To Compare Technologies for Treatment of Different Types of Metal Cutting Fluid

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Abstract— Metal Cutting Fluid is a type of fluid used in metal processing industries for stamping, drilling cutting and as lubricant and coolant. The different method used for the treatment for metal cutting fluid wastewater are chemical methods, AOPs, emulsion breakdown method and other combined methods, sono-fenton method, acoustic oxidation, ultrasonication-fenton oxidation process. The Aim of this work is to evaluate the use of electrolytes (NaCl and CaCl2) in the breakdown of Metal Cutting Fluid (MCFs) emulsion for the extraction of recovered phase. In addition, the aim of this study is to reduce the COD of waste generated after extraction. For the removal of COD by using FENTON's process was used on the metal cutting fluid after extracting was synthetic metal cutting fluid and mineral metal cutting fluid. Two metal cutting fluids were used to evaluate the comparison by different methods: 1) Synthetic cutting fluid (water-in-oil) and Mineral oils, all the MCF's collected in the emulsified form. 2) In this study technologies used for recovery of waste oil are by using Electrolytes and followed by Fenton's process for removal of COD.

Keywords: Metal Cutting Fluid, Synthetic cutting fluid

I. INTRODUCTION

Metal Cutting Fluids are the type of fluids used in the metal processing industry, stamping, drilling cutting any many other processes. With increase in manufacturing industries, there is demand in growing for low cost, high productivity and good product quality. Good Productivity is inherently associated with high cutting speed, feed rate and depth of cut, which lead to large amount of heat and raise in temperature at cutting zone. The main functions of cutting fluids are cooling, lubrication, removing chips and metals from the tool/work piece interface, flushing, prevention of corrosion.

Cutting fluids are used in machine shops to improve the life and function of cutting tools. They act as a key factor in the machine shop productivity and the production of good quality machine parts. The attention is mainly concentrated on improving of working conditions, reducing the health danger for machine operators, and application of new manufacturing procedures, material and technologies.

II. TYPES OF METAL CUTTING FLUIDS

There are now several types of metal cutting fluids available in the market, the most common of which are used broadly categorized as cutting oils or water- miscible fluids, water miscible fluids, including soluble oils, synthetics, and semi-synthetics, are now used in approximately 80 to 90 % of all applications.

Although straight cutting oils are less popular than they were in the past, they are still the fluid of choice for certain metal-working applications. Cutting fluids can be divided into two categories i) water-based fluids –including straight oils and soluble oils, ii) oil-based fluids –including synthetic and semi-synthetics. When used in machine processes, these emulsions lose its properties and effectiveness due to the thermal degradation and contamination. The replacement of these emulsions is responsible for the production of oily wastewaters.

Residual fluids have high concentration of carcinogenic potential due to presence of products derived from degradation of additives, polycyclic aromatic hydrocarbon (PHA), nitrosamines among others. The other substances which are formed due to degradation of cutting fluid are foreign bodies and microorganisms. It is essential to treat the cutting fluid wastewaters before its disposal in environment considering the risk presented and the presence of strict environmental regulations.

The Metal Cutting Fluid is not modified with its use, making possible to recycle it several times by replacing the missing additives. Considering the poor biodegradability of the recovered oil phase, recycling is the best alternative to address these threatening residues. The reuse of the recovered oil phase in new cutting fluids prevents its disposal or burning and reduces the extraction of non-renewable resources for the production of new ones.

Because of the stability of these emulsions there is not universal solution for their treatment and sometimes it is necessary to combine one or more process to have a good effectiveness purification.

Fig. 1: Metal Cutting Fluid

III. HISTORY OF METAL CUTTING FLUID

Cutting fluid is an important supporting material for metal cutting. In 1775 John Wilkinson (J. wilkinson) successfully developed order processing Watt steam engine cylinder boring machine from the beginning, along with water and oil in metal cutting. 1860 after a lengthy development car, milling, planing, grinding, gear cutting and thread processing a variety of machine tools have appeared, and also marks the cutting fluid to begin large-scale applications.

