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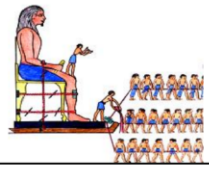

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NATURAL OILS AS AN ECO-FRIENDLY LUBRICANT FOR MACHINING OPERATIONS, A REVIEW

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ABSTRACT
Machining processes are the most common manufacturing operations for a wide range of products in our daily life produced from metallic, polymeric, and composite materials that undergo processing steps to be converted into final products. Turning operations for circular cross-section parts, drilling for cutting a rounded hole, and milling for cutting various configurations are the popular conventional machining processes for the manufacturing of different products. During the turning process, the work part is subjected to rotating speed as well as cutting force from the single point cutting tool which generates high friction forces between the pairs of contact surfaces – work part and tool- that lead to increases in temperature at the contact area. For drilling and milling operations, the cutting tools rotate at high cutting speeds and act by the cutting force on the work part, which also raises the heat at the contact area. Increases of generated heat at the cutting zone between the cutting tool and working material lead to several problems like wear of tool, tool failure, surface damage of machined parts, increased power consumption, and many hazardous effects to the operator by flying hot chips. To prevent or reduce the hazardous effect of heat on the working area, machining liquids are used for the purposes of cooling and lubricating of the contact zone. This comprehensive review concerned the importance of cutting fluids that are used during machining processes. It will focus light on natural lubricants; the pros and cons, economic and environmental impacts of using natural oils and lubricants as well as the challenges and prospects.

KEYWORDS
Machining Processes, Cutting Fluids, Natural Lubricants, and vegetable oils.

INTRODUCTION
The presence of cutting fluids during machining operation is very important for metallic or non-metallic work parts (Ibrahem 2021). Increases in friction coefficient at the working area between the cutting tools and the work part led to high temperature which threatens the tool's working life and the efficiency of produced parts, [1-2]. The function of cutting fluids during cutting operations is to decrease the cutting temperature besides the reduction of friction coefficient and rate of wear at

the contact area. One method for lowering heat at the cutting region is the appropriate selection and use of cutting fluids, [3-5]. Researchers established that cutting fluids enter between tools and chips under leaking mechanism from the edges of chip. Due to capillary network tiny size, cutting liquids have weak molecular interactions and display acceptable wetting characteristics, [6,7]. Cutting fluids comprise both lubricants and coolants, [8, 9]. Coolants serve the purpose of dissipating heat generated during metal deformation, while lubricants aim to reduce wear and friction at contact area between the tool and the workpiece. The introduction of nanoparticles as additives has been demonstrated to improve the lubricating properties of base oil, resulting in decreased friction and wear. Moreover, cutting fluids contribute to enhanced surface finish and more precise dimensional control. Commonly used cutting fluids in machining operations typically include mineral oils with added additives to enhance their properties. However, these cutting fluids often present drawbacks related to environmental and economic concerns. Several studies have proposed alternative lubricants, such as vegetable oils, animal oils, semi-solid lubricants, and solid lubricants. A study by A. Yadav et al. suggested that vegetable-based lubricants offer a promising alternative to mineral oils because of the biodegradable properties, low hazardous effect, and safe characteristics, [10-16]. These vegetable oils are derived from plants, fruits, and seeds, [17-20]. Natura lubricants, characterized by their biodegradability, non-toxicity, and renewability, are considered ideal as raw materials for lubricant production. Researchers have focused on enhancing the properties of vegetable-based lubricants by incorporating various thermal and oxidative stability enhancers.

Friction reduction has been observed in four-ball tribometer tests conducted under varying loads (40, 80, 120, and 160 kg) at rotating speed of 1200 rpm and room temperature for 10 minutes. In these tests, palm trimethylolpropane ester was used as a bio-lubricant with the addition of nanoparticles. Other researchers have explored the use of synthetic chemical substances as additives to enhance lubricant properties, addressing parameters such as oxidation stability, wear resistance, anti-friction, anti-corrosion, and resistance against biological degradation. Typically, final lubricant compositions include approximately 10 % weight ratio of additives, although this percentage can vary depending on application requirements, [21].

