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 synthetics, since these are most widely used. When appropriate, information on prolonging the service life of straight oils is also provided.

4.1 ADMINISTRATION

Without disciplined administration, a fluid management program is doomed to fail from the beginning. In order to be successful, the cooperation and support of management, employees, fluid suppliers and equipment vendors must be obtained. Management must commit to acquiring the equipment and other resources necessary to implement and sustain the program. Management must also educate employees on the importance of fluid management in an effort to gain their commitment to the program. This includes involving employees in the decision making process for implementation and upkeep of the program. Fluid and equipment suppliers must be capable of providing the necessary technical and laboratory support.

4.11 FLUID MANAGEMENT PERSONNEL

One of the first steps in setting up a program consists of designating fluid management personnel to implement the program [16,17,18]. Initial duties of fluid management personnel consist of surveying the shop to gather information on the types and volumes of fluids used, the types of machine tools used, sump capacities, and fluid management practices already in place. Figure 4-1 illustrates the type of data to obtain and record during the shop reconnaissance survey. This information forms the baseline needed to develop a fluid management program. Once a program is implemented, program personnel become responsible for monitoring and maintaining fluid quality, machine cleanup schedules, and fluid recycling [6].

4.12 RECORD KEEPING

Record keeping is an important aspect of fluid management, and it begins with the initial preparation of the fluid. Following its preparation, the pH and concentration of the fluid should be measured and recorded.

MACHINE SHOP SURVEY Date ____________

Machine Description/ Sump Volume	Metal Worked	Fluid Type/ Mix Ratio	Management/ Disposal Practices	Comments

Figure 4-1

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.

FLUID MANAGEMENT LOG

Date ____________

Machine ______________________________
Sump Capacity _________________________
Type of Fluid Used _____________________

Initial Parameter Readings for Fresh Fluid
Concentration Reading = _______________
pH = ________________________________

Date	Fluid Concentration	pH	Biological Monitoring	System Inspection Observations: Rust	Tramp Oil	Excessive Cuttings	Rancidity	Color	Fluid Adjustments: Concentrate Added	Water Added	Other Additives	Fluid Changed Out	Problems / General Comments
												Y or N	
												Y or N	
												Y or N	
												Y or N	
												Y or N	
												Y or N	
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Figure 4-2

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 rancidity.

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 premixed 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 though 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.

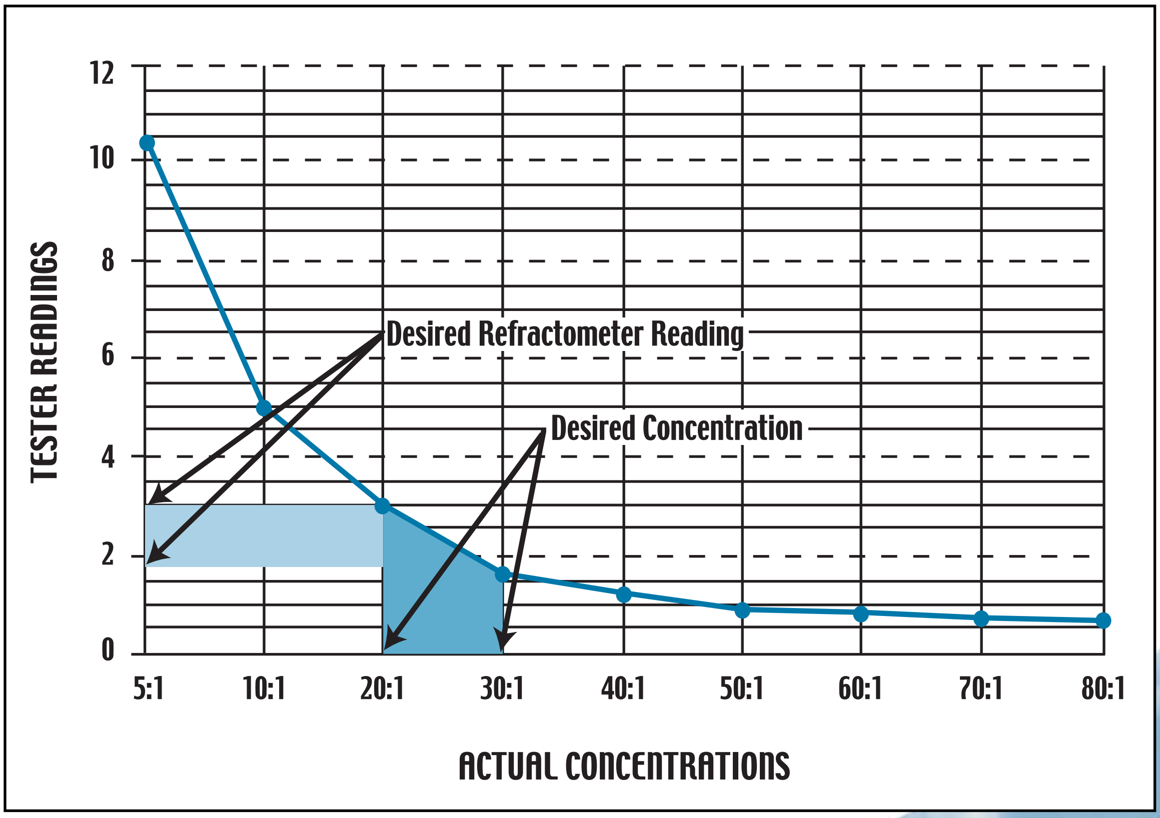

Figure 4-3. Example relationship between refractometer readings and fluid concentration.

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 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].

