A Review: Palm Oil-Based Cutting Liquid for MQL System Feeders in Hard Machining Application

U I Purba¹, A Ginting* and D Y Nasution²

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

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

Abstract. The cutting fluid has an important role to cool the cutting zone by lubricating the workpiece surface and cutting tools. But if the use of cutting fluid and the disposal method is not carried out properly it can affect human health and have a negative impact on the environment. In addition, expensive cutting fluids make industrial production costs increase. Currently, among the various techniques that exist in metal cutting, one of them is the MQL (Minimum Quantity Lubricant) technique, which is a cutting technique using an air jet to flow it (cutting fluid droplets) into the cutting zone. in the form of a spray. This paper contains an explanation of the MQL technique and various cutting fluid engineering. Several experimental studies suggest that the MQL technique provides better surface finish than dry and wet machining. In addition, the MQL technique also has other advantages such as reducing the coefficient of friction, tool wear, cutting temperature, cutting force compared to dry and wet machining techniques. Therefore, the MQL technique is a viable alternative to lubrication. In addition, the cutting fluid used must also be able to decompose naturally (biodegradable).

1. Introduction

The MQL technique is one option that is very profitable if it is managed properly to meet demand in a sustainable manner and can be applied in various machining processes such as grinding, lathe, sawing and milling operations. MQL is a spraying method using water jet to distribute lubricant (oil droplets) to the cutting zone. MQL is used in machining processes with the aim that dry machining can compete in supporting the idea of environmentally friendly machining [1]. Sharma et al. [2] revealed that the Industrial 4.0 was a production concept in the manufacturing industry using digital technology support where productivity and efficiency remained the basis of the best production concepts. In addition, the issue accompanying the concept of production to date is clean production (cleaner production). The industrial revolution 4.0 characterizes the sustainable manufacturing process (Sustainable Manufacturing Processes) by promoting productivity, production optimization and environmentally friendly production processes for engineering on manufacturing technology [2].

More about environmentally friendly production processes, machining experts recommend the concept of green machining (eco machining), namely the use of cutting fluid in very minimal quantities to support the machining process [3]. In addition, the cutting fluid used must also be able to decompose naturally (biodegradable). The machining industry is currently almost entirely still using...
large amounts of water and oil-based cutting fluids to reduce cutting temperatures, improve the quality of surface finishes of components and increase tool life [4].

Even though many losses are obtained if you still use this method, that is if the cutting fluid is contaminated with the machine during the work process, when it is discharged into the environment, this will cause the surrounding environment to be damaged in other words unable to decompose. In addition, oil-based working fluids can irritate the throat, nose, lungs and cause chronic bronchitis, exacerbating respiratory problems, and asthma [5]. Then there are several disadvantages such as the effect of lubrication, waste disposal, stability of cutting fluid, increased production costs, and marketing [6].

The use of cutting fluid greatly affects the environment and human health in that environment time of use or during disposal. So excessive use of cutting fluid should be avoided. Sharma et al. [2] stated that there are several types of cooling techniques, such as flood chillers, MQL, high pressure chillers, solid lubricants, air coolers, etc., as shown in Figure 1 to control the temperature cutting zone. The MQL technique using vegetable oil-based lubricants has a good effect on the machining process. So it can be concluded that the MQL technique is better than the others [2].

![Figure 1. Different cooling techniques](image_url)

Based on these problems it is necessary to have a new continuous cutting fluid. Where cutting fluid is expected to meet the effects of cooling, lubrication, environmental friendliness and operator health also in terms of cost effectiveness.

Madan et al. [4] have succeeded in making MQL samples by dissolving four constituents of 0.01 gram of Menthol, 1 gram of amorphous silicon dioxide nanoparticles, 0.03 gram of Xanthan and 0.03
gram of sodium dodecyl benzene sulfonate (SDBS) and 100 ml water. The optimal weight proportion of each constituent is obtained by conducting an experiment first [4]. Several experiments were carried out to analyze and compare the properties of MQL liquids that were developed with conventional MQL liquids such as viscosity, thermal conductivity, MQL density, specific heat capacity, rheological properties, studies of skin irritation toxicity and coefficient of friction. The results show that the developed MQL properties are better than existing conventional based MQL [8].

