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Research Article

Experimental evaluation of thermal conductivity and thermogravimetric analysis of Jatropha Oil-based titanium nano-cutting fluid

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ABSTRACT

Nanoparticles have several potential applications due to their advantageous properties, which have been identified as the main driving force behind nanofluid research. In this study, Jatropha Oil, extracted from the Jatropha plant seeds, was characterized by investigating the physico-chemical properties. Jatropha Oil was used as the base fluid for nanofluid formulation by enhancing it with titanium oxide (TiO_2) at 0.1%, 0.15%, and 0.2% volume concentrations. The formulated nanofluid was characterized by evaluating the thermal conductivity and degradation profile (thermogravimetric analysis). The findings revealed that the locally sourced Jatropha Oil has 0.916 Specific gravity, 7.85 mg/100g Acid value, 189.33 mgKOH/g saponification value, 219^0C flash point, -7°C pour point, 5.09 pH, 113.4 g/100g of KOH iodine value, and 32 mm^2/s viscosity at room temperature. It was also found that the nanoparticle cutting fluid enhanced with TiO_2 had a better thermal conductivity at 0.15% concentration than the pure base fluid and other enhanced nanofluid modified with 0.1 and 0.2% TiO_2 concentration. In addition, the thermogravimetric analysis (TGA) and Differential ThermoGravimetric (DTG) results revealed that the pure Jatropha Oil degraded fastest with a broad peak and a more comprehensive degradation temperature range (226.12°- 449.69°C) compared with modified nanofluid with a smaller degradation temperature range (229.11°-438.33°C). Therefore, it was concluded that the nanoparticle cutting fluid modified with TiO_2 (0.15% concentration) can be adopted as cutting fluid for machining operations.

1. Introduction

In machining, achieving purposeful efficiency and accuracy is impossible without cutting fluids [1]. It is, therefore, safe to posit that the usefulness of cutting fluids in machining operations cannot be overstated. Though it has many functions, the function of a lubricant is often considered primary. As lubricants, cutting fluids reduces the resistance to the cutting tool as it moves across the workpiece. Many researchers have demonstrated that cutting tools last longer and suffer a low wear rate when lubrication is used during machining. Okokpujie et al. [2] and Khajehzadeh et al. [3] decreased the cutting forces and friction and achieved a relative reduction in the tool wear using TiO2 nanolubricants. Furthermore, Talib et al.[4] developed Modified Jatropha Oil, an enhancement of Jatropha Oil by hBN and MoS2, which has been demonstrated to improve tool life and reduce wear. Another factor that contributes to good performance characteristics is the chip evacuation. The chip evacuation process, aided by cutting fluids, ensures the machining process goes off without a hitch by keeping chips from accumulating in the cutting tool and halting. It is a shared knowledge that the chip thickness ratio significantly impacts chip evacuation performance machining processes. Kannan et al. [5] formulated a nanofluid by dispersing nano-hexagonal boron nitride

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(nhBN) in jatropha oil. They applied it in the MQL machining of the Nimonic 75 superalloy. The result showed significant improvements in chip thickness ratio, amongst other factors, compared to dry machining. Cooling the workpiece and the tool is another crucial function of cutting fluids [6]. Cutting fluids helps avoid thermal damage to the workpiece and also helps maintain dimensional accuracy by removing the heat generated during machining [7]. The thermal conductivity of Jatropha Oil has been studied, and the result gives a good prospect for enhancement opportunities through the addition of nanoparticles, particularly for the CuO and MWCNTs[8]–[11].

When selecting cutting fluids for machining applications, priority is often given to those with the prospect of the least environmental and health impacts. Since conventional cutting fluids contain mineral oils and other harmful chemical additives, the possibility of soil and water pollution due to inappropriate disposal raises environmental sustainability concerns. [12]. More so, conventional machining (with cutting fluids) creates mist and aerosols, which, when inhaled, have adverse effects on the human respiratory system. On the other hand, nano-lubricants provide better lubrication and cooling, saving time and energy and, therefore, cost. They are very environmentally friendly. This prompted the earlier work on nanoparticle implementation in base oil during machining processes [13].

