

EFFECT OF CUTTING FLUIDS ON METAL REMOVAL PROCESS

A Project Thesis

By

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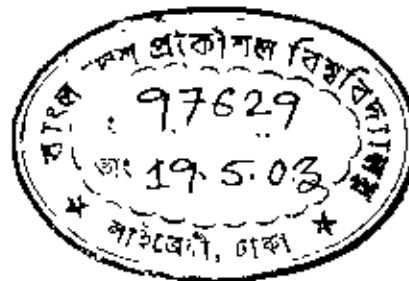
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Submitted to the Department of Industrial & Production Engineering, Bangladesh University of Engineering & Technology, Dhaka, in partial fulfillment of the requirements for the degree of **MASTER OF ENGINEERING** in Industrial & Production Engineering.

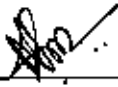
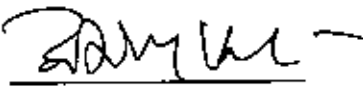
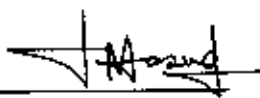
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The thesis titled **Effects of Cutting Fluids on Metal Removal Process**, submitted by K. M. Arshed Alam, Roll No. 9608035P, session 1995-96-97, has been accepted as satisfactory in partial fulfillment of the requirement for the degree of **MASTER OF ENGINEERING** in Industrial & Production Engineering on April 2003.

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April, 2003

Declaration

I do hereby declare that this work has been done by me and neither this thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma except for publication.

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Abstract

Historically, cutting fluids have been used extremely in metal cutting operations for the last 200 years. Cutting fluids play a significant role in machining operations and impact shop productivity, tool life and quality of work. The primary function of cutting fluid is temperature control through cooling and lubrication. 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. Secondary functions include flushing chips and metal fines from the tool-work interface to prevent a finished surface from becoming marred, corrosion inhibition, and reducing the occurrence of built-up- edge (BUE). Cutting fluid systems are complex, biologically active, and constantly changing in response to conditions of use. Cutting fluid systems can be maintained in a stable condition over relatively long periods of time, but to do so requires a well thought-out and consistently enforced management plan. With the recent emergence of environmental management standards and regulations for metal working industries, effective management of cutting fluids in machining facilities has become an issue of increased significance.

In all machining operations, tool wear is a natural phenomenon and it eventually leads to tool failure. Tool failure is considered to have occurred when there is a poor surface finish on the work-piece. The application of coolant during any machining operation is believed to reduce tool wear since the cutting fluid produces a lubricating as well as cooling effects. The experimental results show that, contrary to common belief, the application of coolant is not necessarily beneficial to tool life. In fact, it was discovered that one effect of the coolant is to slightly increase the crater wear and more importantly, to shift the position of the crater wears nearer the tool tip. The worn crater also becomes deeper and narrower as a result of the coolant. This causes the tool cutting point to become weaker. The flank wear is even

more significantly affected by the application of coolant, especially at high cutting speeds. This large increase in flank wear due to the application of coolant can drastically decrease tool life

Cutting fluids are important causes of occupational contact dermatitis, which may involve either irritant or allergic mechanisms. Water mixed fluids generally determine irritant contact dermatitis and allergic contact dermatitis when they are in touch with workers skin. Non-water-miscible fluids usually carcinoma. Exposure to cutting fluids effects health such as skin disorders, dermatitis, hyperkeratosis, and infrequently, skin tumors including cancer. Recent studies with cutting fluids showed that paraffin-based oils induced skin tumors whereas soluble oil did not. The potential health effects of exposure to cutting fluid mists cause potential health effects like throat, pancreas, rectum, and prostate cancers, as well as breathing problems and respiratory illnesses.

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Chapter-1



Introduction

Any manufacturing process for its fruitful implementation essentially needs to be technologically acceptable, technically feasible and economically viable. The fourth dimension that has been a great concern of the modern industries and society is environment-friendliness in and around the manufacturing shops.

The performance and service life of engineering component depend on their material, dimensional and form accuracy, and surface quality. Machining and grinding to attain the desired accuracy and surface integrity finish the preformed blanks. In industries, the machining temperature and its detrimental effects are generally reduced by:

- proper selection of process parameters, geometry of the cutting tools and application of cutting fluid
- using heat and wear resistant cutting tool materials like carbides, coated carbides and high performance ceramics (CBN and diamond are extremely heat and wear resistive but those are too expensive and are justified for very special work materials and requirements where other tools are not effective)

Cutting fluid not only cools the tool and job but also provides lubrication and cleans the cutting zone and protects the nascent finished surface from contamination by the harmful gases present in the atmosphere. But the

conventional types and methods of application of cutting fluid have been found to become less effective with the increase in cutting velocity and feed. The cutting fluid cannot properly enter the chip-tool interface to cool and lubricate due to bulk plastic contact of the chip with the tool rake surface. Besides that, often in high production machining the cutting fluid may cause premature failure of the cutting tool by fracturing due to close curling of the chips and thermal shocks. For which application of high cooling type water base cutting fluids are generally avoided in machining steels by brittle type cutting tools like carbides and ceramics. But what is of more serious concern is the pollution of the working environment caused by use of cutting fluid particularly oil-based type.

Past research has been focused on the temperature and its distribution in the cutting zone because it is believed that it has a direct impact on tool life [Chao and Trigger, 1955]. The primary function of cutting fluids is to reduce this cutting temperature and increase tool life [Shaw et al, 1951]. The cutting fluids are believed to reduce cutting temperature either by removing heat as a coolant or reducing the heat generation as a lubricant. In addition, the cutting fluid has a practical function as a chip-handling medium. Cutting fluids also help in machining of ductile materials by reducing or preventing formation of a built-up edge (BUE) which degrades the surface finishes.

It is generally agreed that the most important function of a cutting fluid is to reduce the rate of tool wear or conversely to improve tool life as compared to dry machining. In the past, it has been assumed that the function arises mainly from its lubricating and cooling action. However, in addition to these, a cutting fluid may confer two further actions like reducing mechanical strength and electrochemical action.

It has been shown [Kurimoto and Barrow, 1982] that the mechanical strength reducing action becomes negligible when machining steel at practical cutting speeds with carbide tools and can safely be ignored. The influence of the electrical current flowing through the cutting zone on the rate

of tool wear is well known [Ellis and Barrow, 1969]. However, most commercial cutting fluids are non electro-conductive and as such the situation with respect to current flow will not vary significantly from the dry cutting case. The electrochemical action can therefore be treated as a corrosive phenomenon in relation to tool wear.

It is accepted that several types of wear mechanism such as abrasive, adhesive, diffusive and corrosive are operating simultaneously, the intensity of each depends not only on the properties of the tool and workpiece material, but also on temperature and normal stress. When a cutting fluid is applied, its effect depends on the relative intensity of the various wear mechanisms and also on the case of access. Since these factors are not uniform over the whole wear region, it would appear that a cutting fluid should produce a different effect at various parts of the tool wear region.

The lubricating actions of a cutting fluid are closely associated with the corrosive action. In fact, the aim of EP lubricating action is to prevent adhesion by deliberately producing a mild form of corrosion. Thus, the lubricating action may accelerate the total rate of wear, if the increase in corrosive wear offsets the decrease in adhesive wear. Such a diverse effect of EP oils on tool wear has been reported elsewhere [Ishibashi, 1974].

When machining steels with carbide tools under practical cutting conditions, it is generally accepted that the lubricating action becomes rather ineffective due to the difficulty of fluid penetration into the contact interface. The cooling action is, therefore, considered to be the most important one for the reduction of tool wear. This appears reasonable in view of the fact that most of the wear mechanisms are essentially temperature dependent and hence anything that lowers the temperature level should result in a reduced rate of wear. However, an extremely applied cutting fluid, whether it exerts lubricating action or not, necessarily implies a change in the surrounding medium that dictates the corrosive wear. Thus, even if it does not penetrate

into the friction interfaces, it can affect the rate of wear where access is available, namely at the border of the wear region.

1.1 Toxicology and Characteristics of Components of Cutting Fluid

The most studied components of metalworking fluids are mineral oils, almost always-fractional distillates of petroleum, but pyrolysates of shale until the early part of the 20th Century. They are principally paraffinic hydrocarbons and may contain simple aromatic compounds. They vary in 'purity', freedom from toxic or carcinogenic components being very important for medicinal mineral oils, which are highly refined and processed. Like all petroleum fractions, mineral oils contain some proportion of polynuclear compounds (condensed aromatic hydrocarbons) among which are found molecules that are potent skin carcinogens; most such compounds are not carcinogenic [Lijinsky, 1991].

Mineral oils have many uses and undergo more or less refining to remove, for example, waxes or aromatic compounds, by solvent refining or treatment with sulfuric acid. The resulting oils will have the characteristic boiling point, viscosity and other properties required. Mineral oils are clear liquids and are immiscible with water and most hydroxylic solvents, but they are fat-soluble.

Although they have a high boiling point, mineral oils do form aerosol mists and it is recommended that human exposure be limited to less than 5 mg/m^3 in this form. When ingested they pass through the gastrointestinal tract unchanged and have no apparent effect, except on the lining of the tract itself; highly refined mineral oil is still used as a 'safe' laxative.

Many samples of mineral oils similar to those used in metalworking fluids have been carcinogenic to mouse skin, although the carcinogenic potency in general declined as the extent of refining of the oil increased. Also the carcinogenic effect increased as the oils were reused or re-cycled, particularly since oils from many sources were often blended in during re-cycling.

It appears that the paraffins and cycloparaffins, which are the main constituents of mineral oils, are not carcinogenic and that such carcinogenic activity as is present in commercial mineral oils is due to impurities. When heated to high temperatures as in engines (and possibly in use on cutting tools) the carcinogenicity of the oils on mouse skin often increases, probably due to formation of carcinogenic impurities, so that 'used' oils are more effective than new oil.

Hydroxyalkylamines are used in water-based metal-working fluids, especially emulsions, because members of this class of compound are excellent emulsifying agents, the most common being triethanolamine. They have also been suggested for use in metalworking fluids because of their anti-microbial properties, propanolamines being particularly effective, compared with ethanolamines and butanolamines [Bennett et al, 1985]. Hydroxyalkylamines are bases and are responsible for the alkaline Ph of water-based metalworking fluids.

The toxicity of hydroxyalkylamines to experimental animals is low. Few have been tested for chronic toxicity and triethanolamine is the only representative of which the tests are reliable and informative. Konishi et al [1992] administered a 1% solution of triethanolamine in drinking water to mice for 1.5 years and found no significant incidence of induced tumors compared with controls. This was a more comprehensive study than two previous bioassays of triethanolamine, in which lower dose rates were used and the numbers of animals were smaller. There is no evidence that alkanolamines used in metalworking fluids present a carcinogenic risk to workers, except, as discussed later, as a precursor of highly carcinogenic N-nitroso compounds.

Chlorinated paraffins are used in metalworking fluids to provide the desired physical characteristics (e.g. viscosity) to the fluid; other substances used for this purpose include natural fats and oils, and waxes. Chlorinated paraffins are made by adding chlorine gas to long chain paraffins until the required proportion has been incorporated. Consequently, chlorinated paraffins are rather ill defined and are characterized as mixtures of compounds with certain average chlorine content.

1.2 Toxicology and Characteristics of Additives and Contaminants

Biocides are substances added to water-based metal-working fluids to prevent or reduce bacterial contamination leading to foul odors and undesirable changes in characteristics of the fluids, particularly after continuous re-use. Of course, the biocides themselves must not be deleterious to the correct action of the fluids.

The list of compounds used or suitable for use as biocides in metalworking fluids is long and will not be enumerated. Alkanolamines have already been mentioned as biocides, although their principal use in metalworking fluids is as emulsifying agents. A number of other agents are so-called 'formaldehyde releasers' and are made by reaction of formaldehyde with ammonia or amines; hexamethylenetetramine is the prototype and has long been used medicinally as a urinary tract antiseptic. A common one is hexahydro-1,3,5-tris-(2-hydroxyethyl)-triazine. They are assumed to act by release of formaldehyde by hydrolysis, although this is not likely in the alkaline conditions of water-based metal-working fluids.

Formaldehyde itself is an enigma, since it is a reactive normal constituent of biological material. In solution or in the form of formaldehyde-generating condensation products (as in biocides) formaldehyde seems not to be carcinogenic. However, when inhaled as a gas it induces tumors of the nasal cavity in rats (these are not the same as sino-nasal tumors that occur in humans). There is not yet evidence that inhalation of formaldehyde is associated with any particular cancers in humans. Since little or no free formaldehyde exists in metalworking fluids containing formaldehyde-releasing biocides, it is unlikely that the risk to workers from inhaling formaldehyde will be significant.

Other biocides include o-phenylphenol, morpholine derivatives of nitroparaffins known as bioban(s), alkyl thiocarbamates, salts of pyridinethiol-1-oxide (omadine) and others. Most of these compounds are not very toxic to animals and there is no evidence of their being carcinogenic (but few have

been tested for carcinogenicity). One, pentachlorophenol has induced liver tumors (including hemangiosarcomas) in mice in a large scale NTP bioassay. Chelating agents, such as ethylenediaminetetraacetic acid, have been found to increase the effectiveness of biocides. Filtering of cutting fluids (through kaolin, bentonite, chalk, etc) to remove metal 'fines' and sludge prior to reuse has frequently reduced bactericidal effectiveness, requiring addition of more biocide.

Elemental sulfur is used in some formulations of metalworking fluids and is of little toxicological significance; sulphurized fats are also used in some straight cutting fluids. The most common sulfur compounds, used in water-based metalworking fluids, are sulphonated paraffins, which are detergents and emulsifying agents. There is some suggestion that bacterial reduction to sulphides is responsible for some of the foul odor of used and recycled fluids.

There is little information about the alkylsulphonates and none about their possible carcinogenicity. However, based on studies with some such detergents, they can be expected to be non-carcinogenic although there have been suggestions long ago that they might be weak skin tumor promoters.

Sodium nitrite is one of the oldest and cheapest corrosion inhibitors. It prevents rusting and has been widely used (as well as other nitrite salts) to line cans in which aqueous solutions are kept. Corrosion inhibitors are essential in metal-working fluids which are sprayed on the tips of cutting tools, so sodium nitrite or, in a few cases, an amine are components of most water-based cutting fluids, as much as 0.8%.

Sodium nitrite is itself a minimal hazard to humans, since it is not absorbed through the skin, is not volatile and is not very toxic to adults (large doses cause methaemoglobinemia in infants). Of several chronic toxicity tests of sodium nitrite, in only one was there a suggestion of carcinogenic activity to the liver of rats [Lijinsky et al, 1985], but this has not been confirmed.

However, the most important toxicological effect of nitrites is their propensity to react with secondary and tertiary amino compounds to form N-nitroso

compounds [Lijinsky and Epstein, 1970], which comprise the most broadly acting group of carcinogens known.

N-Nitroso compounds, often loosely called nitrosamines, are the products of interaction of amines with nitrosating agents, which include nitrogen oxides as well as nitrites. Consequently, they are found wherever such reactions can take place, include metalworking fluids. Reaction with nitrite is more rapid with secondary amines than with tertiary amines, for example the emulsifying agent triethanolamine; however, diethanolamine is a common contaminant of commercial triethanolamine. This explains the frequent presence of nitrosodiethanolamine (NDELA) in water-based cutting fluids; reaction with nitrogen oxides in the air is the probable source of this nitrosamine in metalworking fluids to which nitrite has not been added. Sophisticated methods have been developed for the determination of NDELA, which is a non-volatile nitrosamine, in various materials and these have somewhat lower sensitivity than the gas chromatographic methods for volatile nitrosamines. Among the nitrite-containing fluids concentrations of NDELA as high as 3% have been reported, although concentrations are usually considerably lower. Although this problem has been known for more than 15 years, metalworking fluids are still found that contain significant concentrations of nitrosamines; one sample analysed in 1989 contained 650 parts per million of NDELA [Keefer et al, 1990].

