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A Review Of The Environmental Impact Of Cutting Fluids Used For Manufacturing And Pharma Industries

Dilip Maruthi G[1*], Rashmi R[2], Rajendra G.[3]

[1 & 2]Assistant Professor, Department of Mechanical Engineering, BMS College of Engineering, Bengaluru
[3]Professor and Head, Department of Industrial Engineering and Management, Dr. Ambekar Institute of Technology, Bengaluru. Email: gdm.mech@bmsce.ac.in

Abstract:
In the era of sustainability, all manufacturing industries, including pharmaceutical, should be responsible for reducing environmental pollution. Thus, Plant-based oils are set to play a crucial role in the lubricant and cutting fluid industries due to their renewable, natural, non-toxic, and environmentally friendly nature. Additionally, they are more cost-effective compared to synthetic alternatives. Unlike mineral oils, plant oils possess unique chemical structures that give them distinct properties. They offer superior lubrication, higher viscosity indices, and excellent anticorrosion characteristics, mainly because of their strong affinity for metal surfaces in this study. Recent research highlights the promising potential of manufacturing and pharma industries in terms of lubrication and cooling during machining, thus reducing the hazards to the operator. The oils used for the machining are also highlighted.

Keywords: Bio oils, MQL, Eco-friendly oils, Cutting fluids, Coolant oil, Machining oil

1. Introduction:

The pharmaceutical manufacturing industry is crucial in public health and is associated with significant environmental challenges. One of the critical areas of concern is cutting fluids during machining processes. These fluids are essential for cooling and lubricating tools, but their ecological impacts, particularly in toxicity and biodegradability, necessitate a thorough examination. This literature review synthesizes recent findings on cutting fluids and their environmental consequences, exploring sustainable alternatives and identifying knowledge gaps for future research. The life-cycle assessment (LCA) methodology has been employed to evaluate the ecological impacts of various manufacturing processes, including cutting fluids. Research indicates that the effects embodied, energy consumption, and waste generation associated with cutting fluids can be significant (Huang et al., 2013; Faludi et al., 2015). By adapting LCA to specifically focus on cutting fluids in pharmaceutical manufacturing, it becomes possible to identify less harmful alternatives that align with sustainability goals. The shift towards more sustainable machining practices is underscored by exploring minimum quantity lubrication (MQL) systems, which utilize significantly lower amounts of cutting fluids. This method has been shown to enhance performance while reducing waste (Boswell et al., 2017). Adopting eco-friendly lubricants, such as vegetable oils and nanofluids, presents a promising avenue for mitigating the environmental impact of cutting fluids. These alternatives reduce toxicity and align with the growing emphasis on sustainability within the manufacturing sector. The exposure of workers to hazardous substances, including cutting fluids, presents significant health risks in pharmaceutical manufacturing environments (Gajrani & Sankar, 2017). Addressing these risks requires a concerted effort to assess the distribution of chemical exposures and prioritize the selection of safer alternatives. By focusing on the health and safety of workers, the pharmaceutical industry can not only comply with regulatory standards but also foster a more equitable workplace. Composition and Types of Cutting Fluids Cutting fluids can be classified into the following categories: Mineral-Based Oils: Derived from petroleum, these provide excellent lubrication but pose disposal challenges. Synthetic Fluids: Chemically formulated to reduce bacterial growth, though some may contain hazardous substances. Semi-synthetic Fluids: A combination of mineral and artificial components that offers improved performance but raises environmental concerns. Water-soluble fluids are more environmentally friendly than oil-based fluids but require frequent maintenance to prevent microbial contamination. Research has consistently demonstrated the benefits of incorporating nanomaterials into cutting fluids. For example, Su et al. (2016) evaluated the performance of nanofluid minimum quantity lubrication (MQL) with vegetable-based oils and ester oils, highlighting the enhanced cooling and lubrication properties afforded by Nano-additives. Similarly, Singh et al. (2017) investigated alumina-graphene hybrid Nano-cutting fluids, revealing significant improvements in tool life and surface finish during hard-turning operations. These findings agree that nanomaterials, such as carbon-based additives, could yield similar or enhanced benefits. Hegab et al. (2018) explored the effects of Nano-cutting fluids on tool performance and chip morphology when machining Inconel 718, although there is a requirement for a mechanism of lubrication enhancement. The lubrication mechanisms proposed in various studies provide insight into how carbon Nano-onions might improve cutting fluid performance. Wang et al. (2016) demonstrated that ionic liquid-capped carbon dots significantly reduced friction and wear, suggesting that carbon

