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# Application of Vegetable Oil Based Machining Fluids in Green Manufacturing Processes, A Review

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## Abstract

Cutting fluids are an inherent part of the modern manufacturing system. In the vegetable oil based cutting fluids, the base fluids should be some vegetable oil. In general, vegetable oil is highly attractive substitutes for petroleum based oils because they are environmentally friendly, renewable, less toxic and readily biodegradable. In this review paper, the author investigates some of the published research papers on the application of vegetable oil based machining fluids (including Nano-fluids) in the different machining processes like turning, milling, grinding and drilling. Besides that, this study also summarize the effect of the different biodegradable oil based machining fluids on the performance factors such as surface integrity, machining force, tool wear, power consumption, and temperature produced during the machining process. It has been reported in various literature that using vegetable oil based Nano machining fluid results high surface features, reduced tool wear, cutting force, power consumption and lower temperature rise in the machining process due to better lubrication and cooling properties.

**Keywords:** Green Machining, Vegetable, Sustainable, Machining Fluid

## Introduction to Green Machining Process

Sustainable manufacturing or green manufacturing can be defined as a method for manufacturing that minimizes waste and reduces the environmental impact. These goals are to be obtained mainly by adopting practices that will influence the product design, process design and operational principles. Sustainable manufacturing can be approached in terms of energy reduction, water reduction, emission reduction, cost minimization, safety maximization, and waste production reduction during a particular manufacturing practice [1, 2]. Various elements of sustainable manufacturing are presented in figure 1.


**Figure 1:** Elements of sustainable manufacturing

### Machining Fluids

The main objective of the application of machining fluids in different manufacturing processes is to remove the heat generated and to decrease the friction between the tool and work piece [3,4]. Reduction in the heat produced in the metal removal processes will result in the longer tool life and less distortion of the work piece and the tool. Machining fluids should possess both coolant and lubrication properties [5]. Common parameters that should be taken into consideration while choosing a machining fluid include performance, environments, and maintainability [6]. The details of these parameters are mentioned in table 1.

| Cutting fluids | | |
|---|---|---|
| Performance | Environment | Maintainability |
| Productivity | Healthy safety | Mix stability |
| Tool life Waste | treatment Water | Tool life Waste |
| Energy | Recyclability | Corrosion sensitivity |
| Quality | Reactivity | Cleanliness |

**Table 1:** Basic parameters of machining fluids

### Application of Vegetable Oil Based Cutting Fluids in Machining

Vegetable oil based machining fluids are the cutting fluids that are prepared from plant oils, water, and air or other raw ingredients [7, 8]. Biodegradable machining fluid is used for cooling and lubrication mechanism particularly for metal removal processes. The main aim of the utilization of these fluids is to decrease harmful gas released during machining operation and to increase the biodegradability [9-11]. In addition, these machining fluids keep the works and tools at a stable temperature, increases tool life, prevent rust formation, highly biodegradable and no adverse environmental impact [12, 13]. Some of the common vegetable-based cutting oils are cottonseed, groundnut, coconut, sesame, canola, soybean, etc. [14-18]. The physical properties of the cottonseed and groundnut oil are presented in table 2.

| parameters | groundnut oil | cottonseed oil |
|---|---|---|
| Flash point | 320°c | 312°c |
| Fire point | 334°c | 360°c |
| Kinematic viscosity | 57.4cSt | 31.347cSt |
| Calorific value | 39.65MJ/kg | 39.27MJ/kg |
| Auto-ignition | Non | Non |
| Density | 923.33kg/m3 | 921.50 kg/m3 |

**Table 2:** Physical properties of the cottonseed and groundnut oil [14]

## Turning

Ghandehariun, A., et, al. [19,20] reported that the exergy analysis of sustainability in the dry machining process. The exergy loss reduces with an increase in the machining speed until it attained the least value. Different researchers [21,22] presented methods of selection of appropriate machining fluids in order to diminish the influence of heat released during machining. This results in better tool life, lesser surface irregularity, and improved accuracy. Researchers [23, 24] reported influence of cutting fluids in machining and its impact on the environment. In this article, a model for the preparation of cutting fluids and its behavior along with how to decrease the flow of machining fluids during different cutting operation is presented.

