in an active form which reacts with the metal (see Table 1).

Water-Soluble (Water-Miscible) Fluids

Water-soluble fluids are primarily used for high-speed machining to prevent thermal distortion of the tool and work-piece. For machining that is high-speed chip making, the oil concentrate is usually blended 1 part with 20 to 30 parts water. For many grinding operations where a lighter fluid with better cooling properties is desired, the ratio of oil to water may be from 1:40 to 1:50. The three types of water-soluble fluids are: emulsifiable oils, synthetic (chemical) fluids, and semisynthetic (semichemical) fluids. Synthetic fluids consist of inorganics and/or other materials dissolved in water. They contain no mineral oil. Semisynthetic fluids are a combination of synthetics and emulsifiable oils (see Table 1).

Paste and Solid Lubricants

Grinding wheels are sometimes impregnated with solids possessing lubricating qualities. In special cases grinding wheels are treated with sulfur to produce a cooling action in wet grinding. Often grease sticks are externally applied to grinding wheels and solid waxes are used on grinding wheels, sanding disks or belts, and band or circular saw blades. Other solids commonly used as heavy-duty lubricants are molybdenum disulfide, tripoli, graphite, mica, talc, glass, pastes, and soaps.[2,3]

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Table 1. Types and Characteristics of Machining Fluids

	Type	Characteristics and Uses
Inactive cutting fluids	Straight mineral oils	Used in light duty operations that require low levels of cooling and lubrication; if kept clean, they can be reused indefinitely; lower in cost than compounded oils
	Fatty oils	Most common types are lard and rapseed oil; high anti-friction properties but poor anti-weld characteristics; have a tendency to emit unpleasant odors
	Compounded cutting oils	Made by blending mineral oils with polar additives and/or chemically active additives
	Fatty-mineral oils	Straight mineral oils blended with up to 40% fatty oil
	Inactive extreme-pressure (EP) additives	Additives such as chlorine, sulfur or phosphorus added to mineral or compounded oils for machining applications where forces are high
Active cutting fluids	Fluids containing sulfur additives	Contain sulfur additives that form metallic sulfide films which act as solid films up to 1300°F; may stain aluminum, copper, brass, bronze, and magnesium; nonferrous metals less likely to be stained
	Fluids containing chlorine additives	Ferrous chloride film that forms when chlorine reacts with ferrous workpieces or HSS (high strength steel) tools; low shear strength reduces friction at temperatures up to 750°F
	Fluids containing phosphorus additives	Phosphorus additives used as friction and wear reducers; will not stain ferrous or nonferrous workpieces
Emulsifiable oils	Emulsifiable mineral oil	Suspension of mineral oil made by blending the oil with an emulsifying agent; emulsifiers break the oil into minute particles and keep the particles dispersed in water for a long period of time; bactericides (commonly nonphenolic compounds) are used to control the growth of bacteria, algae, and fungi; phenolics may be used when disposal is not a concern
	Extreme-pressure emulsifiable oils	Sometimes referred to as heavy-duty soluble oils; contain sulfur, chlorine, or phosphorus; may also contain some fatty oils to increase lubricity
Synthetic fluids	True solution fluids	Chemical solutions containing rust inhibitors, sequestering agents, amines, phosphates, borates, glycols or ethylene oxide condensates; have a tendency to leave a residue of hard or crystalline deposits that are formed when water evaporates
	Surface-active chemical fluids	Fine colloidal solutions of organic or inorganic materials dissolved in water; wetting agents are usually added to provide moderate lubricity; have low surface tensions; usually contain rust inhibitors; when they dry onto a work-piece they usually leave a powdered residue
	EP surface-active chemical fluids	Similar to surface-active fluids but contain EP additives such as chlorine, sulfur, and phosphate to give the fluid extreme pressure lubrication qualities

Aqueous Cleaner Components

Aqueous cleaner chemistries are complex and cleaning formulations vary greatly. Aqueous cleaners use water as the primary solvent. Formulations may be divided into categories by what combination (types and percent concentration) of builders, additives, and surfactants are present in a formulation, however formulators do not typically disclose this information due to its proprietary nature. MSDSs contain basic properties (pH, flash point, etc.) of the cleaner and product information sheets include information such as substrate compatibility. Surfactants are combined with builders and additives such as pH buffers, rust inhibitors, chelating agents, and saponifiers. These agents provide multiple degrees of freedom in formulating, blending, and concentrating. They also provide useful synergistic effects. A brief description of each component and its function follows.

