EXPERIMENTAL DETERMINATION OF THERMOPHYSICAL AND HEAT TRANSFER PROPERTIES OF THREE HYBRID DIESEL-NANO-CATALYST BLEND WITH THEIR SIGNIFICANT COMPARISON

Prabhat Patel[1], Dr. Ravindra Pathak[2]

Article History: Received: 16.08.2021 **Revised:** 01.10.2021 **Accepted:** 18.11.2021

Abstract

There are numerous technological and industrial uses for hybrid nanofluids formed by suspending two or more different types of nanoparticles in the base fluid. The current study looks at the different thermo-physical and heat transfer properties of hybrid nanofluids that could be used as industrial coolants or heat transfer fluids. The hybrid nanofluid (hybrid nano-diesel) is composed of diesel as the base fluid and hybrid nanoparticles consisting of copper-alumina oxide (CuO-Al2O3), graphene-alumina oxide (Gr-Al2O3), and copper-graphene oxide (CuO-Gr) for this analysis. The major purpose of developing hybrid nanofluids is to improve the characteristics of mono nanofluid by significantly improving their thermal or rheological properties over ordinary nanofluids or nanolubricants. According to the results, CuO-Gr hybrid nano-diesel increases thermal conductivity by 29.5% and reduces specific heat by 5% at mass fractions of 2%. However, as more mass of nanoparticles is added, the hybrid nano-diesel's viscosity increases; however, the effect of surfactant addition with increasing mass fraction causes the viscosity to fall by 17.5% at the same mass fraction of 2%. The same sample's surface tension also lessens by 10%. According to the experimental findings, CuO-Gr hybrid nano-diesel performs extremely well across the board in thermal analysis. The Nussult number of CuO-Gr hybrid nano-diesel increases by 11%, as do the heat transfer properties. At 2% mass fraction, the heat transfer coefficient increased by the most, at roughly 18% corresponding to Reynolds number of 5474, showing that the matching sample is the best suited for heat transfer applications out of all samples. The Prandtl number of the sample reduces by 5.5% for a mass fraction of 2%.

Keywords: Hybrid nanoparticle, Nano-diesel, Specific heat, Thermal conductivity, Viscosity.

[1]Research Scholar, Department of Mechanical Engineering, Medi-Caps University, Indore
[2]Associate Professor, Department of Mechanical Engineering, Medi-Caps University, Indore
prabhat.patel@medicaps.ac.in,

1. Introduction

In order to increase effective thermal conductivity and, consequently, heat transfer efficiency, solid nanometer-sized particles are dispersed into more traditional heat transfer fluids like water, diesel, or EG (ethylene glycol) to produce a cutting-edge heat transfer fluid known as nanofluid[1-3]. The number of dispersed particles, material type, particle shape, and other factors are known to have an impact on the effectiveness of heat transfer enhancement[4-6]. It is anticipated that nanofluid will be employed, among other things, in automobiles cars, airplanes, and microreactors, etc. The two types of nanofluids are mono nanofluids (nanofluids with a single type of nanoparticle) and hybrid nanofluids (nanofluids distributed with two or more distinct nanoparticles)[7-9]. Nanofluids are commonly employed in many energy transfer applications because of their high effective thermal conductivity[10-14]. According to an analysis of thermal properties, liquids used for convectional heat transmission, such as water, EG, diesel, petrol and oil, are less effective at transferring heat than solid metals[13]. In view of the previous problem, several researches have been carried out to improve the fluids' capacity for heat transmission. Including millimeter or micrometer-sized nano particles in fluids is one method for enhancing heat transmission[9, 15-17]. In recent years, the concept of "nanofluids" has been recognized as a prime contender for improving heat transfer[18]. in order to enhance the basic fluid's thermal properties, nanoparticles are dispersed in them to create newly engineered fluids called nanofluids [1, 19, 20]. An extension of mono nanofluid, a hybrid nanofluid is made by dispersing two distinct nanoparticles or a composite nanopowder in the base fluid. After this, base fluid and nanoparticle combination has undergone ultrasonication for a set of time and temperature, a fluid known as hybrid nanofluid is prepared for further experimental test analysis[9]. It is predicted that the hybrid nanofluid will offer base fluid and nanofluid containing single nanoparticles thermal characteristics that are superior due to combined effects[21]. TEM, HRTEM, and magnetization measurements were used to examine the synthesis features of the hybrid magnetic polymer[16, 22]. According to [10], by combining silver nanoparticles with multi-walled carbon nanotubes, heat conductivity was improved. The influence of hybrid Al2O3 nanoparticles and micro-encapsulated phase change material particles on cooling effectiveness has demonstrated a significant improvement when compared to single nanoparticles and water [23].