In the 1880s, American scientists had first evaluation of cutting fluid. F · W · Taylor and clarifies the cutting speed can increase by 30% to 40% aqueous sodium carbonate solution using a pump supplying phenomena and mechanisms. Cutting fluid also suggests the word "coolant", Since then, the cutting fluid is referred to as a cooling and lubricating fluid. Earlier animal and vegetable oil were used as cutting fluid. In the beginning of the 20th century, people began using lubricating oil, refined from crude oil and invented the performance lubrication additives. After World War I, people began to study and synthesis of composite oil with mineral oil, animal and vegetable oils. In 1924, sulfur, ne patented cutting oil and applied to heavy cutting, broaching, thread and gear processing. Due to increase in cutting speed and temperature of steel improvement of cutting fluid were made with time. In 1915 the production of water-in-oil type emulsion, and in 1920 became the preferred cutting fluid for heavy cutting.

The first oil-free synthetic cutting fluid was developed in 1948 in UNITED STATES. Over the last decade, due to the cutting technology continues to improve, advanced cutting machine tools continue to emerge, the tool and the work piece material development, and promote the development of cutting fluid technology. With the in-depth development of state-of-the-art manufacturing technology and the strengthening of the people's awareness of environmental protection, the new requirements of the cutting fluid technology, it will certainly promote cutting fluid technology to the development of the higher realms.

IV. NEED OF THE STUDY

Oil-droplets of Metal cutting fluids is difficult to treat biologically, chemically and by conventional processes because it requires high temperature and pressure with high treatment cost. Cutting oil contained in metal processing wastewater has high COD content level which causes severe problems. Available technologies like Evaporation and Reverse osmosis methods creates blocking of membranes and high cost for treatment of cutting oil wastewater with high energy requirement. There have been many health problems reported among the workers who were exposed to MCF's. Based on the literature review done shows that elevated respiratory diseases, digestive and skin cancer in exposed populations and increased rates of cough and phlegm were seen.

There are many treatment technologies which do not encourage the reuse and recycling of the MCF's. Keeping in mind the scenario of the oily wastewater treatment, there is a need to adopt the advanced treatment technologies over the conventional treatment technologies. To avoid above problems, it is required to determine efficient & economical methods to treat Metal Cutting Fluids (MCFs).

V. CLASSIFICATION OF CUTTING FLUIDS:

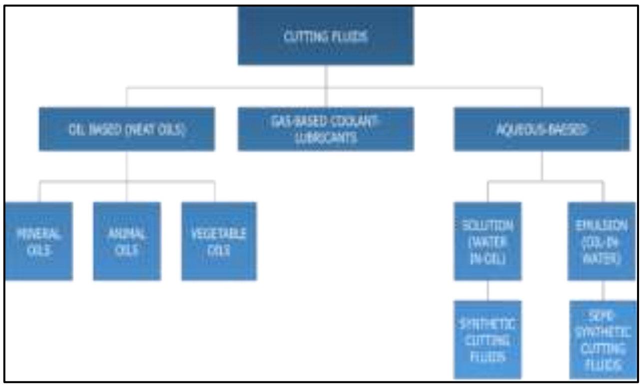

Fig. 2: Classification of cutting fluids

A. Oil-based cutting fluids

An oil based lubricant (neat oils) is derived from mineral, animal, vegetable, and synthetic oils. Mineral oils (petroleum based) are the major type due to their desirable lubricating characteristics. These cutting fluids usually contain some additives oil enhance their applications. For instance, the characteristics of naphthenic mineral oils and paraffinic mineral oils are usually enhanced through the addition of fatty lubricants, extreme pressure additives, odorants, thickness modifiers, and polar additives. Mineral-based are used to lubricate the tool-chip interface and consequently minimize the friction and friction induced heat at the cutting zone. As a result, low cutting forces are required to reduce the crater wear on the tool rake face. Besides, it is useful in lubricating the moving part of the machining tool, as it prevents corrosion on the machined surface and machine tool.

