IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 11 Issue 04, April 2024
ISSN (Online) 2348 – 7968 | Impact Factor – 6.72
www.ijiset.com

Thermophysical Properties of Corn Oil Biodiesel Mixed With Nanoadditives

[1]Raviteja Surakasi, [1]Ravi Ganivada, [1]Bobbadi Ushaswini

[1]Department of Mechanical Engineering, Lendi Institute of Engineering and Technology, Jonnada, Vizianagaram, Andhra Pradesh- 535005

Address for correspondence: Raviteja Surakasi (ravitejasurakasi@gmail.com)

Abstract:

The primary goal of this study is to analyze the thermophysical characteristics of nanopowder-enhanced biodiesel produced from corn oil. Transesterification of corn oil is the initial step in making biodiesel, which is then fortified with CuO as well as TiO2 nanopowders at different concentrations. Density, viscosity, calorific value, cetane number, flash point, along with fire point are only some of the thermophysical factors considered while evaluating biodiesel blends. The augmentation in weight percentages of nanopowder leads to a corresponding elevation in the magnitudes of all associated attributes. In general, the dispersion of CuO and TiO2 nanoparticles has led to improvements in thermophysical characteristics.

Keywords: Density, Viscosity. Calorific value, Cetane number, Flash point, Fire point

1. Introduction:

Biodiesel is made from renewable resources such as vegetable oils, animal fats, and various other materials, and it may be used as a substitute for fossil fuels. Corn oil is one such feedstock that is widely used for biodiesel production due to its abundance and low cost. However, the properties of biodiesel can be improved by adding nanomaterials such as CuO and TiO2 to enhance its thermo-physical properties [1].

Due to their useful qualities including large surface area, catalytic activity, along with thermal stability, nanomaterials like copper oxide (CuO) and titanium dioxide (TiO2) are often employed in biodiesel additives. These nanoparticles may enhance the viscosity, density, flash point, and cetane number of biodiesels made from corn oil [2].

The objective of this research is to examine the impact of CuO and TiO2 nanoparticles as additions on the thermo-physical characteristics of maize oil biodiesel. The parameters that will be examined include density, viscosity, flash point, cetane number, as well as oxidative stability. A comprehensive comprehension of these features is of utmost importance in order to enhance the efficiency and effectiveness of biodiesel production and use, hence resulting in biodiesel with enhanced attributes [3].

The thermo-physical qualities of a material are those that define its physical and thermal behavior under varying circumstances of temperature and pressure. The aforementioned characteristics are crucial to the planning and execution of several industrial operations, such as the manufacturing and consumption of fuels, chemicals, and materials [4].

Some of the key thermo-physical properties of a substance include:

Density: Density is the mass per unit volume of a substance. It is a fundamental property that determines the amount of a substance that can be contained in a given volume. The density of a substance can be affected by changes in temperature and pressure.

Viscosity: The ability of a fluid to deformation & flow may be measured using a characteristic known as viscosity. The viscosity of a fluid is assessed by the intermolecular friction within the fluid and is subject to several influencing variables, including temperature, pressure, along with the presence of contaminants or additives.

Calorific value: Calorific value, often known as heating value, represents the quantity of heat released by a substance upon complete combustion. The energy content of a fuel is quantified by means of a metric, often stated in measures such as joules per kilogram (J/kg)

Flash point: When a material is exposed to an ignition source like an open flame or spark, its flash point is the lowest temperature at which combustion may occur and a visible flame can be produced. It is an important safety parameter for flammable substances such as fuels and chemicals.

Fire point: The fire point refers to the temperature that occurs when a material sustains combustion after its initial ignition. The autoignition temperature refers to the specific temperature at which the material undergoes continuous burning in the absence of an external igniting source.

Cetane number: The cetane number serves as an indicator of the ignition characteristics shown by diesel fuels. This parameter serves as an indicator of the fuel's propensity to undergo ignition and combustion inside a diesel engine. Fuels that have higher cetane values often exhibit enhanced combustion characteristics and provide reduced emissions.

2. Preparation of Biodiesel Samples:

2.1.Materials used

- Oil – Corn Oil
- Fuel - Diesel
- Strong Base - Methanol
- Catalyst - Potassium Hydroxide
- Nano powders – CuO, TiO_2

2.1.1. Copper Oxide (CuO) and its properties:

Copper oxide (CuO) is a chemical compound composed of copper and oxygen atoms. It is commonly found as a black powder or in the form of solid black crystals. CuO has a wide range of potential applications due to its unique properties, including its electrical and catalytic properties, thermal stability, and magnetic properties [5].
CuO has been extensively studied for use in electronic devices, such as transistors and solar cells, as well as in energy production, catalysis, and magnetic storage. In recent years, CuO has also gained attention for its potential applications in bio diesel production, as it can act as a catalyst to improve the efficiency of the transesterification process [6].
Further research on CuO is needed to fully understand and harness its properties for various applications. With its diverse range of potential uses, CuO is a material of significant interest

and importance in the field of materials science and engineering. Table 1 shows the properties of CuO nanopowder

Property	Value/ Description
Molecular Weight/Molar Mass	79.55 g/mol
Density	6.31 g/cm³
Melting Point	1,326 °C
Refractive Index	2.72
Polarity	Polar
Oxidation Number	+2
Dielectric Constant	18.4

Table1: Properties of Copper oxide

2.1.2. Titanium dioxide (TiO_2) and its properties:

Titanium dioxide (TiO2) is a common industrial mineral that occurs naturally. The substance under consideration is a white, odorless powder which exhibits limited solubility in water and several organic solvents. Titanium dioxide (TiO2) has a diverse array of physical and chemical characteristics, making it very advantageous for several applications. Notably, TiO2 possesses a high refractive index, low toxicity, as well as exceptional resistance to ultraviolet (UV) radiation.