The results show that at mass fractions of 2%, the CuO-Gr hybrid nano-diesel boosts thermal conductivity by 29.5% and decreases specific heat by 5% confirmed by [5, 7, 24, 25]. In general, the hybrid nano- diesel's viscosity rises with the addition of the mass of nanoparticles, but the viscosity is reduced by 17.5% as a result of the addition of surfactant at the same mass fraction of 2%[26, 27]. The surface tension of the identical sample likewise decreases by 10%[28]. The experimental results show that CuO-Gr hybrid nano-diesel performs very well in all thermal analyses. The Nussult number for CuO-Gr hybrid nano-diesel increases by 11%, and the maximum improvement in heat transfer coefficient was about 18% at 2% mass fraction at Reynolds number of 5474, demonstrating that the corresponding sample is the most appropriate for heat transfer application out of all samples while Prandtl number decreases by 5.5%[14]. It is observed that as the mass particle fraction of alumina, copper, and graphene oxide nanoparticles rises, the electrical conductivity of the nanofluid increases practically linearly. According to the experimental results, temperature rises will result in an increase in the electrical conductivity of the suspension for a given volume percent. The CuO-Gr hybrid nano- diesel's electrical conductivity peaked at 351 μS/cm for a mass fraction of 2% at 48 °C; the corresponding value at ambient temperature (T=26 °C) was 17.58 μS/cm [5, 7, 24, 25].

In general, the hybrid nanofluid's thermal conductivity is a crucial characteristic for improving heat transfer. Many variables, including base fluid type, fluid temperature, stability, nanoparticle type, and size all affect the thermal conductivity and heat transfer parameters of a nanofluid[23, 29-35]. Diesel is used as the base fluid in the hybrid nanofluid (hybrid Nano-diesel) for this study and experiment. Copper-alumina oxide (CuO-Al2O3), copper-graphene oxide (CuO-Gr), and graphene-alumina oxide (GrO-Al2O3) are the hybrid nanoparticles. In order to create the hybrid nano diesel, 5 to 100 mg of nanoparticles and 100 to 300 mg of surfactant were added to one liter of diesel. The five samples with the highest likelihood out of 50 were excluded from additional research. High-shear mixing equipment or an ultrasonic vibrator may be utilized to spread the newly formed hybrid nanopowder into the base fluid[3]. This method is relatively inexpensive for the mass production of hybrid nanofluids. Using diesel as the basis fluid, we developed a hybrid nanofluid composed of Al2O3, CuO, and Gr. The composite powders were created by mechanical alloying. The surfactant sodium dodecyl sulfonate (SDS) is acidically treated to give stability and fluidity to the hybrid nano-diesel[26, 27].

Table 1 Characteristics & properties of nanoparticles provided by Nano Amor

Nanoparticles	**Nanoparticle Dosage (mg/ L)**	**Colour of Nanoparticle**	**Size(nm)**	**Supplier**	**Purity (%)**	**Thermal Conductivity (W/mK)**	**Density (kg/m3)**
Al_2O3	5 – 200	White	20-30	NanoAmor	99.97	25	2700
CuO	5 – 200	Black	30-50	NanoAmor	99	33	6310
Gr	5 – 200	Black	5-10	NanoAmor	99	2000	2500

Experimental study

Alumina oxide, copper oxide, and graphene oxide have typical particle sizes of 20 to 30 nm, 30 to 50 nm, and 5 to 10 nm respectively, with a purity of roughly 90%. Table 2 shows how the nanoadditives with surfactant were disseminated equally in diesel using an ultrasonication technique with varying mass fractions. The homogeneous distribution of nanoadditives in the gasoline was continually monitored. A 160 W ultrasonicator with a frequency of 40 kHz[27]. The effect of employing hybrid nanofluids on different heat transfer properties like thermal conductivity, dynamic viscosity, density, and specific heat were summarized in this section[6, 36-38]. Figure 2.2 & 2.3, displays instruments frequently used to measure the different properties of nanofluids and hybrid nanofluids.

