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Full Length Article

# Measurement of tribological properties of Cu and Ag blended coconut oil nanofluids for metal cutting

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ABSTRACT

Lubricants are used during the metal cutting process to remove the heat generated during the process and to reduce the Coefficient of friction (CoF). In this paper an attempt was made to synthesize an environment-friendly nano-lubricant using virgin coconut oil as base fluid by separately blending Copper (Cu) and Silver (Ag) nanoparticles in concentrations of 0.1%, 0.25%, 0.5% and 1% on the mass basis. The nanoparticles were blended in coconut oil by the means of ultrasonic shaking to obtain a uniform blend. The dependence of the Coefficient of friction of nanofluids and its performance on the concentration of the nanoparticles is well reported by researchers; therefore the optimal concentration of the nanoparticles was identified by Pin-on-Disk tribological testing. The following tests were conducted on the synthesised nano-lubricant such as Coefficient of friction (Pin-on-disk test), viscosity, flash & fire point and real time turning operation to determine the cutting force, and operating temperature. From the wear test results, it was inferred that copper added coconut nanofluids exhibited lower Coefficient of friction as compared to silver added coconut nanofluids. Further, it was identified that the lowest Coefficient of friction in the range was exhibited by copper added coconut nanofluids of 0.25% concentration. When these nanolubricants were tested in a real time turning operation using lathe tool dynamometer, it was found that 0.25% concentration of copper added coconut nanolubricant exhibited minimum cutting force and operating temperature indicating minimum coefficient of friction.



## 1. Introduction

Tribology is an ancient science, the application of which dates back to circa 1880BCE and with the interest and awareness towards sustainability, the conservation of energy and materials is gaining importance. However, ignorance of tribology is still a major impediment and leads to large monetary losses [1]. Scott (1983) mentioned that an estimated 11% savings in annual US energy consumption equivalent to sixteen billion US dollars. While wear is a major cause of material wastage and friction is the principal cause of energy loss. Lubrication is the most effective means of controlling friction and wear [2]. Thus lubrication is unequivocally imperative in the industry today and demands extensive research and development; also, expected savings are expected to be of the order of fifty times the costs associated with research. Despite conventional oils possessing lubricating and cooling properties, on account of environmental and health issues, there is increasing apprehension over the use of mineral oils in lubrication. Further, It was also stated that coconut oil has a superior lubricity compared to mineral oils and it has biodegradable and non-toxic characteristics [3].

### 1.1. Coconut oil as the base fluid

The applicability of coconut oil as lubricants has been widely experimented because of its biodegradability and other advantages [4]. Coconut oil, a vegetable oil, is listed as Generally Regarded As Safe (GRAS) product in USFDA (USFDA).

Coconut oil has a high viscosity index (1 3 0) and a high flash point (294 °C), and because of its saturated nature, coconut oil has a strong resistance to oxidation [5]. A disadvantage of coconut oil is its high pour point of 23 °C (with respect to other vegetable oil sunflower and sesame), thus it is not suitable for use in cold climatic conditions. Coconut oil also has a lower inception temperature for thermal degradation of 257 °C (with respect to other vegetable oil sunflower and sesame). Despite its lower thermal

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degradation temperature; coconut oil is still a better choice of lubricant, especially in areas with warmer climatic conditions, due to its better oxidative stability. The oxidative stability is a more important factor in the use of vegetable oils as industrial lubricants since oxidative degeneration starts at a lower temperature than thermal degradation [6]. Furthermore, there is an advantage of coconut oil as an appropriate base fluid for the dispersion of nanoparticles [7]. Hence coconut oil was chosen as a base fluid in this study.