Titanium dioxide (TiO2) is often used in the manufacturing of pigments for various applications such as paints, plastics, and ceramics. This is mostly attributed to its inherent opaqueness and capacity to effectively reflect light. Moreover, it finds use as a photocatalyst in the purification of air and water, and also plays a vital role in the manufacturing of solar cells along with other electrical gadgets. TiO2 has been extensively researched for use in biomedical applications, such as drug delivery and cancer treatment [7].

In recent times, there has been a tremendous interest in TiO2 nanoparticles owing to their distinctive characteristics, including their elevated surface area along with reactivity. However, their potential environmental and health risks are still being studied and evaluated [8]. Table 2 shows the properties of TiO_2 nanopowder.

Property	Value/ Description
Molecular Weight/Molar Mass	79.87 g/mol
Density	4.23 g/cm³
Melting Point	1,843 °C
Refractive Index	2.76 (anatase), 2.55 (rutile)
Polarity	Nonpolar
Oxidation Number	+4
Dielectric Constant	85 (anatase), 60 (rutile)

Table2: Properties of Titanium dioxide

Figure 1 shows the samples prepared, Figure 2 and Figure 3 shows the biodiesel preparation process and flow chart of biodiesel preparation.

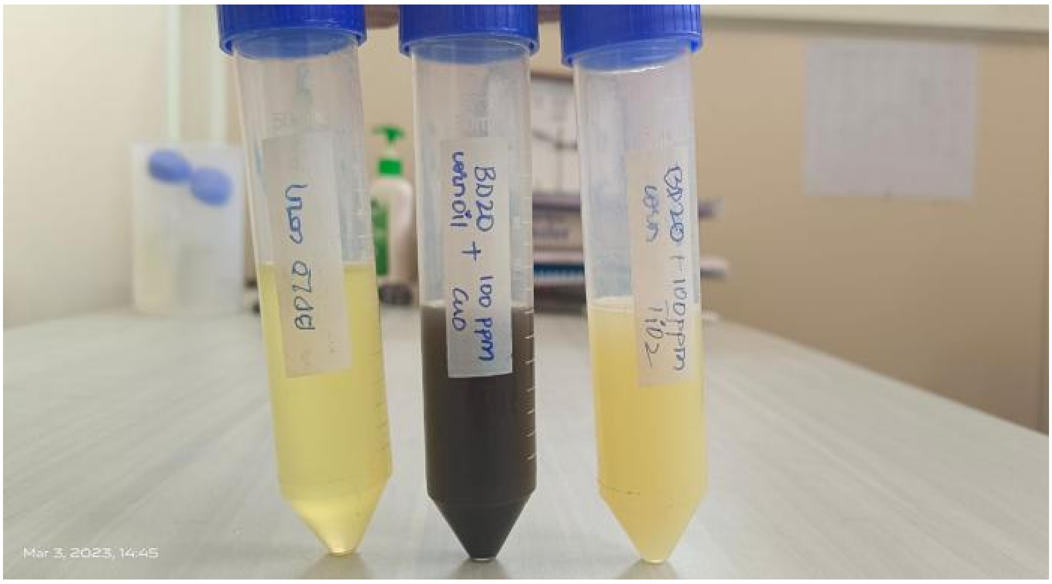


Figure 1: Samples prepared

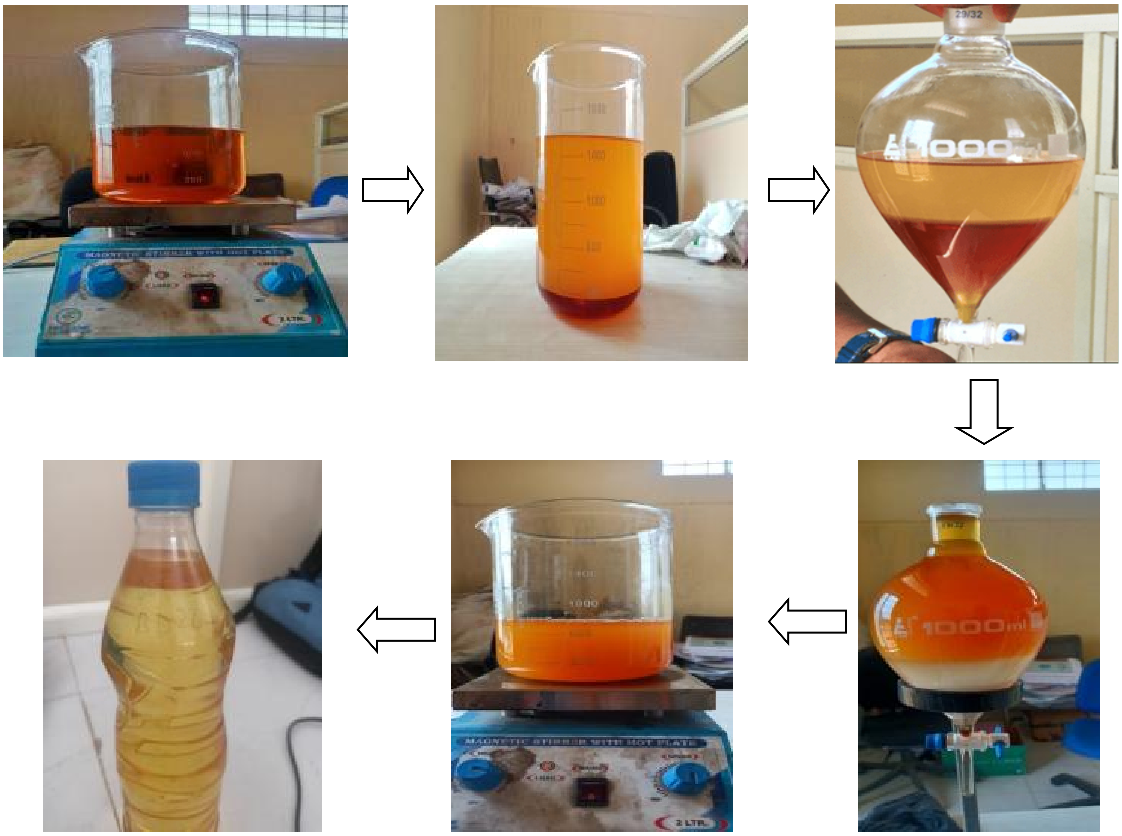


Fig.2. Biodiesel preparation process

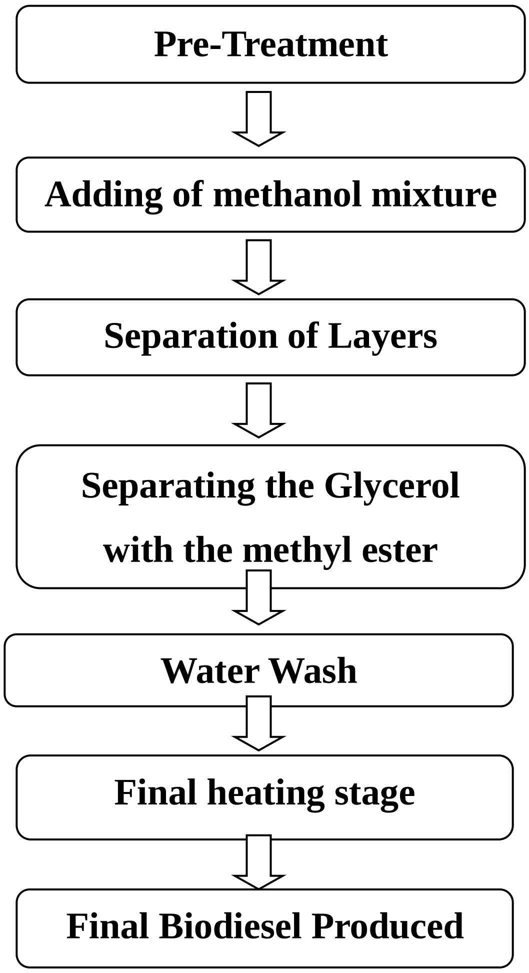


Fig.3. Flow chart of biodiesel preparation

3. EXPERIMENTAL SETUP AND PROCEDURE:

3.1. EXPERIMENTAL SETUP:

3.1.1. Magnetic Stirrer:

A magnetic stirrer is a laboratory device used for mixing liquids or suspending solids in a liquid by means of a rotating magnetic field. A magnetic stir bar, also known as a stir bar, is rotated within a container containing the liquid along with mixture that needs to be stirred. The rotating magnetic field induces a circular motion in the stir bar, which in turn creates a vortex in the liquid, thereby mixing the contents.

The experimental setup for a magnetic stirrer typically consists of the following components:

Stir plate: This is the main component of the setup and consists of a flat surface with a rotating magnetic field generator. The surface is usually made of ceramic, glass or metal and has a series of circular magnetic poles or grooves on the surface, where the stir bar sits.

Stir bar: The stir bar is a small magnetic rod, usually made of Teflon or glass, that is placed inside the container holding the liquid. The size and shape of the stir bar can vary depending on the volume and viscosity of the liquid being stirred.

Container: The container is usually made of glass or plastic and holds the liquid or mixture being stirred. After setting the container on the stir plate, the stir bar may be lowered into the liquid via the lid's hole.

Power supply: The power supply is used to supply power to the stir plate and generate the magnetic field that rotates the stir bar. The power supply is usually an AC transformer that converts the mains voltage to a low voltage AC current that is used to generate the rotating magnetic field.

To set up the magnetic stirrer, the stir bar is placed in the container holding the liquid, and the container is then placed on top of the stir plate. The power supply is turned on, and the magnetic field is generated, causing the stir bar to rotate and create a vortex in the liquid. Changing the voltage of the power source or moving the stir bar closer to or further from the magnetic poles onto the stir plate will affect the speed operating the magnetic stirrer.

Common uses for magnetic stirrers include chemical synthesis, pharmacological research, and microbiological studies. They are particularly useful for mixing or suspending solids in a liquid, as the vortex created by the stir bar helps to evenly distribute the solid particles throughout the liquid.

3.1.2. Ultrasonicator:

An ultrasonicator, also known as an ultrasonic homogenizer or sonicator, is a laboratory device that uses high-frequency sound waves to disrupt, emulsify, or disperse materials. The device works by converting electrical energy into high-frequency mechanical vibrations that are transmitted to a probe or horn, which is immersed in the liquid or mixture being processed.

