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Review

State-of-the-Art and Future Perspectives of Environmentally Friendly Machining Using Biodegradable Cutting Fluids

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Abstract: The use of cutting fluids has played a vital role in machining operations in lubrication and cooling. Most cutting fluids are mineral oil-based products that are hazardous to the environment and the worker, cause severe diseases and pollute the environment. In addition, petroleum resources are becoming increasingly unsustainable. Due to environmental and health issues, legislations have been established to ensure that the consumption of mineral oil is reduced. Consequently, researchers are making efforts to replace these mineral oil-based products. Vegetable oils are grasping attention due to their better lubricating properties, ease of availability, biodegradability, low prices, and non-toxicity. In this study, a detailed review and critical analysis are conducted of the research works involving vegetable oils as cutting fluids keeping in view the shortcomings and possible solutions to overcome these drawbacks. The purpose of the review is to emphasise the benefits of vegetable oil-based cutting fluids exhibiting comparable performance to that of mineral oil-based products. In addition, an appropriate selection of non-edible vegetable oil-based cutting fluids along with optimum cutting parameters to avoid a scanty supply of edible oils is also discussed. According to this research, vegetable oils are capable of substituting synthetic cutting fluids, and this option might aid in the successful and cost-efficient implementation of green machining.

Keywords: cutting fluids; mineral oils; biodegradability; vegetable oil; surface roughness; sustainable machining

1. Introduction

The shearing action between tool and workpiece during machining results in chip formation, which generates high heat at the contact surface. This heat increases the cutting zone temperature, which needs to be reduced; otherwise, this could cause rapid tool wear, degrade surface integrity and reduce dimensional accuracy [1,2]. This poor surface finish and tool wear lead to low productivity. The increased cutting force required due to the non-removal of the chip also increases energy consumption. Thus, to reduce this friction as well the temperature lubrication was required that would ensure a better surface finish. Initially, manufacturers started using cold water to reduce cutting region temperature. This practice resulted in the removal of chips as well as temperature reduction, and a 30% increase in productivity was reported [3]. However, this method was not effective to provide better lubrication due to the less lubricating ability of water. Lubrication is necessary to reduce the friction between two surfaces in contact [4,5]. Lubricants can be solid or liquid and are used for many applications where a greasing effect is required [6]. Mineral oils (MOs) possess excellent lubricating properties, so they were used to lubricate workpieces and tools. Usually, these mineral oils are utilised as cutting fluids in conjunction with additives. So these mineral oil-based cutting fluids possess excellent lubrication as well as cooling properties [7].

Cutting fluids are indispensable in machining processes comprising up to 17% of total production cost [8]. The use of cutting fluids is reported since the 19th century. Cutting fluids are the interacting medium between tool and workpiece. They perform multiple functions of cooling, lubrication and reduction in cutting power [9]. Cutting fluids cause a reduction in temperature and cutting forces improving the tool life. The increased tool life enhances the production system [7]. Excellent surface finish is also obtained, which also reduce the friction to a greater extent [10]. Cutting fluids and coolants or lubricants are used in hard machining processes to improve tool life and cutting conditions. So, these gained as much importance as other cutting parameters like feed rate (FR), depth of cut (DOC), and cutting speed (V_C) [11]. Generally, the cutting fluids are composed of petroleum products based on mineral oils. However, some high pressure and polar additives, as well as thickness and odour modifiers, are also utilised. A good cutting fluid must act as a good lubricant, a coolant, be non-flammable, be anti-corrosive, possess antioxidation properties and remain stable at high temperatures [9].

Throughout the world, engineering workshops are utilising neat oils as well as water-miscible oils as cutting fluids. For hard-to-cut materials, mostly neat cutting oils were preferred over water-miscible oils as they provide multiple functions of cooling, lubrication, anti-friction, anti-wear, anti-built up edges and help in flushing the chips from the hot area of cutting [12]. Apart from cooling and lubrication, the cutting fluids must also meet the local and international regulations [13]. Almost 85% of the cutting fluids which are being consumed are composed of petroleum products based mineral oils that have more complex chemical structures and eco-toxicity [14,15]. It was reported that over 2 billion gallons of cutting fluids were used by North American manufacturers alone in 2002 [16]. In addition, more than 2,000,000 m^3 of cutting fluids are used each year globally [15]. Reports additionally indicate that almost two-thirds of these cutting oils need to be disposed of or dumped after their usage, which is alarming due to the hazardous and toxic nature of these oils [17,18].

Economical manufacturing processes having a less negative impact on the environment and contributing positively to society are treated as sustainable manufacturing [19]. The evolution of precision and sustainable machining has forced manufacturers to fabricate excellent products with a focus on environmental protection [20,21]. For sustainable manufacturing, disposing of a large number of mineral oil wastes is a problem to be thought about carefully. As mentioned earlier, cutting fluids comprises up to 17% of the total production cost. Thus this is an important consideration in sustainable manufacturing. The most used cutting fluid application strategy is the flooding technique [22]. There are also alternative strategies such as minimum quantity lubrication (MQL) and dry machining. Figure 1 shows a comparison of the environmental burden of these three types of application, and the flooding technique has the maximum environmental burden of any strategy [23,24].

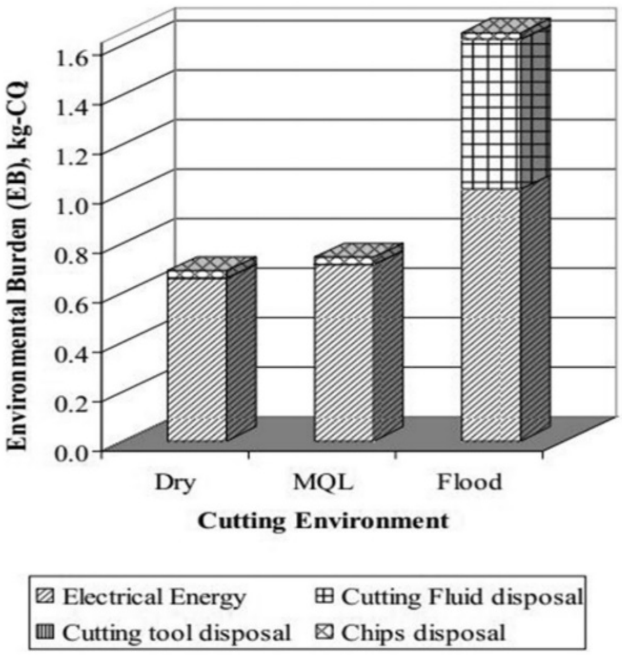

Figure 1. Comparison of the environmental burden of dry, flooded, and minimum quantity lubrication (MQL) [23].

The MQL method is the most used alternative to flooding. Reduction in power consumption and cutting fluid amounts can be made with the help of this technique. In MQL, a mixture of oil with pressurised air is injected into the cutting region. Oil provides lubrication, and cooling is obtained by the air. The compressed air exposure helps in removing away the chips as well. Thus, minimum surface roughness (R_a) and tool wear are obtained. Additionally, the cost of cutting fluid as well the disposal is reduced due to less cutting fluid use [25]. However, the performance of the MQL system is limited at higher cutting speeds as a small portion of the cutting fluid can reach the cutting zone. This factor leads to less lubrication in comparison to the flooding technique [26]. This uncertainty in lubrication ability forces manufacturers to use the flooding method having more quantity of disposal [27].

Petroleum reservoirs are limited to some specific countries of the world [28]. Because of their high demand, the prices of petroleum products are taking a toll. Hence manufacturers have to invest more in purchasing these cutting oils and invest further to dump them carefully and sustainably. These factors have increased the unit cost of products [29,30]. This literature review aims to look into the usage of vegetable oils to replace the mineral oil-based cutting fluids and minimise mineral oil usage in the major manufacturing processes. This approach will help industries to manufacture products sustainably.

Cutting fluid should primarily offer adequate lubrication and cooling. Vegetable oils as neat oils and in the form of emulsion have been tested as cutting fluids to ensure a green and sustainable manufacturing system [18,31–33]. Vegetable oils are mainly composed of triglycerides which consist of glycol molecules that have three long-chain fatty acids [34–39]. These fatty acids are attached to the hydroxyl group with the aid of ester linkages [40–42]. The triglycerides structure provides desirable lubricating properties in an effective manner [38,43,44]. Wear and friction are reported to be lowered through the generation of the lubricating film between the surfaces in contact [45–49]. This film is generated due to longer and polar chains of fatty acids [14,50]. Additionally, vegetable oils are easily available, cost-effective, less toxic, and eco-friendly [42,51–53].

A large portion of cutting fluids needs to be disposed of, which contribute to environmental pollution by contaminating soils, rivers, and underground water reservoirs [54]. Due to these environmental and health hazards, legislations have been established to minimise the usage of these cutting fluids to ensure environmental sustainability [19]. The suitability of a substance concerning environmental protection is examined by the Global Warming Potential (GWP) [55,56]. US Environmental Protection Agency defines GWP as it is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2) [52]. Climate changes are noticed with variations in GWP [57]. In Figure 2, the GWP of some oils is shown, which depicts mineral oils have 45 times negative impact on the environment compared to CO_2 [52]. For vegetable oils, it ranges between 5–15 times showing them to be more degradable. The above-mentioned characteristics have increased the trend of using vegetable oil-based cutting fluids [58–60]. It is necessary to select novel, innovative and sustainable cutting operations to provide an excellent surface finish, which will cause a reduction in cost and increase productivity [61–63].

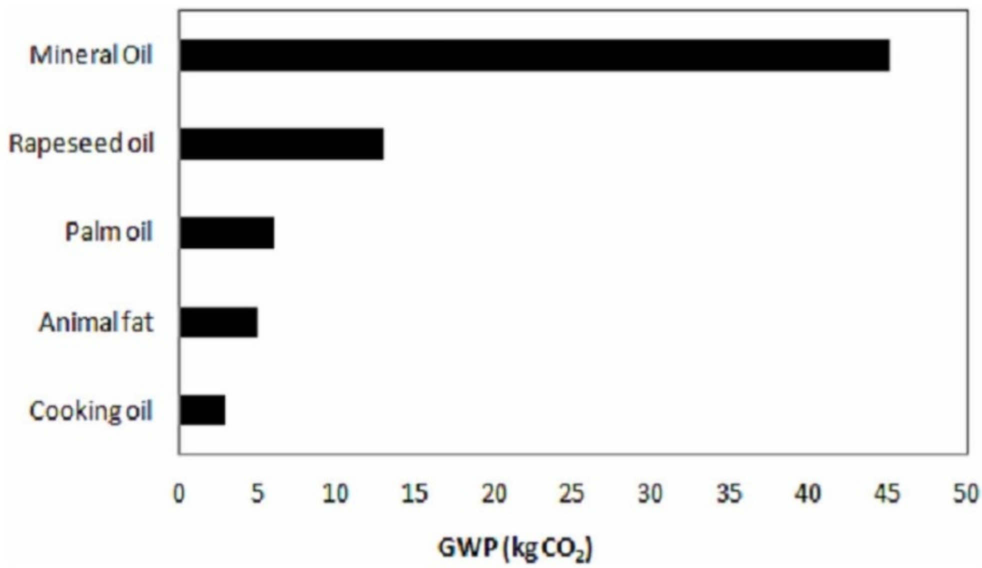

Figure 2. Global Warming Potential of Various Oils [58].

Several reviews have been published on this topic during the last decade. For example, R. et al. [64] recently published a review article that focuses on the accomplishment of sustainable green manufacturing using several vegetable oil-based metal cutting fluids. This article analyses the economic, technical, and environmental liabilities of these green fluids in association with machining operations. Debnath et al. [9] reviewed the then developments of vegetable oil-based metal cutting fluids and their performances in machining. Nagendramma and Kaul [65] attempted to highlight the then-current status of eco-friendly/biodegradable lubricants for the formulation of new generation lubricants. The present article attempts to present the state-of-the-art of understanding of sustainable machining using vegetable-oil based cutting fluids for turning, drilling and milling operations. It also provides a guideline for industries to ensure green manufacturing through sustainable cutting fluid use.

2. Cutting Fluids

Cutting fluids (CFs) are delivered to the chip production zone gravitationally or under suitable pressure to increase cutting performance through cooling and/or lubrication effects [66]. In general, these effects are proportional to the quantity of heat produced. There are four primary types of CFs, according to popular belief [11,67]:

1. Mineral oils that are used undiluted are known as straight or neat oils. They do, however, commonly contain additional lubricants such as fats, vegetable oils, esters, and extreme-pressure compounds based on chlorine, sulphur, and phosphorus to increase lubricity, and other agents to improve wear and corrosion resistance, dura-

bility, and foaming propensity. Although neat CFs are excellent lubricants, they are poor coolants. Mineral oils are presently used in the vast majority (about 90%) of instances [68].

2. Mineral-soluble oils (emulsions) are composed of oil and emulsifiers, which allow the oil to disperse in water prior to use. These oils are frequently used in diluted form, with concentrations ranging from 3–15 per cent. The amount of emulsifier employed determines the size of the oil droplets, which typically ranges between 1 and 10 μm [68]. Although the high concentration of water (up to 99 per cent) provides good cooling, wet machined components are prone to corrosion.
3. Semi-synthetic fluids (or micro-emulsions) are a mixture of synthetic and soluble oil fluids with features of both types of substances. Natural and manufactured emulsifiers, oil droplets, and transparent emulsions comprise them. They offer high corrosion resistance, lubrication, and contaminant tolerance.
4. Synthetic fluids are mineral oil-free solutions manufactured from alkaline inorganic and organic compounds, which are often laced with corrosion inhibitors. They are diluted with water prior to use, with concentrations ranging from 3% to 10%. These fluids typically provide the best cooling performance, according to industry standards.

Degradation of cutting fluid is a key factor when we must dispose of the used CF. A large portion of cutting oils needs to be disposed of after their usage. After being dumped, the cutting fluids contribute to environmental pollution by contaminating soils, rivers, and underground water reservoirs, ultimately contaminating the crops being harvested in such agricultural areas [54]. Apart from being harmful to the environment, these cutting fluids directly affect the health of workers in machine shops. Asthma, cough, and other infections are dominantly found in the operators working in such environments. Even skin cancer and lung cancer are also reported in workers [69]. Due to these environmental and health hazards, legislations have been established to minimise the usage of these cutting fluids to ensure environmental sustainability [19]. Another significant characteristic of CFs is their lubrication, which helps to lubricate the contact regions between the rake face and chips, the flank face and the machined surface, and reduces adhesion and abrasion at low cutting speeds [13]. As a lubricant, CF decreases friction and, as a result, the heat generated by friction. Lubricant qualities in cutting fluid aid in reducing rake-face friction and increasing shear angle in low-speed sliding friction cutting [70]. As a result, thinner and more tightly curled chips are produced, decreasing the heat generated in the shear zone and cutting power consumption [71].

