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A Review on Sustainable Eco-friendly Cutting Fluids

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Abstract: In machining industries, cutting fluids plays a vital role as they are used to improve machinability and to have better productivity. Using mineral oil as cutting fluids has a negative impact on environment and also on the operator's health as it is non-bio-degradable and hazardous. Research work is been carried out for replacing these mineral oils by bio-degradable oils. The few vegetable oils possess characteristics of good cutting fluids such as viscosity, heat absorption capacity, fatty acid chains, biodegradability, non-toxicity etc. This paper reviewed research works carried out on different types of eco-friendly oils used as cutting fluids for different machining operations and on different materials. The effects of using different vegetable oils as cutting fluids on machining parameters have been discussed. From the results, it was observed that, the bio-oils possesses properties of good cutting fluids and has shown better results in terms of improving machining efficiency when compared to mineral or petroleum oils. These bio-oils possess better sustainability and biodegradability. Hence also called as eco-friendly cutting fluids. There is more scope for modification of bio-oils by having some additives and nano particles to have improved lubricating properties.

Keywords: *Bio-degradable oils, Cutting fluids, Flooded cooling, Machining operations, Mineral oils, MQL*

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1. Introduction

The key objective of any Industries is to deliver finished goods as per the customers' requirements. In machining Industries, to deliver finished goods, raw metals are processed under various machining operations. During machining, the friction takes between work piece and tool which will lead to increase in heat at the machining zone. The heat generated will lead to tool wear and increases surface roughness of work piece. To minimize this heat generation between work piece and tool, cutting fluids were introduced in early 1900 (1984) which was reported by F.Taylor i.e. application of large amount of water as cutting fluid can increase 33% of cutting speed without affecting the tool life (Jeevan & Jayaram, 2018).

Later, lot of research works were carried out on different types of cutting fluids and mineral or petroleum based oils as cutting fluids. Majority of industries were using petroleum based oils as cutting fluids for machining. But, it was observed that, the use of mineral based cutting fluids had negative impact on health related issues of operators like skin diseases, as well as environment pollution because of their non-biodegradability. To overcome these problems and to have green manufacturing system, the research work has been focused on eco-friendly cutting fluids. The property of eco-friendliness and biodegradability was found in vegetable based oils and therefore the vegetable based oils have gained attention to use as cutting fluids.

2. Literature Review

2.1. Vegetable based cutting fluids

Many researchers were started working on vegetable based oils which can be used as cutting fluids and have potential to replace mineral based oils. Lawal et. al. (2011) reviewed the application of vegetable oils as metalworking fluids in machining ferrous metals. The paper highlighted the advantages and disadvantages of using vegetable oils as cutting fluids which was given by Shashidhara et al. (2010) is shown in Table 1.

Table 1: Advantages and disadvantages of vegetable oils as lubricants (Shashidhara & Jayaram, 2010).

Advantages	Disadvantages
High biodegradability	Low thermal stability
Low pollution of the environment	Oxidative stability
Compatibility with additives	High freezing points
Low production cost	Poor corrosion protection
Wide production possibilities	
Low toxicity	
High flash points	

Further, to explore the use of Bio-oils for the purpose of cutting fluids for machining nonferrous metals, Lawal (2013) has reviewed vegetable oils as cutting fluids in machining non-ferrous metals. Major focus has been made on application of vegetable based cutting fluids for nonferrous materials like titanium alloys, aluminum, copper and brass. The effect of feed rate on cutting force for aluminum and copper has been noted using Ground nut oil, coconut oil, Palm kernel oil, and shear butter oil as cutting fluids for cylindrical turning (Ojolo, Amuda, & Ogunmola, 2008).

Gaps in application of vegetable oils as metal working fluids was reviewed by Lawal et al. (2014). Different researcher's work on application of vegetable oil as MWFs in machining processes such as turning, milling, grinding and drilling has been explained in detail. A summary of research has been given which is shown in Table 2 in which , for drilling of AISO 316L,304 steel, Titanium alloys, rapeseed oil, sunflower oil, Palm kernel oil has been used respectively by different authors and results were investigated.

Table 2: Application of bio-oils as MWFs for machining operations (Sunday Albert Lawal, Choudhury, Sadiq, et al., 2014)

Machining process	Work piece material	Tool material	Type of cutting fluid	Investigation	Author(s)
Turning	AISI 4340 steel	Coated carbide	Palm kernel and cottonseed oil-in-water emulsions and mineral oil emulsion	Cutting force and surface roughness Tool	Lawal et al. (Sunday Albert Lawal, Choudhury, & Nukman, 2014)
Turning	AISI 304 steel	Carbide	AISI 304 steel Carbide Coconut oil, emulsion and neat cutting oil immiscible with water	Tool wear and surface roughness	Xavior et al (Xavior & Adithan, 2009)
Turning	AISI 9310 steel	Uncoated carbide	Vegetable oil (type not specified)	Temperature, chip formation, tool wear and surface roughness Cutting force	Khan et al.(Khan et al., 2009)
Turning	Mild steel, aluminum and copper	Tungsten carbide	Groundnut, coconut, palm kernel and shear butter oils	Cutting force	Ojolo et al. (Ojolo, Amuda, Ogunmola, et al., 2008)
Turning	Mild steel, brass and aluminum	HSS	Palm kernel oil	Cutting force	Ojolo and Ohunakin (Ojolo & Ohunakin, 2011)
Turning	AISI 1040 steel	Cemented carbide	SAE – 40 and coconut oil	Temperature, flank wear and surface roughness	Krishna et al. (Vamsi Krishna et al., 2010)
Drilling	AISI 316L steel	HSS tool	Rape seed oil	Tool life, cutting	Belluco and De

			and mineral oil	force	Chiffre (Belluco & Chiffre, 2004)
Drilling	AISI 304 steel	HSS-E	Sunflower oil and mineral oil	Surface roughness and thrust force	Kuram et al. (Kuram, Ozcelik, et al., 2010)
Drilling	Titanium alloys (Ti-6Al-4 V	Carbide coated with AlTiN	Palm kernel oil and synthetic ester	Thrust force, torque and temperature	Rahim and Sasahara (Rahim & Sasahara, 2011)
Grinding	SAE 1020 steel	Cubic Boron Nitride (CBN) tool	Vegetable oil and semi-synthetic oil	Wheel wear, work piece roughness	Alves and Oliveira (Alves & de Oliveira, 2006)
Grinding	100Cr6 steel	CBN	Mineral oil, rape seed oil, palm kernel oil, animal oil and cooking oil	Work piece roughness, ecological and cost assessment	Hermmann et al. (Herrmann et al., 2007)
Milling	AISI 420 steel	Carbide-TiAIN and AIT	Palm kernel oil	Cutting force, tool life and surface roughness	Sharif et al. (Safian et al., 2009)
Milling	AISI 304 steel	HM90 APKT, 100304PDR IC908	Canola oil and sunflower oil	Tool wear and cutting force	Kuram et al.(Kuram, Simsek, et al., 2010)