Author [25,26] reported performance of coconut and Canola oil-based machining fluid is superior than refined sunflower oil while turning AISI 304L. In addition, they also used different percentages of additives while machining and compared them with dry cutting conditions. Abdalla, HS. et, al. [27,28] prepared sustainable machining fluids using oils such as coconut, sunflower, rapeseed, palm olive, and high Erucic rapeseed. Physical properties such as melting point, pour point, kinematic viscosity, oxidation stability, lubricity, etc. reported that low frictional values were obtained for naturally derived vegetable oils as compared to conventional fluids. Different authors [29-33] accomplished a comparative study of mineral oil based machining fluid with vegetable oil based fluid and found that traditional machining fluid can be substituted by vegetable-based machining fluids because mineral cutting fluids are toxic and harmful to the aquatic life while disposal of cutting fluid. Many researchers performed an investigation on the machining of the AISI4340 using various machining fluids like canola oil, coconut oil, and soybean oil [34-36]. It is observed that canola oil is a superior machining fluid in comparison to coconut and soybean oil.

Various author [37-39] performed a comparative study using biodegradable and traditional machining fluids in the turning of AISI 1050 steel. It is reported that the vegetable oil based machining fluid accomplished superior in relation to cutting force during machining and wettability angle. Many researchers carried out an investigation to estimate the influence of mixing of solid lubricant in vegetable-based machining fluid while machining Inconel 718 [40, 41]. The author has observed that the mixing of MoS2 enhances tool life to a great extent and also enhances the machined surface features with a lower value of cutting forces during machining.

## Milling

Authors performed examination of the influence of various input parameters on the machining force and tool life in the milling of Inconel 718 under dry and MQL conditions [42, 43]. It is observed that on the application of MQL technique during the machining operation, a remarkable improvement in the cutting force exerted and extension of the tool life.

Researchers [44, 45] developed vegetable-based machining fluids to investigate machinability in terms of specific energy, surface irregularity, and life of the cutting tool. However, Burton, Whereas Shankar, S. et. al. [46] reported that palm oil-based machining fluid results in lower cutting force and minimum vibration in comparison with other types of biodegradable machining fluids. Junior, A.S.A. et, al. [47] Moreover, a comparative study on the use of different biodegradable vegetable oil based machining fluids in milling of AISI 1045 steel under the MQL technique.

### Grinding

Alves, S.M. et, al. [48] performed grinding operation on SAE 8640 with vitrified CBN wheel. It was found that wheel wear and machined surface irregularity were less by using biodegradable machining fluid in comparison with the conventional fluid. Yuan Z. [49] performed study of the influence of various machining fluids during surface grinding of Ti-6Al-4V, WT-22 and TIGER 5. Various machining oil includes emulsion, oil, dry grinding, propylene glycol, micro 3000, eco cut Mikro 82, bio cut 3000. The author has concluded that using propylene glycol, cutting fluid is easily accessible, less harmful, environment friendly, lower value of cutting force with less surface damage and deformation.

Wang, Y et, al. [50] investigated the surface grinding of nickel-based alloy GH4169 using several biodegradable machining fluids such as soybean, peanuts, maize, rapeseed, palm, castor, and sunflower oil. The author has reported that castor oil-based cutting fluid results in the excellent surface morphology and least surface irregularity (Ra = 0.366 and RSM =0.324) with lesser friction and specific grinding energy. Liu ZQ et, al. [51] in this research the author has done a comparative study of the surface grinding of Ti6Al4V using dry and biodegradable machining fluids and concluded that vegetable-based these fluids results in superior surface quality than dry grinding with the least value of Ra at various grinding depth.

