

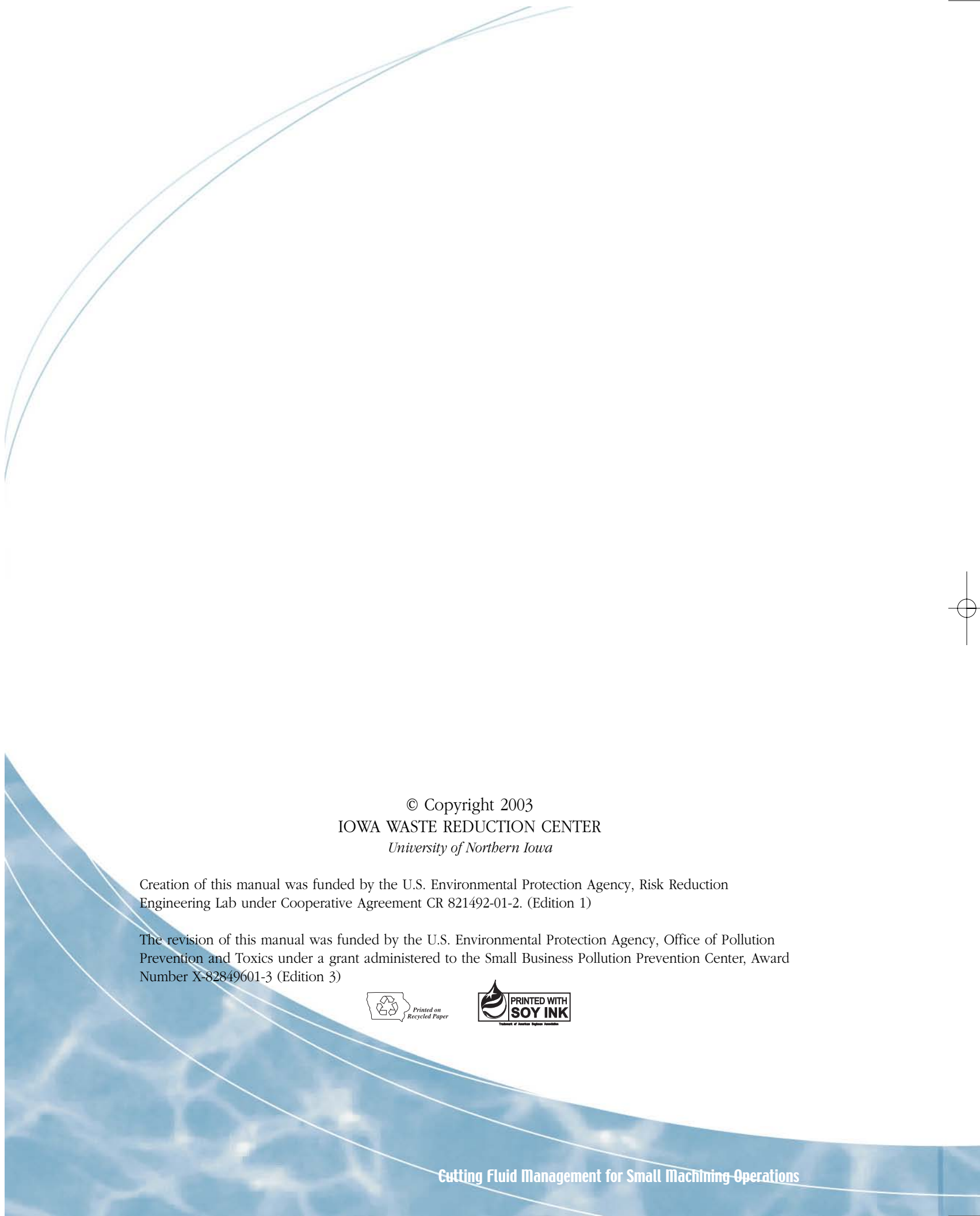
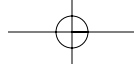


CUTTING FLUID MANAGEMENT

for **Small Machining Operations**

A Practical Pollution Prevention Guide

3rd edition



© Copyright 2003
IOWA WASTE REDUCTION CENTER
University of Northern Iowa

Creation of this manual was funded by the U.S. Environmental Protection Agency, Risk Reduction Engineering Lab under Cooperative Agreement CR 821492-01-2. (Edition 1)

The revision of this manual was funded by the U.S. Environmental Protection Agency, Office of Pollution Prevention and Toxics under a grant administered to the Small Business Pollution Prevention Center, Award Number X-82849601-3 (Edition 3)

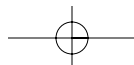


TABLE OF CONTENTS

1.0	INTRODUCTION	1
2.0	CUTTING FLUID CHARACTERISTICS	2
2.1	CUTTING FLUID SYSTEMS	2
2.2	FUNCTION OF CUTTING FLUID	2
	2.21 Temperature Control	3
	2.22 Removal of Cuttings and Particulates	3
2.3	FLUID PROPERTIES	3
	2.31 Corrosion Protection	3
	2.32 Stability/Rancidity Control	4
	2.33 Transparency and Viscosity	4
	2.34 Health and Safety Considerations	4
3.0	FLUID SELECTION	5
3.1	OIL-BASED CUTTING FLUIDS	6
	3.11 Straight Oils	6
	3.12 Soluble Oils	6
3.2	CHEMICAL CUTTING FLUIDS	9
	3.21 Synthetics	10
	Figure 3-1	9
	3.22 Semisynthetics	11
4.0	CUTTING FLUID MANAGEMENT FOR POLLUTION PREVENTION	14
4.1	ADMINISTRATION	15
	4.11 Fluid Management Personnel	15
	4.12 Record Keeping	15
	Figure 4-1	15
4.2	MONITORING AND MAINTENANCE	16
	4.21 Fluid Preparation	16
	Figure 4-2	17
	4.22 Fluid Concentration	19
	Figure 4-3	20
	4.23 Microbial Contamination	21
	Figure 4-4	23
	4.24 Fluid pH	23
	4.25 System Maintenance	24
	4.26 Foaming	27
4.3	FLUID RECYCLING	28
	4.31 Recycling Equipment	28
	Figure 4-5	28
	Figure 4-6	29
	4.32 Recycling System Selection	31
	4.33 Recycling Schedules	31

TABLE OF CONTENTS (CONTINUED)

5.0	WASTE MANAGEMENT AND ENVIRONMENTAL REGULATIONS	34
5.1	HAZARDOUS WASTE	34
5.11	Characteristic Wastes	34
5.12	Listed Wastes	35
5.2	CUTTING FLUID DISPOSAL	35
5.21	Disposal of Nonhazardous Fluid	37
5.3	DISPOSAL OF METAL CUTTINGS	38
5.4	DISPOSAL OF SUMP SLUDGE	39
5.5	DISPOSAL OF USED OIL	39
6.0	ALTERNATIVES TO CUTTING FLUIDS	40
6.1	DRY MACHINING	40
6.2	MINIMUM QUANTITY LUBRICANT	40
6.3	LIQUID NITROGEN TECHNOLOGY	41
7.0	HEALTH AND SAFETY CONSIDERATIONS	44
7.1	REDUCING EXPOSURE	44
7.11	Fluid Selection	44
7.12	Exposure Limits	44
7.13	Health Effects	44
7.14	Engineering Controls	45
7.2	OTHER CONTROL METHODS	46
7.21	Personal Protective Equipment	46
7.22	Establishing a Metalworking Fluid Management Program	46
7.23	Exposure Monitoring	46
	Appendix A: Case Studies	48
	Case Study A	48
	Case Study B	50
	Case Study C	52
	References	54

MANUAL ORGANIZATION

This manual has been organized into seven sections. Section 1 introduces the reader to fluid management and potential rewards of a fluid management program.

Section 2 provides a brief review of cutting fluid systems, functions of cutting fluids and characteristics a fluid should have in order to perform safely and effectively.

Section 3 presents information on cutting fluid selection and types of cutting fluids available. It covers the four types of metalworking fluids used today, their advantages and disadvantages, and factors to consider in selecting a fluid.

Section 4 is the main focus of this manual. It discusses the four integral components of fluid management—administration, monitoring, maintenance, and recycling. It provides information on practices that can be readily adopted to prevent the onset of fluid degradation, maintain fluid quality, extend fluid service life and reduce waste.

Section 5 presents information on waste management and disposal. It provides an overview of environmental regulations that pertain to spent cutting fluid and reviews possible disposal alternatives for waste cutting fluid.

Section 6 looks at alternatives to cutting fluids. Advantages and disadvantages of dry machining and other existing technology is examined, and information is presented on a number of emerging technologies that can extend cutting fluid life or even eliminate traditional cutting fluids altogether.

Section 7 provides detailed information on the subject of worker health and safety, and provides sources for additional information on this subject.

Appendix A contains several case studies. These studies demonstrate how the many pieces of a cutting fluid management system can be fit together to provide an effective, economical and efficient operation.

1.0 INTRODUCTION

Cutting fluids have been used extensively in metal cutting operations for the last 200 years. In the beginning, cutting fluids consisted of simple oils applied with brushes to lubricate and cool the machine tool. Occasionally, lard, animal fat or whale oil were added to improve the oil's lubricity. As cutting operations became more severe, cutting fluid formulations became more complex. Today's cutting fluids are special blends of chemical additives, lubricants and water formulated to meet the performance demands of the metalworking industry.

There are now several types of cutting fluids on the market, the most common of which can be broadly categorized as cutting oils or water-miscible fluids. Water-miscible fluids, including soluble oils, synthetics and semisynthetics, are now used in approximately 80 to 90 percent of all applications [1]. Although straight cutting oils are less popular than they were in the past, they are still the fluid of choice for certain metalworking applications.

Cutting fluids play a significant role in machining operations and impact shop productivity, tool life and quality of work. With time and use, fluids degrade in quality and eventually require disposal once their efficiency is lost. Waste management and disposal have become increasingly more complex and expensive. Environmental liability is also a major concern with waste disposal. Many companies are now paying for environmental cleanups or have been fined by regulatory agencies as the result of poor waste disposal practices.

Fortunately, cutting fluid life may be extended significantly by implementing an effective fluid management program. The primary objective of fluid management is to maintain fluid quality and performance through administration, monitoring, maintenance and recycling practices. This allows machine shops to make the most cost-effective use of their fluid. It is also the best pollution prevention technology available. Overall, fluid management provides a means to:

- ✓ Operate in a more environmentally sound manner;
- ✓ Improve productivity and reduce costs;
- ✓ Increase competitiveness;
- ✓ Maintain environmental compliance and reduce environmental liability;
- ✓ Consistently manufacture quality products; and
- ✓ Provide a healthier and safer work environment for employees.

Proper management of cutting and grinding fluids may also prevent them from being declared a hazardous waste at the end of their useful life. With increasing environmental regulation, a reduction in cutting fluid waste is an economical, practical and achievable goal.

2.0 CUTTING FLUID CHARACTERISTICS

Cutting fluids are used in machine shops to improve the life and function of cutting tools. They are also a key factor in machine shop productivity and production of quality machined parts [1,2,3].

2.1 CUTTING FLUID SYSTEMS

Cutting fluid may be applied to a cutting tool/workpiece interface through manual, flood or mist application [3,4,5].

Manual application simply consists of an operator using a container, such as an oil can, to apply cutting fluid to the cutting tool/workpiece. Although this is the easiest and least costly method of fluid application, it has limited use in machining operations and is often hampered by inconsistencies in application.

Flood application delivers fluid to the cutting tool/workpiece interface by means of a pipe, hose or nozzle system. Fluid is directed under pressure to the tool/workpiece interface in a manner that produces maximum results. Pressure, direction and shape of the fluid stream must be regulated in order to achieve optimum performance.

Cutting fluids may also be atomized and blown onto the tool/workpiece interface via mist application. This application method requires adequate ventilation to protect the machine tool operator. The pressure and direction of the mist stream are also crucial to the success of the application.

Metalworking fluid used in flood or mist applications is typically stored and distributed utilizing an individual machine tool system or a central reservoir system [3]. Individual machine tools with internal cutting fluid systems consist of a sump for fluid storage, a pump, delivery piping, a spent fluid collection and return system, and a filter to remove contaminants. Coolant recirculates from the machine sump to the machine tool.

Centralized reservoir systems may contain hundreds of gallons of cutting fluid which is distributed to individual machine tools via a pump and piping system. Prior to fluid returning to the central reservoir, it is passed through a filtering system designed to remove contaminants such as metal chips and other particulates.

2.2 FUNCTIONS OF CUTTING FLUID

The primary function of cutting fluid is temperature control through cooling and lubrication [1]. Application of cutting fluid also improves the quality of the workpiece by continually removing metal fines and cuttings from the tool and cutting zone.



2.21 TEMPERATURE CONTROL

Laboratory tests have shown that heat produced during machining has a definite bearing on tool wear. Reducing cutting-tool temperature is important since a small reduction in temperature will greatly extend cutting tool life [3].

As cutting fluid is applied during machining operations, it removes heat by carrying it away from the cutting tool/workpiece interface [1,4]. This cooling effect prevents tools from exceeding their critical temperature range beyond which the tool softens and wears rapidly [8]. Fluids also lubricate the cutting tool/workpiece interface, minimizing the amount of heat generated by friction [1,4]. A fluid's cooling and lubrication properties are critical in decreasing tool wear and extending tool life. Cooling and lubrication are also important in achieving the desired size, finish and shape of the workpiece [2].

No one particular fluid has cooling and lubrication properties suitable for every metalworking application. Straight oils provide the best lubrication but poor cooling capacities. Water, on the other hand, is an effective cooling agent, removing heat 2.5 times more rapidly than oil [2]. Alone, water is a very poor lubricant and causes rusting. Soluble oils or chemicals that improve lubrication, prevent corrosion and provide other essential qualities must be added in order to transform water into a good metalworking fluid.

2.22 REMOVAL OF CUTTINGS AND PARTICULATES

A secondary function of metalworking fluid is to remove chips and metal fines from the tool/workpiece interface. To prevent a finished surface from becoming marred, cutting chips generated during machining operations must be continually flushed away from the cutting zone [1].

Application of cutting fluid also reduces the occurrence of built-up edge (BUE). BUE refers to metal particulates which adhere to the edge of a tool during machining of some metals. BUE formation causes increased friction and alters the geometry of the machine tool. This, in turn, affects workpiece quality, often resulting in a poor surface finish and inconsistencies in workpiece size [3]. Metalworking fluids decrease the occurrence of BUE by providing a chemical interface between the machine tool and workpiece.

2.3 FLUID PROPERTIES

In addition to providing a good machining environment, a cutting fluid should also function safely and effectively during machining operations.

2.31 CORROSION PROTECTION

Cutting fluids must offer some degree of corrosion protection. Freshly cut ferrous metals tend to rust rapidly since any protective coatings have been removed by the machining operation. A good metalworking fluid will inhibit rust formation to avoid damage to machine parts and the workpiece [3]. It will also impart a protective film on cutting chips to prevent their corrosion and the formation of difficult-to-manage chunks or clinkers [1].

To inhibit corrosion, a fluid must prevent metal, moisture and oxygen from coming together. Chemical metalworking fluids now contain additives which prevent corrosion through formation of invisible, nonporous films. Two types of invisible, nonporous films are produced by metalworking fluids to prevent corrosion from occurring. These include polar and passivating films [6]. Polar films consist of organic compounds (such as amines and fatty acids) which form a protective coating on a metal's surface, blocking chemical reactions. Passivating films are formed by inorganic compounds containing oxygen (such as borates, phosphates and silicates). These compounds react with the metal surface, producing a coating that inhibits corrosion.

2.32 STABILITY/RANCIDITY CONTROL

In the early days of the industrial revolution, lard oil was used as a cutting fluid. After a few days, lard oil would start to spoil and give off an offensive odor. This rancidity was caused by bacteria and other microscopic organisms that grew and multiplied within the oil. Modern metalworking fluids are susceptible to the same problem [1].

No matter how good the engineering qualities of a coolant, if it develops an offensive odor, it can cause problems for management. The toxicity of a fluid may also increase dramatically if it becomes rancid due to chemical decomposition, possibly causing the fluid to become a hazardous waste. Fluid rancidity shortens fluid life and may lead to increased costs and regulatory burdens associated with fluid disposal.

A good cutting fluid resists decomposition during its storage and use. Most cutting fluids are now formulated with bactericides and other additives to control microbial growth, enhance fluid performance and improve fluid stability.

2.33 TRANSPARENCY AND VISCOSITY

In some operations, fluid transparency or clarity may be a desired characteristic for a cutting fluid. Transparent fluids allow operators to see the workpiece more clearly during machining operations.

Viscosity is an important property with respect to fluid performance and maintenance. Lower viscosity fluids allow grit and dirt to settle out of suspension. Removal of these contaminants improves the quality of the fluid recirculating through the machining system. This can impact product quality, fluid life and machine shop productivity.

2.34 HEALTH AND SAFETY CONSIDERATIONS

Workers in machining operations are continually exposed to cutting fluid. A fluid must be relatively non-toxic, non-flammable and non-misting to minimize health and safety risks [5].

TOXICITY. Most metalworking fluids are not highly toxic. Toxicity problems associated with metalworking fluids are usually caused by the fluid becoming rancid, superconcentrated or contaminated [3]. The main routes of exposure for metalworking fluid include inhalation (via vapor, smoke or mist), ingestion and skin absorption [7]. Dermatitis and respiratory problems are the most frequent health problems of machine shop personnel.