2.2. Selection, application and technical viabilities of vegetable oils

Selection of bio oil as cutting fluids is one of the important aspect for different applications (Mannekote et al., 2018) has carried out review on associated technical viabilities with vegetable oil based lubricants in different applications. The review has been carried out in two parts, in the first part a discussion has been carried out on environmental regulations, eco labelling, source, composition and availability of vegetable oils. In the second part, performance evaluation of vegetable oils in different applications has been covered. The criteria's for environmentally friendly lubricants such as biodegradability, toxicity has explained in detail. Objectives of Eco labelling i.e. to protect environment, to encourage environmental innovation, to build consumer awareness on environmental issues has been studied and ISO classification of labelling has explained as type I, type II and type III and comparison is as shown in Table 3.

Table 3: Comparisons of the three types of labels and declarations (Network et al., 2004)

Criteria Areas	Metrics Life Cycle Metrics Type
Type I Multiple	Type I Yes
Type II Single	Type II No
Type III Multiple	Type III Yes
Selectivity	Third party Verification
Type I Yes	Type I Yes
Type II No	Type II No
Type III Yes	Type III Yes

The classification of Vegetable oils based on source, availability, end use has been mentioned. The importance of fatty acids in vegetable oils, various vegetable oils like coconut oil, Palm oil, sunflower oil, rapeseed oil, castor oil, Ground nut oil as lubricants in different applications such as metal working operations, metal forming operations, two and four stroke engine lubrication and hydraulic operations has been studied. The table 4 provides source of important fatty acids.

Table 4: Source of important fatty acids

Fatty acid	Common Name	Source
Hexanoic acid	Caproic (6:0)	Butter and Coconut
Octanoic acid	Caprylic (8:0)	Coconut
Decanoic acid	Capric (10:0)	Coconut
Dodecanoic acid	Lauric (12:0)	Coconut and palm kernel
Tetradecanoic acid	Myristic (14:0)	Coconut and palm kernel
Hexadecanoic acid	Palmitic (16:0) Palm,	Cotton and Butter
cis−9-hexadecenoic acid	Palmitoleic (16 :1)	Butter and Animal fat
Octadecanoic acid	Stearic (18:0)	Butter and Animal fat
cis−9-octadecenoic acid	Oleic (18 :1)	Olive, Peanut and butter
cis,cis−9,12-octadecadienoic acid	Linoleic (18 :2)	Soy, Sesame and Sunflower
12-hydroxy-cis−9-octadecenoic acid	Ricinoleic (18:1)	Castor
Eicosanoic acid	Arachidic (20:0)	Groundnut oil

Table 5: Chemical and Physical properties of selected vegetable oils

Vegetable oils	Density (g/ml)	Kinematic Viscosity @40 °C (mm2/sec)	Viscosity Index	Saponification Value	Iodine Value	Pour point °C	Flash Point °C
Coconut	0.915	27.9	155	250–264	7–12	20	240
Palm oil	0.910	41.9	189	196–209	50–55	12	304
Sunflower oil	0.890	38.2	205	186–194	113–148	−15	272
Soybean oil	0.9075	30.3	224	117–141	189–195	−12	254
Castor oil	0.970	249.8	85	170–185	85–90	−31	260
Groundnut oil	0.914	36.84	144	184–195	84–95	3	336
Rapeseed oil	0.918	42.9	208	170–180	100–115	−21	316

Wegener et al.(Wegener et al., 2016) has briefed about the development of cutting technologies and challenges for difficult to cut materials.it has been mentioned that, cutting speed is one indicator of improvements in cutting and data from History with respect to cutting Speed has showed increase in cutting speed more than 5% per year that is from 15 m/min to 2000 m/min. a broad classification of difficult to cut materials like titanium alloys, stainless steel, magnesium alloys etc. has been given and discussed in detail. As the main ingredients of success in cutting are machine tool, tool and process, a review has been made on different cutting tools, coatings, cutting edge radius, drills and end mills for hard materials, machine tools and accuracy, coolant and lubrication. Resource Efficiency, ultra-precision machining, micro machining were the other aspects considered for cutting.

2.3. Methods of applying cutting fluids for different machining operations

Bio- degradable oils are considered as eco-friendly because of their biodegradability, so an attempt was made by Debnath (2014) to emphasize on ecofriendly cutting fluids and on different methods of applying cutting fluids in machining process. It has been mentioned from the report in 2005 that, there is increase of 1.2% amount of lubricants will be used in next decade. There is demand for about 85% of mineral based cutting fluids around the world. This may lead to environmental pollutions throughout the life cycle. This is non-biodegradable and requires expensive treatment prior to disposal, also increasing its disposal cost (up to two to four times of purchasing cost). It has been mentioned that, a number of identified Nano-lubricants sustain and provide good lubricity over an extensive range of temperatures. It will be a novel type of engineering system which consists Nano sized particles dispersed in base oil. A detailed study has been made on functions such as cooling, lubrication, chip removal and types of cutting fluids. Toxic effect of cutting fluids will cause health issues to the operator and this lead to emphasize on environment friendly cutting fluids. Different application methods of cutting fluids such as mist cooling technique, wet cooling technique; High pressure cooling technique has been explained. Dry machining, MQL, cryogenic machining also discussed. The method of applying cutting fluid like flooded system, Minimum Quantity Lubrication on cutting zone has also effects the quality of product, Srikant et al. (2017) presented MQL and vegetable based cutting fluids for sustainable machining. The Table 6 gives the some of the results obtained for vegetable oil-based MQL in machining processes.

Agrawal & Patil (2018) worked on turning operation by MQL technique using M2 (molybdenum high speed steel) using Aloe Vera oil which is non-edible as cutting fluid. Turning operation was carried out on CNC lathe machine. Coated Carbide tool inserts having four cutting edges was used. For every 3 experiments, new cutting edge was used. Cutting fluid was prepared and properties were determined. The experiments were carried out using Design Of Experiments.

