



Vegetable Oils as Metal Cutting Fluids in Machining Operations: A Review

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Abstract Cutting fluids in machining operations produce three prime positive effects, heat evacuation, lubrication on the chip–tool interface and chip removal. However, growing environmental concerns such as renewability, biodegradability, safety and health of operators pose great concern over the use of conventional mineral oils as cutting fluids. These give vegetable oils the advantage to serve as lubricants for industrial applications since they offer significant environmental benefits with respect to resource renewability, biodegradability, as well as providing satisfactory performance in a wide array of applications. Many researchers have explored the use of vegetable oils as lubricants in metal cutting. This work presents a review on performance evaluation of different types of vegetable oils as cutting fluids in the machining operations. Generally, vegetable oils have been found to be good alternative to the conventional mineral oils as cutting fluids in terms of temperature reduction, tool wear, force and surface roughness during various machining operations.

Keywords biodegradability, vegetable oil, cutting fluid, temperature

1. Introduction

Machining is a process designed to change the size, shape, and surface of a material through removal of materials that could be achieved by straining the material to fracture or by thermal evaporation. Machining offers important benefits such as excellent dimensional tolerances, sharp corners, grooves, fillets, various geometry, and good surface finish. The three principal machining processes are turning, drilling and milling. Other operations falling into miscellaneous categories include shaping, planning, boring, broaching and sawing [1]. During machining operation, cutting or machining fluids are applied between the cutting tool and workpiece interface.

1.1 Cutting Fluids

Cutting fluids also known as metal working fluid (MWF), coolants, cutting oils, machining fluids or lubricants, are fluids used in manufacturing industries as coolants and lubricants, designed specifically for metal working and machining processes. Cutting fluids are used to reduce the negative effects of heat and friction on both tool and work piece [2].

Historically, the use of cutting fluids in metal cutting was first reported by F. Taylor in 1894. He observed that cutting speed could be increased up to 33% without reducing tool life by applying large amounts of water in the cutting zone [3]. The cutting fluids produce three positive effects in the process of machining, heat evacuation, lubrication on the chip–tool interface and chip removal [4]. Higher surface finish, quality and better dimensional accuracy are also obtained from cutting fluids [5].



1.2 Types of Cutting fluids

Cutting fluids are usually classified into four main categories: straight oils, water soluble oils, synthetics, and semi-synthetics oils.

i. Straight Oils

Straight oils, so called because they do not contain water, and are basically petroleum, mineral based oils. They may have additives designed to improve specific properties. The major advantage of straight oils is the excellent lubricity they provided between the workpiece and cutting tool. However, these are particularly useful for low speed, low clearance operations requiring high quality surface finishes [6]. They are used without dilution and have good lubricating properties, as well as good corrosion protection and resistance to biodegradation, but their cooling abilities are the weak in comparison with other types of metal working fluids (MWFs) [7].

ii. Soluble Oils

Soluble oils are also called emulsions, water-soluble oils or emulsifiable oils a soap-like material. They are generally comprised of 60-90 percent petroleum or mineral oil, emulsifiers and other additives. When mixed, emulsifiers cause the oil to disperse in water forming a stable “oil-in-water” emulsion. Soluble oils offer improved cooling capabilities and good lubrication due to the blending of oil and water [6]. They tend to leave a protective oil film on moving components of machine tools and resist emulsification of greases and slide way oils. However, the presence of water makes soluble oils more susceptible to rust control problems, bacterial growth and rancidity, tramp oil contamination, and evaporation losses. Soluble oils are usually formulated with additives to provide additional corrosion protection and resistance to microbial degradation. Maintenance costs to retain the desired characteristics of soluble oil are relatively high [8].

iii. Synthetics Fluids

Synthetic fluids contain no petroleum or mineral oil base and instead are formulated from alkaline inorganic and organic compounds. Synthetic fluids can be further classified as simple, complex or emulsifiable synthetics based on their composition [9]. Simple synthetic concentrates (also referred to as true solutions) are primarily used for light duty grinding operations [6]. Due to their wettability, good cooling and lubricity, emulsifiable synthetics are capable of handling heavy-duty grinding and cutting operations on tough, difficult-to-machine and high temperature alloys [8]. Although synthetics are less susceptible to problems associated with oil-based fluids, moderate to high agitation conditions may still cause them to foam or generate fine mists. A number of health and safety concerns, such as misting and dermatitis, also exist with the use of synthetics in the shop. Ingredients added to enhance the lubricity and wettability of emulsifiable synthetics may increase the tendency of these fluids to emulsify tramp oil, foam and leave semi-crystalline to gummy residues on machine systems, particularly when mixed with hard water [6].