The experimental setup for an ultrasonicator typically consists of the following components:

Ultrasonic generator: This is the main component of the setup and consists of an electronic circuit that produces high-frequency electrical signals that are transmitted to the ultrasonic probe or horn. The ultrasonic generator can be a stand-alone device or integrated into the ultrasonic bath.

Ultrasonic probe or horn: This is the part of the ultrasonicator that is immersed in the liquid or mixture being processed. The probe or horn is typically made of titanium, stainless steel, or other materials that can withstand the high-frequency vibrations. The probe or horn is connected to the ultrasonic generator via a cable that transmits the electrical signals to the vibrating tip.

Ultrasonic bath: The ultrasonic bath is a container that holds the liquid or mixture being processed. The ultrasonic probe or horn is immersed in the liquid, and the high-frequency vibrations generated by the ultrasonic generator are transmitted to the liquid through the probe or horn.

Temperature control: Ultrasonication can generate heat, so it is important to control the temperature of the liquid or mixture being processed. Temperature control can be achieved using a water bath or other cooling system.

To set up the ultrasonicator, the ultrasonic probe or horn is connected to the ultrasonic generator and immersed in the liquid or mixture being processed. The ultrasonic generator is turned on, and the high-frequency vibrations are transmitted to the liquid through the probe or horn. The ultrasonication process's power and duration may be tailored to the processing material and final goal.

Ultrasonication is commonly used in a variety of applications, including sample preparation, cell disruption, emulsification, and nanoparticle synthesis. When processing materials that resist homogenization by traditional techniques like shear mixing or grinding, this technique comes in very handy. The high-frequency vibrations generated by the ultrasonicator can disrupt and disperse particles or cells in a non-invasive manner, making it a valuable tool in biomedical research and industrial applications.

3.2. EXPERIMENTAL PROCEDURE:

3.2.1 Transesterification Procedure:

- The oil sample with a volume of 1200ml is subjected to heating at a temperature of 40˚C using a Magnetic Stirrer or a Mixer.
- The next step is to combine 125 ml of methanol with 3.5 g of sodium hydroxide (KOH) pellets. As soon as the oil reaches 56 to 58 degrees Celsius, the temperature should be lowered [9]. Allow the oil to rest for one hour. Allow the oil to undergo a process of separation, whereby the glycerol and fatty acid components sink to the bottom.
- The glycerol may be separated from the oil by using a separating funnel.
- Subsequently, the oil is subjected to a thorough rinsing process using either distilled water or simply hot water.
- Furthermore, it is necessary to subject the acquired oil to a further reheating process using a Magnetic Stirrer, raising the temperature to 90˚C. This step is crucial in order to eliminate any water bubbles that may be present within the oil [10].
- The user's text does not contain any information to rewrite.The oil should be gathered and transferred into designated containers for further processing, specifically for the purpose of blending.

3.2.2 Blending Procedure:

- The first stage in the process of blending biodiesel involves the determination of the appropriate blend ratio. Typically, the proportion of biodiesel with petroleum diesel is denoted as a percentage, for instance, B5 (comprising 5% biodiesel along with 95% petroleum diesel) or the B20 (comprising 20% biodiesel along with 80% petroleum fuel) [11].
- After the preparation of Biodiesel with the necessary blend ratio, it is then combined with CuO and TiO2 in concentrations of 50 ppm as well as 100 ppm respectively, using an Ultrasonicator apparatus.
- The manufactured biodiesel mixed nano additions are used for the assessment of several properties including density, viscosity, calorific value, cetane number, flash point, and fire point. [12]

4. Results:

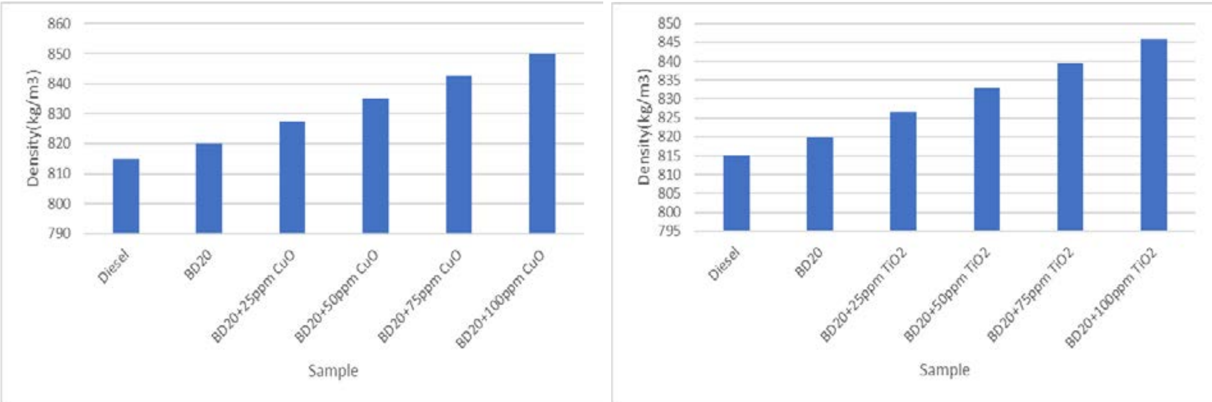
4.1.Density:

Density indicates the mass of fuel per unit volume. Fig.5(a). As the volume of CuO increases, the value of density is also increases. The minimum and maximum value of density is 820

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 11 Issue 04, April 2024
ISSN (Online) 2348 – 7968 | Impact Factor – 6.72
www.ijiset.com

kg/m^3 and 850 kg/m^3 for diesel and Biodiesel with 100ppm CuO (i.e., BD20+100ppm CuO) respectively [13]. Fig.5(b). As the volume of TiO_2 increases, the value of density is also increases. The minimum and maximum value of density is 820 kg/m^3 and 846 kg/m^3 for Biodiesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [14].

