REVIEW ARTICLE

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The Emergence of MQL with Vegetable Oil as a Green Manufacturing Technique: A Review

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Abstract

For every manufacturing industry, product rejection is not tolerable. Productivity suffers because of rejection, material cost, and labor cost increases. Cutting fluids are used to protect the tool and work-piecework-piece from the damaging effects of high temperatures and poor surface finishes. Cutting fluids are used as lubricating and cooling agents. Due to cost constraints, most small-scale industries in developing nations employ conventional flood lubrication systems, resulting in increased exposure to dangerous chemicals and environmental issues. As a result of increased health concerns and rigorous government regulations, innovative methods to decrease or remove harmful cutting fluid have been developed. In this review paper, three approaches are considered while surveying the literature. Hazardous effects of the cutting fluids; comparison of dry, flood, and MQL cutting; and performance of the cutting fluids prepared using vegetable oil. It is found that vegetable oil with minimum quantity lubrication under different machining conditions gives better performance and reduces health hazards.

Keywords: Cutting fluids, Edible Oil, Vegetable Oil, Machining, MQL.

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Introduction

The productivity of any production system depends upon the tool cost, machining cost, and cutting fluid cost. Cutting fluid influences overall cost since it affects the cutting tool's performance and the job. Using the right cutting fluid extends the life of the cutting tool. This will enhance the productivity of the production system. It is, nevertheless, responsible for environmental deterioration and has a negative impact on human respiratory systems. This study reviews new approaches to minimize cutting fluid use and develop environmentally friendly cutting fluids.

Cutting Fluids: Ecological damage, Health Consequences, and Regulatory Issues

Mineral oil-based cutting fluids generate numerous environmental problems regardless of its contribution to industry growth. In the European Union, cutting fluid is consumed at a rate of nearly 32 00 tonnes per year. Waste disposal of this used cutting fluid is a prominent concern from an environmental perspective. Mineral oil is not a renewable source. They are depleting. Gases exerted from these oils also result in ozone depletion and contribute to global warming. Cutting fluid overuse poses environmental challenges such as soil contamination, eutrophication, recycling, as well as dumping difficulties. The recycling cost of the waste cutting fluid is high, as it requires separate setup and maintenance.

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Thus, mineral oil-based cutting fluids are accountable for upsetting the natural system balance. This disturbance in the natural system will definitely affect the next generation badly.

The operator's health is the most crucial factor. The operator might get skin or respiratory problems, leading to cancer. Cutting fluids might potentially expose 1.2 million employees to dangerous or chronic toxicological impacts. Pollutants such as cancerous nitrosamines, microbial agents, bacteria, fungi, klebsiella, coli, salmonella, and pseudomonas are found in the manufacturing system. These pollutants react with cutting fluid, posing health and safety risks for workers. Cutting fluid exposure causes epidermal sensitivity, erythema, corneal discomfort, and breathing difficulties.[1]

Exposure to cutting floods has been linked to the development of cancers in humans. Workers exposed to metalworking fluids had developed malignancies of the esophagus, perineum, gastrointestinal, conjunctiva, scortum, and kidneys. *Chlorinated paraffin, Nitrosamines, Ethanolamine, alkanol amines, diethanolamine, triethanolamine, and nitroso diethanolamine* are some of the chemicals found in cutting fluids, additives, and reaction products. The Environmental Protection Agency has banned the use of certain chemicals because they are carcinogenic and negatively impact DNA structure.[1][2]

One of the major causes of pollution in the environment in the industrial sector. All businesses need to adhere to the ISO-9000 quality standards, the ISO-14000.ISO-45000 guidelines. The national institute for occupational safety and Health (USA) has established a limit for metalworking fluid exposure. During the usage of cutting fluid, 0.5 mg/m^3 of metalworking fluid is permitted to be exposed. This demonstrates the government's strict guidelines for the usages of metalworking fluid.[2]

According to Bennett *et al*., exposure to fluid mist may raise pulmonary irritation, respiratory infections, asthma, and perhaps tracheal cancer.[3]

Aronson identified the primary drawbacks of flood lubrication and metalworking fluid. Cutting fluids have several disadvantages, including uncleanliness of the working environment, corrosion of machine tools, mixing lubricant and coolant, pollution, harmful gases, and biological hazards to operators. He also mentioned the necessity for extra systems for storage, pumping, purification, reprocess, a huge amount of space, cutting fluid disposal, and soil sacrilege and water adulteration. This increases the cost of the system.[4]

When cutting fluids are used in a machining operation, they typically generate an airborne mist. According to medical research, exposure to cutting fluid vapor causes respiratory problems and numerous forms of cancer.[5]

T. Simpson provides work-related hygiene data from an industrial sector examination of exposure to metalworking fluids. Grinding and drilling processes, according to research, resulted in greater risks than turning and milling in terms of cutting fluid exposure. Fluid management was found to be deficient in several organizations. Industry best practices or executive regulations for health and safety were not followed. Bacterial adulteration and endotoxin were found in significant concentrations in the mists. This study's findings helped establish industry best practices and determine the values for MWF mist and sump fluid pollutants.[6]

Cutting Fluids and Cost

The economy of the production system depends upon equipment, cutting tool, energy consumption, labor cost, cutting fluid cost.