For turning of hardened AISI 4340 steel Gunjal & Patil (2018) used canola oil, coconut oil and soya bean oil as cutting fluids under MQL. The work piece of 90mm length, 250mm diameter was used. PVD AlTiN coated carbide inserts was used. Tool holder of DCLNL 2525 M12 was selected. A CNC lathe machine was used. The results were determined for different cutting speed (m/min) 200,220,240 with constant feed of 0.1 mm/rev and depth of cut 0.25mm

Mild steel is most commonly used material in various applications, Odusote et al. (2013) evaluated the performance of Palm oil and Ground nut oil as cutting fluids for milling of MS material. Temperatures of work piece and chip formation rate are compared with mineral oil and dry machining under different cutting speed (rev/min), feed (mm/rev) and depth of cut. The work was carried out on 20 pieces of mild steel plate of 90mm x 75mm x 15mm. SGHI- 8890 CNC milling machine of maximum speed of 12000 rpm and 15 kW drive motor was used for machining. The other equipment's used are optical electron microscope, digital thermocouple, stop watch, ball viscometer Bunsen burner, stirrer, ice block, micrometer screw gauge, mesh sieve, 4 liter gallon of water, electric juice extractor, lemon fruits which was used as an antioxidant to improve the oxidative stability of vegetable oil and digital weighing balance. The drilling was carried out using 4 different CNC milling machines at ambient temperature of 290C. Cutting speed of 95 rev/min and feed of 0.25 mm/rev was kept constant at first for all machines. Later speed has changed to160 rev/min keeping feed constant to determine chip thickness. Material were drilled through a hole of 5mm, 10mm and 15 mm. The cutting fluids applied through double hose by flooding means. The chip thickness and viscosity for different cutting fluids are represented in table 7 and table 8 respectively.

Table 6: Bio- oil based MQL in different machining processes (Srikant & Rao, 2017)

Machining process	Material	Cutting fluid	MQL parameters	Reference	Cutting process improvement
Drilling	Al alloy ACP 5080, BHN 85	Vegetable oil	20 mL/h, 6 bar pressure	(Belluco & De Chiffre, 2002)	Surface finish improved
	Titanium, Ti6Al4V	Synthetic ester, palm oil	10.3 mL/h, 165 L/min air flow at 0.2 MPa	(Rahim & Sasahara, 2011)	MQL comparable to flooding with Palm oil. Synthetic ester is inferior

	AISI 316 stainless steel	Coconut oil, palm oil, olive oil, and sesame oil	10 mL/h	(Belluco & Chiffre, 2004)	Coconut oil gave the smoothest surface and the best performance at cutting speed = 12.192 m/min, depth of cut = 23 mm, feed rate = 54.8 mm/rev, and spindle speed = 456 rpm
Turning	AISI 9310 steel	MQL—food-grade vegetable oil, Flood-Ecocut San 220 AISI	100 mL/h	(Khan et al., 2009)	MQL resulted in improved tool life, surface finish, and chip characteristics at all considered cutting conditions
	AISI 52100 S steel	Coconut oil, Servocut	1 L/h	(Gu et al., 2014)	Coconut oil produced lesser surface roughness
	AISI 1040	NanoMoS2 + coconut oil, sesame oil, and canola oil	10 mL/min	(Padmini et al., 2015)	Coconut oil—cutting forces reduced by 37%, temperatures by 21%, tool wear by 44% compared to dry machining
Milling	Inconel 718	Biodegradable vegetable oil, Bescut 173	8 mL/h	(Zhang et al., 2012)	Tool life increased by 1.57 times in MQL compared to dry machining Reduced
	AISI 1040	Vegetable esters	11.5 mL/h	(Hadad & Sadeghi, 2013)	Reduced tool wear, forces in MQL compared to dry machining
Grinding	Ti–6Al– 4V	Castor oil + Al2O3	18 mL/h	(Setti et al., 2012)	Grinding forces and surface roughness reduced with MQL
	GH4169 Ni-based alloy	Synthetic lipids + MoS2 and CNT	50 mL/h	(Wang et al., 2016)	Nanofluid MQL gives better precision and surface quality due to lubrication. Performance related to concentration levels

Table 7: Variation of chip thickness using different cutting fluids and parameters (Kolawole & Odusote, 2013)

Cutting Fluids	**Chip thickness (mm) at 95 rev/min, 0.25 mm/rev, 15mm depth**	**Chip thickness (mm) at 160 rev/min, 0.25 mm/rev, 15mm depth**
Palm oil	0.28	0.26
Groundnut oil	0.23	0.20
Mixture	0.25	0.21
Conventional Oil	0.22	0.20
Dry Machining	0.15	0.18

Table 8: Variation of Viscosity for with respect to temperature of the different cutting fluids (Kolawole & Odusote, 2013)

S.N.	Temperature (°C) of cutting fluids	Mixture (A) Viscosity (Poise)	Palm oil(B) Viscosity (Poise)	G/nut oil (C) Viscosity (Poise)	Conventional oil (D) Viscosity (Poise)
1	20	46.7	49.8	36.6	40.4
2	25	43.3	45.7	33.2	35.6
3	30	38.9	43.8	31.9	32.7
4	35	31.5	40.2	28.2	30.1
5	40	30.2	35.7	26.8	26.5
6	45	27.2	32.4	22.2	22.3
7	50	23.7	28.6	16.6	20.7
8	AVERAGE	34.5	39.5	28.0	29.8