There are a number of other considerations to weigh when selecting a cutting fluid [72]:

- The cutting fluid must not cause any undesirable side effects such as odours or allergic responses
- It should be able to withstand high-pressure equipment like centrifuges without foaming
- The cutting fluid must not dissolve paint, damaging the machine's coating. It should also not corrode seals
- The cutting fluid should not be the source of corrosion on the workpiece. Because a variety of materials are often machined, the cutting fluid should be acceptable for all of them, or at least the majority of them, without the need to change cutting fluids. The danger of corrosion attack with non-ferrous materials, such as copper, brass, and aluminium, is especially important
- The cutting fluid must not cling or adhere, allowing chips and particles to become attached, making tank cleaning more difficult or destroying the workpiece's surface
- Most machines leak oil, and modern ones can leak up to one litre every day. Thus, it is ideal if the cutting fluid can dissolve leaking oil without affecting its performance

3. Application of Vegetable Oil-Based Cutting Fluids for Turning Operation

3.1. Edible Vegetable Oils as Cutting Fluids for Turning Operation

The turning operation has been conducted by many researchers using edible vegetable oils, and performance was compared with the mineral oils or dry turning. Coconut oil is an abundant vegetable oil worldwide, and it has less viscosity compared to other vegetable oils. Coconut oil was tested as a biodegradable cutting fluid in a study, and a performance comparison was made with a commercial mineral oil [73]. EN8 Steel was used as a workpiece, and machining was executed on a CNC lathe at various FR, DOC, and V_C where high V_C, medium FR, and medium DOC were recommended as optimum cutting parameters after machining, as shown in Table 1. The minimum R_a value obtained using Coconut oil was 0.93 µm compared to 1.37 µm of mineral oil. In addition, the cutting force was also minimised to 180 N using Coconut oil compared to the 200 N value of mineral oil. Less fluidity and the high saturated fatty acid ratio of Coconut oil enabled it to be a good cutting fluid compared to commercial mineral oil.

Properties of vegetable oils as cutting fluids can be enhanced by the addition of nanoparticles of highly conductive materials [74,75]. This increases the thermal conductivity of the cutting fluid to remove the heat of cutting. A research work comprised of adding nano boric acid particles (0.25% by weight) in the Coconut oil, and its performance as cutting fluid was equated with drying cutting and conventional cutting fluid [76]. Machining was conducted on AISI 1040 Steel with the help of a precision lathe machine and at constant FR, DOC, and V_C. The conventional cutting fluid and nanofluid reduced cutting forces by 8.5% and 14.5%, respectively, when compared with the dry cutting environment. In the same manner, R_a values were reduced to 24.24% and 12.19%. Tool wear value for dry cutting was 0.16 mm, whereas, for conventional cutting fluid and nanofluid, the values were 0.15 mm and 0.14 mm. As far as cutting temperature was concerned, its values came out to be as high as 280 °C, 200 °C and 150 °C for dry, nano-enhanced, and conventional fluid environments. So, the addition of nanoparticles enhances the performance of cutting fluids to a great extent.

Soybean and Cottonseed oils are abundant vegetable oils worldwide. In another research, Soybean and Cottonseed oils were used as cutting fluids [77]. Their performance was compared with Servocut oil while turning AISI D2 Steel using the CNC lathe machine. Flooded lubrication technique was used, and turning was performed by Ti-Al-N coated carbide tool at different FR, DOC, and V_C. The lowest FR and moderate values of V_C and DOC mentioned in Table 1 proved to be the best for surface quality. A minimum R_a of 1.2 µm was obtained using Cottonseed oil, whereas R_a value for commercial Servocut oil was 1.62 µm. This indicates that an excellent surface finish is obtained using Cottonseed oil.

Canola oil has been tested as a cutting fluid as well [14]. A study collated the performance of Canola oil and commercial synthetic oil to promote environment-friendly turning operations [78]. A conventional lathe machine was used for turning with a cemented carbide tool for two specimens, one specimen of Mild Steel and the other of Carbon Steel. The specimens were machined at different speeds, but the highest speed proved to be optimum, as indicated in Table 1. R_a for Mild Steel was 3.08 µm in the case of synthetic oil compared to 2.99 µm of Canola oil. Likewise, R_a value for Carbon Steel specimens was 4.856 µm using commercial oil and 4.697 µm with the help of Canola oil. The same trend was observed for tool wear where tool wear for Mild Steel with the help of Canola oil-based cutting fluid was 5.276 mm, and for synthetic oil, the tool wear came out to be 3.987 mm. The Carbon Steel tool wear value in the case of synthetic oil was 13.6112 mm compared to the Canola oil value of 9.2743 mm. Thus, canola oil-based cutting fluid can help in refining surface finish and reducing the tool wear.

As discussed previously, the MQL technique is often used to minimise the use of cutting fluids [79,80]. In one research work, the turning operation was conducted on Titanium alloy using a polycrystalline diamond tool to optimise various parameters resulting in a decrease in R_a [81]. Palm oil was used for MQL, whereas for flooding, 5% water emulsion of Vasco 1000 (phenol-free, chlorine-free) was used, and machining was conducted at FR, DOC, and V_C showed in Table 1. High speed and low values of FR and DOC produced minimum R_a values. Analysis of R_a values indicated that using MQL with vegetable oil was the best approach to reduce R_a. The combination of Palm oil with MQL provided R_a value of 0.89 µm. For flooding using commercial cutting fluid, R_a value was 0.99 µm and for dry condition R_a value was 1.75 µm. Hence using MQL in combination with Palm oil based cutting fluid can be an effective and environmentally friendly perspective.

Just like many other edible oils, Groundnut oil is easily available and non-toxic vegetable oil. Researchers employed Groundnut oil as a cutting fluid while turning Stainless Steel, and a performance comparison was made with the commercial water-soluble mineral oil [82]. Machining was conducted on a manual lathe using an HSS tool at various V_C, FR, and DOC, whose values are indicated in Table 1. R_a was chosen as the performance evaluation criteria. The minimum R_a value of 3.84 µm was obtained using Groundnut oil compared to 9.21 µm of mineral oil. The soluble oils have excellent cooling capacities but having good lubricating properties. Groundnut oil can be used as an effective cutting fluid.

Another research was conducted using Groundnut oil-based cutting fluid while comparing its performance with Cottonseed oil-based cutting fluid [83]. The turning operation was performed on a lathe machine using EN8 steel specimens. Both the oils were used in two different concentrations, i.e., 10% and 20% concentrations of oils in 90% and 80% water. So, four different cutting environments were tested to find out the best option. Turning was performed at $V_{C,}$ and DOC showed in Table 1. Temperature variations using Groundnut oil and Cottonseed oils are shown in Figure 3 clearly indicating lower temperature values in the case of 80% water and 20% oil.

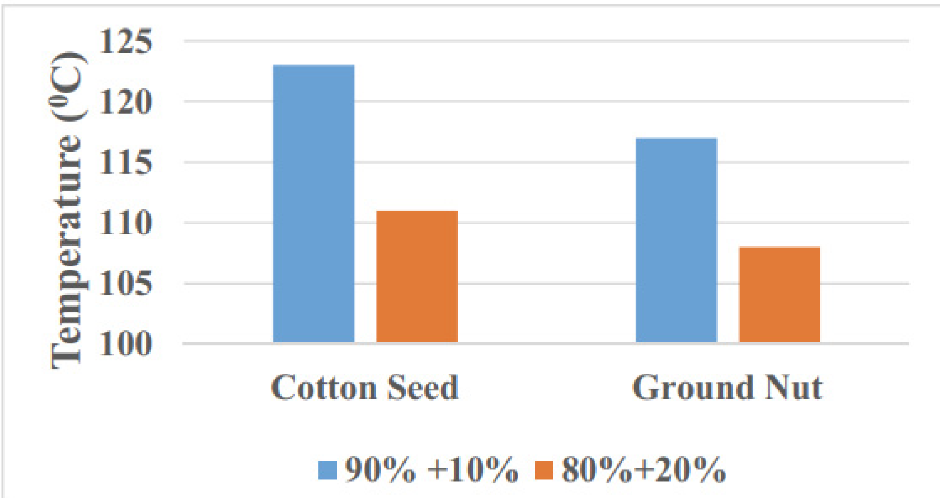

Figure 3. Temperature Variation at Different Cutting Environments [83].

Further its can be seen that Groundnut oil performed better than Cottonseed oil. The relation between V_C and DOC with R_a is shown in Figure 4.

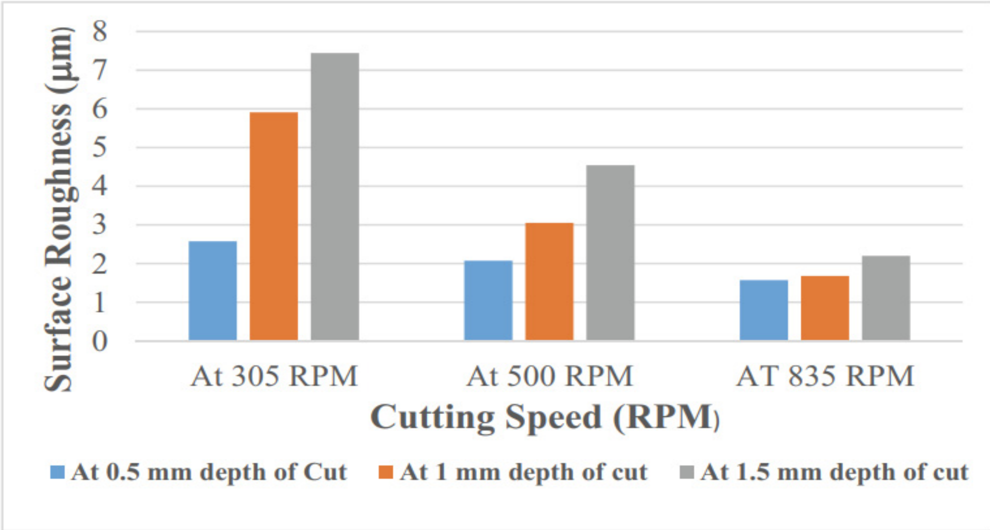

Figure 4. Relation of Cutting Speed and Depth of Cut with Surface Roughness [83].

The figure indicates the recommendation of high V_C with low DOC to achieve an excellent surface finish. So, to obtain the best results, Groundnut oil with a 20% concentration in water must be used as cutting fluid, and turning must be conducted at high speed and low DOC to generate minimum R_a.

When only lubrication is the major requirement of the cutting process, pure oil can be used as a cutting fluid. However, when both cooling and lubrication are needed, emulsions are used, which assists in cutting down the consumption of a fluid by mixing the oil in water. From an environmental perspective, the consumption of oil is reduced, and less amount of oil needs to be disposed of. Additionally, if emulsions of edible oils are used, less edible oil consumption helps food security. Emulsions can be prepared by mixing a small quantity of oil in water and stabilising the emulsion with additives. Hence both cooling and lubrication effects are obtained with small consumption of cutting oil [84]. Vegetable oil emulsions along with proper additives are an effective choice as cutting fluids so that consumption of oils is minimised. False Walnut oil, Groundnut oil, and conventional mineral oil emulsions were used as cutting fluids in a study [85]. Emulsions of oil in water were prepared using additives (Tween 80 as an emulsifier, Butyl Hydro toluene BHT as an antioxidant, banana sap as a corrosion inhibitor, biocide, and distilled water). Turning was conducted on annealed AISI 1330 alloy Steel using HSS as cutting insert, and various FR, DOC, and V_C showed in Table 1 were used. High V_C, medium FR, and low DOC proved to be the best cutting parameters. Groundnut oil provided a R_a value of 5.05 µm compared to 5.11 µm of mineral oil. This research indicates the importance of vegetable oils as cutting fluids in the form of an emulsion. Maximum R_a was noted in the case of mineral oil (1.46 µm).

Emulsions of some other vegetable oils have been used as cutting fluids as well. Experiments were conducted using non-toxic Peanut, and Palm oil emulsions and performance were compared with commercial Servo-cut oil [86]. All three emulsions were prepared using 95% water, 4% oil and 1% additives. The turning operation was performed on a high-speed CNC machine at different cutting parameters shown in Table 1 and the above-mentioned cutting conditions. The performance was evaluated based on temperature and R_a. Variation in R_a under the three emulsions is shown in Figure 5.

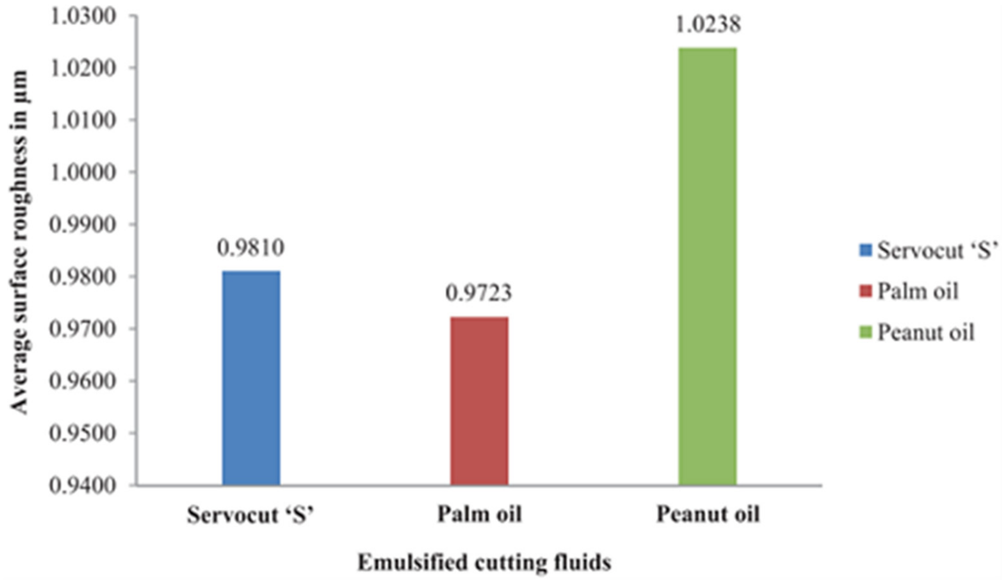

Figure 5. Surface Roughness Variation under Different Cutting fluids [86].

Similarly, temperature variation is shown in Figure 6. It is evident from the Figures that Peanut oil is not a good cutting fluid in comparison to Servo-cut and Palm oil. Servo-cut performed far better in temperature reduction, and Palm oil proved best for minimizing R_a.

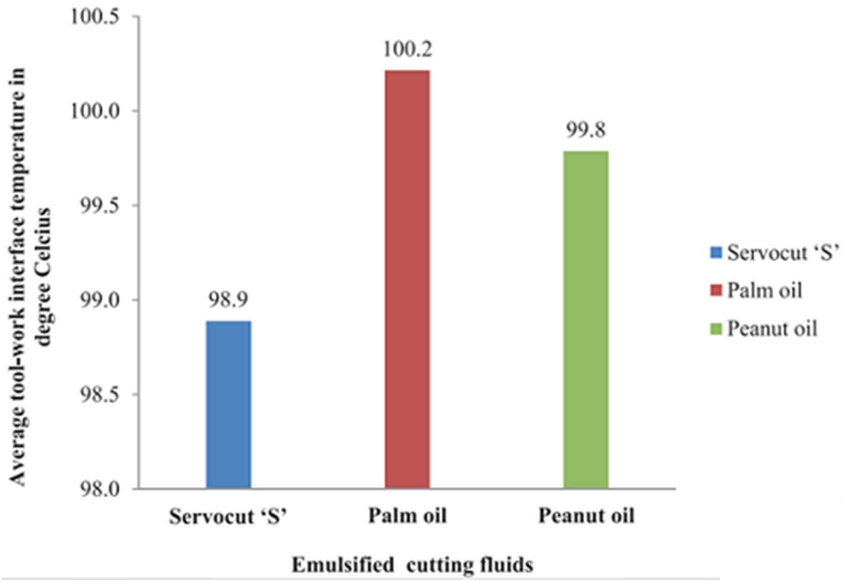

Figure 6. Temperature Variation under Different Cutting fluids [86].