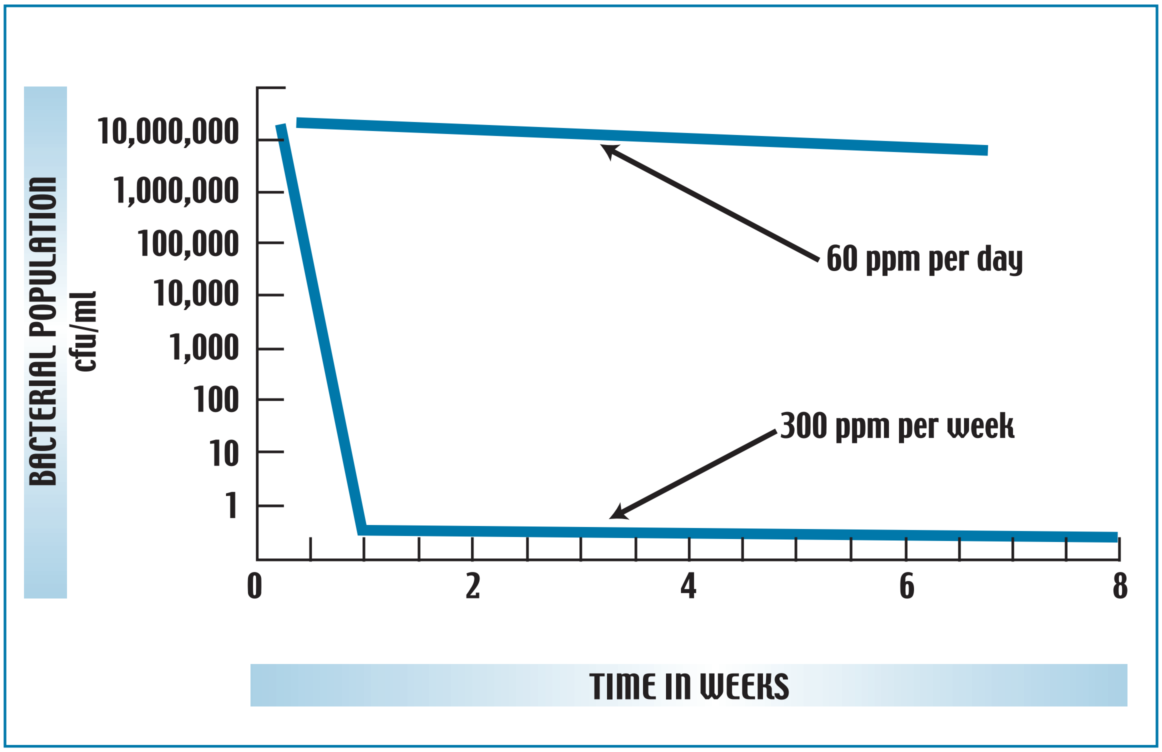

Figure 4-4. Comparison of Biocide Dose Rates

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.

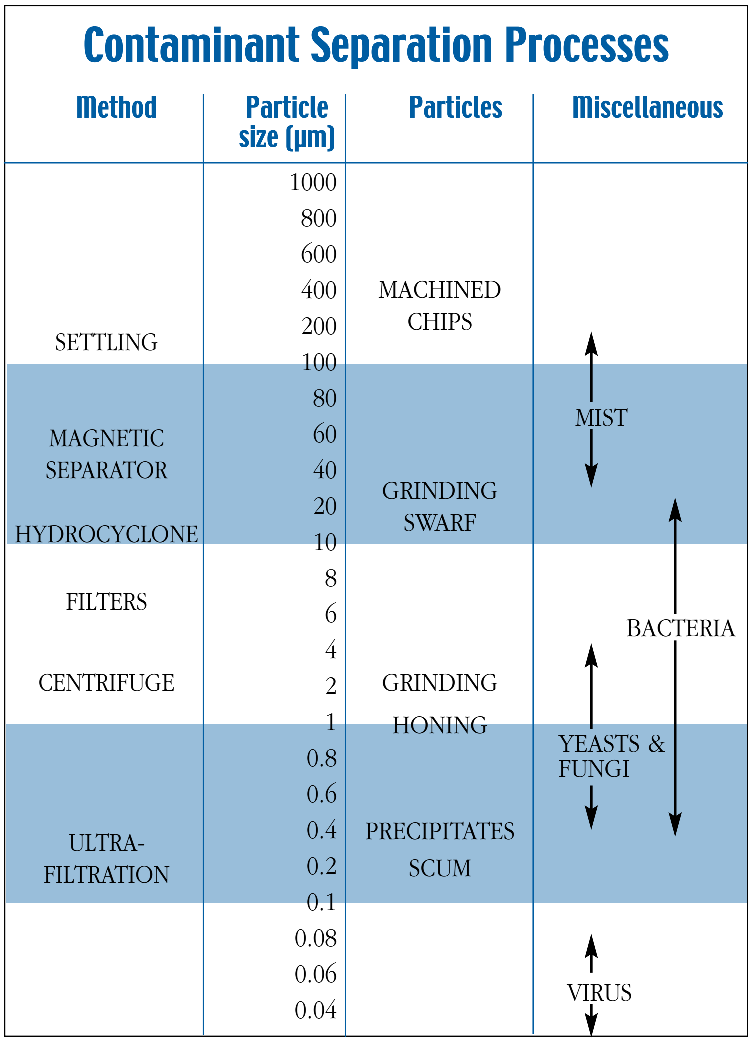

Figure 4-6. Summary of contaminant removal methods. (Modified from Bienkowski, April 1993)

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.