The advantage of neat oil lubricants is that are excellent in lubrication, anti-seizure, and corrosion resistance. However, their main disadvantage is the high flammability as they are good in lubrication but poor when machining in higher load and temperatures, resulting in mist and smoke.

Hence, neat oil lubricants are used principally for low-speed operations where temperature rise is not significant. Chemical additives such as Sulphur, chlorine, and phosphorous are always added in neat oil lubricant to form thin solid salt layer on the hot and clean metal surfaces. This extreme pressure film reduces the friction between chip and tool in metal cutting effectively.

B. Aqueous-Based Cutting Fluids

Usually, the aqueous-based products are provided in a concentrated form which must be mixed with water to the desired concentration prior to use. Once this aqueous-based product is mixed with water, the "emulsifiable" form an emulsion, while the "soluble" type forms a solution. The emulsion is formed by blending oil (usually mineral oil) in water with an emulsifying agent at a typical ratio of water to oil 30:1. The function of emulsifier is to disperse the oil in water in order to form a stable oil-in-water emulsion. Stability of emulsion is the most vital property of soluble oil. The presence of water makes emulsion superior in cooling while the presence of oil reduces the tendency of water to cause oxidation. Similarly, extreme pressure additives are used in this cutting fluid under extreme pressure condition. The emulsion is recommended to be used in high-speeds and low pressures operations where the temperature rise is significant.

The advantages of emulsions are that it has no fire hazard and lower rate of oil misting. Besides, the cost is reduced since it can be diluted with water. However, infestation by micro-organisms such as bacteria, yeasts, and fungi is the weakness of emulsion due to the high amount of water. The presence of bacteria causes separation in the emulsion.

C. *Synthetic Cutting Fluids*

Synthetic cutting fluid which is made of chemical with additives and diluted in water, is free from mineral oil. They tend to have a clear, watery appearance, while dye may be added to make a clear green or yellow liquid. Synthetic cutting fluid forms transparent solutions and provides good visibility of cutting operation. The addition of organic and inorganic chemical solutions in synthetics cutting fluid provides water softening, corrosion resistance, lubrication, reduction of surface tension and blending. Synthetic cutting fluid is a good coolant but it provides insufficient lubrication compared to other cutting fluids due to lack of oiliness. As, a result, they are particularly used for low force operations where cooling is a primary requirement.

D. *Semi-Synthetic Cutting Fluids*

Semi-synthetic fluids are chemical emulsion, which contain mineral oil diluted in water with some additives to reduce the size of oil particles making it more effective lubricant. The only difference between synthetic and semi-synthetic fluids is that there is no oil present in synthetic cutting fluid.

Semi-synthetic fluids contain mineral oils of concentration varying between 10% and 50%, providing more lubrication than synthetic oils. Both the synthetic and semi-synthetic fluids show good cooling property as they have a low corrosion rate with low vulnerability for bacteria growth, lead to a decrease in irritation to the skin and odor.

VI. ADVANTAGES & DISADVANTAGES

Type of cutting fluids	Advantages	Disadvantages
Straight oil	Excellent viscosity and rust control	Low cooling, fire hazard, create mist or smoke, limited to low-speed and heavy cutting operations
Soluble oils	Good lubricity and cooling	Rust control problems, bacterial growth, evaporation losses
Semi synthetics	Good cooling, rust control and microbial control	Foam easily, stability is affected by water hardness, and easily contaminated by other machine fluids
Synthetics	Excellent cooling, microbial control, non-flammable, non-smoking, good corrosion control, reduced misting and foaming problems	Poor lubricity and easily contaminated by other machine fluids

Table 1: Advantage and Disadvantages of cutting fluid type:

VII. APPLICATION OF CUTTING FLUIDS:

Type of oil	Appearance	Use	Dilution
Neat/Straight Oils	Oily, wastes	Heavy-duty Material, corrosion Inhibition	Not Required
Soluble/ Emulsifiable Oils	Milky colour, aqueous	Coolant and lubrication, corrosion inhibition	Yes,2-3%
Semi-synthetic Oils, soluble	Translucent	Coolant and Less Lubrication Than for Aqueous Oils	Yes,1-3%
Synthetic Oils	Transparent	Excellent Coolant, minimal Lubrication	Yes,1-5%

Table 2: Application of cutting fluids:

VIII. DIFFERENT TECHNOLOGIES USED FOR TREATMENT OF METAL CUTTING FLUIDS

- Demulsification method or Emulsion Breakdown
- Chemical method
- Advanced oxidation processes

A. *Demulsification Method or Emulsion Breakdown:*

Demulsification is the breaking of a crude oil emulsion into oil and water phases. From a process point of view, the oil producer is interested in three aspects of demulsification:

1) Rate or the speed at which this separation takes place
2) Amount of water left in the crude oil after separation
3) Quality of separated water for disposal

1) *Mechanism involved in Demulsification*

- Flocculation or aggregation
- Coalescence
- Sedimentation or creaming

B. *Flocculation or Aggregation:*

First step in Demulsification is the flocculation of water droplets. During flocculation, the droplets clump together, forming aggregates or "flocs." The droplets are close to each other, even touching at certain points, but do not lose their identity (i.e., they may not coalesce). Coalescence at this stage only takes place if the emulsifier film surrounding the water droplets is very weak. The rate of flocculation depends on the following factors.

- Water content in the emulsion The rate of flocculation is higher when the water cut is higher.
- Temperature increases the thermal energy of the droplets and increases their collision probability, thus leading to flocculation.
- Viscosity of the oil is low, which reduces the settling time and increases the flocculation rate.
- Density difference between oil and water is high, which increases the sedimentation rate.
- An electrostatic field is applied. This increases the movement of droplets toward the electrodes, where they aggregate.

C. Coalescence:

Coalescence is the second step in demulsification. During coalescence, water droplets fuse or coalesce together to form a larger drop. This is an irreversible process that leads to a decrease in the number of water droplets and eventually to complete demulsification. Coalescence is enhanced by the following factors.

- High rate of flocculation increases the collision frequency between droplets.
- The absence of mechanically strong films that stabilize emulsions.
- High interfacial tension. The system tries to reduce its interfacial free energy by coalescing.
- High water cut increases the frequency of collisions between droplets.
- Low interfacial viscosity enhances film drainage and drop coalescence.
- Chemical demulsifiers convert solid films to mobile soap films that are weak and can be ruptured easily, which promotes coalescence.
- High temperatures reduce the oil and interfacial viscosities and increase the droplet collision frequency.

D. Sedimentation or Creaming:

Sedimentation is the process in which water droplets settle down in an emulsion because of their higher density. Its inverse process, creaming, is the rising of oil droplets in the water phase. Sedimentation and creaming are driven by the density difference between oil and water and may not result in the breaking of an emulsion. Unresolved emulsion droplets accumulate at the oil/water interface in surface equipment and form an emulsion pad or rag layer. A pad in surface equipment causes several problems including the following.

- Occupies space in the separation tank and effectively reduces the retention or separation time.
- Increases the BS&W of the treated oil.
- Increases the residual oil in the treated water.
- Increases arcing incidences or equipment upset frequency.
- Creates a barrier for water droplets and solids migrating down into the bulk water layer.

E. Chemical Method:

Some water soluble cutting fluids are formulated to reject tramp oil contamination, floating them to surface of the fluid for easy skimming. Reuse of the fluid is done after separating settled solids, which makes it a conservative and economical step. Certain fluids need proper disposal for the used fluids, chemical method have been successfully proved for treatment of emulsion. These treatment methods use strong chemicals, so proper safety precaution is taken care of.