Many studies have reported enhancement in lubricity of lubricating oils after addition of nanoparticles and have attributed the same to the addition of nanoparticles to the lubricant [8]. The addition of silver nanoparticles to cutting fluids results in improvements in thermal and frictional properties compared with other metal oxide nanoparticles [9]. The addition of nanoparticles in vegetable oils and the corresponding improvement of machining performance, reduction of cutting tool temperatures and reduction in tool wear have been demonstrated. Further, the addition of nano lubricants in vegetable oils has been shown to be superior lubricants [10]. Nanofluids based on Coconut oil of different concentrations have been prepared through the ultrasonically assisted sol-gel method. Experimental studies have been made for the coconut oil based nanofluids at different temperatures. The molecular interactions responsible for the changes in acoustical parameter with respect to concentration and temperature are discussed [11]. The size and morphology of nanoparticles also decide the lubrication characteristics also spherical shaped nanoparticles (as opposed to fibrous nanoparticles) exhibit a lower coefficient of friction and agglomerate less easily when dispersed in oils [12]. Enhancement in lubrication characteristics was also reported by the use of graphite nanoparticles, graphite nano-fibres, carbon black and multi-walled carbon nanotubes. Similar behavior [13] was observed for $ZrO_2$ and ZnO. The increase in lubricating characteristic to "mending" effect have proved [14]. The dispersed nanoparticles form a layer (soft film) on the surfaces which reduces the shear strength of the tribo-pairs [15]. The tribological properties of a coconut oil nanofluid to which, CuO nanoparticles were added by Thottackkad et al. [16]. A similar study was conducted using coconut oil and $MoS_2$ nanoparticles and the enhancement of tribological and thermo-physical properties was reported. In the Hall-Petch regime, (size greater than or equal to 100 nm); the hardness of materials increases with the decrease in grain size [17]. High hardness may cause scratching and indentation of the surface. However, in the inverse Hall-Petch regime (less than 10 nm), the hardness decreases with decreasing size [18]. It is infereed that the viscosity of nanofluids increases with the increase in concentration [19]. The significance of selecting a suitable lubricant in enhancing productivity and characteristic of product manufactured in a machining process [20]. Vegetable based metal working fluids have been applied in machining of ferrous metals and coconut oil was reported to provide better performance [21].

The objective of the study is to synthesize pollution free nanolubricant using coconut oil as base fluid. The coefficient of friction of the nanolubricant is directly proportional to the concentration of nanoparticles in the lubricant. Thus it is necessary to identify the optimum concentration of nanoparticles in the lubricant for better surface finish during metal cutting process.

## 2. Methodology

### 2.1. Materials

The Copper (Cu) and Silver (Ag) nanoparticles were procured from NANOLABS India Private Ltd. The nanoparticles were of 99% purity. Their size, morphology and density were provided by the supplier along with the respective proof i.e. UV spectrometry analysis and Raman analysis. Table 1, indicates the properties of Silver and Copper nanoparticles. The specifications of the nanoparticles were carefully selected based on the literature survey. The nanoparticles of spherical morphology were selected based on supportive studies which reported the lower Coefficient of friction (CoF) for spherical nanoparticles. The nanoparticle size was kept lower to increase the settling time of the nanoparticles in oil suspension. This was a derivation from Stokes law which stipulates that the speed of settling of a nanoparticle in a suspension was proportional to the square of the radius of the nanoparticle. Pursuant to the literature, the appropriateness of coconut oil as the base fluid for dispersion of nanoparticles is well established. This is corroborated by Sarfaraz et al. Furthermore, the advantages of coconut oil have been stated in many studies. Also, the biodegradability and application of coconut oil as a lubricant is well researched [5].

The base oil was virgin coconut oil manufactured and packed by Vama Oil (P) Ltd, Coimbatore. The oil was clear and had 49% (wt/wt) of Lauric acid, the component of coconut oil responsible for its lubricating properties. The oil had a density of 910 $kg/m^3$.

### 2.2. Preparation of nanolubricants

The density of the base solution was found to be 0.91 g/cc, the weight was calculated for 125 ml solution (batch volume), nanoparticles of suitable proportion are blended by ultrasonication for a period of one hour, the samples were then visually inspected for sedimentation.

### 2.3. Properties

#### 2.3.1. Determination of viscosity

The viscosity was measured using a redwood viscometer as per ASTM D445-06 standards. The details of the viscosity for different concentrations of nanolubricants considered for analysis are provided in Table 2.

#### 2.3.2. Determination of coefficient of friction (Pin-on-disk test)

The test was conducted on DUCOM® tribometer as shown in Fig. 1. The technical specifications for the test are indicated in Table 3. The parameters of the CoF (wear test) were pursuant to the literature in the ASTM G99-05 standard

The pins were machined to a size of 9 mm diameter as shown in Fig. 2. After the machining operation, the pins were polished by an emery paper of grit size 600. To achieve uniform surface roughness over the cylindrical surface of the pin, the pin was fixed in a hand drill and the aforementioned emery paper was pressed against the pin surface. The rotating action of the pin in conjunction with the rubbing action against the emery paper resulted in the polishing of the pins. The surface roughness of the pins was measured using a surface profilometer, to ensure that the surface roughness was less than 0.8 μm, i.e. in compliance with the ASTM G99-05 standard.