Due to the variety of ingredients contained in metalworking fluids, it is often very difficult to anticipate whether the fluid will affect individuals constantly exposed to this material. The Material Safety Data Sheet (MSDS) for a metalworking fluid contains important health and safety information and should be reviewed as a first step in fluid selection [8].

FLAMMABILITY. Machining operations typically generate a significant amount of heat which can cause cutting fluids to smoke and/or ignite. A fluid should have a high flashpoint to avoid problems associated with heat damage, the production of smoke, or fluid ignition.

MISTING. High speed metalworking operations such as grinding may atomize fluid, creating a fine mist which can be an inhalation hazard for machine tool operators [3]. Misting also creates a dirty work environment by coating equipment and the surrounding work area [1]. Non-misting fluids provide safer working conditions for the machine operator.

3.0 FLUID SELECTION

Choosing the right metalworking fluid for your operation can be confusing and time consuming. To select a fluid for your application, advantages and disadvantages of metalworking fluid products should be compared through review of product literature, supplier information, and usage history. Product performance information shared by other machine shops is another means of narrowing choices. Ultimately, the best indicator of fluid performance is through actual use.

In addition to the fluid properties discussed in Section 2, the following factors should be considered when selecting a fluid [1,2,8,9]:

- ✓ Cost and life expectancy
- ✓ Fluid compatibility with work materials and machine components
- ✓ Speed, feed and depth of the cutting operation
- ✓ Type, hardness and microstructure of the metal being machined
- ✓ Ease of fluid maintenance and quality control
- ✓ Ability to separate fluid from the work and cuttings
- ✓ The product's applicable temperature operating range
- ✓ Optimal concentration and pH ranges
- ✓ Storage practices
- ✓ Ease of fluid recycling or disposal

One thing must be remembered when choosing fluids – you generally get what you pay for. Don't choose a fluid just on its initial cost but on the cost per gallon divided by its life expectancy. Although purchase of a premium product is initially more expensive, the long-term cost of the fluid will likely be lower than products of inferior quality because of its superior fluid life.

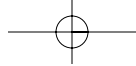
During fluid selection, the benefits of a fluid's versatility should be weighed against its performance in each metalworking application [1,10]. Because of significant improvements in fluid formulations, today's fluids are capable of handling a wide variety of machining applications [2]. Machine shops that once required several types of fluids may now find that one or two fluid types meet their needs. Consolidating the number of fluids used in the shop simplifies fluid management.

The most common metalworking fluids used today belong to one of two categories based on their oil content [2,8]:

- Oil-Based Fluids** - including straight oils, soluble oils and ag-based oils
- Chemical Fluids** - including synthetics and semisynthetics

Fluids vary in suitability for metalworking operations. For example, petroleum-based cutting oils are frequently used for drilling and tapping operations due to their excellent lubricity while water-miscible fluids provide the cooling properties required for most turning and grinding operations.

The following provides a description of the advantages, disadvantages and applications of each metalworking fluid category.



3.1 OIL-BASED CUTTING FLUIDS

3.11 STRAIGHT OILS (100% petroleum oil)

Straight oils, so called because they do not contain water, are basically petroleum, mineral, or ag-based oils. They may have additives designed to improve specific properties [1,3]. Generally additives are not required for the easiest tasks such as light-duty machining of ferrous and nonferrous metals [8,11]. For more severe applications, straight oils may contain wetting agents (typically up to 20% fatty oils) and extreme pressure (EP) additives such as sulfur, chlorine, or phosphorus compounds. These additives improve the oil's wettability; that is, the ability of the oil to coat the cutting tool, workpiece and metal fines [12]. They also enhance lubrication, improve the oil's ability to handle large amounts of metal fines, and help guard against microscopic welding in heavy duty machining. For extreme conditions, additives (primarily with chlorine and sulfurized fatty oils) may exceed 20%. These additives strongly enhance the antiwelding properties of the product [11].

ADVANTAGES. The major advantage of straight oils is the excellent lubricity or “cushioning” effect they provide between the workpiece and cutting tool [3]. This is particularly useful for low speed, low clearance operations requiring high quality surface finishes [8,11]. Although their cost is high, they provide the longest tool life for a number of applications. Highly compounded straight oils are still preferred for severe cutting operations such as crush grinding, severe broaching and tapping, deep-hole drilling, and for the more difficult-to-cut metals such as certain stainless steels and superalloys. They are also the fluid of choice for most honing operations due to their high lubricating qualities [12].

Straight oils offer good rust protection, extended sump life, easy maintenance, and are less likely to cause problems if misused. They also resist rancidity, since bacteria cannot thrive unless water contaminates the oil [8].

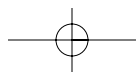
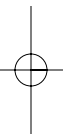
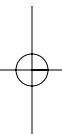
DISADVANTAGES. Disadvantages of straight oils include poor heat dissipating properties and increased fire risk [8,11]. They may also create a mist or smoke that results in an unsafe work environment for the machine operator, particularly when machines have inadequate shielding or when shops have poor ventilation systems. Straight oils are usually limited to low temperature, low-speed operations [1]. The oily film left on the workpiece makes cleaning more difficult, often requiring the use of cleaning solvents.

Straight oil products of different viscosities are available for each duty class. Viscosity can be thought of as a lubricant factor—the higher the oil's viscosity, the greater its lubricity. Highly viscous fluids tend to cling to the workpiece and tool. This causes increased cutting fluid loss by dragout and necessitates lengthier, more costly cleanup procedures. It can be more efficient to choose a low-viscosity oil that has been compounded to provide the same lubricity as a highly viscous one.

3.12 SOLUBLE OILS (60–90% petroleum oil)

Soluble oils (also referred to as emulsions, emulsifiable oils or water-soluble oils) are generally comprised of 60-90 percent petroleum or mineral oil, emulsifiers and other additives [1,8,13]. A concentrate is mixed with water to form the metalworking fluid. When mixed, emulsifiers (a soap-like material) cause the oil to disperse in water forming a stable “oil-in-water” emulsion [2,12]. They also cause the oils to cling to the workpiece during machining. Emulsifier particles refract light, giving the fluid a milky, opaque appearance.

ADVANTAGES. Soluble oils offer improved cooling capabilities and good lubrication due to the blending of oil and water [12]. They also tend to leave a protective oil film on moving components of machine tools and resist emulsification of greases and slideway oils [2].



Soluble oils are a general purpose product suitable for light and medium duty operations involving a variety of ferrous and nonferrous applications. Although they do not match the lubricity offered by straight oils, wetting agents and EP additives (such as chlorine, phosphorus or sulfur compounds) can extend their machining application range to include heavy-duty operations. Most cutting operations handled by straight oils (such as broaching, trepanning, and tapping) may be accomplished using heavy-duty soluble oils.

Soy-based cutting fluid

The University of Northern Iowa's (UNI) Ag-Based Industrial Lubricants (ABIL) Research Program, established in 1991, is a nationally recognized technical service group offering guidance and expertise on biobased (soybean) industrial lubricants. It is one of nine outreach programs sponsored by UNI's Business and Community Services (BCS) group. Research conducted at ABIL provides our nation's agricultural community with an expanded market for soy products. UNI-ABIL is a not-for-profit organization that receives support from federal, state, and private organizations.

The use of soybean oil for metalworking began as an alternative to conventional products. The performance observed shows a significant breakthrough in the use of soybean oil in metalworking applications. Soybean oil, like many other vegetable oils, presents superior lubricity in many industrial applications. Metalworking applications present an extremely harsh environment for lubricating oils. Exposure to air, heat, moisture, light and metal shavings (which act as catalysts in the breakdown of the lubricant) creates special problems when using metalworking lubricants.

UNI-ABIL researchers have been using a genetically altered strain of soybeans that produces soybean oil rich in tri-olein. This high molecular weight oil has a flash point of about 600°F (320°C) as compared to 420°F (216°C) for petroleum-based oils. Due to the polar nature of the oil, it bonds well with metal surfaces and therefore is very effective as a friction reducer. The oil has very high film strength. This helps prevent boundary lubrication and therefore helps reduce heat and tool wear. In addition, the low volatility of the oil prevents evaporation at the tip of the tool thus further preventing tool wear.

Metalworking fluids and machine lubricants developed at UNI-ABIL offer a number of ways to reduce operating costs. Most companies are interested in biodegradable products, especially those produced from renewable resources that help agribusiness. Soy based cutting oils produce less smoke and less mist, which are both important health concerns. Soy oil contains no chlorine or sulfur which are common to petroleum based cutting oils. Because of superior lubricity of soy-based oils, tool costs are greatly diminished and production gains are achieved because of increased feed rates and improvement in part finish. Grinding applications have actually shown a 50% reduction in wheel costs with the introduction of soy-based lubricants. In the brief period since the initial development of soy-based cutting fluids, more than 50 industries have made the change to the more environmentally friendly material. UNI-ABIL has found that most industries want to be pro-active where environmental issues are involved.

The acceptance by industry of the cutting oil developed by researchers at UNI-ABIL has exceeded expectations. Business is driven by profit and is therefore reluctant to change current practice or methods unless it can be demonstrated there is an advantage to change. Some

issues to be considered when changing metal cutting coolants include cost, productivity, equipment compatibility, operator acceptance and health issues. In spite of all these issues, UNI-ABIL has been given the opportunity to test at more than half of the companies that have been contacted.

Clearline Cutlery, located in Traer, Iowa, is a company that recently converted to SoyEasy™ Cool in its surface grinding operations. Clearline Cutlery uses grinding wheels to manufacture and recondition blades for the food industry. The number of grinding wheels used per year dropped from 162 using petroleum-based lubricants to 60 grinding wheels with the soy-based cutting oil developed at UNI-ABIL. This change resulted in a cost savings of over \$11,000 in its first year of operation. Similar savings were noted at Hawkeye Tool and Die. Hawkeye was using petroleum-based cutting coolant in a power band saw to cut 12-inch diameter stainless steel bar stock. SoyEasy™ Cool with its superior lubricity and cooling ability was able to prevent the blade from wandering. This improvement helped reduce the safety stock by 0.38 inches per piece. This resulted in a net savings of over \$4,000 per 50-piece run of this stainless steel part.

Health concerns are a major issue in any tooling operation. Smoke caused by heat from the tooling operation and mist generated by the cutting tools or grinding wheels are major health concerns. UNI-ABIL, Waterloo John Deere Tractor Works, and Castrol Industrial Americas are currently funding (\$28,000) a toxicity study of bio-based machining fluids at the Environmental Health Sciences Research Center at the University of Iowa, Oakdale Campus. Comparisons are being made between neat and used metalworking fluids. The test subjects for this study are mice. The scope of work centers on respiratory and vision difficulties that may result from exposure to mists of the various fluids. Preliminary results indicate there is no pathological inflammation occurring in the lungs or eyes of mice subjected to acute concentrations of either neat or used petroleum-based or soy-based cutting fluids. In the microbial assessment of soy and petroleum-based cutting fluids, all samples showed fungal growth. Bacterial breakdown of petroleum and soy-based cutting fluids continues to be a problem, however preliminary results being carried on at UNI-ABIL indicate breakdown of soy-based oil can be abated with suitable additives.

The use of soybean oil for metalworking fluids started as an alternative to conventional products. The performance observed shows a breakthrough in the metal working area. Soy-based oils currently match the price and performance of petroleum or semi-synthetic oils. UNI-ABIL has licensed several of the metalworking fluids for commercialization. The future for soy-based lubricants is very encouraging. UNI-ABIL is positioned to be a leader in this new technology.

For more information regarding the ABIL Research Program please visit our website at www.uni.edu/abil. For additional information please send questions or comments to Dr. Lou Honary, Director, to email address abil@uni.edu. If you would like additional information regarding products developed by ABIL Research Program for commercial sale please contact ELM Inc., at (319) 352-5300, or visit their website, www.elmusa.com for a full product listing.

Soy-based cutting fluid

3.0

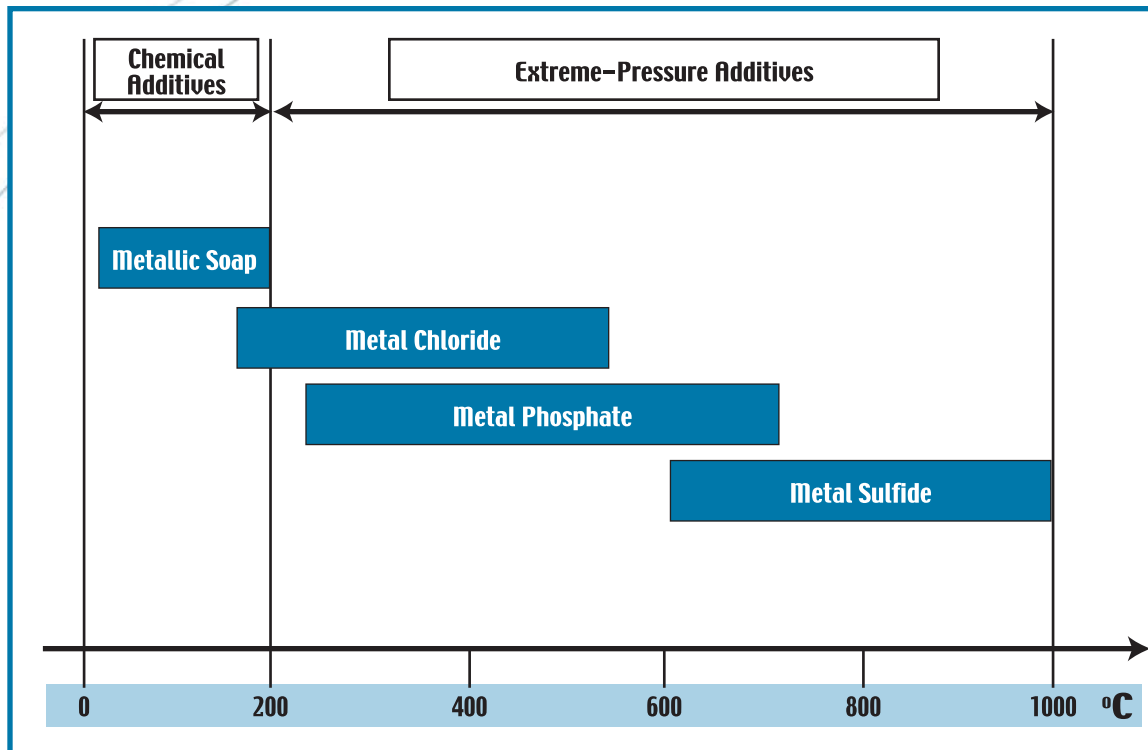


Figure 3-1 Temperature efficiency range of chemical and EP lubricant additives (modified from K. Bienkowski, 1993).

DISADVANTAGES. The presence of water makes soluble oils more susceptible to rust control problems, bacterial growth and rancidity, tramp oil contamination, and evaporation losses. Soluble oils are usually formulated with additives to provide additional corrosion protection and resistance to microbial degradation. Maintenance costs to retain the desired characteristics of soluble oil are relatively high. Other disadvantages of soluble oils include the following:

When mixed with hard water, soluble oils tend to form precipitates on parts, machines and filters [8,11]; Due to their high oil content, they may be the most difficult of the water-miscible fluids to clean from the workpiece. As a result of these disadvantages, soluble oils have been replaced in most operations with chemical cutting fluids.

Misting of soluble oils may produce a dirty and unsafe work environment, through slippery surfaces and inhalation hazards.

3.2 CHEMICAL CUTTING FLUIDS

Chemical cutting fluids, called synthetic or semisynthetic fluids, have been widely accepted since they were first introduced in about 1945. They are stable, preformed emulsions which contain very little oil and mix easily with water. Chemical cutting fluids rely on chemical agents for lubrication and friction reduction [8].

These additives also improve wettability. At temperatures above approximately 390°F (200°C), these additives become ineffective and EP lubricant additives (chlorine, phosphorus and sulfur compounds) are utilized.

These compounds react with freshly-machined metal to form chemical layers which act as a solid lubricant and guard against welding during heavy-duty machining operations. Fluids containing EP lubricants significantly reduce the heat generated during cutting and grinding operations. Figure 3-2 illustrates the temperature efficiency range of chemical and EP lubricant additives [8].

3.21 SYNTHETICS (0% petroleum oil)

Synthetic fluids contain no petroleum or mineral oil [2,11]. They were introduced in the late 1950's and generally consist of chemical lubricants and rust inhibitors dissolved in water. Like soluble oils, synthetics are provided as a concentrate which is mixed with water to form the metalworking fluid. These fluids are designed for high cooling capacity, lubricity, corrosion prevention, and easy maintenance. Due to their higher cooling capacity, synthetics tend to be preferred for high-heat, high-velocity turning operations such as surface grinding. They are also desirable when clarity or low foam characteristics are required. Heavy-duty synthetics, introduced during the last few years, are now capable of handling most machining operations.

Synthetic fluids can be further classified as simple, complex or emulsifiable synthetics based on their composition [8,11]. Simple synthetic concentrates (also referred to as true solutions) are primarily used for light duty grinding operations [2]. Complex synthetics contain synthetic lubricants and may be used for moderate to heavy duty machining operations. Machining may also be performed at higher speeds and feeds when using complex synthetics. Both simple and complex synthetics form transparent solutions when mixed in a coolant sump, allowing machine operators to see the workpiece.

Emulsifiable synthetics contain additional compounds to create lubrication properties similar to soluble oils, allowing these fluids to double as a lubricant and coolant during heavy-duty machining applications. Due to their wettability, good cooling and lubricity, emulsifiable synthetics are capable of handling heavy-duty grinding and cutting operations on tough, difficult-to-machine and high temperature alloys [2]. The appearance of emulsifiable synthetic fluids ranges from translucent to opaque.