iv. Semi-synthetics Fluids

Semi-synthetic fluids also referred to as semi-chemical fluids, are essentially a hybrid of soluble oils and synthetics. They contain small dispersions of mineral oil, typically 2 to 30 percent, in a water-dilutable concentrate [6]. Semi-synthetics are suitable for use in a wide range of machining applications and are substantially easier to maintain than soluble oils. They have better cooling and wetting properties than soluble oils, allowing users to cut at higher speeds and faster feed rates and provide good lubricity for moderate to heavy duty applications. Semi-synthetics provide better control over rancidity and bacterial growth, generate less smoke and oil mist (because they contain less oil than straight or soluble oils), have greater longevity, and good corrosion protection. However, water hardness affects the stability of semi-synthetics and may result in the formation of hard water deposits. They also foam easily because of their cleaning additives and generally offer less lubrication than soluble oils [9], [8].

1.3 Conventional Mineral Oils

In 2002, an estimated annual growth rate of 7 – 10 % for environmentally benign lubricants was expected on the US market for few years compared to a rate of only 2 % for the overall lubricant market [7]. Reports indicate



that nearly 38 million metric tonnes of lubricants were used globally in 2005, with a projected increase of 1.2% over the next decade [10]. Due to their advantages, the consumption of metal working fluids (MWFs) is increasing in machining industry. It is reported that European Union alone consumes approximately 320,000 tonnes per year of MWFs of which, at least two-thirds need to be disposed [7]. Hence, the awareness of the hazardous effects caused by the use of mineral oil based lubricants has resulted in legislations to regulate the usage of lubricants in countries like Austria, Canada, Hungary, Japan, Poland, Scandinavia, Switzerland, U.S.A, and E.U [10].

1.4 Current Challenges Associated with Conventional Cutting Fluids

Conventional metalworking fluids are complex chemical formulations tasked to perform multiple functions in the machining process [11]. Despite their widespread use, they pose significant health and environmental hazards throughout their life cycle.

a. Human Hazard

Research reports [12, 13] indicate that about 80% of all occupational diseases of operators were due to skin contact with MWFs. Estimation says that in the USA alone about seven hundred thousand to one million workers are exposed to MWFs [10]. As cutting fluids are complex in their composition, they may be irritant or allergic. Even microbial toxins are generated by bacteria and fungi present, particularly in water-soluble MWFs, which are more harmful to the operators [14]. Typical health problems of metalworking machine operators resulting from inhalation exposure to liquid aerosol from the process fluids include respiratory diseases (asthma, chronic bronchitis, and hypersensitivity pneumonitis), cancer, allergies, and skin diseases [15]. To overcome these challenges, various alternatives to mineral-based MWFs are currently being explored by scientists and tribologists. Approximately 85% of lubricants being used around the world are mineral-based oils [16].

b. Degradability and Environmental Hazard

Biodegradability of any component is the ability to decay by microorganism. A lubricant is classified as biodegradable if its percentage of degradation in a standard test exceeds a certain marked level [16]. Enormous use of mineral based oils, created many negative effects on environment. The major negative effects is particularly linked to their use, which results in surface water and groundwater contamination, air pollution, soil contamination and consequently, agricultural product and food contamination [17].

Hence, there is a growing public interest in environmentally friendly lubricants due to awareness of environmental problems associated with conventional mineral oil-based lubricants [14]. Even though the toxicity of lubricants is low, their accumulation in the environment may cause damage in the long run. A large proportion of the lubricants pollute the environment either during or after use. In many countries, there are well defined guidelines and legislations for environmentally friendly lubricants [18]. Several organizations around the world are working to improve such lubricants by evaluating their potential for environmental hazard. Examples include the German “Blue Angel”, USA “Green Seal”, and Canadian “Environmental Choice” [19]. Mineral oil-based lubricants contain many kinds of additives such as antioxidant, anti-wear, detergents, dispersants, anti-foams, extreme pressure agents, friction modifiers and viscosity improvers. Some of these additives are toxic and harmful to human health, wildlife and environment [20]. The environmental and toxicity issues of mineral oil-based lubricants and their additives as well as their rising cost related to a global shortage have led to renewed interest in the use of vegetable oils, such as soybean oil, canola oil, sunflower oil, coconut oil, sesame oil, castor oil etc. as environmentally friendly lubricants and industrial fluids [21], [22].