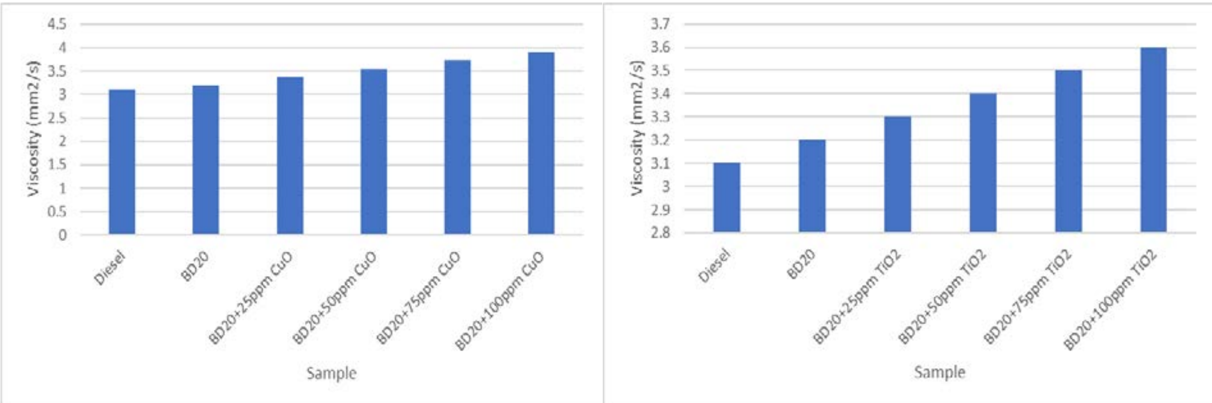
Upon comparing both the nano additives for density, Biodiesel with 100ppm CuO has maximum density which is 850 kg/m^3.



(a) (b)

Fig.5(a). graph drawn between Density and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.5(b). graph drawn between Density and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

4.2.Viscosity:



(a) (b)

Fig. 6(a) graph is drawn between viscosity and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.6(b) graph drawn between viscosity and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

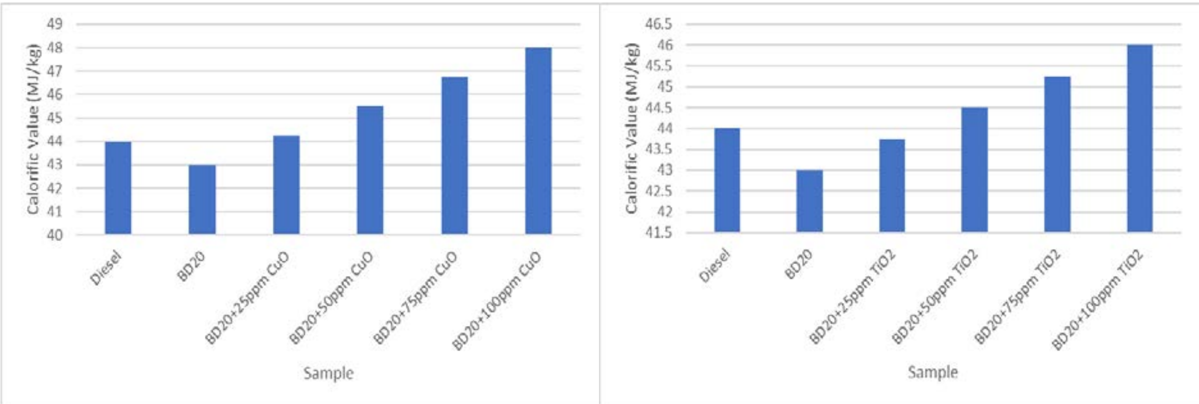
Fig.6(a) The value of Viscosity also increases with the increase of the volume of CuO. The minimum value of viscosity is 3.2 mm^2/s and maximum value of viscosity is 3.9 mm^2/s for Biodiesel and Biodiesel with 100ppm CuO (i.e., BD20+100ppm CuO) respectively [15]. Fig.6(b). The value of Viscosity is also increases with increase of volume of TiO_2. The minimum value of viscosity is 3.2 mm^2/s and maximum value of viscosity is 3.6 mm^2/s for diesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [16].

Upon comparing both the nano additives for Viscosity, Biodiesel with100ppm CuO has maximum viscosity which is 3.9 mm^2/s.

4.3.**Calorific Value:**

Fig.7(a). The value of Calorific value is also increases with increase of nano powder from 0 to 100 ppm of CuO. The minimum and maximum value of calorific value is 43 MJ/kg and 48 MJ/kg for Bio diesel and Bio diesel with100ppm CuO (i.e., BD20+100ppm CuO) respectively [17]. Fig.7(b). The value of Calorific value is also increases with increase of nano powder from 0 to 100 ppm of TiO_2. The minimum and maximum value of calorific value is 43 MJ/kg and 46 MJ/kg for Bio diesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [18].