Over the last few years, there has been significant advancement in nano-based cutting fluids technology following the advancement in nanotechnology, which has attracted the attention of many stakeholders. These fluids contain nanometer-sized particles called nanoparticles. [14] with a typical size range from 0-100 nm. Nanoparticles have several potential applications [15] amongst which is application in the enhancement of the thermal properties of fluids. Peker *et al*. [16] used Al_2O_3 and CuO nano-particles to increase the heat transfer coefficient of a heat transfer fluid and further derive the optimal conditions.

Similarly, Shokoohi and Shekarian [17] reviewed the applications of Nanofluids in the machining process and reported a general improvement in grinding, turning-milling, and drilling operations. The research further posited that a proper selection of nanoparticle type, size, concentration, and base fluid could achieve the right lubrication traits and physical characteristics that could improve thermal conductivity, reduce the coefficient of friction, cutting forces and temperatures, and increase viscosity, reduce the cutting tool wear. Darabi *et al*. [18] demonstrated the use of nano-particles (MWCNT) in extending the frontiers of knowledge in sensing muscle and joint motions.

In line with the growing concerns about climate change and campaigns/calls for carbon footprint reduction through the promotion of sustainable practices (such as green machining[[19]), the application of vegetable oil as a base oil in nanofluids has been getting the deserved attention. Research has been published on the technological and ecological merits of vegetable oil-based nano-cutting fluids. Experience from machining with nanofluids formulated from combinations of various nano-particles and vegetable oil is reported in [20]. Nano-cutting fluids formulated by suspending graphene oxide (GO) separately, molybdenum disulfide (MoS_2), titanium dioxide (TiO_2), and aluminium oxide (Al_2O_3) In vegetable oil, all showed to reduce friction and heat generation during machining and improve surface roughness and tool wear[21]. Similarly, Nwoguh *et al.*, [22] achieved a significant improvement in the thermal conductivity of high oleic soybean vegetable oil (HOSO) using each of Al_2O_3,MoS_2, and TiO_2 nanoparticles. From the review above, it can be adduced that evaluating the thermal conductivity and thermogravimetric properties of formulated nano-cutting fluid is vital to a successful application.

Therefore, this study investigates the thermal conductivity and thermogravimetric analysis of Jatropha Oil-based titanium nano-cutting fluid to understand the extent of its property enhancement and guide the decision on application in the machining of hard-to-cut material successfully.

2. Materials and Methods

2.1 Materials

The materials used in this study are presented in Table 1.

Table 1. List of Materials

Material and model	Sources
Jatropha Oil	[23],[24].
Titanium dioxide nanoparticles	[23],[24]
Viscometer (Series300) Afora Cannon Fenke	
Litmus paper	
Pycnometer (flash point tester)	
Ultrasonic cell crusher (Model OLT – UCC650Y).	Xiamen Ollital Technology Company Ltd, China
DTC 204 Thermal conductivity	
Thermogravimetric analyzer TGA 1150	Bonnin Instrument Technology LTD

2.2 Methods

2.2.1 Characterization of Jatropha Oil

The Jatropha Oil used to formulate the nanofluids was characterized to determine the properties before enhancement with the nanoparticles. This involves investigating the physicochemical properties -i.e., density, flash point, pH, acidity, and viscosity- following the ASTM D445 standards. The density was obtained at room temperature using a 10ml pycnometer; the flash point was determined with the aid of a flash point tester; the acidity of the oil was determined using litmus test paper, and the viscosity was obtained at a temperature of 40°C using Afora Cannon Fenke Viscometer (Series300).

2.2.2 Formulation of Nano-cutting fluid

Three samples of Nano-Cutting Fluids (NCF) were formulated by dispersing pre-determined volume concentrations (0.1%, 0.15%, and 0.2%) of TiO_2 nanoparticles into 100 ml of Jatropha base oil. Homogeneous dispersion was ensured by stirring and ultrasonication in an ultrasonic cell crusher (Model OLT—UCC650Y) at a 30 to 70% ultrasonic power range of reaction time and 2-second oscillating on/off generator parameters.

2.2.3 Characterisation of Nano-cutting fluid (*NCF*)

a. Thermal conductivity measurement

Thermal conductivity of the jatropha (base oil) and samples of NCF were determined using the DTC 204 thermal conductivity testing machine (Figure. 1) following ASTM D2717 standard.