c. Other challenges include

- i. Un-renewability – this is the ability of the fluid not to be renewed once when used.
- ii. Foaming - which is usually created as a result of entrainment of air in a fluid through chemical or mechanical process.
- iii. All conventional fluids have a “minimum concentration” level, which must be adhered in order to maintain bio-stability, good corrosion protection and cutting performance. The fluids are formulated to work within a specific concentration range. If this concentration level is allowed to drop below minimum level for any given length of time, various problems such as bio-instability and bio-mass development, low pH, corrosion of ferrous alloys (red rust),



emulsion splitting, poor cutting performance and ultimately the metal removal fluid disposal can arise [11].

1.5 Prospects - eco friendly and biodegradable lubricants

With the above knowledge of the MWFs of mineral oil accompanying challenges, lines of thinking have been in progress world over in making use of vegetable oil based lubricants, which are liquid agricultural products and are produced from plant and cash crops. These are highly attractive substitutes for petroleum based oils because they possess naturally occurring high viscosity and high flash point, in addition to being renewable, biodegradable and non toxic [23].

The use of vegetable oil in metal working applications alleviates problems faced by workers such as skin cancer and inhalation of toxic mists in the working environment. Such lubricants have the tendency to get ingested and metabolized by microorganisms, thus achieving complete biodegradability and thereby return to nature [24].

By progressively enhancing the usage of vegetable oil based metal working lubricants, energy security for the countries that use them will be obtainable and such a situation will help to create local and regional economic development opportunities [25]

The Rheological properties of various vegetable oils are presented in Table 1.

Table 1: The Rheological properties of various vegetable oils

	Castor oil	Coconut oil	Rapeseed oil	Neem seed oil	Cotton seed oil	Palm kernel oil	Groundnut oil	Water melon seed oil	Orange seed oil	Pumpkin seed oil
Kinematic Viscosity at 40°C (cSt)	220.60/258	36.20	45.60	68.03	33.50	35.75	38.00	-	91.21	93.18
Kinematic Viscosity at 100°C (cSt)	19.72/48.54	6.76	10.07	10.14	-	7.37	8.42	8.56	-	-
Viscosity index	220	130	216	135	-	179.7	207.6	-	-	-
Saponification value (mgKOHg⁻¹)	180.00	248-265	180.00	166.00	-	-	-	200.50	190.32	189.29
Total acid value (mgKOH⁻¹)	01.40	-	1.40	23.00	-	-	-	3.25	8.20	7.59
Iodine value (mgI g⁻¹)	87	6-8	104	66	-	-	-	142	141	104
Pour point (0°)	-27.0	20	-12.0	8.0	-15.0	21.0	-12.0	-8.0	-	-
Flash point (0°)	250/349	240	240	248	234	250	320/328	117	151	-
Fire Point	366	329		285	342/357	341			173	

Source: [1], [26], [27], [28] and [29].

2. Performance of Vegetable Oil Based MWFs In Metal Cutting - Reports Of Study

Ademoh, *et al.*,(2016) [30] investigated the performance of neem seed oil as an alternative metal cutting fluid in machining operation using mild steel at three different values each of cutting speeds, depth of cut and oil ratios. The results obtained indicated that neem seed oil has good physicochemical values that can compete with the conventional soluble oil. Cooling effect was found to be comparable at different oil ratios and speeds, but dry machined surfaces produced the least cooling effect with the highest temperature rise. In conclusion, neem was found to perform slightly better than the soluble oils in most of the test results in respect to temperature reduction and surface roughness quality.



Ademoh, *et al.*, (2016) [31] also carried out the comparative performance of neem seed oil, water melon seed oil and soluble oils as metal cutting fluids in a turning operation using mild steel. Some physicochemical properties relating to cutting fluids were also investigated. The least temperature of 37.33°C was obtained while machining with 25% neem seed oil and 75 % water emulsion. All the oils–water emulsion ratios were effective as coolants comparable to the conventional cutting oil tested. It has been established that environmental-friendly vegetable-based oils can successfully replace petroleum-based mineral oils as cutting fluids. They concluded that with slight modifications and deliberate manipulation of some of components of the oils, even better performing cutting fluids can be obtained.