2.4. Challenges and prospects of vegetable oils as cutting fluids

Even though vegetable oils possesses properties of cutting fluids, there were some challenges like poor oxidative stability, higher cost etc. So Timothy et al. (2019) studied these challenges, prospects and efforts to improve properties of vegetable oils as cutting fluids. The detail of various vegetable oils used as cutting fluid has been mentioned. The consumption of oils as lubricants in world has considered. The important challenges such as under sliding, high wear occurs at high temperature, poor hydrolytic stability, cold flow properties, high cost and food vs. lubricant challenge were discussed. To overcome these challenges, current research efforts were highlighted like use of non-edible oils, chemical modifications of vegetable oils, additives, thermal modifications. It has been observed that, to alleviate food and bio lubricant competition, non-edible oils like Jatropa, Moringa, Pongamia, and Neem were gaining attention. Some practical applications of vegetable oils as cutting fluid like use of Modified Jatropa Oil, blended sunflower and canola oil etc. were mentioned. As various vegetable oils (edible and non-edible) are available in nature that can be used as metal working fluids and can replace the use of mineral oil, the extractions of oils from seeds were discussed by Atabani et al. (2013). Detailed information has been given on sources of non-edible vegetable oils like Jatropa, Pongamia pinnata L. (Karanja), Moringa, castor, Neem etc. Advantages and problems associated with Non-edible vegetable oils have been discussed. Oil extraction techniques, Fatty acid composition, properties and characteristics of non-edible bio-oils have also presented. The different bio oils are having different composition, properties which can used as cutting fluids for different applications Gajrani et al.(Kumar Gajrani & Ravi Sankar, 2017), has studied on individual vegetable oil as cutting fluid, its composition, physic-chemical properties, advantages, application and its practical use. The potential applications of different vegetable oils studied by various researchers are listed in Table 9.

Performance of bio oils like Palm kernel oil, coconut oil, Ground nut oil etc. on turning of copper, mild steel, and aluminum were discussed. The performance of conventional flood lubrication , MQL, dry machining on drilling using vegetable oil as cutting fluid has been studied. The vegetable oils can be modified chemically to improve the characteristics as cutting fluids, Talib et al. (Talib & Rahim, 2015) has evaluated the performance of chemically modified Jatropa oil based tri methyl propane (TMP) ester from Crude Jatropa Oil (CJO) as bio based MWFs. The low temperature and lack of oxidative stability for bio based oils was crucial problem occurred, which can be improved through chemical modification and mix with additives. The crude Jatropa oil is chemically modified to improve oxidation and thermal stability. The orthogonal cutting process was carried out on AISI 1045 mild steel disk of thickness 2mm and diameter 150mm.a Titanium coated tungsten carbide insert was used. The comparison was made between Synthetic Ester, CJO and Modified Jatropa Oil (MJO) with two different molar ratios i.e. (Jatropa Modified Ester) JME: TMP; 3.1:1(MJO1) and JME: TMP; 3.3:1 (MJO3) at various cutting speeds and feed rates. Cutting force is compared at different feed rates for various cutting conditions. Talib & Rahim (2016) again evaluated tribology behavior of Jatropa oil on machining performance by considering another molar ratio of Jatropa oil i.e. JME:TMP;3.5:1(MJO5) at various cutting speeds and feed rates. Some vegetable oils are used as cutting fluids by mixing with water with the help of emulsifier (Water Miscible Oils). Srikant & Ramana (2015)worked on coconut oil and sesame oil based emulsifier for machining of AISI 1040 steel and results were compared with regular cutting fluid. The structure of emulsifier has shown in figure 8, which was used to hold water and oil particles that can co-exist and form emulsion fluid. The emulsifier used is Sodium Petroleum Sulphonate (SPS)

5% of sesame oil CAPB(Coco Amido Propyla Betine) mixture was diluted with 95% of water and emulsifier content varied in the mixture as 5%, 10%, 15%, 20% and 25%. AISI 1040 of size diameter 35 mm and 350 mm length was used. A 10 HP lathe was used for machining. Cutting speed of 560 rpm, feed as 0.4396 mm/rev and depth of cut as 1mm were selected based on recommendation of the tool supplier. Uncoated carbide tool was use as cutting tool. Fluid is supplied through 0.2 HP submersible pump at constant flow rate and circulated fluid was filtered, collected into source container, recirculated again during machining. Piezo electric dynamometer used to measure cutting force, embedded thermocouple technique used to measure temperature. Tool wear and surface roughness were measured using metallurgical microscope, talysurf respectively. Lubricity is the one of the main characteristics of cutting fluid, Olawale et al. (2018) studied on lubricity of Neem and Castor oils with their blends which were used as cutting fluids for turning of Mild steel. The physicochemical parameters and fatty acid profiles were investigated for these oils. The oils were extracted from castor seeds and Neem kernel seeds by mechanical pressing method and cutting fluids were formed by mixing these oils in various proportions as 90:10, 80:20,70:30,60:40,50:50 Neem and castor respectively, also 100 % Neem and 100% Castor oils. The experiment is carried out on lathe machine model XL 400 using HSS cutting tool. From results of fatty acid profile, it has been seen that 100% castor oil is more stable than other formulated oil. The experimental results showed relatively high thickness of 1.68 mm than conventional cutting fluid of 1.43 mm at cutting speed of 250 rpm, feed 0.5 mm/rev and depth of cut 2mm. this indicates low coefficient of friction which shows good lubricating property of oil. The Table 10 below shows results of the lubricity test in which Coefficient of friction and wear are listed for different blends of Castor and Neem oil.

Muhammad et al. (2018) carried out experiment on straight turning of AISI 1027 steel bar using Shea butter and Neem seed oil (fixed oil) as cutting fluids.E3N-01 Centre lathe for machining and single point HSS tool was used. Phenol as disinfectant, Sulphur as extreme pressure agent and washing soda as emulsifier were used. The cutting fluids were formed in the proportion of 80% fixed oil, 10% emulsifier, 5% extreme pressure agent and 5% disinfectant. Again this fluid is mixed with water in the ratio of 1:10 (cutting fluid: water). The viscosities, acidic values, machining and temperature dissipation abilities were determined and machining is carried out. Each experiment was run for at least 10 minutes and temperature variation vs. cutting speed was noted.