Table 2 Sample sizes for experimental study are set by the range of nanoparticle and surfactant concentrations per liter of base fluid (diesel).

Hybrid Nano-diesel (HND) Mixture Name	**Parent Fluid**	**Mass of Hybrid (50:50) Nanoparticle Range (mg/ L)**	**Mass of Surfactant (SDS) Range (mg/ L)**	**Hybrid Mixture Ultrasonication Time (Mints)**
HND_1	Pure Diesel	5	100	20
HND_2	Pure Diesel	44	140	24
HND_3	Pure Diesel	102	200	30
HND_4	Pure Diesel	160	259	35
HND_5	Pure Diesel	200	300	40

Figure 2.1 Samples of Diesel+CuO+Gr, Diesel+Gr+Al2O3, and Diesel+Al2O3+CuO hybrid nano-diesel

Figure 2.2 Photographs of Ultrasonication & PH measurement of Diesel+CuO+Gr, Diesel+Gr+Al2O3, and Diesel+Al2O3+CuO hybrid nano-diesel

Figure 2.3 Measurement of thermal conductivity, surface tension & viscosity of Diesel+CuO+Gr, Diesel+Gr+Al2O3, and Diesel+Al2O3+CuO hybrid nano-diesel

Empirical Relation for Thermo-Physical Characteristics of Composite Nanofluids:

The mass balance and energy balance are used to calculate the hybrid nanofluid's density ratio and specific heat capacity, respectively[1, 39, 40], have the following generalized forms according to [4]:

$$\rho_{nf} = \sum\varphi_p\rho_p + \rho_{bf}(1 - \sum\varphi_p) \quad (1)$$

$$\rho_{nf}\, C_{nf} = \sum\varphi_p\rho_p c_p + \rho_{bf}\, C_{bf}(1 - \sum\varphi_p), \quad (2)$$

he researchers' proposed empirical correlation for the hybrid nanofluids' thermal conductivity [4].

$$\frac{k_{nf}}{k_{bf}} = \left(\frac{k_1 + (n_1 - 1)k_{bf} - (n_1 - 1)(k_{bf} - k_1)\phi_1}{k_1 + (n_1 - 1)k_{bf} + (k_{bf} - k_1)\phi_1}\right)\left(\frac{k_2 + (n_2 - 1)k_{nf} - (n_2 - 1)(k_{nf} - k_2)\phi_2}{k_2 + (n_2 - 1)k_{nf} + (k_{nf} - k_2)\phi_2}\right) \quad (3)$$

Where the shape functions n1 and n2 have different values for various shapes. K_{bf} and K_{nf}, respectively, stand for the base fluid's and the hybrid nanofluid's thermal conductivities. Particles 1 and 2 have thermal conductivities of k_1 and k_2, respectively. The mass fractions of nanoparticles 1 and 2 are ϕ_1 and ϕ_2 , respectively.

According to its shape function, a correlation for the hybrid nanofluids' viscosity was created[4]. the value of Ψ1 and Ψ2 which are constant of coefficients, provided by data from [4].

$$\frac{\mu_{nf}}{\mu_{bf}} = 1 + \varphi_1\phi + \varphi_2\phi^2 \quad (4)$$

The researchers' suggested mathematical relation for the surface tension of hybrid nanofluids [4].

$$Ş_{nf} = (d_{nf}/d_w)*(n_w/n)*Ş_w \quad (5)$$

Where d_{nf} & d_w are the density of hybrid nano-fluid and water n_w & n are the number of drops of water and hybrid nano-fluid, respectively. $Ş_w$ (taken 72 dyne/cm) is surface tension of water.

