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# Enhancement of thermo-physical and lubricating properties of SiC nanolubricants for machining operation

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**Abstract**

Vegetable oils have been adjudged a suitable replacement for conventional cutting fluid in metal cutting process because of its biodegradability, less toxic, high lubricity and environmental friendly. However, efficient performance of vegetable oil has been limited when machining at higher cutting speed or elevated temperature as the cutting fluid evaporates when in contact with cutting tools already heated to high cutting temperature. Thus, nanoparticles are introduced into base lubricating oils to improve their thermal and lubricating properties. The present work is to investigate the thermal and lubricating properties of coconut oil-based Silicon Carbide (SiC) nanofluid at varying concentration of 0.35wt.%, 0.7wt.% and 1.05wt.%. Thermal conductivity and viscosity of the nanofluid was measured with the aid of KD2 Pro thermal analyser and LVDV-III Rheometer respectively while the four-ball wear and friction tester will be used to measure anti-wear property of the nanofluid. Thermal conductivity and viscosity of nanofluid improved with increase of nanoparticle concentration but decrease with increase of temperature. The highest ratio of enhancement of thermal conductivity of is 1.038 while increase of viscosity of nanofluid at temperatures of 30°C and 70°C are 1.277 and 1.397 respectively. The nanofluid was deficient in performance of tribological properties.



*Keywords:* vegetable oil, nanofluid, concentration, enhancement, thermal conductivity, properties

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## 1. Introduction

Silicon carbide is a ceramic type nanoparticle with diverse applications due to its exclusive properties which includes high strength and hardness, chemical and thermal stability, high melting point, oxidation resistance, etc. They are used in high temperature electronic devices as well as abrasion and cutting applications [1] in addition to its ability of improved resistance to oxidation when used as coating material [2]. Vegetable oil-based lubricants has been adopted as suitable substitute to mineral oils as machining lubricants due to its excellent lubricity, biodegradability, low volatility and good viscosity-temperature characteristics [3-5]. Vegetable oils have indicated outstanding performance over mineral oils in forming and cutting operations due to their desired lubricity, friction reduction and anti-wear properties. They possess excellent boundary layer lubricants that enhance better interaction between lubricated contacting surfaces because of the high polarity of the base oils [3, 4, 6-10]. However, their performance is restricted by poor oxidative and thermal stability as they become less effective at extreme loads [4, 5, 11, 12]. These challenges can be improved through modification of the base oil with addition of additives and chemical structure modification of the base oil [13-16]. Nanoparticle inclusion in vegetable oils is one of the ways in which the poor properties of base fluid are improved. Nanofluids are colloids of nanomaterials with higher thermal conductivity usually dispersed in base fluids such as water, oil, ethyl-glycol etc to enhance the heat transfer rates in addition to modifying the properties of the base fluid [17-20]. Reports from literature reveals that thermo-physical and tribological properties of base fluids are enhanced with nanoparticle as additives [21-26]. The thermal conductivity and viscosity of nanofluids have been evaluated by several researchers. Heat transfer properties of water based silicon carbide (SiC) nanofluids was investigated and found that thermal conductivity and viscosity of the nanofluid increases with increases of particle concentration [27]. Manna et [28] evaluated the thermal enhancement of water based SiC nanofluid at various concentration range of to 1% vol. fraction and observed significant increase of 12% of thermal conductivity enhancement at 0.1 % volume fraction. Thermal conductivity of mono-ethylglycol and water-based Copper oxide nanofluids were evaluated by Khedkar et al. [29] and observed that volume concentration and sonication time play significant role in the thermal conductivity enhancement under same condition. Volume fraction was reported to be responsible for the increase of thermal conductivity during the investigation of SiC in deionized water nanofluid [30]. Yu et al. [31] reported that thermal conductivity of nanofluid suspension with SiC nanowires increased significantly with increased volume fraction and that further investigation reveals that thermal conductivity enhancements is not temperature dependent but volume fractions.