Importance of machining processes

Machining processes are used to remove excess material from raw workpieces, shaping them into the desired form and size. This material removal capability is fundamental for creating intricate and complex shapes in a wide range of materials, including metals, plastics, and composites. Machining processes like turning, milling, shaping, grinding, and drilling are essential for achieving high levels of precision and accuracy in the production of parts and components. This precision is crucial in industries like aerospace, automotive, and medical devices where even minor deviations can have significant consequences. Machining allows for the attainment of smooth and fine surface finishes, critical in applications where parts need to meet specific aesthetic or functional requirements. For example, the quality of surface finish in mold-making directly affects the final product's appearance. Industries rely

on machining to achieve tight tolerances and exact measurements. This is vital in applications where parts need to fit together precisely or where there are strict quality standards to meet. Machining is not limited to just manufacturing new parts. It is also vital for repair and maintenance operations, allowing for the restoration of worn or damaged components, which can extend the lifespan of machinery and equipment. Machining processes are versatile and adaptable to various materials and shapes. They can be used for producing everything from simple, cylindrical parts to complex and highly detailed components. Cutting fluids also are important for machining processes because they acts as cooling and lubricant medium for the cutting area which helps on improving the surface quality of the machined part and increases the working life of the cutting tool, [22-26].

Cutting fluids and their Importance

Cutting fluids, commonly employed in various machining operations such as milling, turning, and drilling, play a vital role in these processes. These fluids serve multiple functions, with one key role being the cooling of both the equipment and the workpiece. Primarily used to dissipate heat generated during metal cutting and machining, cutting fluids also function as lubricants. They contribute to improving cutting conditions and extending tool life by reducing friction between the tool and the chip, as well as between the tool and the workpiece. The proper application of cutting fluid, in the correct amount, enables the swift removal of generated heat, thereby enhancing production efficiency. It's essential to note that each type of cutting fluid comes with its unique set of advantages and disadvantages. The selection of the right type of cutting fluid depends on various factors such as:

- **Type of cutting process,**
- **Machined material,**
- **Material of the cutting Tool.**

Properties of good cutting fluids include:

- **High thermal conductivity**
- **High flash point**
- **Low freezing point**
- **Low viscosity**
- **Good lubrication properties**

Cutting fluids must provide the following functions:

- **Heat Dissipation: One of the primary functions of cutting fluids is to dissipate heat generated during the machining process. As cutting tools contact with the workpiece, the friction and cutting forces generate significant heat. Cutting fluids help absorb and carry away this heat, preventing overheating of the tool and workpiece.**
- **Tool Life Extension: Cooling and lubrication provided by cutting fluids increase the lifespan of cutting tools. Prolonged tool life results in cost savings and reduced downtime for tool changes, particularly in high-production environments.**
- **Improved Surface Finish: Cutting fluids help maintain a smooth and consistent surface finish on the workpiece. They reduce friction between the**

tool and workpiece, minimizing the likelihood of surface defects and improving the overall quality of machined parts.

- **Reduction of Tool Wear: By reducing friction and heat. This not only extends tool life but also ensures that tools maintain their sharpness, leading to better precision in machining operations.**
- **Chip Evacuation: Effective chip evacuation is essential for continuous and efficient machining. It help flush away chips and debris from the cutting zone, preventing them from interfering with the machining process.**
- **Improved Dimensional Accuracy: Cutting fluids aids in maintaining dimensional accuracy and tight tolerances. By minimizing thermal expansion and tool deflection, they contribute to the precise machining of components.**
- **Reduced Residual Stresses: Heat generated during machining can result in residual stresses in the workpiece. Cutting fluids help to control and minimize these stresses, reducing the likelihood of part distortion or cracking.**
- **Environmental and Health Benefits: In addition to their performance advantages, cutting fluids can have environmentally friendly formulations. Using biodegradable or environmentally safe cutting fluids reduces the environmental impact and minimizes health risks to machine operators.**
- **Prevention of Corrosion: Cutting fluids can protect workpiece materials, particularly metals, from corrosion during and after machining. This is essential in applications where the corrosion resistance of the final product is critical.**
- **Enhanced Productivity: Cutting fluids contribute to increased machining efficiency and productivity. They allow for higher cutting speeds and feeds, reducing machining cycle times.**
- **Safety: Cutting fluids can enhance safety by reducing the risk of tool breakage, minimizing the generation of hot chips that can cause injury, and providing a cleaner and safer working environment.**
- **Materials Versatility: Cutting fluids are formulated for use with a wide range of materials, making them suitable for various machining applications.**