The performance of vegetable oils in their virgin and emulsion states may differ from each other. So, research work was conducted to compare the performance of two vegetable oils in their emulsion and virgin states [87]. Palm oil and Coconut oils in their virgin and emulsion states were utilized as cutting fluids. Emulsions of both the vegetable oils were prepared in the same proportions (i.e., 32% oil, 32% surfactant and 36% water). Turning operation for Titanium Alloy (TC4) was conducted on OPTIMUM lathe machine under the mentioned cutting conditions and varying cutting parameters shown in Table 1. Tool wear, temperature, and chip reduction coefficient were considered as output parameters. The tool wear using virgin Palm oil and emulsified Palm oil was reported to be 122.37 µm and 323.33 µm, respectively. Whereas for virgin Coconut oil and emulsified Coconut oil, the tool wear was found out to be 517.7 µm and 1046.3 µm. The optimum conditions for minimum cutting temperature (32.2 °C) were V_C = 90 rpm, FR = 0.10 mm and DOC = 0.3 mm using virgin Palm oil as cutting fluid. As far as chip reduction co-efficient is concerned, its minimum value of 1.2 was attained at optimum conditions of V_C = 215 rpm, 0.25 mm/rev, and 0.9 mm DOC with the help of pure Palm oil as cutting fluid. So, it can be concluded that emulsions of both the oils proved better as cutting fluid and out of the two oils Palm oil has the best performance.

Another research selected emulsions of Melon Seed oil and Beniseed oil as CFs and compared performance to the mineral oil while machining on a conventional lathe machine [88]. The turning operation was conducted on AISI 304 L Steel using a tungsten carbide tool. The V_C, FR, and DOC (values are shown in Table 1) were used as the input parameters. To evaluate the performance of the oils as CFs, surface roughness, and temperature values were measured. High values of speed and medium DOC were recommended as the best input parameters for cutting and their values are mentioned in Table 1. Maximum R_a was noted in the case of mineral oil (1.46 µm). Using Beniseed oil provided R_a value as 1.50 µm and a value of 1.46 µm was obtained for mineral oil. Likewise, for temperature, a minimum temperature of 37.9 °C was in the case of Melon Seed oil. On the other hand, for Beniseed oil and mineral oils, the values of temperatures were 43.4 °C and 46.3 °C, respectively. The fatty acid composition along with properties like flashpoints, density, etc. enables emulsions of vegetable oils to be used as CFs.

Table 1. Turning Operation Using Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
1	Coconut oil	No Additive	EN8 Steel	V_C = (750, 1500, 2250) m/min DOC = (0.5, 1, 1.5) mm FR = (0.10, 0.15, 0.20) mm/rev	V_C = 2250 m/min DOC = 1 mm FR = 0.15 mm/rev	R_a, Cutting Force	Less fluidity of Coconut Oil makes it an effective cutting fluid.	[73]
2	Coconut oil	Nano Boric Acid	AISI 1040 Steel	V_C = 60 m/min DOC = 0.5 mm FR = 0.14 mm/rev	Cutting parameters were kept constant.	R_a, Tool Wear, Temperature, Cutting Force	Enriching coconut oil with nanoparticles enhances the performance of cutting fluid.	[76]
3	Soybean oil, Cottonseed oil	No Additive	AISI D2 Steel	V_C = (1700, 1800, 1900) m/min DOC = (0.5, 0.75, 1) mm FR = (0.15, 0.2, 0.25) mm/rev	V_C = 1800 m/min DOC = 0.75 mm FR = 0.15 mm/rev	R_a	Cottonseed Oil performs better than Soybean Oil and mineral oil.	[77]
4	Canola oil	No Additive	Mild Steel, Carbon Steel	V_C = (120, 141, 174) m/min DOC = 0.1 mm FR = 1 mm/rev	V_C = 174 m/min	R_a, Tool Wear	Canola Oil is an effective cutting fluid for Mild Steel as well as Carbon Steel.	[78]
5	Palm oil	No Additive	Titanium Alloy	V_C = (50, 100, 150) m/min DOC = (0.25, 0.5, 0.75) mm FR = (0.15, 0.25, 0.35) mm/rev	V_C = 150 m/min DOC = 0.25 mm FR = 0.15 mm/rev	R_a	MQL technique helps in reducing the usage of cutting fluids without affecting the performance of machining.	[81]
6	Groundnut oil	No Additive	Stainless Steel	V_C = (75, 100, 135) m/min DOC = (0.01, 0.05, 0.08) mm FR = (0.01, 0.03, 0.05) mm/rev	V_C = 135 m/min DOC = 0.08 mm FR = 0.05 mm/rev	R_a	Groundnut Oil has better lubricating properties in comparison to mineral oil.	[82]
7	Groundnut oil	Emulsifier	EN 24 Steel	V_C = (305, 500, 835) rpm DOC = (0.5, 1, 1.5) mm	V_C = 835 rpm DOC = 1.5 mm	R_a, Temperature	Groundnut Oil performed dominantly to reduce the cutting temperature in comparison to Cottonseed Oil.	[83]

Table 1. *Cont.*

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
8	False Walnut oil, Groundnut oil	Tween 80 Emulsifier, Butyl Hydro Toluene, Banana Sap, Distilled Water	AISI 1330 Steel	V_C = (28, 35, 42) m/min DOC = (0.3, 0.6, 0.9) mm FR = (0.124, 0.178, 0.249) mm/rev	V_C = 42 m/min DOC = 0.3 mm FR = 0.178 mm/rev	R_a	Just like mineral oils, vegetable oils perform better in an emulsion state.	[85]
9	Peanut oil, Palm oil	Emulsifier	AISI 1045 Steel	V_C = (3200, 3400, 3600)rpm, FR = (0.1, 0.15, 0.2)mm/rev, DOC = (0.1, 0.15, 0.2)mm	V_C = 3200 rpm, FR = 0.1 mm/rev, DOC = 0.1 mm	R_a, Temperature	Palm Oil emulsion can be utilized as a cutting fluid to enhance surface quality and ensure biodegradability.	[86]
10	Palm oil, Coconut oil	Surfactant	Titanium Alloy (TC4)	V_C = 90, 108, 140, 215 m/min, FR = 0.10, 0.15, 0.20, 0.25 mm/rev, DOC = 0.3, 0.6, 0.9, 1.2 mm	V_C = 90 m/min, FR = 0.10 mm/rev, DOC = 0.3 mm	Tool Wear, Temperature, Chip Reduction Co-efficient	Palm oil possesses excellent properties as a cutting fluid when compared to Coconut Oil in terms of temperature, tool wear and chip reduction coefficient.	[87]
11	Melon seed oil, Beniseed oil	Emulsifier, Biocide, Anti-corrosive Agent, Antioxidant	AISI 304 L Steel	V_C = (93, 126, 159) rpm DOC = (0.8, 1, 1.2) mm FR = (0.5, 0.7, 0.9) mm/rev	V_C = 159 rpm DOC = 1 mm FR = 0.9 mm/rev	R_a, Temperature	The fatty acid composition and properties like flashpoints, density, etc., enable emulsions of vegetable oil to be used as cutting fluids.	[88]

3.2. Non-Edible Vegetable Oils as Cutting Fluids for Turning Operation

Non-edible vegetable oils are an excellent choice as cutting fluids because their usage does not harm the food chain, which may be a drawback in the case of edible oils. Jatropha and Pongamia are non-edible, easily available, and biodegradable vegetable oils. A study was carried out while consuming Jatropha and Pongamia oils as straight cutting fluids after epoxidizing (to boost oxidative stability) them, and their performance was compared with commercially available mineral oil-based cutting fluids [89]. The turning process was performed on an AA 6061 workpiece using the HSS tool at different FR, DOC, and V_C, out of which less DOC, FR, and elevated speeds were optimum, as mentioned in Table 2. The value of roughness using Jatropha was as low as 0.7 µm, and for Pongamia oil, it was up to 0.8 µm. On the contrary, the R_a value was more than 1 µm in the case of mineral oils. Not only less R_a values were obtained using vegetable-based cutting fluids, but additionally, a reduction in cutting forces was observed. The minimum cutting force for mineral oil was 465 N, and for Jatropha, the value was 235 N. On the other hand, Pongamia oil reduced the cutting force to a minimum, i.e., 100 N. Jatropha is highly viscous oil in its crude state, so it does not flow easily. Researchers utilised the trans-esterification process and added 0.05% by weight of boron nitride in Jatropha oil to increase its performance as a cutting fluid [90]. A CNC lathe machine was used in experimentation to machine AISI 1045 specimens using a commercial cutting fluid, Jatropha oil as cutting fluid, and modified Jatropha oil. MQL technique was adopted to transport the cutting fluid to the hot zone, and turning operation was conducted under constant cutting conditions shown in Table 2. Cutting force was minimised to 375 N by using the modified Jatropha oil (with 0.05% boron nitride) compared to simple Jatropha Oil (425 N) and commercial cutting oil (475 N). In the same manner, a reduction in cutting zone temperature was observed where the maximum values of temperature for commercial oil, Jatropha oil, and boron nitride enhanced Jatropha oil came out to be 235 °C, 225 °C, and 215 °C. This research emphasised that non-edible oils have all the desirable characteristics to be used as cutting fluids after some chemical modifications.

The effectiveness of Jatropha oil-based cutting fluids has been tested in another experimental work [91]. Emulsion of Jatropha oil in water by 1:9 was prepared to be used as cutting fluid using emulsifier and additives shown in Table 2. Properties of Jatropha oil are enhanced by the addition of anti-corrosive and anti-oxidation additives. The turning operation was conducted on a lathe machine using the Tungsten Carbide tool at different V_C, DOC and FR values shown in Table 2. To examine the performance, tool wear and R_a were considered as output parameters. The results indicated that the minimum R_a in the case of Jatropha based cutting fluid was 0.56 µm in comparison to 1.40 µm of mineral oil clearly indicating dominating performance of Jatropha oil. As far as tool wear was concerned, minimum wear in the case of Jatropha was 0.09 µm when compared with 0.07 µm of mineral oil. So, it can be pointed out that mineral oil performed a little better in the case of tool wear. But if we consider surface quality and biodegradability factors as well, Jatropha emulsion performs exceptionally well.

The properties of nanoparticles of a single material can be limited to a certain extent. These properties can be enhanced by adding nanoparticles of different materials to the base fluid. A combination of nanoparticles of different materials in a liquid is called a hybrid nanofluid. A hybrid nanofluid combines the physical and chemical properties of two or more nanofluids [92,93]. Research was carried out in which Carbon Nano Tubes (CNT)/Molybdenum Di Sulfide (MoS_2) nanoparticles were added by (0.5, 1, 1.5, 2, 2.5, 3) wt.% with a hybrid ratio of 1:2 in Sesame oil [94]. The formulated vegetable oil was emulsified with the aid of Sodium Dodecyl Sulfate. The performance of these hybrid nanofluids as cutting fluid was compared with the conventional cutting environment. Turning operation on AISI 1040 Steel was conducted on a lathe machine at constant cutting parameters shown in Table 2. Cutting force, tool wear, R_a and temperature were determined to find out the best cutting environment. The results revealed the best performance in terms of reduction in cutting force and R_a at 2 wt.% of hybrid nano cutting fluid. Cutting force was reduced by 32% and 27.3% in comparison to dry cutting and conventional cutting fluid. At the same time, R_a values were reduced to 28.5% and 18.3%, respectively. As far as cutting temperature and tool wear were concerned, 3 wt.% of hybrid nano cutting fluid performed superiorly. Cutting temperature was reduced by 43.4% and 28% in comparison to dry and conventional cutting fluid. Further tool wear reduction was by 81.3% and 75%. Hence other hybrid nano cutting fluids can opt as good alternatives to conventional cutting fluid.

Table 2. Turning Operation Using Non-Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
1	Jatropha oil, Pongamia oil	No Additive	AA6061	V_C = (800, 1270, 1600) rpm DOC = (0.5, 1, 1.5) mm FR = (0.1, 0.175, 0.250) mm/rev	V_C = 1600 rpm DOC = 0.5 mm FR = 0.1 mm/rev	R_a, Cutting Force	Epoxidation of vegetable oils improves their oxidative stability to use them as cutting fluids.	[89]
2	Jatropha oil	Boron Nitride	AISI 1045	V_C = 350 m/min FR = 0.08 mm/min	Cutting parameters were kept constant.	Cutting Force, Temperature	Non-edible oils have all the desirable characteristics to apply them as cutting fluids just like edible oils.	[90]
3	Jatropha oil	Emulsifier, Anticorrosive agent (banana plant juice), Antioxidant, Biocide		V_C = (500, 630, 800, 1250) rpm DOC = (0.3, 0.65, 1, 1.24) mm FR = (0.52, 0.65, 0.82, 1) mm/rev	V_C = 1250 rpm DOC = 1 mm FR = 1 mm/rev	R_a, Tool Wear	Special focus must be on the selection of additives of biodegradable nature, just like Banana plant juice has been used as an anti-corrosive agent.	[91]
4	Sesame oil	Sodium Dodecyl Sulfate	AISI 1040 Steel	V_C = 80 m/min DOC = 0.5 mm FR = 0.161 mm/rev	Cutting parameters were kept constant.	R_a, Tool Wear, Cutting Force, Temperature	Increasing the concentration of nanoparticles increases specific heat and thermal conductivity. So proper concentration of nanoparticles in fluids plays a vital role.	[94]
5	Neem oil	No Additive	Mild Steel	V_C = (58, 85, 125, 180, 260, 540) rpm DOC = 6 mm FR = (1, 0.8, 0.6, 0.4, 0.2) mm/rev	V_C = 58 rpm FR = 1 mm/rev	Temperature	Neem oil reduces cutting zone temperature and is anti-bacterial, so it is a good cutting fluid.	[95]
6	Jojoba oil	Nano MoS_2 Particles	Ti-6Al-4V Alloy	V_C = 80 m/min DOC = 0.4 mm FR = 0.16 mm/rev	Cutting parameters were kept constant.	R_a, Cutting Force	The adequate concentration of nanoparticles in cutting fluids improves their performance.	[96]
7	Gingelly oil	No Additive	AISI 1014	V_C = 328 m/min DOC = (0.25, 0.5) mm FR = 0.6 mm/rev	Cutting parameters were kept constant.	R_a, Cutting Force	Gingelly oil, due to its better lubricating properties, is an excellent alternative as a cutting fluid.	[97]

Neem oil is non-edible vegetable oil with anti-bacterial properties. So, research work conducted using neem oil as a cutting fluid and performance were compared with commercial cutting oils. The performance comparison was based on temperature reduction criteria [95]. The oils were used as cutting fluids while turning Mild Steel at different V_C and FR showed in Table 2. Additionally, the optimum values of V_C and FR are mentioned in Table 2, which indicated less cutting zone temperature at low V_C and FR. Results indicated that cutting zone temperature was most effectively lowered down (up to 39.53 °C) using Neem oil. For the soluble and straight oils cutting zone temperatures were as low as 40.51 °C and 43.21 °C, respectively. Consequently, Neem oil reducing cutting forces and being non-edible and anti-bacterial is an excellent choice for usage as a biodegradable cutting fluid.