According to King *et al*., the expenses involved with cutting fluids ranged from 7% to 17% of the entire manufacturing expenditure. Cutting fluids have a multifold cost associated with them in machining operations. The price includes the expenditure of the cutting fluid as well as the repair and commissioning of excessive fluid handling equipment.[7][8]

Blasser Inc., a global supplier of cutting fluid, undertook a review on coolant consumption in the industry. They found that the use of coolant in machining operations accounts for up to 16% of overall production costs. Figure 1 depicts the cost of cutting fluid as a proportion of the total cost. Cutting fluid costs about 8-16 percent of overall production costs, which is more than the cost of cutting tools (4 percent only). Thus elimination of the cutting fluid will result in saving money.[9]

Dry cutting, flood cutting, and MQL

P.S. Sreejith *et al*. promoted dry cutting. i.e., operations without cutting fluid. According to them, coolant and lubricant account for more than 16 to 20% of the production cost. Higher temperatures resulted from dry cutting, but the thermal shock was lessened.[10]

According to Anselmo Eduardo Diniz and Ricardo Micaroni, tool dimensions and the cutting velocity substantially impact tool life, cutting period, and surface geometry. Increased feed rate, nose radius, and decreased cutting speed during dry cutting improved tool performance and reduced surface properties. They claimed that choosing the input parameter is more important than choosing the cutting oil.[11]

Bordina, S. Bruschia *et al*. tested surface integrity on the dry turning of a CoCrMo alloy. The test work was comprised of four test runs with two machining speeds of 40 and 60 m/min and two feed rates of 0.1 and 0.15 mm/rev, respectively. The cut depth was held constant at 0.25 mm throughout the experiments, and no lubricants were used. Their research yielded some novel and intriguing findings for difficult-to-cut metals under dry circumstances, all while maintaining the metal's surface integrity.[12]

The term "dry cutting" refers to the lack of any cutting oil. It is one of the solutions to flood cutting. It is a first step in the direction of ecologically responsible production. When better machining success, improved surface quality, and extreme cutting environment are required, dry cutting fails. The increased rate of wear and the rising temperature are important concerns. As a result, dry cutting has not been proven the best option for flood cutting. Dry cutting and

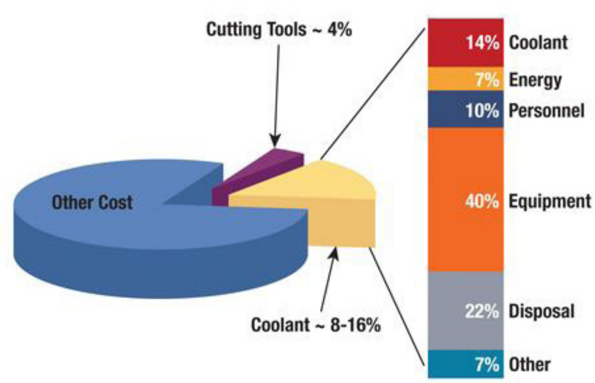

Figure 1: Cutting fluid cost[9]

flood cutting are being replaced by near-dry cutting, micro lubrication, and minimal quantity lubrication.

Emergence of new technique-MQL

Minimum Quantity Lubrication

Figure 2 illustrates the MQL System. The kit combines an air compressor, an oil tank, a mixing chamber, and a nozzle.