In addition, excessive use of cutting fluids during conventional wet machining processes and incorrect disposal methods can adversely affect human health and the environment [1]. Sharma et al. [2] in an experimental study found that mixing vegetable oil emulsion water with TiO2 nanoparticles in different concentrations will result in the performance of TiO2 nanofluids in terms of tool wear, surface roughness, cutting forces that are much better than dry machines, wet machines, MQL technique contains conventional cutting fluid. Padmini et al. [3] machining performance during the AISI 1040 steel turnover process using the MQL method, focusing on the performance of vegetable oil-based nanofluids. It was observed that the yield of 0.5% CC (coconut oil) + nMoS2 (nano molybdenum disulphide) showed better machining performance than all lubrication conditions. Temperature, cutting force, tool wear and surface roughness were reduced by 37%, 21%, 44% and 39% respectively using CC + nMoS2 at 0.5% npi compared to dry machining [3]. Previously developed MQL still focused on synthetic cutting. Where the development of cutting fluids in general is still oriented or not specifically for hard machining.

2. Hard Machining

The cutting surface of the nanoparticle material produces the lowest surface roughness compared to all other types of lubrication. This is because the nanoparticle material in the cutting fluid can increase heat dissipation drastically to increase machine wetting and lubricate the surface of the tool so that the result is smoother machining with respect to tool sharpness. With the use of nanoparticle-based cutting fluids, it was observed that the mean surface roughness was reduced by 34.7%, 11.64% and 7.22%, respectively, compared to conventional dry, wet and mist machines [9]. In the MQL method, the results showed that the surface finish increased by 30%, the cutting temperature was reduced by 36%, the cutting force was reduced by 40% compared to the use of dry rotation. The reduction in cutting temperature and cutting force that can be produced as well as the final result of the surface of the tool using the MQL method are in accordance with those obtained with wet machining. The MQL system can increase the material change by about 40% and increase the tool life compared to the coolant water. The results of the cutting work with the MQL method are better than dry machining. The use of the MQL method on the machine can make the temperature change at the tip of the tool become 6.72% and the cutting strength is reduced by 17.07% compared to the use of dry machining [1].

Nanofluids are not recommended as cutting fluids in wet machining. However, so far the MQL technique has used nanofluid as a viable alternative for the wet machining process. Systematically, the MQL technique uses nanofluid as the cutting fluid. There are several effects of the use of nanofluids on the machining performance parameters in various machining processes. Such as turning, cutting, drilling, etc. [2]. The cutting depth is 0.5 mm and 1 mm, with a leg speed of 0.12 mm / r and a tangential cutting speed of 800 r / min. The total cutting time was 10 minutes for all cutting tests due to investigate the wear evolution, and the tool side wear values [10].

Although high speed machining is needed to achieve higher productivity targets, tool wear limits the increase in cutting speed beyond the limit. Overheating the chisel can reduce the sharpness of the cutting edge and using blunt tools consumes more power resulting in poor surface quality. To keep the temperature within the desired limit, the heat generated around the cutting zone needs to be extracted continuously. This can be achieved with fluid cutting applications in the cutting zone [1].

One of the most important capabilities of a machine is the temperature caused by heat. Because high temperatures affect surface integrity, dimensional accuracy, tool life and tool wear, etc. [11]. There is no stable wear stage in healing wear. However, there are three stages of wear to two cuts. And the cutting process is more than 12 minutes. With the initial processing stage of about 1 minute and
then the tool enters the stable stage [12]. Although the use of MQL coolant shows that the level of air pressure and the flow rate of the coolant have little effect on the cutting force, the rate of velocity affects surface roughness [8]. With the nanofluid experiment obtained from the dispersion of nMoS2 in three vegetable oils namely coconut oil, sesame oil and canola oil when compared to dry oil, conventional cutting fluid and pure oil in terms of machining performance. It was found that the performance of the vegetable oil-based nanofluids was shown to be better than the conditions of conventional cutting fluids, pure oil, dry cutting and micro fluids in terms of reduced cutting temperature, cutting strength, surface roughness and tool wear when turning AISI 1040 steel under constant cutting conditions [3].