Jojoba oil is a non-edible oil having preference over other vegetable oils due to its more oxidative stability. A study used Jojoba oil based nano cutting fluid to compare its performance with the commercial mineral oil for the turning operation of Ti-6Al-4V alloy [96]. The mineral oil used was LRT 30, and cutting fluids were used in their pure form as well as by adding MoS_2 nanoparticles. Constant FR and V_C values shown in Table 2 were adopted. Machining was performed under dry conditions, using the MQL technique (for pure fluids of both LRT 30 and Jojoba oil) and MQL technique with MoS_2 enhanced nanofluids. Nanofluids were prepared for both the oils with 0.1%, 0.9%, and 0.5% by weight concentrations of MoS_2. The nanofluids were homogenised using 0.1% by weight of lauryl sodium sulphate as an emulsifier and magnetic stirring. A lathe machine was used for turning operation selecting PVD coated carbide tool. The concentration of MoS_2 by 0.1% of weight both in mineral and Jojoba oils produced the best results for all the output parameters. A maximum cutting force of 112 N was used in dry cutting, whereas for Jojoba, a minimum cutting force of 73.62 N was needed comparing to that of LRT30 nanofluid (76.4 N). Similarly, for R_a, a minimum value (0.1358 µm) was obtained in the case of Jojoba nanofluid compared to LRT 30 nanofluid (0.1407 µm) and dry cutting (0.2289 µm). A similar tendency was noticed for tool wear, where minimum tool wear (0.1 mm) was obtained in the case of nano Jojoba oil. For nano mineral oil, the tool wear was 0.14 mm, and for dry cutting, the value was 0.19 mm. The high value of viscosity index and the long-chain fatty acid structure of Jojoba oil help it to be more effective and provide better results as cutting fluids. Further, at 0.1% concentration, more particles of MoS_2 provide a high value of thermal conductivity.

Gingelly is a natural and biodegradable oil of sticky nature to provide better lubrication and heat transfer. In previous research, Gingelly oil was selected as a cutting fluid to compare its effectiveness with the mineral cutting oil and dry cutting [97]. The turning operation was performed on a medium-duty lathe using AISI 1014 Steel as a workpiece under constant FR and V_C shown in Table 2. Cutting forces and R_a values were measured in all three cutting environments. The minimum cutting force of 243 N was required in the case of Gingelly oil. On the other hand, for mineral oil-based cutting fluid and dry cutting, required cutting forces were 258 N and 285 N. Similarly, a minimum R_a value of 0.86 µm was obtained in the case of Gingelly oil compared to 1.3 µm and 1.1 µm for mineral oil-based and dry cutting, respectively. Bio-based oil usage as cutting fluid is environment friendly as well as energy-efficient.

4. Application of Vegetable Oil-Based Cutting Fluids for Drilling Operation

4.1. Edible Vegetable Oils as Cutting Fluids for Drilling Operation

Like turning, many researchers conducted drilling operations using edible vegetable oils, and performance comparison was made with dry cutting or commercial cutting fluids. Sunflower oil has a triglyceride structure, and its non-volatile nature can opt as a cutting fluid. So, research was carried out using Sunflower oil as a cutting fluid. AISI 321 SS square blocks were drilled using a drilling machine of 5 KW power, and fresh HSS drills were used for each experiment [98]. FR and V_C and drilled hole depth values are shown in Table 3. Cutting fluid was supplied to the cutting area using MQL of pure Sunflower oil and nanoparticles enhanced Sunflower oil. Nanofluids of vegetable oil was prepared by adding 0.5%, 1% and 1.5% by wt. of nanographene. The performance of both MQL conditions was examined based on thrust force, torque, R_a and friction co-efficient. Results showed that at 1.5 wt.% of nanographene, the values of thrust force, torque, R_a, and friction co-efficient were reduced by 27.4%, 64.9%, 33.8% and 51.7%. The addition of an adequate proportion of nanographene stabilized the lubrication film, effectively boosting the machining performance.

Table 3. Drilling Operation Using Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
1	Sunflower oil	Nanoraphene = 0.5%, 1% and 1.5% by wt.	AISI 321	V_C = 7.91 m/min FR = 0.125 mm/rev DOC = 8 mm	Cutting parameters were kept constant	R_a, Thrust Force, Torque	The addition of nanoparticles helps in the effective stabilization of lubricating film.	[98]
2	Palm oil	No Additive	Inconel 718	V_C = (30, 40, 50) m/min FR = (0.05, 0.1) mm/rev	V_C = 30 m/min FR = 0.05 mm/rev	Temperature	Workpiece temperature and thrust force reduction make it possible to use Palm oil as an effective cutting fluid through the MQL technique.	[99]
3	Pongamia oil	No Additive	AISI 316	V_C = (45, 76, 156, 277) m/min Depth of Hole = (5, 2) mm	V_C = 277 m/min	R_a, Cutting Force	Continuous chip formation indicates the superior performance of the Pongamia oil-based cutting fluid.	[100]
4	Coconut oil, Peanut oil	A4140 Emulsifier, Water	Al based Metal Matrix Composites (MMC)	V_C = (15.07, 22.61, 30.15) m/min FR = (0.05, 0.125, 0.2) mm/rev	V_C = 15.07 m/min FR = 0.05 mm/rev	Cutting Force, Cutting Torque	A mixture of vegetable oils can additionally prove effective as cutting fluid.	[101]
5	Coconut oil	Emusifier (40%), Polysorbate 85, Poly sorbate 80, Triethanolamine, Additives (20%), Azadrirachta Indica oil, Ocimum Tenuiflorum oil, Cumbopogon Citratus oil, Jaggery Syrup	EN8 Mild Steel	V_C = (355, 710, 1120) rpm FR = (4, 10, 25) mm/min	V_C = 1120 rpm FR = 4 mm/rev	Cutting Force, Cutting Torque	While selecting additives and surfactants, special care must be adopted in terms of toxicity.	[102]
6	Soybean oil	Al_2O_3 Nanoparticles	Aluminum 6063	V_C = (30, 53.7) m/min Depth of Hole = 20 mm FR = 60 mm/min	V_C = 53.7 m/min	R_a	The infusion of nanoparticles improves the performance of cutting fluids.	[103]

Palm oil is an edible vegetable oil having a rich concentration of unsaturated fatty acids of the carbon chain. In a study, drilling of Inconel 718 was conducted using Palm oil as cutting fluid, and its performance was compared with mineral oil-based cutting conditions and air blowing [99]. Palm oil was supplied through MQL, and commercial oil was used in MQL as well as flooding situations. Drilling was performed using Palm oil (MQL), commercial oil (MQL), commercial oil (flooding), and air blowing using different V_C and FR values mentioned in Table 3. High values of V_C and FR cause more workpiece temperature. The performance of these drilling conditions was investigated based on thrust force and workpiece temperature. Thrust force values for Palm oil, commercial oil MQL, flooding, and air blowing condition were 2638 N, 2886 N, 3443 N, and 3699 N, and correspondingly workpiece temperatures were 125 °C for both MQL conditions, 135 °C for flooding, and 183 °C for air blowing. Workpiece temperature and thrust force reduction make it possible to use Palm oil as an effective cutting fluid through the MQL technique.

Pongamia oil was used by the MQL technique to compare its performance with commercial mineral oil. Researchers conducted drilling of AISI 316 Steel using Pongamia and mineral oil, and an HSS drill was used to drill holes [100]. Machining was performed at various speeds and depths of holes shown in Table 3. At maximum speed, both cutting force and R_a came out minimum. The value of cutting torque using Pongamia oil was reduced up to 36%, while thrust force and roughness were additionally 34% less in comparison to the commercial MO. Moreover, continuous chips were formed when vegetable oil was used to ensure that Pongamia is additionally a good alternative to commercial mineral oil.

Emulsions of vegetable oils in water can be prepared to minimise the cost of cutting fluid. A study comprised of drilling experiments using Coconut and Peanut oils with water and drilling parameters was optimised for difficult-to-drill Aluminium-based metal matrix composites using vegetable oil-based cutting fluid [101]. The cutting fluid used was C40P10W50, where C is the weight percent of Coconut oil, P is the weight percent of Peanut oil, and W is the weight percent of water. A4140 was used as an emulsifier to promote the mixing of oils and water. V_C and FR showed in Table 3 were the input parameters used at three different levels, whereas cutting force and torque were the output parameters. Less cutting speed and low FR proved to be optimum for machining. The performance of the formulated cutting fluid was compared with the dry drilling process. Vegetable-based cutting fluid reduced cutting force to 94.87 N compared to 120.6 N of dry drilling. Similarly, torque was minimised to 0.72 N-mm, which was 2.81 N-mm in case of dry cutting. Significant improvement in the drilling process can be attained with the help of a combination of vegetable oils as cutting fluids.

Another research for drilling was carried out using Coconut oil-based green cutting fluid, and its performance was compared with the Commercial cutting fluid [102]. Concentrated green cutting fluid was prepared using non-toxic emulsifiers (40%), natural additives (20%) and pure Coconut oil (40%). The composition of emulsifiers and additives is shown in Table 3. Five best cutting fluids available in the market were chosen, and out of them, the best cutting fluid was selected to be compared with the formulated green cutting fluid. The drilling operation was conducted on an HMT FN2 drilling machine using HSS drills. The machining was conducted on EN8 Mild Steel at FR and V_C showed in Table 3. In the case of torque, green cutting fluid showed comparable performance to green cutting fluid. Furthermore, higher speeds caused less torque, and at higher FR more torque was noticed. Additionally, green cutting fluid usage required low cutting forces in comparison to commercial cutting fluid. For a sustainable manufacturing operation, cutting fluid toxicity and biodegradability must be focused. As far as current regulations are concerned, they take only machining into consideration, neglecting vital factors of biodegradable ingredient selection and toxicity tests. These vital factors contribute to the overall quality of a product.

Just like turning, Soyabean oil has additionally been used as a drilling cutting fluid. In a research work drilling operation was performed on Al 6063 alloy using a CNC 3-axis drilling machine [103]. Drilling was conducted in dry, flooded, pure MQL, and nanoparticles enhanced MQL environments utilising Soyabean oil as biodegradable cutting fluid at different speeds shown in Table 3. For drilling 10 holes at a speed of 30 m/min under dry condition, the R_a value was 2 μm, for flooded cutting environment 1.65 μm, for MQL 1.6 μm, and for nanofluid MQL, R_a value was 1.3 μm. Nanoparticles cause a reduction in roughness by depositing on the surface.

4.2. Non-Edible Vegetable Oils as Cutting Fluids for Drilling Operation

Many non-edible oils like Neem, Karanja, Mahua, and Honge have been tested as cutting fluids for drilling operations. Neem and Mahua oils contain more than 40% mono-saturated content that exhibits them to provide lubricity, and they have good low-temperature properties. Researchers conducted research in which Neem and Mahua oils were used as cutting fluids (epoxidation was conducted to improve oxidative stability), and their performance was compared with that of commercial Servocut-945 [104]. Cutting fluid was supplied through the MQL technique while drilling AISI 304 L Stainless Steel at a constant depth of the hole, and different FR and V_C showed in Table 4, where higher speed provided optimum results. Thrust force was minimum when using Mahua oil (351.54 N), and for Neem Oil the thrust force value was 489.45 N compared to the Servo cut cutting fluid environment (674.87 N). In the same way, R_a values for Mahua, Neem, and MOs were 2.10 μm, 2.21 μm, and 2.89 μm, respectively. As far as the temperature was concerned its values for mineral, Neem, and Mahua oils were 83.45 °C, 71.46 °C, and 72.65 °C. Vegetable oils, due to their stable thin film formation ability, provide better lubrication, thus ensuring a better surface finish.

Table 4. Drilling Operation Using Non-Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
1	Neem oil, Mahua oil	No Additive	AISI 304 L SS	V_C = (2000, 2500, 3000) rev/min Depth of Hole = 10 mm FR = (0.003, 0.006, 0.009) mm/rev	V_C = 2000 rev/min FR = 0.003 mm/rev	R_a, Thrust Force, Temperature	Due to their stable thin film formation ability, Vegetable oils provide better lubrication, thus ensuring a better surface finish.	[104]
2	Karanja oil, Neem oil	No Additive	Mild Steel	V_C = 800 rev/min Depth of Hole = 30 mm FR = 10 mm/rev	Cutting parameters were kept constant.	R_a, Cutting Force	Mixing two vegetable oils can work as a cutting fluid.	[105]
3	Honge oil, Neem oil	No Additive	Mild Steel	V_C = 800 rev/min Depth of Hole = 30 mm FR = 10 mm/rev	Cutting parameters were kept constant.	R_a, Temperature	Blends of different vegetable oils in proper proportions can prove to be effective as cutting fluids.	[106]
4	Neem oil	2,4,4-Trimethyl Pentyl Phosphinate 2% *w*/*w*, Tween 20, Span 80	Al grade T6061	V_C = (355, 710, 1120) rpm, FR = 10 mm/min	V_C = 710 rpm	Cutting Force, Torque, R_a	Blends of ionic liquid with cutting fluid show excellent anti-wear and anti-scuffing properties.	[107]
5	Castor oil	No Additive	Al 6063 alloy	V_C = (80, 122, 160, 244, 290, 445, 580, 890) rpm, FR = 0.2 mm/rev	V_C = 890 rpm	Thrust Force, Torque, R_a	Convenient sliding of chips over tool surface results in low R_a.	[108]
6	Rapeseed oil	Ag nanoparticles	AISI 304 SS	V_C = (12, 16) m/min, FR = (0.08, 0.12) mm/tooth	V_C = (16) m/min, FR = 0.12 mm/tooth	Cutting Force, R_a	Reduction in viscosity occurs due to the addition of silver nanoparticles resulting in a better surface finish as cutting fluid is easily penetrated in the holes.	[109]

Blends of oils help in minimising the usage of specific oil to avoid shortage. In another research, experiments were performed in which Mild Steel was drilled on a CNC machine with different cutting fluid environments [105]. Cutting fluids used were petroleum-based SAE 20W40 oil, Karanja oil, Neem oil, and different blends of Neem and Karanja oils. The values of FR, DOC, and V_C were kept constant and are exhibited in Table 4. The suitability of these cutting fluids was established based on chip formation, surface finish, and cutting forces. A blend of 50% Karanja and 50% Neem oil proved to be the best of all, providing longer and continuous chips along with less cutting forces and an excellent surface finish. Minimum cutting force (151 N) was required when using a blend of 50% Neem and 50% Karanja whereas maximum cutting force was required for dry cutting (251 N) and for MO-based cutting (301 N) was required. The same was the case for R_a values which were 4.1 µm, 3.5 µm, and 1.25 µm for dry cutting, mineral oil-based cutting fluid, and 50% blend of Karanja with 50% Neem Oil, respectively.

Neem oil performs exceptionally well in the form of blends with other oils. Hence another research work was conducted in which drilling was performed on a CNC machine using SAE 20W40 oil, Honge oil, Neem oil, and different blends of Neem and Honge oil [106]. This time performance of cutting fluid was examined based on temperatures of tool and workpiece at constant cutting conditions shown in Table 4. At the same time, the hardness test and R_a tests were additionally the performance evaluation criteria. Again, a blend of 50% Honge and 50% Neem oil provided the best results as cutting fluid. Tool and workpiece temperature (40 °C) was minimum using a blend of 50% Honge and 50% Neem oil when equated to dry cutting temperatures (60 °C). This combination outperformed other combinations by providing a minimum R_a value of 1.1 µm. Surface hardness test before and after drilling was additionally conducted, which concluded that the difference of surface hardness was minimum when using 50% Honge Oil and 50% Neem oil blend. Consequently, blends of different vegetable oils in proper proportions can prove to be effective as cutting fluids.