Nitrosation of amines usually occurs most rapidly in acidic solution, but was found to take place quite readily in alkaline solution in the presence of carbonyl compounds [Keefer et al, 1990] such as formaldehyde. Since other amines, such as diisopropanolamine are used in metalworking fluids, their N-nitroso derivatives (in this case, nitrosodiisopropanolamine which induces pancreas cancer in hamsters) can be present. Another consequence of the particular composition of metalworking fluids is that cyclic nitrosamines can form from hydroxyalkylamines, such as ethanolamine, in the presence of formaldehyde [Eiter et al, 1972]. Loeppky has extensively discussed this subject in relation to the reduction of nitrosamine contamination in cutting fluids.

The properties of nitrosamines underlie the concern for the presence of these compounds in metalworking fluids. Nitrosamines are absorbed through the skin, including nitrosodiethanolamine [Lijinsky et al, 1981] and they act systemically whatever the route of exposure, inducing tumors in certain target organs in a particular species. It cannot be predicted from one species to another which organ will be the target of a particular nitrosamine. For example, nitrosodiethanolamine induces tumors of the liver, esophagus and kidney in rats, but only tumors of the nasal cavity in hamsters [Lijinsky, 1991]. Therefore, results of testing a nitrosamine in rats, mice or hamsters provide no guide to which would be the target organ(s) for tumor induction in humans. NDELA induces mainly liver tumors in rats, as do nitrosooxazolidines, but nitrosodisopropanolamine induces tumors of the esophagus in rats and pancreas tumors in hamsters. Explanations of mechanisms by which these nitrosamines induce tumors are confusing, since NDELA is not mutagenic to bacteria with rat liver enzyme activation.

Cumulative doses of as little as 2 to 5 milligrams of some nitrosamines have been sufficient to induce significant incidences of tumors in experimental animals. Nitrosodiethanolamine is somewhat less potent, because 90% or more of the applied dose of this hydrophilic compound is excreted unchanged in the urine of rats, so that the effective dose in the animal is much smaller. Nevertheless, quite small doses have been effective in inducing a high incidence of liver tumors in rats [Lijinsky and Kovatch, 1985]. Nitrosodiethanolamine might represent the largest (but not necessarily the most potent) exposure of humans to an environmental carcinogen.

Polynuclear hydrocarbons products of pyrolysis of organic material were first isolated from coal tar pitch in the 19th century and have since been found almost ubiquitously, in air, water and soil. They are present in petroleum and, therefore, in most materials made from petroleum, including mineral oils and lubricating and metalworking fluids. The concentrations of the polynuclear hydrocarbons in these materials varies and in the case of the larger molecules, which are carcinogenic, concentrations of the order of parts per million are the rule. Nevertheless, these compounds are potent carcinogens

to the skin of mice and are responsible for most of the skin-cancer causation among workers exposed to petroleum-derived metalworking fluids.

In products such as mineral oils which are fractional distillates of petroleum, polynuclear hydrocarbons containing three fused rings like anthracene, phenanthrene, fluorene are the most abundant, those with four fused rings like chrysene, benz(a)anthracene, triphenylene, pyrene, fluoranthene are less abundant and those with 5 or 6 fused rings are quite rare. It is among the last that the most potent carcinogens are found. Unsubstituted anthracene and phenanthrene are not carcinogenic, benz(a)anthracene and chrysene are very weak carcinogens at best, and benzo(c)phenanthrene somewhat stronger, although their derivatives with alkyl (methyl) substituents in particular positions are often quite potent carcinogens. Some of these alkyl derivatives might or might not be present in a mineral oil; they are seldom reported.

The most potent carcinogens among the 5 and 6 ring polynuclear hydrocarbons [Lijinsky, 1991] are benzo(a)pyrene—a standard reference compound and some isomeric benzofluoranthenes, together with dibenz(a,h)anthracene. Benzo(e)pyrene, perylene, pentaphene and benzo(b)chrysene are inactive, while dibenz(a,c)anthracene and dibenz(a,j)anthracene are relatively weak carcinogens. Several dibenzopyrenes are potent carcinogens, especially by subcutaneous injection (they tend to be so little soluble in organic solvents that skin painting of solutions is inadequate to elicit skin tumors); benzo(g,h,i)perylene (commonly found and difficult to differentiate from benzo(a)pyrene), coronene and anthanthrene are not demonstrably carcinogenic (but they, too, are difficult to dissolve).

Not all of the above hydrocarbons have been detected in all of the mineral oils and metalworking fluids examined, although sophisticated methods are available for their determination [Grimmer and Boehnke, 1979].

The carcinogenic potency of polynuclear hydrocarbons is usually measured by the time taken for tumors to arise in the skin of mice painted. With a

solution of a hydrocarbon in a solvent such as acetone or highly purified mineral oil, the number of tumors and their malignancy are other gauges of relative potency. Whereas a cumulative dose of 0.01 to 0.1 millimole in frequent applications is needed to induce tumors by a polynuclear hydrocarbon itself, as little as few micrograms are sufficient to 'initiate' tumor formation which can then be 'promoted' by substances such as phorbol diesters in the initiation/promotion protocol described by Berenblum and Shubik [1947]. If the human skin responds in the same way, very small quantities of carcinogenic polynuclear hydrocarbons as are present in metalworking fluids could be significant factors in the causation of skin tumors in exposed workers.

The risks to other organs of exposure to carcinogenic polynuclear hydrocarbons are much harder to pin down. These compounds do not induce tumors of the skin in guinea pigs and were less effective in rats, rabbits and hamsters; the mouse seems to be the most sensitive species. Inhalation experiments or those using instillation of benzo(a)pyrene in the lungs (together with ferric oxide in some cases) induced lung tumors in rats, hamsters and monkeys, but the effective doses were quite large, often 100 milligrams. Oral administration of benzo(a)pyrene in solution to mice or hamsters gave rise to tumors (mainly papillomas) of the nonglandular stomach, whereas in rats mammary tumors were induced; the doses were fairly large. It is unwise to dismiss or ignore the possible contribution of polynuclear hydrocarbons in metal-working fluids to the cancer risk of exposed workers, simply because information about their carcinogenic effectiveness is inadequate.

1.3 Adverse Effects of Cutting Fluid Applications

Traditionally, the manufacture of a product had been attempted to be done as quickly and inexpensively as possible. Now that more environmental regulations are being put in place, manufacturers are forced to re-evaluate their manufacturing processes and reduce or eliminate their waste streams.

The waste streams present in machining include cutting fluid flow, chip flow, and cutting tool usage.

The application of cutting fluid may not always reduce the cutting tool wear as is commonly believed. Rather some conditions like machining steels by carbide tools, the use of coolant may increase tool wear.

It has been experienced [Shaw et al. 1951] that there was more tool wear when cutting with coolant than cutting dry in case of machining AISI 1020 and AISI 4340 steels by M-2 high speed steel tool cutting. Seah et al. [1995] also reported that at the first stage of machining (first 40 seconds or so), tool wear was faster in wet cutting than in dry cutting. Later on, the wear rate stabilized and was somewhat the same for both dry and wet cutting.

During machining, the cutting tool generally undergoes [Trent 1983] both flank wear and crater wear. Flank wear generally causes an increase in the cutting forces, dimensional inaccuracy and vibration. Crater wear takes place on the rake face of the tool where the chip slides over the tool surface.

Another experimental investigation was conducted [Cozzens et al. 1995] on single point boring. This was aimed to study the role of cutting fluid, tool and workpiece material, tool geometry and cutting conditions on machinability. The results indicated that the cutting fluid conditions had no significant effect on surface texture, forces and built-up edge. Since boring is a high speed operation and lubrication is ineffective, no effect was seen on the forces. However, the cutting fluid was found to have a significant effect on surface integrity.

Proper selection and application of cutting fluid generally improves tool life. At low cutting speed almost four times longer tool life was obtained [Satoshi et al. 1997] by such cutting fluid. But surface finish did not improve significantly.

Wearing of cutting tools not only causes loss of the cutting edges or tips of the inserts but loss of the entire insert after wear of all the corners. From an environmental perspective, therefore, the significant waste is not the portion of the tool worn away by the tool-work contact, but the remaining portion of the tool that is disposed after its useful life [Sheng and Munoz 1993].

1.4 Environmental Problems

Manufacturing by machining constitutes major industrial activities in global perspective. Like other manufacturing activities, machining also leads to environmental pollution [Ding and Hong 1998 and Hong et al. 1999] mainly because of use of cutting fluids. These fluids often contain sulphur (S), phosphorus (P), chlorine (Cl) or other extreme-pressure additives to improve the lubricating performance. These chemicals present health hazards. Furthermore, the cost of treating the waste liquid is high and the treatment itself is a source of air pollution. The major problems that arise due to use of cutting fluids are [Aronson 1995]:

- environmental pollution due to breakdown of the cutting fluids into harmful gases at high cutting temperature and biological hazards to the operators from the bacterial growth in the cutting fluids
- requirements of additional systems for pumping, local storage, filtration, temporary recycling, cooling and large space requirement
- disposal of the spent cutting fluids which also offer high risk of water pollution and soil contamination

The physiological effects on the operator, namely, toxic vapors, unpleasant odors, smoke, fumes, skin irritations (dermatitis), or effects from bacteria cultures from the cutting fluids and its overall effect on the worker safety and on the environment. In some applications the consumption of cutting fluids has been reduced drastically by using mist lubrication. However mist in the industrial environment can have a serious respiratory effect on the operator. Consequently high standards are being set to minimize this effect. Use of

cutting fluids will become more expensive as stricter enforcement of new regulations and standards are imposed.

Since beginning of twentieth century people [Peter et al.1996, Welter 1978, Kennedy 1989 and Thony et al. 1975] were concerned with possible harmful effects of various cutting fluid application.

It has been estimated [Bennett 1983] that about one million workers are exposed to cutting fluids in the United States alone. Since cutting fluids are complex in composition, they may be more toxic than their constituents and may be irritant or allergenic. Also, both bacteria and fungi can effectively colonize the cutting fluids and serve as source of microbial toxins. Hence significant negative effects, in terms of environmental, health, and safety consequences, are associated with the use of cutting fluids. The effects of exposure to the fluids on health have been studied for over 50 years, beginning with the concern that cutting fluid (oil) is a potential etiologic factor for occupational skin cancer. Epidemiological studies indicate that long-term exposure to metalworking fluids can lead to increased incidence of several types of cancer. The International Agency for Research on Cancer has concluded that there is sufficient evidence that mineral oils used in the workplace are carcinogenic [Peter et al. 1996]. Basically, workers are exposed to metal cutting fluids via three routes [Bennett et al. 1985]; skin exposure, aerial exposure and ingestion.

Skin exposure is the dominant route of exposure, and it is believed that about 80 percent of all occupational diseases are caused by skin contact with fluids [Bennett et al.1985]. Cutting fluids are important causes of occupational contact dermatitis, which may involve either irritant or allergic mechanisms. Water mixed fluids generally determine irritant contact dermatitis and allergic contact dermatitis when they are in touch with workers skin. Non-water-miscible fluids usually cause skin disorders such as folliculitis, oil acne, keratoses and carcinomas.

Iowa Waste Reduction Centre reported that besides potential skin and eye contact, inhalation is also a way to occupational exposure. Mists are aerosols comprised of liquid particles (less than 20 μm). During machining process, a considerable amount of heat is generated for which the cutting fluid may attain a temperature sufficiently higher than the saturation temperature. The vapour is produced at the solid-liquid interface as a result of boiling. Vapour may be generated also at the liquid-air interface when the fluid vapour pressure is less than the saturation pressure, namely as evaporation phenomena. Vapour generated then may condense to form mist. The non-aqueous components of the cutting fluid, such as the biocide additives, appear as fine aerosol that can enter the workroom air. Additionally, the cutting fluids impact with both stationary and rotating elements within the machine tool system, which leads to mechanical energy being transmitted to the fluid. Thus, the cutting fluid has higher surface energy and becomes less stable and disintegrates into drops (atomisation). The spray from the fluid application also may generate mist. A total fluid loss of 5 to 20 percent may occur due to evaporation, atomisation, splashing, and dragout processes. Whether formed by atomisation or evaporation/condensation, small droplets may be suspended in the air for several hours even several days in the workers breathing zones. These drifting droplets tend to evaporate further. Inhaled particles (with aerodynamic diameters less than 10 μm) deposit in the various regions of the respiratory system by the complex action of the different deposition mechanisms. The particulate below 2.5 μm aerodynamic diameter deposit primarily in the alveolar regions, which is the most sensitive region of lung. The particulate in size ranging from 2.5 μm to 10 μm deposits primarily in the airways. The potential health effects of exposure to cutting fluid mists have been the subjects of epidemiological studies in the automotive industry. The mist droplets can cause throat, pancreas, rectum, and prostate cancers, as well as breathing problems and respiratory illnesses. One acute effect observed is mild and reversible narrowing of airways during exposure to cutting fluid mist. [Kennedy 1989].

Several other epidemiological studies have also suggested that exposure to fluid mist may be associated with increased risk of airway irritation, chronic bronchitis, asthma and even laryngeal cancer [Bennett et al. 1985]. The Occupational Safety and Health Administrations (OSHA) standard for airborne particulate (largely due to fluid mist) is 5 mg/m^3 , and the United AutoWorkers (UAW) has proposed a reduction in the standard to 0.5 mg/m^3 . The oil mist level in a plant ranged from 4.2 to 15.6 mg/m^3 but fell to between 0.47 to 1.68 mg/m^3 when a different cutting fluid was substituted in the system [Welter 1978].

Anti misting compounds, such as a polymethacrylate polymer, polyisobutylene and poly-n-butane in concentrations of 0.2% as well as poly (1,2-butene oxide) have been suggested for addition into cutting fluids [Bennett et al. 1985]. But, consideration must be given to the effects of these chemicals upon humans. The most effective way to control mist exposure is to use mist collector to prevent mist from entering plant air. Many collectors use several stages of filters in series for the purpose. Other collectors use centrifugal cells or electrostatic precipitators as intermediate stages. Any collector using a 95% Dioctyl Phthalate (DOP) or High-Efficiency Particulate Air (HEPA) filters as a final collection stage has been tested as high efficiency when new. However, its efficiency will decrease with time. Moreover, the oil droplets may undergo partial or complete evaporation as they travel to collector. The generated organic vapours may return to the room and affect work health, and may re-condense on the cool surface causing safety and maintenance problems.

Pollution free manufacturing is increasingly gaining interest due to recent development of pollution-prevention legislation, European initiatives on product take-back or recycling, which affect many export industries in the US, and a growing consumer demand for green products and production processes. Concern for the environment, health and safety of the operators, as well as the requirements to enforce the environmental protection laws and occupational safety and health regulations are compelling the industry to

consider a cryogenic machining process as one of the viable alternative instead of using conventional cutting fluids.

1.5 Objectives of the Present Work

The main objective of the present work is to make a thorough and systematic investigation on two important phases of cutting fluid management like maintenance and selection of cutting fluids and its effect on metal removal process with a special consideration of cutting fluid health hazards. This project work was carried out with the following objectives:

- i. To identify the main elements of a cutting fluid management plan.
- ii. To determine the appropriate actions which can prolong the useful life of the cutting fluid.
- iii. To propose an effective cutting fluid monitoring program both for water based and oil based cutting fluids.
- iv. To analyze different selection criteria of cutting fluids.
- v. To analyze the effect of cutting fluids on metal removal process and
- vi. To find out different health hazards associated with the use of cutting fluid.