2.5. Non edible vegetable oils as cutting fluids

There is sufficient availability of non-edible oils in nature which can be used as metal working fluids. Therefore an attempt is made by Jeevan et al. (2018) to explore potentiality of non-edible Jatropa and Pongamia oil as cutting fluid in turning of AA 6061. The Jatropa and Pongamia oils were chemically modified by addition of oxygen atom by the process epoxidation. The work piece of diameter 45 mm and length 200mm was chosen. Engine lathe-LB-20 and uncoated carbide cutting tool was used. MQL method with pressure of 3 to 4 bars was used. Cutting force was measured by strain gauge type lathe tool dynamometer. Surface roughness is measured using Surfcom Flex-50. Tool maker’s Microscope was used to measure tool wear. Analysis of results was carried out using ANOVA and S/N ratio. Optimal turning parameters of cutting force were 0.5 mm depth of cut and 0.1 mm/rev of feed rate, and 1600 rpm of spindle speed. Souza et al. (2019) worked on Jatropa and Moringa oils as lubricants for milling operation. The machining centre HERMLE C600U was used to carry out experiments. The block of 7050-T7451 aluminium alloy was used as work piece. The Jatropa based MWF, Jatropa ester-based MWF, canola based and mineral based MWF were used for experiments. The investigation has been made on potential use these oils as lubricants, their performance in tribological tests, in milling tests. Jatropa oil emulsion was considered as cutting fluid by Roberto et al. (D’Amato et al., 2019) for milling operation on Aluminium alloy and Carbon steel. The cubical geometry of 37x37 mm in case of aluminium, 50x50 mm in case of steel were used as work samples. Universal milling machine Alecop MU-8000 was used to carry out milling operation. The machining was carried out for three processing strategies namely 1) dry condition; 2) lubricated condition using mineral emulsion; 3) using Jatropa Curcas L (JCL) emulsion. The thermal imaging camera, FLIR T1020 450 was used to measure temperature during the process and thermocouple was used to calibrate. Non-edible oil i.e. Karanja oil in water based cutting fluid was used by Mohammad et al. (2018) for orthogonal cutting of AISI 1045 steel. Tween 80 emulsifier is used to obtain the Karanja based soluble oil as cutting fluid and servo cut S as conventional cutting fluid. CNC lathe machine was used with PVD (TiN/TiAlN) coated carbide inserts and PCNLR 2525M 12 as tool holder. Carl-Zeiss digital tool makers’ microscope is used. Response surface methodology using central composite rotatable design (CCRD) matrix varying the cutting speed, feed rate and depth of cut was used to plan the experiment. Regression equations were developed to determine chip thickness and effect of cutting parameters on chip thickness was observed.

Table 9: Potential applications of vegetable oils (Choi et al., 1997; Erhan & Asadauskas, 2000; Horner, 2002; Cermak & Isbell, 2003)

Vegetable oil type	Application
Soyabean	chain bar fluid, greases, industrial and food grade hydraulic fluids, Lubricants, marine and automotive, metal working fluids, bio-diesel fuel, paints, sources of oleic acid for oleo chemical production, coatings , soaps,
Sunflower	lubricants, Cooking oil, sources of oleic acid for oleo chemical production, grease substitutes,

Palm	Chain bar lubricants, food processing machines lubricant, metal working fluids, textile lubricants, anti- wear hydraulic fluid, Two stroke engine oil.
Pongammiapinnata	Cooking lamp fuels, water-paint binder, pesticides, soap, tanning industries, herbal medicines
Jatrophacurcass	Cooling lubricants, Bio-diesel, base stock for metal working fluids.
Castor	Greases, gear lubricants Medicines, metal working lubricants base stock,
Neem	Medicines, coolants, cutting fluids,
Coconut	Grease, engine oils, Surfactants, Chain bar fluids.
Jojoba	Color dies, Surfactants, surfactants, resins, emulsifiers, protective coatings, fibers.

Table 10: Wear and Coefficient of friction for different blends of Castor and Neem

Sample	Co-efficient of friction	Wear (mm)
100% Neem	0.25	0.29
100% Castor	0.20	0.16
90% Neem and 10% Castor	0.21	0.17
80% Neem and 20% Castor	0.26	0.23
70% Neem and 30% Castor	0.19	0.18
60% Neem and 40% Castor	0.14	0.13
50% Neem and 50% Castor	0.17	0.15
Soluble oils	0.32	0.38

3. Materials and methods

Influence of cutting fluids will be different based on type of work piece material and type of machining operation performed. This paper discusses the results obtained using different bio-oils as cutting fluids on different machining operations on different materials based on secondary literatures available online.

4. Results and discussion

Lawal et. al (2014) has carried out a detail discussion on advantages and disadvantages of cutting fluids, machining various ferrous metals with different cutting conditions such as cutting speed, cutting fluids and measuring machining parameter like surface roughness, tool flank wear, cutting temperature, tool wear. The hazardous effect of using mineral oil as cutting fluid on environment was also highlighted. From his review it has been concluded that Coconut oil and Palm oil in turning, Sunflower oil in drilling showed best performance w.r.t decreased surface roughness, longer tool life, improvement in MRR, productivity. Amuda, & Ogunmola (2008) and Lawal (2013) reviewed on use of oils as cutting fluids for non-ferrous metals, the results of cutting force with respect to feed for aluminium with 2mm depth of cut using four lubricants and copper at 2mm depth of cut using four lubricants are as shown in Figure 1(a) and Figure 1(b). From the figure, it has been observed that ground nut and palm kernel oils were gives reduced cutting force. Over all from the review, it has been concluded that use of Palm oil for drilling of titanium alloy with MQL has lowest thrust force, use of Ground nut, coconut, Palm kernel and shear butter oil for cylindrical turning has shown reduction in cutting force.

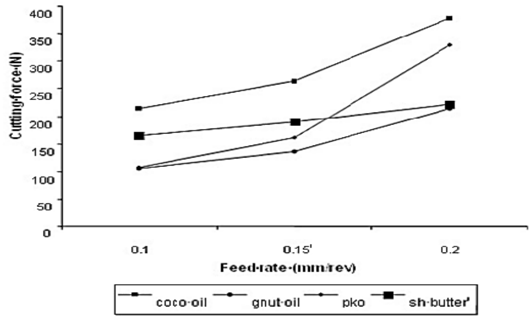


Figure 1 (a): Cutting force vs. feed rate on aluminium (Ojolo, Amuda, & Ogunmola, 2008)

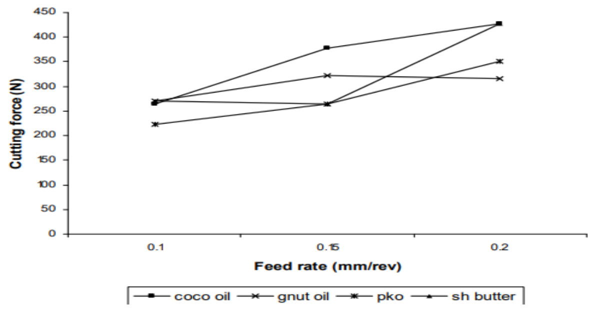


Figure 1(b): Cutting force vs. feed rate on copper (Ojolo, Amuda, & Ogunmola, 2008)