2. Experimental Results & Discussion:

Table 3 demonstrates how thermal conductivity and specific heat are affected by the mass fraction of nanoparticles and surfactants. The experiment's results are shown in the graph below, K_{diesel}=0.13 W/mK & C_{diesel}=2.1 KJ/kgK

Hybrid nanoparticles mass in (mg)	Mass of surfactant (mg)	Thermal conductivity of hybrid nano-diesel (W/mK)			Specific heat of hybrid nano-diesel (KJ/kgK)		
		Diesel+CuO+ Al2O3	Diesel+ Gr CuO	Diesel+Al2O3 +Gr	Diesel+CuO+ Al2O3	Diesel+ Gr CuO	Diesel+Al2O3 +Gr
200	300	0.1510	0.1684	0.1625	2.0316	1.9957	2.0104
160	259	0.1480	0.1618	0.1557	2.0452	2.0005	2.0241
102	200	0.1402	0.1548	0.1460	2.0631	2.0166	2.0387
44	140	0.1336	0.1471	0.1368	2.0886	2.0411	2.0734
5	100	0.1305	0.1415	0.1318	2.0990	2.0566	2.0840

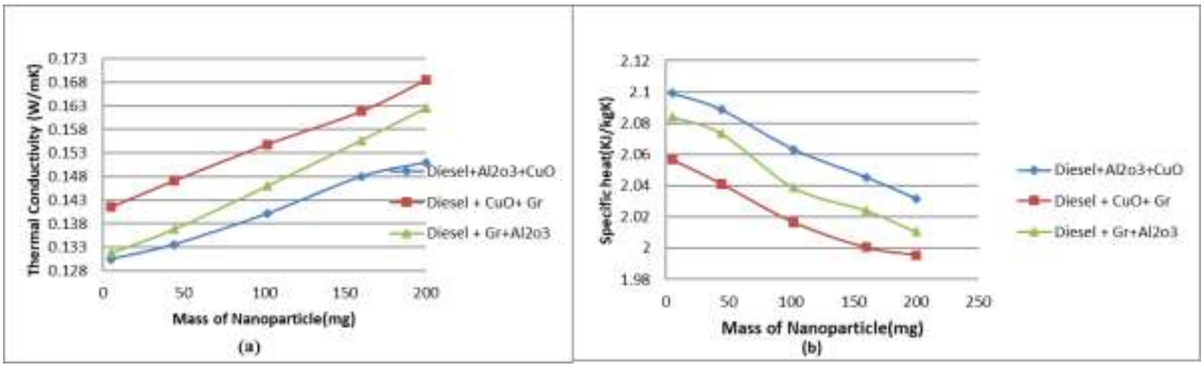

Figure 3.1 Comparison of experimental thermal conductivity & specific heat of different hybrid nano-diesel

A KD2 conductometer thermal properties analyzer and Brookfield were used to evaluate the nanofluid's thermal conductivity and specific heat. Corresponding properties of the diesel+CuO+Gr, diesel+Gr+Al2O3, and diesel+Al2O3+CuO hybrid nanofluids are depicted in fig. 3.1(a) and (b) as a function of hybrid nanoparticle mass concentration. t has been shown that the effective specific heat drops and the effective thermal conductivity of the hybrid nanofluid increases linearly as the volume % of the hybrid nanoparticles hike.

Except for the possibility that this behavior may be connected to a number of parameters such as particle size, the method used to prepare nanofluids, the kind of nanofluid, etc., the conclusive interpretation of the data is, in our opinion, very difficult and difficult to convey. However, when the fraction of particle volume increases at increasing particle densities, thermal conductivity rises and specific heat falls. A combination of unique characteristics results in a high rate of heat conductivity within the molecular structure, additionally, the mathematical relationship demonstrates it. The capacity of the nanodiesel to transmit heat is revealed by improvements in thermal conductivity. Surfactant enhances secondary atomization and mixing of oxide nanoparticles in blend mixes. At different mass fractions, pure diesel demonstrated maximum thermal conductivity gains of 29.5%, 25%, and 16.2% compared to diesel+CuO+Gr, diesel+Gr+Al2O3, and diesel+Al2O3+CuO.Refs. [2, 5, 22, 37, 40-42]confirm results.