Chapter-2

Maintenance and Condition Monitoring of Cutting Fluids

Historically, cutting fluids have been used extremely 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, synthetic and semi-synthetics, are now used in approximately 80 to 90 percent of all applications [Aronson, 1992]. Although straight cutting oils are less popular than they were in the past, they are still the fluid of choice for certain metalworking operations.

Cutting fluids play a significant role in machining operations and impact shop productivity, tool life and quality of the 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 manufacturer quality products and
- Provide a healthier and safer work environment for employees.

Proper management of cutting and grinding fluids may also prevents 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.

2.1 Introduction

The current attention to the environmental impacts of industry by governmental regulation and by consumers is forcing manufacturers to decrease the amount of their process-generated wastes. Virtually every process that a product undergoes during its transformation from raw material to an item of finished goods has an associated waste stream. The cost of treating these waste streams is significant. To reduce these costs, it is necessary to focus attention on the reduction of generated wastes, rather than simply on their efficient disposal and treatment.

In metal machining, one of the largest waste streams is the used cutting fluid (as shown in Fig. 2.1 and Fig.2.2). Millions of dollars can be attributed to the consumption and maintenance of the cutting fluid systems for one production facility. To reduce this waste stream the use of cutting fluid must be eliminated or minimized. From an environmental standpoint, it would be desirable to eliminate cutting fluids completely from machining processes. But due to the lack of advancement of proper alternative machining without cutting fluid, they are widely utilized to optimize the process of machining operations such as turning, drilling, boring, grinding, and milling in various machine shops till today. So at present instead of eliminating cutting fluids, machine shops can adopt a good fluid management program which will help them to ensure the proper use of cutting fluids with longer service lives providing a significant decrease in the costs associated with their cutting fluid system.

Historically, cutting fluids have been used extensively for the last 200 years. There is a wide variety of cutting fluids available today. Many new coolants have been developed to meet the needs of new materials, new cutting tools and new coatings on cutting tools. Today, It is estimated that over 100 million gallons of metalworking oil is used each year in the US and since cutting fluids are often times diluted metalworking oils, the volume of cutting fluids used is many times more. The National Institute for Occupational Safety and Health (NIOSH) estimates that 1.2 million workers are exposed to cutting fluids each year [Byers, 1994]

The most common cutting fluids used today belong to one of two categories based on oil content like (a) oil-based fluids including straight oils and soluble oils and (b) chemical fluids including synthetics and semi-synthetics.

The primary functions of cutting fluids are heat transfer and lubrication [Aronson, 1995]. The cooling and lubrication properties are critical in extending tool life and maintaining dimensional control/surface finish [Silliman, 1992]. Secondary functions include flushing chips and metal fines

from the tool/work interface, corrosion inhibition, and reducing the occurrence of built-up- edge (BUE)

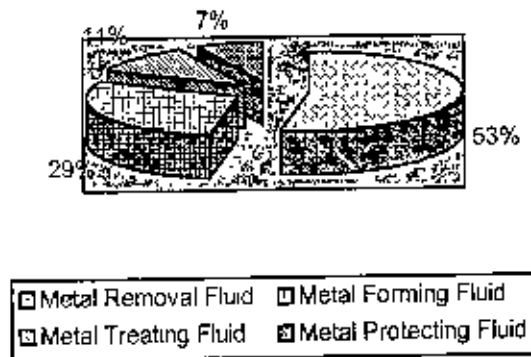


Fig. 2.1 Global Utilization of Metalworking Fluids (640,000,000 gallons/ year) [NCMS Report,1997]

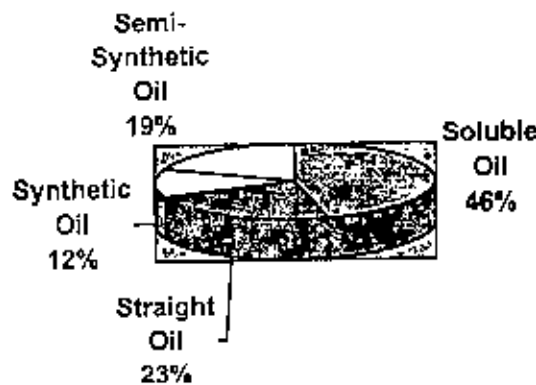


Fig 2.2 US Utilization of Metal Removal Fluid (95,000,000Gallon/year) [NCMS Report,1997]

Cutting fluids may contain a variety of additives (chlorine, sulfur, fatty oils, oxazolines, biocides, dyes, odorants, phosphorus, etc) which are included to achieve specific performance characteristics. Due to their complex composition, they may be more toxic than their components and may be irritant or allergic even if the raw materials are safe [NCMS Report, 1997, Marano and Mac, 1997, and Metal Removal Fluids, 1997]. Bacteria and fungi can effectively colonize the cutting fluids and serve as a source of microbial toxins [Metal Removal Fluids, 1997].

2.2 Management and Condition Monitoring of Cutting Fluids

Cutting fluid systems are complex, biologically active and constantly changing in response to conditions of use. Cutting fluid systems can be maintained in a suitable condition over relatively long periods of time, but to do so requires a well thought-out and consistently enforced management plan. If cutting fluids are to be used safely and effectively, a written management plan should be in place. Such a plan should specifically identify key elements of the program and the individual(s) responsible for their implementation. Managing cutting fluids well requires that all factors be considered in a systematic way. The management program should include a health and safety plan for workers as well. Cutting fluid management may include six areas like (a) selection (b) storage (c) distribution (d) maintenance (e) recycling and (f) disposal.

Metal cutting fluids are dynamic systems due to their usage and environment. Because its characteristics are widely changing during time, the same product may have a different composition after using in different systems for enough long time period. Cutting fluid systems often need close monitoring and maintenance due to contamination and degradation, requiring additions such as emulsifiers, concentrated oil, anti-corrosion agents, biocides, etc., with attention focused on such characteristics as fluid pH and oil concentration. There are obvious costs associated with the maintenance of a fluid system: labor cost associated with mixing, maintaining and fluid change outs; material cost associated with purchasing chemicals and equipment for maintaining cutting fluids and finally fluid disposal costs. Due to changing federal, state, and local regulations, cutting fluid disposal costs are rapidly increasing and are becoming a primary cost driver in the selection and use of metal removal fluid. The best way to minimize the cost associated with cutting fluids is to increase the service lives of cutting fluids by proper management program.

Clean system before introducing fresh cutting fluid: In shops usually used cutting fluid is pumped out of the sump and new cutting fluid is put into the sump for minimizing production downtime. However, it's a matter of being pennywise and dollar foolish. Actually by doing so one exposes the new cutting fluid to the exact same conditions that forced him to change the fluid anyway. This is particularly true in the case of bacteria and / or fungi. Although the sump is drained but as long as there is some residual fluid in the system, there will be some residual bacteria./fungi. These bacteria/fungi consume the organic components (oil and other additives) present in the cutting fluid. By allowing them to come in contact with fresh fluid, one is basically providing them with a free lunch.

By cleaning the machine tool cutting fluid delivery system, we can minimize the exposure of new cutting fluid to the factors that caused it to fail in the first place. This will extend the life of the cutting fluid and prevent production downtime.

Cutting fluid supplier should provide a machine cleaner with instructions on how to use it. The clean out procedure should include circulation of the cleaner through the machine tool fluid delivery system to insure that locations that are hard to reach in the machine tool have been reached. This is very easy for machines with individual cutting fluid sumps but can become complex for individual machines connected to central systems. While cleaning a machine connected to a central system, one has to make sure that machine cleaner should not contaminate the central fluid system. The use of dams is highly recommended.

Operate system in correct concentration: The single most important fluid characteristic is concentration. All water based cutting fluids are designed to operate at a given concentration dissolved or emulsified with water. The correct concentration of cutting fluids is essential for its performance characteristics-for optimal cooling and lubricity, corrosion protection and resistance to bacteria and fungus.

High concentration increases fluid costs through wasted concentrate, reduces dissipation of heat, foaming, lubrication, increases risk for generating BUE, dermatitis, etc. Basic reason for high concentration in cutting fluids is water evaporation due to heat generated in machining processes. Since the fluids evaporate under STP, high concentration can additionally increase its toxicity.

Operating a system at a low concentration usually causes poor lubricity, shorter tool life, increased biological activity and increased risk of rust formation on contacted metal surfaces and eventual downtime. Many chemical and physical processes influence oil concentration decay: bacterial attack, reaction of oil molecules with elements in water or metal, lubricant adhesion to the metal parts, degradation due to temperature and pressure in the cutting region, etc.

Cutting fluid concentration may vary depending upon plant location, operation, or machinist. Plants that run multiple shifts are likely probable to have variable concentration in a machine by shifts. The operators of the machine change the concentration at the start of their shift as all of them differ in their opinions about the proper concentration.

Proper mixing procedures are critical in attaining long cutting fluid life and economical use of cutting fluid concentrate, as well as to the elimination of cutting fluid concentration related problems. Premixing of the cutting fluid concentrate with pure water should be in accordance with fluid supplier's recommendation to ensure efficient use of the concentrate. Two types of cutting fluid mixer are venture type and positive proportioning pump equipped with interconnected water and concentrate cylinders.

Users should work with the fluid supplier to develop the correct make-up concentration. Most cutting fluid suppliers recommend using a lower concentration of cutting fluid to maintain the initial concentration. For

example, to maintain a 5% concentration of a semi-synthetic cutting fluid, the concentration of make up solution should be of 2-3%.

Ensure the adequate quality of the make up water: The chemistry of the water is probably the single most common reason for the success or failure of a cutting fluid. The life of the system, filter efficiency, foam characteristics and even tool life and finish, are influenced by the quality of the water. Very few plants invest the money necessary to install effective water purification systems using deionization or reverse osmosis technology.

Unfortunately, the chemical present, or not present, in the water used to reconstitute a cutting fluid makes a tremendous difference in its performance and sump life. Most manufacturers of cutting fluids will perform the necessary water testing to determine exactly what minerals are dissolved in water and make a fluid recommendation based on the results. Minerals in cutting fluid water can cause corrosion of machine tools and machined parts, can aggravate deposition of residues on machine tools and can increase the rate at which bacteria and fungi grow in the cutting fluid.

Water hardness uses up the cutting fluid concentrate and tends to force it out of solution. The net effect is that part of the concentrate does not contribute to cutting efficiency; instead, it may appear as a gummy deposit or residue on the machine parts. In addition, the lost concentrate can cause machine parts to rust. Table-2.1 shows a classification of water depending on hardness. The **hardness** of water is calculated on the basis of 17 parts per million of calcium carbonate per US gallon as being equal to one **grain**.

Table- 2.1 Water Hardness Chart [Annon]

Water Hardness Chart		
Water Type	Parts per Million (ppm)	Grains (1 or = 17 ppm)
Soft	0-50	0-3
Moderately soft	50-100	3-6
Slightly hard	100-150	6-9
Moderately hard	150-200	9-12
Hard	200-300	12-18
Very hard	Over 300	Over 18

Minerals other than hardness salts, such as chlorides and sulfates, contribute to rust and, the higher their concentration; the more of the cutting fluid concentrate is require preventing corrosion. The sulfates are particularly detrimental because they promote the growth of the sulfate-reducing bacteria *desulfovibrio desulfuricans* that produce a *rotten egg* odor.

With the evaporation of water from the cutting fluid, the minerals in the water increase resulting in more residuas to form and corrosion to increase. Usually, fluid makeup to the machine sump is on the order of 5 to 20% per day, depending upon the sump capacity and the severity of the operation. Hence, over the period of a month, solids buildup in the fluid mixture can be three to four times that of the original water.

Minerals (hardness and/or salts) are very detrimental to the stability cutting fluid mixtures. The more concentrated these minerals are to begin with, the faster they affect the fluids adversely and the more rapidly they build up to cause instability. In fact, minerals can become so troublesome that the concentrate will not mix properly, or that cutting fluid tanks would have to be dumped and refilled every week to prevent gumming and corrosion problems. Minerals in water not only cause residues to form and corrosion to occur, but they also help bacterie to grow. These aspects are among the most important considerations in water miscible fluid usage, and the results can be of substantial economic effect.

Minimize and control bacteria: Bacteria usually need water in order to grow and they can enter the cutting fluid from the following sourcas: make-up water, parts, air, operator's hands, sludge deposits in the machine tool sump. Two types of bacteria are found in the cutting fluid namely: *Aerobic Bacteria* and *Anaerobic Bacteria*. Aerobic bacteria prefer air (oxygen) for their best growth, but can adjust themselves to grow in the absence of oxygen. Anaerobic bacteria (*Desulfovibrio desulfuricans*) grow in the absence of oxygen but also can survive in the presence of oxygen. They grow much more slowly than the aerobic, but the results of their growth can be very

objectionable. They usually grow in a fluid that has been attacked by the aerobic bacteria rather than growing in a fresh clean fluid.

The faster the bacteria multiply the faster they will attack the cutting fluid and reduce lubricating effect and increase corrosion tendencies of the cutting fluid. So controlling the rate of bacterial growth can minimize the harmful effects of bacteria. The two most troublesome aerobic bacteria are *Pseudomonas oleovorans* and *Pseudomonas aeruginosa*. The bacterium *Pseudomonas oleovorans* lives in oil. So for controlling it two steps are (a) take all steps to reduce lubricating and hydraulic oil leakage and (b) if leakage cannot be prevented, the free-floating tramp oils should be skimmed from the surface and the partially emulsified and mechanically mixed tramp oil should be removed by centrifugation.

The bacterium *Pseudomonas aeruginosa* lives on practically anything: minerals in the water, metal removal fluid concentrate, discarded food, oils, etc. Note that *Pseudomonas oleovorans* and *Pseudomonas aeruginosa* are both aerobic and facultative (presence of more than one type of bacteria at a time) and are two species which are present in all water miscible fluids in use because they are difficult to kill.

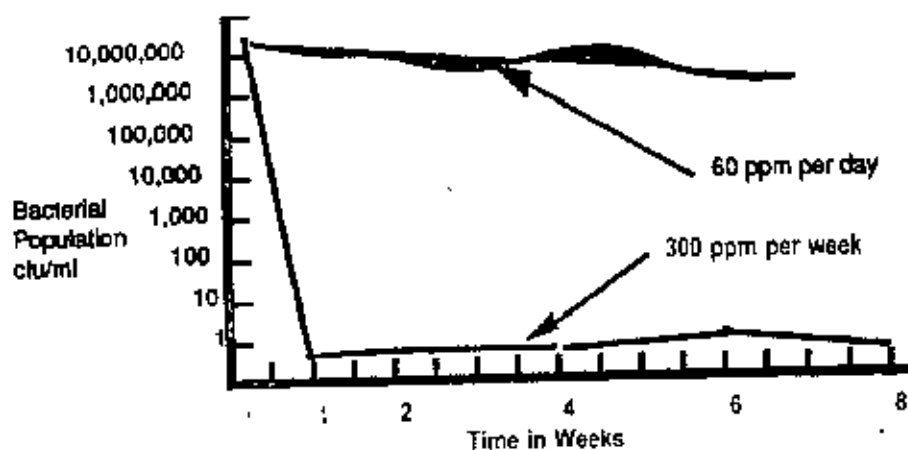


Fig. 2.3 Comparison of Biocide Dose Rates [Bennett, 1983]

The main type of anaerobic bacteria that grows in water miscible fluids is *Desulfovibrio desulfuricans*. It is very difficult to control and is found in almost all-cutting fluids. It produces a very strong odor of rotten eggs and can cause severe dark staining of machines and workpieces. In the presence of iron it can eventually make the fluid turn a black color. When this occurs, it is practically impossible for an operator to stand by the machine because of the foul odors. Studies have been done on the effect of biocide treatment patterns on anti-microbial efficacy in cutting fluid. 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 anti-microbial control was found to vary widely with treatment pattern. Less frequent doses with higher concentrations of biocide were found to be much more effective than low-level, frequent doses (as shown in Fig.2.3).