MQL works by injecting a jet of pressurized air and cutting fluid into the cutting tool-to-workpiece contact area. The coolant droplet is atomized by high pressure. The high-velocity air-oil jet penetrates the tool-workpiece interface area more precisely than flood cutting. This results in a decrease in temperature and a reduction of frictional forces.[14]

The Tool Manufacturing Engineers, Handbook explained four mechanisms of cutting fluid flow. Two bodies in contact with each other have a gap between them. This gap creates channels like capillaries for the flow of the cutting fluid. The capillary action aids to flow of the fluids between two nearby surfaces. The fluid particles penetrate and create bonds with the metallurgical structure of the work-piecework piece. The viscosity of a fluid is changed when it is vaporized, and the fluid is converted into vapor. The vapor phase penetrates efficiently. Capillary action and volatilization play a larger role in MQL application.[15]

McClure *et al*. proposed the concept of *micro lubrication*. The flow rate for MQL is only 50–500 mL/hr. which is very little compared to flood conditions. More than a 2 to 4 liters per hour flow rate is used in flood conditions. There was an extensive saving of cutting fluid. [McClure *et al*. 2007].[16]

The MQL systems were tested with dry and flood cutting to verify their performance in terms of different parameters. A.S. Varadararajn, PK. Philip and B. Ramamurthy (1999) compared dry and flood cutting too hard turning with restricted fluid delivery. Cutting pressures and temperatures

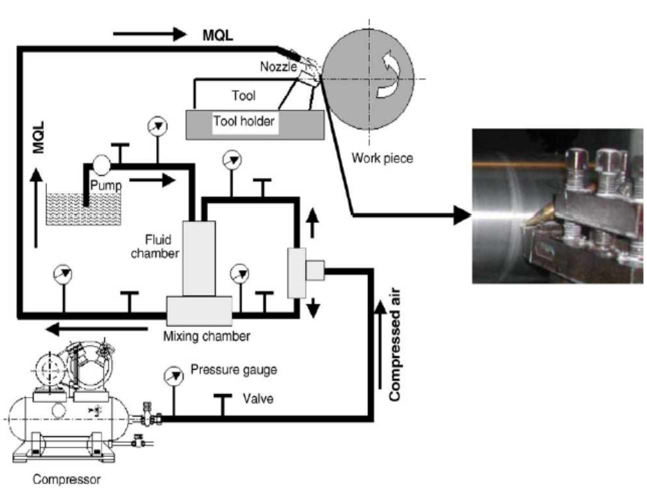

Figure 2:. Schematic of MQL system[13]
(*Source -N. R Dhar, journal of material process technology, 171(2006)93-99*)

were decreased, while tool life and surface quality were improved when MQL systems were used.[17]

Hadad *et al*. verified the influence of dry, MQL, and flood cooling environments (2013) while machining of AISI 4140 steel. The largest cutting forces were recorded during dry cutting, whereas the lowest cutting forces were found under MQL lubricating conditions. During minimum quantity lubrication, the frictional force is alleviated due to jet of air and cutting fluid.[18]

Ronan Autret and Steven Y. Liang compared the mechanical performance of minimal amount lubrication vs. dry lubrication during machining of bearing grade steel. Researchers observed that a modest quantity of lubricant lowers surface roughness, tool flank wear, and cutting temperature. There was a very minute impact on machining forces.[19]

NR. Dhar and MW Isalm conducted studies to assess the effect of MQL on cutting temperature, chip morphology, and job quality after AISI-1040 turning. As a cutting fluid, Mobil Cut-102 was utilized. The use of MQL led to a decrease in the cutting temperatures and an improvement in tool geometry. Under the MQL environment, chip production and chip–tool interaction become more feasible. Cutting forces were lowered by around 5–15% with MQL. MQL contributes to environmental friendliness while it also improves machinability.[20]

P.S. Sreejith researched the effects of various lubricants on the performance of diamond-coated carbide tools when milling 6061 aluminum alloy. A comparison of dry cutting, MQL, and flooded coolant conditions was conducted in terms of machining forces, the surface value of the machined work-piecework piece, and tool wear. The cutting speed was set at 400 m/min. The feed rate and cutting depth were set at 1.0 mm and 0.15 mm/rev, respectively. For MQL, two flow rates were used (50 mL/hr and 100 mL/hr). Tool wear and surface quality were unaffected by increasing the flow rate. The quantity of coolant has an impact on cutting forces. The MQL was found to be an effective option to flood cutting environments.[21]

Tasdelena, T. Wikblomb, and S. Ekered *et al*. explored the influence of oil droplets and air in the aerosol at MQL cutting. The trials were run at 155 m/min with a 0.11 mm/rev feed rate. The tests were carried out in three different environments: dry, compressed air, and emulsion. In connection to the findings, tool attrition, chip contact, forces, and surface integrity were investigated. Cutting using compressed air resulted in a reduced surface quality. Emulsion generated longer chips than MQL and air-assisted drilling.[22]

MCS. Alves and colleagues investigated the effects of MQL and traditional cooling on grinding operations. The performance of the work-piecework piece was assessed using specific energy, radial cutting force, surface roughness, cylindricity errors, acoustic emission, residual stresses, micrographs, and microhardness. The optimized and MQL techniques were used to improve hardness and surface integrity.[23]