Figure 1. Thermal Conductivity Test kits for Fluids

b. Thermogravimetric analysis

The thermogravimetric analysis (TGA) was conducted to reveal the degradation characteristics of the Jatropha Oil and the three (3) nanofluid samples at elevated temperatures using a Thermogravimetric analyzer (Figure 2). The procedure saw 20 mg of each nanofluid sample heated in an oxygen-rich environment- at 15°C/min heating rate and 50ml/min airflow rate- to about 600°C. This is termed gradually increasing programmed heating process [25].

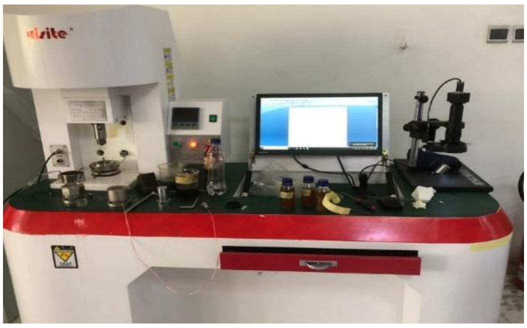

Figure 2. TGA 1150 – Thermogravimetric Analyzer

TGA and DTG graphs evaluated the thermal stability of the base oil and nanofluids and the decomposition and mass loss extracted to assess the thermal degradation.

3. Results and Discussions

3.1 Physicochemical Properties of Jatropha Oil

The physicochemical properties of the Jatropha Oil are presented in Table 2. Based on the results, it can be observed that the specific gravity of Jatropha Oil is 0.916, which confirms that it is lighter than water and also within the standard range of 0.76 - 0.92 [26]. Also, the flash point of the Jatropha Oil is 219°C, which falls within the range and is considered safe for cutting fluid or lubricant use. This result also agrees with the findings of Huang *et al*. [27] reported that Jatropha Oils have high flash points that are considered an enhancement against fire risk. In addition, the pH value of the base oil is 5.09, which indicates that it is acidic, which agrees with the earlier work by Joshi [28] who reported a pH of 6.5 to 7.4. Huang *et al*. [27] have reported that the oil's acidity is the reference point for monitoring oil conditions during use. Also, the viscosity of the Jatropha Oil used was $32mm^3/s$, and this agrees with the findings in [29], while the saponification value (SAP) of the oil was 189.33 mg KOH/g. Agu *et al*. [30] have revealed that an SAP value of greater than 100 indicates the existence of unsaturated fatty acids with characteristics of foaming ability. In addition, The Iodine value of 113.4 mg/g of oil obtained in this research is the same for a Jatropha Oil sample sourced from India, as reported [31]. This reflects the degree of unsaturation of fats and oil. A higher Iodine value reflects a higher saturation of fats and oils [32]. The values obtained for other parameters tested are also within an acceptable range, confirming Jatropha Oil's suitability for cutting fluid formulation.

Table 2. Physiochemical Properties of Jatropha Oil

S/N	Parameter	Value
1.	Specific gravity	0.916
2.	Acid value (mg/100g)	7.85
3.	Free Fatty Acid (mg/100g)	3.93
4	Saponification value (mgKOH/g)	189.33
5	Flashpoint (^{0}C)	219
6.	Pour point (^{0}C)	-7
7.	Moisture content (%)	0.89
8.	pH value	5.09
9.	Iodine value g/100g of KOH	113.4
10.	Viscosity@ 25^{0}C (mm^2/s)	32

3.2 Thermal conductivity of the nano-cutting fluid

The effect of dispersed nano-additives on thermal conductivity on base fluids has been a fundamental research interest. Titanium oxide was dispersed into the Jatropha Oil using varying volume concentrations of 0.1, 0.15, and 0.2%. The thermal conductivity of nano-cutting fluids was evaluated at 50°C, and the results are presented in Table 3 and Fig. 3. From the table of results for thermal conductivity, the titanium oxide at 0.15% volume concentration exhibited the best thermal conductivity enhancement. The least enhancement was observed with titanium oxide at 0.1% volume concentration. However, Figure 1 indicates that the thermal conductivity of the base fluid increases with the increase of nano-additives up to the 2nd level of dispersion. However, there was a decrease in thermal conductivity with a further rise in titanium oxide dispersion in the Jatropha Oil. The decline can be attributed to the agglomeration of particles within the base fluid, thereby impeding the increase in performance. However, their performance at the concentration level was better than that of the pure base fluid, and the first-level concentration was lower than that of the second. Referencing the base Jatropha Oil thermal conductivity, the enhancement infused with adding nano-additives was observed to be 2.63%, 20.62%, and 8.62%, respectively, for 0.1%, 0.15%, and 0.2% volume concentrations. The result indicated that adding nano-additives to base fluid enhances thermal conductivity.