Maintain good housekeeping: Maintaining good housekeeping practices is essential for long cutting fluid lives. A cutting fluid is subjected to the metal chips and fines of the process, airborne contamination from cascading fluid over a part and the machine, machine leakage, residues left on the part from previous operations, water, operators, etc. Whenever possible, these contaminants need to be removed. Filtration may just be one part of an extensive system that also includes skimmers, chip conveyors and return troughs.

The build up of chips and metal fines in the cutting fluid delivery system provide an excellent "nesting" area for anaerobic bacteria. The periodic removal of this debris minimizes the potential for bacteria growth and extends metal removal fluid life.

Many of us accept tramp oil as a way of life. Tramp oil is a contaminant that is generated by the leaking of the machine lubrications and hydraulic oils into the cutting fluid sump. When it enters the cutting fluid system it is in a free state. It is not emulsified in the cutting fluid. As it mixes with the cutting fluid

and circulates in the system, the tramp oil breaks down into droplets as small as 20 microns. Tramp oil will encapsulate metal particulate (fines), and coat the walls of the sump, piping and components.

Tramp oils also diminish the ability of the cutting fluid to remove heat from the work piece. This causes the cutting fluid and the material to increase in temperature, to the point where it can effect dimensional quality. In addition, this temperature rise will enhance the environment for bacteria growth. Bacteria feed on the fatty acids in the tramp oil. The heat accelerates this activity. As the bacteria slime grows and manifests itself in the machine cutting fluid, it causes the deterioration of the cutting fluid, accelerates tool wear, diminishes quality, both dimensionally and surfaces finish, and results in health problems for the operator with rashes and allergies.

Maintaining the tramp oil levels can control bacteria. Tramp oil is considered to be a more serious cutting fluid contamination problem than that of particulate. Sometimes it is difficult to determine if the contamination problem is the result of particulate or tramp oil, or both. If tramp oil is a concern, maintenance should be done to minimize or eliminate the source. Some oil will leak into the cutting fluid stream on almost any machine. Maintenance should be done to find and correct any excess leakage. Once complete oil separators can be installed.

Maintaining good housekeeping also means teaching company's employees not to use machine tool sumps as trash receptacles. In many plants, one finds paper cups, banana peels, sandwiches, cigarettes butts, and other trash floating in the cutting fluid. These not only introduce bacteria into the sump but also provide nutrients for bacteria. Trash should go in trash containers even if it means the employee has to walk away from the machine tool.

Just doing these five things will prolong the life of the cutting fluids and help a company save some money. However, a company should start a well-structured fluid maintenance program to make it more effective.

2.3 Water Based Cutting Fluid Monitoring Program

The concentration of an aqueous cutting fluid can be measured in several ways. Refractometry is the most widely used method of measuring fluid concentration. Oil concentration measurements by using refractometer is based on a property that fluid refraction index (how much light is bent as it passes through a liquid) depends on its density. A small hand held optical instrument called refractometer is used to measure the refractive index of the water based cutting fluid. The reading obtained from the refractometer is compared to against a concentration calibration chart or multiplied by a factor to obtain the concentration of the sample as shown in Fig.2.4. The problem arises if we are forced to change cutting fluids or there is a modification in cutting fluid concentration that changes the concentration calibration curve or multiplication factor. The individual performing the test should be well aware of this change so that he can calculate concentration correctly.

In case of using a soluble oil or semi-synthetic, oil contents (oil split) can be used as an indicator of fluid concentration. The idea of this test is to destabilize cutting fluid emulsion and separate it in two layers one of which is water and other is present oily material. A sample of fluid is placed in a graduated centrifuge tube and sulfuric acid is added. The mixture is then centrifuged for approximately 10 minutes at 1000 rpm. The volume of free oil floating of the top of the mixture is then read from the centrifuge tubes graduation. This volume compared to a concentration calibration chart provides the fluid concentration.

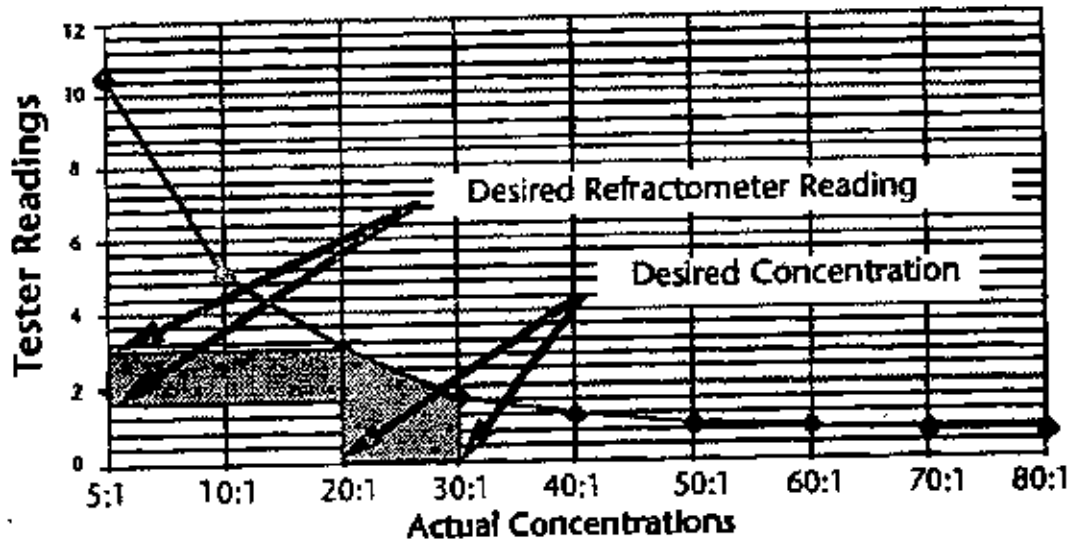


Fig. 2.4 Refractometer / Concentration Chart [Bennett, 1983]

As with oil content, chemical titration method must be conducted in the "laboratory". By using titration method concentration of specific chemicals or group of chemicals in the mixture can be measured. It usually involves adding a known volume of metal removal fluid to a clear container. A water insoluble solvent and a colored indicator is added to the container and then a titrant solution is added slowly until a color change occurs. The cutting fluid concentration is proportional to the number of titrant drops added. This method is more accurate than other two and is less affected from tramp oil or water quality. Chemical Titration often measures the Alkalinity or Emulsifier Content of cutting fluid. However, contamination and age (particularly the build up of carbonates from water salts) can cause inaccurate readings. The chemical titration procedure used depends on the cutting fluid being used. The cutting fluid supplier is the only source for obtaining the chemical titration test procedure for their cutting fluid.

The appearance of a cutting fluid should be recorded on a daily basis. A sample of cutting fluid should be stored in a glass bottle for reference as a later date to compare the physical appearance of the cutting fluid at various

times. A healthy fluid will be milky (soluble oils), clear (synthetics) or transparent to milky (semi-synthetic).

An increasing milky appearance in synthetic or semi-synthetic fluids indicates either entrained or emulsified tramp oil. On standing, entrained oil will rise to the surface while emulsified tramp oil will remain emulsified. The presence of free oil indicates the presence of tramp oil or possible destabilization of the cutting fluid. Cream or free oil present in soluble oil indicates instability.

Odor is generally due to bacteria and microorganisms present in the fluid will be aerosolized into the air as part of the mist. Aqueous cutting fluids are typically formulated to have a mild odor. Any cutting fluid that has a foul odor most likely contains bacteria. A rotten egg odor is due to anaerobic bacteria that will produce H_2S gas.

Cutting fluid pH is a very good indicator of consistent fluid quality. It represents a concentration of hydrogen ions. Practically, pH determines how acidic (<7) or alkaline (>7) the cutting fluid is. Recommended pH region for water-miscible cutting fluids is 8.8-9.2. For pH value lower than 8.0 fluid is losing its efficiency, its corrosion prohibition properties are becoming reduced and increased microbial contamination is recognizing. If the pH level becomes more than 9.5, risk for skin irritation and dermatitis significantly increases. It is important to record the pH daily to monitor any gradual decreases in the pH of the cutting fluid. Litmus paper provides the cheap and fast indicator of pH. Indicator stripes are dipped into the cutting fluid and its changing color will depend on the pH level. Since the accuracy of this method is limited and it can not predict bio-contamination of the fluid, another pH indicators are using more often. An inexpensive hand held pH meter is preferred and it should be calibrated with standard buffer solutions each day. Titration, as a quantitative method for determining alkalinity, is also developed. Advantage of this method is that it additionally determines the rate of change of alkalinity. This helps in estimating the cause of alteration.

The high water content of aqueous cutting fluids can be very conducive to biological growth. The level of bacteria or fungus should be monitored regularly to ensure optimum fluid operation. The presence of bacteria can lead to a drop in the pH, emulsion instability, rancid odors, decreased corrosion protection, plugging of filters and eventual downtime. Bacteria and fungal levels can be measured using biological dipslides. These dipslides consist of a plastic paddle coated with Agar. Agar is a medium type of microbial growth medium. One side of the plastic paddle is specific for bacteria while the second is specific for fungi.

As the name implies, the dipslide is dipped into the cutting fluid, withdrawn, and sealed in a clear airtight vial. The vial is then incubated near room temperature for 24-36 hours. During this incubation time, bacteria and/or fungi grow on the agar. At the conclusion of the incubation period, the amount of growth that has occurred is compared to a chart that gives an approximate indication of the amount of bacteria present in the fluid.

The growth of aerobic bacteria in an aqueous based cutting fluid will cause the dissolved oxygen level of the fluid to decrease over time as the bacteria consume the oxygen. So Microbial Contamination of a cutting fluid can be estimated by indicating dissolved oxygen in the mixture. A low dissolved oxygen reading (less than 3ppm) may be indicative of a problem associated with bacteria. Higher levels of dissolved oxygen (6-8 ppm) indicate relatively little bacterial activity. Dissolved oxygen meters are available through scientific laboratory suppliers.

The level of biocide in some aqueous systems can be determined. The fluid manufacturer should be consulted to determine the method of testing biocide level.

2.4 Oil Based Cutting Fluid Monitoring Program

During the course of operation, the oil based cutting fluid may be contaminated or oxidized which may affect its performance as a lubricant. Testing of the used fluid to determine the condition of the fluid for its suitability of continued use by evaluating TAN, water contents, viscosity, trace metal levels and IR parameters on a regular basis will ensure the continued success of an oil based cutting fluid.

The total acid number (TAN) is the quantity of base, expressed in terms of the equivalent number of milligrams of potassium hydroxide, that is required to titrate the strong acid constituents present in 1 gram of sample. The method is used to determine the amount of oxidation products present in a given sample.

Mineral oil based cutting fluids are designed to operate with no water content. The tolerable amount of water will vary in a fluid but generally levels of 1% are excessive. A hazy or emulsified appearance often indicates the presence of water in the product. This often results in a decrease in corrosion protection and tool life. The water should be removed by on or off site reclamation of the fluid should be replaced. The used oil should be disposed of in accordance to local, state and federal regulations.

The viscosity of a fluid may be very critical depending on the application. Viscosity may be changed due to following reasons:

- Oxidation of certain components of a mineral oil based cutting fluid may so happen due to high temperature generation in the cutting zone and this may cause an increase in viscosity of the fluid and consequently a decrease in the performance of the fluid.
- Contamination of the cutting fluid by hydraulic fluids or other machine lubricants may also change the viscosity. These contaminants may be detrimental to the performance of the fluid.



The trace metal level in a fluid provides (a) an indication of additive level or the presence of contamination from other fluids and (b) information on levels of machining debris such as Iron, Copper and Magnesium. By analyzing the trend of data may indicate the source of contamination and also provide information on the suitability of continued use of the fluid.

Infrared analysis (IR) provides a qualitative "chemical fingerprint" of all the components of a cutting fluid. It provides information concerning additive chemistry, contamination, water content and many other properties.

The cutting fluid within a coolant system degrades with time due to bacterial growth and contamination with tramp oil and fine metal swarf from the machining operation. So cutting fluid maintenance is very important for its proper application in processes. In addition, keeping the fluid properties between the proposed limits will increase its lifetime and consequently an organization can minimize the different costs associated with it. The problem may not be with the cutting fluid but with what an organization is doing with it. Many companies are running different maintenance programs, all focussed on monitoring particular fluid properties and proper addition of chemicals in order to keep fluid parameters between the proposed limits. Most important parameters that are monitored are oil concentration, pH level, and microbial contamination, tramp oil concentration and corrosion inhibition. Depending on the type of cutting fluid being used a fluid maintenance program should be sorted out and carried on under the supervision of a well-structured team. It is also important to maintain a good bridge with the cutting fluid supplier for resolving different problems and logistical helps to carry out different tests.

The science to maintain and extend the life of cutting fluid is well known and not necessarily expensive nor difficult but generally is not used. Additionally, many organizations fail to recognize that many of their everyday practices abuse cutting fluids and sooner, much more than later, they experience problems with their cutting fluid. Upon experiencing these problems, the first inclination is to throw the problem fluid out of the organization and find a new

one. Six months to a year later, they run into a similar problem with the new fluid and throw that one out of the organization. As this is written, there are six to eight major cutting fluid manufacturers in the United States. Each manufacturer makes approximately 200 different fluids. Therefore, there are between 1200-1600 different fluids to evaluate. It is highly likely that an organization would close its operation before it ran out of fluids to test. So it is always wise to maintain a well-defined fluid management system to avoid the recurrence of such problems.

Chapter-3

Selection of Cutting Fluid in Metal Machining

Choosing the right metalworking fluid for machining operations can be confusing and time consuming. To select a fluid for machining application advantages and disadvantages of metalworking fluid products should be compared through review of product literature supplied 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. During selecting cutting fluids the following factors should be considered [Aronson, 1995]:

- Cost and life expectancy
- Fluid compatibility with 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

This chapter presents some issues that may be considered in evaluating a cutting fluid for any machine shop. Available cutting fluids are categorized in to four major groups. The specific characteristics, major constituents, advantages, limitations and specific application of each group are described. Different selection criteria concerning machine tool, operation, work piece etc. are pointed out. Real cost estimates of different activities about cutting fluids are shown. Environmental rules and regulations affecting the use and disposal of cutting fluid and several rating systems used to rank the cutting fluid are also provided.

3.1 Introduction

The goal of machining operations must be to improve productivity and reduce costs. This is accomplished by machining at the highest practical speed while maintaining practical tool life, reducing scrap and producing parts with the desired surface quality. Cutting fluids play an important role in machining operation and impact shop productivity, tool life and quality of work. They remove temperature from cutting zone by cooling mechanism, reduce friction at the tool chip interface and welding of contact edges by lubricating mechanism, help to prevent rust and corrosion and flush chips away [Annon]. There is a wide variety of cutting fluids available today. Many new coolants have been developed to meet the needs of new materials, new cutting tools and new coatings on cutting tools. Most shops try to reduce the number of different types of fluids that they keep in stock due to the high cost associated with the maintenance, disposal and liabilities. They try to stock fluids that have long-life, do not need to be changed constantly, don't smoke in use, and don't cause skin irritation and easy to dispose of proper selection and use of cutting fluids can help achieve all of these goals [Annon].

