A Review: The Use of Nanoparticles in Cutting Fluid as an Effort to Improve the Performance of Hard Machining in Sustainable MQL Systems

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Abstract. To obtain high machining performance on metal cutting, several supporting factors include the selection of tools and workpieces. To obtain the environmentally friendly cutting conditions known as green machining currently a minimum quantity cutting fluid (MQL / MQCL) is required. Based on the literature related to green machining problems in the material cutting process, this paper focuses on the addition of nanoparticle additives and observes aspects of operator safety and environmental pollution. The focus of selecting machining methods is in the form of dry and wet machining, the use of minimized fluids (MQL), and the use of vegetable oil as the base material for cutting fluids. The approach taken to focus attention is MQL / MQCL, the use of tools, and machinability which includes machining process parameters. Most of the studies indicated that the addition of nanoparticles to the developed cutting fluid had a significant effect on the machining performance parameters using the MQL / MQCL method. The study presented in this paper is a summary analysis of the impact of the nanoparticles on cutting fluid developed on the performance of the machining process carried out to help generate new research ideas for realizing green machining technology in the future.

1. Introduction
During the cutting process will cause heat on both sides of the cutting tool surface as well as the workpiece, this is due to plastic deformation and friction in the area of the cutting zone that occurs. One effort to reduce the heat is by adding cutting fluid when the process occurs. In the manufacturing industry, the goal achieved is sustainable production at a low cost, so cutting fluid is considered part of efforts to increase the productivity of a product. Cutting fluid contributes to increasing tool life, lowering cutting temperatures thereby increasing the dimensional quality of the cutting results as well as improving the tribological properties of the surface quality. Cutting fluid used in the machining process is generally large in volume (flood cooling) and is not easily decomposed (non-biodegradable) so that if the cutting fluid that is used up is discharged to the wild it will bring the impact of environmental pollution [1-2]. Previous researchers [3-5] reported that cutting fluids based on mineral oil as a base accounted for 16-20% of production costs and related to efforts to dispose of them, had a risk of environmental pollution (air, soil, water) with high toxicity. In addition, it is also dangerous for the health of workers / machine operators who are vulnerable to the risk of dermatitis, respiratory and...
cancer. In an effort to minimize the use of cutting fluid as well as cost efficiency the researchers tried to develop an alternative, namely the use of cutting fluid which is limited (maximum 100 mL/hour) for certain machining processes. Support the use of limited cutting fluid is done by using a system called minimum quantity lubricant (MQL) [6-7].

Application system Metal cutting in industries generally uses commercial cutting fluids, followed by the development of cutting fluids from vegetable oil based ingredients and mixtures added by nanoparticles. Sustainable manufacturing is carried out by modifying or replacing cutting fluid which is environmentally friendly and provides lubrication and cooling effects [8-9]. In an effort to optimize machining, it is necessary to consider the type of liquid with nanoparticles applied to the MQL system so that the direction of green technology in the machining process can be improved [10], so that the addition of nanoparticles can have an impact on increasing stability, thermal conductivity and pressure reduction [11]. The researchers have conducted experiments and tests related to the development of cutting fluid which is applied to the MQL system. They present with the results of work and research that refers to the effect of cutting fluid that is applied to the MQL system in other words observation due to the impact of the addition of cutting fluid which is done by considering various techniques and models of mixing basic materials and adding nanoparticles to the cutting process parameters. But it does not yet lead comprehensively to the cutting conditions and the character of the machining process in terms of the characteristics of hard machining technology which is characterized by high cutting temperatures, abrasives as well as impacting tool wear and surface roughness.

2. Cutting Fluid

The cutting fluid cools the tool and the workpiece when heat is generated during machining operations. When friction is reduced, the tool life will increase, and the surface finish of the work will be increased. The cutting fluid prevents the workpiece from excessive thermal distortion [1]. In the operation of the cutting fluid machinery is used as a lubricant and also as a coolant is also good to improve the tribological process when there is friction between cutting tools and workpieces [12] so that it helps in improving the performance of the machine and the process as a whole. The cutting fluid also functions as a medium in the effort to evacuate chips from the cutting zone and as a protection against corrosion.

2.1. Characteristics of Cutting Fluid

The main function of cutting fluid is as a coolant in order to reduce the temperature due to friction, in addition it can reduce the cutting force, feed force, surface roughness of the workpiece in an optimized system [13-14]. Basically, this cutting fluid consists of mineral oil (MO) and chemically produced performance enhancing additives. However mineral oil (MO) has adverse environmental effects and causes health hazards. Therefore, (MO) is gradually replaced by green cutting fluid (GCF) [15], according to Nune et al. [16] the properties of the developed cutting fluid are measured and compared with conventional cutting fluid which is related to density, rheology test, stability, alkali (acid) pH, and also parameter tests that affect the foam.