The control of the wear testing machine is by DUCOM software. The speed was set and the arrangement was moved back to the disk. Further, the wear scar radius was fixed as per the test. The load was set by attaching weights to the tray which was connected to the arm to which the pin was attached. Afterwards, the IV drip

**Table 1**
Properties of Nanoparticles.

| Property | Silver | Copper |
|---|---|---|
| Size (nm) | 10–20 | 20–30 |
| Morphology | Spherical | Spherical |
| Density (g/cc) | 10.5 | 8.9 |
| Colour | Grey | Brown |

**Table 2**
Redwood seconds for different concentrations of nanoparticle.

| Sl No | Nanoparticle blended | Concentration (weight %) | Redwood Seconds |
|---|---|---|---|
| 1 | Pure Coconut Oil | – | 116.40 |
| 2 | Silver | 0.1 | 225 |
| 3 | Silver | 0.25 | 225.50 |
| 4 | Silver | 0.5 | 229.56 |
| 5 | Silver | 1 | 235.97 |
| 6 | Copper | 0.1 | 194.81 |
| 7 | Copper | 0.25 | 195.31 |
| 8 | Copper | 0.5 | 199.03 |
| 9 | Copper | 1 | 205.68 |

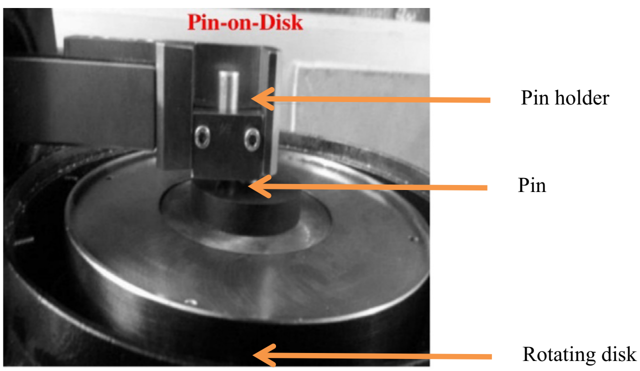


**Fig. 1.** Pin-on-Disk set up.

**Table 3**
Specifications of Wear Testing Machine.

| Sl No | Parameter | Value |
|---|---|---|
| 1 | Sliding velocity (m/s) | 1.4 |
| 2 | Disk material | EN 31-b; 60 HRC |
| 3 | Disk diameter (mm) | 55 |
| 4 | Pin material | Aluminium 6063 |
| 5 | Wear scar diameter | 22 mm, 42 mm |
| 6 | Load (kgf) | 1.5 kgf |
| 7 | Rotational speed of motor (rpm) | 47 at (d = 42 mm), 1228 at (d = 22 mm) |
| 8 | Sliding distance (m) | 1000 m |

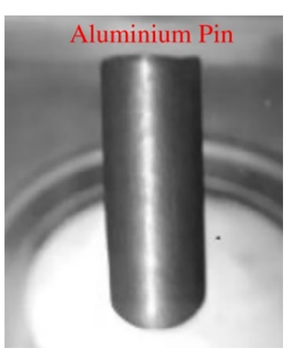


**Fig. 2.** Aluminium Pin.

lubricating system was set up so as to ensure uniform lubrication to the junction of the pin and disk. The motor was started and the fractioned forces were monitored. The nanolubricants – both Cu and Ag- at concentrations of 0.1%, 0.25%, 0.5% and 1% were successively tested. Also, for comparison, blank virgin coconut oil (without nanoparticles) was also subjected to the above test.

*2.3.3. Determination of flash and fire point*

The Flash and fire points were measured using automated Cleveland open cup apparatus as per ASTM D92-05 standards. No change in flash and fire point was observed for different concentrations of nanoparticle. Changes in lauric acid at higher temperatures might account for the above phenomenon.

## 3. Experimentation of Cu/Ag nanolubricants for turning operation

The turning experiments were performed at the "Centre for Advanced Material Testing", at VIT University as indicated in Figs. 3a–c. EN 31b billets of diameter 23.3 mm, were turned in the lathe using carbide tool inserts (CNMG120408 C42) to a machining length of 56 mm, nanolubricants were supplied at a flow rate of 10 ml/min using IV drip bag. The nanolubricants used are virgin coconut oil and four samples each of silver and copper-based nanofluids with concentrations 0.1%, 0.25%, 0.5% and 1%. The cutting forces and temperature during turning were measured using a lathe tool dynamometer and an infrared thermometer respectively.