The last decade has witnessed the application of nanofluid in metal cutting process due to its efficient cooling and lubrication of nano-enhanced cutting fluids. In 2010, the effects of cutting fluid with nanoparticles inclusion was evaluated by Liao et al [32] during the grinding of titanium alloy. They reported that use of nanocutting fluid caused less loading of the wheel and improve ground surface as the lotus effect of the nanocutting fluid lower grinding forces and coefficient of friction. Amrita et al [33] in 2013 evaluated the performance of mist application of nanographite-soluble oil in comparison with dry cutting, flood lubrication and mist application of pure soluble oil in the turning of AISI 104steel. They reported that cutting force was reduced by 84.02% and 77.76% in comparison of dry and flood cutting conditions. Yigit et al [34] observed that there was improvement of surface roughness under all cutting speed during the milling of Aluminium 7075 using Al2O3 nanocoolant to reduce adhesion of material onto the machined workpiece surface. Prasad and Srikant [35] reported that increase of concentration of nanographite particles suspended in water soluble oil from 0.1wt.% to 0.5wt.% influence reduction of cutting force, cutting temperature, tool wear and enhance the surface roughness. Performance of vegetable oil based nanofluid in comparison with mineral oil and conventional cutting fluid have been investigated in metal cutting process. Nam et al [36] reported that vegetable oil based nanofluid at 2% volume concentration indicated superior performance over paraffin based nanofluid in the micro-drilling of Aluminium 6061. Coconut oil based nanofluid indicated superior performance over engine lubricating oil (SAE-40) for all the volume fraction considered in turning operation of AISI 104steel as evaluated by Krishna et al [37]. Increase of volume fraction of nanoparticle inclusion in vegetable oils was reported by Vasu and Pradeep [38] to improve surface roughness and reduce tool wear when compared to pure vegetable oil and dry machining. Su et al [39] reported that at same volume concentration, vegetable oil based nanofluid indicated superior performance over ester oil based nanofluid in the reduction of cutting force and temperature, and that lower cutting force and temperature was further enhanced with increased volume fraction. However, few researchers who applied nanofluid in machining processes investigated the thermo-physical and tribological properties of nanofluids [26, 37, 40]. There is need to investigate the properties of nanofluids to determine their suitability for machining process. In this research, a vegetable oil (coconut oil) with Silicon Carbide nanoparticles inclusion at varying volume concentration will be evaluated to determine suitability of their thermos-physical and lubricating properties as a machining lubricant. Their behavior under varying temperature and volume concentration as it affects their thermal conductivity, viscosity and friction properties will be investigated.

**Nomenclature**

| | |
|---|---|
| COF | coefficient of friction |
| SiC | Silicon carbide |
| WSD | wear scar diameter |
| $K_r$ | thermal conductivity enhancement ratio |
| $k_{NL}$ | thermal conductivity of nanolubricant |
| $k_{bf}$ | thermal conductivity of base fluid |

## 2.0 Materials and methods

### *2.1 Materials and nanofluid preparation*

Silicon carbide nanoparticles at 130nm and coconut oil are used in formulation of the nanofluids at varying concentration levels of 0.35, 0.70 and 1.05 wt.%. The two-step method of nanofluid preparation as used by Su et al. [41] was adopted in the dispersion of silicon carbide nanoparticles into coconut oil and manually stirred for few minutes before subjecting it to the silverson multifunctional L5 series for homogeneous of nanofluids for 1hr 40mins at rotational speed of 3,200 rpm. Silverson L5M mixer is found suitable for mixing, emulsifying, dissolving, disintegration, etc of particles within the base fluids.