Methods:

- Acid split
- Acid/Alum split
- Epsom Salt Split
- Chloride salt split

1) Acid Split

Metal cutting fluid is Accumulated in a holding tank. 50% hydrochloric acid solution or commercial muriatic acid is added to reduce the pH to 3.5-4.0. Depending on the alkalinity of the used emulsion, 2% to 10% of the acid may be required to reach the desired low pH. Agitate gently to disperse the acid. Allow the mixture to set without further agitation while oily components float to the surface. Separation of the oil and oil soluble components should occur within 24 hours, usually much sooner. Skim floating oil for disposal as waste oil in accordance with local, state and federal regulations. Neutralize remaining clarified watery liquid by carefully adding 50% sodium hydroxide solution (liquid caustic) to adjust the pH to 6.8-7.2. The clarified and neutralized watery phase should be acceptable to local sanitary districts but check before dumping to be sure you are in compliance with local ordinances.

2) Acid/Alum Split

This method complete “polished” emulsion breakdown. Cutting fluid is accumulated in a holding tank. Aluminum sulfate (alum) or ferric sulfate at a concentration of 0.5% wt. to 2.0% wt.is added and, stirring in gently done to dissolve. Immediately 50% hydrochloric acid or commercial muriatic acid is added to adjust to pH 3.5 stirring very gently, just enough to disperse the acid. Stirring too vigorously will upset the coagulating characteristic of the alum reducing the outstanding efficiency of the acid/alum combination. Allow the mixture to settle down quiescently, without further agitation while the oily components, separate, for satisfactory clarification 2 to 12 hours should be given. Skim floating oil for disposal as waste oil in accordance with local, state and federal regulations. Removal of settled sludge is done by means of a bottom drain or better, pump the clarified watery layer into a second tank leaving the settled floc behind. Add sodium hydroxide solution (liquid caustic soda) to the clarified acidic water to neutralize to pH 6.8 to 7.2. The clarified, neutralized watery phase should be suitable for dumping with the provisions noted in ACID SPLIT method.

3) Epsom Salt Split

In this method Emulsion breakdown is done without using strong acids and alkalis. Waste fluid is accumulated in a holding tank. 40% aqueous solution of magnesium sulfate (Epsom salts) is prepared in separate tank, for example, add 50 pounds of Epsom salts to 75 pounds (9 gallons) of water. Stir until completely dissolved and clear. Add Epsom salt solution to fluid at a concentration of about 10% and stir gently to disperse. Separation of oil and oil soluble components should occur within 24 hours. Skim floating oil for disposal as waste oil in accordance with local, state and federal regulations. The watery portion should be suitably used for dumping to a suitable drain for final treatment by a municipal sewage treatment plant.

4) Chloride Salt Split

This method is used for coarse, creamy type emulsions. Waste emulsion is accumulated in treatment tank. A vertical cylinder tank equipped for mixing by air bubbling is ideal. In a separate tank, prepare a water solution of calcium chloride by adding at a ratio of 4 pounds of calcium chloride per 1,000 gallons of emulsion to be processed. Add calcium chloride solution to the treatment tank and agitate by air-bubbling for one hour. The addition of a mixture of 4 pounds of ferric sulfate in 10 gallonsof warm water with further air-bubbling for 30 minutes to disperse the mixture will enhance splitting. Turn off air and allow mixture to set quiescent. A satisfactory degree of separation should occur within 24 hours. Skim floating oil for disposal as waste oil in accordance with local, state and federal regulations. The watery portion should be suitable for disposal by dumping to a municipal sanitary waste treatment facility.

The methods used above are time tested and proven under commercial conditions, not all these methods may produce satisfactory results with mixture of cutting fluids and contaminants, so pre-treatment on a small scale batch is strongly advised for better results for testing in large scale treatment is undertake.

