A Review: Development of MQL systems applied for metal cutting

M I J Lubis¹, A Ginting*¹, Sutarman²

¹ Laboratory of Machining Processes, Department of Mechanical Engineering, Faculty of Engineering, Universitas Sumatera Utara, Jalan Almamater, Building J17.01.01, Medan 20155, Indonesia
² Department of Mathematics, Faculty of Mathematics and Sciences, Universitas Sumatera Utara, Jalan Bioteknologi, Medan 20155, Indonesia

*Corresponding author: armansyah.ginting@usu.ac.id jamal.lubis@gmail.com

Abstract. Today, there is a remarkable progress to reduce the costs of tooling, production, maintenance and to increase efficiency in metal cutting operations. The practice of machining process under dry cutting has become common in the metal machining industry, but it has weaknesses. To enhance dry cutting, the minimum quantity lubrication (MQL) technique has been introduced. MQL is a very promising solution as an alternative both to replace the conventional flood cooling and to enhance the dry cutting. MQL has been proven to be a superior mechanism with some benefits such as cost effective, worker safety, improved cooling performance, and improved system performance. MQL can be regarded as technology that connecting dry and conventional flood cooling. This study is aimed to discuss MQL including its development and its application in machining processes.

1. Introduction

In the minimum lubricant quantity (MQL) system, cutting fluid with compressed air is sprayed into the cutting zone during the machining process. That way the cutting fluid will penetrate the cutting zone thereby increasing machining capabilities. Then at the same time, the cutting fluid used at MQL is mostly evaporated so that it is not harmful to the environment and workers’ health. In addition, MQL requires less investment in cutting fluid materials and minimal waste disposal costs compared to conventional flood cooling or wet cutting.

Many research has been done on MQL applications for machining processes. The researchers showed that the results of the study using the MQL system showed better results in terms of surface quality and cutting force than others [1]. When turning titanium alloy steel, MQL nano-based fluids improve CBN cutting tool performance better than its performance under dry cutting [2].

MQL system with liquid water-miscible oil (ratio of oil and water 1:20) and pressure of 0.6 MPa applied for cutting super duplex steel increased the performance of tungsten carbide insert grade KCM15 by 11.95% to 33.08 [4]. In another study, an MQL unit fed with mineral water-based oil-cooled and oil-free Blasocut 4000CF minerals was applied for turning 1.4462 stainless steel (DIN EN 10088-1). In this
In the case, the performance of the TNMG160408 carbide cutting tool could be increased about 8% compared to dry machining. MQL systems that work with liquid droplets and reinforced with compressed air are widely used in producing mist for metal cutting [5]. In another form of the MQL system, it was reported that the success of the mixing chamber unit to support the MQL system that was applied to spin the Ti-6Al-4V alloy was to use an uncoated solid-carbide end mill compared to the MQL drip system. There are droplets as small as 2 μm which can be produced in the mixing chamber. The resulting droplet size is smaller than conventional MQL 10 μm to penetrate into the cutting area [6]. So far it has not been widely reported the use of MQL units equipped with mixing chambers whose characteristics are based on hard machine characteristics.

2. Hard Machining

Hard machining is a manufacturing process that is developing and is becoming a most suitable technology, replacing alternatives for milling for the completion of hardened machined parts. Dry machining operation is preferred because of the cutting results which flatten the workpiece and this is due to temperature changes. But problems such as tool life span and tool wear are very influential because temperatures are too high and need to be monitored so that the machine operation process can run effectively and economically. So, a minimum quantity lubrication (MQL) is needed because it is preferred because it produces good cooling properties and lubrication conditions. This is because the cutting fluid is in the form of oil mist and has pressure because it is sprayed by a jet of water into cutting zone resulting in an efficient and environmentally friendly machining state [7].

The droplet MQL system was reported applied when turning of hardened AISI 4340 steel with uncoated cermet cutting tool for the study of some machinability aspects [8]. Also on hard machining, the MQL system filled with jatropha-based cutting fluid was applied when turning of AISI 1045 using cermet insert. It was reported that the droplet MQL system with jatropha-based coolant reduced cutting force by 12%, cutting temperature by 9%, surface roughness by 7% and extending tool life by up to 50% compared to commercial MQL cutting fluids [9].

The mixing chamber MQL system was reported providing good support for turning Medium Carbon Steel using Coated Tungsten Carbide cutting tool. After the mixing chamber, two spray nozzles were focused at the cutting edge and thus, increasing 73.4% of tool life versus dry cutting [10].

Kumar et al. [11] noted that the spray-assisted cooling operation can better reduce side wear, temperature and surface conditions in the AISI D2 hard steel machining process. Dhar et al. [12] conducted a job comparing the performance of the MQL method for the drying process on AISI 1040 steel machines. The results obtained from MQL conditions such as cutting forces, tool wear, surface roughness and cutting temperature. Gaitonde et al. [13] investigated that MQL and optimized cutting conditions to produce better brass machining performance can minimize surface roughness. Sahoo and Mishra [14] developed an optimal working system for the cutting temperature in hard steel machining operations. This system can be statistically significant for knowing the approximate cutting temperature of the machine. Zhao et al. [15] investigated how much influence the velocity of the sharp edge radius on the hard rotation of bearing steel in terms of surface conditions and tool wear. Cutting tools with a nominal edge radius (30 mm) are proven to produce better machining conditions than others. Ramesh et al. [16] said that the cutting force affects the surface roughness when the titanium alloy rotates will result in a good surface response.