Chemical agents found in most synthetic fluids include:

- ✓ Amines and nitrites for rust prevention
- ✓ Nitrates for nitrite stabilization
- ✓ Phosphates and borates for water softening
- ✓ Soaps and wetting agents for lubrication
- ✓ Phosphorus, chlorine, and sulfur compounds for chemical lubrication
- ✓ Glycols to act as blending agents
- ✓ Biocides to control bacterial growth

ADVANTAGES. Synthetic fluids have the following qualities which contribute to superior service life [8,23]:

- ✓ Excellent microbial control and resistance to rancidity for long periods of time;
- ✓ Nonflammable, nonsmoking and relatively nontoxic;
- ✓ Good corrosion control;
- ✓ Superior cooling qualities;
- ✓ Greater stability when mixed with hard water;
- ✓ Reduced misting problems; and
- ✓ Reduced foaming problems.

Synthetics are easily separated from the workpiece and chips, allowing for easy cleaning and handling of these materials. In addition, since the amount of fluid clinging to the workpiece and chips is reduced, less makeup fluid is needed to replace coolant lost to drag-out.

Good settling properties allow fine particulates to readily drop out of suspension, preventing them from recirculating and clogging the machine-cooling system. Overall, synthetics are easier to maintain due to their cleanliness, they offer long service life if properly maintained and can be used for a variety of machining operations.

DISADVANTAGES. Although synthetics are less susceptible to problems associated with oil-based fluids, moderate to high agitation conditions may still cause them to foam or generate fine mists [1]. A number of health and safety concerns, such as misting and dermatitis, also exist with the use of synthetics in the shop [8]. Ingredients added to enhance the lubricity and wettability of emulsifiable synthetics may increase the tendency of these fluids to emulsify tramp oil, foam and leave semi-crystalline to gummy residues on machine systems (particularly when mixed with hard water) [2].

Synthetic fluids are easily contaminated by other machine fluids such as lubricating oils and need to be monitored and maintained to be used effectively [1,12].

3.22 SEMISYNTHETICS (2–30% petroleum oil)

As the name implies, semisynthetics (also referred to as semi-chemical fluids) are essentially a hybrid of soluble oils and synthetics. They contain small dispersions of mineral oil, typically 2 to 30 percent, in a water-dilutable concentrate [1,8,14]. The remaining portion of a semi-synthetic concentrate consists mainly of emulsifiers and water. Wetting agents, corrosion inhibitors and biocide additives are also present. Semisynthetics are often referred to as chemical emulsions or preformed chemical emulsions since the concentrate already contains water and the emulsification of oil and water occurs during its production.



The high emulsifier content of semisynthetics tends to keep suspended oil globules small in size, decreasing the amount of light refracted by the fluid. Semisynthetics are normally translucent but can vary from almost transparent (having only a slight haze) to opaque [8,11]. Most semisynthetics are also heat sensitive. Oil molecules in semisynthetics tend to gather around the cutting tool and provide more lubricity. As the solution cools, the molecules redisperse.

ADVANTAGES. Like synthetics, semisynthetics are suitable for use in a wide range of machining applications and are substantially easier to maintain than soluble oils. They provide good lubricity for moderate to heavy duty applications. They also have better cooling and wetting properties than soluble oils, allowing users to cut at higher speeds and faster feed rates [8]. Their viscosity is also less than that of a soluble oil, providing better settling and cleaning properties. Semisynthetics provide better control over rancidity and bacterial growth, generate less smoke and oil mist (because they contain less oil than straight or soluble oils), have greater longevity, and good corrosion protection.

DISADVANTAGES. Water hardness affects the stability of semisynthetics and may result in the formation of hard water deposits. Semisynthetics also foam easily because of their cleaning additives and generally offer less lubrication than soluble oils.

WHY IT'S SOYEASY TO SWITCH

To SoyEasy™ Biotechbased Metalworking Fluids

CHARACTERISTIC	BENEFIT	CHARACTERISTIC	BENEFIT
BIOBASED	<ul style="list-style-type: none"> • Comes from US grown soybeans - a renewable U.S. resource. • Aids our farm and U.S. economy. • Reduces dependence on foreign oil. 	MULTIPLE USES	<ul style="list-style-type: none"> • The SoyEasy Metalworking Fluid line includes products for: cutting, grinding, hobbing, forming, drawing, tapping, reaming. It may also be used as a way lube and hydraulic oil.
LOWER OPERATING COSTS	<ul style="list-style-type: none"> • Increased productivity, reduced coolant usage and less tramp oil to dispose of. 	SAFETY BENEFITS	<ul style="list-style-type: none"> • Higher flash and fire points than conventional fluids. • Produces less mist and smoke in the workplace. • No Chlorine or Sulfur.
SUPERIOR LUBRICITY	<ul style="list-style-type: none"> • OptiBase™ 3000 high oleic soybean oil has superior lubricity. Better adhesion to metal surfaces 		
LONGER TOOL LIFE	<ul style="list-style-type: none"> • Extends tool life by up to 50%. 	 	
FEED RATES & SPEEDS	<ul style="list-style-type: none"> • Increases feed rates and production conventional fluids. 		
SURFACE FINISH	<ul style="list-style-type: none"> • Improves surface finishes and centricity. 		
SAVES ENERGY	<ul style="list-style-type: none"> • Reduces friction, lowers power consumption and saves energy. 		
PRICE & VALUE	<ul style="list-style-type: none"> • Priced similar to conventional metalworking fluids. • Better end-use cost and value to improve your bottom line. 		
BIODEGRADABLE	<ul style="list-style-type: none"> • Readily biodegradable. Safer for the environment. • Easier to dispose. 		
ISO 14000 BENEFITS	<ul style="list-style-type: none"> • Mostly natural ingredients. Less hazardous in the workplace. Helps comply with ISO 14000 - Environmental Management \ Standards. 		
COMPATIBILITY	<ul style="list-style-type: none"> • SoyEasy Cut (Straight cutting oils) are completely compatible with conventional petroleum fluids. 		

Soy fluid in screw machine

3.0

CUTTING FLUID TYPES: Advantages vs. Disadvantages

Straight Oils

ADVANTAGES - Excellent lubricity; good rust protection; good sump life; easy maintenance; rancid resistant

DISADVANTAGES - Poor heat dissipation; increased risk of fire, smoking and misting; oily film on workpiece; limited to low-speed, severe cutting operations

Soluble Oils

ADVANTAGES - Good lubrication; improved cooling capabilities; good rust protection; general purpose product for light to heavy duty operations

DISADVANTAGES - More susceptible to rust problems, bacterial growth, tramp oil contamination and evaporation losses; increased maintenance costs; may form precipitates on machine; misting; oily film on workpiece

Synthetics

ADVANTAGES - Excellent microbial control and resistance to rancidity; relatively nontoxic; transparent; nonflammable/nonsmoking; good corrosion control; superior cooling qualities; reduced misting/foaming; easily separated from workpiece/chips; good settling/cleaning properties; easy maintenance; long service life; used for a wide range of machining applications

DISADVANTAGES - Reduced lubrication; may cause misting, foaming and dermatitis; may emulsify tramp oil; may form residues; easily contaminated by other machine fluids

Semisynthetics

ADVANTAGES - Good microbial control and resistance to rancidity; relatively nontoxic; nonflammable/nonsmoking; good corrosion control; good cooling and lubrication; reduced misting/foaming; easily separated from workpiece/chips; good settling/cleaning properties; easy maintenance; long service life; used for a wide range of machining applications

DISADVANTAGES - Water hardness affects stability; may cause misting, foaming and dermatitis; may emulsify tramp oil; may form residues; easily contaminated by other machine fluids

4.0 CUTTING FLUID MANAGEMENT FOR POLLUTION PREVENTION

In the past, it was commonplace for machine shops to dispose of their metalworking fluids as soon as they showed signs of degradation and decreased performance [10]. This practice resulted from fewer environmental regulations in place at the time. It was simply easier and more economical to “dispose and replenish” than to manage fluids, extend fluid life and prevent pollution [15].

With the arrival of tighter environmental regulations, more strict sanitary sewer discharge limits, rising fluid costs, additional environmental liability concerns, and increasing disposal costs, the environmental and economic advantages associated with prolonging fluid life became apparent [8,15,16,17,18]. Fluid management has become an even more attractive pollution prevention alternative since increased automation in the metalworking industry allows costs to be kept at an acceptable level. These combined factors have resulted in the replacement of dispose and replenish routines with in-house fluid management programs.

Effective programs can keep metalworking fluid as clean as the initial raw product, significantly prolonging its service life. In addition to waste reduction, a number of other incentives exist for establishing a fluid management program [6,12,15,19]. These include:

- ✓ Reduced environmental liability due to waste reduction and reduced off-site disposal
- ✓ Compliance with environmental regulations is easier
- ✓ Fluid consumption may be reduced up to 40%, reducing purchase costs and disposal expenses [19]
- ✓ Improved productivity due to decreased down time and tool wear, more consistent machining tolerances and higher quality finished parts
- ✓ Machines stay cleaner, require less maintenance/repair and cutting tools have longer life
- ✓ A healthier and safer work environment for the machine operator

Facilities may realize a savings of 15 to 50 percent by implementing a thorough fluid management program [15,19]. Payback for establishing a management program is often achieved within one or two years [6].

OBJECTIVES

The objectives of this section include:

- ✓ Educate fluid management personnel on processes that affect fluid performance and contribute to fluid failure;
- ✓ Identify corrective action procedures that can be utilized to maintain fluid performance and extend fluid life; and
- ✓ Provide management personnel with a useful reference for implementing an effective fluid management program.

The three components of a successful fluid management program are:

- ✓ Administration
- ✓ Fluid Monitoring and Maintenance
- ✓ Fluid Recycling

This section reviews the role each component plays in an effective fluid management program. The fluid management information presented in this section pertains primarily to soluble oils, semisynthetics and

These initial readings should correspond to the acceptable product quality ranges provided by the fluid supplier. They also provide a baseline from which to evaluate the condition of the fluid over time. Fluid pH and concentration measurements are compared to “new fluid” values to assess fluid quality.

A detailed log book documenting fluid usage information should be maintained [18]. Fluid management logs for each machine should include the following information:

- ✓ Brief description of the machine and sump/reservoir capacities
- ✓ Type of fluid used
- ✓ Fluid mixing ratios and initial parameter readings
- ✓ Water quality data
- ✓ Monitoring data including pH readings, biological monitoring data, fluid concentration measurements and inspection observations
- ✓ Adjustments made as part of fluid maintenance
- ✓ Fluid recycling and/or disposal frequencies, including dates of coolant change out and reason for change out
- ✓ Equipment cleaning and maintenance activities, dates and comments
- ✓ Quantity of coolant added (both change out and periodic additions)
- ✓ Documentation of problems that occur
- ✓ General comments

An example of a fluid management log which may be used to record fluid monitoring and maintenance data is presented as Figure 4-2.

Fluid usage information should be compiled for the entire facility. This allows tracking of the quantity of fluid purchased, recycled and disposed on a yearly basis. It also provides a check on the efficiency of the management program and identifies areas of the program that can be improved.

4.2 MONITORING AND MAINTENANCE

Monitoring and maintaining fluid quality are crucial elements of a successful fluid management program. A fluid must be monitored to anticipate problems. Important aspects of fluid monitoring include system inspections and periodic measurements of fluid parameters such as concentration, biological growth, and pH. Changes from optimal fluid quality must be corrected with appropriate adjustments (such as fluid concentration adjustments, biocide addition, tramp oil and metal cuttings removal, and pH adjustment). It is important to know what changes may take place in your system and why they occur. This allows fluid management personnel to take the appropriate steps needed to bring fluid quality back on-line and prevent fluid quality problems from recurring.

4.21 FLUID PREPARATION

Proper fluid preparation is an important first step toward extending fluid life, achieving the best fluid performance and using fluid concentrate efficiently. Problems associated with high or low fluid concentrations are avoided. Coolant mixtures should be prepared according to manufacturer's directions (as obtained through the fluid supplier and/or product literature). Specifications regarding the recommended diluent water quality, concentrate to water dilution ratio, and additive requirements should be followed. Information on the product's life expectancy and acceptable operating range for parameters such as pH, concentration, and contaminant levels should also be available. These ranges provide benchmarks for coolant adjustment or recycling.

Mixing

The manner in which the concentrate is mixed with water is important. Many machine shops have experienced poor fluid performance and wasted concentrate due to improper mixing. In order to achieve proper fluid performance, concentrate and water should always be mixed in a container outside the sump according to manufacturer's directions. This ensures the preparation of a well-mixed fluid for maximum fluid performance.

Although mixing concentrate and water directly in the sump is a quick and easy method of fluid preparation, it is also a practice that results in incomplete mixing and improper fluid concentration. Fluid performance suffers and problems such as parts oxidizing or staining, dermatitis, and machine downtime may occur.

Water Quality

Since water-miscible fluids may consist of up to 99% water, the quality of the water used to dilute fluid concentrate is an important consideration in fluid preparation [6]. Dissolved minerals and gases, organic matter, microorganisms or combinations of these impurities can lead to problems. The following water quality characteristics should be monitored to achieve the best fluid performance and extend fluid life.

Hardness. Hardness, a measure of the dissolved calcium, magnesium and iron salts in water, has a significant affect on metalworking fluid performance [6]. "Soft" water generally refers to water with a hardness ranging from 0-100 parts-per-million (ppm) while "hard" water contains concentrations of 200 ppm or more. For metalworking fluids, the ideal hardness for makeup water is generally 80-125 ppm [6]. Foaming may become a problem when concentrate is mixed with water having a hardness below this range, particularly in systems where the fluid is subjected to excessive agitation. A hardness above this range may cause dissolved minerals to react with fluid additives, lowering fluid performance. "Hard" water minerals combine with emulsifiers contained in synthetic or semisynthetic concentrates to form scum deposits on sumps, pipes, filters and even the machine. Hard water can also cause the oil to separate out of suspension.

Dissolved Solids. Hardness is not the only water quality parameter of concern. The total dissolved solid (TDS) concentration of water is an important factor in fluid management. Sulfates promote bacterial growth that cause fluids to become rancid. In many areas, drinking water may have sulfate concentrations of 50 to 100 ppm. Chloride salts and sulfates at concentrations above 80 ppm contribute to corrosion [6]. Chloride levels are generally less than 10 ppm in untreated water but are greatly increased by common water softening. Phosphate concentrations above 30 ppm also react with the fluid to stimulate bacterial growth, irritate the skin and cause acidity.

WATER QUALITY GUIDELINES

Initial Fluid Preparation

- ✓ Hardness of 80-125 ppm
- ✓ Less than 80 ppm chloride and sulfates
- ✓ Less than 30 ppm phosphates

Make-up Fluid Preparation

- ✓ Demineralized or deionized water

During normal fluid use, evaporation of water increases the concentration of the metal-working fluid. As new water is introduced to replenish system evaporation losses, additional dissolved minerals are also added. Consequently, the TDS concentration of a fluid builds up over time [6]. The greater the TDS concentration of the make-up water, the faster these concentrations increase in the metalworking fluid.

In order to maintain proper fluid chemistry, untreated water with an acceptable mineral content should be

used for initial fluid makeup. When replenishing evaporation losses, machine operators should add pre-mixed fluid, not just water, to the system. Adding fresh fluid to the system ensures that needed additives such as rust inhibitors and emulsifiers are maintained at desired concentrations [18]. Demineralized or deionized water should be used as the make-up water for fluid additions to prevent TDS levels from building up in the fluid.

If fluid life is a problem, it is important to have a water analysis completed. Shops served by a public water supply may contact their local water works department to obtain the needed data. The fluid manufacturer may recommend some form of water treatment based on the water analysis such as deionized water from an in-line tank, or a reverse-osmosis unit [6,13]. These types of water purification equipment extract ions. Deionizers produce the purest of waters. Distillation units may also be an option.

In some cases, a common water softening unit may be added before the water purification system to reduce water hardness. Although water softeners can be used to obtain the correct water hardness, they are not capable of removing the minerals that contribute to metal corrosion and/or salt deposits. A common home-type water softener is not considered adequate for fluid preparation or fluid make-up water treatment.

4.22 FLUID CONCENTRATION

Fluid concentration measures the active ingredients present in the mixture. Monitoring and maintaining proper fluid concentration is essential in assuring product quality, maximizing tool life, and controlling microbial growth rates. High fluid concentrations may result in increased fluid cost through wasted concentrate, reduced dissipation of heat, foaming, reduced lubrication, residue formation and a greater incidence of built-up edge (BUE) [3]. Highly concentrated fluid may also stain the workpiece and/or machine tool and increase the toxicity of the fluid, particularly if the fluid becomes super concentrated due to evaporation [3]. This results in increased skin irritation and an undesirable work environment for the machine operator. Dilute concentrations may result in poor lubricity, shorter tool life, increased biological activity, and an increased risk of rust formation on newly machined surfaces [6].

Evaporation can lead to a 3 to 10 percent loss of water from the fluid per day [6]. Water and concentrate are both lost as a result of splashing, misting and dragout. A total daily fluid loss of 5 to 20 percent may occur from the combination of these processes. Consequently, coolant concentration will vary and concentration of metalworking fluid must be monitored regularly to determine if the fluid is too dilute or too rich. Monitoring provides data for calculating the amount of concentrate and water needed to replenish the system and keep the fluid at its recommended operating concentration. Best monitoring frequencies range from daily monitoring for small sumps or stand-alone machines to weekly monitoring for larger systems. These monitoring frequencies are site specific, however, and are best determined through experience.

