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Minimum Quantity Lubrication: Health Effects

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Abstract

Micro lubrication is a green machining technique that reduces the amount of cutting fluid during the machining process. Cutting fluids (CFs) are used in machining processes to lubricate and cool the cutting tool and work piece interface. It is well known that the application of CF performs several important functions including reducing the friction-heat generation and dissipating it. The use of CFs cannot be completely stopped because of their beneficial contributions. The objective is to find ways to reduce their usage and improve their characteristics due to their effects on health due to exposer and negative effects on polluting the environment. This paper focuses on characterizing micro and nano fluids, outlines their effects on health, and summarizes applications, classification of fluids and systems presently used.

Keywords: *Micro lubrication, Nano lubrication, Minimum Quantity Lubrication*

1. INTRODUCTION

Micro lubrication consists of atomizing a very small quantity of cutting fluid ranging between 2 to 200 ml/hr directed toward the cutting tool/workpiece interface in the form of an aerosol. In conventional flood cooling, the flow rate is typically about 20 L/min. Flood cooling systems require infrastructure for delivery, recycling, filtration, and waste-fluid treatment. Furthermore, the systems demand constant monitoring and treatment to control CF concentrations and to avoid fungal and bacterial growth. Worldwide, manufacturers currently consume over two billion liters of water-based and straight-oil CFs each year, which creates a significant demand for sustainable lubricants and machining processes [1,2]. Vegetable oil-based lubricants are sustainable and environmentally friendly because of their non-toxicity, renewability and biodegradability. Many positive results in terms of machinability and tool life have been reported by the use of vegetable oil during micro lubrication [3,4].

Nano fluids are a relatively new category of fluids that are created by the dispersal of nanometer-sized particles in the base fluids in order to increase tribological properties and heat transfer. Various studies conducted into Nano fluids have demonstrated that the convection heat transfer and the thermal conductivity can be greatly improved by the aforementioned suspended particles. In addition, recent research into tribology shows that the Nano-particle added to lubricating fluids have a higher load carrying capacity, friction reduction, and anti-wear capacities. With such features, it is obvious that the Nano fluids are very attractive in lubrication and cooling applications in various industries such as energy, manufacturing, transportation, and electronics among others. The base fluids can include the previously mentioned lubricants or even water.

2. NANO-FLUIDS IN COOLING APPLICATIONS

The heat transfer fluids are critical the modern industries such as energy, manufacturing, transportation, and electronics among others. New and emerging developments such as highly integrated microelectronic devices, reduction in the applied cutting fluids and higher output engines have created a demand for advanced cooling capacities. The result of this has been a critical need to provide an innovative new mode of heat transfers and improvements of the present heat transfer fluids [5].

Heat transfer fluids are limited in the rate of transfer of heat with solids demonstrating a higher rate of transfer of heat. Therefore, suspending pieces of solids in the liquids results in significant increases in the thermal conductivity of the Nano fluids as compared to the conventional heat transfer fluids. The suspension of particles in liquids has been the subject of numerous studies going back a century. However, the studies were limited by the technology to millimeter or even micrometer-sized particles that were not small enough to make a significant difference. Recent developments in Nano-particle synthesizing techniques including the ability to suspend Nano-particles uniformly and in a stable manner in the fluid, have made it possible to generate a new class of engineered fluids that have a high heat transfer rate [5]. The Nano particles are small enough to act as the molecules of the fluids, therefore, do not clog or block the fluid passages but increase the thermal capacities drastically.

3. SYSTEMS USED PRESENTLY FOR MINIMUM QUANTITY LUBRICATION

To understand the different systems used one must realize that the primary purpose of minimum quantity lubrication is to provide lubrication to the point of contact for the tool especially the cutting edge. For the single-purpose machines such as the sawing, broaching shaping the simple minimum quantity lubrication devices that have different functional modes are used. These are typically the systems that use pressure tanks and metering pumps. Depending on the ease of accessibility to the cutting edge, different requirement will apply for the devices in use. The differing requirements lead to two systems; the external and internal feed that reflects on the cost of the device.

In the external feed, the lubrication is usually applied via spray nozzles surrounding the circumference of the tool. The internal feed is most suited for the entrance-level implantations for the standard processes such as milling, turning and drilling. The devices usually transport the lubricant and atomize it at the contact point. The process occurs in a parallel or coaxial pipework packet. The lubricant is atomized at the end of the pipes and it is sprayed to the tools as an aerosol. There are two technologies in use whose key differences are in the lubrication transportation. These are; Devices with metering pumps, oil droplets target bombardment and devices with pressure tank. The devices with metering pumps transport the lubricant with a pneumatic micro-pump and the dosage of the lubricant is regulated by the frequency and the stroke of the pump plunger.

The advantages offered by these devices are the modular design and the exact dosage regulation. Furthermore, the assembly of the pump elements makes the installation of any number of pump elements possible. These devices must be secured against unauthorized usage.

The devices with a pressure tank, involve the lubricant being forced out of a pressurized tank. The metering in these devices is conducted using throttle elements in the pipework and the supply pressure settings. For these devices to be effective the air atomization, tank pressure and the oil quantity should be adjustable separately. The advantages of the devices with a pressure tank over the micro pump systems are the lack of moving parts that are subject to wear and the uniform lubrication stream.

The oil droplets targeted bombardment shoots single lubricants droplets at the point of contact in trough a high speed valve. The process allows the distances of up to 800mm between the tool and the valve without atomization of the lubricant or the air mixing. The droplets land on the precise point where they are targeted. The method is used in lubricating the very small tools that lack internal cooling systems.