Xavior and Adithan, (2009) [6] determined the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel. They performed turning operation by using AISI 304 work piece material. They used three different oil based cutting fluids; namely coconut oil, soluble oil and straight cutting oil. They concluded that feed rate affects surface roughness and cutting speed affects tool wear with coconut oil as a better cutting fluid than the conventional mineral oils in reducing the tool wear and surface roughness.

Yakubu and Bello, (2015) [32] evaluated the neem seed oil as a cutting fluid in orthogonal machining of Aluminium manganese alloy (Al-Mn) in turning operation. The oil was used as a cutting fluid to machine aluminium manganese alloy 3003 in a centre lathe machine under varying parameters (Spindle, depth of cut and feed rate). Carbide tool insert grade SNMG 120408-QM H13A was used as the cutting tool. The results of the neem seed oil in terms of the surface rough, tool wear were compared with that of the soluble oil and ‘dry’ machining. Based on the obtained results, the neem oil reduced the surface roughness better and gave the lowest flank wear when compared to soluble oil and dry machining. It was concluded that the neem seed oil is not only suitable for cutting fluid, but it is more effective than the soluble oil as a cutting fluid.

Elmunafi, *et al* (2015) [33] evaluated the performance of Minimal Quantity Lubrication (MQL) using castor oil as cutting fluid. The workpiece was hardened stainless steel 48 HRC. Results were compared with dry cutting. It was found that using small amount of Castor oil of 50 ml/h during the particular turning process produces better results compared to dry cutting, in terms of longer tool life. Surface roughness and cutting forces were also enhanced albeit slightly. From the results, it was concluded that MQL using castor oil can be a good technique for turning hardened stainless steel using coated carbide cutting tools for cutting parameters of up to 170 m/min cutting speed and 0.24 mm/rev feed.

Obi, *et al.*, (2013) [34] conducted a verification of some vegetable oils (palm, groundnut, shear butter and cotton seed oil) as cutting fluid for Aluminium. The oils are all used as lubricant in a turning operation under varying spindle speeds, feed rates and depth of cut. The parameters investigated are the chip thickness ratio, surface finish and surface temperature. Their performances when compared with the conventional soluble oil have shown that they can perform the same functions as imported ones in the machining of aluminium. They reduced chip thickness ratio, improved surface finish and exhibited good cooling behaviour at the work piece-tool interface. This performance is due to their high viscosities and the presence of surface active agents such as *stearic* acid and halogens, such as chlorine which help to reduce surface energy of a liquid and increase its wetting ability or oiliness

Ojolo *et al.*, (2008) [35] investigated effect of some vegetable based oils on cutting force during cylindrical turning of mild steel, aluminium and copper. The results showed that bio oils are suitable as metal cutting fluids but that the effect of bio-oils on cutting force were material dependent. Groundnut oil exhibited the highest reduction in cutting force when aluminium was turned at a speed of 8.25m/min and feed rate of 0.10, 0.15 and 0.20mm/rev respectively. Palm kernel oil had the best result when copper was turned at feed rates lower than 0.15mm/rev. However, at higher feed rates, groundnut oil gave best result in copper turning. Coconut oil gave the highest cutting force in all three materials machined, followed by shear butter. They were very mild in reducing cutting force during cylindrical turning. Though the lubricating and cooling action was material dependent, groundnut oil was best amongst the four bio-oils investigated.

Adebisi, *et al.*, (2010) [36] analysed the effect of cutting fluids on the mechanical properties of mild steel in a turning operation. Turning was done under dry condition and also using three coolants. It was found that Palm



kernel oil performed very well the specific functions of soluble oil as cutting fluid which includes good chip formation, reduction of heat generated and realization of a good surface finish.

Fairuz *et al* (2015) [37] Investigated chip formation and tool wear in drilling process using various types of vegetable-oil based lubricants. Their work represents the machinability of using several possible vegetable oils as cutting fluid in term of chip formation and tool wear during drilling operation on stainless steel, AISI 316. The performance of the vegetable oils which include palm oil, sesame oil, olive oil and coconut oil were compared under minimum quantity lubrication (MQL) technique. In term of highest and uniform chip thickness and least wear on the drill bit, the result obtained revealed that the coconut oil indicates the best machinability, followed by palm, olive and sesame oil. Furthermore, the viscosity measurement of the oils indicates that coconut oil has the lowest value which can possess better fluidity and faster cooling capacity than other oils. In conclusion, coconut oil was recommended as viable alternative lubricants during drilling of stainless steel.