### *2.2.1 Thermo-physical Properties*

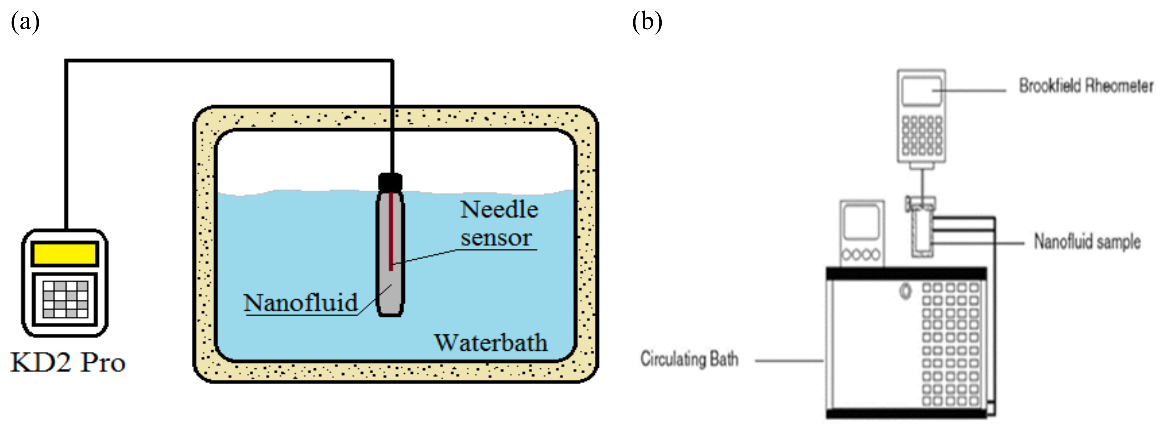


Fig. 1. (a) KD2 pro thermal property analyser (b) LVDV III Brookfield viscometer for measuring thermal conductivity and viscosity respectively.

### *2.2.2 Thermal conductivity measurement*

KD2 pro thermal property analyser apparatus which is in conformity with both standards of ASTM D5334 and IEE 442- 1981 was employed to measure thermal conductivity of the base fluid and the formulated nanofluids. The apparatus consists of a handheld (power control) and sensor for measuring the thermal conductivity of the fluid in a controlled constant temperature environment using a water bath within accuracy of 0.1°C. Schematic diagram of the thermal property analyser is shown in Figure 1a. The needle sensor (KS-1) is usually calibrated with determination of thermal conductivity of glycerine with ±5% deviation. Nanofluid samples are placed in a bottle container containing about 30ml and the sensor inserted through the orifice at the top of the bottle cover which is designed for perfect fit by the needle. The sample with the incorporated sensor is lowered into the water bath which maintain the set temperature. Five sets of readings were taken at interval of 15mins for each sample and the average value considered at that temperature. Temperature range of 30°C to 70°C was considered for the investigation. Thermal conductivity enhancement ratio is the ratio of nanolubricant to the thermal conductivity of base fluid. It can be expressed mathematically as below:

$$k_r = \frac{k_{NL}}{k_{bf}} \quad (1)$$

### *2.2.3 Viscosity measurement*

Viscosity of fluids are measured with the aid of Brookfield LVDV III Ultra Rheometer incorporated with a circulating water bath which is capable of measuring viscosity in the range of 1 to 6,000,000 mPa.s. A Rheocal programme is used in acquiring the data at specified temperature and torque for each measurement. In this study, viscosity of sample is measured for a temperature range of 30°C to 70°C. 16ml of sample to be evaluated is placed in the cylinder jacket and the entire unit is attached to the rheometer after the sample is heated with a sensor to the specified test temperature. Minimum of 3 experimental trials for each test temperature are taken with an average value considered for analysis. Schematic diagram of the apparatus is shown in Figure 1b.

### *2.3 Tribology test*

Tribological behaviour of coconut oil and nanofluids of varying concentration are evaluated for wear and friction using the four-ball wear test according to ASTM D4172-94 method. The apparatus is used to determine wear preventive properties (WP), extreme pressure properties (EP) and friction behaviour of the base fluid and nanofluids. In this study, wear preventive properties and coefficient of friction of the lubricants are evaluated using steel ball (AISI 52100) of diameter 12.7 mm and a hardness value of 62HRC. Three (3) steel balls are submerged in 10ml of lubricant in a collet pot and clamped under a rotating spindle used to hold the upper steel ball pressed against the steel balls firmly held together immersed in the lubricant under test. The test load, time, temperature and speed of rotation selected in accordance with standard test schedule for this study are 392 N, 60mins, 75°C and 1200rpm respectively. The wear scar diameter (WSD) was then calculated from the average scar diameter and coefficient of friction (COF) determined. Lower WSD and COF indicates better wear preventive properties and friction wear resistance.