Lawal et al. (2014) carried out detailed literature on MWF for different machining operations since from 1900 A.D. some of the works on drilling has been mentioned and it has been observed to explore more on drilling as it internal metal removal process. From this review it has been concluded that focus is needed on application of vegetable based MWFs on machining such as grinding and milling of super alloys. Review on technical viabilities and methods of application of cutting fluid carried out by Mannekote et al (2018). It is noted that, vegetable oil used in MQL application showed better improvement in the productivity with reported increase of 117% in tool life and 7% reduction in thrust force with better surface finish. Studies have showed that use of Palm oil based lubricant was effective in reducing the emissions level for CO compared to conventional lubricants. Based on the review it has been concluded that Vegetable oils become the primary choice for environmentally sensitive and total loss lubricant applications ranging from hydraulic oils to grease as they are renewable, non-toxic and biodegradable and as studies showed that use of vegetable oil based MWFs brings combined benefit of high performance in machining in terms of improved efficiency, less tool wear with good environment compatibility. It is observed that, the selection of lubricant is based on price, then on performance, and lastly on environmental consideration as different regions of the world have different policies, laws, and regulations to control the production, use and disposal of lubricants. But it is needed to reverse this process so that environmental consideration should be given first preference for selection of cutting fluids. A brief explanation presented by Wegener et al.(Wegener et al., 2016) on the challenges and development of cutting technologies for difficult to cut materials and from the study it has been concluded that continues success of cutting is due to its uniqueness in creating high accuracy, good surface finish and its flexibility. The cutting machines are the prerequisite for cutting processes. Coolants are used to achieve energy efficiency, quality of products and reduce thermal errors. Coolants also reduce friction and cutting force by their chemical and physical properties. Debnath (2014) emphasized on eco-friendly cutting fluids and studied the effect of cutting fluids and cutting parameters on surface roughness and concluded that dry machining can be applicable for milling, turning, gear cutting but it has a limitation during drilling because of generation of large amount of heat during drilling. As vegetable based cutting fluids are environmental friendly, it has been observed that future research should be concentrated on development of these cutting fluids and focus should be given on composition, selection and application, quantity optimization, recycling of vegetable based cutting for green machining. The work carried out by Srikant & Rao (2017) mentioned that MQL gives better performance compared to flooding because the small particles in mist improve penetrating ability of cutting fluids and rapid vaporization. It has been noted that, due to use of little amount of cutting fluid MQL has received increased attention. Further to study the impact of MQL on biodegradable oils, review has been made on vegetable oils as cutting fluids which use flooded lubrication system, dry machining and MQL. Based on the available experimental results for vegetable oil based MQL, it has been summarized that, MQL has becoming significant as fluid is supplied small quantity on cutting zone in the form of neat oil or as water miscible cutting fluid and vegetable oils are being used as cutting fluids due to their superior properties, better performance compared to mineral oil. It has mentioned that researches are being carried out on inclusion of Nano particle to cutting fluids to enhance the performance.

The results of surface roughness vs. speed, feed for turning operation on M2 (molybdenum high speed steel) by Agrawal & Patil (2018) were compared for both Aloe-Vera oil as cutting fluid and conventional cutting fluid as shown in figure 2. It has been observed that Aloe Vera oil gave better surface roughness than conventional cutting fluid except at 500 rpm and 0.36 mm/rev. as conclusion, it has been given that surface roughness using Aloe Vera oil is lowered by 6.7%, tool wear is lowered by 0.14% as compared to conventional cutting fluid and increase in cutting speed decreases surface roughness, increase in feed surface roughness also increases.

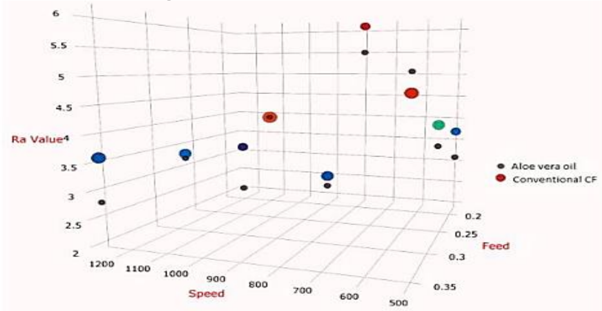


Figure 2: Surface roughness vs. speed, feed using conventional cutting fluid and Aloe Vera as cutting fluid (Agrawal & Patil, 2018)

The results of experiments carried out by Srikant et. al. (2018) were shown in figure 3, it has been observed that tool life decreases with increased speed. From the results it was concluded that, better results were observed for tool life, tool wear and surface roughness using Canola oil as compared to Coconut oil and soybean oil and at higher cutting speed, synthetic oil gave better performance. The decrease in tool life with increase in speed is represented graphically as shown figure 3.

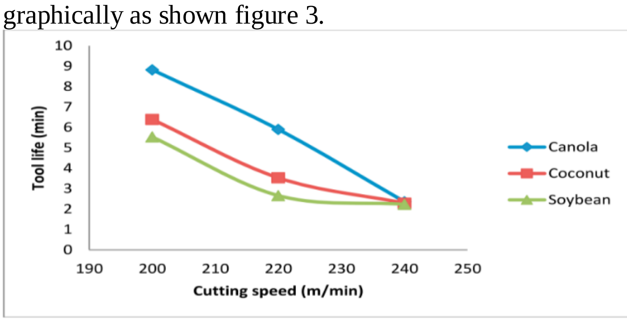


Figure 3: Cutting speed Effect on tool life under different cutting environments

The experimental results of milling on Mild Steel done by Kolawole & Odusote (2013) are shown in figure 4.The graph describes Variation of temperature at feed rate of 0.25 mm/rev and 15mm depth with respect to Cutting speed.

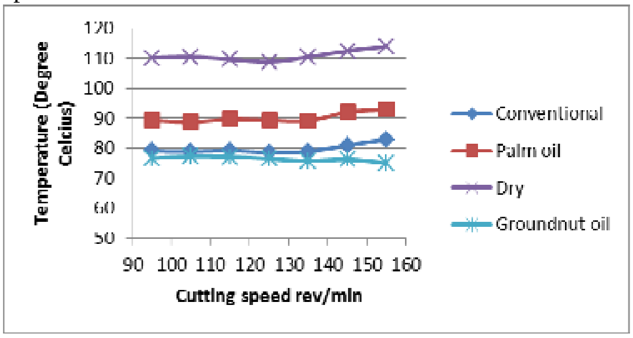


Figure 4: Temperature of Work piece with varying cutting speed and cutting fluids

From the experimental results it has been concluded that chip thickness was highest using Palm oil and viscosity was low means high viscosity index using Ground nut oil, the result of micrograph in machining with Ground nut oil sample was competitive compared with mineral oil. This was indication of good surface finish. The oxidative stability can be controlled by using lemon fruit extract. Timothy et al. (2019) reviewed and represented consumption of oils as lubricants in world which is shown in Figure 5.