Nano-onions could similarly benefit from mechanisms such as film lubrication and Nano-lubrication to enhance tribological performance. Furthermore, Meng et al. (2017) illustrated the effectiveness of a nanocomposite made from gold nanoparticles and graphene oxide in reducing friction rates, hinting that carbon Nano-onions may employ comparable tribological behaviors. Zeng et al. (2013) examined the super lubricity behaviors of Si3N4 against diamond-like carbon films with Nano boron nitride as a lubricant, emphasizing the formation of transfer films and solid lubrication roles in reducing wear and friction. These tribological insights could inform the development of carbon Nano-onion-based cutting fluids, potentially leading to improved surface interactions and reduced tool wear during machining. The tool life studies are shown in Fig. 1 by John S. et al.(2018)

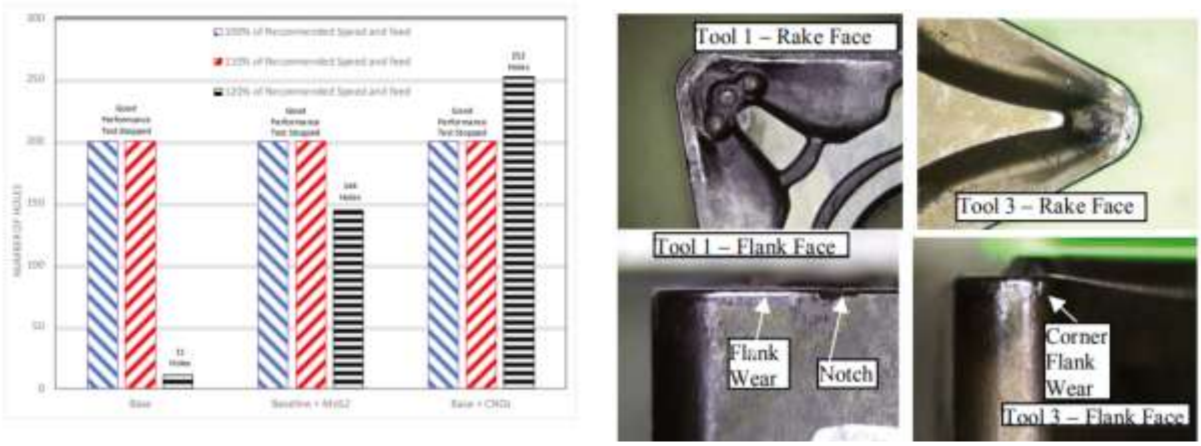

Fig.1(a) Tool life comparison when drilling with three different coolants. b) Crater and Flank wear for Tools 1 and 3

2. Biological Stability and Environmental Considerations

The biological stability of cutting fluids is a crucial factor in their environmental impact. Over time, cutting fluids can degrade due to microbial contamination, producing harmful by-products and reduced performance. Water-based cutting fluids are particularly prone to bacterial and fungal growth, which can deteriorate fluid quality and release harmful bioaerosols into the environment. While some cutting fluids naturally biodegrade, others contain synthetic compounds that persist in the ecosystem, contributing to pollution and long-term ecological harm. Additionally, as these fluids break down, they may release toxic substances such as ammonia, hydrogen sulfide, or volatile organic compounds (VOCs), which pose significant environmental and health risks. Regulatory bodies impose strict guidelines on the disposal and handling of cutting fluids to mitigate these impacts and ensure environmental compliance. To improve biological stability and minimize environmental damage, industries should adopt biostable fluid formulations that resist microbial degradation, implement rigorous fluid maintenance strategies such as filtration and biocide treatments, transition to biodegradable and non-toxic alternatives, and invest in advanced waste treatment technologies like bioremediation and green chemistry solutions. These measures can significantly enhance sustainability while reducing hazardous emissions and contamination risks. Hegab, H.(2016). Fig 2 shows how the cutting fluid interacts with the material. The Nano-fluid additives interact with the work surface's asperities, increasing cutting forces. Increasing the concentration of Nano-additives leads to more wear. Moreover, the shift towards environmentally friendly manufacturing processes necessitates the exploration of sustainable additives. Rapeti et al. (2018) highlighted using vegetable oil-based Nano-cutting fluids as a step towards sustainable manufacturing. Incorporating carbon Nano-onions into such formulations could further align with this trend, offering both performance benefits and reduced environmental impact.