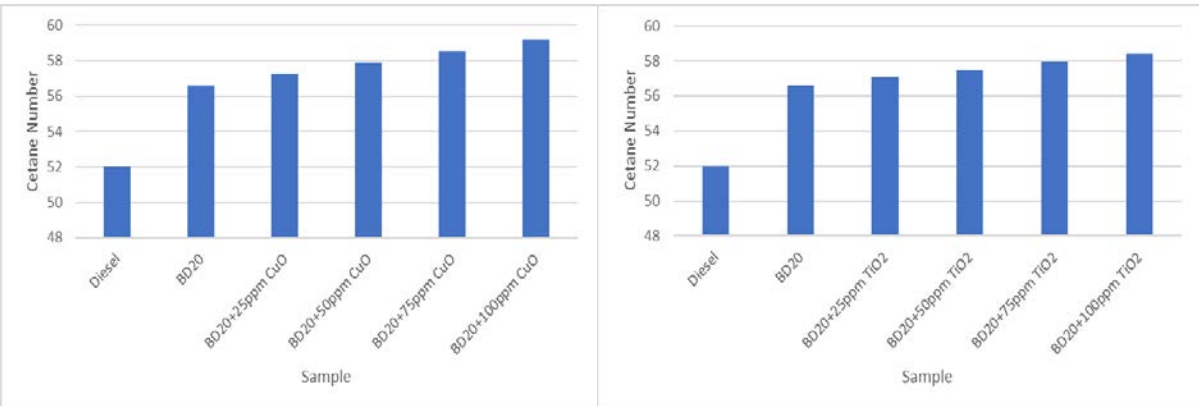
Upon comparing both the nano additives for calorific value, Biodiesel with100ppm CuO has maximum calorific value which is 48 MJ/kg.



(a) (b)

Fig. 7(a) graph drawn between calorific value and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.7(b) graph drawn between calorific value and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

4.4.Cetane Number:



(a) (b)

Fig.8(a) graph drawn between cetane number and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.8(b) graph drawn between cetane number and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

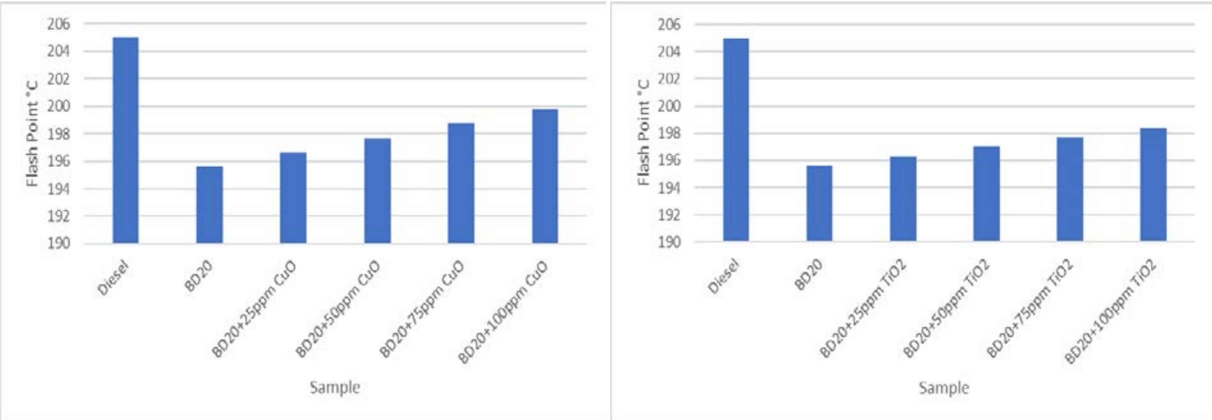
Fig.8(a). The cetane number is slightly increases with increase of nano powder from 0 to 100ppm CuO. The minimum and maximum cetane number is 52 and 59.2 for Bio diesel and

IJISET - International Journal of Innovative Science, Engineering & Technology, Vol. 11 Issue 04, April 2024
ISSN (Online) 2348 – 7968 | Impact Factor – 6.72
www.ijiset.com

Bio diesel with100ppm CuO (i.e., BD20+100ppm CuO) respectively [19]. Fig.8(b). The cetane number is slightly increases with increase of nano powder from 0 to 100ppm TiO_2. The minimum and maximum cetane number is 52 and 58.4 for Bio diesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [20,21].

While comparing both the nano additives for cetane number, Biodiesel with100ppm CuO has maximum cetane number which is 59.2.

4.5.Flash Point:



(a) (b)

Fig.9(a) graph drawn between flash point and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.9(b) graph drawn between flash point and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