Fluid concentration may also be controlled through the installation of closed loop and open loop cooling units on machine sumps or central reservoirs. These cooling units reduce evaporation losses by regulating fluid temperature. This helps tighten tolerances, extend tool life by inhibiting microbial activity and increase the fluid's ability to remove heat from the tool/workpiece interface [6].

Determining Fluid Concentration

Fluid concentration is measured using a refractometer or through chemical titration [6]. The following overview describes each method and discusses advantages and disadvantages.



REFRACTOMETERS. Refractometers are an inexpensive tool (\$200 to \$250) capable of measuring fluid concentration. A refractometer is a portable, hand held optical device that reads a fluids' index of refraction. The term "index of refraction" refers to a measurement of how much light is bent as it passes through a liquid. A fluid's index of refraction changes with the density and chemical composition of the fluid. Therefore, refractometer readings obtained for a metalworking fluid correspond to its concentration (the higher the reading, the greater the fluid concentration).

By measuring a metalworking fluid's index of refraction, the optimum fluid concentration can be maintained.

Refractometers are typically available through coolant suppliers and provide fast, reliable results. Tramp oils, cleaners, hydraulic fluids and other contaminants reduce its accuracy.

Manufacturers recommend dilutions and corresponding refractometer readings for specific operations. For example, some fluids use a 20:1 to 30:1 dilution ratio. As illustrated in Figure 4-3, a shop would need to keep the fluid's refractometer reading between 1.8 and 3.0 to maintain the 20:1 to 30:1 concentration.

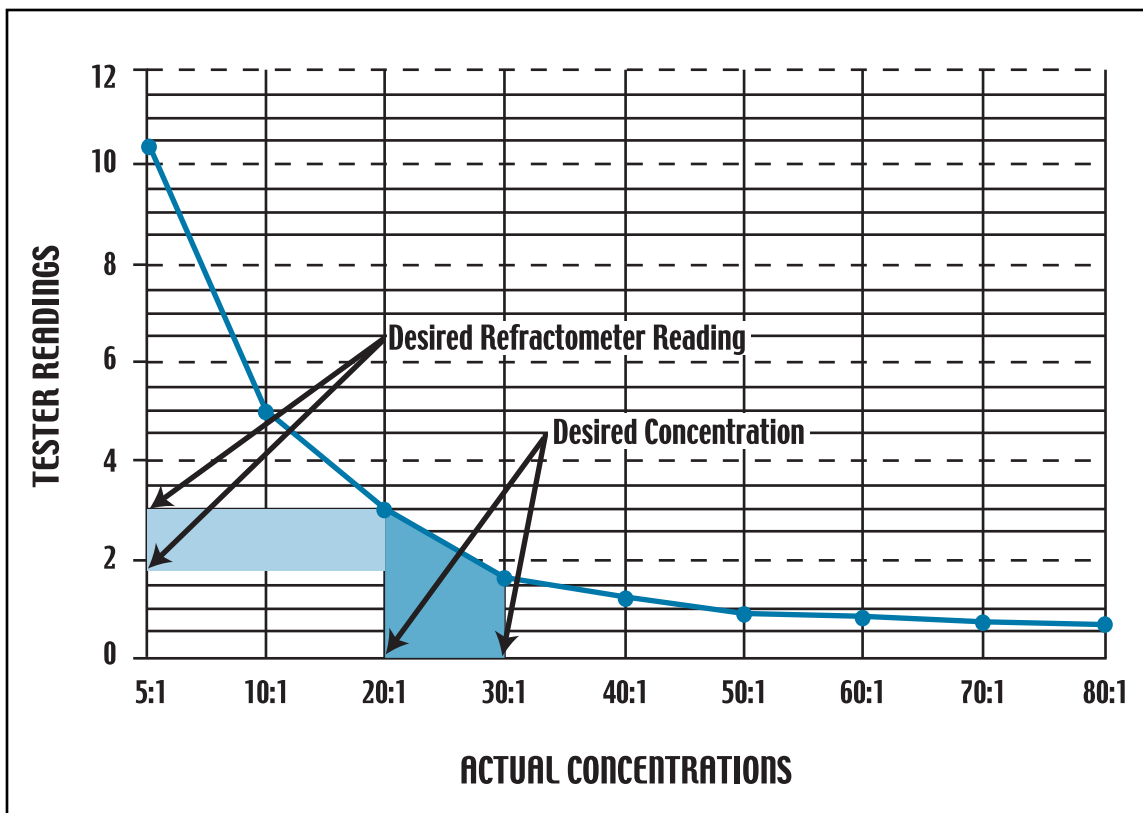


Figure 4-3. Example relationship between refractometer readings and fluid concentration.

TITRATION METHODS. Refractometer measurements are fast but are less accurate when the fluid is contaminated with tramp oils. To overcome this problem, vendors of fluids have developed titration kits to determine fluid concentration. The titration measures a specific chemical or group of chemicals and is less affected by interferences from tramp oil or water quality. While titration is more accurate than refractometer readings, the procedure varies by coolant, and excess contaminants can affect accuracy.

The titration is done by taking a measured volume of fluid, adding an indicator, and then adding the titrant drop by drop until a color change is noted. The coolant concentration is determined from the number of drops of titrant added.

4.23 MICROBIAL CONTAMINATION

Microbial contamination is a major cause of fluid spoilage [20]. All water-miscible fluids are susceptible to microbial deterioration that can significantly reduce fluid life [2]. Fluid manufacturers are constantly developing formulations that are more resistant to microbial degradation. This is accomplished by using high quality ingredients and incorporating biocides in the product.

BACTERIAL CONTAMINATION

Tramp oil and other contaminants are food for microorganisms and can make a sump an ideal breeding ground for bacteria [6,13]. Bacteria populations can double as frequently as every 30 minutes [19,21]. If allowed to multiply, microorganisms will ruin a fluid, cause odor problems and degrade fluid performance. Successful bacterial control is a must.

Bacteria feed on a variety of substances contained in the fluid including the concentrate, tramp oils (including lubricants and hydraulic oils leaked by machinery), minerals in the water and other contaminants. The greater the bacterial growth rate in a fluid, the faster the fluid becomes rancid. As bacteria multiply, they produce acids which lower the pH of the fluid, causing increased corrosion and reduced lubricity. Acid produced by bacteria may also dissolve metal chips and fines, possibly causing the material to meet the definition of a hazardous waste due to toxicity from heavy metals. Bacteria may also darken the fluid significantly, resulting in stained parts.

Most bacteria which cause fluid to become rancid are aerobic. That is, they need oxygen rich environments. Bacteria may also be anaerobic (bacteria which grow in oxygen-poor environments). Anaerobic bacteria grow in systems that are inactive for long periods of time. Inactivity allows tramp oil to rise to the top of the sump, creating an effective barrier between the metalworking fluid and atmospheric oxygen. Consequently, the amount of oxygen present in the fluid decreases, aerobic bacteria die, and anaerobic bacteria begin to flourish. Anaerobic bacteria generate hydrogen sulfide, which produces the rotten-egg odor affectionately referred to as "Monday Morning Stink".

Fungi

Fungi, which include mold and yeast, may degrade metalworking fluids by depleting rust inhibitors. Fungi also cause musty or mildew-like odors and form slimy, rubber-like masses on machine system components that may eventually plug fluid lines.

Monitoring

Two common tests for microbial monitoring include plate counts and dipslide tests. Plate counts involve growing a culture using a sample of the fluid. Microorganism colonies that grow on the plate are later counted and identified [6]. Like plate counts, dipslide tests also involve growing cultures using a sample of

the fluid. Dipslides provide a more simple, rapid screening method since cultures are grown overnight and a visual approximation is used to assess microbial contamination. When rancidity is a problem, microbial-growth dipslide monitoring provides a chance to add biocide before problems arise. Reliable microbial-growth dipslides are available through fluid suppliers and laboratory-supply houses. Tests cost less than ten dollars each and are useful in setting up biocide-addition programs.

Weekly or biweekly monitoring is typically recommended for detection of microbial contamination, especially during the early stages of developing a fluid management program. With experience, machine shops may determine that a less frequent monitoring schedule is suitable for their operation.

Biological Control

Biological growth is controlled through a combination of practices. These include water quality control, proper maintenance of fluid concentration and pH, routine equipment maintenance, biocide treatment and aeration.

WATER QUALITY CONTROL. Fungi feed on dissolved minerals in water. Controlling the mineral content of the water used for metalworking fluids can control fungi growth.

Maintain proper fluid concentration and pH. Many coolant concentrates contain biocides and pH buffers. Therefore, maintaining proper fluid concentration helps control microorganisms.

ROUTINE MAINTENANCE OF MACHINES, LINES AND SUMPS/ RESERVOIRS. Microbial contamination is significantly accelerated by poor housekeeping practices [20]. The best method for controlling biological growth is through routine cleaning of machines, coolant lines and sumps/reservoirs. Machines, exhaust blowers, and hydraulic seals should also be maintained to prevent oil leaks from contaminating the fluid.

Accumulations of chips and fines in a sump also promote bacterial and fungal growth [1]. These particulates increase the surface area available for microbial attachment and prevent biocides from effectively reaching the fluid trapped in these fines. Particulates in the bottom of a sump become septic or rancid if not periodically removed.

Even if the majority of the fluid is free of bacteria, the sludge in the bottom will continue to harbor bacteria and create a septic condition. This can dissolve metals, possibly increasing the toxicity of the fluid to a level at which disposal through a local wastewater treatment plant is no longer permitted.

BIOCIDES. The addition of biocides inhibits biological degradation of the fluid by controlling bacteria and fungi [8,21]. Relying strictly on biocides for microbial control is discouraged since these chemicals are expensive and can create hazards for the operator's skin [18].

Generally, biocides should be used sparingly in as low a concentration as possible [8,21]. Due to the variety of bacteria that may be present in a fluid, use of only one biocide may control certain bacterial species while allowing others to proliferate. **Random use of various types of biocides may prove to be more effective [6,4].**

Biocide treatment patterns play an important role in controlling microbial growth. During one study on biocide treatment patterns, fouled fluids were treated with a commercial biocide at various concentrations and frequencies while microorganism populations were monitored. For all biocide-application rates tested, the efficiency of antimicrobial control was found to vary widely with treatment pattern. As shown in Figure 4-4, less frequent doses with higher concentrations of biocide were found to be much more effective.

tive than low-level, frequent doses. The reasons for these reactions were investigated and found to be related to biocide residual concentrations, biocide consumption by microorganisms, and changes in the predominant species of bacteria which populated the fluids.

Selection of an effective biocide should be based on laboratory tests and actual “real life” performance. Biocides that reduce microorganisms present in the fluid and do not interfere with fluid performance should be selected [8].

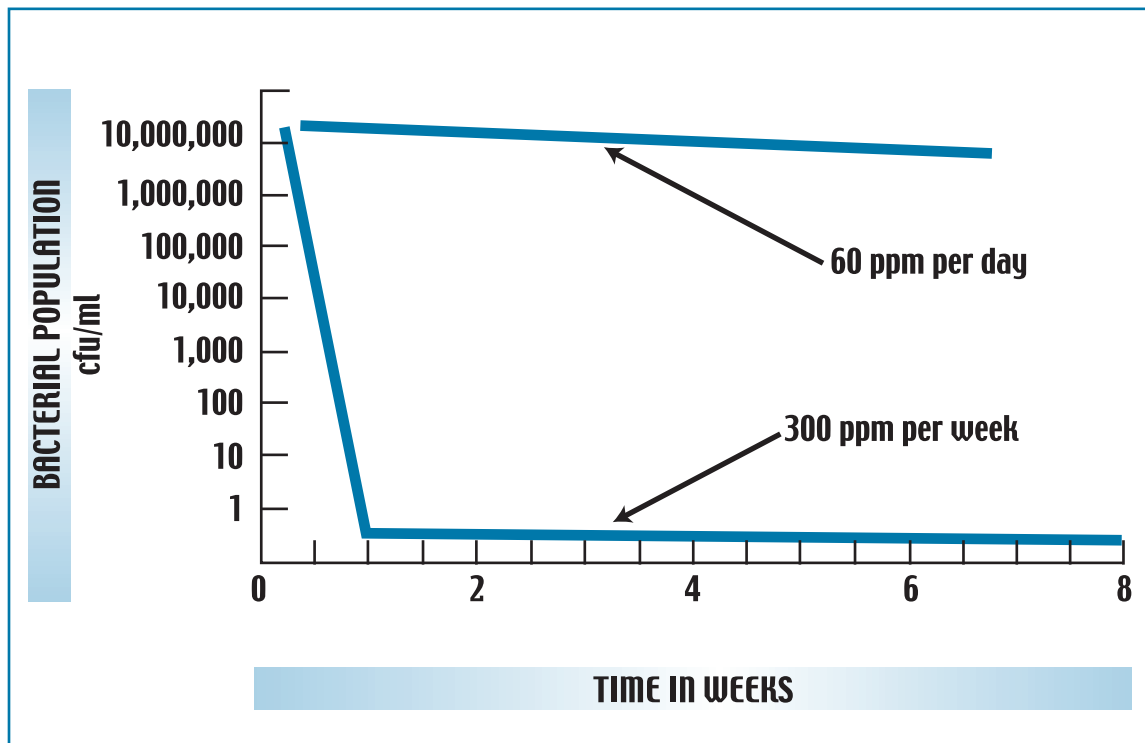


Figure 4-4. Comparison of Biocide Dose Rates

AERATION. Aeration can be used in conjunction with biocide additives to control anaerobic microbial growth in systems during periods of inactivity. Aeration oxygenates the fluid, producing an atmosphere hostile to the odor producing anaerobic bacteria [22]. A small pump can bubble air into machine sumps, either continuously or periodically, to agitate stagnant areas within the sump.

4.24 FLUID pH

pH is the measurement of hydrogen ion concentration. A pH of 7 is considered neutral. Higher pH values represent alkaline solutions while pH values below 7 represent acidic solutions. Ideally, the pH for water-miscible metalworking fluids should be kept in the limited range of 8.6 to 9.0 [6]. This slightly alkaline range optimizes the cleaning ability of the fluid while preventing corrosion, minimizes the potential for dermatitis and controls biological growth. If the pH drops below 8.5, the fluid loses efficiency, can attack ferrous metals (rusting), and biological activity will significantly increase. A pH greater than 9.0 may cause dermatitis and corrosion of nonferrous metals.

Tips on using pH Meters

1. pH electrodes must be kept wet and clean. If one dries out, soak it in water or an appropriate buffer solution for 24 hours.
2. pH meters and testers must be calibrated with buffer solutions. It is best to use two buffers such as pH 7 and pH 4 to make sure the meter is working properly.
3. Mix the solution and let the meter reading stabilize for 10 to 20 seconds. Take the measurement by immersing the tip of the electrode only 1 inch into the solution.
4. Do not be alarmed when white crystals form on the electrode, just soak the electrode in buffer or water.
5. Always read and follow the manufacturer's instructions that are provided with the meter.

Regular monitoring of a fluid's pH is a simple means of anticipating problems. Fluid pH should be measured and recorded daily after the machine is placed in operation. Steady pH readings give an indication of consistent fluid quality. Swings in pH outside the acceptable range indicate a need for machine cleaning, concentration adjustment or the addition of biocide. Each action taken to adjust the pH to the desired operating range should be documented in the machine log book and evaluated for effectiveness. Any rapid change in pH should be investigated and action should be taken to prevent damage to the fluid.

Although fluid pH usually remains constant because of buffers contained in the concentrate, it can change after initial mixing due to water evaporation [6]. Improper control of microbial growth will also alter fluid pH. By-products of microorganisms produce offensive odors and lower fluid pH. As the fluid becomes rancid or septic, it becomes more acidic. Sudden downshifts in pH usually indicate increased biological activity or a sudden change in concentration due to contamination. If coolant concentration and pH both jump downward, the sump has been contaminated. If coolant concentration remains fairly constant while pH decreases, biological activity has probably increased significantly.

The pH of a metalworking fluid is readily determined using litmus paper (available through fluid suppliers or laboratory-supply companies) or a handheld pH meter [6,13]. Litmus paper provides a quick, low cost means of estimating fluid pH. Its accuracy is limited to plus or minus one full pH unit and is not particularly effective in predicting biocide failure.

pH meters are more expensive but provide more accurate readings. Depending on the degree of accuracy and other desired options, pH meter kits may be purchased at a cost ranging from as little as \$50-\$700. Low- to medium-cost pH meters are accurate to plus or minus 0.2 pH units, an accuracy sufficient for monitoring biological degradation. Although high-cost meters are accurate to hundredths of a pH unit, this degree of accuracy is of little benefit with regard to fluid management.

4.25 SYSTEM MAINTENANCE

Fluid contaminants must be controlled in order to obtain optimum fluid performance and life. These contaminants can be kept to a minimum with regular system inspections, maintenance and housekeeping practices.

System Inspections

Brief inspections of the fluid and system cleanliness are an important aspect in monitoring fluid quality and avoiding premature fluid failure. Operators and maintenance personnel should be aware of signs

which indicate a need for fluid maintenance or recycling. Such observations include excessive tramp oil accumulation, buildup of metal cuttings within the sump, foaming problems and leaky machinery. Machines must also be inspected for stagnant areas, dirt and bacterial slime accumulations. Observations regarding fluid quality should also be documented in the machine log book.

Difficulties observing and cleaning problem areas often justify modifying equipment to eliminate hard-to-reach or stagnant locations. Retrofitting machines with external sumps often improves accessibility, allowing particulates and tramp oil to be removed on a regular basis.