There are different types of oils available for different cutting operations and materials. Some of the most common cutting fluids are:

- **Pure Oil,**
- **Oil Solution,**
- **Mineral Oils,**
- **Synthetic fluids, and**
- **Semi-Synthetic liquids.**

Natural lubricants

Natural lubricants are lubricants that are produced from natural sources, such as vegetable oils, animal fats, or plant extracts. They are often used as alternatives to synthetic or traditional mineral-based lubricants in machining processes, especially when environmental or health concerns are involved. *Rasaq Kazem et al.*, in a comprehensive study evaluating the influence of various cutting fluids, including vegetable oils, vegetable oils emulsions, and nano-cutting fluids with vegetable-oil, on

cutting force, surface roughness, tool wear, and cutting area temperature in comparison to traditional mineral oils, concluded that vegetable-oil-based cutting fluids adhere to cleaner manufacturing standards while maintaining comparable or superior efficiency. Vegetable oils fall into two categories: (i) eaten oils, serving diverse purposes in nutrition, makeup and soap production, fuel, medical products, and various industrial applications, and (ii) non-eaten oils, devoid of potential human use. Both types of vegetable oils exhibit compatibility with both human health and environmental considerations. In machining operations, different lubrication mechanisms utilize various fluids or lubricants. The selection of lubricant and lubrication techniques depends on factors such as the nature of the cutting process, the type of material, cutting conditions (cutting speed, feed rate, and depth of cut), as well as the tool material and geometry. While mineral oils are commonly used in conventional machining operations with additives to enhance their properties, it's noted that many of these cutting fluids present environmental and economic drawbacks. Natural oils were recently introduced as a promising alternative to conventional cutting fluids because their properties encourage researchers to study them for application in machining operations [27-31]. This review article will clarify the different types of natural oils and natural additives-based cutting fluids, their pros and cons, and their environmental, economic, and technical impacts on machining operations. According to a review paper by Kumar et al., sunflower oil has been used as a base fluid for eco-friendly cutting fluids. They also reported that different nanoparticles have been mixed in cutting fluids to enhance their cooling and lubrication properties. Another review paper by *ogedengbe et al*. compared the performance of groundnut oil and soluble oil as cutting fluids during the machining of stainless steel. They found that groundnut oil reduced the surface roughness more than soluble oil, which indicated that vegetable oil is a better lubricant than mineral oil [32-35]. Natural lubricants have some pros and cons when compared to other types of lubricants. Here are some of them:

Pros:

- **Natural lubricants are biodegradable, which means they can be broken down by microorganisms in the environment. This reduces the risk of pollution and contamination of soil and water sources.**
- **Natural lubricants are generally less toxic and more compatible with human skin than synthetic or mineral-based lubricants. This can reduce the exposure to harmful chemicals and allergens for workers and customers.**
- **Natural lubricants are renewable and can reduce the dependency on imported petroleum oils. This can lower the cost and improve the sustainability of machining operations.**

Cons:

- **Natural lubricants have lower oxidative stability than synthetic or mineral-based lubricants. This means they can degrade faster when exposed to heat, oxygen, or moisture. This can result in increased wear, corrosion, and deposits on the equipment and workpiece.**
- **Natural lubricants have a lower viscosity index than synthetic or mineral-based lubricants. This means they can change their viscosity more with**

temperature changes. This can affect the performance and efficiency of the machining process.