### Drilling

Mendes, OC et. al. [52] this research paper presents a comparative study to estimate the performance of machining fluids in the drilling of AA1050 and turning of AA 6262-T6 aluminum alloy. During the machining of AA 1050-O Aluminum, on the increasing flow rate of the mist results in higher torque and lower feed force while surface finish remains unaffected. However, Bhowmick, S. et, al. [53] carried out a comparative study in the drilling of Al–6%Si (319 Al) alloy under MQL and conventional lubrication techniques. The experimental result shows that under the MQL technique, the drilling torque reduced significantly as compared to conventional lubrication techniques. Whereas researchers [54-57] performed a comparative experimental investigation using biodegradable and conventional machining fluids to estimate cutting force and surface irregularity in the drilling of stainless steel 304 (SS304) with a HSS tool. The paper concluded the lower values of the cutting force experienced and the least surface irregularity at high cutting speed. Braga D.U. [58] reported a comparative study of palm oil and synthetic ester under the MQL technique in the drilling of aluminum–silicon alloys and reported that the palm oil performed better than synthetic ester in terms of specific cutting energy, power and cutting force.

## Application of Vegetable Oil Based Nano Fluids

### Turning

Ranjbarzadeh R et, al. [59] carried out experiments on the thermal behavior of graphene oxide enriched nano-fluids. The author has reported that the thermal conductivity of the Graphene oxide nano machining fluid enhanced by 71% in comparison with conventional machining fluids due to higher heat transfer capability. Jamil, M et, al. [60,61] performed an investigation on the effects of cryogenic $CO_2$ and hybrid nano-fluid in the machining of Ti6Al4V. The author has used vegetable-based hybrid Nano fluid of $Al_2O_3$ and CNT nanoparticles mixed in vegetable oil. Form the reported results it is observed that average surface irregularity and cutting force reduced by 8.72% and 11.8% respectively compared to the cryogenic cooling. Moreover, Hegab, H. et, al. [62] presented the influence of nanotube-based machining fluids in the turning of Ti6Al4V to enhance machinability. Su Y et, al. [63-65] evaluated the performance of vegetable-based Nano-fluids in terms of cutting force and temperature-induced during turning of AISI 1045 steel. It is reported that at higher cutting speed results in reduced cutting force and temperature as compared to other cooling and lubrication techniques. It is also reported that cutting force, surface irregularity, temperature and tool wear are reduced by 37%, 39%, 21%, and 44% respectively in contrast to dry machining process. Gupta MK et, al. [66-68] investigated that $MoS_2$ and graphite-based Nano-fluids provide better results at higher machining speed as compared to conventional machining fluids. It has been reported that the mixing of nanoparticles in the cutting fluids remarkably improves the performance parameters mentioned earlier.

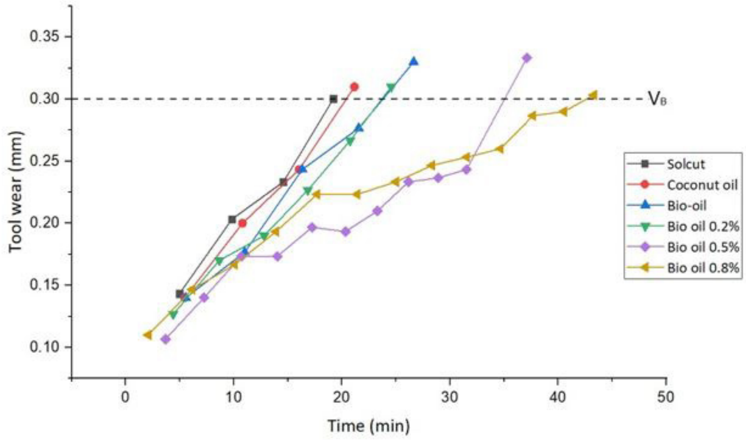


**Figure 2:** Influence of different types of vegetable-based Nano machining fluids on tool wear [68]

## Milling

Uysal, A et, al. [69] concluded that the least values of the surface irregularity and tool wear occurred at 40 ml/h flow rate of Nano machining fluid under MQL. While, Uysal A et, al. [70] carried out investigations on tool failure in the milling of SS304 using biodegradable Nano machining fluid. It can be concluded that on the application of Nano machining fluid various modes of tool wear reduced to a great extent. However, Prasad MG et, al. [71] optimal values of these parameters were estimated by the Taguchi technique and the reported optimal parameters are the spindle speed of 510 rpm, feed rate of 16 mm/min, and depth of cut of 0.6 mm for minimum surface irregularity. The effects of various machining fluids on tool wear shown in figure 3.