Routine Maintenance Practices

Maintaining clean machines, coolant lines and sumps is an integral part of fluid management. Clean machines use metalworking fluids more economically and extend fluid life. Any dirt and oil allowed to remain in the system simply recirculates, resulting in plugged coolant lines, unsightly machine buildup and bacterial growth [6].

PARTICULATE REMOVAL. Excessive chip accumulation reduces sump volume, depletes coolant ingredients and provides an environment for bacterial growth. Excessive solids buildup can also cause increased fluid temperature. Machine turnings should be removed as often as possible. Mobile sump cleaners such as sump suckers or high quality drum vacs are useful for this purpose.

TRAMP OIL CONTROL. Tramp oils such as hydraulic oil, lubricating oil or residual oil film from the workpiece are a major cause of premature fluid failure. These oils provide a source of food for bacteria, interfere with the cooling capability of the fluid and contribute to the formation of oil mist and smoke in the workplace [23]. Tramp oils also interfere with fluid filtration and form residues on machining equipment [24]. Tramp oil contamination must be controlled through prevention and removal.

Ultimately, the best method for control of tramp oil is to prevent it from contaminating the fluid in the first place. Routine preventive maintenance should be performed on machine systems to prevent oil leaks from contaminating the fluid. Some facilities have reportedly substituted undiluted, petroleum-based fluid concentrate for gear box oil lubricants, machine way oils or hydraulic oils [19,24]. Instead of becoming contaminated with leaking oil, the fluid is actually enriched by the concentrate. To ensure this practice does not harm the machine's operation or performance, this should only be done if machines are properly prepared for using a fluid concentrate substitute [24]. Machining equipment is also available which has been designed to operate using less hydraulic oil or direct lubricating and hydraulic oil leakage away from the machine sump [24].

Even with the best preventive maintenance programs, some tramp oil contamination is inevitable and will require removal. Depending on its water miscibility, tramp oil will either "float out" when the fluid is allowed to sit for a period of time or be emulsified by the fluid. Free floating tramp oil should be removed on a regular basis (either continuously or periodically) as part of fluid maintenance. Oil skimmers, coalescers or oil-absorbent pads can remove floating oils. A centrifuge is needed to remove emulsified tramp oils. More detailed information on tramp oil removal equipment is provided in Section 4.31 of this manual.

Tramp oil separation and removal can also be improved by purchasing fluids that resist tramp oil emulsification or by using hydraulic and lubricating oils that won't readily emulsify with the fluid [16]. Use of high quality lubricants with ingredients that won't be a food source for bacteria is another alternative [16].

GENERAL HOUSEKEEPING. Cutting fluid contaminants such as lubricating oils, greases and metal particulates are an expected part of machining operations. Many of the contaminants that cause fluids to be disposed of prematurely consist of foreign materials such as floor sweepings, cleaners, solvents, dirt, waste oils, tobacco, and food wastes. These contaminants have obvious detrimental effects on fluid quality and should be eliminated through improved housekeeping and revised shop practices. Facility personnel should learn not to dispose of these materials in machine sumps.

ANNUAL CLEANOUT. Machine systems must be thoroughly cleaned out at least once a year in order to keep biological growth in check and maintain proper system operation. During clean-out, each machine should be thoroughly cleaned and disinfected. Simple flushing of cleaning solution through the system does not provide adequate cleaning. To clean a machine system properly, biocide should be added to the dirty fluid and allowed to circulate before pumping out the reservoir. All chips, swarf and visible deposits should be removed.

Although accessibility is often an inherent problem because of a machine's design, extra effort should be made to thoroughly clean all hidden areas. If these difficult-to-reach areas are not addressed, they simply become a source of bacteria that rapidly attack the fluid used to refill the sump after cleaning.

Following cleanout of the sump/reservoir, the system should be charged with water (preferably hot water) and mixed with a machine cleaner. This mixture should then be circulated through the system for several hours in order to loosen and remove any hardened deposits, oily films or gummy residues [6]. The cleaner must be:

1. Compatible with the metalworking fluid (in case some cleaner remains in the system after rinsing);
2. Low foaming to prevent pump cavitation; and
3. Resistant to short-term rusting between cleanout and recharge.

Chemical suppliers often provide instructions for equipment cleaning including information on safe, effective and compatible cleaning materials.

Bacteria flourish in machines which leak lubricating or hydraulic oils into the metal-working fluid [16]. While the cleaning solution is circulating, leaking equipment should be repaired and the outside of the machine cleaned. If possible, troublesome areas should be steam cleaned. Finally, once the machine has been thoroughly cleaned and inspected, any residual cleaning solution must be rinsed from the equipment. Fresh water should be circulated through the system at least twice to rinse off any remaining cleaner. To protect against flash rusting, a small amount of fluid concentrate (0.5 - 1%) should be added to the rinse water [6]. After completely draining the rinse solution, the system can be charged with fresh fluid. The fluid should then be circulated for at least 15 minutes prior to production.

The cleanout procedures described above are provided as general guidance. Each individual facility should develop a cleanout schedule and system suitable for their own operation.

MAINTENANCE OF STRAIGHT OILS. Straight oils are generally easier to maintain than water-based fluids. In fact, straight oils may be the most environmental friendly fluid for certain applications (e.g. honing) due to their extraordinary stability, recyclability and long life [12]. Maintenance on straight oils consists of keeping the fluid free of contaminants (such as water or tramp oils generated in other areas of the shop), adequate particulate removal through filtration and the addition of antioxidants. The presence of water promotes microbial growth while tramp oil contamination dilutes the ingredients added to straight oil for enhanced lubricity and wettability. Tramp oil contamination also increases the viscosity of the straight oil, lowering its filterability.

Straight oils that are kept contaminant free and adequately filtered may still require replacement due to the effect of oxidation. Oxidation of straight oil increases its viscosity, making particulate filtration more difficult. As a result, additives referred to as antioxidants may need to be used to prevent oxidation from occurring.

The following is an example of a fluid change-out procedure found to be most efficient for extending fluid life at one small machine shop.

1. Skim all tramp oil from fluid surface.
2. Pump fluid from sump.
3. Vacuum chips from sump.
4. Remove sump-access covers.
5. Vacuum chips from sump.
6. Clean and vacuum sump (repeat until clean).
7. Replace sump-access covers.
8. Replace original coolant.

This change-out procedure was performed every 2-3 months and required an average of 5.21 hours to accomplish on cast sumps with 20-100 gallon capacities. Sumps made of sheet metal take less time because corners are generally rounded and more easily cleaned. These system maintenance practices, when combined with improved, ongoing fluid maintenance, can greatly extend fluid life.

4.26 FOAMING

Under certain conditions, additives and surfactants contained in fluids may cause it to foam. Foaming affects fluid performance by suspending dirt and swarf (i.e. metal chips and fines), slowing filtration and obscuring the workpiece. It can also cause a sump to overflow, creating housekeeping and safety problems [6]. Fluids are more likely to foam when fluid concentrations are too high or when soft water is used for fluid preparation. Mechanical effects that agitate fluid (such as fluid pressure and entrained air) also contribute to foaming [1].

Foaming problems can usually be solved by proper fluid concentration, use of high quality water, proper fluid selection and reducing fluid agitation. The following practices can reduce fluid agitation and foaming:

- ✓ Replace high velocity flush nozzles with high volume, low velocity nozzles.
- ✓ Eliminate areas of free-falling fluid by extending return piping outlets beneath the fluid level in the sump.
- ✓ Modify piping runs which contribute to turbulent flow and agitation by replacing undersized piping and eliminating sharp corners or interruptions in fluid return lines.
- ✓ Clean nozzles of dirt or other matter which might constrict fluid flow and lead to air entering the system.

- ✓ Repair/replace defective pumps.
- ✓ Inspect the intake pump and piping for air leaks and repair if necessary.
- ✓ Maintain proper fluid levels in the sump to keep the pump from sucking air.
- ✓ Any phosphate-based cleaners used around the shop should be kept away from metalworking fluids since these cleaners promote foaming.
- ✓ Use antifoaming agents such as a liquid calcium water hardener to reduce or eliminate foaming. Silicon-based antifoaming agents should be avoided. These additives tend to coat and absorb into the pores of metal surfaces, creating masking problems for subsequent plating and surface finishing.

4.3 FLUID RECYCLING

Despite all efforts to extend fluid life, fluid quality will eventually reach a point where routine maintenance is no longer effective. At this stage, the fluid either needs to be recycled for contaminant separation or disposed.

The key to effective recycling is knowing when to recycle. Fluid should be recycled well before it becomes significantly degraded since fluids with excessive bacterial counts or tramp oil concentrations cannot be restored [19]. This is why monitoring of microbial activity, concentration, pH and contamination levels are such a critical aspect of fluid management [19].

If the fluid exhibits any of the following characteristics, it should not be recycled. Instead, the fluid should be disposed and the machine thoroughly cleaned before recharging with fresh fluid.

- ✓ pH is less than 8.0 (normal pH range is 8.5 to 9.4).
- ✓ Fluid concentration is less than 2.0% (normal is 3.0% to 12.0%).
- ✓ Appearance is dark gray to black (normal is milky white).
- ✓ Odor is strongly rancid or sour (normal is a mild chemical odor).

4.31 RECYCLING EQUIPMENT

A wide variety of recycling equipment is available for contaminant removal and most recycling equipment is generally easy to operate and maintain. The choice of recycling equipment will depend on the needs, objectives and financial resources of the shop. As a general guideline for equipment selection, Figures 4-5

EQUIPMENT	CONTAMINANT REMOVED
Skimmers	Tramp Oil
Coalescers	Tramp Oil, Particulates
Settling Tanks	Particulates
Magnetic Separators	Particulates
Hydrocyclones	Particulates
Centrifuges	Tramp Oil, Particulates, Bacteria
Filtration Equipment	Particulates
Flotation	Tramp Oil, Particulates

Figure 4-5. Fluid recycling contaminant removal equipment.

and 4-6 illustrate contaminant removal capabilities for various types of equipment used in fluid recycling [6]. Cutting fluid recycling equipment includes filters, centrifuges, skimmers, flotation and magnetic separators.

SKIMMERS

Skimmers are specifically designed to remove tramp oils that float to the surface of cutting fluid after it has been allowed to sit still for a period of time [25]. Skimming is most effective when tramp oils have a low water miscibility and the cutting fluids used by the shop reject tramp oil emulsification. Since oil has an affinity for plastic, most skimmers consist of plastic belts or disks that are partially submerged in the fluid. Tramp oil adheres to the skimmer as it passes through the fluid. The tramp oil is then scraped from the skimmer with a blade and collected for final disposition.

For small sumps, oil absorbent fabrics or pillows (treated to repel water and absorb hydrocarbons) may suffice for tramp oil removal. The fabric can be drawn across the sump pit for tramp oil removal or pillows may be allowed to float in the sump to absorb oils. The disadvantage of using absorbents is their subsequent need for disposal.

COALESCERS

Coalescers are often used in conjunction with skimmers to enhance tramp oil removal. Coalescers are porous-media separators which use oleophilic (oil-attracting) media beds (typically constructed out of polypropylene) to attract oil in preference to water. These media beds often consist of inclined corrugated plates or vertical tubes [25]. As cutting fluid is passed through the coalescer unit at a low, non-turbulent flow rate, dispersed tramp oil droplets attach to the media and coalesce to form larger and larger droplets. Eventually, these droplets reach a size at which they rise to the top of the coalescing unit for removal with a skimmer. Coalescer units have no moving parts, are generally self cleaning and may be purchased for \$1,000 to \$5,000.

Contaminant Separation Processes			
Method	Particle size (µm)	Particles	Miscellaneous
SETTLING	1000	MACHINED CHIPS	↑
	800		
	600		
	400		
	200		
MAGNETIC SEPARATOR	100	GRINDING SWARF	↑ MIST ↓
	80		
HYDROCYCLONE	60	GRINDING SWARF	↑
	40		
FILTERS	20	GRINDING SWARF	↑
	10		
CENTRIFUGE	8	GRINDING SWARF	↑
	6		
CENTRIFUGE	4	GRINDING SWARF	↑
	2		
ULTRA-FILTRATION	1	PRECIPITATES SCUM	↑ BACTERIA ↓
	0.8		
	0.6		
	0.4		
	0.2		
	0.1	PRECIPITATES SCUM	↑ YEASTS & FUNGI ↓
	0.08		
	0.06		
	0.04		↑ VIRUS ↓

Figure 4-6. Summary of contaminant removal methods. (Modified from Bienkowski, April 1993)

Like skimmers, coalescers are ineffective for removing emulsified tramp oils. They may also accumulate fine particulate matter during their operation. If these units are not cleaned periodically, the dirty media will provide a breeding ground for microorganisms [25].

SEPARATION EQUIPMENT

Separation equipment includes settling tanks, magnetic separators, hydrocyclones and centrifuges. The primary function of this equipment is particulate removal. Settling tanks and centrifuges may also be used to remove tramp oil.

SETTLING TANKS The simplest separation system consists of settling tanks. Settling tanks use baffles and weirs designed to promote settling of heavy particulates to the bottom of the tank while allowing tramp oil and light particulates to float to the surface of the fluid. Settling tanks are equipped with skimmers to remove the floating oil and light particulates. Chips and other particles which settle to the bottom are removed using baskets or automatic chip conveyors.

MAGNETIC SEPARATORS Magnetic separation tanks use cylindrical magnets to remove ferrous particulates [5,6]. Contaminated fluid flows over slowly rotating magnetic cylinders that extract ferrous particulates from the fluid. The ferrous particles are then scraped from the magnetic cylinder into a tote bin for final disposition. Nonferrous metals that pass by the magnetic cylinder are removed with another separation process, typically settling.

HYDROCYCLONES Hydrocyclones and centrifuges create artificial gravity for contaminant separation [5,6]. Density differences between the cutting fluid and contaminants cause their separation. In a hydrocyclone, cutting fluid rapidly enters a cone-like vessel, producing a vortex that forces denser solids down and out. The disadvantage of hydrocyclones is that they tend to emulsify tramp oils.

CENTRIFUGES

Centrifuges use a spinning bowl to develop the centrifugal force needed for contaminant removal, exerting a force up to 6,000 times gravity (6,000 Gs) on the cutting fluid [3,23]. However, unlike hydrocyclones, some centrifuge units can remove free, dispersed and emulsified tramp oil. High speed centrifuges also offer the extra benefit of bacterial removal [24]. Removal of emulsified tramp oils requires a centrifugal force of 4,000 to 6,000 Gs. These units often use several coalescing disks to aid tramp oil separation. The disadvantages of centrifuges are the intensive maintenance required for the system and cost. In addition, under certain conditions, centrifuges used for removal of emulsified tramp oils may also separate fluid concentrate from the working solution [25]. Fluid suppliers should be consulted beforehand to ensure centrifuging will not have a detrimental impact on fluid quality.

Filtration Equipment

Filtration involves passing cutting fluid through a permeable material for particulate removal. Filters may be permanent or disposable and are rated on an absolute or nominal scale [6]. The absolute rating of a filter refers to smallest size particle that will be removed during filtration while nominal ratings refer to the average particle size that will remain in the fluid after filtration. Filters are typically made from materials such as wedge wire, microscreens, paper, cloth and manmade fibers such as nylon, polypropylene or polyester [1]. In some applications it may be necessary to use a series of progressively finer filters in order to achieve the desired level of particulate removal.

Filtration systems used for recycling cutting fluid include vacuum, pressure and gravity filtration [3,6]. Vacuum filtration pulls cutting fluid through the filter for particulate removal while pressure filtration uses a pump to force the fluid through the filter. The filtered fluid then enters the reservoir for redistribution.

As chips and other contaminants build a cake on the filter media, resistance to flow increases. At a preset limit, the filter medium (usually rolled paper and wedge wire filters) indexes to expose a clean surface.

Gravity filtration systems involve cutting fluid flowing onto a blanket of filter media suspended over a reservoir tank [3]. Particulates are then removed as the fluid passes through the filter into the reservoir for redistribution.

Flotation

Flotation is a process in which cutting fluid is aerated to achieve contaminant separation. During aeration, oil and particulate matter adhere to the air bubbles and are carried to the surface where they are mechanically skimmed off. This contaminant removal process is typically used after larger and heavier particulates have already been removed by settling.

4.32 RECYCLING SYSTEM SELECTION

A wide variety of recycling systems or, as they are sometimes called, “contaminant-removal systems” are available for purchase. Such systems incorporate the above recycling equipment in their design in order to remove contaminants such as tramp oil, particulates and bacteria. They are also capable of readjusting the fluid’s concentration before it is returned to the individual machine. The following factors should be considered when selecting a recycling system in order to ensure it meets the needs of the shop:

- ✓ Particulate and tramp oil removal requirements
- ✓ Type of material machined at the shop and hours of operation
- ✓ Type of metalworking operations performed at the shop
- ✓ Types of cutting fluids used by the shop and their optimal concentrations
- ✓ What additives will be needed

Recycling systems consist of both batch and continuous in-line systems. For small shops, the most effective method to recycle fluid for individual machines is the use of a batch-treatment system. Batch-treatment systems are portable or nonportable fluid recycling units. Fluid from individual machine sumps is treated in batches for contaminant removal. A recycle system for a small shop can cost from \$7,500 to over \$15,000 depending on the equipment options selected.