- **Natural lubricants may require chemical modification or additives to improve their properties and performance. This can increase the cost and complexity of using natural lubricants.**

Choosing the optimal lubricant for a machining process involves considering factors like material type, tool specifications, the specific operation, and the environmental conditions. Natural lubricants, including vegetable-based or bio-based cutting fluids, are considered an eco-friendly alternative to traditional mineral-based cutting fluids. While natural cutting fluids may offer certain advantages in certain scenarios, it's essential to weigh them against potential disadvantages. Here are some key points about natural cutting fluids:

- **Environmental Friendliness: Because of it was Derived from renewable resources, particularly vegetable oils, natural cutting fluids offer a sustainable alternative to traditional lubricants. These fluids are biodegradable and pose fewer environmental risks compared to petroleum-based counterparts. Opting for natural cutting fluids can contribute to a reduction in the overall environmental impact associated with machining processes.**
- **Health and Safety: These cutting fluids are typically safer for machine operators as they have lower toxicity levels and reduced health risks.**
- **Improved Lubrication: Natural cutting fluids provide effective lubrication at the cutting zone. This reduction in friction and wear rate, increases the lifespan of tools and improving machining precision.**
- **Heat Dissipation: They have good heat dissipation properties, helping to control cutting temperatures and prevent tool and workpiece overheating. This feature contributes to extended tool life and consistent part quality.**
- **Biodegradability: Natural cutting fluids break down more easily in the environment, reducing the long-term impact on ecosystems. This biodegradability is particularly important when it comes to disposal and waste management.**
- **Renewable Resource: The sustainability of Soybean oil, rapeseed oil, or other vegetable oils, makes natural cutting fluids an attractive option in industries focused on reducing their carbon footprint.**
- **Compatibility: Natural cutting liquids are generally compatible with a wide range of materials, including metals and plastics. They can be used in various machining applications without sacrificing performance.**
- **Reduced Odor: Natural cutting liquids often have a more pleasant odor compared to mineral-based fluids. This can lead to a more comfortable working environment for machine operators.**
- **Corrosion Protection: Some natural cutting fluids offer effective corrosion protection for workpiece materials, enhancing the durability and quality of machined parts.**
- **Cost Considerations: While natural cutting fluids may be competitively priced with traditional cutting fluids, their cost-effectiveness can be influenced by factors such as tool life extension and reduced downtime due to tool changes.**

The most common types of cutting fluids used for machining operations consist of mineral oils and other additives to enhance their properties, but; unfortunately, most of these cutting fluids have some cons related to environmental and economic issues. More studies proposed other types of lubricants, such as vegetable oils and vegetable oils-based lubricants, animal oils, semi-solid lubricants as well as solid lubricants. [36-39].

Vegetable oils and vegetable-based oils cutting fluids.
Vegetable oils have attracted the focus of scientists and the industrial community for the past three decades to be used as an alternative to mineral oils during the machining processes, they could be used as emulsion or straight oil for different machining operations. Vegetable oils are predominantly composed of triglycerides, which consist of glycerol molecules with three long-chain fatty acids attached to the hydroxyl groups through ester linkages. Several types of vegetable oils were studied to be used as lubricants for machining processes, for example:

- **Cotton seeds oil,**
- **Corn oil,**
- **groundnut oil,**
- **soybean oil,**
- **sunflower seeds oil**
- **peanut oils**
- **coconut oils**
- **jatropha oils**
- **canola oils**
- **castor oils**
- **almond oils**
- **hazelnut oils**
- **olives oils.**

Cotton seed, corn, olives, and all other vegetable oils have a similar structure to other oilseeds such as sunflower seed, having an oil-bearing kernel surrounded by a hard outer hull. A lot of scientific studies concerned with the method of applying vegetable oils and vegetable-based oil lubricants during machining, flood and Minimum Quantity lubrication -MQL- were investigated.

Flooded lubrication (FL)
A lubrication system characterized by the continuous supply of lubricant at low pressure, with subsequent drainage, is known as flood cooling. This method is enhanced by flooding the tool with a consistent flow of cutting fluids, typically under 300 kPa pressure or higher, at a rate of approximately 20 L/min on the clearance face. Despite its effectiveness in machining processes, it has been observed that more than 80% of illnesses in cutting fluid operators result from physical contact [9-14]. Due to the elevated costs of widespread coolant and lubricant usage, the associated detrimental environmental impacts as well as hazardous effect on workers, and the challenges of disposing of significant waste volumes, flood cooling is currently being avoided in manufacturing processes.

