

Characteristics and treatability of oil-bearing wastes from aluminum alloy machining operations

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Abstract

Enomoto Industry Co., exclusively uses water-based cutting fluids in its aluminum alloy machining operations. Since the cost of disposal can be much greater than the cost of purchase, the treatability of spent cutting fluids is becoming a major criterion for cutting fluid selection. Samples were collected from the machining lines at Enomoto's facility to determine their characteristics and evaluate their treatability with centrifugation, chemical coagulation and electrochemical coagulation. As expected, oil and grease (O&G) and total suspended solids (TSS) are the main reasons that spent cutting fluids are prohibited from being discharged into local swage systems. The average O&G found in the spent cutting fluids is 87,354 mg/L with TSS of more than 70,000 mg/L. Both O&G and TSS are the major contributors to the high turbidity of these waste effluents. A centrifuge with a relative centrifugal force of $1318 \times g$, was able to reduce 60% of the turbidity. By adding the coagulant aluminum chloride, the oil–water emulsion was destabilized, and the turbidity was reduced from 3249 Formazin Attenuation Units (FAU) to around 314 FAU. With freshly generated aluminum ions in the spent cutting fluid, the electrochemical process destabilized the oil–water emulsion system. The coalesced oil droplets were adsorbed onto the highly dispersed aluminum coagulant. The oil-rich sludge that was generated in the operation was then floated to the surface, forming a blanket that was removed by skimming. The electrochemical treatment was able to reduce the turbidity to less than 14 FAU, which is the detection limit of the Hach DR/4000 UV–vis spectrophotometer.

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1. Introduction

Enomoto Industry Co., exclusively uses water-based cutting fluid in its aluminum alloy machining operation. After spraying onto the work pieces, the cutting fluid is collected together with aluminum chips, coarse particles, fine particles, sludge and others. The chips are settled on a conveyor at the bottom of a collecting pan, and are carried out of the cutting fluid mechanically, while coarse particles are removed by drum filter. However, fine particles remain suspended in the emulsion. Even when recycling options are used, the cutting fluids have a finite useful life. The disposal of cutting fluids involves the evaluation of corrosion, dermal irritation, reduced tool life, color and odor [1,2]. The disposability of the spent cutting fluids is becoming a major

criterion for cutting fluid selection, since the cost of disposal can be much greater than the cost of purchase.

Currently, the pretreatment of spent, water-based cutting fluids is to remove the water portion from the cutting fluids, so that the remaining concentrate can be disposed of at lower cost. Pretreatment is usually divided into three steps. The primary treatment utilized is to separate the floatable and non-emulsified oils and suspended solids from the cutting fluid through sedimentation, filtration, centrifugation, skimming and coalescing [3,4]. Secondary treatment includes evaporation, chemical treatment and ultrafiltration. Evaporation is easy to operate and can reduce the disposed mass by 90%. However, the intense energy input is significant enough to offset most of the disposal cost savings. In water-based cutting fluid, oil droplets are stabilized by surfactants, forming micelles in aqueous solutions. Chemical treatment of an oil-in-water emulsion is usually directed toward the destabilization of the dispersed oil droplets, or the destruction of emulsifying agents present in a first stage, followed by

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the removal of the separated oil [5,6]. Although other coagulants are under development, ferric and aluminum salts are still the most widely used agents for demulsification. The process usually consists of the rapid mixing of the coagulant chemicals with the emulsion, followed by flocculation and flotation, or settling.

Ultrafiltration is a pressure driven process that uses the sieving action of polymeric membranes to control the flow of molecules and particles larger than the membrane pores [7–9]. Water, dissolved salts and metals, along with very small organic molecules, pass through the membrane, while high-molecular weight compounds, such as hydrocarbons, fats and grease are trapped. Typical ultrafiltration membranes have a porosity of about 80%, and average pore sizes ranging between 0.1 and 1.0 μm . Such membranes, characterized by means of a nominal molecular weight cut off, are available in 1000, 10,000, 100,000 and 1,000,000 Da. Molecular weights between 500 and 300,000 Da are commonly found in these kinds of wastes.