Eco-friendly Neem oil was used in another drilling operation by emulsifying it with water [107]. The used additives and surfactants are shown in Table 4. The performance of Neem Oil based cutting fluid for drilling was compared with the conventional cutting fluid in the market. Workpieces of Al grade T6061 were used for drilling using HSS drill at constant FR, and different speeds are shown in Table 4. The cutting force, torque and surface finish were selected to compare the performance of Neem oil-based cutting fluid with commercial fluid. Drilling was conducted under five different cutting environments, i.e., dry, deionized water, Koolkut commercial cutting fluid, Neem oil emulsion and Neem oil emulsion with ionic liquid. After conducting experiments, the results showed that minimum axial force (332.01 N) and torque (1.03 N-m) were observed at a medium drilling speed of 710 rpm, and an 11.7% reduction in R_a was observed using an emulsion of Neem oil with ionic liquid. So, a conclusion can be drawn that Neem oil emulsion with ionic liquid as an additive can enhance the performance of vegetable oil-based cutting fluid.

Castor oil extracted from Castor seeds consists of a mixture of triglycerides enabling it to be used as a lubricating cutting fluid. So, researchers conducted Castor oil assisted drilling operation on rectangular blocks of Al 6063 alloy [108]. The drilling operation was conducted on a manual drilling machine at constant FR, and various speeds are shown in Table 4. An uncoated HSS drill was used, and drilling was conducted under dry, flooded and MQL based cutting environments. Considering thrust force, torque and R_a as output parameters, vegetable oil-based cutting fluids provided the best results in terms of all the output parameters. The friction coefficient was reduced due to MQL causing convenient sliding of chips over the tool surface. As a result, a reduction in R_a is observed.

Non-edible Rapeseed oil with low cost and oil-enriched seeds is one of the largest vegetable oil resources. Consequently, research work was conducted by researchers using Rapeseed oil as a cutting fluid for drilling of AISI 304 SS [109]. Performance of vegetable oil-based cutting fluid and nanoparticles enhanced vegetable oil-based cutting fluid was compared with Boron oil. Nanoparticles of silver were used for the preparation of nano cutting fluid (15% of silver particles were added in 85% of Boron oil or vegetable oil). MQL was adopted in both cases, and drilling was conducted on rectangular prisms at high as well as low speeds and feeds shown in Table 4. R_a and cutting forces were selected as performance evaluators. At low speed and low feed, minimum roughness of 1.64 µm was observed using nano cutting fluid. Whereas minimum cutting force of 928 N was consumed with pure Boron oil and the addition of silver nanoparticles in vegetable oil required a maximum cutting force of 1140 N. Further at high V_C and feed a minimum R_a of 1.36 µm was noted by using silver nanoparticles in vegetable oil compared to all other conditions. As far as cutting force was concerned minimum cutting force of 1146 N was observed in the case of silver enhanced vegetable oil. So the best option for machining is to use high speed and feed using silver nanoparticles enhanced vegetable oil as cutting fluid.

5. Application of Vegetable Oil-Based Cutting Fluids for Milling Operation

5.1. Edible Vegetable Oils as Cutting Fluids for Milling Operation

Many researchers utilised edible vegetable oils as cutting fluids during milling processes. Mostly flood cooling technique is used while machining alloys. Researchers performed a side milling process on Carbon Steel with the help of Coconut oil and conventional mineral oil as cutting fluid [110]. Then comparison was made, keeping surface quality in view. Machining was performed using a conventional vertical milling machine at various V_C, FR, and cutting depths displayed in Table 5. Moderate values of feed, speed, and DOC provided optimum results. Additionally, the results indicate R_a of 2.565 µm in the case of Coconut oil and 2.978 µm for mineral oil using the flood cooling technique. Coconut oil being nontoxic and oxidatively stable is an excellent choice as vegetable-based cutting oil.

Table 5. Milling Operation Using Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Ref.
1	Coconut oil	No Additive	Carbon Steel	V_C = (2.67, 8.33, 22.72, 31.11, 40.86) m/min DOC = (3.63, 5, 7, 9, 10.36) mm FR = (0.033, 0.05, 0.075, 0.10, 0.117) mm/min	V_C = 31.11 m/min DOC = 5 mm FR = 0.05 mm/min	R_a	Coconut oil being nontoxic and oxidatively stable is an excellent choice as vegetable-based cutting oil.	[110]
2	Palm oil	No Additive	ASTM A36 Steel	V_C = 95 m/min, FR = 0.114 mm/tooth, DOC = 1 mm	Cutting parameters were kept constant.	Flank Wear, Cutting Forces	MQL is the best option to cut down the consumption of cutting fluids.	[111]
3	Palm oil	No Additive	Ti6Al4V Alloy	V_C = (1700, 2350, 3000) rpm, FR = 0.075 mm/rev, DOC = 0.5 mm	V_C = 2350 rpm, FR = (0.025, 0.05, 0.075) mm/rev, DOC = (0.5, 0.675, 0.75) mm	Cutting Force, Temperature	Palm oil combination with MQL approach seems to be an economical and environmentally friendly approach.	[112]
4	Olive oil	No Additive	AISI 304 Steel	V_C = (100, 150) m/min DOC = 2 mm FR = (300, 400, 500) mm/min	V_C = 150 m/min FR = 300 mm/min	R_a	Vegetable oil combination with MQL can provide better results compared to the flooding method with mineral oil.	[113]
5	Black Mustard oil	No Additive	AISI H13 Steel	V_C = (30, 45, 60, 75) m/min DOC = 1 mm FR = (0.08, 1, 1.2) mm/min	V_C = 75 m/min FR = 1.2 mm/min	R_a, Temperature	Shining chips show a considerable decrease in temperature using vegetable oil.	[114]
6	Sunflower oil	Nanoparticles of Al_2O_3	SS 316	V_C = (30, 50, 60, 90, 120) m/min, FR = (25, 50, 100, 125) mm/min	V_C = 50 m/min FR = 25 mm/min	Power Consumption, R_a	Non-toxicity of both Al_2O_3 nanoparticles and sunflower oil enables this combination to be used as an environment friendly cutting fluid.	[115]
7	Soyabean oil	MWNCTs	Inconel-62, SS-304	For Inconel: V_C = (40, 45, 50) m/min, FR = (0.05, 0.062, 0.075) mm/tooth, DOC = (0.15, 0.225, 0.3) mm For SS-316: V_C = (100, 130, 160) m/min, FR = (0.075, 0.11, 0.15) mm/tooth, DOC = (0.3, 0.45, 0.6) mm	For Inconel: V_C = 50 m/min, FR = 0.05, mm/tooth, DOC = 0.3 mm	Tool Wear, R_a	The addition of MWNCT in adequate wt.% enhances the suitability of vegetable oil as a cutting fluid.	[116]

Just like turning and drilling, Palm oil has been used as cutting fluid by researchers due to its non-toxicity. A research was conducted in which Palm oil was used as a cutting fluid both in flooding conditions and MQL method [111]. Dry milling was additionally conducted to compare the performance with Palm oil. A milling operation was conducted on the ASTM A36 steel plate. Machining was conducted on a vertical milling machine, and values of FR, DOC, and V_C are shown in Table 5. Flank wear and cutting forces were selected as output parameters. Maximum flank wear and cutting forces were noticed for dry cutting. Whereas wet milling provided the best results. However, MQL assisted machining provided almost similar results as flooding. Hence MQL may easily opt as a cutting fluid supply method using Palm oil to minimize the usage of cutting fluid and ensure biodegradability.

Another research was conducted with Palm oil-based cutting fluid [112]. In another study, a Palm oil assisted MQL cooling system was compared to the flood cooling of commercial water-soluble oil. The end milling process on difficult-to-drill aerospace grade Titanium alloy was conducted under the above cooling and lubricating conditions. Machining was performed at V_C, FR and DOC values shown in Table 5. R_a, cutting force and temperature values have been opted as performance evaluation factors. A reduction of 35% in cutting force and roughness was observed for MQL (Palm oil) in comparison to flooding (Commercial oil). Additionally, the cutting zone temperature was additionally reduced by 47% more in the case of MQL when compared with flooding. Hence Palm oil combination with MQL is far more effective than the flooding of commercial oil.

AISI 304 is the most widely used steel and requires massive amounts of cutting fluids for machining. A study was conducted in which AISI 304 Steel was machined under MQL, flooding method, and dry environmental cutting conditions [113]. Here Olive oil was used as a biodegradable cutting fluid while machining in an MQL environment, and for flooding, mineral oil was utilised. End milling was conducted on a CNC machine with FR, experimental cutting environment, and cutting speed shown in Table 5 as input parameters, whereas R_a was the response. Higher V_C and low FR proved to be optimum parameters for milling. Minimum roughness was measured as 0.37 μm in the case of Olive oil-based cutting fluid, whereas, for mineral oil flooding and dry cutting, R_a values came out to be 0.58 μm and 1.58 μm, respectively. Vegetable oil combination with MQL can provide better results compared to the flooding method with mineral oil.

Another research used the MQL technique with Black Mustard oil-based cutting fluid, comparing its performance with the mineral oil-based flood cooling and dry milling [114]. A vertical milling machine was used for end milling of AISI H13 Steel with a coated carbide tool at different V_C and feed shown in Table 5. It was noted that high speed and feed cause high temperatures and poor surface quality. The results additionally revealed that using MQL (Mustard oil), reduction of temperature was enhanced to about 52–57% more than dry milling, and 38–45% improvement was noticed compared to wet machining (Commercial oil). In the same manner, the surface finish utilising MQL was improved to 53–64% and 22–40% in comparison to the dry and wet milling process. Additionally, burnt chips were obtained in dry milling, whereas light blue and shining silver chips were obtained using flooded and MQL techniques, respectively. Burnt chips show elevated temperatures due to dry machining; blue chips indicate mediocre temperature because of wet milling, and shining chips show a highly considerable decrease in temperature using vegetable oil.

Sunflower oil has additionally been used as a cutting fluid for milling operations. Research work was conducted in which end milling of AISI 316 SS was performed on a conventional vertical milling machine using a solid Tungsten Carbide tool [115]. Three different cutting conditions were used, i.e., dry MQL (pure Sunflower oil) and nanoparticles enhanced MQL (NMQL). Nanoparticles of Al_2O_3 were added by 0.2 wt.% in Sunflower oil to prepare nano cutting fluid. End milling operation was conducted at various V_C and FR showed in Table 5. Power consumption and surface quality were examined to determine best cutting conditions. A reduction in power consumption by MQL and NMQL was 4.7% and 8.6%, respectively, compared with the dry case. Whereas R_a values were reduced by

40% and 44% for MQL and NMQL conditions compared to dry cutting. A smoother surface with an excellent surface finish was obtained using NMQL. Hence higher V_C and feeds combination can be used with NMQL to improve productivity without compromising on quality.

As in the case of turning and drilling operations, Soyabean oil has been used as a cutting fluid in milling operations as well. For this purpose, experimental work was conducted for face milling of Inconel-62 and SS-304 using Soyabean oil under two conditions, and dry cutting was additionally conducted [116]. Operator friendly MQL was adopted as a cutting fluid supply method to ensure less consumption of cutting fluid. MQL was opted in two different manners, i.e., using pure Soyabean oil and Multi-Walled Nano Carbon Tubes (MWNCTs) enhanced Soyabean oil. MWNCTs were added in different proportions (0.5, 0.75, 1, 1.25, and 1.5) wt.% to prepare nanofluid. As materials were very hard-to-cut, down milling was opted, which causes more tool vibrations and the role of proper cutting fluid and cutting parameters gain significant importance. PVD coated carbide tools were used for machining, and the experiments were conducted under two stages. In the first stage, tool wear and surface roughness were examined to find out the optimum input parameters of V_C, DOC and FR for both the materials. Various values of input parameters were selected for the materials and are shown in Table 5. For Inconel, optimum values of V_C, DOC and FR were determined to be 50 m/min, 0.3 mm and 0.05 mm/tooth. In the case of SS-316, the optimum V_C, DOC and FR were 160 m/min, 0.3 mm and 0.15 mm/tooth. After optimization of parameters, stage 2 was initiated in which at optimum cutting parameters, the optimum cutting condition was determined in terms of tool wear of at optimum cutting parameters. For Inconel-625, minimum average tool wear values of (214, 218.5 and 243) µm were determined in the case of nanofluid MQL, pure MQL and dry cutting. The same trend was observed in the case of SS-316, where tool wear values for NMQL, MQL, and dry cutting were (233.5, 236.75 and 248) µm. Hence for both the materials, nanoparticles enhanced vegetable oil-based cutting fluid provides the best results as cutting fluid. Furthermore, at 1 wt.% concentration of MWNCT, Soyabean oil provided the least tool wear. So, the performance of vegetable oil-based cutting fluid should be enhanced by nanoparticles in suitable concentrations.

5.2. Non-Edible Vegetable Oils as Cutting Fluids for Milling Operation

To avoid a shortage of edible oils, some non-edible vegetable oils have additionally been tested as cutting fluids to replace them with toxic commercial mineral oils. Researchers performed face milling of Aluminium alloy 7075 using Cottonseed oil-based cutting fluid and compared the performance with commercial soluble oil and dry milling [117]. Cottonseed oil was utilised through the MQL technique once in its pure form and secondly in form of a nanofluid prepared by adding 0.5% by weight of Al_2O_3 nanoparticles. Table 6 displays the cutting conditions. R_a values for dry, mineral oil emulsion, MQL (Cottonseed oil), and MQL (nanofluid) were measured to be 0.1724 µm, 0.1647 µm, 0.1443 µm, and 0.1316 µm. In the same manner for the mentioned conditions, the cutting forces were 234 N for dry milling, 197 N for mineral oil, 189 N for pure MQL, and 187 N for nanoparticles enhanced MQL. Nanofluid of vegetable oil can perform better than flooded lubrication of mineral oil.

Emulsions of various vegetable oils have additionally been tested as cutting fluids for milling. In a research face milling experiments on AISI 1045 Steel were conducted using emulsions of commercial oil, Castor oil, Cottonseed oil, and Neem oil [118]. All the oils were emulsified using water. Milling was conducted on a vertical milling centre, keeping the number of passes, DOC, FR, and V_C as input parameters, whose values are shown in Table 6. High speed, moderate FR, and low DOC provided the best results. R_a values for all the oils were measured to find out the best option. The least surface roughness (0.786 µm) was obtained using Castor oil, whereas maximum roughness (0.931 µm) was in the case of Cottonseed oil. Mineral oil and Neem oil produced R_a values equal to 0.805 µm and 0.790 µm. Consequently, vegetable oils in an emulsion state can additionally out-perform mineral oils. Emulsions of Castor oil and Neem oil are the best options to be utilised as cutting fluids.

Table 6. Milling Operation Using Non-Edible Vegetable Oil-Based Cutting fluids.