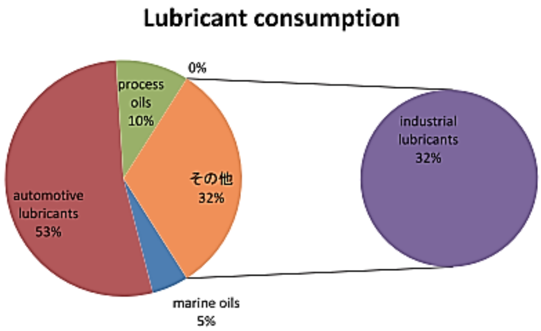
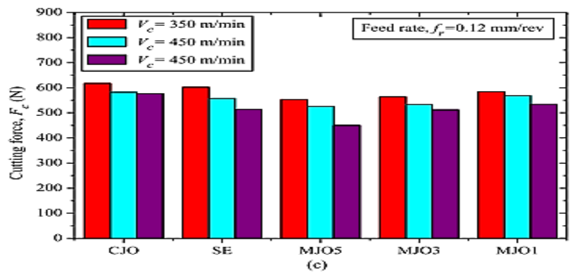


Figure 5: The consumption of lubricants in different fields

From the review it has been concluded that, vegetables oils can be used as an alternative to mineral oils as they possesses high viscosity index, lubricity, high flash point and low evaporative loss. The challenges can be overcome by use of non-edible oils, additives. The results of Atabani et. al. (2013) Concluded that production of non-edible oil resources can solve land problem as it can be grown in waste land areas, an alternative to issue of food v/s fuel, huge chance to produce biodiesel from non-edible sources in the future.

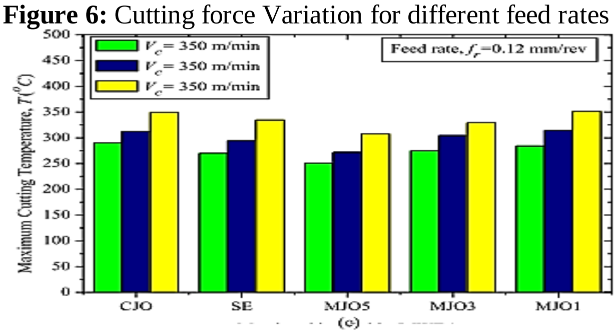
Gajrani et al. (2017) in his study, observed that crude sunflower oil based cutting fluids reduced more thrust force compared to refined sunflower oil, however better surface finish has shown by refined sunflower oil. For grinding, castor oil based cutting fluids, vegetable based emulsions with different concentrations were used and effect is studied and results showed reduced, better surface finish compared to mineral oil. From the review, it has been concluded that, in next 10-15 years vegetables oils will be able to replace petroleum based mineral oil because of their Eco friendliness, biodegradability and ease of availability. As per government enforced environmental law and ASTM standards for lubricants, some vegetable oils are already available commercially for specific use and performance.

The evaluation of MWF carried out by Talib & Rahim (2015), based on the results of MWFs properties, cutting forces and maximum cutting temperature, it has concluded that as the lubricant viscosity decreases, the cutting force and maximum cutting temperature increases. Reduction in thin lubrication film in the tool-chip interface generates high cutting force and maximum cutting temperature with highest Wear Scar diameter (WSD) and COF. It was not recommended to be applied as lubricant due to lack of oxidation and thermal stability.MJO1 was found substitute to SE as a sustainable MWFs in the machining operation as it is recorded comparable performances in terms of lubricant properties and machining performance. Talib & Rahim (2015), presented tribology behavior of cutting fluids and The graph below shows results of cutting force and Maximum cutting temperature.



Cutting force for all samples at (a) f_r= 0.08 mm/rev, (b) f_r = 0.10 mm/rev and (c) f_r = 0.12 mm/rev

Figure 6: Cutting force Variation for different feed rates



Maximum cutting temperature for all samples at (a) f_r= 0.08 mm/rev, (b) f_r = 0.10 mm/rev and (c) f_r = 0.12 mm/rev

Figure 7: Variation of cutting temperature for different feed rates

It has been observed that MJO5 presented highest viscosity index, WSD of MJO5 reduces 19.73% when compared to SE.MJO5 noted lowest cutting force for increase in cutting speed from 350 m/min to 550 m/min.MJO5 presented lower cutting temperature when compared to SE, MJO3 and MJO1. From the analysis results, it has been concluded that MJO5 reduced cutting force 5 to 12% compared to SE and cutting temperature reduced 6 to 11% compared to SE. MJO5 has better tribology behavior and reduces friction between surfaces compared to SE. so MJO5 showed sustainable MWFs in machining operation as well as environment friendly and health concern.

Srikant & Ramana (2015) give structure of water miscible oils which is shown below and from the experimental results, it has been observed that, as increase in content of CAPB in fluids, there is decrease in tool wear. Nodal cutting temperature decreased with increase in emulsifier content of the fluids. Cutting forces are least with 10% of CAPB. Surface roughness is also low for 10% of CAPB content in fluid. From the results, it has been concluded that, replacing petroleum oils and emulsifier by vegetable oil and vegetable emulsifier has reduced about 35% of tool wear, nodal temperature by nearly 40%, lesser surface roughness for 10% CAPB. The CAPB is available easily with lesser cost and have potential to adopt in machining industries

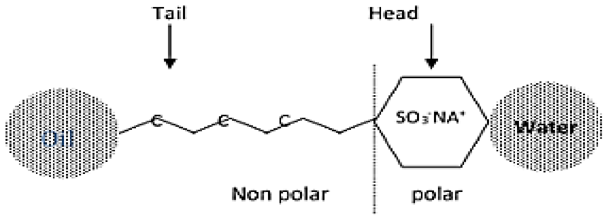


Figure 8: Structure of Emulsifier molecule (bounding water and oil molecules)