Cutting fluid in MQL systems generally has the property as biodegradable, high lubrication, high stability, this is due to the requirement as sustainability and low consumption [17]. Padmini et al. [18] developed an oil-based cutting fluid-based vegetable oil (Coconut Oil) with MoS₂ nanoparticles in AISI 1040 steel turning with MQL system. The investigation showed the performance of the basic properties of MoS₂ nanoparticles (0.5%) increased with the NPI in coconut oil (CC) thereby reducing the cutting force by (37%), decreasing temperature (21%), tool life (44%) and surface roughness (39%) compared to dry machining. Increased consistency in the nature of the NPI is said not to mean the same, this must be demonstrated with nanoliquid during the machining process. So that among the experiments conducted 0.5% NMoS₂ on CC is better than other lubricants, even compared with dry machining and pure oil. In line with the research for cutting fluid, Sharma et al. [19] added vegetable oil with water emulsifiers (5% O/W) enriched with Al₂O₃, TiO₂, and SiO₂ nanoparticles with six perforations differing from 0%-3%, a state of temperature differs from 25°C-50 °C. The results show the thermal conductivity
and viscosity of the three nanoparticles increases with the increase of particles at all temperatures (see Figure 1).

![Graphs showing thermal conductivity of Al₂O₃, TiO₂, and SiO₂ nanofluid at different volumetric concentration.](image)

**Figure 1.** Thermal conductivity of Al₂O₃, TiO₂, dan SiO₂ nanofluid at different volumetric concentration [19].

The histogram above shows that nanoparticles in a base fluid increase cooling capability without affecting viscosity and increasing thermal conductivity. Yasar et al. [16, 20] stated that the use of appropriate surfactants in the developed cutting fluid is useful in terms of increasing colloidal stability, so that the concentration of nanoparticles increases and is effective in heat transfer.

### 2.2. MQL/MQCL

MQL is a lubrication system by spraying lubricants and air into the cutting zone in an effort to reduce friction and increase temperatures and extend tool life. The air mixed with the lubricant forms aerosols that are sprayed at high pressure with the help of a nozzle so that it effectively reduces production costs by up to 20% [1,3]. The use of vegetable oil base cutting fluids in machining improves the surface quality of workpieces and accurate tolerances to increase production efficiency [21]. Application of the MQL system is very important in contributing to reduce dimensional deviations due to heat generated during the cutting process. Referring to the literacy of the paper submitted by Sharma et al. [3] MQL contributed to a reduction in temperature of 36% and a surface quality of 30%, resulting in an increase in tool life by 40% compared to dry machines. The improvement of the machine's performance also on
the working of AISI D2 steel by adding nano-Carbon Tube particles was carried out in the turning process [22].

2.3. MQL Construction and Systems

MQL is an alternative to the use of flood fluids in conventional processes, with precise measurements and limited use of the amount of the liquid doses agreed upon by experts, ranging from 5-50 mL / h [23] also reaching a maximum range of 100 mL/hour for a particular machining process [2,8-9]. In its application, the MQL system is to flow some liquid bursts in the form of compressed air or droplets that lead to the chip angle between the surface of the workpiece and the cutting tool. From the type of construction, the lubrication liquid feeder is divided into two basic differences namely external feeder and internal feeder as shown in Figure 2.

**Figure 2.** Basic differences between external feeders and internal feeders [3].

Most basic task of the MQL system is to provide the right liquid supply in the area where the cutting zone is taking place, so the purpose is available and classified as in Figure 3.

**Figure 3.** Classification of feeder types in MQL [6].

Addition that is applied to the external feeder system in the form of injecting nozzle in spraying the liquid is done with the ejector application on the nozzle or conventionally [24]. Using different Doppler
Anemometry Phase techniques, Rahem et al. [25] evaluated the performance of the spray nozzle parameters, each with a diameter of 2.5 mm (OD25) and 3.0 mm (OD30). From the measurement results the estimated nozzle distance has found good results in terms of cutting parameters at turning, while the suitable mist flow under the input air pressure is 0.4 MPa. In other words, the selection of 6-9 mm nozzle spacing is agreed on cutting style and cutting temperature. Meanwhile, Maruda et al. [26] proves by positioning the nozzle distance in the cutting zone by using an air blowing arrangement that can affect the size of the liquid droplets in the cutting zone. This concludes at the same time that the particle size of the liquid and the air flow affecting the wetted area are added to the distance the measurement of the nozzle in the cutting work area takes place.