Minimum Quantity Lubrication (MQL)

This lubrication mechanism, considered as a safe environmentally and economically viable alternative to conventional flood cooling methods, has been acknowledged for its potential in enhancing sustainability in machining operations. Minimum quantity lubrication involves supplying small amounts of fluid directly to the work-tool interface, creating a near-dry machining environment where minute quantities of green lubricants are introduced to the machining zone [40]. In this approach, a modest fluid volume (typically 10-100 ml/h) is sprayed onto the cutting zone using compressed air, marking an intermediary solution between flood cooling and dry machining. To optimize MQL parameters, various studies have focused on several factors. Extensive investigations have explored the impact of MQL on the working life of cutting tools, corrosion of tool, surface properties of work materials, cutting forces, and consumed energy across different cutting techniques for diverse substances [41-42]. It was observed by *Roshan et al*. that revealed enhanced surface integrity and reduced energy consumption during grinding when employing sunflower-based lubricants, particularly when incorporating Al2O3 nanoparticles. Similar positive results were obtained in turning operations using palm oil mixed with Al2O3 nanoparticles, outperforming coconut oil and olive oil. Palm oil, olive oil, and coconut oil with some additives proposed as cutting fluids for turning operation applying minimum quantity lubrication technique, it was concluded that adding of Al_2O_3 nanoparticle to palm oils outperform coconut oil and olive oil [43-44]. Shreeshail et al were investigate some types of natural oils such as palm, sunflower, coconut, and peanut oils; to be used as cutting fluids while milling of AISI 9310 alloy steel, it was concluded that groundnut oil and soybean oil shows better results in terms of surface roughness, surface finish and cutting forces [45]. Surface finish and tool wear were improved under using vegetable oils as minimum quantity lubrication method as compared to dry and flood techniques. Moreover, minimum quantity lubrication technique has been deemed a favorable alternative cooling technique, providing superior surface finish and reduced tool wear compared to dry and flood techniques [46-47]. When turning AISI 1045 at a faster cutting speed of 250–350 m/min, Rahim et al. [48] examined the effectiveness of MQL over non-lubricated cutting. The findings showed that the suitable cooling effect of air consistent aerosol flow reduced the cutting temperature in minimum quantity lubrication by 10% to 30%, as well as the tool chip contact length by 12%, and the cutting force by 5% to 28%. Minimum quantity lubrication at 200 m/min produced a better surface quality based on experimental and numerical findings. Dureja et al. proposed minimum quantity lubrication as an alternative to dry and flood cooling for stainless steel, aiming to minimize tool wear and surface roughness [49]. To convert highly alloyed steel, Sankar and Choudhury [50] used dry air cooling, flood cooling, and lubrication utilizing a small amount of cutting fluid. Mineral oils of the emulsion type were utilized as lubricants. According to the experimental findings, lubricating using a small amount of cutting fluid may be a more cost-effective and environmentally friendly option than flood cooling. MQL has proven advantageous in this context, with potential improvements in tool life and overall lubrication effectiveness [51]. It was concluded by Ekinovic et al. that up to 15% of the manufacturing costs related

to the use and disposal of cutting fluids, besides the environmental and economic concerns that associated with cutting fluids [52]. MQL has been effective in reducing cutting force during turning low carbon steel, showcasing its potential impact on energy efficiency [53]. For drilling operations, chip extraction is a critical concern impacting the surface integrity of drilled holes [53,54].

CONCLUSIONS

From the current review for natural lubricants, it can be concluded that:

1- It is important for different machining operation to apply cutting fluids for cooling, lubrication, and chip disposal.

2- A lot of scientific studies conclude that using of mineral or synthetic lubricants have some environmental impacts and health hazardous.

3- Vegetable oils and vegetable-based lubricants promising an attractive alternative for other cutting fluids.

4- Vegetable oils and vegetable-based lubricants obtain an effective lubricant and cooling medium for machining operations for different types of hard to be machined materials.

5- Vegetable oils with some additives improving the surface finish of machined parts.

6- Using natural lubricant by means of MQL technique helps in reducing the tool wear, cutting temperature and surface roughness.

7- Palm oils, ground nut oils, sunflower oils, and soybean oils were proposed as good alternatives for a lot of mineral and synthetic lubricants.

8- Vegetable oils and their based lubricants show safe operational environment as well as good economical alternatives.

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