The technical specifications of the lathe, tool dynamometer, infrared thermometer, and the process parameters are depicted in the following Tables 4–7. The process parameters well within the experimental range and are based on generally accepted good engineering practices.

## 4. Uncertainty analysis

Uncertainty analysis was conducted to determine the uncertainties in a measured variable which are created by environmental, manual and instrumental errors. This is used to avoid errors in the measured variables. The uncertainity analysis was carried out according to perturbation techniques, and the relative errors are provided in the Table 8 [22]. It is inferred that the range of errors obtained in the analysis is less than 5%. In order to determine the uncertainty, the parameters were measured thrice and applied on the following equation. Uncertainty was determined for single independent variable and several independent variables using Eqs. (1) and (2) respectively [22].

Sensitivity coefficient of R with respect to $X_i$ is

$$\delta R_{Xi} = \frac{\partial R}{\partial X_i}\delta X_i \quad (1)$$

For measurement of dependent variable as a function several independent variable,

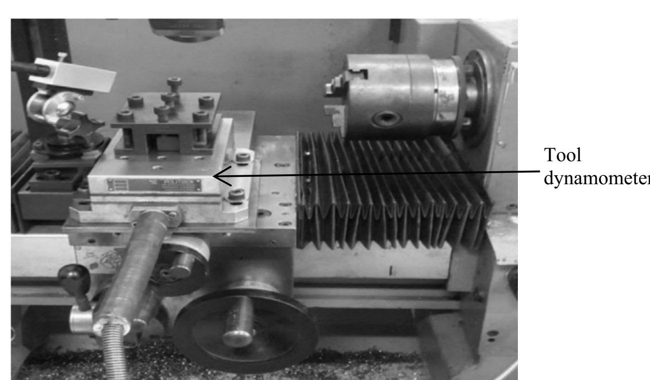


**Fig. 3a.** Lathe with tool dynamometer.

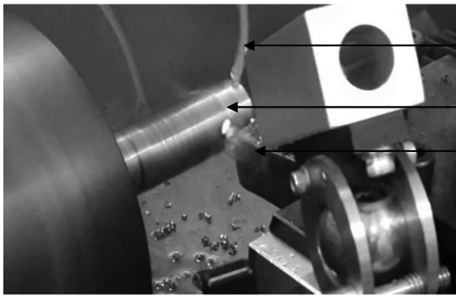


**Fig. 3b.** Turning operation in progress.


**Fig. 3c.** I V drip lubrication.

**Table 4**
Specification of the Lathe.

| SL. No | Parameter | Value |
|---|---|---|
| 1 | Model | MLZ250V |
| 2 | Manufacturer | Geedee Weiler |
| 3 | Swing over bed (mm) | 250 |
| 4 | Swing over cross Slide (mm) | 140 |
| 5 | Range of speed (rpm) | 60–3000 |
| 6 | Power | 1.6 kW |

**Table 5**
Lathe Tool Dynamometer.

| Sl. No | Parameter | Value |
|---|---|---|
| 1 | Model | 9257B |
| 2 | Manufacturer | KISTLER |
| 3 | Type | Three component dynamometer |
| 4 | Measuring Range (kN) | −5 to 5 |
| 5 | Operating Temperature (°C) | 0–70 |
| 6 | Weight (kg) | 7.3 |

**Table 6**
Infrared thermometer specification.

| Sl No | Parameter | Value |
|---|---|---|
| 1 | Model | IRT 207 |
| 2 | Manufacturer | GENERAL |
| 3 | Temperature Range (°C) | −20 to 320 |
| 4 | Accuracy | ±2% or ± 2 °C |
| 5 | Repeatability (°C) | ±1 |
| 6 | Response Time (ms) | 500 |

**Table 7**
Process parameters.

| Sl No | Parameter | Value |
|---|---|---|
| 1 | Cutting Velocity (m/min) | 65.87 |
| 2 | Depth of cut (mm) | 1 |
| 3 | Feed Rate (mm/rev) | 0.1 |
| 4 | Lubricant flow (ml/min) | 10 |
| 5 | Spindle speed (rpm) | 900 |