F. Advanced Oxidation Process:

- Advanced Oxidation Processes (AOP) refers to a set of chemical treatment procedures enhanced by Ultra sound and UV activation, designed to remove organic and inorganic materials in waste water.
- Contaminants are oxidized by four different reagents: ozone, hydrogen peroxide, oxygen, and air, in precise, pre-programmed dosages, sequences, and combinations. These procedures may also be combined with Ultra Sound reactors, UV irradiation and specific catalysts. This results in the development of hydroxyl radicals.
- The AOP procedure is particularly useful for cleaning biologically toxic or non- degradable materials such as aromatics, pesticides, petroleum constituents, and volatile organic compounds in waste water.
- The contaminant materials are converted to a large extent into stable inorganic compounds such as water, carbon dioxide and salts, i.e. they undergo mineralization.
- A goal of the waste water purification by means of AOP procedures is the reduction of the chemical contaminants and the toxicity to such an extent that the cleaned waste water may be recycled or, at least, dumped into a conventional sewage treatment.
  - Combined process of Fenton process and Sono-Fenton process
  - Acoustic oxidation
  - Chemical oxidation

G. Combined process of Fenton process and Sono-fenton process

Fenton process is one of the advanced oxidation process using FeSO4, known as Fenton’s reagent, to catalyze hydroxyl radical production. The principle of the Fenton process is the catalytic cycle of the reaction between iron (catalyst) and hydrogen peroxide (oxidant) to produce hydroxyl radical is produced according to.

The main concept of the processes is to generate hydroxyl radical (OH), which is a very strong oxidant, to virtually oxidize any compound present in water matrix. Consequently, OH reacts unselectively once formed, contaminants will be quickly and efficiently fragmented and converted into small inorganic molecules. Fenton’s reagent can be used to destroy organic compounds such as trichloroethylene (TCE) and tetrachloroethylene (perchloroethylene, PCE). It was developed in 1890s by Henry John Horstman Fenton as an analytical reagent.

Ferrous oxide is oxidized by hydrogen peroxide to Ferric oxide, forming a hydroxyl radical and a hydroxide ion in the process. Ferric oxide is then reduced back to Ferrous oxide by another molecule of hydrogen peroxide, forming a hydro peroxyl radical and a proton. The net effect is a disproportionation of hydrogen peroxide to create two different oxygen-radical species, with water (H+ + OH−) as a by-product.

1) $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + HO\bullet + OH^-$
2) $Fe^{3+} + H_2O_2 \rightarrow Fe^{2+} + HOO\bullet + H^+$

The free radicals generated by this process then engage in secondary reactions. For example, the hydroxyl is a powerful, non-selective oxidant. Oxidation of an organic compound by Fenton's reagent is rapid and exothermic and results in the oxidation of contaminants to primarily carbon dioxide and water.

Fenton's reagent is also used in organic synthesis for the hydroxylation of arenas in a radical substitution reaction such as the classical conversion of benzene into phenol.

3) $C_6H_6 + FeSO_4 + H_2O_2 \rightarrow C_6H_5OH$

1) Sono-Fenton Process

Sono- Fenton process is a post treatment process which should be applied after the separation process, as it has a drawback from high energy consumption of chemical and energy. The effluent COD can pass the industrial standard with less chemical and energy usages.

2) Acoustic oxidation:

Acoustic oxidation is a type of advanced oxidation process in which oxidation process is carried out with ultrasonic irradiation passing through the process. In experimental set-up it is shown that, four 150-ml beakers containing degassed raw water is placed in ultrasonic cleaner bath. The temperature of the experiment is controlled. Furthermore, a beaker is reserved for measuring the oxidation reduction potential (ORP) as a control system. Oxidants and reagents prepared in a separated vessel were added into the sample and the ultrasonic irradiation was immediately turned on.

3) Chemical oxidation

Chemical oxidation is a form of advanced oxidation processes and advanced oxidation technology, is an environmental remediation technique used for soil and/or groundwater remediation to reduce the concentrations of targeted environmental contaminants to acceptable levels.

Chemical oxidation is carried out with, Acoustic Oxidation with Hydrogen Peroxide and Acoustic Oxidation with Air Bubbling. Chemical oxidation is accomplished by injecting or otherwise introducing strong chemical oxidizers directly into the contaminated medium (soil or groundwater) to destroy chemical contaminants in place. It can be used to remediate a variety of organic compounds, including some that are resistant to natural degradation.

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