The use of vegetable oil can be used as an oil lubricant in accordance with the specimen or workpiece being worked on. Improved tool life, reduced tool wear and cutting forces can be mitigated by the new formulation of edible oils while investigating the same effect on surface integrity and parts accuracy during re-evaporation and tapping of AISI 316 L stainless steel. Castor oil as edible oil degradability was also found to reduce wear, grinding methods and surface roughness. Vegetable oil made from coconut oil has been shown to reduce wear and tear on AISI 304 stainless steel [3]. Conventionally, the cutting fluid can lower the temperature and act as a lubricant in turning operations. The cutting fluid function can be defined as cooling and lubrication because it can reduce heat on the workpiece, lubricate tools and prevent flood the cutting zone [13].

In general, the machining process is divided into three main phases, namely the heating phase, the usage phase and the deionization phase. Where in the heating phase, there is a high voltage EDM module in the form of a plasma channel. And the plasma channel cannot survive due to the high velocity of air flow, therefore it is necessary to process the discharging and deionization so that the results are neutral [14].

3. Ceramic Metal (Cermet) as Cutting Tool
Cutting fluid has become a way to deal with the existing air temperature during the machining process. Baradie et al [7] in another study classifying the cutting fluid together with a nanodroplet-shaped cutting fluid (NDCFs) as shown in Figure 2. Development of cutting fluids with biodegradable materials using different types of vegetable oil to improve the performance of cutting fluids in the machining process can significantly reduce the problem. Environmental damage due to use of cutting fluids with mineral materials [15].

3.1. Construction and MQL Systems
Technique emulsion can be defined as water in diesel fuel and added surfactant as an emulsifier. An emulsion can also be defined as a mixture of two insoluble liquid materials such as water and oil which can then be stabilized by an emulsifier with a certain material. There are three basic rules for obtaining a stable emulsion, namely the two liquid materials used cannot dissolve each other's liquids, then for the transfer of one liquid to another, the appropriate effect is needed and material emulsion to make the emulsion.

Primary emulsion is also known as two-phase emulsion as shown in Figure 3. The two phases are the continuous phase and the dispersed phase. The continuous phase is when water is in oil and water which acts as a continuous phase. Meanwhile, the dispersed phase is oil in water and oil which acts as a dispersed phase [17].
Secondary emulsion is also referred to as a three-phase emulsion as shown in Figure 4. Where if there is one continuous phase then two or more dispersed phases in the emulsion are called secondary emulsions. The resulting three-phase emulsion fluid is denser than the two-phase emulsion.
Figure 4. Three phases (oil in water in oil) and (water in oil in water) emulsions [17].

A double emulsion is represented by Water / Oil / Water or Oil / Water / Oil as shown in Figure 5. A double emulsion is an emulsion which contains two different internal phase droplets which have the same or different properties but also differ in size. Emulsion in water oil (Water / Oil / Water) is recommended for use in the pharmaceutical emulsion field while Oil in water (Oil / Water / Oil) is recommended for the preparation of fuel.

Figure 5. Multifunctional emulsion [17].