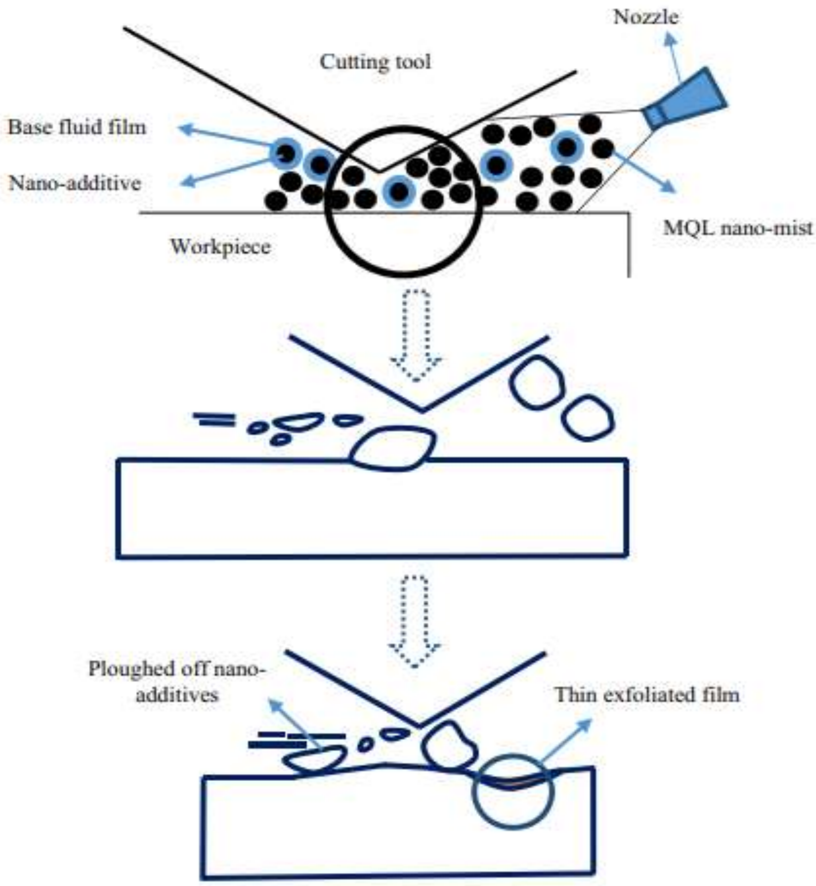

Fig.2 Schematic of the rolling and plowing MQL nano-cutting fluid mechanism Hegab, H(2018)

Increasing tool life, decreasing workpiece and thermal deformation, enhancing Finishing surfaces, and removing chips from cutting zones. While cutting fluids extends tool life and improves machine efficiency, they can pose environmental and health risks and recycling and disposal challenges. These issues allowed for using mineral, vegetable, and animal oils. These oils enhance machining qualities such as corrosion resistance, lubricity, antibacterial protection, emulsibility, and chemical stability. Vegetable oils have a higher viscosity index, flash point, lubricity, and lower evaporative losses than mineral oils. Vegetable oils can be either edible or not. Ravindra S et al. studied that. Plant oil will play a significant role in lubricant and cutting fluid industries because plant oils are renewable, natural, non-toxic, non-polluting, and cheaper than artificial synthetic oils. Compared to mineral oils, plant oils have different properties due to their unique chemical structures. Plant oils have better lubrication ability, viscosity indices, and superior anticorrosion properties due to the higher affinity of plant oils to metal surfaces. For this Work, jatropha curcas seed was extracted to obtain crude oil. Recent research has found that jatropha curcas have good potential as biodiesel and lubricant. Jatropha oil is nonedible due to the toxic content of its oil. Therefore, its usage as a biofuel will not compete with other edible plant-based oils needed in the various food industries. It was also seen from the results that the substantial reduction in tool wear resulted in enhanced tool life and surface finish. Furthermore, Jatropha bio lubricant, along with MQL, provides environment friendliness, maintaining a neat, clean, and dry working area, avoiding inconvenience and health hazards due to heat, smoke, fumes, gases, etc., and preventing pollution of the surroundings and improving the machinability characteristics. Ravindra S (2016). Rakesh et al. studied Mineral oils, chemically synthesized emulsifiers, and additives, which are the basic ingredients of commercially available metalworking fluids. Its application in metal cutting has earned widespread acceptance all over the world. However, their harmful effects on the environment and life-threatening health hazards to workers are of great concern, and a better alternative is called for. In this present study, a green 2017 metalworking fluid / green cutting fluid (GCF) was formulated, and the performance was compared with the commercial metal working fluid (COM) used in industries for machining processes. The obtained eco-friendly formulation has material properties equivalent to the commercial formulation without any environmental hazard. GCF is comparable to COM in corrosion prevention, inhibition of microbial growth, and other machining processes. It was reported that vegetable oil-based green cutting fluids have more Gram-negative bacterial growth, whereas mineral oil-based ones have more Gram-positive bacteria. These bacteria cause environmental hazards, and antimicrobials can be included to improve their antimicrobial properties. GCF supersedes COM by being non-toxic at LC50 >1000 mg/L and COM being toxic at LC50 & lt; 100 mg/L according to OECD 203 test methods. GCF, produced only from renewable sources, is non-toxic and biodegradable, and helps contribute to green and sustainable manufacturing processes without any environmental pollution or hazards.