Moreover, Settu S et, al. [72] reported that the machinability of the Corn-based Nano machining fluids increased very significantly as compared to the conventional machining fluids. All figures, graphs and photographs should be clear and of high quality. Photographs should be good quality halftones, black-and-white and camera ready. Figures and photographs must be placed within the text of the paper, immediately following the text reference of the figure.

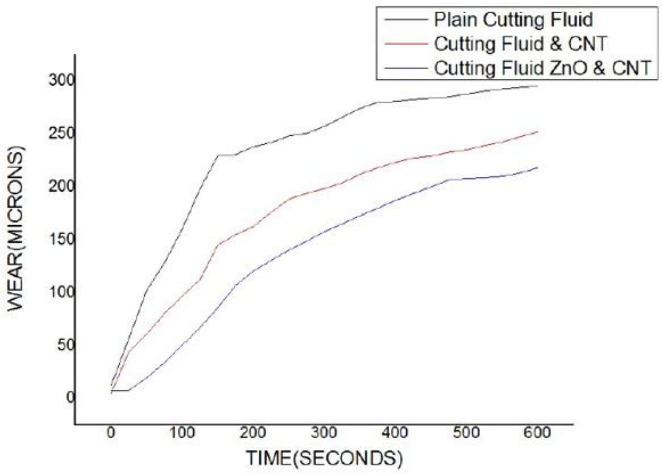


**Figure 3:** Effects of several machining fluids on tool wear [71]

## Grinding

The Author [73,74] carried out experiments on the micro-grinding process with Nano-fluid using MQL techniques. The investigated result shows that on the addition of nanoparticles in the machining fluid, the grinding force decreases significantly with enhanced surface quality due to the superior lubrication properties.

Li B et, al. [75] carried out surface grinding on Ni-based alloy using six different types of nanoparticle in palm oil-based cutting fluid and reported that CNT mixed nan-fluid has lowest grinding temperature with high thermal conductivity results in excellent heat transfer performance. Chakule RR et, al. [76-78] applied an optimization technique to study the effects of the Nano fluids in surface grinding using the MQL technique. They reported that due to the application of Nano-machining fluids, the cutting force and temperature-induced decreases. Influence of various machining fluids on the surface roughness shown in figure 4.