Table 3. Thermal conductivity of nano-cutting fluids with varying concentration

Tested Lubricants	Thermal conductivity, k (W/m°C) @ 50°C	Enhancement (%)
JAT	0.383	-
0.1%TiO_2	0.390	2.63
0.15%TiO_2	0.462	20.62
0.2%TiO_2	0.416	8.62

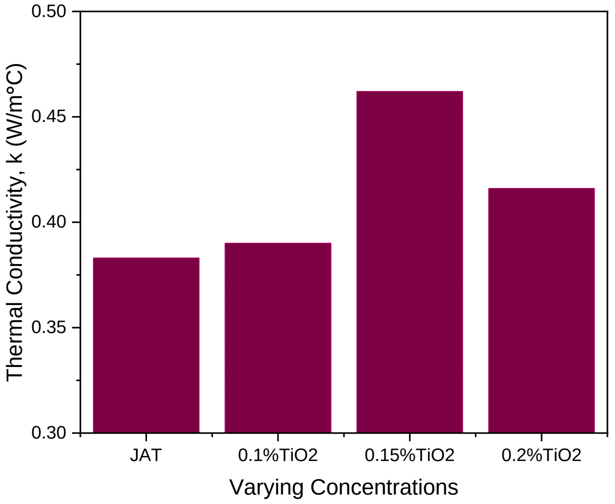

Figure 3. Thermal Conductivity Enhancement of nano-cutting fluids dispersed with varying concentrations of TiO_2

3.2 Thermogravimetric analysis and Differential Thermogravimetric

The TGA and DTG thermograms of pure Jatropha Oil and oil-containing TiO_2 nanoparticles are presented in Figures 4 and 5. Data extracted from the thermograms are presented in Table 3. Figures 4 and 5 show that the thermal decomposition profiles for the base oil and that modified with TiO_2 have similar characteristics, displaying two thermal decomposition steps. The first step is between 30 to 180°C. The peak in this region could be attributed to the evaporation of water and decomposition of lower molecular weight polyunsaturated fatty acids. The second decomposition is seen to begin at 220° and end at 420°C. During heating, the triglycerides produce volatile compounds, which are removed by the vapour generated during heating. These products are shorter fatty acid chains (dimers, trimers, tetramers) formed primarily by the thermo-chemical reactions of unsaturated fatty acids, such as linoleic acid. The second step is between 220° and 420°C, corresponding to the decomposition of monounsaturated and unsaturated fatty acids, such as oleic and palmitic acids. During this reaction, the double bonds are broken, causing the triglyceride molecules in the oils to become more saturated [33].

The data presented in Table 3 revealed the temperature at which the degradation begins. The onset temperature is also shown. The onset temperature (T_{onset}) indicates that the TiO_2-modified oil started to degrade at a higher temperature (229.11°C) relative to the base oil samples. On the other hand, this sample had the shortest degradation temperature range of 229.11°C-438.33°C and residue (15.53%), a disadvantage in thermo-chemical reactions. However, high T_{onset} is an indication of improved thermal stability when compared to the base oil samples. This implies that modifying the oil with TiO_2

prevented the easy breakage of the double bonds in the triglycerides during heating, thereby rendering the sample more thermally stable [24]. In addition, pure Jatropha Oil is degraded fastest, with a broad peak and a more comprehensive degradation temperature range (226.12-449.69°C). This may indicate that the unmodified oil has a broader molecular weight distribution than the modified ones [34]. Although this oil presented the highest degradation peak temperature (T_p) of 330.40°C, the onset temperature (228.79°C) and residue (13.27%) show that its performance in thermo-chemical environments alongside other samples may be low. It, therefore, may not be suitable for use as a lubricant in high-temperature environments. The temperature at 50% degradation shows no verifiable trend. This may mean that all the samples will degrade to the same level at temperatures of 325° to 326°C.