Table 1. Properties of coconut oil.

| Basic properties of coconut oil | Column A (*t*) |
|---|---|
| Density at 30°C | 0.9246 g/cm$^3$ |
| Flash point | 290°C |
| Pour point | 21°C |
| Colour | Colourless at 30°C and above |

## 3.0 Results and discussion

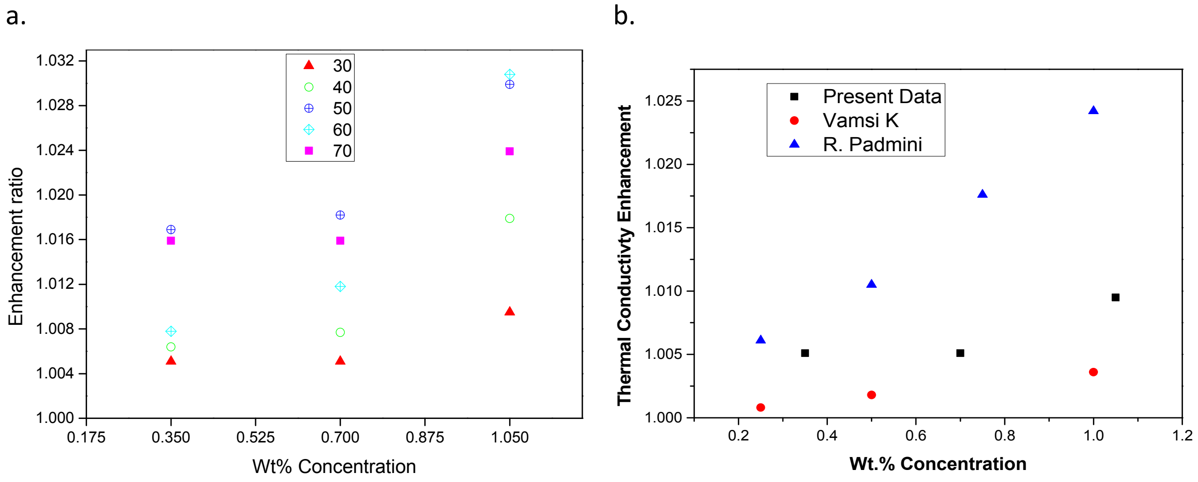


Fig. 2. (a) thermal conductivity enhancement with increase of particle concentration (b) Comparison of present data of thermal conductivity enhancement with previous research at 30°C

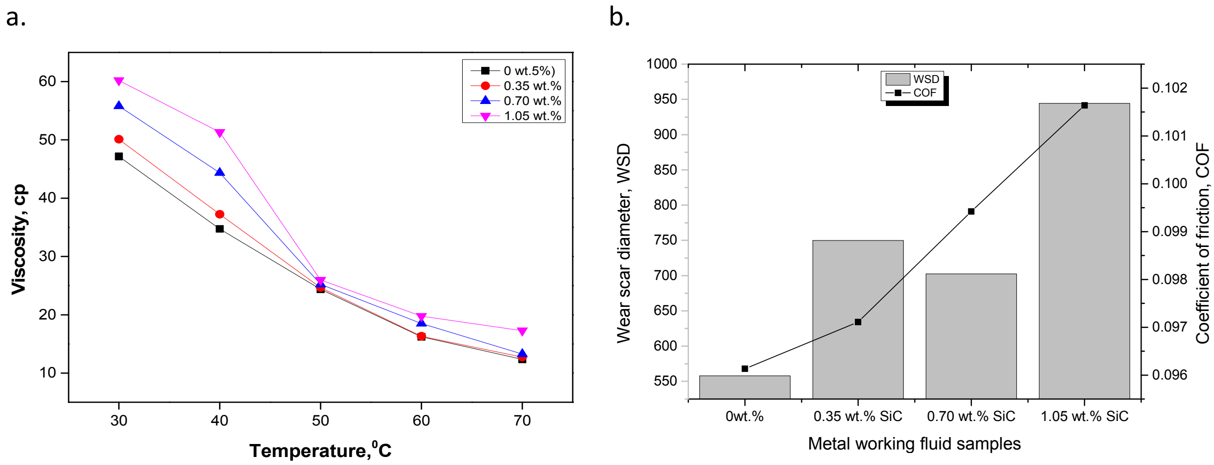


Fig. 3. **(a)** variation of viscosity of lubricants under influence of temperature **(b)** tribological behaviour of lubricants using WSD and COF