2.4. MQL System Cutting Fluid

From the results of experiments carried out by Sani et al. [27] as shown in Figures 4 and 5. they studied that the effects of developed lubrication fluids were superior to MWF-based synthetic esters. Besides, MJO + ionic liquid (IL) 10% outperforms all other lubricant samples related to engine capability, so vegetable oils are believed to outperform conventional synthetic ester oils. From the results of their studies turning AISI 1045 steel with using MJO compared to SE shows that achieving an axial cutting length of 5500 mm with a total material transfer of $1.69 \times 10^3$ m$^3$ over a cutting period of 28 minutes. So that the developed fluid increases the tool life and total material transfer compared to SE. While the longest tool life of the total material transfer is a lubricant with MJO + AIL 10% with an increase of 50% and more than 36% compared to the tool of each SE lubrication. thus the ILs mixture in base oil causes an increase in lubrication even though this depends on the level of treatment at ILs.

![Figure 4](image.png)

**Figure 4.** Results of (a) tool life and (b) total material removal after MQL machining of AISI 1045 lubricated with all lubricant samples [27].
Then arithmetic averages are shown that the type of lubrication used affects the value of surface roughness. Where the surface roughness lubricated by SE and MJO shows an average of 1.70 µm and 1.66 µm while the best sample lubrication is (MJO + AIL 10%) 1.60 µm & (MJO + PIL 1%) 1.61 µm. This is shown in Figure 5.

![Figure 5](image)

**Figure 5.** Arithmetic average of surface roughness profile on machined surfaces lubricated with all lubricant samples [27].

When machining takes place with the MQL system to achieve significant efficiency, an understanding of the nature of the lubricating fluid and the properties of the coolant is required. So that researchers can determine the choice of the right lubrication fluid with the MQL method. The development of clean and sustainable production continues to be done using various methods and techniques in cutting fluids. Gajrani et al. [5] through a study he carried out, namely developing cutting fluid by comparing it to mineral oil (MO) liquids which were done with AISI H-13 steel material through the MQL system feeder technique. The results show that the coefficient of friction, cutting force, surface roughness, and viscosity significantly give better performance results. The high flash point obtained causes the liquid to become a high-performance lubricant. Correspondingly, biodegradable testing on liquids with (2005 standard method) shows that the cutting fluid developed was declared biodegradable 96.67% compared to mineral oil (MO) which was only 18.32%. This is in line with the angle setting of the nozzle by 45° so that liquid can penetrate the edges of the air limit when the engine is spinning. To optimize the performance of the cutting fluid he argues that he should pay attention to the composition of the liquid and the investigations. In this case maximizing the development of fluids with the MQL system is a serious concern in order to achieve fluid penetration which can effectively penetrate the cutting zone so that maximum results are obtained on engine performance and green machine technology.

3. Hard Machining

Hard machining is a growing trend in the manufacturing industry because it is superior in surface quality and dimensional accuracy compared to other machineries but has increased heat so as to affect machine performance. The use of minimized cutting fluid is more effective in terms of cost and environmental pollution, [28] concludes that the MQL system helps in improving the quality of the results compared to the dry or wet conditions in turning AISI 4340 with CBN cutting tool experiments. Machining of hardened steel having a hardness beyond 45 HRC was mostly tried by researchers under dry cutting conditions using ceramic tools and polycrystalline cubic boron nitride (PCBN). Low thermal conductivity and high rotational speed in hard steels lead to high cutting temperatures resulting in
workpiece yield quality, tool wear and high productivity costs, this is caused by friction that occurs between the workpiece and the cutting tool, causing heat to the zone (chip). Surface roughness that occurs affects the corrosion resistance, speed and nature of engine tribology.

Elmunafi et al. [28] evaluated the performance of castor oil as a cutting fluid performed on a MQL 50 ml/hour stainless steel (48HRC) turning system compared with dry cutting resulted in good performance in terms of tool life, surface roughness and cutting force. Whereas Sekhar et al. [29] in their experiment by turning AISI 1040 steel using a layered carbide chisel through the MQL feeder system by adding nano MoS₂ crystals, they argued that the effectiveness of adding crystal particles affects the ability of the lubricating properties and the optimal results can be achieved by suitable weight proportion. Other evidence carried out by Zhang et al. [30] by comparing various work methods, namely MQCL with vegetable oil and dry machining applied to factory work with Inconel 718, the conclusions obtained at the beginning of the experiment (Figure 6a) cutting force components are relatively similar to the cutting conditions with the MQCL system whereas in the end (Figure 6c) the cutting force with the dry method ranges from 100-650 N, the MQCL method obtained the cutting force around 30-300 N.

![Figure 6](image_url). Cutting force variations with cutting time under different cutting conditions: (a) cutting force Fx, (b) cutting force Fy and (c) cutting force Fz [30].