The internal feed devices allow direct supply of the lubrication to the working zone. In these systems, the lubricant must be channeled through the tool revolver, the spindle or any other tool being used. Therefore, the machine components designs are significantly influenced by the operation of the minimum quantity lubrication system ,and occasionally necessitate the optimization of the entire systems. The systems allow the lubrication to reach the critical points throughout the process; this allows the drilling of deep holes to be done cheaply and efficiently. The internal feeds are applied when the external feeds are no longer feasible such as when drilling with large L/D ratio.

4. CLASSIFICATIONS OF NANOFLUIDS

Nano fluids are classified into two categories: Metallic and non-metallic fluids.

The metallic Nano fluids contain metallic nanoparticles such as Gold (Au), Iron (Fe), Silver (Ag), and Copper (Cu). The non-metallic Nano fluids contain non-metallic particles such as Silicon Carbide (SiC), Aluminum Oxide (AL2O3) and Copper Oxide (CuO) [6].

The heat conduction models for the solid-liquid mixtures were established more than a century ago with models such as Maxwell model in 1904. However, as mentioned earlier the size of these particles severely limited the effectiveness of the fluids as in heat conduction. As such when the models are applied to the Nano fluids, they tend to underestimate the fluid’s thermal conductivity.

Thermal conductivity of Nano fluids is best tested by the transient hot-wire method. Metallic nanofluids have been systematically studied, with their respective changes in conductivity being recorded. For example, the thermal conductivity of ethylene glycol improved by 40 percent on the addition of 0.3 percent of Copper nanoparticles of 10 nm in diameter. Also, the thermal conductivity of water has been demonstrated to increase by up to 78 percent by an addition of 7.5 percent Copper particles of 100 nm in diameter [7].

Non-metallic fluids such as CuO, TiO2, Al2O3, SiC and even carbon nanotubes have also correspondingly been studied. Various studies have had differing results; in 1993, it was reported that the thermal conductivity of water increased by 30 percent with an addition of 4.3 percent AL2O3 nanoparticles of the average diameter of 13 nm. However, another study by Lee obtained the results of only a 15 percent increase for the same nanoparticles used. In 2002, the thermal conductivity of water for the same nanoparticle loading had obtained a 22 percent increase. The differences in the results are attributed to the differences in average particle sizes in the samples used [8]. Nano fluids of CuO particles, when added to ethylene glycerol, have a greater increase in the thermal conductivity of the glycerol than when the nanoparticles of AL2O3 are added.

In large-scale, industrial manufacturing applications, synthetic esters and fatty oils that have a high flash point and favorable vaporization behavior provide the most suitable lubricants.

Synthetic Esters

These provide the best option for machining processes that require significant prevention of abrasion wear. Examples of such process include drilling, and threading.

Synthetic esters are advantageous in that they have a high boiling and flash point in spite of their low viscosity. The high boiling and flash point translate into much lower emissions of vapor. Furthermore, ester oils are highly biodegradable and are non-hazardous to water due to their low levels of toxicity [5].

Fatty Alcohols

When contrasted with ester oils,fatty alcohols exhibits a lower flash point with the same viscosity and offer slightly less lubricity. They are mostly preferred for machining processes that have a greater need for separation than they have for the lubricating effects such as the machining of some non-ferrous metals.

The fatty alcohols are highly biodegradable, are toxicologically harmless and are not hazardous to water [5].

Other factors that may influence a lubricants feature includes: Smell, spray-ability, additives, the viscosity range, corrosion protection, viscosity range, and lubricant change.

Some lubricants are unsuitable for the minimum quantity lubrication. These include natural oils and greases as a result of their vulnerability to oxidation that gums up the machinery. Lubricants with additives that contain organic zinc or choline, the high temperatures and pressures can lead to reactions whose products are harmful to health [6].

The National Institute for Occupational Safety and Health (NIOSH) recommends that the exposure level that workers encounter from metalworking fluids should be limited to 0.5 mg/m³ during a 10 hour day for a 40 hour workweek ("Workplace Safety and"). The U.S. Occupational Safety and Health Administration (OSHA) states the permissible exposure level is 5 mg/m³ based on an 8 hour workday . However, it has been found in the past that the oil mist produced by traditional flood cooling methods in U.S. automotive parts manufacturing facilities range from levels of 20-90 mg/m³ [9]. Workers are exposed to these fluids by direct skin contact from splashes or mist during the machining process or handling the tools, parts and equipment. Workers also inhale the mist by means of the fluid circulation system and the exhaust system in the room . This contact can result in a number of health issues. Such concerns are dermatitis, acute and chronic respiratory diseases, skin cancer and other cancers .

A study conducted by Boubekri et al [10] showed that concentration levels produced in drilling steel using microlubrication were greater than the above recommended levels. Moreover 82% of the resulting concentrations were greater than 7 mg/m³ indicating a definite high concentration if people are exposed.

The study also showed that athough no guidlines exist for the resulting particles size,the results indicate that at least 86% of the resulting particle diameters were smaller than 0.8 µm which increases the likelihood of potential skin or respiratory problems if a person is exposed.

5. CONCLUSIONS

Advantages of using minimum quantity lubrication in machining are significant and compare favorably to flood cooling in terms of the resulting quality of parts. However, designing machine systems with high efficient mist collectors and reliable air tight machine enclosures are necessary to minimize exposure and increase worker safety.

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