Typically, contaminated fluid is removed from the machine sump using a mobile sump cleaner (i.e. a sump sucker or high quality drum vac) and placed in the batch-treatment recycling unit for contaminant removal. To keep fluid clean, batch treatment must be done on a frequent basis. Many shops find that batch treatment must be done two to three times as often as the fluid’s life expectancy. Thus, if a fluid lasts three months before it needs disposal, it will need to be batch treated monthly. If the fluid only lasts two or three weeks, it will need to be batch treated weekly.

4.33 RECYCLING SCHEDULES

How often a fluid must be recycled depends on the following factors:

- ✓ Fluid type
- ✓ Water quality
- ✓ Fluid contamination
- ✓ Machine usage
- ✓ Machine filtration
- ✓ Fluid control
- ✓ Fluid age

A fluid that is stable and resists biological contamination will be able to withstand repeated recycling and will require less recycling. Poor water quality (water that is too hard or too soft) will cause excess dissolved minerals to accumulate in the fluid and may require more frequent recycling.

The level of shop productivity will also affect the frequency of recycling. Large shops that operate at maximum capacity around the clock will need to recycle fluids more frequently than smaller shops whose work schedule is less demanding. It is generally recommended that coolants be recycled every two or three weeks on average to keep coolants fresh and usable for extended periods of time. Some manufacturers of recycling equipment recommend a thirty day recycling schedule for each machine [17].

COMPONENTS OF FLUID MANAGEMENT PROGRAM

Administration

- ✓ Commit the personnel, equipment and other resources necessary for the program.
- ✓ Encourage employee support and participation.
- ✓ Designate fluid management personnel to implement the program.
- ✓ Survey the fluids, machines and sump capacities of the shop.
- ✓ Develop a record keeping system to track the program.

Monitoring and Maintenance

- ✓ Prepare and mix the fluid according to manufacturer's directions.
- ✓ Use quality water to dilute fluid concentrate and replenish evaporation losses.
- ✓ Monitor and maintain proper fluid concentration.
- ✓ Monitor for microbial contamination and control microbial growth through water quality control, maintaining proper fluid concentration and pH, routine maintenance of equipment, biocide additions and aeration.
- ✓ Monitor pH for signs of fluid degradation.
- ✓ Perform regular machining system inspections and maintenance practices, particulate removal, tramp oil control, general housekeeping and annual cleanouts.
- ✓ Prevent foaming with proper fluid concentration, quality water and eliminating mechanical effects that agitate cutting fluid.

Recycling

- ✓ Recycle fluid well before it becomes significantly degraded. Never attempt to recycle rancid fluid.
- ✓ Select fluid recycling equipment based on the needs, objectives and financial resources of the shop.
- ✓ Determine a fluid recycling schedule for the shop based on fluid type, water quality, fluid contamination, machine usage, machine filtration, fluid control and fluid age.

5.0 WASTE MANAGEMENT AND ENVIRONMENTAL REGULATIONS

Numerous environmental regulations at the federal, state, and local levels regulate waste materials. Failure to comply with these regulations could result in expensive penalties. This section presents an overview of the existing regulations that may affect metalworking facilities.

5.1 Hazardous Waste

Congress defined the term “hazardous waste” in the Resource Conservation and Recovery Act (RCRA) as a solid waste, or combination of solid wastes which, because of its quantity, concentration, or physical, chemical, or infectious characteristics may:

- ✓ Cause or significantly contribute to an increase in mortality or an increase in serious irreversible, or incapacitating reversible illness;
- ✓ Pose a substantial present or potential hazard to human health or the environment when improperly treated, stored, transported, disposed of, or otherwise managed;

Hazardous wastes are defined in terms of properties of a solid waste. It should be stressed that a solid waste need not be a solid; it can also be a liquid, semisolid, or a contained-gaseous material. To correctly manage wastes, facilities must first determine if wastes generated by their operations are hazardous or nonhazardous. A solid waste is hazardous if it meets one of three conditions:

- ✓ Exhibits one or more characteristics (ignitability, corrosivity, reactivity, or toxicity) of a hazardous waste.
- ✓ Has been identified and listed as a hazardous waste by the Environmental Protection Agency (EPA).
- ✓ The waste consists of a mixture containing a hazardous waste and a nonhazardous solid waste.

5.11 Characteristic Wastes

Characteristic hazardous wastes exhibit one or more of the following four characteristics:

IGNITABILITY. A solid waste exhibits the characteristic of ignitability if a representative sample of the waste has any of the following properties:

- ✓ Liquid with a flash point less than 140° F (60° C);
- ✓ Non-liquid and is capable, under normal conditions, of spontaneous and sustained combustion;
- ✓ Ignitable compressed gas per Department of Transportation (DOT) regulations; or
- ✓ Oxidizer per DOT regulations.

EPA included ignitability as a characteristic of wastes that could cause fires during transport, storage, or disposal. Examples of ignitable wastes include many waste solvents such as mineral spirits or naphtha. Ignitable hazardous wastes have the EPA hazardous waste number D001.

CORROSIVITY. A solid waste exhibits the characteristic of corrosivity if a representative sample of the waste has any of the following properties:

- ✓ Liquid with a pH less than or equal to 2 or greater than or equal to 12.5; or
- ✓ Liquid and corrodes steel at a rate greater than 1/4 inch per year at a test temperature of 130° F (55° C).

EPA selected pH as an indicator of corrosivity because wastes with high or low pH can directly affect human health, the environment, react dangerously with other wastes, or cause toxic contaminants to migrate from certain wastes. Examples of corrosive wastes include acidic wastes and spent pickling liquor (used to clean steel during manufacture). Corrosive hazardous wastes have the EPA hazardous waste number D002.

REACTIVITY. A solid waste exhibits the characteristic of reactivity if a representative sample of the waste has any of the following properties:

- ✓ Normally unstable and readily undergoes violent change without detonating;
- ✓ Reacts violently with water;
- ✓ Forms a potentially explosive mixture with water;
- ✓ Generates toxic gases, vapors, or fumes when mixed with water
- ✓ Contains cyanide or sulfide and generates toxic gases, vapors, or fumes at a pH between 2 and 12.5
- ✓ Listed by the DOT as a forbidden explosive or as a Class A explosive or a Class B explosive

Reactivity is a characteristic that identifies unstable wastes that can pose a problem, such as an explosion, at any stage of the waste-management cycle. An example of a reactive waste is used cyanide solution. Reactive wastes have the EPA hazardous waste number D003.

TOXICITY. A solid waste exhibits the characteristic of toxicity if, by using designated test methods, the liquid waste or extract from a representative sample contains any of the following contaminants at concentrations equal to or greater than the corresponding regulatory limit. A specific laboratory analytical procedure, identified as the Toxicity Characteristic Leaching Procedure (TCLP), is used to determine the toxicity of a waste. A waste that exhibits the characteristic of toxicity has an EPA hazardous waste number that corresponds to the toxic contaminant(s) which cause it to be hazardous.

Many small businesses such as machine shops generate fluids that may contain heavy metals. Heavy metals refers to metals such as arsenic, barium, cadmium, chromium, lead, mercury, selenium and silver. These metals are hazardous due to their toxic effects on human health and the environment. Metalworking fluids and other wastes that may contain these metals are potential hazardous wastes and must undergo TCLP analyses in order to make a hazardous/nonhazardous determination prior to disposal.

5.12 Listed Wastes

The EPA has specifically listed over 400 wastes which are considered hazardous because they exhibit a hazardous waste characteristic or contain toxic constituents that are harmful to human health and the environment. These include wastes generated from manufacturing processes and discarded commercial chemical products. Examples of some common listed hazardous wastes include toluene, methyl ethyl ketone, methylene chloride and xylene.

5.2 CUTTING FLUID DISPOSAL

Even with the best fluid management program, cutting fluid will not last indefinitely and will eventually require disposal. Environmental regulations are making disposal increasingly difficult. Generators are responsible for determining if a particular waste generated at their facility is hazardous or nonhazardous. The waste material must be tested using standard methods or the generator must have sufficient knowledge about the waste to assess whether it is a hazardous waste.

TCLP TESTING PARAMETERS

TCLP Contaminant	Regulatory Concentration (mg/l)	EPA Hazardous Waste Number
Arsenic	5.0	D004
Barium	100.0	D005
Benzene	0.5	D018
Cadmium	1.0	D006
Carbon tetrachloride	0.5	D019
Chlordane	0.03	D020
Chlorobenzene	100.0	D021
Chloroform	6.0	D022
Chromium	5.0	D007
o-Cresol	200.0	D023
m-Cresol	200.0	D024
p-Cresol	200.0	D025
Cresols (total)	200.0	D026
1,4-Dichlorobenzene	7.5	D027
1,2-Dichloroethane	0.5	D028
1,1-Dichloroethylene	0.7	D029
2,4-Dinitrotoluene	0.13	D030
Endrin	0.02m/l	D012
Heptachlor	0.008	D031
Hexachlorobenzene	0.13	D032
Hexachloro-1,3-butadiene	0.5	D033
Hexachloroethane	3.0	D034
Lead	5.0	D008
Lindane	0.4	D013
Mercury	0.2	D009
Methoxychlor	10.0	D014
Methyl ethyl ketone	200.0	D035
Nitrobenzene	2.0	D036
Pentachlorophenol	100.0	D037
Pyridine	5.0	D038
Selenium	1.0	D010
Silver	5.0	D011
Tetrachloroethylene	0.7	D039
Toxaphene	0.5	D015
Trichlorethylene	0.5	D040
2,4-D	10.0	D01
2,4,5-TP	1.0	D017
2,4,5-Trichlorophenol	400.0	D041
2,4,6-Trichlorophenol	2.0	D042
Vinyl chloride	0.2	D043

5.0

Following a hazardous/nonhazardous determination for the waste, an appropriate disposal alternative may be selected. Disposal costs may range anywhere from 25 to 50 cents per gallon for nonhazardous waste up to several hundred dollars per drum for hazardous waste [6]. Spent cutting fluid that is determined to be hazardous must be disposed by an EPA-permitted hazardous waste management company in accordance with applicable federal and state regulations. Selecting a certified hauler and treatment facility registered with the EPA is critical.

5.21 Disposal of Nonhazardous Fluid

If the waste fluid is determined to be nonhazardous, it may be hauled to a treatment facility or, following permission from local wastewater treatment plant authorities, discharged to a municipal sanitary sewer system for disposal. Spent fluid should never be discharged to a septic tank system or dumped on the ground.

Nonhazardous fluid may also be pretreated on site prior to disposal. Treating or condensing water-miscible fluids on site prior to disposal may reduce a shop's disposal costs and environmental liability. Techniques for on-site treatment include chemical treatment, ultrafiltration, and evaporation. Each process involves the removal of metal fines and other solid contaminants, concentrating the oil phase, and discharging the water phase to either the sanitary sewer or the atmosphere. The concentrated oil phase can be managed as a used oil and the solids may be disposed or reclaimed.

Following are disposal and pretreatment alternatives available for nonhazardous water-miscible cutting fluid.

Contract Hauling and Disposal Services

Studies have shown that it may be cheaper to have small volumes of waste fluid (less than 200 gallons) hauled away by a waste management company for chemical treatment or incineration. Many large machine shops opt for in-plant waste treatment since contract hauling and disposal services become cost prohibitive with larger quantities of waste fluid.

Chemical Treatment

Chemical treatment is the addition of chemicals which change the nature of the liquid waste. Simple chemical-treatment methods work well on some wastewater. Metalworking wastes are too complex for most treatment processes. Chemical treatment beyond pH control is generally not an option for small facilities.

Ultrafiltration Systems.

Ultrafiltration systems were created for the metalworking industry to treat such wastes as used cutting fluids, detergents, parts-washing solutions, and other oily wastewaters. Strict environmental laws require proper treatment prior to discharge. Ultrafiltration systems provide effective treatment of this wastewater by separating the water from the oily waste. The quality of water is then ready for sewer disposal. The oily concentrate generated from ultrafiltration may be processed for oil recovery or incinerated.

Ultrafiltration systems are usually better than chemical treatment, less expensive than incineration and contract hauling, are easily operated and space efficient. Units process from 100 to 300 gallons per day and cost from \$5,000 to \$13,000.

Evaporators

As water-miscible fluids are normally 90-95% water, evaporators can be used to remove the water from waste fluid, reducing the volume of waste requiring disposal. The advantages of evaporators include:

- ✓ Simple to operate;
- ✓ Use very little space; and
- ✓ Type of fluid used (synthetic, semisynthetic, or soluble oil) is not critical.

Evaporators are generally suitable for low volumes of waste due to the amount of energy required to evaporate even a small volume of material. Evaporators are also labor intensive when it comes to cleaning the units. Evaporators may be a consideration when other treatment systems do not meet a shop's needs.

Centrifugation

Centrifuges can be used to remove particulates and tramp oil from waste fluid prior to disposal. However, centrifuges are expensive and other contaminant removal methods such as oil skimmers are more economical for small volumes of fluids.

Disposal as Wastewater

Following approval by local wastewater treatment authorities, it may be possible to dispose of small amounts of nonhazardous, spent cutting fluid to the municipal sanitary sewer system. Spent cutting fluids with the following characteristics are generally acceptable for discharge to municipal sanitary sewer systems.

- ✓ Water soluble
- ✓ Regular biocide additions were applied
- ✓ Fluid has not become septic
- ✓ Chips and fines have been removed
- ✓ Tramp oil concentrations do not exceed 100 mg/l
- ✓ Fluid's pH is between 6.0 and 9.0
- ✓ Spent fluid does not contain toxic concentrations of heavy metals

Wastewater regulations are based on state and federal guidelines but vary from city to city depending on the municipality's wastewater treatment capabilities and local ordinances. Local wastewater treatment plant authorities may require analytical data beyond that identified above (such as biological oxygen demand [BOD] and chemical oxygen demand [COD]) before discharge approval can be obtained. Local wastewater treatment plant authorities should be contacted to determine what sampling and analytical requirements must be met in order to discharge fluid to the sanitary sewer.

If the city will not allow sewer discharge, off-site commercial disposal or in-house chemical/physical treatment (with subsequent sewer disposal of treated water and off-site disposal of treatment sludge) will be necessary.

5.3 Disposal of Metal Cuttings

The EPA specifically exempts recycled metal from hazardous waste management requirements. Therefore, it is both economically and environmentally wise to recycle all metal scrap. Scrap metal dealers may require the removal of any residual fluid on chips and cuttings prior to accepting them for recycling.

5.4 Disposal of Sump Sludge

All waste streams generated at a facility must be classified as hazardous or nonhazardous and disposed of accordingly. Machine sump sludge must be analyzed using the TCLP or evaluated by thorough knowledge to determine whether it is hazardous or nonhazardous. If the sump sludge is found nonhazardous, it may be possible to dispose of it at a landfill following approval from local landfill authorities. Otherwise, it may be shipped off-site for disposal as a nonhazardous waste using a reputable waste management company. If the sump sludge is hazardous, it must be managed and disposed as a hazardous waste.

5.5 Disposal of Used Oil

Used oil includes spent metalworking fluid, tramp oil, hydraulic fluid and other lubricating oils. Generators of used oil should be familiar with both state and federal regulations on used oil management. Used oil is not regulated as a hazardous waste by the federal EPA (provided it is not mixed with a hazardous waste) if recycled or burned for energy recovery. However, some state regulatory agencies are more stringent and consider used oil a hazardous waste [8]. Used oil management requirements that must be met to comply with federal regulations include:

- ✓ Used oil may be provided to a marketer. The used oil marketer is responsible for testing the used oil for specification parameters.
- ✓ The used oil may be provided directly to a burner. In this case, the generator is also the used oil marketer. Used oil marketers must test the used oil for specification parameters and obtain an EPA identification number.
- ✓ Used oil may be burned on site by the generator in a oil-fired furnace without testing for specification parameters.
- ✓ The generator may transport less than 55 gallons of used oil to a public collection facility or an aggregation point owned or operated by the generator in a vehicle owned by the generator or by an employee of the generator.
- ✓ Used oil in quantities greater than 55 gallons can be picked up only by transporters that have an EPA identification number.
- ✓ Generators must store used oil in containers that are in good condition and clearly labeled with the words "Used Oil".

6.0 ALTERNATIVES TO CUTTING FLUIDS

In the pursuit of profit, safety, and convenience, a number of alternatives to traditional machining are currently under development. Dry machining has been around for as long as traditional machining, but has seen a recent surge in interest as more people are realizing the true cost of cutting fluid management. Minimum Quantity Lubrication is an obvious, but very intricate balance between dry machining and traditional methods. Other novel cutting fluids, such as liquid nitrogen, are also being explored for their unique properties. The following sections provide a few details about each of these technologies.

6.1 Dry Machining

Machining without the use of cutting fluids has become a popular option for eliminating the problems associated with cutting fluid management. One of the greatest obstacles to acceptance of dry machining is the false belief that cutting fluids are needed to produce a high-quality finish. Studies have shown that with proper equipment and tooling, machining without fluids can produce a high-quality finish, and be less costly than machining with fluids [26].

The advantages of fluidless cutting include cleaner parts, no waste generation, and in some cases, more precise machining [27]. In addition to these benefits, worker health concerns related to metalworking fluid exposure are eliminated. Recycling is simpler because chips generated from this technique have no residual oil on them and can be combined with other scrap metal.

These advantages do have a cost. The most prohibitive part of switching to dry machining is the large capital expenditure required to start a dry machining operation. Machines and tools designed for cutting fluids cannot be adapted to dry cutting. New, more powerful machines must be purchased, and special tooling is often needed to withstand the very high temperature generated by dry cutting [28].

Tools are often treated with a coating that insulates the tool and the part from the heat of the cut. These tools are more expensive than traditional tools and must be replaced more often. Tool wear can increase so much that certain extreme cuts must be divided into separate processes to facilitate tool replacement [29].