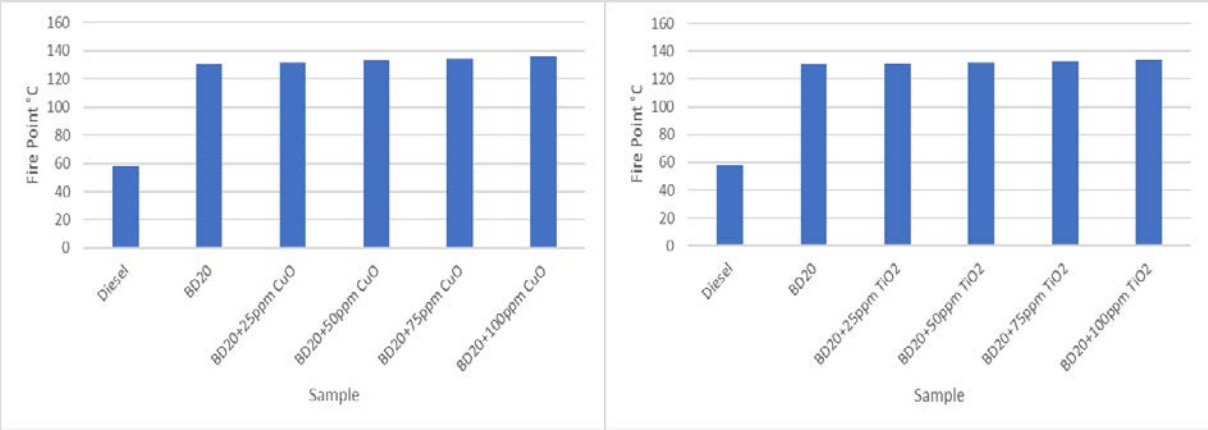
Fig.9(a). The flash point is also slightly increases with increase of volume of CuO from 0 to 100ppm. The minimum and maximum value of point is 195.6 °C and 199.8 °C for Bio diesel and Bio diesel with100ppm CuO (i.e., BD20+100ppm CuO) respectively [22]. Fig.9(b). The flash point is also slightly increases with increase of volume of TiO_2 from 0 to 100ppm. The minimum and maximum value of point is 195.6 °C and 198.4 °C for Bio diesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [23,24].

While comparing both the nano additives for flash point, Biodiesel with100ppm CuO has maximum flash point which is 199.8 °C.

4.6.Fire Point:

Fig.10(a). The fire point is also slightly increases with increase of volume of CuO from 0 to 100ppm. The minimum and maximum value of point is 130.4 °C and 135.6 °C for Bio diesel and Bio diesel with100ppm CuO (i.e., BD20+100ppm CuO) respectively [25,26]. Fig.10(b). The fire point is also slightly increases with increase of volume of TiO_2 from 0 to 100ppm. The minimum and maximum value of point is 130.4 °C and 133.8 °C for Bio diesel and Bio diesel with100ppm TiO_2 (i.e., BD20+100ppm TiO_2) respectively [27,28].

When comparing both the nano additives for fire point, Biodiesel with 100ppm CuO has maximum fire point which is 135.6 °C.



(a) (b)

Fig.10(a) graph drawn between fire point and Sample with varying ppm of CuO from 0 to 100 ppm. Fig.10(b) graph drawn between fire point and Sample with varying ppm of TiO_2 from 0 to 100 ppm.

5. Conclusions:

1. Corn oil has been taken for the preparation of biodiesel
2. Biodiesel has been prepared by transesetrifcation process and mixed along with TiO2 and CuO nanopowders
3. Thermophysical properties have been evaluated for the prepared biodiesel samples
4. Biodiesel with 100ppm CuO has maximum density which is 850 kg/m^3.
5. Biodiesel with100ppm CuO has maximum calorific value which is 48 MJ/kg.
6. Biodiesel with100ppm CuO has maximum cetane number which is 59.2.
7. Biodiesel with100ppm CuO has maximum flash point which is 199.8 °C.
8. Biodiesel with 100ppm CuO has maximum fire point which is 135.6 °C.
9. Finally it can be concluded that the biodiesel sample prepared with 100 ppm CuO has been exhibiting good thermophysical properties

6. Future Scope:

The thermophysical properties can also be evaluated using different biodiesel samples and by varying the nanoadditives.

REFERENCES:

1. Wei B, Zou C, Yuan X, Li X (2017) Thermo-physical property evaluation of diathermic oil based hybrid nanofluids for heat transfer applications. Int J Heat Mass Transf 107:281–287
2. Holmberg, K.; Erdemir, A. The impact of tribology on energy use and CO2 emission globally and in combustion engine and electric cars. *Tribol. Int.* **2019**, *135*, 389–396.
3. Raviteja Surakasi, Yenda Srinivasa Rao, Sd. Abdul Kalam, Naziya Begum, "Emissions and Performance of Diesel Engines Correlated with Biodiesel Properties", *Journal of Engineering*, vol. 2023, Article ID 5274325, 4 pages, 2023. https://doi.org/10.1155/2023/5274325
4. Ali, M.K.A.; Xianjun, H.; Abdelkareem, M.A.A.; Gulzar, M.; Elsheikh, A.H. Novel approach of the graphene nanolubricant for energy saving via anti-friction/wear in automobile engines. *Tribol. Int.* **2018**, *124*, 209–229.
5. Wu, B.; Song, H.; Li, C.; Song, R.; Zhang, T.; Hu, X. Enhanced tribological properties of diesel engine oil with Nano-Lanthanum hydroxide/reduced graphene oxide composites. *Tribol. Int.* **2020**, *141*.