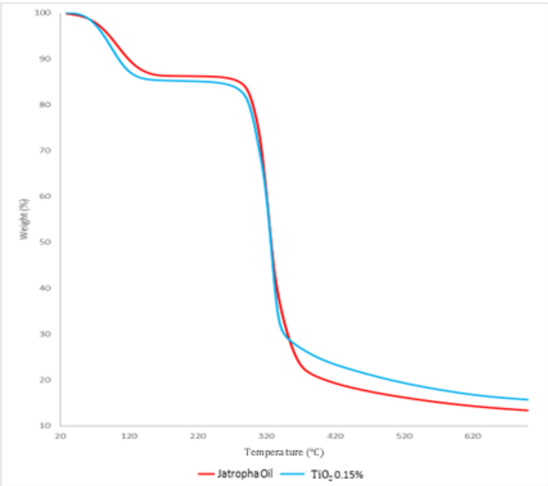

Figure 4. TGA thermograms of pure Jatropha Oil containing TiO_2 nanoparticles

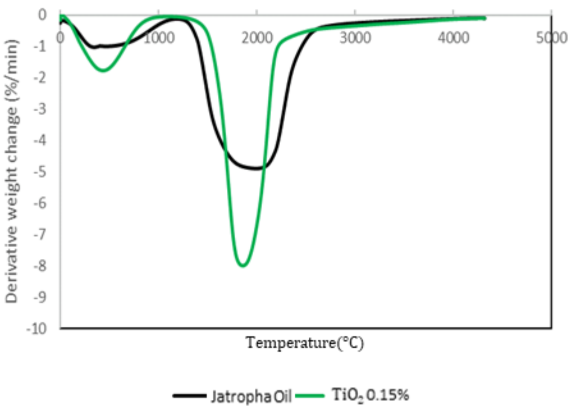

Figure 5. DTG thermograms of pure Jatropha Oil containing TiO_2 nanoparticles.

Table 4. Data extracted from the thermograms

Sample	T_{onset} (°C)	$T_{50\%}$ (°C)	T_p (°C)	Degradation Temperature Range (°C)	Residue (%)
Pure oil	228.79	326.58	330.40	226.12-449.69	13.27
Oil + TiO_2	224.7	325.80	317.06	229.11-438.33	15.53

4. Conclusion

This study investigated the thermal conductivity and thermogravimetric analysis of Jatropha-based titanium nano-cutting fluid at different concentrations using Jatropha Oil as base oil since it is biodegradable and less hazardous than conventional mineral oil. Based on the findings of this study, the following conclusions can be drawn;

i. The physiochemical properties of the Jatropha Oil are within an acceptable range, which confirms its suitability for cutting fluid formulation. However, the higher Iodine value obtained reflects a higher saturation of fats and oils.

ii. The addition of nano-additives TiO_2 to base fluid enhances thermal conductivity. However, the thermal conductivity at the second concentration level (0.15% TiO_2) was better than that of the pure base fluid, the first concentration level (0.1% TiO_2), and the third concentration level (0.2% TiO_2).

iii. Pure Jatropha Oil degraded fastest, with a broad peak and a more comprehensive degradation temperature range (226.12°−449.69°C), compared with modified nanofluid, which had a smaller degradation temperature range (229.11°C− 438.33°C). Hence, the unmodified oil has a broader molecular weight distribution than the modified ones. However, adjusting the base oil with TiO_2 improves the thermal stability of the nanofluid.

iv. Generally, the nano-particle cutting fluid modified with TiO_2 (0.15% concentration) can be adopted as cutting fluid for machining operation

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Author contributions

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Conflict of Interest

The authors declare that they have no conflict of interest.

References

[1] M. Grine, M. Slamani, M. Arslane, M. Rokbi, and J.-F. Chatelain, 'Investigation of the machining behavior of unidirectional Alfa (Stipa tenacissima L.)/epoxy composite material', *Int. J. Adv. Manuf. Technol.*, vol. 128, no. 7–8, pp. 3183–3196, 2023.