Various input parameters like cutting velocity, feed, and depth of cut and their effect on surface finish and other performance parameters were studied by Kedare S. B *et al*. End milling were done with an end mill cutter under the minimum quantity lubrication condition (900 mL/hr). It was compared to standard flooding lubrication (2 liters per minute). The surface finish has been increased by 27%. The MQL provided advantages by lowering the interface temperature, which improved cooling and resulted in a superior surface finish.[24]

Vegetable Oil as a substitute for Mineral Oil

Vegetable oils are agricultural products that the crushing of seeds can obtain. They can be genetically engineered and grown. They are nontoxic, renewable, and biodegradable. Their viscosity, boiling temperature, and flash point are all high. The primary constituents of vegetable oils comprise triacylglycerols, polar lipids, and polyisoprenoids. Triglycerides are long chains of fatty acids. The vegetable oil's triglyceride structure offers high viscosity and good boundary lubrication. (MMA. Khan, Mithu *et al*.). Vegetable oil contains a long, hefty dipolar molecule that produces a strong, uniform film. They can be employed in high-temperature applications because of their high flash point. Evaporation and misting losses are significantly reduced because of the higher boiling point and molecular weight.[25]

According to I. Shyhaa, S. Gariania, and M. Bhattia *et al*. vegetable oils provide strong degradability, high lubricity, eco-friendliness, additive compatibility. They are nontoxic, volatile, highly flammables, and highly viscous.[26]

R.B. Brown and L. Ottena (1992) calculated thermal parameters such as thermal conductivity and convective heat transfer coefficient for white bean and soyabean seeds. The thermal conductivity of soybean seeds ranges from 0.211 to 0.221 W/M°C. The heat transfer coefficient for soybean seeds was 131 W/M^2 °C, while it was 106 W/M^2 °C for white beans.[27]

The fatty acid composition of any vegetable oil is an essential feature that determines the oil's lubricating effectiveness. Sodamade A, Oyedepo T. A, and Bolaji analyzed the fatty acid content of soybean oil, groundnut oil, and coconut oil. The main saturated fatty acids in the oil are palmate acid (C16; O), stearic acid (C18; O), and oleric acid (C18:1). Coconut oil consists of 2.09%, 8.584% of palmate acid and stearic acid, respectively. Soyabean oil has 1.496% stearic acid. All three acids are found in groundnut, palmate acid, stearic acid, and oleic acid (4.76, 12.75, and 12.72%), respectively. Polyunsaturated (essential) fatty acids are also called linoleic acid (C18:2 Omega-6). Myristic acid (C14: O) was the most abundant soyabean and coconut oils component, accounting for 41.039 percent and 33.544 percent, respectively. Lauric acid (C12: O) is groundnut oil's most abundant fatty acid.[28]

Ester C. de Souza *et al*. (2013) investigated the cooling heat transmission capabilities of old and unaged vegetable oils. In comparison with petroleum oil, soybean, canola, corn, cottonseed, and sunflower oils have less oxidative stability, whereas peanut (groundnut) oil and coconut oil exhibit better properties due to their more appropriate molecular configuration. The quenching performance of a variety of vegetable oils was evaluated.[29]

According to Fox and Stachowaik, one of the distinctive qualities of plant oils necessary to be lubricants is the triglyceride structure. Long, polar fatty acid chains result in lubricating coatings with great strength. This lubricating film reduces friction. The inter-molecular bonds are also resistant to temperature fluctuations, resulting in a more viscosity, or high viscosity co-efficient. However, VBCFs are prone to oxidation and have weak thermal stability. VBCFs formulated with chemical additives in the cutting zone had a reduced coefficient of friction, corresponding scuffing load capacity, and superior pitting resistance.[30]

Sharafadeen Kunle Kolawole, Jamiu Kolawole Odusote, and colleagues evaluated the ability of palm, groundnut, and mineral-based oils to cut mild steel machining. To enhance the antioxidant capacity of the vegetable oils, a vitamin-C-rich citrus fruit extract was added as an antioxidant. Groundnut oil was found to have superior fluidity and a more rapid cooling rate than other oil samples.[31]

Minimum Quantity Lubrication by Vegetable Oil

The machining performance is improved by using a small amount of lubricant. Cutting fluid cannot be removed with MQL. Vegetable-based oil with MQL has been developed as a more sophisticated machining technology.