The formation of mist from cutting fluids represents a significant waste stream. Marano et al. [1991] described some of the negative effects of fluid mist: poor air quality, housekeeping safety issues, fire propagation upon introduction of a spark and environmental concerns if oil on the roof is carried

down storm water drains. In the automotive industry, collection systems have been implemented to reduce the workers' exposure to cutting fluid mist. The Occupational Safety and Health Administration (OSHA) standard for oil mist is 5 mg/m^3 and UAW has recently proposed the reduction of the fluid mist standard to 0.5 mg/m^3 [Annon]. To ensure that workers have minimal exposure to cutting fluid mist, all processes using any type of oil cutting fluid will require machine enclosures and mist collectors with high collection efficiency [Mahdi and Skold, 1991]. However, the collectors and machine enclosures are expensive to purchase, install, operate and maintain. In order to reduce worker exposure to oil mist and eliminate cutting fluid mist control costs, reduce company exposure to environmental regulations and liability, a better understanding of the mechanism and types of cutting fluid mist formation is required.

3.2 Cutting Fluid Selection

Practically, all cutting fluids presently in use fall into one of four categories like (a) straight oil (b) soluble oil (c) semi-synthetic fluid and (d) synthetic fluids. A characteristic property of different cutting fluids is shown in Table-3.1.

Straight cutting oils are not mixed with water. They can be applied where the speed of the tool is very low, depth of cut taken is high, cutting pressures are high. They are generally mixtures of mineral oil and animal, vegetable or marine oils to improve the wetting and lubricating properties. Sulfur, chlorine, and phosphorous compounds are sometimes added to improve the lubrication qualities of the fluid for extreme pressure applications. There are two main types of straight oils: active and inactive. Inactive oils contain sulfur that is very firmly attached to the oil. Very little sulfur is released in the machining process to react with the work piece. They provide excellent lubrication, but are not very good at heat dissipation. They are particularly suited to nonferrous materials such as aluminum, brass, and magnesium. Active oils contain sulfur that is not firmly attached to the oil and released

during the machining operation to react with the work piece. These oils have good lubrication and cooling properties. They are recommended for tough low carbon and chrome-alloy steels. They are widely used in thread cutting and also good for grinding.

Important properties of neat oils to be borne in mind while selecting them for a given application are viscosity, flash point and wetting agents.

Table-3.1 Characteristics properties of different cutting fluids [Byers, 1994]

Cutting Fluid Characteristics					
Characteristics	Synthetic Oils		Semi-synthetic Oils	Soluble Oils	Neat Oils
	Inactive Oils	Active Oils			
Lubricity	Poor	Excellent	Fair to Good	Fair to Good	Good to Excellent
Cooling	Best	Good	Fair to Good	Poor to Fair	Worst
Wetting	Poor	Excellent	Fair to Good	Poor to Fair	Good
Residue	Worst	Poor to Good	Fair to Good	Best	Best
Foam	None to Low	Medium to High	Low to High	Low to Medium	Medium to High
Ferrous	Fair to Good	Good	Good	Fair to Good	Good to Excellent
Non-ferrous	Poor to Fair	Fair to Good	Fair to Good	Best	Fair
Cast Iron	Poor to Good	Good	Fair to Good	Poor	Good to Excellent
Tram Oil Rejection	Best	Worst	Fair	Poor to Fair	Good
Disposability	Poor	Poor	Poor	Best	Poor
Recyclability	Poor to Good	Fair to Good	Fair to Good	Poor to Good	Excellent
Maintenance	Good	Good	Fair	Worst	Excellent
Environmental	Excellent	Excellent	Good	Fair	Worst
Cost	Lowest	Lowest	Low	Medium	High

Soluble oils disperse in water when emulsifiers are added. Petroleum or mineral oil combined with emulsifiers and blending agents is basic components of soluble oils. They provide good lubrication and heat transfer performance, excellent aluminum and copper corrosion control, good

rancidity control, and good concentrate and mix stability. They are generally suitable for moderate to heavy-duty machining and grinding of all non-ferrous metals, carbon and cast steels, and in applications where dissimilar metals such as aluminum and steel are present. They can also be used in turning, drilling, tapping, reaming, gear cutting, broaching, as well as internal and center less types of grinding operations. Soluble oil emulsions have a pH of 8.5. So, Continuous contact of skin with soluble oil emulsions results in drying of the skin due to neutralization reaction. Dry skin is prone to injuries.

Synthetic oils are completely oil-free solutions and mix with water easily. Synthetic Fluids contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds along with additives for corrosion inhibition. Inactive chemical cutting fluids are usually clear fluids with high rust inhibition, high cooling, and low lubrication qualities. Active chemical fluids include wetting agents. They have excellent rust inhibition and moderate lubrication and cooling properties. Some contain sulfur or chlorine additives for extreme pressure cutting applications. Synthetic fluids often provide the best cooling performance among all cutting fluids. These clear, low foaming, and bio-stable synthetics are ideal for machining and grinding of ferrous materials, carbon steels, or cast iron, well suited for tough-to-machine materials such as stainless steels and high-temperature alloys, not affected by bacterial growth, and capable of forming emulsions in hard water. Certain synthetics are specifically designed to address the primary failure modes of flank wear and nose wear. But they provide very poor lubricity, may cause staining of non-ferrous materials, and peel of poor quality epoxy paints on the machines. Synthetic coolants have a very high detergency property. This results in collection of large quantities of muck and dirt in the coolant pump. Unless the filtering mechanism is very good, this property can lead to a lot of undesirable machining conditions. They can be applied in carbide grinding with diamond wheel, very sophisticated CNC machines with low stock removal and no operator contact with coolant and in ordinary commercial grinding where surface finish is not very critical.

Semi synthetic oils contain both constituents of synthetic and soluble oils. So their characteristic properties are common to both synthetics and water-soluble oils. They have moderate lubrication and cooling and high rust inhibition properties. They are chlorine-free to reduce bi-metallic corrosion and staining of metals. Sulfur, chlorine and phosphorous are added sometimes to improve the extreme pressure characteristics. They can be applied in general purpose cylindrical and center less grinding where very high surface finishes are not required. They work extremely well on all non-ferrous metals such as titanium, aluminum, copper, brass, bronze and stainless steel in both machining and grinding and can be used on ferrous metals, too

3.3 Cutting Fluid Selection Criteria

The principal criteria for selection of a cutting fluid are (a) process performance (b) machine tools (c) machining operation (d) cost Performance (e) environmental performance and (f) health hazard performance. Selection of cutting fluid for different types of machining operation is shown in the Table-3.2.

For a given machining operation the performance of cutting fluid are considered as heat transfer performance, lubrication performance, chip flushing, fluid mist generation, fluid carry-off in chips, corrosion inhibition and fluid stability (for emulsions) etc

The age of the machine tool can be a critical factor in choosing a metal removal fluid. Older machines may have open gearboxes or seal materials that are made of product specific materials designed for water or oil based fluids. Machine tool enclosures can also be a factor in fluid evaluation since mist generation is an area of concern for the workers

Many machine tools leak lubricating oils, sometimes by design. These non-product contaminants affect the fluid performance and can shorten its useful life. Every effort should be made to keep these oils from leaking into the metal removal fluid. Seal materials must be compatible with fluid types. Seal swelling or cracking can cause major machine tool damage. The type of fluid used may also affect wire coatings. Many machine tools are made of many types of metals, ferrous and non-ferrous. Some are painted while others are not. Fluid and machine tool components must be compatible.

Handling of the fluids is critical. Sump design, sump size, location and contaminant removal can determine what fluid to use. Some fluids are designed for high-speed operations, such as water based where some fluids are designed for slow speed operations such as straight oils. Proper fluids and tooling selection can minimize power consumption.

The hardness and machinability of the workpiece is critical and will in most cases determine what fluid for fluid type to use. For example a soft cast iron requires different lubricity than a titanium alloy. Ferrous and non-ferrous metals have different corrosion control chemistries. It is vital that a fluid be used that protects the workpiece from corrosion.

Whether the operation is machining, grinding, or drawing, all types of metalworking operations have various levels of severity. The correct fluid selection can minimize potential problems. The operation itself and how the metal removal or deformation takes place can affect fluid selection.

Tools are made up of a variety of metallurgy's, such as high-speed steels, cemented carbides, carbons, or a variety of metals bonded with a variety of binders such as cobalt. Fluids must be compatible and can prolong tool life. Tool suppliers sometimes have databases on what fluid types perform best with their particular products

Table-3.2 Selection of cutting fluid for different types of machining operation [Byers, 1994]

Material	Milling	Drilling	Tapping	Turning
Aluminum	Soluble oil (96% water) or mineral oil	Soluble oil (70-90% water)	25% sulfur-base oil mixed with mineral oil	Mineral oil with 10% fat (or) soluble oil
Brass	Soluble oil (96% water)	Soluble oil	10-20% lard oil with mineral oil	Mineral oil with 10% fat
Bronze	Soluble oil	Soluble oil	30% lard with mineral oil	Soluble oil
Alloy Steel	10% lard oil with 90% mineral oil	Soluble oil	30% lard oil with 70% mineral oil	25% sulfur base oil with 75% mineral oil
Cast Iron	Dry	Dry	Dry or 25% lard oil with 80% mineral oil	Dry
Malleable Iron	Soluble oil	Soluble oil	Soluble oil	Soluble oil
Copper	Soluble oil	Soluble oil	Soluble oil	Soluble oil
Low Carbon and Tool Steel	Soluble oil	Soluble oil	25-40% lard oil with mineral oil	25% lard oil with 75% mineral oil

The purposes of the fluid in most grinding operations can be clarity, lubricity or keeping the wheel clean and free of loading. The determination needs to be made as to what function is wanted from the fluid when grinding.

Many times the tool and the tool holder are made of non-similar metals. Care in the selection of the fluid should be taken to avoid bi-metallic corrosions. Many new tools are now dispensing fluid through the center of the tool to better provide lubrication and cooling at the point of the cut. Because of the high pressure and velocity of this operation, fluids (typically water based) used in these applications need to be low foaming.

Water quality will be critical to the long life and performance of water based metal removal. Prior to recommending any water based metal removal fluid, the metal removal fluid salesman should ask for a sample of the metal removal fluid make up water for evaluation.

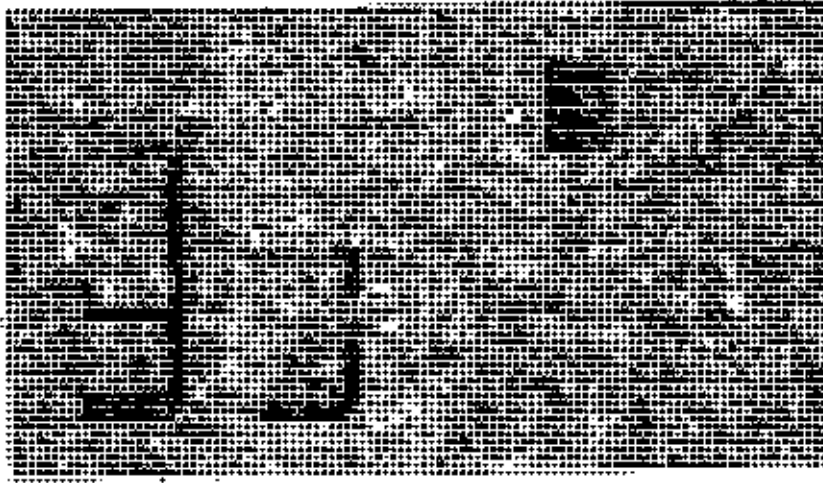


Fig. 3.1 Cost and health hazard of cutting fluid [Lea, 1955]

If shops cut only one material, whether it is aluminum, stainless steel, or cast iron, the selection of a good cutting fluid would be much easier to make. But most shops handle a variety of workpiece materials on a regular basis making the selection process complicated. The chemistry of the water is probably the single most common reason for the success or failure of a cutting fluid. Unfortunately, the chemical present, or not present, in the water used to reconstitute a cutting fluid makes a tremendous difference in its performance and sump life. Manufacturers of cutting fluids should perform the necessary water testing to determine exactly what minerals are dissolved in your water and make a fluid recommendation based on the results.

Without a doubt, this is the top priority associated with selecting a new metal removal fluid. Cutting fluids are important causes of occupational skin diseases. Water based fluids cause irritant and allergic contact dermatitis and non-water-miscible fluids usually cause skin disorders such as folliculate, oil acne, keratoses and carcinomas etc. During cutting process a considerable amount of heat generated may result evaporation of cutting fluid and the vapor then may condense to form mist and deposit in the various regions of the respiratory system. The mist droplets can cause throat, pancreas, rectum, and prostate cancers, as well as breathing problems and respiratory

illnesses (as shown in Fig 3.1). Different cutting fluids exhibit the different tendency to produce smoke or mists. The oil mist level in a plant ranged from 4.2 to 15.6 mg/m³ but fell to between 0.47 to 1.68 mg/m³ when a different cutting fluid was substituted in the system. The Occupational Safety and Health Administrations (OSHA) standard for airborne particulate (largely due to fluid mist) is 5 mg/m³ and the United Auto-Workers (UAW) has proposed a reduction in the standard to 0.5 mg/m³.

There are several rules and regulations affecting the use of metal removal fluids, there are also some rating systems for ranking the safety of the metal removal fluids. Some major regulations affecting the use of metal removal fluids under OSHA (Occupational Safety & Health Administration), EPA (Environmental Protection Agency), and EH&S (Environmental Health and Safety) are listed below:

OSHA's Hazard Communication Standard is the major regulation, which covers an employee's right-to-know of potential health and physical hazards in the workplace. Hazardous Waste Operations and Emergency Response (HAZWOPER) Standard covers the responsibilities of the employer to establish procedures to ensure the safe handling of hazardous waste. The development and implementation of emergency response teams to respond to spills, leaks, fires, releases and other emergencies at the facility and the training of employees involved in both hazardous waste handling and emergency response teams.

Resource Conservation and Recovery Act (RCRA) is a series of regulations, which covers the disposal of both non-hazardous and hazardous waste. It sets up requirements for generators, transporters, and treatment, storage and disposal facilities (TSD) for licensing, standards of operations and reporting.

Toxic Substances Control Act (TSCA) is a regulation, which is important for the users of metal removal fluids to ensure that all of the substances within the metal removal fluids are listed on the TSCA Inventory.

The Environmental Health and Safety (EH&S) was developed to bring some awareness to EH&S issues associated with the end use of metal working fluids, by allowing a wide range of end users to compare one fluid with another. This is accomplished by researching the question, scoring the various metal working fluids based on the end users EH&S concerns, and then deciding which metal working fluid best meets the EH&S needs of the end user.

Selection of cutting fluid is important not only to reduce cost and improve machining efficiency but also to reduce health and environmental hazards. Better understanding of the classification of cutting fluids is necessary. Process performance would be much more useful than chemical composition when selecting a fluid. Additionally, such factors as toxicity, flammability, acidity, compatibility with other elements of the machine tool, and ease of waste treatment are of critical concern. In order to reduce the environmental impact of cutting fluids, a better understanding of the role and function of cutting fluids is required. Research is needed to better classify fluids and understand which chemical constituents (e.g., oil concentration, emulsifiers, biocides, and anti-corrosive agents) are needed for various applications. Also to be considered is the interaction between cutting fluid and chips. The ultimate goal for research on this issue is the elimination of cutting fluids from the majority of machining processes.