The combination of diesel, graphene & copper nanoadditives has a lower specific heat than the other two hybrid nano-diesels because of its outstanding effective thermal conductivity. The nano-diesel's specific heat drop reveals how well it can transport heat. Surfactant enhances secondary atomization and mixing of oxide nanoparticles in blend mixes. Diesel+CuO+Gr, Diesel+Gr+Al2O3, and Diesel+Al2O3+CuO showed lower specific heats than pure diesel at different mass fractions of 5%, 4.2%, and 3.5%, respectively Refs. [2, 5, 22, 37, 40-42]confirm results.

Table 4 demonstrates how surface tension and viscosity are affected by the mass fraction of hybrid nanoparticles and surfactants, Surface tension (S_{diesel})=25.84 MN/m & Viscosity (μ_{diesel}) =5 Centi Poise

Hybrid nanoparticles mass in (mg)	Mass of surfactant (mg)	Surface tension of hybrid nano-diesel (MN/m)			Viscosity of hybrid nano-diesel (Centi Poise)		
		Diesel+CuO+ Al2O3	Diesel+ Gr CuO	Diesel+Al2O3 +Gr	Diesel+CuO+ Al2O3	Diesel+ Gr CuO	Diesel+Al2O3 +Gr
200	300	24.93	23.18	21.98	5.6	4.7	4.5
160	259	24.68	22.80	21.68	5.4	4.5	4.3
102	200	23.52	22.44	21.07	5.3	4.4	4.2
44	140	22.78	21.49	20.26	5.2	4.3	3.9
5	100	21.82	20.82	19.57	5.1	4.1	3.8

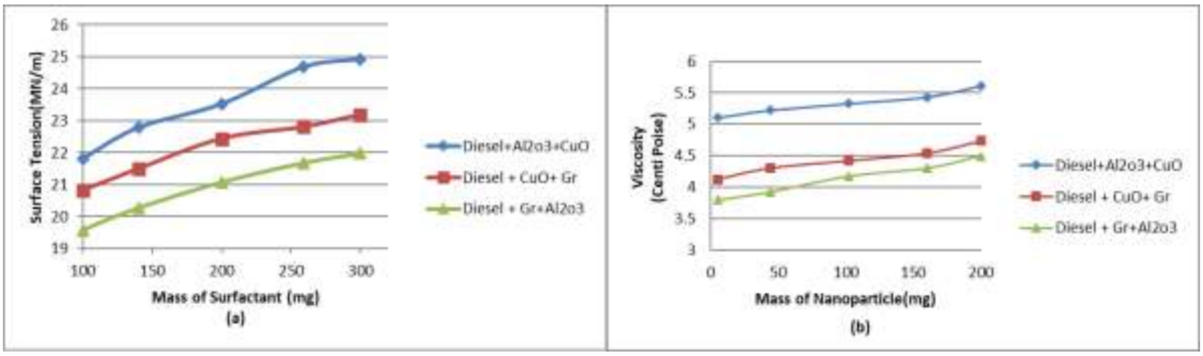

Figure 3.2 Comparison of experimental surface tension & viscosity of different hybrid nano-diesel

The inherent quality of a fluid that influences the phenomena of heat transmission and flow is its viscosity. By incorporating hybrid nanoparticles into the (diesel) base fluid, effective viscosity of hybrid nano-fluids can either exhibit Newtonian or non-Newtonian behavior, depending on variables including particle mass concentration, size, temperature, and shear rate. An Ostwald viscometer was employed in this investigation to compare the rheological behavior of the produced hybrid nano-fluids to diesel[9, 15, 17, 22]. To ensure that the data collected with the viscometer was accurate, the experiment was repeated again. Tables 2 illustrate the change in viscosity for the hybrid nano-diesel formulations of Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO at various concentrations and temperatures. As can be shown, all nanofluids display a rise in viscosity with nanoparticle mass concentration. Viscosity has the effect of preventing the fluid from moving relative to another. In fact, it is essential for the movement between those fluid layers as well as the transmission of momentum between them. A larger increase in viscosity results from the nano-clusters' ability to stop the flow of oil layers over one another. According to the viscosity findings, this nanofluid may be beneficial in engineering applications where pressure loss is not a problem. According to our understanding, engine oil would be better suited for thermal applications if temperature-related variations in viscosity were less pronounced. The variations in viscosity with temperature at various mass concentrations are shown in Table 4 to help understand how nanofluid viscosity changes with temperature. As can be observed, a nanofluid's surface tension falls as temperature rises. Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO at various mass fractions had the biggest reductions in surface tension when compared to pure diesel, at 15%, 10%, and 3.5%, respectively. The results support those mentioned in references [2, 5, 22, 37, 40-42].