[2] I. P. Okokpujie and L. K. Tartibu, 'Comparative Study of the Effect of Dry, Mineral Oil, and TiO 2 Nano-Lubricant on Tool Wear During Face-Milling Machining of Ti-6al-4v-Eli Using Carbide Tool Insert.', *Math. Model. Eng. Probl.*, vol. 9, no. 2, 2022.

[3] M. Khajehzadeh, J. Moradpour, and M. R. Razfar, 'Influence of nanolubricant particles' size on flank wear in hard turning', *Mater. Manuf. Process.*, vol. 34, no. 5, pp. 494–501, 2019.

[4] N. Talib *et al.*, 'The performance of modified Jatropha-based nanofluid during turning process', in *AIP Conference Proceedings*, 2021, vol. 2339, no. 1.

[5] V. Kannan, 'Experimental Study of an Eco-friendly Turning Process of Nimonic 75 Combining Minimum Quantity Lubrication and Hexagonal Boron Nitride-Enhanced Neem and Jatropha Oil Nanofluids', *J. Inst. Eng. Ser. C*, vol. 103, no. 4, pp. 785 – 812, 2022.

[6] R. Prakash, M. R. Ravindra, and M. Manjunatha, 'Enhanced heat transfer with nanofluid media: principles, methods, and applications in dairy industry', *Nanotechnol. Appl. Dairy Sci.*, pp. 83–122, 2019.

[7] N. Khanna, F. Pusavec, C. Agrawal, and G. M. Krolczyk, 'Measurement and evaluation of hole attributes for drilling CFRP composites using an indigenously developed cryogenic machining facility', *Measurement*, vol. 154, p. 107504, 2020.

[8] S. Gobane, T. Dama, N. Hasan, and E. Yanmaz, 'Characterization of Copper Oxide--Jatropha Oil Nanofluid as a Secondary Refrigerant', *J. Nanomater.*, vol. 2023, no. 1, p. 7612959, 2023.

[9] W. U. Rehman *et al.*, 'Synthesis, characterization, stability and thermal conductivity of multi-walled carbon nanotubes (MWCNTs) and eco-friendly jatropha seed oil based nanofluid: An experimental investigation and modeling approach', *J. Mol. Liq.*, vol. 293, p. 111534, 2019.

[10] V. Shalimba and V. Sopko, 'Jatropha Oil with Iron Nanoparticules Application in Drilling Process', *Acta Polytech.*, vol. 59, no. 3, pp. 299–304, 2019.

[11] A. R. Amin, A. Ali, and H. M. Ali, 'Application of nanofluids for machining processes: a comprehensive review', *Nanomaterials*, vol. 12, no. 23, p. 4214, 2022.

[12] S. Pervaiz, S. Kannan, and H. A. Kishawy, 'An extensive review of the water consumption and cutting fluid based sustainability concerns in the metal cutting sector', *J. Clean. Prod.*, vol. 197, pp. 134–153, 2018.

[13] Y. Zhang *et al.*, 'Nano-enhanced biolubricant in sustainable manufacturing: from processability to mechanisms', *Friction*, vol. 10, no. 6, pp. 803–841, 2022.

[14] J. P. Singh, A. K. Gautam, J. Srivastava, T. Nandi, and E. P. Namburi, 'A New Frontier in Functional Fluids: Nano Lubricating and Thermally Conducting Fluids', in *Novel Defence Functional and Engineering Materials (NDFEM) Volume 1: Functional Materials for Defence Applications*, Springer, 2024, pp. 93–129.

[15] I. Khan, K. Saeed, and I. Khan, 'Nanoparticles: Properties, applications and toxicities', *Arab. J. Chem.*, vol. 12, no. 7, pp. 908–931, 2019.

[16] G. Peker, C. Y\ild\iz, G. Çakmak, Y. Bilgiç, and A. Y\ild\iz, 'Thermal performance of new type plate heat exchanger with spring turbulence generator using nanofluid flow', *Exp. Heat Transf.*, vol. 36, no. 7, pp. 919–933, 2023.

[17] Y. Shokoohi and E. Shekarian, 'Journal of nanoscience and technology', *J. Nanosci. Technol.*, vol. 2, no. 1, pp. 59–63, 2016.

[18] M. A. Darabi, A. Khosrozadeh, Q. Wang, and M. Xing, 'Gum sensor: a stretchable, wearable, and foldable sensor based on carbon nanotube/chewing gum membrane', *ACS Appl. Mater. \& interfaces*, vol. 7, no. 47, pp. 26195–26205, 2015.