Builders

Builders are the alkaline salts in alkaline cleaners. An aqueous cleaning formulation usually includes two or more builders that serve many functions which depend on the type of builder used. There are three main groups: phosphates, silicates, and carbonates.

Phosphates soften water, eliminating the flocculent precipitate caused by calcium, magnesium and iron. They also act as a soil dispersant, a buffer, and a source of alkalinity. Silicates provide alkalinity, prevent redeposition of soil by keeping it suspended, provide detergency, and act as inhibitors protecting metals such as zinc and aluminum from other alkaline salts.

Carbonates are an inexpensive source of alkalinity and act as buffers in solution. Carbonates can also be an adsorbing media for the liquid components of the cleaner when the cleaner is in a powdered form. Two other substances that are used as builders in aqueous cleaning formulations are hydroxides and borates. Hydroxides are a relatively inexpensive source of alkalinity. Borates act as buffers and provide some detergency and metal protection.[4]

Additives

Additives are organic or inorganic compounds that provide many functions including additional cleaning or surface modification. They also soften water and complex or tie up metal ions. The three main types of additives are chelating agents, rust inhibitors, and sequestering agents.

Chelating agents solubilize metal salts by forming chemical complexes. Chelating agents are sometimes used as builders in place of phosphates to eliminate the possible problem of eutrophication of water bodies.

Inhibitors minimize the negative effects alkaline cleaners may have on certain metal substrates. They prevent rusting of the part being cleaned and of the cleaning equipment. Inhibitors are found in high pH cleaners to prevent the cleaner from attacking non-ferrous metals. Low pH cleaners do not usually contain inhibitors. Inhibitors may be used in the wash stage of a single stage cleaning operation or in the rinse phase of a multiple stage cleaning process. Inhibitors may deposit a film on a part which may interfere with future processing or increase the difficulty of rinsing.[5]

Sequestering agents combine with heavy metal ions, (calcium and magnesium) in hard waters to form molecules that can no longer react. Sequestering agents also prevent salts from recontaminating parts.

Surfactants

Surfactants are organic compounds in aqueous cleaning formulations that provide solubilization, emulsification and wetting. Because of their unique chemical characteristics, surfactants lower the surface tension of water. This enables the detergent to wet small areas otherwise inaccessible to water. The hydrophobic portion of the surfactant molecule may react with the machining fluid and remove it from the part.

There are four main types of surfactants: nonionic, anionic, cationic and amphoteric. The two main types used in aqueous cleaning are nonionics and anionics.

Nonionic Surfactants

- most widely used in metal cleaning
- useful over a wide range of pH
- effective at solubilizing nonpolar soils
- effectiveness is temperature dependent
- no charged group
- low-foaming

Anionic Surfactants

- most widely used in the surfactant industry due to their low production costs
- not as commonly used in metal cleaning due to foaming
- work effectively in immersion applications where foaming is not a factor
- effectiveness not temperature dependent
- negatively charged end
- can solubilize polar soils

Cleaning Equipment

Process equipment used with aqueous-based cleaners can be divided into three categories: cleaning, rinsing, and drying. The washing equipment may be immersion, spray, or ultrasonic.

Immersion

In an immersion system the parts are immersed in a solution and some form of agitation adds the energy needed to displace and float away contaminants. Soil is removed from the metal surface by a combination of the aqueous cleaner and the currents in the solution. The currents are created by heating coils or by mechanical action such as rotation, agitation, or circulation. The method of agitation selected can be tailored to part size and geometry.