Chandrakar and Suhane (2014) [38] studied the prospect of vegetable based oils as metal cutting fluids in manufacturing application. They authors were able to showed that lubricants provide smooth operation between movable parts of all machines. It maintains the reliability of machine functions and reduces the risk of failures. Vegetable bio-lubricants are non-toxic, degradable, and renewable also possess good lubricating properties. The authors reviewed papers on edible oils as cutting fluids. While in few papers non-edible oils such as castor, Karanja, Mahua were used and proved to have a great potential as lubricant for some of the machining operations.

Kolawale and Odusote (2013) [39] evaluated performances of vegetable oil-based cutting fluid in mild steel machining. The vegetable oils used were palm oil and groundnut oil. When compared with that of mineral oil based cutting fluid during machining operation of mild steel, it was discovered that Palm oil gave the overall highest thickness of 0.27mm probably due to its better lubricating property followed by the groundnut oil. It was also found that viscosity of groundnut oil-based sample was lowest and the range was closest even at very high temperature. Based on these results, they concluded by recommending groundnut oil and palm oil as variable alternative lubricants to the mineral oil during machining of mild steel.

Kuram *et al* (2012) [40] carried out the performance analysis of developed vegetable based cutting fluids by D-optimal experimental design in turning process. They work focused on formulation and machining of vegetable-based cutting fluids (VBCFs). Performances of three VBCFs developed from crude sunflower oil, refined sunflower oil, refined canola oil and commercial semi-synthetic cutting fluid are compared in terms of tool wear, thrust force and surface roughness during drilling of AISI 304 austenitic stainless steel with HSSE tool. Experimental results show that canola based cutting fluid gives the best performance due to its higher lubricant properties with respect to other cutting fluids at the constant cutting conditions.

Lawal *et al* (2011) [41] conducted a review on the application of vegetable oil-based metal working fluids in machining of ferrous metal. The authors focused on the performance and environmental impact of these vegetable oils as emulsion and straight oils for various materials and machining conditions. They concluded that Coconut oil showed the best performance when compared to mineral oil on turning of AISI 304 austenitic stainless steel. When vegetable oil was applied to turning of AISI 9310 alloy steel using MQL mode of application, they observed a remarkable improvement of metal removal rate (MRR). High productivity means that higher feed rate was achieved when vegetable-oil-based metalworking fluid was used.

Khan *et al* (2009) [42] studied the effects of minimum quality lubrication (MQL) by vegetable oil based cutting fluid under turning operation of low alloy steel AISI 9310. The results were compared with completely dry and wet machine in terms of tool-chip interface temperature, chip formation mode, tool wear and surface roughness. Results show that MQL by the vegetable oil provides environmental friendliness and improves the machinability characteristics.

Nyior (1994) [43] investigated the performance of some vegetable oils (Palm, groundnut, Soybean and Shear butter oils) as lubricants for cold extrusion of Aladja ST 60-02 structural steel and found out that they all performed better than the standard zinc phosphate/sodium stearate lubricant.

Obi and Oyinlola (1996) [44] investigated the frictional characteristics of Palm and Shear butter oils in wire drawing operation. They observed that Palm oil performed better than the standard sodium stearate drawing lubricant. They also established that physicochemical properties of these oils (especially iodine and fatty acid



values) enhanced their performance and that large amount of lubricating agents such as Palmitic and oleic acids were reported to give better performance advantages in wire drawing.

Obi (2000) [8] evaluated the lubricity assessments of vegetable based oils in some metal forming processes. He concluded that their performances varied in the order of groundnut oil, Palm kernel oil, Palm oil and Shear-butter in respect to tool wear measurement, surface roughness and chip rate formation.

3. Conclusion

Several researches have indicated that vegetable based oils could effectively replace conventional mineral oils as mineral working fluids. This study outlined the disadvantages associated with using conventional mineral oils as cutting fluids and also revealed the prospects of vegetable oil as cutting fluids. Vegetable oils show promising scope of their emergence as metal working fluids in terms of temperature reduction, tool wear, force and surface roughness during various machining operations.

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