Oil / Water separation emulsion and emulsion water in oil (Water / Oil) uses two opposite properties, namely hydrophilicity and hydrophobicity. When the Oil / Water emulsion is filtered through the hydrophilic surface, the water phase can easily penetrate while the oil phase is rejected. Meanwhile, hydrophobicity can be used to separate Water / Oil emulsion in the oil phase which can permeate as long as the water phase is maintained. Therefore, the emulsion separation method can produce more effective and environmentally friendly oil / water [18]. The emulsion phase made by a mixture of oil and water is in the middle where the droplets settle and form an aqueous layer. The characteristics of the emulsion phase can vary with the texture of the coarse material and the types of impurities present in the oil phase. If the emulsion has entered the oil phase, this can affect the downstream processing operation while the oil leaving with the wastewater stream will require additional treatment in order to reduce the adverse environmental impact [19]. The comparison technique with dry and wet cutting is found in the depth of machine cutting. With the MQL technique, the result is that the strength of the cutting technique is reduced by 40%, the heat due to cutting is reduced by 36% and the surface conditions can be increased by 30% when compared to dry turning. The use of the MQL technique can reduce the cutting heat and the strength and surface roughness similar to that obtained by using a wet
machine. The MQL system increases tool life and increases material removal by about 40% compared to cooling water. The results of the machining process using the MQL method were found to be much better than dry machining and its use could reduce the cutting strength by 17.07% and the heat of the tip temperature to 6.72% than using dry machining. MQL with chemical compounds provides a better lubrication effect than MQL with oil from seeds. If MQL is implemented properly, it can provide a safer machine working environment and also improve the characteristics of surface roughness conditions, frictional strength and cutting strength [2].

3.2. Setting of MQL Systems
MQL can reduce surface roughness, long tool life and shaping process during milling process. MQL can cool down and show similar results with wet machining for surface roughness, tool wear and cutting forces. In the drilling process tool life can be increased by continuous MQL applications. The MQL method can also reduce environmental damage and reduce the required production costs. MQL can be applied as a solution to reduce flooding in cutting areas and can produce clean products or reduce fouling. The use of cutting fluids with the MQL method has many influences on machining processes such as turning, drilling, milling, etc. [1]. MQL in hardened steel final grinding. The cutting force affects the resulting surface conditions and tool wear. MQL will produce better engine capability in dry conditions. There have been many studies examining that MQL is very profitable if the machining process is carried out correctly. So, it can be concluded that the MQL method is better than other lubrication and cooling methods [20].

4. Characterization of Natural Cutting Fluid
As part of the cooling and lubrication functions, conventional cutting fluids when used as lubricants in machines result in various environmental problems. Although conventional cutting fluids are often used by industry in a number of applications, they can cause dangerous effects such as skin disease on machining process operators. Provide an examination of the ecological balance as it cannot destroy its characteristics. The number of cutting fluids used by manufacturing companies is around 38 million metric tons of lubricants and is used globally at an increase of 1.2% every ten years. Therefore, in order to reduce the large number of uses of conventional cutting fluids and to minimize the adverse impacts that can occur on the environment and operators. Thus, an alternative to another cutting fluid is being scrutinized by researchers. The MQL method or lubrication technique with a minimum amount is a machining process with solid lubricants and cryogenic cooling. It is an alternative to conventional cutting fluid [3].

Regulatory Parameters in the form of nozzle size, nozzle shape, oil flow speed, intake air pressure, etc. are very important for MQL applications because they affect the level of engine efficiency. The initial experiment was used for MQL parameter selection. Based on this, the results obtained in the form of a flow rate of 50 ml / hour, air pressure of 8 bar, a spray distance of 15 mm and a spray angle of 30° [11]. The MQL method is an alternative which has been found to be beneficial in terms of both machining, ecology and better production targets. The machining process using the MQL method affects the milling, drilling, turning, etc. [21].

4.1. Wet Machining or Cooling
Regarding the analysis of cutting fluids, Adler et al. [22] stated that one of the advantages of cutting fluids in machining operations is their ability to transfer heat. Heat transfer can be of great use in reducing surface friction errors, where an irregular machining surface size of the surface is generated under ideal conditions.