Compressed air is used to remove chips that might otherwise interfere with the machining operations [28]. Dry machining leaves an unprotected surface, which on some materials may be prone to rapid oxidation (rust) [27].

The capital expenditure required may prevent many small shops from seriously considering dry machining as an option. However, if the true cost of cutting fluid management is figured into the decision, dry machining may be a competitive or even superior investment.

6.2 Minimum Quantity Lubricant

Minimum Quantity Lubricant (MQL), also known as Near Dry Machining (NDM) or semi-dry machining, is another alternative to traditional use of cutting fluids. There are many similarities between dry machining and MQL, in fact, many research papers treat true dry machining and MQL as the same technology. As the name implies, MQL uses a very small quantity of lubricant delivered precisely to the cutting surface. Often the quantity used is so small that no lubricant is recovered from the piece. Any remaining lubricant may form a film that protects the piece from oxidation or the lubricant may vaporize completely due to the heat of the machining process.

This process, like dry machining, generates no waste cutting fluid. Small quantities of cutting fluid may need to be removed by a subsequent cleaning step. In some cases, the fluid is selected so that residual fluid does not interfere with future processing. Depending on the application, the fluid may be left on as a protective coating or anti-oxidation layer.

With the large volumes of cutting fluid used in traditional machining, misting, skin exposure, and fluid contamination are problems that must be addressed to assure minimal impact on worker health. With MQL, the problem of misting and skin exposure is greatly reduced, and fluid does not become contaminated because it is not re-used. However, fluid is still present. Proper ventilation is required to prevent buildup of vaporized fluid.

In MQL operations, fluid selection is one of the most critical decisions. The most common fluids are vegetable oil, ester oil, or a synthetic equivalent because of their superior lubrication and high-pressure performance [30]. These fluids are often much more expensive than traditional cutting fluids but, if properly selected and used, they may result in less cost per cut than the combined cost of fluid, fluid disposal, and a continuous fluid management system.

As with dry machining, special equipment and special tooling may be required. However, it may be possible to adapt some existing equipment to MQL operation. Fluid delivery is a critical operation. Cutting fluid must be delivered to the part where it is needed most. In some instances, brushing a layer of fluid over the part is sufficient. In more extreme applications, a precisely controlled stream or mist must be introduced to the cutting surface at an exact location. The degree of lubrication required and the delivery system chosen will depend on the material, the extremity of the cut, and the design of the equipment used.

While MQL may not require as large a capital expenditure as dry machining, it is a very technical method and requires detailed knowledge of metallurgy, chemistry, and the physics of cutting in order to be implemented correctly.

6.3 Liquid Nitrogen Technology

One solution to the problem of cutting fluid management currently under development is the use of liquid nitrogen as a coolant and lubricant. This technique is not the same as cryogenic machining, where the material to be cut is cooled to a very low temperature prior to the machining operation. Rather, the method currently under development uses liquid nitrogen to perform the cooling and lubricating job of the cutting fluid. Much of the part remains at ambient temperature while the flow of nitrogen is carefully delivered to the point where it is needed. The small flow rate and low cost of liquid nitrogen make this technique a very attractive alternative [31].

This technique can be used on equipment that has been designed for use with cutting fluids, and because the nitrogen evaporates harmlessly into the air, there is no cutting fluid to dispose.

If successful, this technique will provide an alternative to businesses that want to eliminate the use of traditional cutting fluids but cannot afford the capital expenditure required to purchase new dry-machining equipment. Reportedly, tool life and finish quality are also improved by this technique due to the low temperatures at the tool/part interface.

Liquid nitrogen is an inexpensive chemical that is environmentally inert. Nitrogen is the most abundant gas in Earth's atmosphere and, when liquid nitrogen warms, it simply mixes with and diffuses harmlessly into the air. Chips generated from this technique have no residual oil on them and can be recycled as scrap metal.

Liquid nitrogen is hazardous to workers due to its extremely low temperature. Exposure can result in mild to extreme frostbite. Nitrogen that is stored in a sealed vessel will increase in pressure dramatically as it warms, potentially resulting in a non-combustion explosion. Large spills can displace all of the oxygen in a room in a short time. However, when proper equipment and handling techniques are used, nitrogen is a very safe and environmentally friendly alternative.

Creare, Inc. has developed a system intended to allow existing equipment to be modified for liquid nitrogen cooling. This system has passed phase 1 development, and is currently being developed for commercial application.

Liquid Nitrogen

Eliminating Cutting Fluids with an Affordable Machine Tool Cooling System

by Jay C. Rozzi

Creare, Inc., Hanover, New Hampshire
E-Mail: jcr@creare.com | Web: www.creare.com | Phone: (603) 643-3800

At Creare, we have developed a novel technology that eliminates the use of machining cutting fluids by indirectly cooling the cutting tool. Our innovation is a prevention-oriented solution to the environmental and occupational health problems posed by cutting fluids that can be easily integrated with existing machine tools. Our proof-of-concept research has clearly demonstrated the technical and economic feasibility of our proprietary cutting tool cooling system. When compared to dry cutting and jet cooling with a synthetic coolant, we demonstrated that our tool cooling technology: (1) reduces the environmental cost of the machining process by 200% for jet cooling with a synthetic coolant and by 21% for dry machining, (2) increases the tool life by 700% at low-cutting speeds and by 50% at high-cutting speeds, (3) decreases part production costs by at least 20%, and (4) improves the final part quality while maintaining a high degree of dimensional accuracy (Rozzi and Elkouh, 2002).

Cutting fluids have long been used in machining processes to decrease the temperature during machining by spraying the coolant into the machining zone directly on the cutting tool and the part. This has the effect of decreasing the tool temperature, which increases tool life and improves the part quality. However, cutting fluids are environmentally unfriendly, costly, and potentially toxic (Sutherland, 2000). The recent shift to dry cutting has not completely solved the problem. Dry cutting increases energy costs, increases per part costs, and requires a capital investment that is too large for most machine shops. New alternatives to traditional flood or jet cooling include mist cooling with natural oil, through-tool delivery of traditional machining coolants, high-flow cryogenic cooling (Hong and Ding, 2001; Wang and Rajurkar, 2000; Zhao and Hong, 1992), and high-pressure water jet cooling (Kaminski and Alvelid, 2000; López de Lacalle, et al., 2000). None of these approaches is a cost-effective or practical way to eliminate the use of environmentally unfriendly cutting fluids. They either require oils of questionable effectiveness or high-flow, high-pressure systems that would be costly and difficult to implement in a production environment

(continued on following page)

(continued from previous page)

Creare plans to continue research and development of this exciting new technology. Our continued research will focus on in-plant testing, integration, design for manufacture, and commercialization of our environmentally-conscious machining system. In addition, we are investigating the application of the technology to the machining of advanced materials, ultra-accurate machining, and vision-based control of machining.

Biography:

Dr. Jay C. Rozzi received undergraduate, master's, and Ph.D. degrees in Mechanical Engineering from Purdue University. He has studied materials processing and non-traditional machining for nearly a decade. Dr. Rozzi's general areas of interest are heat transfer, materials processing, materials science, aerodynamic heating, two-phase flow, and cryogenics. While at Creare, Dr. Rozzi has led or executed projects including aircraft fuel-tank inerting systems, novel corrosion-resistant blankets, the laser annealing of plasma-sprayed ceramic coatings, environmentally-conscious machining, and high-efficiency paper drying.

Acknowledgement:

This work was sponsored by the Environmental Protection Agency under Contract Number 68-D-02-016.

References:

Hong, S.Y. and Ding, Y., "Micro-Temperature Manipulation in Cryogenic Machining of Low Carbon Steel," *Journal of Materials Processing Technology*, Vol. 116, 2001, pp. 22-30.

Kaminski, J. and Alvelid, B., "Temperature Reduction in the Cutting Zone in Water-jet Assisted Turning," *Journal of Materials Processing Technology*, Vol. 106, 2000, pp. 68-73.

López de Lacalle, L., Pérez-Bilbatua, J., Sánchez, J., Llorente, J., Gutiérrez, A., and Albóniga, J., "Using High Pressure Coolant in the Drilling and Turning of Low Machinability Alloys," *International Journal of Advanced Manufacturing Technology*, Vol. 16, 2000, pp. 85-91.

Rozzi, J.C. and Elkouh, N.A., 2002, "Low-Cost Machining Without Cutting Fluids," Environmental Protection Agency Phase I SBIR Final Report, Contract No. 68-D-02-016,.

Rozzi, J.C., 2002, "Low-Cost Machining Without Cutting Fluids," Environmental Protection Agency Phase II SBIR Proposal, Solicitation No. PR-NC-02-10447.

Sutherland, J.W., 2000, "Cutting Fluid Issues," www.mfg.mtu/marc/research.

Wang, Z. and Rajurkar, K., "Cryogenic Machining of Hard-to-Cut Materials," *Wear*, Vol. 239, 2000, pp. 168-175.

Zhao, Z. and Hong, S.Y., "Cooling Strategies for Cryogenic Machining from a Materials Viewpoint," *Journal of Materials Engineering and Performance*, Vol. 1, No. 5, 1992, pp. 669-678.

Liquid Nitrogen

7.0 CUTTING FLUID HEALTH AND SAFETY CONCERNS

The following is a brief outline of health and safety practices. For more detailed information on cutting fluid health and safety, see METALWORKING FLUIDS: Safety and Health Best Practices Manual, available from OSHA at WWW.OSHA.GOV.

7.1 Reducing Exposure

Limiting metalworking fluid exposure of workers is the most effective way to reduce health risks. This section discusses some steps that can be taken to reduce exposure.

7.11 Fluid Selection

Fluid manufacturers often provide the most valuable source of information on fluid safety. The manufacturer should be familiar with health effects associated with the fluid and can provide companies with up-to-date Material Safety Data Sheets (MSDS).

Some of the points to consider when selecting a fluid include *toxicity*, *flammability*, and *disposal*.

MSDS provide information in regards to MWF toxicity. Therefore, product MSDS should be reviewed for health effects and recommended personal protective equipment. The cost of personal protective equipment should always be figured into the cost of cutting fluids, along with potential liability for adverse health effects.

The MSDS will also provide information about flammability. Flammability is a concern with many straight oils. This information is important both for the potential hazards, and the effect it will have on disposal. Any waste with a flash point of 140 degrees F or lower is a hazardous waste and must be disposed of by a hazardous waste management company.

Finally, disposal is often a significant factor in determining which cutting fluid will work for a given application. Always refer to applicable regulations for fluid disposal or recycling. Generally the most important consideration is determining if the waste is hazardous. Check with local officials prior to disposing of any industrial process waste through a publicly owned treatment works (POTW).

7.12 Exposure Limits

OSHA has established two exposure limits that may apply to cutting fluids. Employees should be exposed to no more than 5mg/m³ of mineral oil mist for an 8 hour time weighted average (TWA), and no more than 15 mg/m³ for any particulate, as an 8 hour TWA.

While these are the only requirements, there are a number of sources that list recommended exposure limits. The National Institute for Occupational Safety and Health (NIOSH) and the American Conference of Governmental Hygienists (ACGIH) have both published recommended limits for metalworking fluids and mineral oils. Limits as low as 0.5 mg/m³ have been suggested [34]. Contact the appropriate agency to receive the most up-to-date figures for these limits.

7.13 Health Effects

Serious health problems have been associated with exposure to MWFs. These range from irritation of the skin, lungs, eyes, nose and throat to more severe conditions such as dermatitis, acne, asthma, hypersensitivity pneumonitis, irritation of the upper respiratory tract, and a variety of cancers [33]. A variety of fac-

tors, including time of exposure, pH of the fluid, presence of contaminants, and personal sensitivity can influence the severity of these problems.

Two of the most common skin disorders associated with MWF's are dermatitis and acne. These problems most often occur where skin comes in contact with MWF. This type of dermatitis is called contact dermatitis. Water based, synthetic, and semi synthetic MWFs are most likely to cause contact dermatitis. Another form of dermatitis, allergic dermatitis, can spread to areas of the skin that have not been exposed to MWF.

Repeated exposure can lead to extreme sensitivity, when small exposures that would not previously have resulted in any symptoms become more and more intense.

Respiratory problems are also a concern for people exposed to mist or vapor from MWF.

Symptoms that are frequently reported include sore throat; red, watery, itchy eyes; runny nose; nose-bleeds; cough; wheezing; increased phlegm production; shortness of breath; and other cold-like symptoms.

For some people, asthma, chronic bronchitis, and hypersensitivity pneumonitis can occur. Coughing and shortness of breath are common symptoms for all of these conditions. Bronchitis may lead to coughing up phlegm, asthma is often associated with wheezing and difficulty breathing, and hypersensitivity pneumonitis may lead to flu-like symptoms [33].

Factors such as smoking increase the possibility of respiratory diseases. Cigarette smoke may worsen the respiratory effects of MWF aerosols for all employees.

7.14 Engineering Controls

There are a number of methods available to control the level of MWF exposure. The techniques range from simple, obvious steps like providing ventilation or collection hoods to draw mist away from operators, to more subtle techniques such as additives that reduce misting, and changing the type of metal working fluid. Isolation of the machining operation, low-pressure delivery, and controls that stop the flow of MWF's when no machining is being performed are also effective at reducing the level of exposure.

For best results, a combination of control methods should be used. For instance, ventilation will be much more effective if the vent is located near the machining surface, and the surface is isolated from the employee by a barrier of some type.

Combining low-misting fluids with low-pressure delivery systems that stop flowing when machining is not being performed can also be an effective combination to control mist exposure.

Assuring that equipment and the fluid itself are maintained can reduce the risks associated with exposure. Proper maintenance will prevent the buildup of hazardous contaminants and help reduce fluid loss [33].

Another option is dilution ventilation. This is ventilation for the entire working area, rather than ventilation that is designed to serve an area very close to the source. This is generally less effective than source ventilation, but can be easier to install and maintain. One obvious drawback is the large quantity of heated air that may be lost from a shop during the winter months.

7.2 Other Control Methods

In some instances, reducing the level of exposure is not possible or practical. In those cases, other techniques must be used to reduce risk.

7.21 Personal Protective Equipment

Although engineering controls, safe work practices, and management programs are the preferred method for dealing with potential hazards, there are times when personal protective equipment (PPE) is appropriate for reducing hazards.

OSHA's Personal Protective Equipment Standard (29 CFR 1910.132) requires employers to evaluate the need for personal protective equipment in their workplaces, and to provide any equipment deemed necessary. The employer must also ensure that equipment is properly used and maintained (even when it is employee owned). Employee training is also required. Each affected employee must demonstrate an understanding of the training before being allowed to use PPE.

Other standards, 29 CFR 1910.133 through 1910.138, clarify and expand the requirements for specific areas such as hand protection, eye and face protection, and protective footwear.

Employers should survey the work area, examining each task for potential exposure to chemicals, projectiles, punctures, high temperatures, falling objects, and noise. The operators manuals for various equipment and MSDS should also be consulted. Any recommended protective equipment should be provided, along with the appropriate training.

Using gloves, aprons, sleeves and caps, can reduce skin contact with MWF. In some cases, such as jobs that require manual dexterity, some equipment such as gloves may not be appropriate. Employers should also consider the potential hazards that may be created by personal protective equipment. Gloves can become slippery, loose protective clothing can become caught in machinery, and heat exposure can damage some types of PPE.

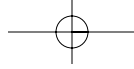
Respirators are a special concern. Improperly fitting or improperly worn respirators can provide a false sense of protection, while still allowing exposure. OSHA regulations for properly equipping employees with respirators are very involved, and it would be impossible to cover them adequately here. When respirators are required, a comprehensive respiratory protection program as outlined in the OSHA respiratory protection standard (29 CFR 1910.134) must be established.

7.22 Establishing a Metalworking Fluid Management Program

There are many advantages to establishing a MWF management program. Most often, a management program is established as a means of tracking costs and assuring compliance with environmental regulations. However, careful fluid management can also have a positive impact on worker health and safety. Many of the negative health effects associated with metal working fluids are the result of contaminants in the fluid, rather than the fluid itself. A monitoring program helps to assure that the fluid quality and concentration is controlled, and prevents buildup of contaminants. For more information on establishing a fluid management program, see section 4.

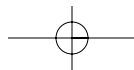
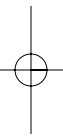
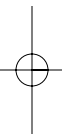
7.23 Exposure Monitoring

Exposure monitoring provides a direct measurement of the exposure of workers to MWF, and can be used to assess the effectiveness of engineering controls, or identify the need for personal protective equipment. The first step in exposure monitoring is to determine if the measurement should be quantitative or qualita-



tive. A qualitative measurement will determine if exposure is occurring, without necessarily pinpointing how much exposure is taking place. This is often a first step in determining where quantitative measurements should be taken.

Qualitative measurements are generally more involved, and can be tied to a particular person, area, or source. Personal breathing samples are generally the most accurate indicators of actual exposure. The details of actual implementation vary depending on the type of monitoring, and are beyond the scope of this document. Help can often be had from insurance carriers, your local or national OSHA contacts, trade associations, or other similar industries.



APPENDIX A: CASE STUDIES

CASE STUDY A – FLUID MANAGEMENT AT A FULL SERVICE MACHINE SHOP

Background Information

A full service machine shop located in eastern Iowa performs metalworking operations on a variety of metals including aluminum, brass, steel, stainless steel and cast iron. The facility employs 22 people, operates 35 to 40 machines (both CNC and manual) and runs one shift Monday through Friday. Being located in a rural setting, the facility lies beyond municipal sanitary sewer system connections. Consequently, few options exist for disposing of spent metalworking fluid. At considerable expense (estimated to be approximately \$1,500 to \$2,000 per month), spent cutting fluid had to be disposed as a hazardous waste through a permitted hazardous waste management company.