### *3.1 Thermal conductivity Enhancement*

From Figure 2a, increase of concentration is responsible for enhancement of thermal conductivity of vegetable oil based SiC nanofluid. The highest enhancement occurred at a temperature of 60°C and concentration of 1.05 wt.%. The revelation from this study agrees with previous research by Krishna et al [37] and Padmini et al [40] when they evaluated thermal conductivity enhancement of coconut oil with nanoboric and molybdenum sulphide nanoparticles at 30°C as shown in Figure 2b. They observed that at a particular temperature, thermal conductivity of nanofluid is enhanced with increase of nanoparticle concentration. As temperature increases, there is higher oxidative degradation which impacts negatively on the thermal conductivity of lubricants. This causes decrease in thermal conductivity with increasing temperature as seen in Figure 1a, where value of thermal conductivity enhancement at 50°C is higher than that at 70°C.

### *3.2 Viscosity of nanofluid*

Viscosity of nanofluid under consideration found to decrease with increase of temperature and increases with increase of particle concentration as shown in Figure 3a**.** The weakened intermolecular forces of lubricant with increase of temperature as observed by Padmini et al [40] is enhanced with nanoparticle inclusion to vegetable oils. Thus, the ability of nanofluid to form lubricating film between contacting surfaces is strengthened with increase nanoparticle inclusion in the base oil and heat dissipation also improves substantially as the viscous nature of the fluid can withstand higher temperature unlike the pure base oil that disintegrate easily under elevated temperature.

### *3.3 Tribological properties*

Silicon carbide nanofluid exhibited poor wear preventive characteristics and coefficient of friction under test condition of four ball test. The WSD and COF results indicated higher value above the base oil. This could be due to the larger particle size of the particles as reports from literature indicates that larger particle size deteriorates machined surface [42] and smaller particle size enhance better lubricating properties [41, 43]. However, increase of concentration affects the wear scar diameter (WSD) as can be seen in Figure 3b where the mid-level concentration shows a reduced wear scar diameter than the lowest concentration level.

## 4.0 Conclusion

This current work studied the enhancement of thermos-physical and lubricating properties of the vegetable oil with silicon carbide nanoparticles inclusion. Three level of nanolubricant concentrations were prepared with dispersion of 0.35, 0.70 and 1.05wt.% silicon carbide nanoparticles and their properties evaluated. Thermal conductivity of nanolubricants was observed to decrease with increase temperature but increases with increased concentration level. Viscosity of vegetable oil based nanolubricants increases with increase of volume concentration and decrease with increase of temperature. The highest thermal conductivity enhancement ratio was observed to be 1.038. Increase of concentration increase the viscous nature of the fluid under temperature variation thereby strengthening the ability of vegetable oil based nanolubricant to form lubricating film between contacting surfaces that aid friction reduction and faster dissipation of heat when compared with pure vegetable oil that disintegrate under higher temperature. The viscosity of nanolubricants increased with increase of particle concentration across temperature range. For instance, at temperature of 30°C and 70°C, viscosity increase at 1.05wt.% over the base coconut oil is found to be 1.277 and 1.397 respectively. The silicon carbide nanofluid indicated poor wear preventive properties as measured by WSD and friction reduction by COF. These properties exhibited deficient performance compared to the base fluid as indicated in the Figure 2d. The findings of this study reveal that increase of concentration enhance the thermal conductivity and viscosity of the vegetable oil which is in conformity with findings from literatures that increase of particle concentration is a key factor for enhancement of thermal conductivity and viscosity of nanolubricants

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