Sr. No.	Vegetable Oil	Additives Used	Workpiece Material	Cutting Parameters	Optimised Cutting Parameters	Investigated Parameters	Remarks	Reference
1	Cottonseed oil	Al_2O_3Nanoparticles	Aluminum Alloy 7075	V_C = 2200 rev/min DOC = 0.4 mm FR = 500 mm/min	Cutting parameters were kept constant.	R_a, Cutting Force	Nano fluid of vegetable oil can perform better than flooded lubrication of mineral oil.	[117]
2	Castor oil, Cottonseed oil, Neem oil	Water and Emulsifier	AISI 1045	V_C = (1000, 1500, 2000) rev/min DOC = (0.1, 0.16, 0.20) mm FR = (300, 400, 500) mm/min	V_C = 2000 rev/min DOC = 0.1 mm FR = 400 mm/min	R_a	Vegetable oils in an emulsion state can additionally outperform mineral oils.	[118]
3	Castor oil, Palm oil	Vitamin C Tablets	Inconel 690	V_C = 140 m/min, FR = 0.2 mm/tooth, DOC = 1 mm	Cutting parameters were kept constant.	R_a, Tool Wear	The mixture of biodegradable oils can be used as cutting fluid to enhance characteristics of the cutting fluid using adequate proportions.	[119]
4	Sago Starch	Distilled Water, Sodium Carbonate, Sodium Hydro Carbonate, Ethanol, Dehydroacetic Acid, Cresol and Soap Solution, Rust Preventive Agent	AISI 316 SS	V_C = (16,000, 17,100, 18,200) rpm, FR = (400, 600, 800) mm/min	V_C = 16,000 rpm FR = 400 mm/min	R_a, Tool Wear	Sago Starch solution can be used as a non-toxic, non-edible categorized and more effective cutting fluid.	[120]
5	Raw Kapok oil	No Additive	AISI 1020 Mild Steel	V_C = (500, 750, 1000) rpm, DOC = (1, 1.5, 2) mm, FR = (0.08, 0.10, 0.12) mm/tooth	V_C = 647.5 rpm FR = 0.09 mm/rev DOC = 1.20 mm	R_a, Cutting Force, Tool Wear	Kapok Oil provides better results in the case of wear and R_a, whereas comparable results are obtained in the case of cutting forces as well.	[121]

Castor oil provides good lubricating properties, but its performance is somewhat limited due to viscosity. More viscosity of Castor oil causes flow difficulty. Research was conducted with Castor oil was mixed with Palm oil to enhance the flow of cutting fluid [119]. Castor oil and Palm oil were mixed with each other in six different volume ratios, as shown in Table 7. Cutting fluids were supplied through MQL technique. Vitamin C tablets were added to enhance resistance against corrosion. The performance of these formulated cutting fluids was examined in an end milling operation on hard-to-cut Inconel 690. Experimentation was conducted at constant cutting parameters shown in Table 7. The performance of the cutting fluids was evaluated by tool wear and R_a. At various volume ratios, the values of roughness and tool wear are also shown in Table 7.

Table 7. Roughness and Tool Wear at Different Oil Ratios.

Sr. No.	Castor Oil-Palm Oil Volume Ratio	Surface Roughness (R_a) (μm)	Tool Wear (mm)
1	1:0.5	0.375	0.436
2	1:1	0.341	0.394
3	1:1.5	0.389	0.381
4	1:2	0.322	0.399
5	1:2.5	0.361	0.412
6	1:3	0.421	0.406

The minimum R_a value is obtained at 1:2, and minimum tool wear is noticed at 1:1.5, as shown in Table 6. So medium values of volume ratio are recommended to obtain the best machining results.

Sago starch is extracted from palm stems and is composed of oval-shaped particles of 30 μm diameter, which enable its solution to behave like nanofluids. So it was tested as a cutting fluid [120]. Laser-assisted high-speed milling of AISI 316 SS was conducted on a CNC milling machine using a micro-grain carbide coated endmill. MQL was adopted as a cutting fluid supply method, and the performance of Sago Starch-based cutting fluid was compared to the commercial mineral oil. Water-soluble Sago Starch was used with the additives shown in Table 7. Milling was conducted at various V_C and feed values which are additionally shown in Table 7. In the case of commercial mineral oil, R_a value of 1.023 μm and tool wear of 5.2960 μm was observed. At the same time, Sago Starch-based cutting fluid provided R_a and tool wear values of 1.023 μm and 5.2960 μm, respectively. Consequently, Sago Starch solution can be used as a non-toxic and more effective cutting fluid.

Raw Kapok oil is non-edible oil. So, to encounter a shortage of vegetable oil for food supply, Kapok oil has been used by researchers for milling Mild Steel (AISI 1020) on a CNC vertical milling machine. The machining performance of Kapok oil was compared to that of the commercial mineral oil (SAE 20 W 40) at various FR, DOC, and V_C showed in Table 7. Wear, cutting force and R_a were determined to evaluate the performance of Kapok oil. It was observed that minimum flank wear and R_a is produced using Kapok oil with the set of FR, DOC, and V_C equal to 0.09 mm/tooth, 1.20 mm and 647.65 rpm, respectively, with the desirability of 82.1%. As far as cutting force was concerned, commercial cutting fluid provided better results by a minimum cutting force of 659.167 N compared to 659.217 N of Kapok oil. However, this small margin can be ignored, keeping in view the other factors. So raw Kapok oil is a good option to be selected for the milling process.

6. Discussion

This review helps us to understand that sustainable machining is necessary to achieve excellent products and provides a guideline for industries to ensure green manufacturing. One of the most important factors for manufacturing concerns is the fine surface finish. So, cutting parameters for different materials must be optimized to achieve excellence in machining and obtain a smoother surface finish. Many research works were conducted to optimize cutting parameters. Analysis of Table 1, Table 2, Table 3, Table 4, Table 5, Table 7 indicate that medium to low feed rates and low depths of cut are the optimum conditions for machining. At higher cutting speeds, more heat is generated at the workpiece surface, causing the softness of the material. The chips will additionally move away easily from the surface at higher speeds. Consequently, excellent surface quality is attained.

The selection of proper cutting fluids is necessary to encounter the heat of cutting as well as a reduction in friction. Mineral oil-based cutting fluids are mostly used, but their toxicity and cost are forcing manufacturers to look for more sustainable manufacturing processes. Sustainable machining is not only limited to achieving high surface quality, but environmental issues, health, and cost of machining are key factors. Keeping in view the environmental and economic aspects, research on the utilisation of vegetable oils as cutting fluids has attained significant importance in recent years. Vegetable oil has begun to replace mineral oil due to environmental concerns worldwide [122–125]. As mentioned earlier, vegetable oils as neat oils and in the form of emulsion have been tested as cutting fluids to ensure a green and sustainable manufacturing system. Primarily the researchers have selected readily available edible vegetable oils as cutting fluids which, due to their triglyceride composition, exhibit excellent performance as cutting fluids.

However, special care must be adopted for the selection of edible vegetable oils as cutting fluids so that their consumption does not affect the food supply. Usage of edible oils with less demand for food must be focused on. Additionally, the usage of non-edible oils is a good option. Further, the cost of the selected vegetable oil should be considered as important as other factors. Many non-edible trees and crops can be cultivated in barren lands. Special attention must be paid to this aspect as well. It can help us to utilize those lands, and this can be cost-effective as well.

Although mineral oil-based cutting fluids are the most common cutting fluids, using them is harmful to the environment and human health, and more cost is encountered. So, this trend of using mineral oils is shifting towards environment-friendly vegetable oil-based cutting fluids.

Approaches like nearly dry machining, solid lubrication, compressed air cooling, cryogenic cooling and minimum quantity lubrication have been utilised to minimise the consumption of cutting fluids. However, dry machining is never a good option for machining of hard materials. Compressed air helps in the removal of chips, but friction is not reduced. Solid lubricants limit the cooling capabilities, and cryogenic cooling is a very expensive approach [6].

Many research works were conducted using biodegradable cutting fluids, and they proved the efficiency of vegetable oil-based cutting fluids. Analysis of research works on machining of hard materials using biodegradable cutting fluids is conducted in this research. In addition to this, values of desired output parameters like roughness, tool wear, cutting forces etc., have been identified. Values of optimum parameters are provided as well. The efficiency of machining is improved by using vegetable oil-based cutting fluids as less roughness is obtained as well as power consumption, tool wear, cutting forces and cost of disposal are reduced.

7. Conclusions

The major advantages of the new developed vegetable-based cutting fluids are high biodegradability and environmentally friendliness while providing the same or better performance than mineral-based cutting fluids. This review paper helps us to draw the following conclusions:

- Optimized cutting conditions (speed, feed, depth of cut and cutting environment) help in minimum tool wear, roughness, cutting forces and power consumption. An increase in productivity is noticed at optimum conditions.
- Although cutting fluid is a basic requirement when materials are hard to cut, but mostly these cutting fluids are composed of mineral oils causing serious harm to

human health and the environment as well. Consequently, it is needed to opt for other alternative options like dry machining, MQL, emulsions, nano cutting fluids etc.

- Minimum quantity lubrication is a better technique compared to flooding when cooling is the major requirement. This is an environmentally friendly and cost-effective approach.
- Edible vegetable oils like Groundnut oil, Walnut oil, Soyabean oil, Sunflower oil, Mustard oil, Cottonseed oil, Coconut oil etc. have been successfully used as cutting fluids. However, keeping the food security aspect in view non-edible oils like Castor oil, Jatropha oil, Gingelly oil, Karanja oil, Neem oil etc. have proved to be excellent choices as cutting fluids.
- It depends upon the cutting requirement (i.e., workpiece and tool material) that how to use a vegetable oil can be beneficial. Vegetable oils in their neat form, in emulsion form, and mixing different vegetable oils are useful options when machining.
- The low thermal conductivity of the vegetable oils is improved by the addition of highly thermally conductive nanoparticles. Nanoparticles of silver, boric acid, graphite, carbon and molybdenum disulphide (MoS_2) have been used as additives.
- High concentrations of nanoparticles affect the surface finish by infusion of nanoparticles in the surface and getting trimmed by the upcoming particles. The rolling of nanoparticles formulates a lubrication film that can shear easily and thus providing better surface polish.
- The best way to utilise vegetable oils as cutting fluids is to supply their nanofluids in adequate concentrations to the cutting zone using the MQL technique. Additionally, the focus must be on the selection of non-edible vegetable oils.

8. Future Work

The recommendations for future research are given as under:

- The performance of vegetable oils may limit due to less oxidative stability and low corrosion resistance. So biodegradable and appropriate additives, e.g., anti-corrosive agents, biocides, emulsifiers, antioxidants, must be used to formulate novel vegetable oil-based cutting fluids.
- Vegetable oils have poor thermal conductivity. So proper concentrations of nanoparticles like graphene, graphite, copper, MoS_2, etc., can be used as additives to improve the thermal conductivity of vegetable oil-based cutting fluids.
- The concept of using hybrid nanofluids i.e., combination of different nanoparticles in a fluid, is additionally an emerging idea.
- A very large amount of cutting fluids is consumed for machining hard materials. Techniques like minimum quantity lubrication must be adopted to cut down the usage of cutting fluids as the flooding method is not cost-effective.
- Non-edible vegetable oils like Karanja, Neem, Honge, Castor, Jatropha, etc. must be utilized as cutting fluids so that the food supply chain is not damaged.

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Abbreviations

R_a	Surface roughness
MWF	Metal working fluid
CF	Cutting fluid
MO	Mineral oil
DOC	Depth of cut
V_C	Cutting speed
VO	Vegetable oil
GWP	Global Warming Potential
MQL	Minimum quantity lubrication
FR	Feed rate
CNT	Carbon nano tube
MWNCT	Multiwalled nano carbon Tube
NMQL	Nanoparticles based MQL
SS	Stainless steel
HSS	High speed steel
COF	Co-efficient of friction

References

1. Xavior, M.A.; Adithan, M. Determining the influence of cutting fluids on tool wear and surface roughness during turning of AISI 304 austenitic stainless steel. *J. Mater. Process. Technol.* **2009**, *209*, 900–909. [CrossRef]
2. Madanchi, N.; Thiede, S.; Gutowski, T.; Herrmann, C. Modeling the impact of cutting fluid strategies on environmentally conscious machining systems. *Procedia CIRP* **2019**, *80*, 150–155. [CrossRef]
3. Ozcelik, B.; Kuram, E.; Demirbas, E.; Şik, E. Optimization of surface roughness in drilling using vegetable-based cutting oils developed from sunflower oil. *Ind. Lubr. Tribol.* **2011**, *63*, 271–276. [CrossRef]
4. Gulzar, M.; Masjuki, H.H.; Kalam, M.A.; Varman, M.; Fattah, I.M.R. Oil filter modification for biodiesel–fueled engine: A pathway to lubricant sustainability and exhaust emissions reduction. *Energy Convers. Manag.* **2015**, *91*, 168–175. [CrossRef]
5. Liaquat, A.M.; Masjuki, H.H.; Kalam, M.A.; Fattah, I.M.R. Impact of biodiesel blend on injector deposit formation. *Energy* **2014**, *72*, 813–823. [CrossRef]
6. Benedicto, E.; Carou, D.; Rubio, E. Technical, economic and environmental review of the lubrication/cooling systems used in machining processes. *Procedia Eng.* **2017**, *184*, 99–116. [CrossRef]
7. Yan, P.; Rong, Y.; Wang, G. The effect of cutting fluids applied in metal cutting process. *Proc. Inst. Mech. Eng. Part B J. Eng. Manuf.* **2016**, *230*, 19–37. [CrossRef]
8. Katna, R.; Suhaib, M.; Agrawal, N. Nonedible vegetable oil-based cutting fluids for machining processes—A review. *Mater. Manuf. Process.* **2020**, *35*, 1–32. [CrossRef]
9. Debnath, S.; Reddy, M.M.; Yi, Q.S. Environmental friendly cutting fluids and cooling techniques in machining: A review. *J. Clean. Prod.* **2014**, *83*, 33–47. [CrossRef]
10. Koushik, A.V.; Shetty, S.N.; Ramprasad, C. Vegetable oil-based metal working fluids—A review. *Int. J. Theor. Appl. Res. Mech. Eng.* **2012**, *1*, 95–101.
11. Brinksmeier, E.; Meyer, D.; Huesmann-Cordes, A.; Herrmann, C. Metalworking fluids—mechanisms and performance. *CIRP Ann.* **2015**, *64*, 605–628. [CrossRef]
12. Abdalla, H.; Baines, W.; McIntyre, G.; Slade, C. Development of novel sustainable neat-oil metal working fluids for stainless steel and titanium alloy machining. Part 1. Formulation development. *Int. J. Adv. Manuf. Technol.* **2007**, *34*, 21–33. [CrossRef]
13. Soković, M.; Mijanović, K. Ecological aspects of the cutting fluids and its influence on quantifiable parameters of the cutting processes. *J. Mater. Process. Technol.* **2001**, *109*, 181–189. [CrossRef]
14. Shashidhara, Y.; Jayaram, S. Vegetable oils as a potential cutting fluid—An evolution. *Tribol. Int.* **2010**, *43*, 1073–1081. [CrossRef]
15. Benedicto, E.; Rubio, E.M.; Aubouy, L.; Sáenz-Nuño, M.A. Formulation of Sustainable Water-Based Cutting Fluids with Polyol Esters for Machining Titanium Alloys. *Metals* **2021**, *11*, 773. [CrossRef]
16. Adler, D.P.; Hii, W.W.-S.; Michalek, D.J.; Sutherland, J.W. Examining the role of cutting fluids in machining and efforts to address associated environmental/health concerns. *Mach. Sci. Technol.* **2006**, *10*, 23–58. [CrossRef]
17. Amrita, M.; Srikant, R.; Sitaramaraju, A.; Prasad, M.; Krishna, P.V. Preparation and characterization of properties of nanographite-based cutting fluid for machining operations. *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.* **2014**, *228*, 243–252. [CrossRef]
18. Gajrani, K.K.; Sankar, M.R. Past and current status of eco-friendly vegetable oil based metal cutting fluids. *Mater. Today Proc.* **2017**, *4*, 3786–3795. [CrossRef]
19. Gupta, K.; Laubscher, R.; Davim, J.P.; Jain, N. Recent developments in sustainable manufacturing of gears: A review. *J. Clean. Prod.* **2016**, *112*, 3320–3330. [CrossRef]
20. Junior, A.S.A.; Sales, W.F.; da Silva, R.B.; Costa, E.S.; Machado, Á.R. Lubri-cooling and tribological behavior of vegetable oils during milling of AISI 1045 steel focusing on sustainable manufacturing. *J. Clean. Prod.* **2017**, *156*, 635–647. [CrossRef]