Due to the regulatory burden and expense associated with disposal of spent cutting fluid as a hazardous waste, the shop eventually purchased a batch recycling system for \$8500 and a sump sucker for approximately \$3750. A fluid management program, tailored to suit the shop's needs, was also developed and implemented at the facility.

Fluid Monitoring and Maintenance

One semisynthetic fluid is presently used for practically all metalworking operations performed at the facility. Water used for preparing the fluid and replenishing evaporation losses is treated only by an industrial water softener. Due to the success of the program, no additional water treatment was deemed necessary by management personnel.

During early stages of developing the fluid management program, samples of the fluid were periodically submitted to a laboratory to monitor biological contamination. Fluid concentration and pH were also monitored using a refractometer and pH meter. Biological and pH monitoring eventually ceased after it became apparent that the management program resulted in a dramatic decrease in biologic contamination and consistent fluid pH. Monitoring at the facility now consists of using a refractometer for concentration control and fluid inspections by machine shop personnel. Machine operators are also responsible for thoroughly cleaning out the machines each month.

Recycling

Fluid from each machine sump is recycled at least weekly, and often twice a week. When metalworking operations involve metals that readily degrade fluid quality (such as cast iron), fluid recycling is performed on a daily basis. One employee is responsible for fluid recycling and fluid management record keeping.

The fluid recycling procedure used by the facility begins by removing cutting fluid from the machine sump with a sump sucker. After the fluid is pumped out, the sump is immediately recharged with recycled fluid. Fluid to be recycled is then transferred from the sump sucker into a batch treatment recycling unit for tramp oil removal, particulate filtration, biocide addition and concentration adjustment.

The recycling unit consists of several compartments including an initial skimmer tank; a filtration bag; a coalescer compartment equipped with a series of weirs; an oil skimmer and aerator; and a polishing tank for biocide and concentration adjustment. Fluid first passes through the initial skimmer tank where a skimmer pump removes any free floating tramp oil. Fluid from the skimmer tank is then pumped through a 100 micron cloth filter bag (for particulate removal) into the coalescer tank where a set of weirs force the fluid to pass through coalescing media for removal of dispersed tramp oil. Tramp oil surfacing to the top of the coalescer compartment is then removed with a disk oil skimmer. The coalescer compartment is also equipped with an aerator to prevent anaerobic bacteria from degrading the fluid while in the recycling unit. Finally, fluid then enters the polishing compartment where biocide and concentration adjustments are made. When cutting fluid in a sump needs recycling, fluid from the polishing compartment is pumped into a mobile container and used to recharge the machine sump being serviced.

In addition to recycling cutting fluid, all tramp oil recovered by the facility is provided to a used oil marketer and metal cuttings are provided to a scrap metal dealer for recycling.

Results

Since acquiring the recycling unit and establishing the fluid management program approximately three years ago, the facility has realized the following benefits:

- ✓ No waste cutting fluid has been generated at the facility since implementing the fluid management program. This has eliminated the regulatory burden and expense associated with off-site disposal of spent cutting fluid as a hazardous waste.
- ✓ Facility purchases of fluid concentrate dropped from approximately 250 - 300 gallons per year to only 100 gallons per year.
- ✓ A noticeable improvement in the employee work environment has occurred at the facility. Since establishing the program, no incidents of dermatitis have been experienced by employees.
- ✓ Consistent product quality and production tolerances have been realized by the facility. The facility has also experienced fewer problems in achieving low machining tolerances.

Based on these benefits and the costs associated with implementing a fluid management program, machine shop management personnel estimate the program paid for itself within two years.

CASE STUDY B – FLUID MANAGEMENT AT A SMALL MANUFACTURING FACILITY

Background Information

In 1990, a small manufacturing facility located in central Iowa purchased recycling equipment to prolong the life and improve the quality of the semisynthetic fluid used for its machining operations. Fluid quality problems experienced in the shop included employee dermatitis, a haze in the machining area from fluid smoking and short fluid life. Failed metalworking fluid was also hauled away as hazardous waste at a disposal cost of \$75 per drum. Just prior to 1990, the total sump capacity for the facility was approximately 150 gallons and approximately 1,300 gallons of coolant were used annually. In 1994 the number of machines used by the facility doubled, increasing the total sump capacity to 300 gallons. The facility now operates six chip-making machines (including five CNC lathes and one CNC mill) for its cast iron and mild steel metalworking operations.

Fluid and Waste Management

At a cost of approximately \$42,000, fluid recycling equipment was purchased and installed at the facility. A fluid management program was also started for the machine shop. A designated coolant technician is now responsible for pumping out machine sumps, operating the coolant recycling unit and monitoring/adjusting coolant concentration at the recycling unit with a refractometer. Deionized water is used for preparing the fluid and replenishing evaporation losses.

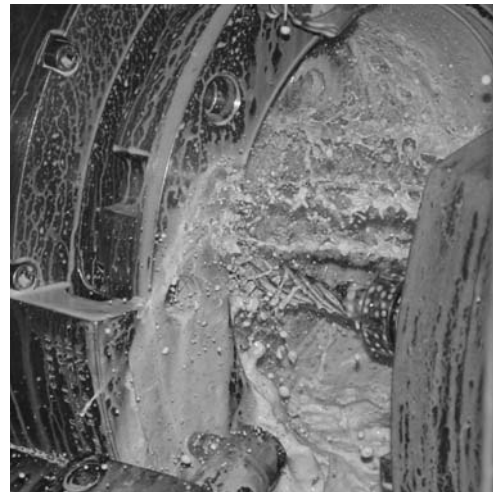
Once a month, coolant from each machine sump is pumped out for recycling using a sump sucker. The fluid is then transferred into the settling tank of the coolant recycling unit for particulate removal. The settling tank is also equipped with a belt skimmer to remove any free-floating tramp oil. After twelve hours in the settling tank, the coolant is drawn through a centrifuge where any residual tramp oil is removed for transfer into a 55-gallon drum. Finally, the coolant enters the bottom chamber of the recycling unit where the fluid concentration is automatically adjusted. No biocide adjustments are performed on the recycled fluid and no other monitoring is performed at the facility. If a problem is experienced with fluid quality, a sample is collected and submitted to the fluid supplier for analysis.

At their discretion, machine operators are responsible for adding make-up coolant or deionized water at the machine sump. Tramp oil recovered by the facility is provided to a used oil marketer and metal cuttings are provided to a scrap metal dealer for recycling.

Results

The facility has realized the following benefits since acquiring the recycling equipment and establishing the fluid management program:

- ✓ Fluid life has been prolonged at the facility and very little, if any, requires disposal. The facility also tested the fluid and obtained permission from local wastewater treatment authorities to discharge small amounts of cutting fluid to the sanitary sewer system when necessary.



Developing fluid in a lathe machine

- ✓ Although the total sump capacity for the facility doubled since installing the recycling equipment, the facility's annual fluid consumption has increased by only 200 gallons (a 15 percent increase in fluid consumption with a 100 percent increase in sump capacity).
- ✓ Management personnel estimate the recycling system paid for itself within two years.
- ✓ No more cases of dermatitis have been reported by employees and the haze in the machining area has been eliminated.

Areas for Improvement

Although the fluid management practices already performed at the facility have significantly reduced consumption rates and virtually eliminated the need to dispose of fluid, management personnel plan to keep refining the program. Management identified the following as areas for improvement:

- ✓ Although machines are thoroughly cleaned out once a year, management intends to increase this cleanout frequency to at least twice a year in an effort to reduce the frequency at which fluid is currently recycled.
- ✓ The facility intends to fabricate external sumps for its machines. The internal sumps on the machines are very inaccessible, requiring significant amounts of downtime for cleaning. Use of external sumps will better accommodate more frequent cleanout schedules and reduce the amount of downtime required for cleaning.
- ✓ Management will continually work with employees in an effort to maintain employee support for the fluid management program.

CASE STUDY C – FLUID MANAGEMENT AT A MANUFACTURING FACILITY

Background Information

In 1986, management personnel at a manufacturing facility in Central Iowa began to review and revise their machining operations in an effort to improve efficiency, reduce waste and reduce costs. At that time, the facility used nine different coolants, had several hand chip-making operations, employees often reported cases of dermatitis, and a heavy haze existed throughout the shop. The facility also disposed of approximately 775 gallons of coolant every three months as hazardous waste. Hand operations were subsequently changed to automated lines and the number of metalworking fluids used by the facility was reduced to two semisynthetic coolants and one straight oil. Management personnel and the facility's fluid supplier also performed a detailed analysis identifying the benefits and cost savings associated with establishing a fluid management and recycling program for the facility. In 1990, a fluid management and recycling program was implemented.

Currently, the facility employs 130 people (100 machinists/assemblers and 30 management personnel) and operates 63 chip-making machines with individual sumps. Sump capacities range from 20 to 1,300 gallons and the total sump capacity for the facility is approximately 4,100 gallons.

Fluid and Waste Management Practices

Administrative Support and Employee Participation - Following the decision to establish a fluid management program, management personnel ensured the support, equipment and resources were made available to develop and sustain an effective program. A coolant technician position was created specifically for the purpose of maintaining the program.

Coolant is viewed as a machine tool and the responsibilities of the coolant technician are considered of equal importance to that of the machine operator. In order to gain employee support for the program, a teamwork atmosphere is encouraged and employees regularly attend fluid management seminars conducted by the coolant manufacturer.

Fluid Monitoring, Maintenance and Recycling - All machines are now on a monthly cleanout schedule which is maintained by the facility's dedicated coolant technician. Other responsibilities of the coolant technician include keeping a daily service log and monitoring for bacterial growth, water hardness, and pH on a daily basis. Each machine operator has a refractometer at the machine and is responsible for checking coolant concentration. Deionized water and coolant makeup lines are piped to each work station so that machine operators can readily replace evaporation/splash losses and adjust fluid concentration at the sump.

Each month, the coolant in each sump is vacuumed out with a sump sucker. After they are pumped out, machines are thoroughly washed out, rinsed with clean water and recharged with fresh coolant. Coolant recovered from machine sumps is transferred to the settling tank of the coolant recycling system. Particulates in the coolant are allowed to settle out for approximately 12 hours while free floating tramp oil is skimmed off of the top with a belt skimmer. The coolant is then drawn through a centrifuge where any residual tramp oil is transferred to a holding barrel. Finally, the coolant is transferred to the bottom chamber where its concentration is automatically adjusted.

During the facility's 1995 shutdown, coolant from the facility's machine sumps was completely replaced with new coolant - the first time in five years! It is now anticipated that the coolant will only need to be completely changed out every 3 to 5 years. The fluid recycling and management program also eliminates the need to dispose of the spent coolant as hazardous waste. To dispose of the fluid, the oil is separated out of the coolant and provided to a used oil marketer for recycling or energy recovery. The remaining water phase is then acceptable for discharge to the municipal sanitary sewer system.

In addition to recycling the semisynthetic coolant, the facility also filters and reuses the straight oil used for the facility's automatic screw machines. Straight oil is reused for approximately 3 years before being provided to a recycler.

EQUIPMENT MODIFICATIONS. In addition to purchasing the coolant recycling system and providing coolant and deionized water lines to each work station, the following equipment modifications were made at the facility to prevent fluid from spoiling:

- ✓ Most of the machines have been modified so that the sumps are external and there are no hard to reach areas where coolant can become trapped and promote bacterial growth.
- ✓ Some of the older machines have also been equipped with skimmers for removing tramp oil right at the machine sump.
- ✓ The facility's 1,300 gallon sump was equipped with its own filtering system and centrifuge for particulate and tramp oil removal.

CUTTINGS AND TRAMP OIL. Metal chips generated by the facility are either spun dry using a centrifuge or the fluid is allowed to drain off through the use of magnetic chip conveyors. Chips are then collected and provided to a scrap metal dealer. Fluid from grinding operations is passed through a vacuum filtration system for particulate removal. Fines collected from this operation are landfilled. Any tramp oil recovered at the facility is provided to a used oil marketer.

Results

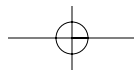
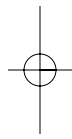
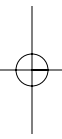
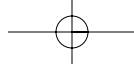
The facility has realized the following benefits since acquiring the recycling equipment and establishing the fluid management program:

- ✓ Not one documented case of dermatitis has been reported since 1990 and the haze that once existed in the shop has been completely eliminated.
- ✓ No hazardous waste is generated from the facility's chip-making operations.
- ✓ Costs for purchasing and installing the recycling system was recovered in approximately 6 to 8 months.

REFERENCES

1. Aronson, R.B. "Machine Tool 101: Part 6, Machine Servers," *Manufacturing Engineering* (June, 1994), 47-52.
2. Sluhan, C.A. "Selecting the Right Cutting and Grinding Fluids," *Tooling & Production* (May 1994), 40-50.
3. Tuholski, R.J. "Don't Forget the Cutting Fluid," *Journal of Industrial Technology* (Fall 1993), 2-5.
4. Silliman, J.D. and R. Perich. "Cutting and Grinding Fluids: Selection and Application - Second Edition," (Dearborn, Michigan: Society of Manufacturing Engineers, 1992), p.216.
5. Villena-Denton, V. "Cutting Fluids Book Hot Off the Press," *Lubricants World* (May 1994), 25.
6. Bienkowski, K. "Coolants & Lubricants - Staying Pure," *Manufacturing Engineering* (April, 1993), 55-61.
7. Doyle, D. and B. O'Keeffe. "Decoding Hazardous Waste Regulations," *Manufacturing Engineering* (March, 1993), 53-54.
8. Bienkowski, K. "Coolants & Lubricants - The Truth," *Manufacturing Engineering* (March,1993), 90-96.
9. Lukas, J. "Auto Industry Seeks Universal Fluids," *Lubricants World* (May, 1994), 30.
10. State of Ohio Environmental Protection Agency. "Extending the Life of Metal Working Fluids," (Columbus, Ohio: Pollution Prevention Fact Sheet No. 11, March 1993), p. 4.
11. Foltz, G. "Definitions of Metalworking Fluids."
12. Koelsch, J.R. "Honing Fluid Performance," *Manufacturing Engineering* (February, 1994), 51-55.
13. Iowa Waste Reduction Center. "Cutting Fluid Management in Small Machine Shop Operations - First Addition," (Cedar Falls, Iowa: University of Northern Iowa, 1990), p.43.
14. Oberg, E., F.D. Jones, H.L. Horton and H.H. Ryffel. "Machinery's Handbook," (New York: Industrial Press Inc., 1992), p. 2543.
15. Jarrard, A. "Metalworking Fluids Management Programs," *Modern Machine Shop* (June, 1993), 81-84.
16. Hydrick, H. "Coolant Management Concern Invites Change," *Lubricants World* (May, 1994), 29 and 34.
17. Lukas, J. "Fluids Getting More Attention from Management," *Lubricants World* (July, 1994), 26.
18. Lukas, J. "What's in the Fluid Often More Important Than the Fluid Itself," *Lubricants World* (May, 1994), 26.
19. Hoobler, G.L. "Coolant Management: A User's Introduction and Guide to Waste Minimization."
20. Carmody, D.P., A.B. Law, and G.L. Willingham. "Microbial Control and its Impact on Waste minimization of Metalworking fluids."

21. Lukas, J. "Chicago Section Examines Myriad Topics," *Lubricants World* (May, 1994), 28.
22. Saunders, J. "Self-Emulsifiable Base Oil Enhances Fluids," *Lubricants World* (May, 1994), 31-32.
23. Sluhan, W.A. "Disc-Bowl Centrifuging of Water-Miscible Fluids," *Cutting Tool Engineering* (December 1988).
24. Sluhan, C.A. "Considerations in the Selection of Coolants Used in Flexible Machining Cells," *Society of Manufacturing Engineers Technical Paper* MS86-124, (Dearborn, Michigan: SME, 1986), 1-5.
25. Sluhan, W.A. "Coolant Management: Rx for Ending Coolant Headaches," *The Carbide & Tool Journal* (March/April 1985).
26. Winkler, J (1998) Dry Drilling [On-Line] www.ifw.uni-hanover.de/industrie/ind_main_e.htm
27. Dry Machining of Plutonium Parts, Case Study, Los Alamos National Laboratory, U.S. Dept. of Energy,
28. Vaughn, Michael J. (1999) Dry Machining: Tech 590w Investigative Report, Purdue University
29. Heine, H. J. (1996) Environmentally Conscious Manufacturing: Dry Machining, A Promising Option (NTIS No. PB96-129093 KZO)
30. Makiyama, Tadashi, (2000) Advanced Near Dry Machining System, R&D Division, HORKOS CORP. 4th Annual NCMS Fall Workshop Series
31. Rozzi, J. "Final Report: Low Cost Machining Without Cutting Fluids," National Center for Environmental Research.
32. S. Paul, "Beneficial Effects of cryogenic cooling over dry and wet machining on tool wear and surface finish in turning ANSI 1060 Steel", *Journal of Materials Processing Technology*
33. "Metalworking Fluids: Safety and Health Best Practices Manual," U.S. Dept. of Labor, OSHA, 2001, www.OSHA.gov.
34. DeMarco, Nancy. "Muddy Waters," *Lubes-n-Greases*, Vol. 8, Dec 2002, P. 22.



IOWA WASTE REDUCTION CENTER | *University of Northern Iowa*