Depending on local regulations, secondary treatment can be acceptable for sewer discharge, but in some districts, the spent cutting fluids may have to undergo a tertiary treatment. One such tertiary treatment is reverse osmosis, which is similar to ultrafiltration, except that it operates under much higher pressure due to the smaller pore size on the membranes. The membranes in reverse osmosis treatment, provide a barrier to the transfer of small molecules and dissolved organics, so are effective for removing water-soluble organics, chlorides and phosphates [10]. Another type of process uses activated carbon to adsorb dissolved organics. However, the most common method for treating water-soluble organics uses biological treatment [3,4,11].

In the early 1980s, researchers at the Ford Motor Co. in Dearborn, MI, tested a newly designed electrochemical reactor in a manufacturing plant that represented highly varied machining operations [12]. It was found that when direct current is applied to water through a pair of electrodes, water molecules are broken down into hydrogen and oxygen gases. However, when the anode is made of metals that have lower oxidation potentials than water (such as iron and aluminum), the anode is dissolved to produce metal ions. The metal ions react with hydroxyl ions, the by-products of hydrogen generation, to produce metal hydroxides. As the electrochemical reaction progresses, the ionic strength of the wastewater increases, and the pH rises. The net result of these reactions is that the emulsion is destabilized, and the dispersed oil droplets begin to coalesce. Ultimately, the destabilized oil droplets are adsorbed into the highly dispersed ferric or aluminum hydroxide particles. The oil-rich sludge floats to the top of the solution. This process was able to reduce the turbidity of the incoming oily wastewater from 2500 NTU (Nephelometer Turbidity Unit) to less than 5 NTU, with a power consumption of 6 kWh/1000 gal. Electrochemical methods for wastewater demulsification have since become an active area of research and development [13–17]. A thorough review on electrochemical technologies for industrial wastewater treatment has been done by Chen [18].

The United States federal government's role in wastewater pretreatment began with the passage of the Clean Water Act in 1972. The Act called for the Environmental Protection Agency (EPA) to develop national pretreatment standards to con-

trol industrial discharges into sewage systems. The standards in effect today consist of two sets of rules: categorical pretreatment standards and prohibited discharge standards. Approximately 1500 publicly owned treatment works (POTW) are participating in the National Pretreatment Program by developing their own local programs. In 1985, the EPA approved the City of New Bedford's industrial pretreatment program and authorized the city to implement this program. The primary responsibilities are (1) adapt federal discharge limitations, or develop local discharge limitations, (2) identify all industrial users (IU) and characterize their pollutant discharges, (3) notify IUs of applicable pretreatment standards, (4) receive and review self-monitoring reports, (5) investigate instances of non-compliance and (6) publish significant non-compliance (SNC). In many cases, federal pretreatment standards do not meet the water quality limitations placed upon the POTW discharge. This has resulted in local municipal authorities adapting much more stringent discharge limitations. Table 1 shows the more stringent regulations and discharge limitations developed and enforced by the City of New Bedford.

The objective of this research is to characterize spent cutting fluid from Enomoto's facility and to evaluate pretreatment methods, such as centrifugation, chemical coagulation and electrochemical coagulation, for the feasibility of on site disposal into local sewage systems.

2. Waste characterization

Cutting fluid samples were collected from sumps in the aluminum machining lines at Enomoto's facility. According to their appearances, the samples were designated as either yellow-white or green-gray. The colors were caused by different machining operations since both fluids were generated from the same starting solution. The samples were characterized using different methods and techniques. Six randomly selected samples were analyzed for their metal contents, total suspended solids (TSS)

Table 1
Local effluent limitations (mg/L) for the City of New Bedford in Massachusetts

Parameter	Limit
Arsenic	1.4
Cadmium	1.2
Chromium(VI)	4.8
Copper	2.3
Cyanide	1.9
Lead	0.6
Mercury	0.01
Nickel	2.0
PCBs	0–0.05
Silver	1.2
Zinc	4.2
Oil and grease	100
pH	5.5–9.5 S.U.
BOD and TSS surcharge system	<50 lbs/day, no charge 51–150 lbs/day, \$0.05/lb 151–250 lbs/day, \$0.07/lb >251 lbs/day, \$0.10/lb

BOD: biochemical oxygen demand; TSS: total suspended solids.

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