21. Agrawal, S.M.; Patil, N.G. Investigation into Dry Machining as Environment Friendly Drilling of Ceramic Reinforced Aluminium Matrix Composites. *Technology* **2020**, *11*, 845–850.
22. Khanna, N.; Shah, P.; de Lacalle, L.N.L.; Rodríguez, A.; Pereira, O. In pursuit of sustainable cutting fluid strategy for machining Ti-6Al-4V using life cycle analysis. *Sustain. Mater. Technol.* **2021**, *29*, e00301. [CrossRef]
23. Sen, B.; Mia, M.; Krolczyk, G.; Mandal, U.K.; Mondal, S.P. Eco-friendly cutting fluids in minimum quantity lubrication assisted machining: A review on the perception of sustainable manufacturing. *Int. J. Precis. Eng. Manuf. Green Technol.* **2019**, *8*, 249–280. [CrossRef]
24. Khanna, N.; Shah, P.; Wadhwa, J.; Pitroda, A.; Schoop, J.; Pusavec, F. Energy consumption and lifecycle assessment comparison of cutting fluids for drilling titanium alloy. *Procedia CIRP* **2021**, *98*, 175–180. [CrossRef]
25. Boswell, B.; Islam, M.N.; Davies, I.J.; Ginting, Y.; Ong, A.K. A review identifying the effectiveness of minimum quantity lubrication (MQL) during conventional machining. *Int. J. Adv. Manuf. Technol.* **2017**, *92*, 321–340. [CrossRef]
26. Osman, K.A.; Ünver, H.Ö.; Şeker, U. Application of minimum quantity lubrication techniques in machining process of titanium alloy for sustainability: A review. *Int. J. Adv. Manuf. Technol.* **2019**, *100*, 2311–2332. [CrossRef]
27. Madhukar, S.; Shravan, A.; Vidyanand, P.; Reddy, G.S. A critical review on minimum quantity lubrication (MQL) coolant system for machining operations. *Int. J. Curr. Eng. Int. J. Curr. Eng. Technol.* **2016**, *6*, 1745–1751.
28. Ramadhas, A.; Jayaraj, S.; Muraleedharan, C. Use of vegetable oils as IC engine fuels—A review. *Renew. Energy* **2004**, *29*, 727–742. [CrossRef]
29. Winter, M.; Bock, R.; Herrmann, C. Investigation of a new ecologically benign metalworking fluid in abrasive machining processes to substitute mineral oil based fluids. *Procedia CIRP* **2012**, *1*, 393–398. [CrossRef]
30. Shokrani, A.; Dhokia, V.; Newman, S.T. Environmentally conscious machining of difficult-to-machine materials with regard to cutting fluids. *Int. J. Mach. Tools Manuf.* **2012**, *57*, 83–101. [CrossRef]
31. Srikant, R.; Ramana, V. Performance evaluation of vegetable emulsifier based green cutting fluid in turning of American Iron and Steel Institute (AISI) 1040 steel—An initiative towards sustainable manufacturing. *J. Clean. Prod.* **2015**, *108*, 104–109. [CrossRef]
32. Rajmohan, T.; Chakravarthy, V.K.; Nandakumar, A.; Kumar, S.S. Eco Friendly Machining Processes for Sustainability-Review. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *954*, 012044. [CrossRef]
33. Saravanakumar, M.; Tamilselvam, P.; Subramanian, M.; Somu, C. Eco-Friendly Machining of Super Duplex Stainless Steel (Uns S32760) under Nitrogen Gas Cooled and Vegetable Oil Based Mql System. *PalArch's J. Archaeol. Egypt Egyptol.* **2020**, *17*, 5267–5295.
34. Osama, M.; Singh, A.; Walvekar, R.; Khalid, M.; Gupta, T.C.S.M.; Yin, W.W. Recent developments and performance review of metal working fluids. *Tribol. Int.* **2017**, *114*, 389–401. [CrossRef]
35. Mahadi, M.; Choudhury, I.; Azuddin, M.; Yusoff, N.; Yazid, A.; Norhafizan, A. Vegetable Oil-Based Lubrication in Machining: Issues and Challenges. *IOP Conf. Ser. Mater. Sci. Eng.* **2019**, *530*, 012003. [CrossRef]
36. Wang, Y.; Li, C.; Zhang, Y.; Yang, M.; Li, B.; Jia, D.; Hou, Y.; Mao, C. Experimental evaluation of the lubrication properties of the wheel/workpiece interface in minimum quantity lubrication (MQL) grinding using different types of vegetable oils. *J. Clean. Prod.* **2016**, *127*, 487–499. [CrossRef]
37. Zainal, N.; Zulkifli, N.; Gulzar, M.; Masjuki, H. A review on the chemistry, production, and technological potential of bio-based lubricants. *Renew. Sustain. Energy Rev.* **2018**, *82*, 80–102. [CrossRef]
38. Fattah, I.M.R.; Masjuki, H.H.; Kalam, M.A.; Mofijur, M.; Abedin, M.J. Effect of antioxidant on the performance and emission characteristics of a diesel engine fueled with palm biodiesel blends. *Energy Convers. Manag.* **2014**, *79*, 265–272. [CrossRef]
39. Fattah, I.M.R.; Masjuki, H.H.; Kalam, M.A.; Hazrat, M.A.; Masum, B.M.; Imtenan, S.; Ashraful, A.M. Effect of antioxidants on oxidation stability of biodiesel derived from vegetable and animal based feedstocks. *Renew. Sustain. Energy Rev.* **2014**, *30*, 356–370. [CrossRef]
40. Mattson, F.; Lutton, E. The specific distribution of fatty acids in the glycerides of animal and vegetable fats. *J. Biol. Chem.* **1958**, *233*, 868–871. [CrossRef]
41. Padmini, R.; Krishna, P.V.; Rao, G.K.M. Effectiveness of vegetable oil based nanofluids as potential cutting fluids in turning AISI 1040 steel. *Tribol. Int.* **2016**, *94*, 490–501. [CrossRef]
42. Fattah, I.M.R.; Ong, H.C.; Mahlia, T.M.I.; Mofijur, M.; Silitonga, A.S.; Rahman, S.M.A.; Ahmad, A. State of the Art of Catalysts for Biodiesel Production. *Front. Energy Res.* **2020**, *8*. [CrossRef]
43. Mannekote, J.K.; Kailas, S.V.; Venkatesh, K.; Kathyayini, N. Environmentally friendly functional fluids from renewable and sustainable sources-A review. *Renew. Sustain. Energy Rev.* **2018**, *81*, 1787–1801. [CrossRef]
44. Shabgard, M.; Seyedzavvar, M.; Mohammadpourfard, M. Experimental investigation into lubrication properties and mechanism of vegetable-based CuO nanofluid in MQL grinding. *Int. J. Adv. Manuf. Technol.* **2017**, *92*, 3807–3823. [CrossRef]
45. Ruggiero, A.; D'Amato, R.; Merola, M.; Valašek, P.; Müller, M. Tribological characterization of vegetal lubricants: Comparative experimental investigation on *Jatropha curcas* L. oil, Rapeseed Methyl Ester oil, Hydrotreated Rapeseed oil. *Tribol. Int.* **2017**, *109*, 529–540. [CrossRef]
46. Talib, N.; Nasir, R.; Rahim, E. Tribological behaviour of modified jatropha oil by mixing hexagonal boron nitride nanoparticles as a bio-based lubricant for machining processes. *J. Clean. Prod.* **2017**, *147*, 360–378. [CrossRef]
47. Talib, N.; Rahim, E. Performance of modified jatropha oil in combination with hexagonal boron nitride particles as a bio-based lubricant for green machining. *Tribol. Int.* **2018**, *118*, 89–104. [CrossRef]

48. Razzaq, L.; Mujtaba, M.A.; Soudagar, M.E.M.; Ahmed, W.; Fayaz, H.; Bashir, S.; Fattah, I.M.R.; Ong, H.C.; Shahapurkar, K.; Afzal, A.; et al. Engine performance and emission characteristics of palm biodiesel blends with graphene oxide nanoplatelets and dimethyl carbonate additives. *J. Environ. Manag.* **2021**, *282*, 111917. [CrossRef]
49. Mujtaba, M.A.; Masjuki, H.H.; Kalam, M.A.; Noor, F.; Farooq, M.; Ong, H.C.; Gul, M.; Soudagar, M.E.M.; Bashir, S.; Fattah, I.M.R.; et al. Effect of Additivized Biodiesel Blends on Diesel Engine Performance, Emission, Tribological Characteristics, and Lubricant Tribology. *Energies* **2020**, *13*, 3375. [CrossRef]
50. Garcés, R.; Martínez-Force, E.; Salas, J.J. Vegetable oil basestocks for lubricants. *Grasas Aceites* **2011**, *62*, 21–28. [CrossRef]
51. Lawal, S.A.; Choudhury, I.A.; Nukman, Y. Evaluation of vegetable and mineral oil-in-water emulsion cutting fluids in turning AISI 4340 steel with coated carbide tools. *J. Clean. Prod.* **2014**, *66*, 610–618. [CrossRef]
52. Vasim, A.S.; Nourredine, B. Using Vegetable-Oil-Based Sustainable Metal Working Fluids to Promote Green Manufacturing. *Int. J. Manuf. Mater. Mech. Eng.* **2020**, *10*, 1–19.
53. Ong, H.C.; Tiong, Y.W.; Goh, B.H.H.; Gan, Y.Y.; Mofijur, M.; Fattah, I.M.R.; Chong, C.T.; Alam, M.A.; Lee, H.V.; Silitonga, A.S.; et al. Recent advances in biodiesel production from agricultural products and microalgae using ionic liquids: Opportunities and challenges. *Energy Convers. Manag.* **2021**, *228*, 113647. [CrossRef]
54. Cheng, C.; Phipps, D.; Alkhaddar, R.M. Treatment of spent metalworking fluids. *Water Res.* **2005**, *39*, 4051–4063. [CrossRef] [PubMed]
55. Schmidt, J.H. Life cycle assessment of five vegetable oils. *J. Clean. Prod.* **2015**, *87*, 130–138. [CrossRef]
56. Rahman, S.M.A.; Fattah, I.M.R.; Ong, H.C.; Ashik, F.R.; Hassan, M.M.; Murshed, M.T.; Imran, M.A.; Rahman, M.H.; Rahman, M.A.; Hasan, M.A.M.; et al. State-of-the-Art of Establishing Test Procedures for Real Driving Gaseous Emissions from Light- and Heavy-Duty Vehicles. *Energies* **2021**, *14*, 4195. [CrossRef]
57. Amoo, L.M.; Fagbenle, R.L. Climate change in developing nations of the world. In *Applications of Heat, Mass and Fluid Boundary Layers*; Elsevier: Amsterdam, The Netherlands, 2020; pp. 437–471.
58. Lawal, S.A.; Choudhury, I.A.; Nukman, Y. Application of vegetable oil-based metalworking fluids in machining ferrous metals—A review. *Int. J. Mach. Tools Manuf.* **2012**, *52*, 1–12. [CrossRef]
59. Fox, N.; Stachowiak, G. Vegetable oil-based lubricants—A review of oxidation. *Tribol. Int.* **2007**, *40*, 1035–1046. [CrossRef]
60. Zhang, Y.; Li, C.; Jia, D.; Zhang, D.; Zhang, X. Experimental evaluation of MoS2 nanoparticles in jet MQL grinding with different types of vegetable oil as base oil. *J. Clean. Prod.* **2015**, *87*, 930–940. [CrossRef]
61. Khandekar, S.; Sankar, M.R.; Agnihotri, V.; Ramkumar, J. Nano-cutting fluid for enhancement of metal cutting performance. *Mater. Manuf. Process.* **2012**, *27*, 963–967. [CrossRef]
62. Sani, A.S.A.; Rahim, E.A.; Talib, N.; Kamdani, K.; Rahim, M.Z.; Samion, S. Performance evaluation of palm-olein TMP ester containing hexagonal boron nitride and an oil miscible ionic liquid as bio-based metalworking fluids. *J. Mech. Eng.* **2017**, *4*, 223–234.
63. Fattah, I.M.R.; Masjuki, H.H.; Liaquat, A.M.; Ramli, R.; Kalam, M.A.; Riazuddin, V.N. Impact of various biodiesel fuels obtained from edible and non-edible oils on engine exhaust gas and noise emissions. *Renew. Sustain. Energy Rev.* **2013**, *18*, 552–567. [CrossRef]
64. Sankaranarayanan, R.; Hynes, R.J.N.; Kumar, J.S.; Krolczyk, G.M. A comprehensive review on research developments of vegetable-oil based cutting fluids for sustainable machining challenges. *J. Manuf. Process.* **2021**, *67*, 286–313. [CrossRef]
65. Nagendramma, P.; Kaul, S. Development of ecofriendly/biodegradable lubricants: An overview. *Renew. Sustain. Energy Rev.* **2012**, *16*, 764–774. [CrossRef]
66. Grzesik, W. Chapter Ten—Cutting Fluids. In *Advanced Machining Processes of Metallic Materials*, 2nd ed.; Grzesik, W., Ed.; Elsevier: Amsterdam, The Netherlands, 2017; pp. 183–195.
67. Boothroyd, G.; Knight, W.A. *Fundamentals of Machining and Machine Tools*, 2nd ed.; Marcel Dekker, Inc.: New York, NY, USA, 1989; Volume 28.
68. Klocke, F.; Kuchle, A. Cutting Fluids. In *Manufacturing Processes 1: Cutting*; Klocke, F., Ed.; Springer: Berlin/Heidelberg, Germany, 2011; pp. 219–236.
69. Amrita, M.; Srikant, R.; Sitaramaraju, A. Performance evaluation of nanographite-based cutting fluid in machining process. *Mater. Manuf. Process.* **2014**, *29*, 600–605. [CrossRef]
70. Cai, C.; Liang, X.; An, Q.; Tao, Z.; Ming, W.; Chen, M. Cooling/Lubrication Performance of Dry and Supercritical CO_2-Based Minimum Quantity Lubrication in Peripheral Milling Ti-6Al-4V. *Int. J. Precis. Eng. Manuf. Green Technol.* **2021**, *8*, 405–421. [CrossRef]
71. Schey, J. *Introduction to Manufacturing Processes*; McGraw-Hill: New York, NY, USA, 1987.
72. Black, S.C.; Chiles, V.; Lissaman, A.J.; Martin, S.J. (Eds.) 10—Cutting Tool Technology. In *Principles of Engineering Manufacture*, 3rd ed.; Butterworth-Heinemann: Oxford, UK, 1996; pp. 267–315.
73. Subramaniyana, K.; Jeyasimmanb, D.; Kesavan, J.; Manivannanb, A. Optimization of Surface Roughness Parameters for EN 8 Steel by Tungsten Carbide Tool in Turning Operation. *Int. J. Eng. Res. Technol.* **2015**, *4*, 776–781.
74. Singh, R.K.; Sharma, A.K.; Dixit, A.R.; Mandal, A.; Tiwari, A.K. Experimental investigation of thermal conductivity and specific heat of nanoparticles mixed cutting fluids. *Mater. Today Proc.* **2017**, *4*, 8587–8596. [CrossRef]
75. Sharma, A.K.; Tiwari, A.K.; Dixit, A.R. Characterization of TiO_2, Al_2O_3 and SiO_2 nanoparticle based cutting fluids. *Mater. Today Proc.* **2016**, *3*, 1890–1898. [CrossRef]