Chapter-4

Effect of Cutting Fluids on Machinability

4.1 Introduction

For a long time, because of the limitations on the tool materials available, the use of cutting fluids was considered as an essential integral part of the machine tool system. All the ill effects associated with the use of cutting fluids were considered as a necessary evil i.e. as a price for improving productivity. Various methods were developed to minimize their adverse effects although progress was far less than desired. Cutting fluids were believed to increase tool life, decrease tool wear, decrease surface roughness, increase dimensional accuracy, decrease cutting force and decrease cutting temperature. But recent research says something different. From recent research and studies it is apparent that cutting fluids do the opposite i.g, decrease tool life, increase tool wear, increase surface roughness, decrease dimensional accuracy, increase cutting force and increase cutting temperature.

In a conventional machining operation, the tool removes material from the workpiece through direct contact. In general, wear due to adhesion, diffusion and oxidation are known to occur, but especially abrasion and attrition between the tool and the workpiece, as well as between the tool and the chip formed, for the case of machining of steel using carbide tools [Kannatey-

Asibu, 1987]. Tool wear thus occurs on these two surfaces and are called crater wear and flank wear respectively.

The application of coolant during a machining operation is believed to reduce tool wear [**Shaw, 1984**]. The cutting fluid acts as a lubricant as well as a coolant during the operation. It reduces the surface friction and temperatures on the tool-work and chip-tool interfaces. The coolant, when applied during a machining operation, can have a significant effect on the cutting temperatures and tool wear.

Chip formation is also affected when coolant is applied during a machining operation [**Shaw, 1984**]. The chip curl changes with the temperature gradient along the thickness of the chip. The direction from which the cutting fluid is applied is therefore a chip curl. Chip curl affects the size of the crater wear and edge. The application of coolant increases or reduces the chip curl, and also shifts the location of maximum crater depth. The combined effects of the size and location of maximum depth of the crater are essential in the investigation of the effect of coolant on tool wear.

In any machining process, heat is generated as a result of work done. The main source of heat are the work done: (a) in the plastic deformation of the layer being cut and (b) in overcoming friction on the chip-tool and work-tool interfaces. According to **Arshinov and Aleksev [1972]** observed that the chip removes a large percentage of the heat, the higher the cutting speed, the higher this percentage is. Removal of heat from the tool is vital because at high temperatures, the tool experiences a reduction in hardness and wear resistance.

Cutting fluids not only reduce heat evolution (by facilitating chip formation and reducing friction), but also absorbed and carry away part of the generated heat, thereby lowering the cutting temperature. Liquids delivered in an atomized state as an aerosol (mist lubrication) removes heat more effectively as compared with an ample flow of ordinary coolant.

During the cutting process, the chip and tool rake faces are in very close contact and the gap in between is only accessible to fluid particles of micron size [Boothroyd, 1981]. Thus the large fluid particles cannot penetrate this very narrow space.

However, when atomized (aerosol) coolant is directed at the tool cutting edge at very high pressure, significant temperature reduction can be expected. In addition to being able to reach inside the gap, these fluid particles remove heat more effectively by means of vaporization.

The application coolant can also cause a change in the distribution and location of the peak temperature region in the tool. This change is directly linked to the effect of coolant on chip curl and tool wear.

4.2 Effects of Cutting Fluids on Several Machining Parameters

The usual pattern and the parameters of wear that develop in cutting tools are schematically shown in Fig.4.1. Fig. 4.2 shows the growth in average flank wear, V_B , on the main cutting edge while machining AISI 1060 steel using two carbide inserts of different integrated chip breaker geometry under dry and wet machining (conventional cooling with 1:20 soluble oil). The gradual growth of V_B , the predominant parameter to ascertain expiry of tool life, observed under all the environments and for both the carbide inserts indicates steady machining without any premature tool failure by chipping, fracturing etc. establishing proper choice of domain of process parameters.

Fig.4.2 further reveals insignificant effect of conventionally applied cutting fluid on growth of tool wear as compared to dry machining for both the inserts undertaken. This may be attributed to ineffective coolant and lubrication action of conventional cutting fluids as supported by previous researchers [Shaw et al, 1951, Cassin and Boothroyd, 1965, Kitagawa et al., 1997].

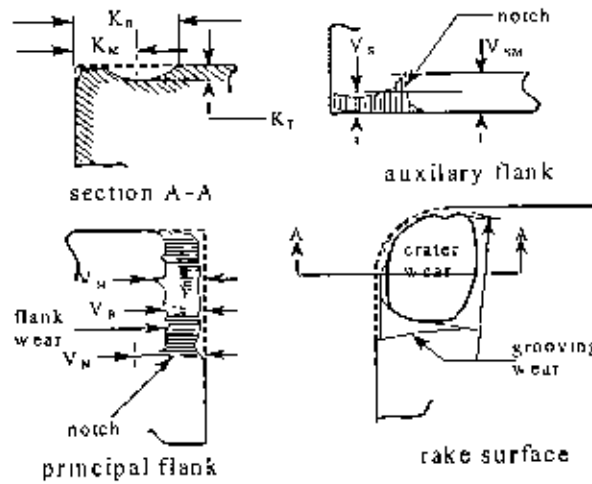


Fig. 4.1 Geometry of wear of turning tools.

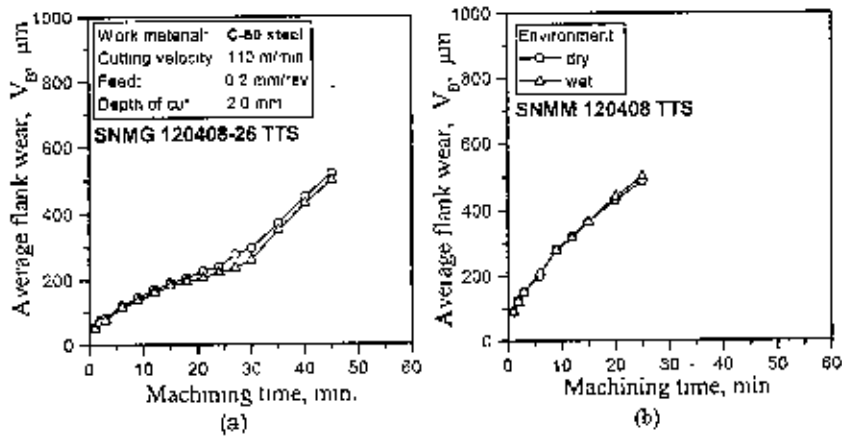


Fig. 4.2 Growth of average flank wear, V_B

Another important tool wear criteria is average auxiliary flank wear, V_S which governs the surface finish on the job as well as dimensional accuracy. Irregular and higher auxiliary flank wear leads to poor surface finish and dimensional inaccuracy [Dhar et al, 2000]. The growth of V_S has been depicted in Fig.4.3 under different environment. The nature of growth of V_S matches with that of V_B expectedly. The application of cutting fluid along the auxiliary cutting edge has increased V_S as compared to dry machining.

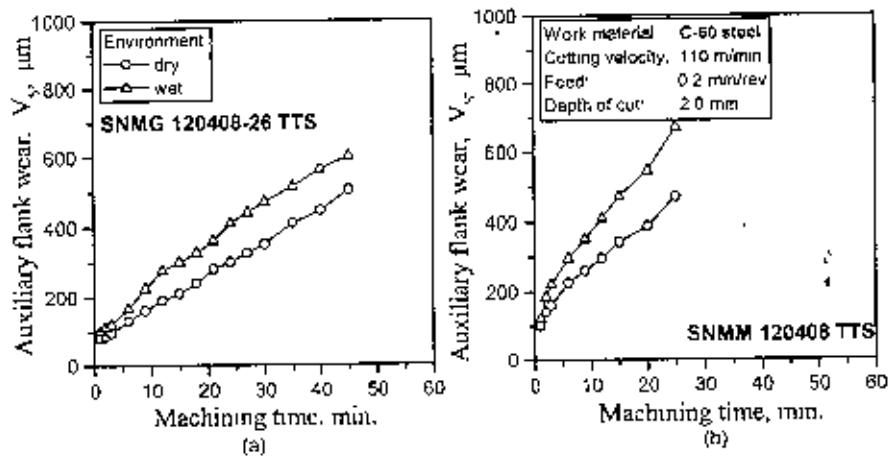


Fig. 4.3 Growth of auxiliary flank wear, V_s

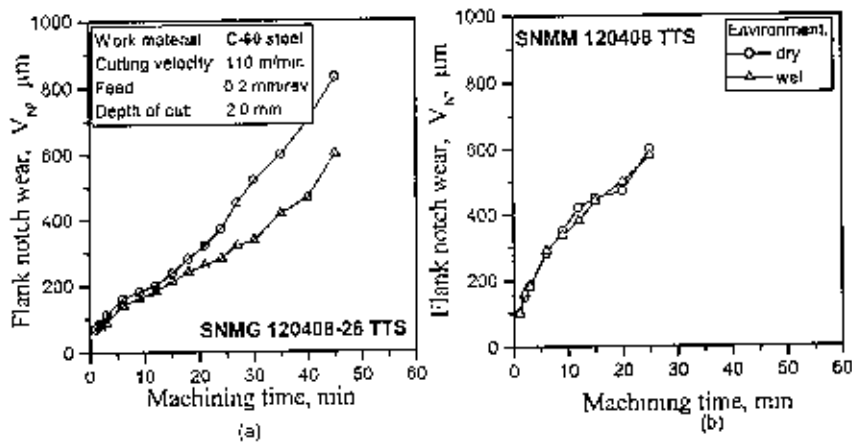


Fig. 4.4 Growth of flank notch wear, V_N

Both under dry and wet machining, severe groove wear and notch wear at the main cutting edge and auxiliary cutting edges were seen in the SNMG and SNMM inserts. The notch wear on main cutting edge develops mainly because of oxidation and chemical wear where the thermo-mechanical stress gradient is also very high. The notch wear on the auxiliary cutting edge develops mainly because of its interaction with the uncut ridges of the work surface and mechanism of this wear is abrasive. Fig. 4.4 reveals insignificant

effect of conventionally applied cutting fluid on growth of notch as compared to dry machining for both inserts undertaken.

The SEM views of the worn out (a) SNMG and (b) SNMM inserts after being used for about 45 minutes and 25 minutes of machining under dry and wet condition are shown in Fig.4.5 and Fig.4.6 respectively. Under all the environments and in both the inserts, abrasive scratch marks appeared in the flanks. The examination of the craters revealed deep scratches left by the backside of the chip on the rake surface of the tool. There has also been some indications of adhesive wear especially in the SNMM insert, which produced longer continuous chips as compared to SNMG which produced mainly broken chips. Some plastic deformation and micro chipping were found to occur under dry and wet machining.

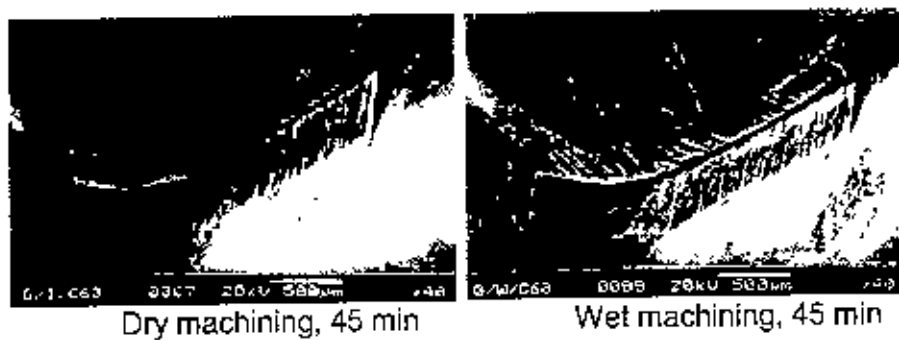


Fig.4. 5 SEM views of the worn out SNMM insert

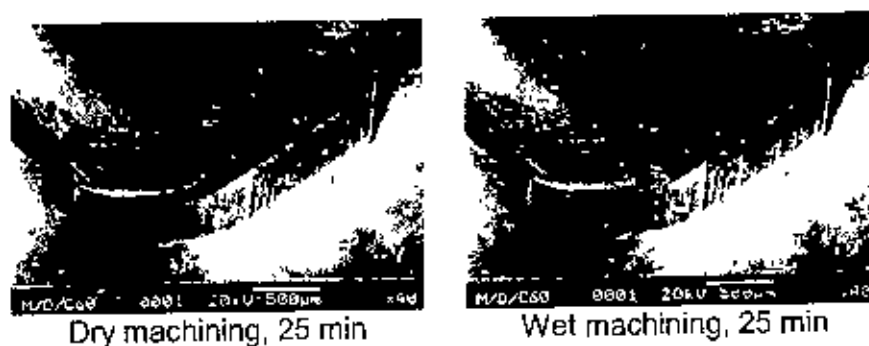


Fig. 4.6 SEM views of the worn out SNMM insert

Fig. 4.7 shows the variation in surface roughness with machining time for both the inserts under the two environments. Conventionally applied cutting

fluid did not reduce tool wear compared to dry machining. But the surface roughness deteriorated drastically under wet machining compared to dry, which may possible be attributed electrochemical interaction between insert and work piece [Ellis and Barrow, 1969].

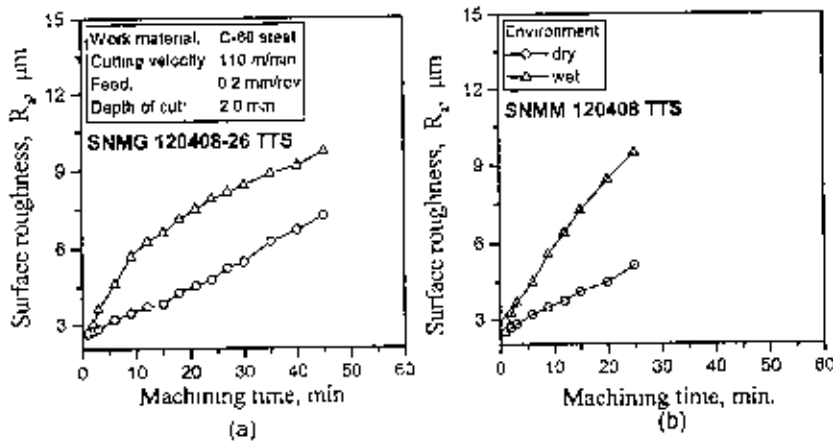


Fig. 4.7 Surface roughness, R_a developed during machining

The increase in maximum crater depth, K_T with machining time is shown in Fig.4.8. From this figure, the difference between the results from machining with and without coolant is quite apparent, especially after about 20 seconds of machining. The graphs showed that for any set of cutting conditions, the crater depth increased at a higher rate when coolant was applied for the period of cut below 60 seconds. After 60 seconds, however, for any set of cutting conditions, the graphs became parallel to each other. This showed that the crater wear in terms of depth grew at the same rate under conditions of cutting with and without coolant.

Fig.4.9 shows the variation of maximum crater width, K_B with machining time for different set of cutting condition. This figure shows that there is no significant difference between the case where coolant is used and that of dry cutting. Although it is quite apparent that with time, the use of coolant slightly increases the maximum crater width, the rates of growth of the maximum

crater width with and without coolant were the same, as indicated by the parallel lines, a trend also seen in Fig.4.8.