Another factor is the ecological effect of applying nanofluids due to their toxic nature when used as cutting fluids in machining. The researchers say that the nanofluid is obtained by mixing a small amount of nanoparticles into a base fluid that is applied to the machine by the MQL method. The result is that a very small form of mist that comes out of the spray is also environmentally friendly and has no adverse impact on human health. When converted into a small proportion of the nanoparticle
with the volume of alkaline liquid, it can be biodegradable (vegetable oil), and produce a composition that is environmentally friendly and user-friendly. Vegetable oils have various advantages such as being biodegradable, easily available in nature, and affordable. Researchers are researching cutting fluids for machining processes with materials such as coconut oil, sunflower oil, canola oil, sesame oil etc. For example, coconut oil has a high level of oxidative stability and is more than 90% saturated fatty acids. Coconut oil also has a viscosity index of 130, while its boiling point is 294ºC. Thus, with all the basic properties of vegetable oil studied exclusively there can be found an environmentally friendly alternative to conventional cutting fluids. The MQL technique also yields economic and operational advantages [3].

4.2. MQL Machining
In 2015, Das et al. [23] investigated that cutting speed turned out to have a negative effect on surface roughness performance. With a variety of existing parameters, surface roughness is basically affected by the feed and the depth of cut. Conventional use of refrigerants during machining processes can cause several technical problems in the environment. Removing the coolant in the conventional cutting fluid is an efficient solution. However, in most of the machining conditions especially the cutting depth, dry machining cannot be carried out because it can reduce the tool life. The MQL method is to spray the cutting fluid onto the tool part in an optimized manner. The results of the experiment using AISI D2 steel using vegetable oil produce environmentally friendly lubricants and the engine characteristics increase to the desired limit [1].

MQLs developed under synthetic cutting fluids are not included in petroleum products. MWF samples were prepared by dissolving four constituents, namely menthol, amorphous silicon dioxide nanoparticles, Xanthan and surfactant sodium dodecylbenzene sulfonate (SDBS). The optimal size of each constituent material is obtained by conducting experiments first. The sizes are determined while ensuring the safety limits for each element based on the material safety data sheet (MSDS). The total weight of each compound used in the MWF developed is 0.01 gram C10H20O (Menthol); 1 gram of SiO2 (silicon dioxide nanoparticles); 0.03 grams of C35H49O29 (Xanthan); 0.03 gram of C18H29NaO3S (Sodium dodecylbenzene sulfonate) for 100 ml H2O (Water) [24].

The cutting fluid used is a vegetable based on Accu-Lube LB 2000 which is recommended for the MQL technique and manufactured by ITW Chemical Products Ltd. The cutting fluid will be mixed with a solid lubricant, namely graphite and molybdenum disulfide with a concentration of 20%. The particle size of graphite ranges between 24 and 27 μm and molybdenum disulfide (MoS2) between 5 and 7 μm. The cutting fluid is sprayed onto the cutting area with an Accu-Lube measuring device manufactured by ITW Chemical Products, Ltda. With oil flow rates ranging from 10 to 200 ml/hour and a maximum air pressure of 0.6 MPa / 6 bar. Then the flow rate used was adjusted and calibrated to a size of 40 ml/hr with an air jet at a pressure of 0.5 MPa / 5 bar. A hose that is flexible and acts as a sprayer will direct the fluid mixture to the cutting area measuring from the nozzle to the end of the tool as high as 30 mm. This device will allow the oil flow velocity to properly mix in the air stream [25].

Recently a vegetable based green cutting fluid (GCF) has been developed where in the properties of GCF were measured and the storage stability as well as the anti-corrosion properties of GCF have been studied. The MQCF machining technique has several parameters such as the composition of the cutting fluid emulsion mixture, and the optimized spray nozzle angle shape. Several machining experiments were carried out using the MQCF machining technique. And the results have been compared for three different conditions such as the cutting force, the feed force, the coefficient of friction (COF) and the surface roughness of the workpiece [2]. MQL with aloe vera oil has also been used for good cooling and lubrication purposes which serves to cool and lubricate the tool as effectively as possible in the cutting zone. A medium capable of dispersing these liquid particles into the cutting zone is required for increased cooling and lubrication capabilities. Therefore, air mixed with cutting fluid and vegetable oil mixture will produce a cutting fluid that functions as a coolant and lubricant in the MQL system [26].
5. Conclusions and Further Studies
This paper provides a brief description of several experiments and findings in a systematic manner. Based on the literature review, there are many material sources and cooling techniques that have been proposed by researchers to produce better and higher quality cutting fluid products especially when handling high hardness materials. Many experimental studies also show that the choice of material for the manufacture of cutting fluid is important for each machining process.