**Table 8**
Uncertainty estimates of the output parameters.

| Sl. No. | **Parameter** | **Uncertainty (±)** |
|---|---|---|
| 1 | Viscosity | 2% |
| 2 | Coefficient of friction | 3% |
| 3 | Cutting force | 3% |
| 4 | Cutting temperature | 2% |

$$\delta R = \left\{ \sum_{i=1}^{N} \left( \frac{\partial R}{\partial X_i} \delta X_i \right)^2 \right\}^{\frac{1}{2}} \quad (2)$$

## 5. Results and discussion

### 5.1. Viscosity of nanolubricant

The viscosity of the nanolubricant is increased with increase in concentration of nanoparticles. The variation is found to be linear for both silver and copper nanoparticle as shown in Fig. 4. Also the viscosity is higher than the viscosity of the base oil on addition of nanoparticles. The increase in viscosity presents an opportunity for the Cu/Ag added coconut oil nano-lubricant to be used for elevated temperature applications. Silver nanolubricant resulted with better augmentation of viscosity when compared to copper nanolubricant.

### 5.2. Coefficient of friction

The variation of CoF for both Cu and Ag nanoluricants of different concentrations is observed and the results are plotted in Fig. 5. Thus the CoF profile obtained can be dichotomized into "expedient region" and "non-expedient region". Expedient refers to the region in which CoF for the concentrations of nanolubricant is less than that of virgin coconut oil, and non-expedient refers to the region

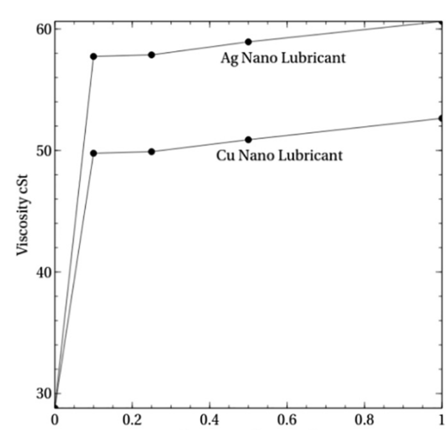


**Fig. 4.** Variation of Viscosity (cst) with Concentration.

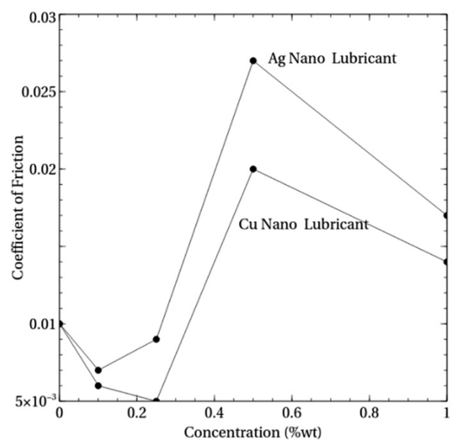


**Fig. 5.** Coefficient of Friction.

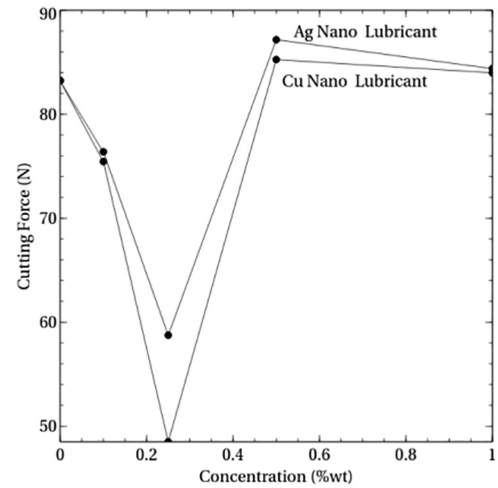


**Fig. 6.** Cutting force distribution.

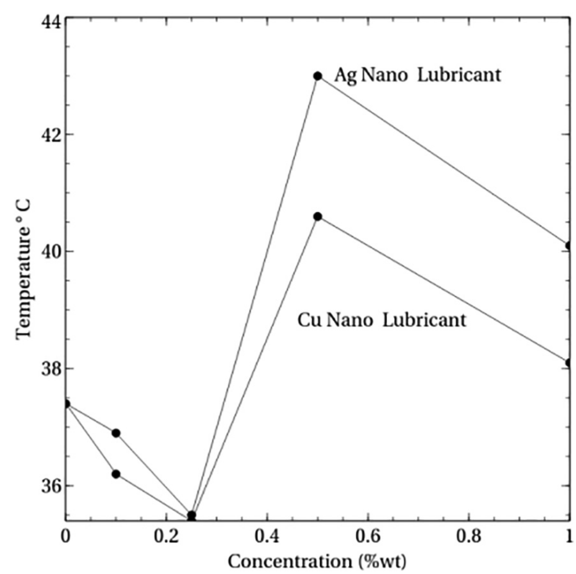


**Fig. 7.** Cutting temperature profile.

in which CoF for the concentrations of nanolubricant more than that of virgin coconut oil.