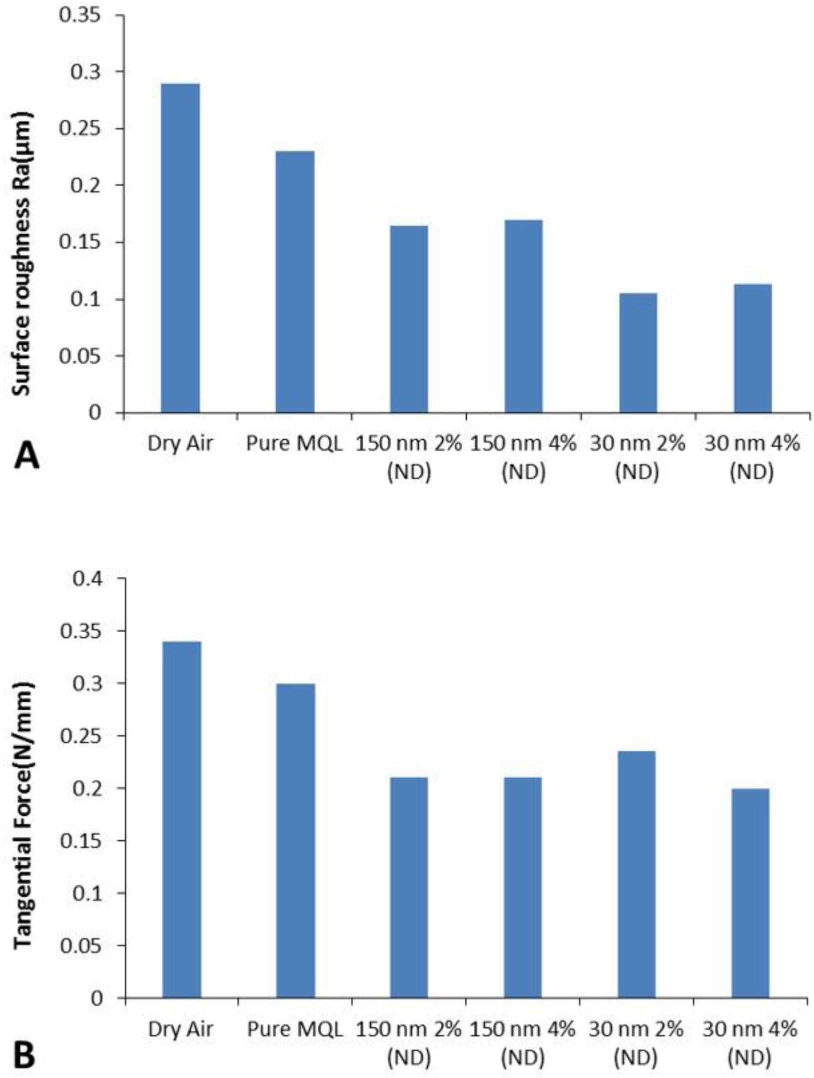


**Figure 4:** A Effects of various fluids on the surface roughness, B on the tangential force [84]

## Drilling

Many researchers [79,80] investigated the performance of drilling parameters in terms of drilling force and torque, hole quality and a number of holes using various cooling and lubrication methods such as compressed air lubrication, pure MQL, and Nano-fluid MQL. Whereas, Liew PJ et, al. [81] reported a comparative investigation of the influence of carbon Nano fiber-based Nano cutting fluid and traditional cooling in the drilling of SS304. The obtained results indicate that carbon Nano fiber-based Nano cutting fluid reduces surface roughness and burr formation along with higher hole accuracy.