In order to advance the cutting fluid manufacturing technology, the emulsion blending technique must be continued in depth. From the literature review, it is known that there are very few studies examining the use of nanofluids in cutting fluids. Therefore, it is suggested that there be further research on the application of nanofluids with an emulsion process to better understand the effect of nanoparticles on machining performance. In addition, it is also recommended that further studies be carried out on the technique of making cutting fluids to improve machining performance.

Acknowledgements
The financial support through grant No. 420/UN5.2.3.1/PPM/2020 is acknowledged.

References
[1] Sharma A K, Tiwari A K, Singh R K and Dixit A R 2016 Materials Today: Proceeding 3 1890
[2] Sharma A K, Tiwari A K, Singh R K and Dixit A R 2016 Materials Today: Proceeding 3 2155
[3] Padmini R, Krishna V and Rao G K M 2015 Tribology International 94 490
[4] Madan M R N and Phaneendra K C 2017 Materials Today: Proceedings 4 1057
[5] Hamid S Y, Saeed Z H, Mehdi S, Ahmad A and Ali K 2017 Powder Technology 310 213
[6] Srikant R R, Ramana P and Vamsi K 2015 Engineering Tribology: Proceeding 229 1479
[7] Baradie M A E 1996 Journal Material Process and Technology 56 786
[8] Giasin K, Ayyar-Soberanis S and Hodzic A 2016 Journal of Cleaner Production 135 533
[9] Sharma A K, Tiwari A K and Dixit A R 2016 Journal of Cleaner Production 127 1
[10] Li T, Xiong J, Guo Z, Yang T, Yang M and Du H 2017 International Journal of Refractory Metals & Hard Materials 69 247
[11] Yildirim A V, Sarikaya M, Kivak T and Sirin S 2019 Tribology International 134 443
[12] Zheng G, Zhao G, Cheng X, Xu R, Zhao J and Zhang H 2018 Ceramics International 44 6878
[13] Liew P J, Shaaroni A, Sidik N A C and Yan J, 2017 International Journal of Heat and Mass Transfer 114 380
[14] Shen Y, Liu Y, Sun W, Dong H, Zhang Y, Wang X, Zheng C and Ji R 2015 Journal of Materials Processing Technology 224 200
[15] Debnath S, Reddy M M and Yi Q S 2014 Journal Cleaner Production 83 33
[16] Sharma V S, Dogra M and Suri N M 2009 International Journal of Machine Tools and Manufacture 49 435
[17] Harsh K, Hardik B, Yuvrajsinh D and Sajan C 2019 Egyptian Journal of Petroleum 6 4
[18] Zuo H J, Yi H G, Chao W X Y, Yan C and Wan Z L 2020 Journal of Membrane Science 595 117
[19] Alshaaffi E A, Prakash A and Mercer S M 2020 Journal of Petroleum Science and Engineering 184 106
[20] Mia M, Dey P R, Hossain M S, Arafat M T, Asaduzzaman M, Ullah M S and Zobaer S M T 2018 Measurement 122 380
[21] Sharma A K, Tiwari A K and Dixit A R 2016 Journal of Cleaner Production 127 1
[22] Adler D, Hii W S, Dassisti M and Sutherland J 2006 Machining Science and Technology 10 23
[23] Das S R, Dhupal D and Kumar A 2015 Measurement 62 108
[24] Nune M M R and Chaganti P K 2019 Ceramics International 137 401
[25] Marques A, Suarez M P, Sales W F and Machado A R 2019 Journal of Materials Processing Technology 266 530
[26] Agrawal S M and Patil N G 2018 Procedia Manufacturing 20 207