Within 0.25% concentration, the CoF is remarkably lesser than that of virgin coconut oil. The favourable results are found in this "expedient region". This result can be attributed by the action of nanoparticles as intermediate between the surfaces in contact, facilitating rolling and taking advantage of less value of friction as compared with sliding.

Beyond 0.25% the CoF is above virgin coconut oil indicating non-expedient region for both Ag and Cu nanolubricants. This trend is because the lubricant regime gradually shifts from being a predominantly rolling based regime to predominantly sliding based regime, causing the increase in friction. This indicates the presence of an optimal concentration of 0.25%. Furthermore, there is a decrease in CoF for concentrations greater than 0.5%, however, this is not significant as the CoF is well above the virgin coconut oil. The trend of CoF was similar for both Ag and Cu nanoparticles. Cu based nanolubricants had lower CoF in comparison to Ag nanolubricants.

The decrease in CoF for concentrations of more than 0.5% can be attributed to the increase in agglomeration of nanoparticles in solution, leading to deposition of nanoparticles on the of the metal surface. Surfactants can be used to reduce the agglomeration of nanoparticles, however, these surfactants are intrinsically non bio-degradable, so it is better to operate with the less concentration of nanoparticles. Thus the optimal concentration of nanoparticles in the lubricants is 0.25%.

In general, the lubricating mechanism is explained by the mending effect of the nanoparticles. This mechanism is more appropriate for soft metals such as silver, copper, lead etc. The dispersed nanoparticles form a tribo-layer between the surfaces in contact. This film separates the two surfaces and thus eliminates direct contact and reduces the shear strength of the tribo-pairs.

### 5.3. Cutting force and cutting temperature

The cutting force or tangential force acting on the single point cutting tool, while machining the workpiece using virgin coconut oil as the lubricant is 83.24 N. From the turning experiment conducted the cutting force and cutting temperature is minimum for 0.25% concentration and this is obtained for both copper and silver nanolubricants. There is an increase in cutting force and cutting temperature for the 0.5% concentration followed by a decreasing trend for 1% concentration as shown in Figs. 6 and 7.

The trend for the cutting forces and temperature when utilizing nanolubricants of different concentrations follows the trend for the coefficient of friction. Therefore the decrease in CoF (explained in the discussion under 4.2) can be attributed as the cause of the decrease in cutting forces. The above is corroborated by Merchant's force relations given by:

$$F_{FR} = F_C(Sin\alpha) + F_{TH}(Cos\alpha) \tag{3}$$

Where $F_{FR}$ refers to the frictional force and $F_C$, $\alpha$ and $F_{TH}$ refer to the cutting force, rake angle and the thrust force respectively. As the rake angle was the same for the entire experiment, therefore the change in force can be attributed to the change in friction. Therefore for cases in which the CoF is the minimum (trend and discussion in 4.2), the forces experienced during cutting are also the minimum. Comparing the Cu and Ag nanolubricants the cutting forces and cutting temperatures are low for Cu nanolubricants as compared to Ag nanolubricants. Thus, the coconut oil based lubricants are not harmful to the skilled personnel, who perform the machining process as coconut oils are edible, however, the mineral oil based lubricant vapours formed during the machining process are hazardous to the human.

## 6. Conclusions

The results of the tribological, rheological and machining tests, conducted on the nanolubricants synthesized by adding various concentrations of Cu, and Ag nanoparticles to coconut oil, help in drawing the following conclusions:

- The optimal concentration of both Cu as well as Ag nanoparticles was found to be 0.25%.
- The addition of Cu or Ag nanoparticles decreased the CoF as compared to the base oil (virgin coconut oil) for the optimum concentration.
- The viscosity of the nanofluids was found to be higher than the base coconut oil.
- The viscosity of the nanofluids increased with the increase in the concentration of the nanoparticles.
- The cutting forces and temperatures decreased similar to the trend in the CoF for the nanofluids.
- The CoF, cutting force, and cutting temperature are all comparatively less for Cu based nanolubricant than Ag based nanolubricant at all concentrations.

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