M.M. Khan *et al*. studied the influence of vegetable oil on cutting temperature, wear rate, surface quality, and tool dimensions in MQL turning of AISI-1060 steel. The author listed the various characteristics of vegetable oil. Non-toxicity, biodegradability, and environmental friendliness were the advantages over mineral-based oil. Testing was done at various speeds (72, 94, 139, and 164 m/min). Feed rates of 0.10, 0.13, 0.16, and 0.20 mm/rev were employed. The cutting depth was kept constant at 1.5 mm. Flank wear, dimensional inaccuracy, and waviness were significantly reduced using MQL. The cutting forces were lowered by 5 to 15%. This was owing to a reduced cutting tool temperature and a better chip-tool-work interface.[32]

Sunday Albert Lawal *et al*. assessed the performance of cutting fluid derived from fixed oil like peanut oil, palm kernel oil, palm oil, and mineral oil. The primary test parameters used to assess performance were temperature and heat generated by cutting fluid. They observed that peat oil gave a superior performance.[33]

SA Lawal, I.A. Choudhury, and colleagues examined the use of metalworking fluids developed from vegetable oil in ferrous metal machining. Performance of metalworking fluids on cutting force, work-piecework-piece material surface quality, tool geometry, and temperature in the cutting area has been considered. The performance of A304 austenitic stainless steel, AISI 1040 steel, AISI 9310 alloy steel, mild steel, AISI 316L austenitic stainless steel, 100Cr6 Alloy, and AISI 4340 steel was evaluated by the author.[34]

Sultana and N.Dhar evaluated the effects of several cutting fluids, such as water-soluble cutting fluid, plant oil, and VG68 cutting oil, on cutting force and surface roughness while converting 42CrMo4 steel. Due to improved cooling and lubrication, VG68 oil performed best at high cutting speeds. The MQL with VG68 oil reduced the temperature by 6 to 12.5% while increasing the chip thickness ratio by 14 to 17%.[35]

Arumugan S and Sriram G synthesized palm oil, sunflower oil, and rapeseed oil methyl ester. Epoxidation and hydrolation were used to modify raw rapeseed oil chemically. Epoxidised rapeseed oil had better oxidation stability, a lower pour point, and less friction than untreated rapeseed oil.[36]

Babatunde Lawal *et al*. evaluated shea butter oil, black soap, groundnut oil, palm oil as lubricants. When evaluated experimentally using a ring compression test, red palm oil was shown to have a significant coefficient of friction.[37]

Gaurav Arora, Ujjwal Kumar, and Papiya Bhowmik employed sunflower oil, coconut oil, castor oil, and mineral oil. They calculated the surface irregularity of aluminum (AA1050) and found that vegetable oil outperformed conventional oil. Using the same machining parameters, a comparison analysis of turning experiments was done between vegetable oil and mineral oil. The findings revealed that vegetable oils, particularly non-edible ones, could be used instead of mineral oils.[38]

Carlos Alberto Schuch Bork *et al*. investigated jatropha, a non-edible oil plant. He discovered that jatropha oil performed the best as per lubricating requirements. It also provided a 30% boost in tool life.[39]

Mohd Saad Saleem *et al*. applied mustard oil as a coolant during the machining. The results were compared to standard coolants such as a mixture of boric acid and SAE-40, molybdenum disulfide, and SAE-40 for tool life and wear. The mustard oil effectively removed heat and provided adequate lubrication. The amount of friction and wear was significantly decreased. The tool's life and finish were both enhanced.[40]

All of the researchers emphasized the benefits of employing MQL in machining operations with various cutting fluids such as soybean, coconut, groundnut, palm oil, canola oil, mustard oil, and jatropha. However, the oxidation stability of vegetable oil as a cutting fluid is a major problem. The MQL system, which uses edible and non-edible oil as a cutting fluid, is still a new research topic that has to be investigated.

Conclusion

People are becoming more health-conscious as a result of health risks. Efforts were made to reduce the application of cutting fluid.

MQL was developed through a series of changes such as dry cutting, air-cooling, spray cooling, near dry machining, and micro lubrication. It was found that MQL effectiveness with dry and flood lubrication was considerably superior to that of flood or dry cutting.

Small-scale firms are unaware of technological advancements in the production area. The main hindrances to the industry's expansion are illiteracy at work and a casual attitude toward employee health. Since existing minimum quantity systems are unaffordable, there is a need to design a low-cost MQL system that small industrial units can deal with.

Government restrictions and health concerns mandate that mineral-based cutting fluid be completely phased out. Various vegetable oils are evaluated as cutting fluids, and the findings reveal that these oils have a lot of promise in various applications. However, further research is needed to create a new cost-effective process for cutting fluids from vegetable oil.

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