Immersion

Advantages	Disadvantages
Can use existing vapor degreasing equipment with some simple changes Will flush out chips Cleans complex parts and configurations Usable with parts on trays Simple to operate	Difficult to automate May require proper part orientation and positional changes while in solution

Spray Washing

In the spray washing method, parts are sprayed with a solution at various pressures from 2 psi to more than 400 psi. Low pressure spray washers may be small, manually operated models which may require some hand scrubbing. The higher pressure spray washers deliver more mechanical action to help remove soils from metal surfaces. Spray cleaners are prepared with low foaming detergents which may be less effective chemically than those used in immersion cleaners. Their effectiveness is due to the increased mechanical action. Although spray cleaning is effective on most parts, certain configurations have soiled areas (such as the interior of an automobile tail pipe) that are inaccessible to the spray stream. In these instances, immersion cleaners are more effective. Optimization of nozzle design parameters such as spray pattern, drop size and formation, pressure/velocity, and volume may have a major impact on effectiveness.

Spray Washing

Advantages	Disadvantages
High level of cleanliness Relatively inexpensive Will flush out chips Can process a high volume of parts at one time Simple to operate Good for continuous processes	Not effective in cleaning complex parts Can process a high volume of parts at one time with blind areas Not effective on very small or light weight parts Contaminants containing fatty oils and/or glycerides may react with alkaline cleaners causing foaming

Ultrasonics

In this cleaning method ultrasonic waves are generated in the cleaning bath which cause tiny bubbles to form and collapse at the surface of the part. This is known as cavitation. Process design requires caution to insure that cavitation erosion of the parts' surfaces is not a problem.

Ultrasonics

Advantages	Disadvantages
Highest level of cleaning Can be automated Cleans complex parts and geometries	Noise may be a nuisance Cannot handle hard soils May damage soft metals Parts need to be arranged so that all surfaces wet

Closed Loop Aqueous Cleaning

Some firms switching to aqueous cleaning do not have a water discharge permit, which may be required for disposal of aqueous cleaning solutions. When aqueous cleaner baths are spent and discharged, they can cause problems with the normal operation of a wastewater treatment system. This makes closed loop filtration systems a necessity. These systems also alleviate some of the water, sewer, and cleaner costs.

Closed loop aqueous cleaning involves the removal of contaminants from the cleaner bath. The useful life of the cleaner is extended and the quantity of waste disposed is minimized. A variety of methods exist for removing contaminants from aqueous solutions. Methods selected for a particular application are often chosen on the basis of contaminant size. Particulate matter may be removed using settling tanks, chip baskets, and media or canister filters. Tramp oils are removed using skimmers and coalescers. Microfiltration can be used to remove particulate matter, tramp oils, and greases and ultrafiltration is effective at removing emulsified oils.[6]

Rinsing

The rinse step in aqueous cleaning is crucial. There are immersion, ultrasonics, and spray rinse systems. The temperature of the rinse water needs to be tailored to the substrate being rinsed. For example, rinse water for brass can not be higher than 150°F to prevent etching. Also, carbon steels need to be cold rinsed to prevent rusting because rusting is a temperature dependant chemical reaction. Water hardness is also a concern for rinse water because hard water will cause spotting during drying.

Drying

There are a number of drying systems available:

- compressed air or blower
- heated compressed air
- infrared lamps
- convection ovens
- vacuum ovens
- centrifugal dryers

The drying temperature should be set for the material being dried because high temperatures may adversely effect some substrates.

Opportunities for Pollution Prevention

Operating and process modifications may be employed to decrease costs and the environmental impact of these processes.

Machining Fluids

- Explore technologies that do not use machining fluids such as: electrical discharge machining; waterjet, plasma arc, or laser cutting; electrochemical machining; electromagnetic forming; and coated tool piece machining.[7,8]

- When selecting a machining fluid, consider other processes such as parts cleaning, cleaning bath extension, and machining fluid life extension and recyclability. Some distributors will work with you to reformulate an existing oil to make it more compatible with other processes.

- Explore reducing the amount of machining fluid used for a given application. There are firms that will monitor tool and work pieces to prevent damage while companies explore reducing their machining fluid use.

- The method of machining fluid application may be a source of inefficiency. Use automated spray nozzles and counters where possible.[9] When selecting spray nozzles consider the spray pattern, angle, and pressure, and the configuration of the nozzles.

- Vegetable-based lubricants should be used when possible because they are produced from renewable resources and pose less environmental impact.