76. Khrisna, P.V. Effectiveness of Vegetable Oil based Nanofluids in Machining of Steel. *Asian J. Multidiscip. Stud.* **2019**, *2*, 49–57.
77. Shaikh, J.; Sidhu, J. Experimental Investigation and Optimization of Process Parameters in Turning of AISI D2 Steel using Different Lubricant. *Int. J. Eng. Adv. Technol.* **2014**, *3*, 189–197.
78. Ahmad, U.; Azman, A.; Maidin, N.; Anuar, N.A.W.; Rahman, M.A. The Significant Study of using Vegetable Oil as a Cutting Lubricant on Conventional Lathe Machine. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *834*, 012014. [CrossRef]
79. Ezilarasan, C.; Nagaraj, M.S.; Kumar, A.J.P.; Velayudham, A.; Betala, R. Experimental analysis of process parameters in drilling nimonic C263 alloy under nano fluid mixed MQL environment. *Manuf. Rev.* **2021**, *8*, 2.
80. Chauhan, P.; Gupta, A.; Thakur, A.K.; Kumar, R. Comparative Investigation of Different Types of Cutting Fluid in Minimum Quantity Lubrication Machining Using CFD. In *Advances in Metrology and Measurement of Engineering Surfaces*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 199–207.
81. Revankar, G.D.; Shetty, R.; Rao, S.S.; Gaitonde, V.N. Analysis of surface roughness and hardness in titanium alloy machining with polycrystalline diamond tool under different lubricating modes. *Mater. Res.* **2014**, *17*, 1010–1022. [CrossRef]
82. Ogedengbe, T.S.; Awe, P.; Joseph, O.I. Comparative Analysis of Machining Stainless Steel using Soluble and Vegetable oils as Cutting Fluids. *Int. J. Eng. Mater. Manuf.* **2019**, *4*, 33–40. [CrossRef]
83. Kumar, P.; Ravi, S. Investigation on effects of vegetable-based cutting fluids in turning operation of "EN 24 Steel". *Mater. Today Proc.* **2021**, *39*, 95–99. [CrossRef]
84. Vieira, J.; Machado, A.; Ezugwu, E. Performance of cutting fluids during face milling of steels. *J. Mater. Process. Technol.* **2001**, *116*, 244–251. [CrossRef]
85. Onuoha, O.J.; Abu, J.O.; Lawal, S.A.; Mudiare, E.; Adeyemi, M.B. Determining the effect of cutting fluids on surface roughness in turning AISI 1330 alloy steel using Taguchi method. *Mod. Mech. Eng.* **2016**, *6*, 51–59. [CrossRef]
86. Dennison, M.S.; Umar, M.M. Data-set collected during turning operation of AISI 1045 alloy steel with green cutting fluids in near dry condition. *Data Brief* **2020**, *32*, 106215. [CrossRef]
87. Chang, K.; Olugu, E.; Yeap, S.; Abdelrhman, A.; Aja, O. Virgin and emulsified vegetable oil on the turning of titanium alloy. *Mater. Today Proc.* **2021**. [CrossRef]
88. Agu, C.; Lawal, S.; Abolarin, M.; Agboola, J.; Abutu, J.; Awode, E. Multi-response optimisation of machining parameters in turning AISI 304L using different oil-based cutting fluids. *Niger. J. Technol.* **2019**, *38*, 364–375. [CrossRef]
89. Jeevan, T.; Jayaram, S. Performance evaluation of jatropha and pongamia oil based environmentally friendly cutting fluids for turning AA 6061. *Adv. Tribol.* **2018**, *2018*, 2425619. [CrossRef]
90. Talib, N.; Sani, A.S.A.; Hamzah, N.A. Modified Jatropha nano-lubricant as metalworking fluid for machining process. *J. Tribol.* **2019**, *23*, 90–96.
91. Awode, E.I.; Abolarin, M.S.; Lawal, S.A.; Oyewole, A. Performance Evaluation of Jatropha Seed Oil and Mineral Oil-Based Cutting Fluids in Turning AISI 304 Alloy Steel. *Int. J. Eng. Mater. Manuf.* **2021**, *5*, 85–97. [CrossRef]
92. Sarkar, J.; Ghosh, P.; Adil, A. A review on hybrid nanofluids: Recent research, development and applications. *Renew. Sustain. Energy Rev.* **2015**, *43*, 164–177. [CrossRef]
93. Babu, J.R.; Kumar, K.K.; Rao, S.S. State-of-art review on hybrid nanofluids. *Renew. Sustain. Energy Rev.* **2017**, *77*, 551–565. [CrossRef]
94. Gugulothu, S.; Pasam, V.K. Experimental investigation to study the performance of CNT/MoS2 hybrid nanofluid in turning of AISI 1040 stee. *Aust. J. Mech. Eng.* **2020**. [CrossRef]
95. LKama, J.; Yusuf, M.; Abdulkadir, S. Effects of Different Cutting Fluids on Temperature Reduction on Mild Steel during Machining Operations. *ATBU J. Sci. Technol. Educ.* **2018**, *6*, 79–89.
96. Gaurav, G.; Sharma, A.; Dangayach, G.; Meena, M. Assessment of jojoba as a pure and nano-fluid base oil in minimum quantity lubrication (MQL) hard-turning of Ti-6Al-4V: A step towards sustainable machining. *J. Clean. Prod.* **2020**, *272*, 122553. [CrossRef]
97. Radhika, A.; Agari, S.; Yogesh, K.B. Evaluating machining performance of AlSI 1014 steel using gingelly oil as cutting fluid. *Aust. J. Mech. Eng.* **2019**. [CrossRef]
98. Pal, A.; Chatha, S.S.; Sidhu, H.S. Experimental investigation on the performance of MQL drilling of AISI 321 stainless steel using nano-graphene enhanced vegetable-oil-based cutting fluid. *Tribol. Int.* **2020**, *151*, 106508. [CrossRef]
99. Rahim, E.A.; Sasahara, H. Performance of palm oil as a biobased machining lubricant when drilling inconel 718. *MATEC Web Conf.* **2017**, *101*, 3015. [CrossRef]
100. Natesha, C.; Amarendra, H.J.; Shashidhara, Y. Studies on Drilling AISI 316L Using Formulated Pongam oil as Straight Cutting Fluid. *Appl. Mech. Mater.* **2019**, *895*, 194–199. [CrossRef]
101. Johnson, R.D.J. Influence of drilling parameters in drilling of Hamc with vegetable based cutting fluid. *Adv. Nat. Appl. Sci.* **2016**, *10*, 300–306.
102. Suvin, P.; Gupta, P.; Horng, J.-H.; Kailas, S.V. Evaluation of a comprehensive non-toxic, biodegradable and sustainable cutting fluid developed from coconut oil. *Proc. Inst. Mech. Eng. Part J J. Eng. Tribol.* **2020**. [CrossRef]
103. Chatha, S.S.; Pal, A.; Singh, T. Performance evaluation of aluminium 6063 drilling under the influence of nanofluid minimum quantity lubrication. *J. Clean. Prod.* **2016**, *137*, 537–545. [CrossRef]
104. Puttaswamy, J.T.; Ramachandra, J.S. Experimental investigation on the performance of vegetable oil based cutting fluids in drilling AISI 304L using Taguchi technique. *Tribol. Online* **2018**, *13*, 50–56. [CrossRef]

105. Susmitha, M.; Sharan, P.; Jyothi, P. Influence of non-edible vegetable based oil as cutting fluid on chip, surface roughness and cutting force during drilling operation of Mild Steel. *IOP Conf. Ser. Mater. Sci. Eng.* **2016**, *149*, 012037. [CrossRef]
106. Jyothi, P.; Susmitha, M.; Sharan, P. Performance evaluation of NEEM oil and HONGE Oil as cutting fluid in drilling operation of mild steel. *IOP Conf. Ser. Mater. Sci. Eng.* **2017**, *191*, 012026. [CrossRef]
107. Srinivas, M.S.; Panneer, R.; Suvin, P.; Kailas, S.V. Synthesis and testing of novel neem oil-based cutting fluid with ionic liquid additives. In *Industry 4.0 and Advanced Manufacturing*; Springer: Berlin/Heidelberg, Germany, 2021; pp. 311–322.
108. Khunt, C.; Makhesana, M.; Patel, K.; Mawandiya, B. Performance assessment of vegetable oil-based minimum quantity lubrication (MQL) in drilling. *Mater. Today Proc.* **2021**, *44*, 341–345. [CrossRef]
109. Cetin, M.H.; Kesen, A.; Korkmaz, S.; Kilincarslan, S.K. Performance evaluation of the nano-silver added vegetable-oil-based cutting fluid in drilling process. *Surf. Topogr. Metrol. Prop.* **2020**, *8*, 025029. [CrossRef]
110. Yanis, M.; Mohruni, A.S.; Sharif, S.; Yani, I.; Arifin, A.; Khona'Ah, B. Application of RSM and ANN in Predicting Surface Roughness for Side Milling Process under Environmentally Friendly Cutting Fluid. *J. Phys. Conf. Ser.* **2019**, *1198*, 042016. [CrossRef]
111. Kamaruddin, A.M.N.A.; Yassin, A.; Mohamaddan, S.; Rajaie, S.A.; Mazlan, M.I.; Total, S.J.; Busrah, R.S. Performance of low cost 3D printed minimum quantity lubrication applicator using palm oil in milling steel. *Mater. Sci. Forum* **2020**, *997*, 85–92. [CrossRef]
112. Narayanan, S.V.; Benjamin, M.; Hariharan, M.V.; Keshav, R.; Raj, D.S. A combined numerical and experimental investigation of minimum quantity lubrication applied to end milling of Ti6Al4V alloy. *Mach. Sci. Technol.* **2020**, *25*, 1–28. [CrossRef]
113. Babu, M.N.; Anandan, V.; Muthukrishnan, N.; Santhanakumar, M. End milling of AISI 304 steel using minimum quantity lubrication. *Measurement* **2019**, *138*, 681–689. [CrossRef]
114. Vishal, R.; Ross, K.N.S.; Manimaran, G.; Gnanavel, B. Impact on Machining of AISI H13 Steel Using Coated Carbide Tool under Vegetable Oil Minimum Quantity Lubrication. *Mater. Perform. Charact.* **2019**, *8*, 527–537. [CrossRef]
115. Abbas, A.T.; Anwar, S.; Abdelnasser, E.; Luqman, M.; Qudeiri, J.E.A.; Elkaseer, A. Effect of Different Cooling Strategies on Surface Quality and Power Consumption in Finishing End Milling of Stainless Steel 316. *Materials* **2021**, *14*, 903. [CrossRef]
116. Singh, P.; Dureja, J.; Singh, H.; Bhatti, M.S. Performance comparison of coated carbide tool under different cooling/lubrication environments during face milling of Inconel-625 and Stainless Steel 304. *World J. Eng.* **2019**, *16*, 287–295. [CrossRef]
117. Gao, W.; Qi, Q.; Dong, L.; Bai, X.; Li, C.; Zhai, M.; Sun, P.; Shan, P. Experimental Analysis of Milling Aluminum Alloy with Oil-Less Lubrication of Nano-Fluid. *J. Phys. Conf. Ser.* **2020**, *1578*, 012182. [CrossRef]
118. Dennison, M.S.; Meji, M.A.; Nelson, A.; Balakumar, S.; Prasath, K. A comparative study on the surface finish achieved during face milling of AISI 1045 steel components using eco-friendly cutting fluids in near dry condition. *Int. J. Mach. Mach. Mater.* **2019**, *21*, 337–356. [CrossRef]
119. Sen, B.; Gupta, M.K.; Mia, M.; Pimenov, D.Y.; Mikołajczyk, T. Performance Assessment of Minimum Quantity Castor-Palm Oil Mixtures in Hard-Milling Operation. *Materials* **2021**, *14*, 198. [CrossRef] [PubMed]
120. Yasmin, F.; Tamrin, K.F.; Sheikh, N.A.; Barroy, P.; Yassin, A.; Khan, A.A.; Mohamaddan, S. Laser-Assisted High Speed Machining of 316 Stainless Steel: The Effect of Water-Soluble Sago Starch Based Cutting Fluid on Surface Roughness and Tool Wear. *Materials* **2021**, *14*, 1311. [CrossRef]
121. Shankar, S.; Manikandan, M.; Raja, G.; Pramanik, A. Experimental investigations of vibration and acoustics signals in milling process using kapok oil as cutting fluid. *Mech. Ind.* **2020**, *21*, 521. [CrossRef]
122. Abedin, M.J.; Masjuki, H.H.; Kalam, M.A.; Sanjid, A.; Rahman, S.M.A.; Rizwanul Fattah, I.M. Performance, emissions, and heat losses of palm and jatropha biodiesel blends in a diesel engine. *Ind. Crop. Prod.* **2014**, *59*, 96–104. [CrossRef]
123. Ashraful, A.M.; Masjuki, H.H.; Kalam, M.A.; Rizwanul Fattah, I.M.; Imtenan, S.; Shahir, S.A.; Mobarak, H.M. Production and comparison of fuel properties, engine performance, and emission characteristics of biodiesel from various non-edible vegetable oils: A review. *Energy Convers. Manag.* **2014**, *80*, 202–228. [CrossRef]
124. Fattah, I.M.R.; Hassan, M.H.; Kalam, M.A.; Atabani, A.E.; Abedin, M.J. Synthetic phenolic antioxidants to biodiesel: Path toward NOx reduction of an unmodified indirect injection diesel engine. *J. Clean. Prod.* **2014**, *79*, 82–90. [CrossRef]
125. Imtenan, S.; Varman, M.; Masjuki, H.H.; Kalam, M.A.; Sajjad, H.; Arbab, M.I.; Rizwanul Fattah, I.M. Impact of low temperature combustion attaining strategies on diesel engine emissions for diesel and biodiesels: A review. *Energy Convers. Manag.* **2014**, *80*, 329–356. [CrossRef]