[19] J. A. Ghani *et al.*, 'Elevating Sustainability: The Role of Machining in Modern Eco-Friendly Manufacturing Processes', *J. Kejuruter.*, 2024.

[20] R. Sankaranarayanan, G. M. Krolczyk, and others, 'A comprehensive review on research developments of vegetable-oil based cutting fluids for sustainable machining challenges', *J. Manuf. Process.*, vol. 67, pp. 286–313, 2021.

[21] F. Hasin, Z. Ahmad, F. Ali, N. Khan, I. Khan, and S. M. Eldin, 'Impact of nanoparticles on vegetable oil as a cutting fluid with fractional ramped analysis', *Sci. Rep.*, vol. 13, no. 1, p. 7140, 2023.

[22] T. O. Nwoguh, A. C. Okafor, and H. A. Onyishi, 'Enhancement of viscosity and thermal conductivity of soybean vegetable oil using nanoparticles to form nanofluids for minimum quantity lubrication machining of difficult-to-cut metals', *Int. J. Adv. Manuf. Technol.*, vol. 113, no. 11, pp. 3377–3388, 2021.

[23] E. O. Ajodoh, 'Development and characterisation of castor oil-based nano-cutting fluid using Al2O3/CNTs nano-composite additives', Federal University of Technology Minna, 2023.

[24] I. A. Ukarajit, 'Development and characterization of vegetable oil-based nano cutting fluid using TiO2 and CNTs nanocomposite additives', Federal University of Technology Minna, 2024.

[25] E. Mansfield and M. Banash, 'Thermal analysis of nanoparticles: Methods, kinetics, and recent advances', in *Modeling, Characterization, and Production of Nanomaterials*, Second Edi., K. T. Vinod and Y. Zhang, Eds. Woodhead Publishing Ltd, 2023, pp. 535–547.

[26] N. Nanihar, A. Khalid, F. Hakim, N. Mohamed Sunar, B. Manshoor, and I. Zaman, 'Influences of Storage Duration on the Fuel Properties of Biodiesel derived from Jatropha and Waste Cooking Oil', in *Journal of Physics: Conference Series*, 2018, vol. 1049, no. 1.

[27] S. Huang, R. Wei, T. Xie, and J. Wang, 'Evaluation of fire hazards in typical vegetable oil residues', *Process Saf. Environ. Prot.*, vol. 154, pp. 223–235, 2021.

[28] A. Joshi, P. K. Singhal, and R. K. Bachheti, '(17) Oil content variation and physico-chemical properties of jatropha curcus seed oil collected from kumaun region of uttarakhand, india', *Int. J. Chem. Sci.*, 2012.

[29] I. S. Ibrahim, I. T. Abdullahi, and F. Y. Muhammad, 'Comparative analyses of biodiesel produced from neem and jatropha seed oil', *Bayero J. Pure Appl. Sci.*, vol. 12, no. 2, 2020.

[30] C. M. Agu, C. C. Orakwue, O. N. Ani, and M. P. Chinedu, 'Kinetics, thermodynamics and characterization of neem

seeds (Azadirachta indica) oil extraction: Extensive study of the processes', *Green Technol. Sustain.*, vol. 3, no. 1, p. 100126, 2025.

[31] A. K. M. A. Islam *et al.*, 'Genotype and age of industrial plant Jatropha curcas L. affect physico-chemical properties of seed oil', *Front. Energy Res.*, vol. 10, 2022.

[32] G. Knothe, 'Structure indices in FA chemistry. How relevant is the iodine value?', *J. Am. Oil Chem. Soc.*, vol. 79, no. 9, pp. 847–854, 2002.

[33] A. Souza, J. C. Santos, M. M. Conceição, M. C. Silva, and S. Prasad, 'A thermoanalytic and kinetic study of sunflower oil', *Brazilian J. Chem. Eng.*, vol. 21, no. 2, 2004.

[34] S. Ahn, J. M. Seo, and H. Lee, 'Thermogravimetric Analysis of Marine Gas Oil in Lubricating Oil', *J. Mar. Sci. Eng.*, vol. 9, no. 3, 2021.