- For soluble fluids, explore alternatives to biocides such as micro or ultrafiltration that eliminate the growth of bacteria and the negative health effects associated with biocides and bacterial growth. This also eliminates the potential need to dispose of these fluids as hazardous waste.[10]

- Remove contaminants continuously using any number of mechanical separators such as coalescers, skimmers, and sump cleaning units. Also, maintain the proper pH and concentration to increase the useful life of the fluid.[11]

- Perform an analysis on the water used as mix water to insure that the water hardness and total dissolved solids content will not interfere with the fluid performance. Deionization, distillation, or reverse osmosis may be desirable.

- Use the fewest number of fluids possible. This will help when segregating waste streams for recycling and it will simplify machining fluid record keeping.[12] Cleaning issues are also simplified when fewer fluids are used.

Aqueous Cleaning

- Knowledge of the contaminants on a part results in a more educated decision about how to clean it. This knowledge could eliminate trial-and-error cleanings.

- For firms that source-out work, assess whether parts are contaminated during shipping and eliminate cleaning steps that must be repeated after shipping. Also, eliminate cleaning steps that provide incomplete removal of contaminants or cleaning steps that result in hard water stains. The vendor that receives the parts may have a more difficult time cleaning the parts.

- Dump wash baths only when necessary. Tests such as pH, conductivity, turbidity, and refractometry are available to determine when a bath is spent. Conductivity and pH tests indicate the concentration of the cleaning formulation while refractometry and turbidity indicate the loading of contaminants in the bath.

- Use a counter-current rinse system to decrease water usage. These systems include two or more rinse tanks in series. The work-pieces move in the opposite direction than the water flow.

- When changing a cleaning bath use rinse water as make-up for the new wash bath.

- Drying may be the most expensive and energy intensive step in an aqueous cleaning process. Firms should determine an acceptable level of dryness and avoid over-drying.

- In non-precision applications use filtration techniques such as coalescing and cartridge filters to extend cleaner and rinse bath lives. These filters remove non-emulsified oils and particulate matter.

- Install a microfiltration system to remove all contaminants (except for emulsified machining fluids). For cleaners that do not emulsify machining fluids microfiltration may extend the cleaner and bath lives indefinitely.

- Ultrafiltration removes emulsified oils. These systems are useful for precision cleaning applications and applications where it is desirable to discharge effluent as non-regulated waste. Savings are realized in water, sewer and cleaner costs.

References

1. TURI performs surface cleaning evaluations as a free service to Massachusetts industries.

2. Society of Manufacturing Engineers, Tool and Manufacturing Engineers Handbook, Vol. 3: Materials, Finishing and Coatings, Fourth Edition, 1985.

3. American Society for Metals, Metals Handbook, Desk Edition, Metals Park, Ohio: ASM, 1985.

4. Quitmeyer, JoAnn, "The Aqueous Cleaning Handbook," Lexington, Mass.: W.R. Grace & Co - Conn., January 1986.

5. U.S. Environmental Protection Agency (EPA), *Solvent Alternative Guide,* Version 2.1, 1995.

6. The Massachusetts Toxics Use Reduction Institute, "Closed Loop Aqueous Cleaning," Technical Report No. 29, September, 1995.

7. As part of a Toxics Use Reduction Institute Matching Grants Project the Norwood Stamping Co., Inc. was able to decrease significantly the use of machining fluids in seven processes by using dies that were precoated with titanium nitride and by reprocessing preformed parts without the use of additional machining fluids.

8. State of Ohio, Environmental Protection Agency, "Extending the Life of Metal Working Fluids," In Office of Pollution Prevention, Ohio Environmental Protection Agency, Metal Working Fluids Pollution Prevention Information Packet, September 1995.

9. The Norwood Stamping Co., Inc. has reduced their use of machining fluids by greater than 50% using spray nozzles and counters. This also reduced the contaminant load on the aqueous cleaning system.

10. State of Ohio, Environmental Protection Agency, "Extending the Life of Metal Working Fluids."

11. Environmental Services Division, State of Michigan, "Ten Ways to Reduce Machining Coolant Costs," In Office of Pollution Prevention, Ohio Environmental Protection Agency, Metal Working Fluids Pollution Prevention Information Packet, September 1995.

12. State of Ohio, Environmental Protection Agency, "Extending the Life of Metal Working Fluids," p. 4.