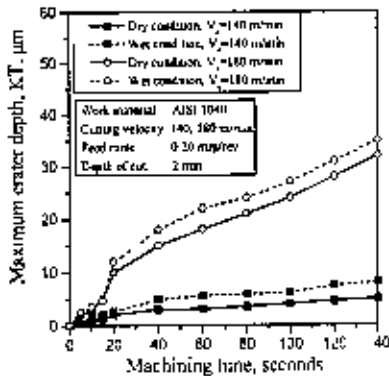


Fig. 4.8 Growth of maximum crater depth with

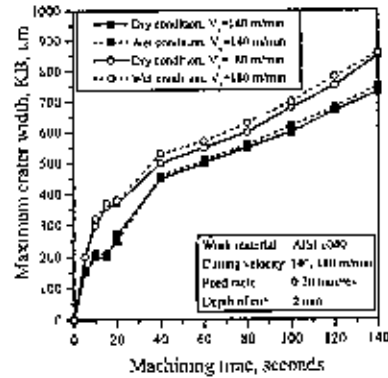


Fig. 4.9 Growth of the maximum crater

In Fig.4.10, the plots show that the maximum crater depth moved closer to the tool cutting point when coolant was applied. This result can also be interpreted as the entire crater depth shifted closer to the tool tip. However, after about 20 seconds of cutting, the deepest point of the crater was located further away from the tool cutting edge in the case when coolant was applied than in dry machining

This phenomenon does not necessarily indicate a reversal in the movement of the crater. Instead, it is interpreted as an indication of the increase in the width of the crater, which shifted the maximum crater depth position away from the tool cutting point. Thereafter, the location of the maximum crater depth was invariably further from the tool tip when coolant was applied than during dry machining.

The progression of the average flank wear, V_B with cutting time at different cutting velocity is shown in Fig.4.11. As in the earlier cases of crater depth and width, all the graphs representing cutting with coolant indicate a marked increase in growth rate over those cases for dry machining, for the period

between 20 to 60 seconds of machining. Beyond 60 seconds, however, the growth rates in the average flank wear were almost equal for cutting with and without coolant, as shown by the parallel lines for each set of cutting conditions

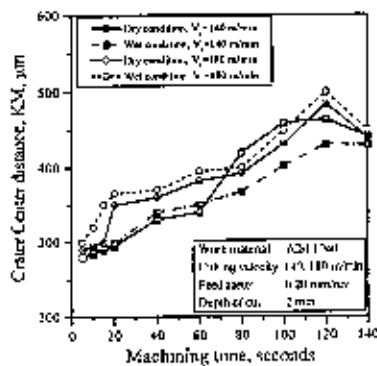


Fig. 4.10 Location of maximum crater depth

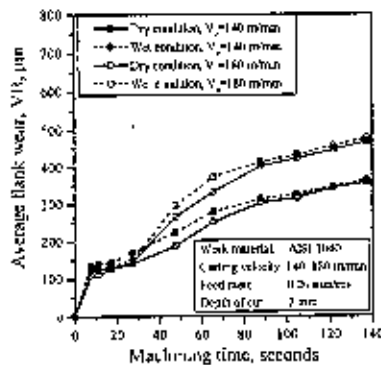


Fig. 4.11 Growth of average flank wear

The above results show that, contrary to popular belief, the application of coolant during machining does not necessarily reduce tool wear. In fact, it tends to aggravate tool wear for those cutting conditions used in the above experiments.

Chapter-5

Cutting Fluid Health Hazards

The development of population-prevention initiatives in the government section and heightened consumer focus on green (i.e., environmentally conscious) products has placed increased pressure on industry to minimize their waste streams. Particularly impacted is the metal working sector, which includes the automotive, aerospace and their supplier base industries. Machine tool builders and their customers represents a significant group within the metal working sector and are therefore faced with the same environmental pressures as other manufacturers. Ever more attention is being directed to such issues as the role of cutting fluids in machining, machine tool energy efficiency and the impact of process waste on the environment. These issues have traditionally been under-emphasized since they have rarely directly influenced product value. Now however, they must be examined because of their associated costs of disposal/treatment and their environmental, health and safety.

The increased environmental concerns of consumers and the government (both of the US and elsewhere) suggest that the machine tool builders and end users must focus on the development of environmentally conscious machine tool systems in order to remain competitive. The system, in this context, considers both the machine tool and the process(es) performed by the machine tool. The builders and users must acquire the knowledge necessary to minimize/eliminate the costs associated with environmental compliance.

5.1 Development of Cutting Fluids-Types & Uses

Cutting fluids have been used since automatic metalworking machines were introduced almost a century ago. They are used to quench the hot metal at the tip of the cutting tools and to wash away the metal filings. Of course, during the cutting much of the liquid splashes and forms a mist, thereby exposing operators of the machines to them. Cutting fluids (which are commonly called cutting oils or fluids) are expensive and are collected and recycled and often blended with other fluids, such as lubricating oils, before re-use. Thereby increasing the possibility of contamination with undetermined amounts of toxic materials.

Not only must cutting oils be sufficiently mobile to be sprayed on to the cutting tools, but they must carry away heat and they must prevent corrosion of the metal. The requirement for particular properties of the oils and more-or-less standard characteristics has resulted in a blending of the basic fluid with a number of additives including, for example, biocides which slow the growth of bacteria in those fluids that are substantially aqueous, this avoids fouling of the fluids, which are frequently used and re-used for 6 months or more.

In the beginning, cutting fluids were mineral oils, particularly shale oil obtained by destructive distillation of shale and later distillates of petroleum. From the earliest days, cutting oils were known to cause dermatitis and skin tumors (cancer) were related to exposure to cutting oils, including shale oil [Lea, 1955]; shale oils were gradually phased out. This so-called **mule-spinners cancer** was cancer of the scrotum caused by exposure to shale oil used as a lubricant on mule spindles since the middle of the 19th century. Later, cancer of the scrotum and of the hands and forearms was related to exposure to cutting oils, mainly mineral oils from petroleum more or less refined. It is very probable that polynuclear hydrocarbons in the cutting oils are the carcinogens mainly responsible for the human skin cancer associated with exposure to these oils.

As with coal tar pitch, the carcinogenic properties of cutting oils has been reproduced in experiments in animals, particularly in mice. Many types of mineral oil, including cutting oils, which contain carcinogenic polynuclear hydrocarbons, have induced skin cancer in mice when painted on their backs for a prolonged period [Berenblum & Shubik, 1947 and Thony et. al., 1975].

The tumors appear within the relatively short life span of the mouse (2 to 3 years), whereas humans develop skin cancer after decades of exposure to these materials. Of course, the experimental animals experience a much higher relative dose than do workers with exposure to cutting fluids, an invariable result when comparing human latent periods for cancer development in animal, carcinogenesis experiments. Many but not all, polynuclear hydrocarbons induced malignant skin tumors when painted on the backs of mice. The concentration of these compounds in petroleum is not high. But processing at high temperatures produces large quantities of polynuclear hydrocarbons containing five or six rings, among which are found the most potent carcinogens [Thony, C. Thony and Lafontaine et. al., 1975]

Partly because of the carcinogenic properties of cutting fluids in the 1940's there were introduced **synthetic and semi-synthetic** cutting oils, which contained less mineral oil or no mineral oil, but contained many additives, including chlorinated paraffins, to provide the necessary physical properties. These oils were favored for high-speed operations. Another later improvement were **soluble cutting oils**, which contained mineral oil, fats, emulsifiers and additives in a water emulsion. Use of the aqueous emulsion required addition of a corrosion inhibitor, typically sodium nitrite, which introduced a different hazard, formation of nitrosamines through interaction with amines. In the 1970's [Keefer, L.K and Roller et. al., 1973], it was discovered that water-based cutting oils contained substantial quantities of N-nitrosodiethanolamine, which is a member of the class of potent carcinogens called N-nitroso compounds. Although not the most potent of these carcinogens, nitrosodiethanolamine has induced tumors of many organs

when administered to experimental animals [Lijinsky, W & Kovatch, 1985 and Lijinsky et. al., 1981]. Concentrations as high as 3% of nitrosodiethanolamine have been measured in undiluted cutting oils. Other nitrosamines, including a nitrosomethylloxazolidine and nitrosodiisopropanolamine (an inducer of pancreas cancer in hamsters) have also been reported: these are carcinogenic and more potent than nitrosodiethanolamine [Farely, Thomas and Lijinsky, 1987].

Contamination of cutting oils with nitrosamines is a serious hazard [Lijinsky, and Epstein, 1970]. Since the latter are easily absorbed through the skin and exert their carcinogenic effect systemically. Recently, therefore, nitrites have been largely eliminated from cutting fluids and other non-nitrosating corrosion inhibitors have been introduced: the toxic properties of these substitutes have not always been determined. Mineral oils from which most of the carcinogenic polynuclear hydrocarbons have been removed by the solvent extraction are now widely used and certainly reduced human exposure to carcinogens from this source [Thony, C. Thony and Lafontaine et. al., 1975]. Moreover, modern water-based cutting fluids are not entirely free of carcinogenic risk because nitrosamines have been found in some fluids formulate without nitrite. In these cases nitrosation might have been come about through contact of the amines in the fluids with nitrite used rust preventive on the lining of a steel container, or through reaction of the amines with nitrogen oxides in air that contains burnt fuel vapors.

Water-based cutting fluids present other possible health risks. Because cutting fluids are recycled for many months and contain a variety of additives, including so-called cutting compounds containing sulfur or chlorine, bacteria of various kinds built up in them leading to increasing malodor [Ding & Hong, 1998 and Hong et. al., 1999]. Even after filtering to remove metal filings and cuttings, the consistency of the fluids often changes because of chemical and bacterial actions. To suppress bacterial growth a variety of biocides are added, Many of these biocides are themselves toxic and some have not been adequately tested and might be carcinogenic. In addition, some biocides are

nitrogen compounds which might be nitrosating agents, which can give rise to nitrosodiethanolamine and other nitrosamines by reaction with amines in the fluids. Furthermore, some bacteriocides are formaldehyde releasers: formaldehyde facilitates formation of nitrosamines, particularly in alkaline solution [Keefer and Roller 1973] and participates in the formation of nitrosooxazolidines. Formaldehyde itself is carcinogenic to rats by inhalation (and potential to humans) but has not caused tumors when ingested or applied in solution to the skin.

Such information suggested strongly that, until recently, operators of machines in which cutting fluids were used, were exposed to a variety of toxic and carcinogenic agents. Those with longest exposures are the most likely to develop tumors, but there were undoubtedly large differences between fluids in their carcinogenic effectiveness, depending on individual composition, recycling, storage conditions, use and other factors. While the health risk from current exposures might be low (but not absent), insufficient time has elapsed since the phasing out of the more egregiously carcinogen-contaminated fluids for the risk of cancer among long-time workers to be much reduced.

5.2 Adverse Health Effects

The earliest reported health effects following exposure to cutting fluids were skin disorders, dermatitis, hyperkeratosis and infrequently, skin tumors including cancer. Before the common use of petroleum-derived oils, shale oil was the common lubricant and skin disorders were associated with worker exposure to it [Lea, 1955]. The effects of these oils in humans was reproduced by the formation of skin tumors in mice following the formation of skin tumors in mice following repeated application of lubricating oils to the skin. In similar experiments showed that many of a large numbers of petroleum-derived oils were carcinogenic. Later it was discovered that the carcinogenic agents in the oils were the same group of compounds, polynuclear hydrocarbons that were responsible for skin cancer induction by coal tar. More recent studies with cutting fluids showed that paraffin-based

oils induced skin tumors (mainly papillomas) when painted on the backs of mice, whereas a soluble oil did not: there were also toxic effects in the livers of mice treated with paraffinic oils. There are few helpful results of analysis of cutting fluids for carcinogenic polynuclear hydrocarbons [Thony, C. Thony and Lafontaine et. al., 1975]: for example, use an indirect method which approximates benzo(a)pyrene content. Cutting oils are unlikely to be very different in their polynuclear hydrocarbon content from other heavy petroleum oils: after use, especially in diesel engines, the polynuclear hydrocarbon content is considerably increased [Grimmer, Jacob and Naujack et. al., 1981].

Since beginning of twentieth century people [Peter, Steven & David, 1996 and Kennedy et. al., 1989], were concerned with possible harmful effects of carious cutting fluid application.

Many reports have been published from several countries of the occurrence of skin lesions, including cancers, in workers exposed to cutting fluids for prolonged periods [Bennett, 1981], cancers appearing as long as 25 years after the beginning of exposure [Bennett, E.O and Bennett D.L, 1985]; cases are still being reported. Malignant melanoma has been related to exposure to cutting oils and other mineral oils in the UK; melanoma has been rarely caused in experimental animals (mice and hamsters) painted on the skin with polynuclear hydrocarbons in solution and some of these carcinogens have been found in mineral oils [Berenblum & Shubik, 1947]

There are many fewer studies and much weaker epidemiological evidence implicating cutting fluids in the causation of other human cancers. A substantial number of these studies were without Substantial number of these studies was without significant results Among the human cancers other than those of the skin which have been linked with exposure to cutting fluids have been those of lung, urinary bladder, prostate, pancreas and sino-nasal cancer [Bennett, E.O and Bennett D.L, 1985]. Huge numbers of machinists work in automobile factories and this provides large populations of

people; exposed to cutting fluids for epidemiological studies, many of which have been conducted in the US factories with their long history of continuous vehicle manufacture. However, results are seldom clear-cut and are often conflicting.

A recent study [Lijinky 1999] in a survey of 30,000 workers found an association between exposure to straight cutting fluids and death from rectal cancer and to cancer of the larynx; there were slight elevations in deaths from cancer of the prostate, esophagus and pancreas, but no connection with lung cancer; stomach cancer only, but no other cancer, was slightly elevated among workers exposed to soluble cutting oils, unlike some areas of the petroleum industry, there was no significant elevation of brain tumors among workers exposed to cutting fluids. In a review of occupationally-related urinary bladder cancer, somewhat increased risks among workers with cutting fluids, but this finding is diminished in importance by the authors' statement that non-occupational confounding is a problem in the analysis.

A Canadian study [Lijinky 1999] among 3700 cancer patients who were exposed to 12 types of petroleum-derived fluids, of which one was cutting fluids, showed that exposure to the latter was associated with excess cancer of the urinary bladder. Of 388 people with bladder cancer who were exposed to various amounts of cutting oils for various times, 3.7% were machinists, 14% were plumbers and pipe fitters and 18% shaped metal or fabricated aircraft. This analysis indicated a weaker association between exposure to cutting oils and other mineral oils with an increased incidence of lung cancer, but no association with stomach cancer. A smaller scale study from France shows a similar association between bladder cancer incidence and exposure among workers to cutting fluids, especially when exposure began before age 20. Another study from England based on a job exposure matrix indicated an association with cancer of the bronchus, the latter with no apparent dose-response.

Sino-nasal cancer has been associated with exposure to cutting fluids in a case-control study in Connecticut, based on death certificates of workers who died between 1953 and 1975. There was a particularly strong correlation in the case of workers older than 68 at death. No doubt inhalation of cutting oil mist was the cause of the cancers; nitrosamines, including nitrosodiethanolamine found in some cutting fluids, have induced tumors of the nasal cavity in rats, mice and hamsters, often by ingestion as well as by inhalation [Lijinsky 1992].

5.3 Formation of Contaminants During use of Cutting Fluids

The risk of formation of carcinogenic contaminants during storage is important only in relation to nitrosamines. The processes by which nitrosamines are formed in the alkaline medium of water-based cutting fluids are slow, whether from nitrite in the fluids, as a lining of the cans in which they are stored or from nitrogen oxides in the air. Although the yields of nitrosamines will be higher because of the higher concentrations of reactants in the undiluted fluid, compared with the material after dilution with water, the nitrosamine contamination will become severe only after prolonged storage. Recycling with addition of more reactants will increase the problem.