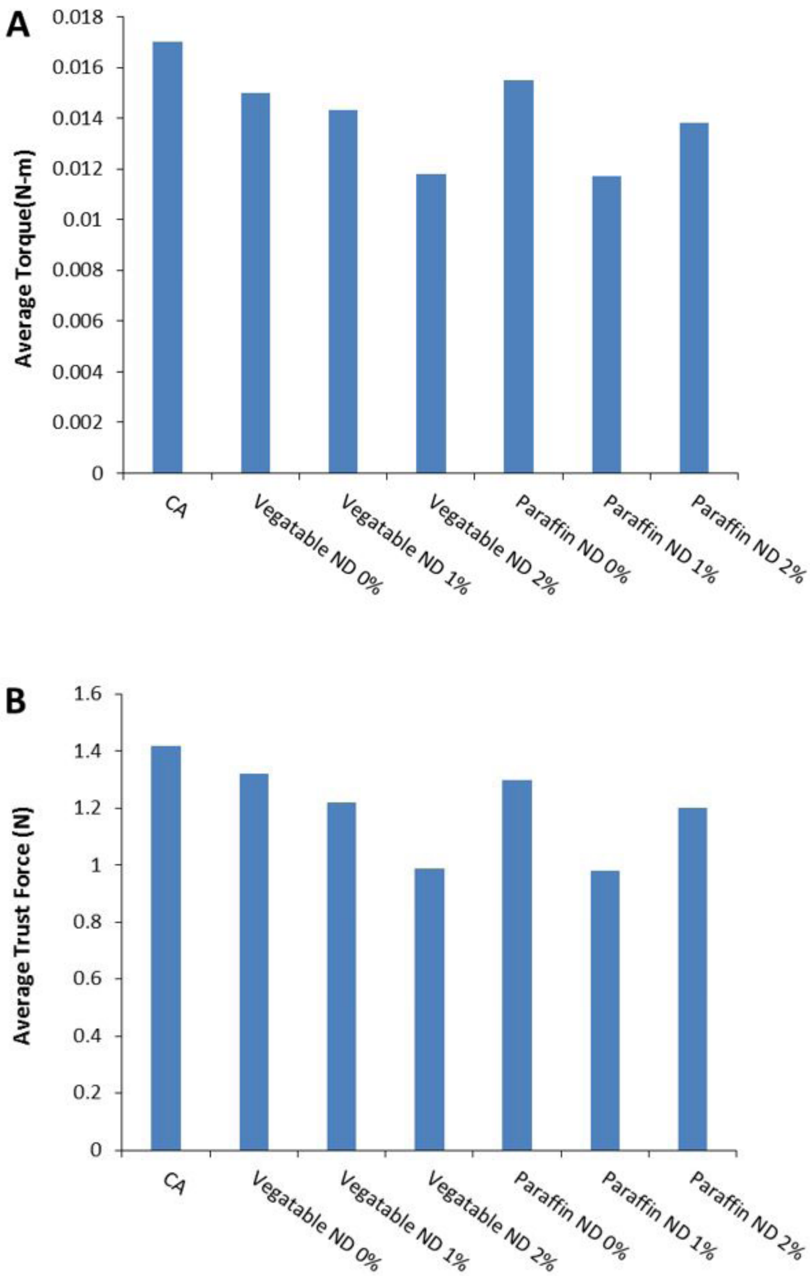


**Figure 5:** Influence of concentration of nanoparticle on average values of torque and thrust force with various vegetable-based Nano-fluids during hole drilling [80]

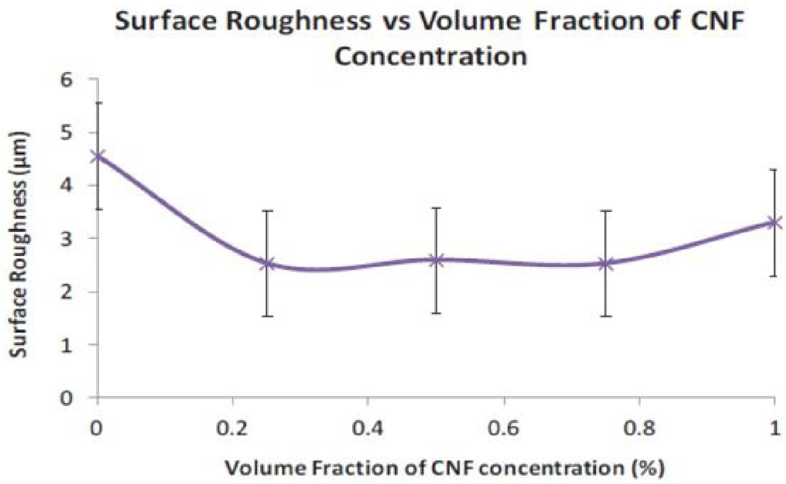


**Figure 6:** Influence of concentration of nanoparticle on surface roughness [81]

| Sl. No. | References | Machining Process | Nanoparticle/ Base fluid | Mode of Nano fluid supply | Findings |
|---|---|---|---|---|---|
| 1 | Ranjbarzad eh, R., Meghdadi, A. H et. al. [59] | Turning | Graphene oxide | Drop by drop using the dropper | Better surface quality and less surface damage due to the high heat transfer capability of Graphene oxide. |
| 2 | Jamil, M., Khan, et. al. [60] | Turning | Al2O3 and CNT | MQL | Average surface irregularity and cutting force reduced by 8.72% and 11.8% respectively compared to the cryogenic cooling. |
| 3 | Sahu, N. K., et. al. [61] | Turning | Multiwalled carbon nanotubes | Supplied through gravity | Cutting force reduced by 28%, surface roughness by 7% and tool wear by 34%. |
| 4 | Hegab, H., et. al. [62] | Turning | Multiwalled carbon nanotubes | MQL | 38% reduction of surface roughness at 4 wt% MWCNTs Nano fluid and 50% improvement in the surface quality at 2 wt% MWCNTs nanofluids. |
| 5 | Su, Y., et. al. [63] | Turning | Vegetable oil | MQL | At higher machining speed, cutting force and temperature reduced significantly. |
| 6 | Padmini, R., et. al. [64] | Turning | MoS2 | MQL | Cutting force, surface roughness, temperature and tool wear are reduced by 37%, 39%, 21%, and 44% respectively. |
| 7 | Padmini, R., et. al. [65] | Turning | MoS2 | MQL | With, nMoS2 suspensions in coconut oil-based cutting fluid higher reduction. |
| 8 | Gupta, M. K., et. al. [66] | Turning | MoS2 | MQL | MoS2 and graphite based Nano-fluids give better results at high machining speeds. |
| 9 | Yıldırım, Ç. V et. al. [67] | Turning | hBN | MQL | With MoS2 and graphite-based Nano fluids significant improvement in cutting force, surface roughness. |