3. Machining with MQL

3.1. MQL (Minimum Quantity Lubricant) System

MQL is also known as a dry machine and a long working time under the MQL environment, a very small amount of coolant (10-100 ml/h) is used directly applied at certain fixed time intervals in the machining zone to reduce friction and machining temperature at the workpiece interface with the MQL technique. Compared to the flood cooling lubrication technique uses about 30,000–60,000 ml/h during
machining refrigeration operations [17]. The use of MQL in machining has succeeded in reducing the problems associated with dry machining [18].

Many research groups also add nanoparticle additives, which have excellent heat absorption but otherwise nanoparticles can enter the human body through skin contact, therefore their effects can be very dangerous and cause organ damage, poisoning, and respiratory problems, and even trigger cancer. In addition to oil, high pressure air coolers, cold air jet spray has been shown to lower temperatures and increase tool life than using dry cutting operations, but engine parts components are subject to rust and corrosion is a serious drawback with this method [19].

Compressed air technology is an air delivery compressor system using a mixing chamber and microns as a flow rate regulator. The tapered shape in the mixing chamber serves to drain the mist into the nozzle connected to the outlet [20]. The result is the fog reaches the interface and functions properly like the schematic below in Figure 1.

![Schematic view of the experimental MQL setup](image)

**Figure 1.** Schematic view of the experimental MQL setup [1].

### 3.2. Mixing Chamber in MQL Unit

MQL method with mixing chamber has been used to obtain better mixing liquid with air or CO2 as the mixing medium [21]. Figure 2 shows that the researchers used cryogenic-MQL engine technology and a liquid carbon system (LCO2) lubricant. The solubility of oil in the use of LCO2 in the mixing chamber is droplets as small as 2 μm produced in the mixing chamber. Size smaller droplets can be achieved with a more equitable distribution of the mixing chamber and provides better lubrication than oil polar and the result is a life of tool length [6].

Engineering unit MQL uses compressed air from the compressor and CO2 forwarded to spaces mixing. To produce an aerosol mist that is so small that it is easy to shoot into a nozzle is to mix CO2 with a liquid or compressed lubrication in the mixing chamber. Micro-size aerosol mist can penetrate into the cutting zone of the workpiece and cermet cutting tool [22].
Awale et. al [23] studied the position of the MQL nozzle which was very influential to determine the quality of the aerosol during the spraying process with MQL liquid. The nozzle angle must be adjusted so that the aerosol can easily penetrate the grinding zone through the rigid peripheral hydrodynamic layer on the surface of the grinding wheel. From Figure 3 (a), it can be seen that the aerosol penetrates the air boundary above the abrasive wheel but is difficult to reach in the grinding zone because of the minimum nozzle angle. This results in a decreased cooling and lubrication effect, which creates more thermal damage to the ground surface. Furthermore, the nozzle position adjusted to the cutting zone in the hydrodynamic boundary layer will produce a sticky effect on the mist flow and will result in the direction of the mist shift towards the workpiece (see Figure 3 (b)).

Jai et al. [24] said that an efficient lubrication and cooling method can be obtained at a nozzle angle position of 10°-20° in the tangent layer of the air boundary layer during the MQL milling process. Then the resulting drop size of the air jet nozzle is important for evaluating the lubrication and cooling performance results during the operation of the MQL implementation on hard machining. In addition,
droplet size also affects the supply of better mist quality in terms of percentage of atomization at high shearing temperatures [25].

3.3. MQL Technique

The minimum quantity lubricant technique (MQL) has been proven to reduce the temperature of the grinding process, increase the lubrication effect and protect the environment. MQL milling technology is environmentally friendly because it uses liquid droplets to lubricate the grinding zone. The MQL milling technique was first proposed by Baheti et al. [26]. Yang et al. [27] MQL produces fluid with high pressure airflow (4.0 bar - 6.5 bar). Where the cooling of the grinding area and chips occurs by the high pressure gas in the MQL grinder. The amount of fluid delivered by conventional flood cooling fluid is 60 L / h in units of grinding wheel width, whereas the fluid requirement of the minimum amount of lubricant (MQL) varies from 30 mL / hour to 100 mL / h in terms of grinding wheel width units [28].

4. Summary and Recommendations

This paper presents a brief description of experiments and findings on the application of minimum quantity lubricant (MQL) system in machining processes. MQL is a very promising solution as an alternative both to replace the conventional flood cooling and to enhance the dry cutting. MQL could be applied for any metal cutting processes including machining with cutting tool and also grinding operation. In case of cutting technology, MQL can also be applied in machining of high temperature alloys and machining of hardened ferrous alloys.

Many types of cutting fluids have been developed and tested for MQL system. They are produced based on water and oil materials and enriched with many types of nano additive materials. Those are aimed to increase the capability in reducing heat and friction during cutting and thus, improved machinability aspects of machined surface resulted under MQL cutting.

For the purpose of obtaining the maximum benefit of MQL system in metal cutting, the following studies may be highlighted for the future works, they are:

- In the aspect of MQL construction, the MQL unit which is able to produce an efficient mixture of air and cutting fluid or fog in terms of cutting fluid volume per unit time, evenly distributed fog or mist coolant in the cutting area, and sufficient pressure to penetrate the cutting area (tool-chip interface). For this purpose, it is recommended that MQL construction be equipped with a mixing chamber rather than the droplet plus compressed air system.

- Development of organic based cutting fluids which are widely available in the manufacturing industry area as the MQL system feeder fluids. For example, in Indonesia, development of the cutting fluid based on palm oil is very potential to be carried out since this material is available in huge amount, easy to obtain, and biodegradable material.

- Optimizing the use of MQL systems based on organic-cryogenic cutting fluids equipped with smart systems where MQL activation is associated with tool wear evolution (for improved productivity) and cutting temperatures (for improved fatigue life of machined products).

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