This shows that the cutting force component in the MQCL condition is smaller than the dry machining method. The factor is influenced by the micro-lubrication effect produced from the liquid droplets of vegetable oil (Figure 7) developed. The microdroplets in the high-speed cutting zone perform the lubrication function and minimize the frictional forces that occur (Figure 8). From the histogram of the cutting force component, it can be concluded that the tool wear propagation contributes to the increase in the cutting force on the tool. It can be categorized that to save energy on the engine,
development, and research related to efforts to reduce the frictional forces that occur in the cutting zone need to be considered to achieve the desired contribution.

Thus, it was concluded that the majority of experimental studies recorded that cooling of cutting zone by MQL, MQCL and all types of EMQL, CAMOL was a very good alternative to dry cutting compared to flood cooling, and also made machining more environmentally friendly [31].

4. Enhancement with Nanoparticles

4.1. Single Nanoparticle
MoS₂ nanoparticles have good physical properties, low coefficient of friction also has a large active surface area, reactivate and in the form of black solids. Suarez et al. [32] concluded that the use of solid lubricants mixed with MoS₂ in hard machining is an alternative as an effort to overcome challenges in machining with materials that are difficult to cut. While Zhang et al. [33] in their experiments revealed that the addition of nanoparticles such as MoS₂ produced the best lubrication conditions in the MQL system, this was due to the high levels of saturated fatty acids and forming films in palm oil.

4.2. Hybrid Nanoparticle
As an effort to take advantage of the sustainability of the cutting fluid system as a cooling medium, MQL comes with a more effective and better offer compared to the flood method. The application of MQL with the addition of several nanoparticles to a liquid is currently more promising, although further research needs to be done in an effort to improve and its effectiveness. Hybrid nanoparticles integrate the properties of two or more types of nanoparticle, so that they have better lubrication performance and heat transfer compared to single nanoparticles [34]. Mosleh et al. [35] conducted an orbital drilling experiment with a concentration of Boelubé liquid added with MoS2 nanoparticles and hBN starting at 2%-4% with the MQL method, resulting in increased character, lower friction and lower surface temperature. Muaz and Choudhury [36] investigated the hard turning of AISI 4340 steel with a coated carbide chisel with chemical vapor deposition of TiCN / Al₂O₃ / TiN using a solid lubricating liquid with the MQL technique feeder system. Four types of cutting are pure emulsion, the addition of boric acid (10% wt) with an emulsifier, graphite (10% wt) with an emulsifier, and a solid mixture with liquid. The results concluded that the low viscosity of the liquid obtained will have an impact on the work of the cutting process and lead to clean and environmentally friendly production.

Next comes the results of his work Gajrani et al. [37] developed a cutting fluid by mixing basic ingredients (coconut oil, Azadirachta indica, lemongrass, and brown sugar) with the addition of MoS₂
and CaF particles (0.3%) tested on AISI H-13 steel turning. The results show that thermal conductivity, specific heat, and viscosity are obtained with good performance results, while the addition of MoS₂ particles significantly reduces the friction that occurs on the surface of the material. Thus, the addition of MoS₂ particles is beneficial in terms of reducing the cutting force and the coefficient of friction improves the quality of surface yields, good thermal conductivity [38-41]. While Li B et al. [42] investigated the performance of six MoS₂, ZrO₂, CNT, Polycrystalline Diamond, Al₂O₃, and SiO₂ nanoparticles with palm oil as basic lubricants using the MQL method in the grinding process with Ni alloying materials, it was concluded that the addition of nanoparticles with CNT produces the lowest grinding temperature and an energy coefficient of 40.1%.

5. Conclusion and Future Works
The sustainability of green machining technology has led to the development of research on the need for manufacturing processes towards a better and environmentally friendly. This is also in line with industry needs in an effort to obtain efficient, low-cost cutting fluids in terms of production costs. In this paper the methods and characteristics of cutting fluid are used in the application of machining process technology. Cutting parameters and specifications of the liquid developed from additives are presented in order to obtain a cooling effect and achieve better machining process performance. The method presented is in the form of developing environmentally friendly cutting fluid, MQL, air cooling as well as hard machining with MQL systems. Ecologically the dry machining method is best offered but an increase in temperature in the cutting zone causes low tool life and also a large cost in production. MQL becomes an alternative to overcome this problem. The best judgment is when dry machining is correlated to MQL. Therefore, the role of viscosity in cutting fluid parameters needs to be considered, the ease of a liquid in penetrating the zone is also balanced with the ease of fluid when passing through the nozzle of the MQL system used.

From the review of several researchers in the literature that research studies conducted are oriented to the maximum results of the performance of the machining process, but further research related to the character of fluids developed based on the type of machining has not been done much, this is of concern in the future. The use of nanoparticles in the developed liquid requires further research to get the effectiveness and efficiency of the cutting fluid performance.

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