The biggest problem with straight cutting oils is the heat created at the tip of the cutting tool, which can possibly be high enough to cause pyrolysis and formation of polynuclear hydrocarbons. The extent to which this takes place is not clear, but studies of cutting fluids after re-use has shown an increase in the content of carcinogenic hydrocarbons. The matter is somewhat confused because the fluids studied have been recycled and reformulated before examination. Certainly, in the case of engine oil the content of polynuclear hydrocarbons has been shown to increase after use [Grimmer, Jacob and Naujack et. al., 1981] but the temperatures in an engine are presumably higher than in metal-working; the formation of the larger polynuclear hydrocarbons increases enormously at high temperatures compared with those somewhat lower [Lijinsky and Raha, 1961]

Information about reformulation of cutting fluids is fragmentary and somewhat anecdotal. It is said that most cutting fluids are recycled (for economic reasons) and that biocides are repeatedly added to water-based fluids to suppress bacterial growth.

Frequently unspecified materials, such as old lubricating oil are added to recycled cutting fluids, thereby adding substances of unknown toxicity, such as PCB's. The manufacturers would undoubtedly prefer that fresh fluid be used each time, but it is probable that in most machine shops workers do not know the composition of the fluids with which they work.

There seems to be little concern for the safety of recycled cutting fluids. It might be that neither workers nor managers care to know about the possible risks. The lack of control is shown by the presence of nitrosamines at considerable concentrations as well as nitrite in cutting fluids in Canada as recently as 1990 [Lijinky 1999], despite recommendations 10 years earlier that the use of nitrite in these fluids should be abandoned for health reasons. It might be that the consequences of ignoring safety standards for cutting fluids will not be discerned by increases in cancer rates for many years (because of the long latent periods), or perhaps will never be known because the additional cases will be submerged in other statistics.

5.4 Risk Assessment

It is difficult to compare the various health risks in exposure to cutting fluids because of the lack of adequate standards for the materials used. Because of the proprietary nature of most of the fluids, which merely have to satisfy standards of physical and (sometimes) aesthetic qualities, it is not possible to compare exposure between factories and across long periods of time, possibly decades. Manufacturers change their formulations and factories change their suppliers. It is possible that the manufacturers do not know accurately what is in their materials. Variations in recycling and reformulation,

coupled with sound or unsatisfactory practices in different machine shops, makes it very difficult to draw reliable conclusion about health effects related to chemical composition of cutting fluids.

Broad and tentative conclusions are that carcinogenic effects related to cutting fluids are not very large, considering the great number of workers engaged in machining. The most noticeable effects seem to be on the skin, the tumors being most likely related to polynuclear compounds in the petroleum-derived oils.

The relation of inhalation of oil mists to lung cancer is not well established. On the other hand, cancers of the stomach, rectum and bladder are more likely to be associated with water-based cutting fluids, either inhaled as mists or splashed on the skin resulting in absorption of the carcinogenic materials. It seems obvious that use of more standardized materials, free as far as possible from carcinogens or their precursors, to formulate the cutting fluids, and taking care to recycle and reformulate only with well characterized additives, will reduce whatever health risks presently prevail.

5.5 Different Diseases Caused by Cutting Fluids

In general respiratory irritation involves some type of chemical interaction between the cutting fluid and the cells that are part of the human respiratory system. These cells can be part of one or more of the following areas: nose, throat (pharynx, larynx), the various conducting airways or tubes (trachea, bronchi, bronchioles), and the lung cells (alveoli). Some examples of respiratory diseases are,

Asthma: This is a common respiratory disease in the general population. Some studies show that asthma may be associated with exposure to cutting fluids. Asthma is an allergic disease of the large airways in the lung. During an asthmatic attack the airways are narrowed, and it is more difficult to get air in and out of the lung. It is unclear whether exposure to in-use cutting fluids

causes asthmatic reactions or the development of asthma in workers without a history of asthma.

Chronic bronchitis: This is a clinical disorder involving the mucus-secreting cells of the large airways. Chronic bronchitis is characterized by chronic productive cough and inflammation. The inflammation is, by definition, chronic. With inflammation comes an excessive production of mucus. The mucus can interfere with air passage into and out of the lungs. As in asthma, particular cutting fluid ingredients or contaminants may cause this condition.

Hypersensitive pneumonitis: This is a rare allergic inflammatory disease of the deep lung. At first symptoms are like those of the flu; however, in some cases it can lead to serious long-term effects.

There are no identified causes of respiratory effects in the cutting fluid environment. Most investigations have focused on irritant chemicals, microbiological contaminants of water-based fluids, and airborne particles as likely causes. To reduce or prevent respiratory effects of in-use cutting fluids we should focus on improving fluid management or reducing aerosol generation:

- Select an appropriate cutting fluid for the operation that does not contain highly irritating components and that will minimize aerosol generation.
- Maintain the fluid properly by monitoring concentration, removing contaminants and controlling microbial growth in water-based fluids. Excessive concentration of tramp oil can increase aerosol generation and minimize mist generation by proper fluid application.
- Maintain cutting fluid delivery systems, including pumps and seals, to minimize aerosol generation. Introduction of air into the fluid through leaking pump seals or inlet lines will increase mist generation.
- Maintain existing machine enclosures and guarding to minimize release of cutting fluid aerosols, restore/ replace missing enclosures and

properly maintain mist collectors and exhaust ductwork leading from machine enclosures.

- Optimize machine tool feeds and speeds to achieve the desired machining performance while minimizing aerosol generation and minimize fluid flow rates, consistent with the desired machine performance.
- Reduce fluid pressure consistent with machine performance and avoid use of compressed air probes or blow off.
- Provide adequate outside air through the general ventilation system and discourage smoking in the MRF environment. Employers should assist workers who want to stop smoking.
- Employees with symptoms of respiratory irritation or other effects should seek medical treatment.

Dermatitis: This is an inflammatory response of skin. Typical signs of dermatitis include, redness of skin, swelling, etching, small blisters etc. In more severe cases, fissures (deep cracks) and ulcers (open sores) may develop. The condition is usually reversible when a person is no longer exposed to the conditions causing dermatitis. A prime cause of dermatitis (and respiratory system complaints; see below) is poor management or maintenance of cutting fluid systems. If the cutting fluid is not monitored closely for contaminants, alkalinity, concentration, and so on, the risk of developing dermatitis increases.

- In the case of oil-based systems, water must be considered a contaminant. Water can dissolve the additives in the cutting fluid and form dilute acids. These acids then become the irritants in the oil-based system. They become concentrated as time goes on and are carried by the oil.
- Tramp oil, which often contaminates the in-use cutting fluid, is one of the main causes of dermatitis. These materials are not developed with repeated skin contact in mind. Some components of these machine lubricants are highly irritating to the skin. Unemulsified tramp oil can

also be a significant carrier of aluminum fines, which aggravates the problem further.

- Bacteria in water-containing metal removal fluids do not cause dermatitis, but may aggravate the situation and cause a secondary infection. Proper maintenance and cleaning of cutting fluid system and especially the sumps can reduce the incidence of dermatitis and respiratory problems reported by employees.
- Some people may develop allergic contact dermatitis from fluid exposure because they are especially sensitive to one or more of the fluid's components.

The dermatitis may be one of two kinds: irritant contact dermatitis or allergic contact dermatitis.

Irritant contact dermatitis, as its name suggests, is dermatitis caused by contact of the skin with some irritant. In machining or grinding operations, it may be caused by any of several possibilities or combination of factors, such as:

- Higher-than-recommended metal removal fluid concentration.
- High alkalinity of in-use fluid which can remove natural skin oils.
- Metal processing aids such as degreasers, cleaners, or rust inhibitors.
- Metal shavings or fines contained in the fluid, which may abrade the skin.
- Prolonged contact with the cutting fluid.
- Tramp oils (e.g., hydraulic fluids, gear or spindle oils, way lubes, and grease).
- Hand washing with abrasive soaps or with water that is excessively hot or cold seasonal conditions (e.g., winter dryness).
- Other contaminants (e.g., water in an oil-based system).
- The longer the exposure to an irritant, the greater the possibility for skin irritation to develop. Activities outside work, (e.g., gardening, painting,

car repair, or household chores), may cause, or contribute to, dermatitis through contact with consumer and household products.

Allergic contact dermatitis is an immune system response that arises in some people who are allergic to a contaminant or ingredient in the cutting fluids, such as metal contaminants (such as chromium, cobalt, or nickel) and some biocides or odorants.

Minimizing contact with the irritant can prevent dermatitis, but this is not always possible. Since excellent manual dexterity is often required of machinists, some personal protective equipment, such as gloves, may not be appropriate for some operations and may even be a serious safety hazard with other operations, such as those using rotating equipment. The employer may specify operations for which gloves are permitted. If used, gloves should not allow fluid to penetrate. Disposable or washable inner gloves may also be considered to eliminate perspiration. If fluid is retained in gloves, the employee should wash exposed skin with warm water and a mild hand cleaner and gently but thoroughly dry. The used gloves should then be disposed of and new ones worn. The use of good quality barrier creams on exposed skin areas can offer protection against the development of dermatitis if used consistently and re-applied as necessary throughout the shift. The following steps will help to prevent irritant dermatitis:

- Where possible, avoid contact with cutting fluid, fluid residues, and soaked rags or clothing and maintain cutting fluid concentration within manufacturer's recommendations. High concentrations can and do cause dermatitis.
- Cutting fluid residues should not be allowed to accumulate and control cutting fluid contamination.
- Clothing and rags should be cleaned as needed. Shop rags should be free of abrasive dirt, metal fines and contaminant chemicals and correct fluid flow rates and adequate splashguards should be used.

- If contact cannot be avoided, an impervious apron and gloves made of a material such as nitrile or PVC should be considered. Disposable or washable inner gloves should also be considered to eliminate perspiration. Great caution must be exercised when using gloves around rotating or moving machinery.
- Gloves, where used, should be changed routinely, especially when wet internally. Gloves should be checked periodically for cuts tears and leaks. At a minimum, this should be done at the beginning of each shift.
- Barrier creams may be applied to exposed skin areas where protective clothing is not possible. To be effective, these creams must be periodically reapplied during the shift. Note: barrier creams are a preventive measure and not a treatment for dermatitis. They should be applied only to healthy skin. Consult a physician prior to using a barrier cream on skin that is being treated with a topical medication.
- Avoid the use of solvents that remove natural oils and cause dry skin, which is more susceptible to irritation and infection.
- At each break, before eating, smoking a cigarette, or going to the toilet, exposed skin should be washed with a mild gel-type hand cleaner or a mild non-abrasive soap, using warm water and drying gently but thoroughly.
- Observance of good personal hygiene should be made part of established shop practices and special precautions must be taken if exposed skin is broken.

If dermatitis occurs, employees should seek medical treatment. Dermatitis should not be considered an expected or acceptable part of the job

Cancer: Scientists and health professionals continue to debate how to interpret the results of the many studies and the significance of the reported findings about the role of cutting fluid in cancer. Studies of workers, using fluids that are no longer manufactured, reported weak associations between fluid exposure and cancer. These fluid formulations were used before the mid-1970s and are now obsolete. Since that time, the impurities suspected of

being carcinogens in metal removal fluids have been removed, and worker exposure has been significantly lowered.

Substantial evidence exists for increased risk of cancer at several sites (larynx, rectum, pancreas, skin, scrotum, and bladder) among workers exposed to cutting fluids before the mid-1970s. The evidence is equivocal for an association between cutting fluid exposure and cancer at several other sites, including the stomach, esophagus, lung, prostate, brain, colon, and hematopoietic system

Over the last several decades, substantial changes have been made in the metalworking industry, including changes in cutting fluid composition, reduction of impurities, and reduction of exposure concentrations. These changes have likely reduced the cancer risks. NIOSH further notes that there is not enough data to conclude that these changes have eliminated all carcinogenic risks.

In summary, there are many millions of pounds of cutting fluids used each year. The composition of these fluids is irregular, the objective being to achieve certain physical properties appropriate to the task. Mineral oil based fluids are relatively simple in composition, with various materials like sulfur, vegetable oils, chlorinated paraffin added for hardness. Water-based fluids may contain mineral oil but they are complex mixtures designed for high-speed machining, the water being needed for cooling of the cutting tools. The aqueous fluids contain emulsifiers, corrosion inhibitors, bactericides and other components, which are perhaps innocuous, but can interact or change to form toxic and carcinogenic products, particularly after protracted use or storage. Control of these materials to protect the health of exposed employees is uncommon and difficult, although some less than adequate epidemiological studies indicate an association with cancer of the gastrointestinal tract, urinary bladder, skin, possibly lung and pancreas.

Chapter-6

Conclusions

Implementing an effective fluid management program may extend cutting fluid life significantly. 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.

Proper management of cutting 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. Some of the major conclusions are presented below:

- If cutting fluids are to be used safely and effectively, a written management plan should be in place. Such a plan should specifically identify key elements of the program and the individual(s) responsible for their implementation. Managing cutting fluids well requires that all factors be considered in a systematic way. The management program should include a health and safety plan for workers, as well.
- There are obvious costs associated with the maintenance of a fluid system and the best way to minimize these costs is to increase the service lives of cutting fluids by proper management program.

- Proper selection of cutting fluids is important for the following reasons: to improve productivity and quality of work, to increase tool life, to choose the proper cutting fluid from huge number of cutting fluids, to reduce cost, to avoid health and environmental hazards and ensure safety. Physical characteristics, compatibility, process performance, machine tools, machining operation, cost performance, supplier performance, environmental performance, health hazard performance etc are some major selection criteria of cutting fluids.
- The awareness of the rules and regulations affecting the use and disposal of cutting fluids is helpful for choosing the right fluid that meets the necessary standards and thereby avoiding unnecessary cost of liabilities.
- The key to extending fluid usefulness is proper fluid maintenance. To maintain a fluid it must be monitored to predict or anticipate problems. In order to determine the condition of the cutting fluid, it is necessary to test various aspects of the fluid. So it is important what tests are to be performed and when and how. Monitoring is only the first step in fluid maintenance. It must be followed with a regular program of maintenance to keep the fluid in the best possible condition. In addition, the metal removal process performance itself must be monitored to make sure the fluid is doing what it's meant to do.
- The application of coolant does not necessarily reduce tool wear as is commonly believed. Under some specific conditions, the use of coolant apparently increases tool wear. Dry machining of steel caused maximum tool wear and surface roughness and wet machining did not show appreciable improvement. The cutting fluid was found to have a negative effect on flank wear, albeit it's cooling action. In spite of their cooling action the cutting fluid was found to accelerate the groove wear on the trailing edge, particularly at low feeds. This effect was found to be related primarily to the relative corrosiveness of the fluids. Under

finishing conditions, tool life can decrease with the cutting fluid due to the accelerated groove wear on the trailing edge.

- Various diseases ranging from dermatitis, respiratory disease such as asthma, pneumonia, bronchitis to cancers at various sites such as larynx, rectum, pancreas, skin, scrotum, and bladder can be caused by cutting fluids
- In Bangladesh, most of the manufacturing shops are using water base soluble oil as a cutting fluid in different machining operations. They have a lack of knowledge on selection of appropriate cutting fluid and their usage. Operators are working in manufacturing shops without any precautionary measure and they are being exposed to cutting fluid through skin and respiratory system. It can cause serious health hazards to operators. Proper selection and management of cutting fluids can minimize these risks of health hazardous. Special technique of machining processes (like dry machining, cryogenic machining, hot machining etc.) is the alternative way of avoiding cutting fluids during machining.

Chapter-7

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