6. Charoo, M.S.; Hanief, M. Improving the tribological characteristics of a lubricating oil by nano sized additives. *Mater. Today Proc.* **2020**, *28*, 1205–1209.
7. J. Arunprasad, Alla Naveen Krishna, Dharavathu Radha, Mandeep Singh, Raviteja Surakasi, Tewodros Derese Gidebo, "Nanometal-Based Magnesium Oxide Nanoparticle with C. vulgaris Algae Biodiesel in Diesel Engine", *Journal of Nanomaterials*, vol. 2022, Article ID 1688505, 9 pages, 2022. https://doi.org/10.1155/2022/1688505
8. Ghasemi, R.; Fazlali, A.; Mohammadi, A.H. Effects of TiO_2 nanoparticles and oleic acid surfactant on the rheological behavior of engine lubricant oil. *J. Mol. Liq.* **2018**, *268*, 925–930.
9. V. Andal, G. Buvaneswari, R. Lakshmipathy. Synthesis of CuAl2O4 nanoparticle and its conversion to CuO nanorods. Journal of Nanomaterials. 2021. Article id: 8082522
10. Mousavi, S.B.; Heris, S.Z.; Estellé, P. Experimental comparison between ZnO and MoS_2 nanoparticles as additives on performance of diesel oil-based nano lubricant. *Sci. Rep.* **2020**, *10*, 1–17.
11. Moldovanu, D.; Molea, A.; Barabás, I. Preliminary results on nano-diamond and nano-graphite testing as additive for an engine lubrication oil. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *724*.
12. Raviteja Surakasi, Balakrishna Gogulamudi, Alla Naveen Krishna, Raja Ambethkar M, Pravin P. Patil, Pradeep Jayappa, "Optimization of the Process of Metal NanoCalcium Oxide Based Biodiesel Production through Simulation Using SuperPro Designer", *Journal of Engineering*, vol. 2022, Article ID 3473356, 6 pages, 2022. https://doi.org/10.1155/2022/3473356
13. Ivanov, M.; Shenderova, O. Nanodiamond-based nanolubricants for motor oils. *Curr. Opin. Solid State Mater. Sci.* **2017**, *21*, 17–24.
14. Beig, G.; Sahu, S.K.; Singh, V.; Tikle, S.; Sobhana, S.B.; Gargeva, P.; Ramakrishna, K.; Rathod, A.; Murthy, B.S. Recent developments of nanoparticles additives to the consumables liquids in internal combustion engines: Part II: Nano-lubricants. *Sci. Total Environ.* **2019**, 136126.
15. Srivyas, P.D.; Charoo, M.S. A review on tribological characterization of lubricants with nano additives for automotive applications tribology in industry. *Tribol. Ind.* **2018**, *40*, 594–623.
16. Surakasi Raviteja, Velivela Lakshmikanth Chowdary, "Liquid Fuels Derived from Microalgae: Physicochemical Analysis", *Journal of Engineering*, vol. 2022, Article ID 1293310, 5 pages, 2022. https://doi.org/10.1155/2022/1293310
17. D. Rodin and S. K. Yee, Rev. Sci. Instrum. **88**, 014902 (2017). https://doi.org/10.1063/1.4973297
18. S. Kommandur and S. K. Yee, J. Polym. Sci., Part B: Polym. Phys. **55**, 1160 (2017). https://doi.org/10.1002/polb.24365
19. Daridon, J. L.; Bazile, J. P. Computation of Liquid Isothermal Compressibility from Density Measurements: An Application to Toluene. J. Chem. Eng. Data2018, 63, 2162–2178.
20. Murnaghan F. D. The Compressibity of Media under Extreme Pressure. J. Franklin Inst.1924, 197, 98.
21. Dymond, J. H.; Malhotra, R. The Tait Equation: 100 Years On. Int. J. Thermophys.1988, 9, 941–951.
22. Tammann, G. Ueber Die Abhängigkeit Der Volumina von Lösungen Vom Druck. Zeitschrift für Phys. Chemie1895, 17U, 620–636.

23. Sekhar, G.C., Thimothy, P., Surakasi, R. *et al.* Graphene Nanopowder and Propylene Glycol Solutions: Thermal and Physical Properties. *Arab J Sci Eng* (2023). https://doi.org/10.1007/s13369-023-07952-0
24. R. Surakasi, G. C. Sekhar, J. Pakalapati, R. Pakalapati, and M. Rafeeq, "Evaluation of electrical properties of graphene nanopowder-dispersed propylene glycol-water solutions," *Engineering Research Express*, vol. 5, no. 3, p. 035019, Jul. 2023, https://doi.org/10.1088/2631-8695/ace58e
25. Haribabu, A., Surakasi, R., Thimothy, P. *et al.* Study comparing the tribological behavior of propylene glycol and water dispersed with graphene nanopowder. *Sci Rep* **13**, 2382 (2023). https://doi.org/10.1038/s41598-023-29349-7
26. A. Jayanthi, R. Krishna Priya, Raviteja Surakasi, Jaya Prasad Vanam, G. Puthilibai, M. Santhanakrishnan, S. Rajkumar, Mechanical and tribological properties of TiC nano particles reinforced polymer matrix composites, Materials Today: Proceedings, Volume 59, Part 2, 2022, Pages 1472-1477, ISSN 2214-7853, https://doi.org/10.1016/j.matpr.2022.01.096.
27. Surakasi, R., Sekhar, K.C., Kavitha, E. *et al.* Evaluation of physico-thermal properties of TiO_2–water mixture dispersed with MWCNTs. *Nanotechnol. Environ. Eng.* **7**, 325–331 (2022). https://doi.org/10.1007/s41204-022-00242-4
28. Surakasi R, Sripathi S, Nadimpalli SP, et al. Synthesis and Characterization of TiO2-Water Nanofluids. *Adsorption Science & Technology*. 2022;2022. doi:10.1155/2022/3286624