Rakesh (2017). Talib et al. Has investigated Metalworking fluids (MWFs) that act as cooling and lubrication agents at the cutting zone in the machining process. However, Conventional MWFs, such as mineral oil, hurt humans and the environment. Therefore, the manufacturer substitutes mineral oil with bio-based oils such as vegetables and synthetic oil. There is a need to develop environmentally friendly MWFs as an alternative to the use of lubricants. This research evaluates the performance of chemically modified jatropha oil-based trimethylolpropane (TMP) 2016 ester from crude jatropha oil (CJO) as bio-based MWFs. Modified jatropha oil (MJO) was developed by a transesterification process with different molar ratios of jatropha methyl ester (JME) to TMP. Afterward, MJOs were tested on viscosity, density, and tribology according to American Society Testing and Materials (ASTM) conditions. Then, the samples were compared with synthetic ester (SE) and CJO on the orthogonal cutting condition. Those lubricants were supplied using the minimum quantity lubrication (MQL) technique. The result shows that the viscosity of oils affects the coefficient of friction (COF) and wear scar diameter (WSD). The machining performance of MJO was comparable with SE in terms of cutting force and maximum cutting temperature. It shows that MJO significantly improved the lubricating effect and thus becomes a suitable candidate to substitute SE as a machining lubricant. Talib(2016). Shyha et al studied Power consumed in metal cutting is typically converted into heat near the cutting tool edge. Cutting fluids are then provided to a Cutting zone to improve the tribological characteristics of machining processes and to dissipate the generated heat. The use of conventional cutting fluids, however, has lately been questioned due to the adverse impact on the environment and human health. Therefore, trends are directed to various alternatives such as vegetable oils (VOs). Vos offers a combination of good biodegradability and high lubricity, eco-friendly and compatible with additives, low toxicity and volatility, high flash points, and high viscosity indices. This paper details preliminary experimental results when turning Ti-6Al-4V. The impact of VO-based cutting fluids, cutting tool materials, and working conditions was investigated. Two sets of experimental plans were designed comprising 25 and 27 tests with analysis of variance (ANOVA) employed to evaluate the effect of process variables on Ra and tool flank wear. In general, surface roughness Ra ranged between 0.56 μm and 1.81 μm and statistical analysis showed that the main contributing factor for Ra is feed rate having a high Percentage Contribution Ratio (PCR) of 94.4%. A noticeable increase in tooltip flank wear was recorded when higher cutting speeds were used.

3. Conclusion:

The main focus of this literature is to conclude the best method to introduce an eco-friendly lubrication effect during the machining of different materials along with other eco-friendly oils. Several researchers have proposed that the MQL technique is the best method for introducing the eco-friendly liquid. It was observed that for hard materials such as Ti-6Al-4V, the surface roughness was in the range of 0.56 μm and 1.81 μm, and also observed that the cutting zone improved wear characteristics during the machining. the other focus is to develop a green lubricant with eco-friendly lubricants. green cutting fluid (GCF) was formulated, and the performance was compared with the commercial metal working fluid (COM) used in industries for machining processes. The obtained eco-friendly formulation has material properties equivalent to the commercial formulation without any environmental hazard. GCF is comparable to COM in corrosion prevention, inhibition of microbial growth, and other machining processes. . It was reported that vegetable oil-based green cutting fluids have more Gram-negative bacterial growth, whereas mineral oil-based ones have more Gram-positive bacteria. These bacteria cause environmental hazards, and antimicrobials can be included to improve their antimicrobial properties which is hazardous to the working environment.

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