| Sl. No. | References | Machining Process | Nanoparticle/ Base fluid | Mode of Nano fluid supply | Findings |
|---|---|---|---|---|---|
| 10 | Ali, M. A. et. al. [68] | Turning | Al2O3 | | Remarkable improvement in the cutting force, specific cutting energy and surface irregularity. |
| 11 | Uysal, A., et. al. [69] | Milling | MoS2 | MQL | Least values of the surface irregularity and tool wear occurred at 40 ml/h flow rate. |
| 12 | Uysal, A. (2016) et. al. [70] | Milling | | MQL | Tool wear reduces to a great extent. |
| 13 | Prasad, M. et. al. [71] | Milling | MWCNT and ZnO | MQL | Optimal parameters are the spindle speed of 510 rpm, feed rate of 16 mm/min, and depth of cut of 0.6 mm for minimum surface roughness. |
| 14 | Settu, S., & Nandagopa [72] | Milling | CuO | Flood type coolant supply | Better machining performance using CuO. |
| 15 | Lee, P. H., et. al. [73] | Grinding | Al2O3 | MQL | The performance of the machining fluid improves to great extent. |
| 16 | Jia, D., Li, C., et. al. [74] | Grinding | MoS2 | MQL | The performance of the machining fluid improves to a great extent. |
| 17 | Li, B. et. al. [75] | Grinding | CNT | MQL | Lowest grinding temperature with high thermal conductivity results in excellent heat transfer performance. |
| 18 | Chakule, R. R., et. al. [76] | Grinding | Dry, wet with soluble oil | MQL | The least surface roughness and coefficient of friction observed were 0.1236 μm and 0.3906 respectively. |
| 19 | Chaudhari, S., et. al. [77] | Grinding | Nano-fluid | MQL | Surface roughness reduced by 14%. |
| 20 | Nandakum ar, A., et. al. [78] | Grinding | SiC | MQL | Reduced cutting force and temperature. |
| 21 | Nam, J. S., et. al. [79] | Drilling | Diamond particles | MQL | Reduced drilling force and torque with increased no. of holes as compared. |
| 22 | Muthuvel, S., et. al. [80] | Drilling | Copper Nano fluid | MQL | Significantly reduction of flank wear and surface roughness. |
| 23 | Naresh Babu, M., et. al. [82] | Drilling | Copper Nano fluid | MQL | Reduced surface irregularity, cutting temperature and tool wear. |
| 24 | Nam, J., & Lee, S. W. et. al. [83] | Drilling | Diamond particles | MQL | Reduced thrust force and torque at a slower feed rate |

**Table 3:** Summary of literature review on vegetable Oils based Nano cutting fluids

## Conclusions

In this review study, the author introduced a brief report of the past and present researches have been done in different machining processes using vegetable oil based machining fluids (including vegetable based Nano machining fluids). In this study, it is derived that Nano particles enriched the vegetable oil-based machining fluids remarkably increases thermal and tribological properties of the fluids.

The following points are taken from the literature review:

1. Vegetable-based machining Nano fluids represent increased tribological and heat dissipation capability.

2. Adding of Nano particles into the base fluids (vegetable oil) significantly decreases surface irregularity, tool wear, machining force, power consumption and interface temperature during the machining operation.

3. Using Nano particles in vegetable oil-based fluids result in enhanced life of the cutting tool used in the machining operation.

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