The lubricity assessment done by Olawale et al. (2018) on Neem and Castor oils with their blends which were used as cutting fluids for turning of Mild steel has shown results which are as follows. It has been observed that higher saponification, presence of higher oleic acid suggests oiliness which is important in boundary lubrication and hence 60N+40C oil exhibit better lubricating property on metal surfaces. The Table 10. Shows results of lubricity test. The results of Coefficient of friction and wear are less for blend of 60% Neem and 40% Castor compared to other ratio of blends so it has concluded that 60% Neem and 40% Castor can be used as standard cutting fluid as it satisfies all requirements of standard cutting fluid and chip formation showed better lubricity of oil. From the experimental results by Muhammad T et al.(Muhammad T. Baba, 2018) , it has been seen that, Shea butter cutting fluid shows more effective in conducting heat away from the chip tool interface and Neem seed oil based cutting fluid performed best at low speed and smaller depth of cut. It has been concluded that fixed oils can substitute conventional cutting fluids for all machining operations because of their biodegradable, less toxic, efficient performance, ease of availability and less cost. The results of work on non-edible oils as cutting fluids which was carried out by Jeevan & Jayaram (2018) analyzed using ANOVA and represented in figure 9 & figure 10.

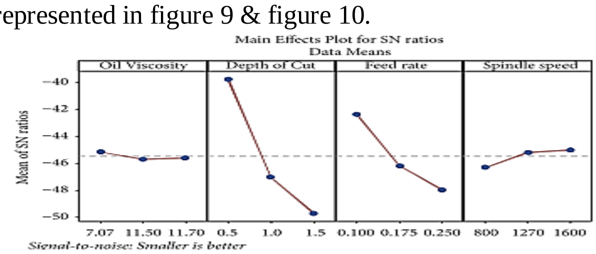


Figure 9: Main Effect Plots for Cutting Force

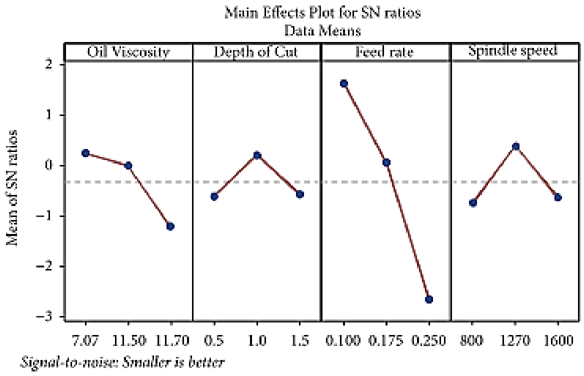


Figure 10: Main effect plots for surface roughness

From the results it has been concluded that, a good surface finish was obtained for Modified Pongamia Oil as cutting fluid at low speeds and Modified Jatropa Oil as cutting fluid for higher speeds and these two modified oils has great potential to use as cutting fluids as they are biodegradable and environmental friendly.Based on the research results by Souza et al.(Chanes de Souza et al., 2019) , it has been concluded that Moringa oil has good lubrication in wear test, possess good physicochemical properties but polymer property of Moringa oil may damage recirculation system of MWF which may lead to sealing of tool. However, Moringa and Jatropa oils as cutting fluids showed better lubrication compared with commercial V-MWF. The experimental results of Roberto et al. (D'Amato et al., 2019) for milling operation of Aluminium alloy and Carbon steel showed that both materials possess instability in terms of vibration and tools had break for dry condition. From the analysis, raw oil emulsion of JCL has shown best performance in terms of surface roughness and tool working temperature, power consumption was stable for both materials. It has been concluded that JCR oil emulsion can be considered as better cutting fluid than mineral oil emulsion; however Jatropa oil has poor corrosion protection. It has mentioned that further study can be made on possibility of antioxidant additive to the emulsion. From the experimental results carried out by Mohammad et al. (2018) it is observed that Karanja based soluble oil given less chip thickness compared to conventional cutting fluid, capable of providing a dense, homogeneous and strong lubricious film providing better support for varying feed, speed and depth of cut. It shows less vaporization and misting due to its higher flash point and greater molecular weight. The shape of chip formation studied in detail and concluded that, Karanja based soluble oil reduced chip thickness by 11% compared to conventional cutting fluid and at lower feed rate, chip thickness increased with increase in depth of cut and vice versa. The Surface Roughness variation with respect to cutting speed, feed, and depth of cut are as shown in figure

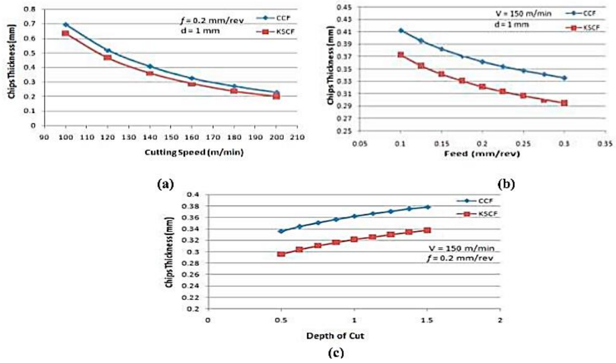


Figure 11: Effect of surface roughness on varying (a) cutting speed; (b) feed; (c) depth of cut

In the figure, it has been observed that chip thickness decreases with increase in feed rate, (Figure 1(a)). But, with increase in depth of cut, chip thickness increases (Figure 1(c)) which results in more lateral vibrations of the tool that leads to increased roughness value of the turned surface.

5. Conclusion

The performance of machining can be improved by using metal cutting fluids in machining zone. Various mineral oils as cutting fluids are being used by industries; however these oils have negative impact on human health as well as on environment. To minimize these effects, ecofriendly vegetable based oils as cutting fluids were introduced and some of the vegetable oils showed better performance as cutting fluids. From the review, it was found that the vegetable oils have a potential to use as metal working fluids because of their high sustainability, biodegradability, low toxicity, high flash points, low production cost even though with minimal disadvantages. Also bio-degradable oils (vegetable oils) like Palm oil, Coconut oil, Sunflower oil, Ground nut oil, Shea butter oil have shown better performance as cutting fluids for various machining operations. Also, non-edible vegetable oils like, Jatropa, Moringa, Neem, Pongamia or Karanja has shown better results compared to mineral based cutting fluids for ferrous and non-ferrous metals and machining operations.

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