The viscosity of Diesel+Gr+Al2O3 is lower than that of the other two hybrid nanodiesels as a result of the maximal dispersion of Gr+Al2O3 with diesel. The reduction in viscosity suggests that the specific Diesel+Gr+Al2O3 hybrid nanodiesel has a greater capacity for heat transmission. The secondary atomization and mixing of oxide nanoparticles are enhanced by the addition of surfactant to the blended fluid. According to Fig. 3.2(b), the viscosity of Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO decreased the most viscosity when compared to pure diesel at various mass fractions, by 10%, 5.5%, and 4.5%, respectively. References [2, 5, 22, 37, 40-42] are used to verify the results.

Table 5 demonstrates how Reynolds number and Prandtl number are affected by the mass fraction of hybrid nanoparticles and surfactants

Hybrid nanoparticles mass in (mg)	Mass of surfactant (mg)	Reynolds number of hybrid nano-diesel			Prandtl number of hybrid nano-diesel		
		Diesel+CuO+ Al2O3	Diesel+Gr+ CuO	Diesel+Al2O3 +Gr	Diesel+CuO+ Al2O3	Diesel+Gr+ CuO	Diesel+Al2O3 +Gr
200	300	5532	5474	5398	76.47	76.30	74.90
160	259	5516	5469	5392	77.19	77.05	75.83
102	200	5478	5448	5383	78.36	78.25	77.37
44	140	5421	5408	5368	79.66	79.60	79.17
5	100	5370	5369	5359	80.64	80.63	80.58

.

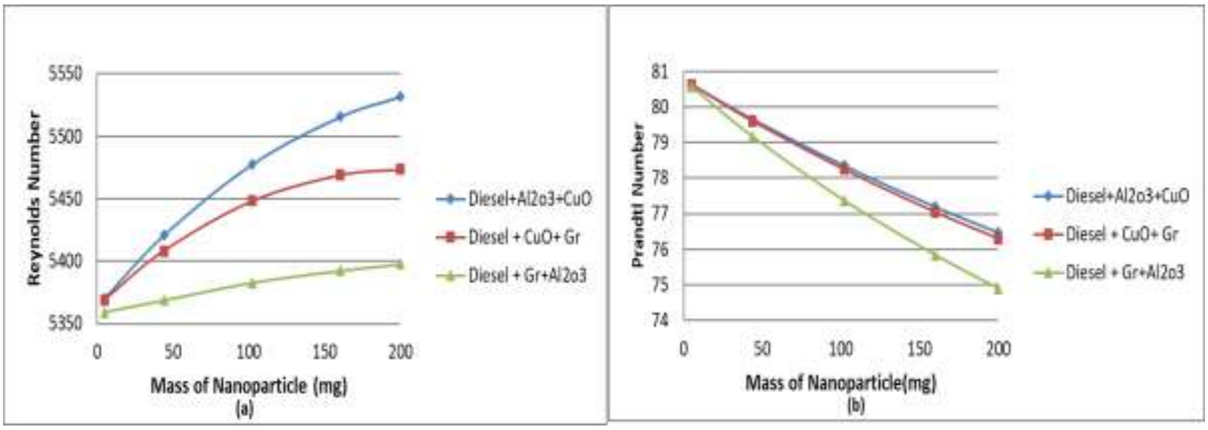

Figure 3.3 Comparison of experimental Reynolds number & Prandtl number of different hybrid nano-diesel

The influence of introducing hybrid nanoparticles of Gr+Al2O3, CuO+Gr, and Al2O3+CuO to neat diesel on Reynolds number and Prandtl number at variable nanoparticle mass fractions with surfactant (SDS) addition are shown in table 5 and figure 3.3. Figure 3.3(a) depicts a typical trend of Reynolds number versus mass fraction for all investigated fuel types. The Reynolds number increases when diesel mixes contain more nanoparticles. Gr+Al2O3 hybrid nanodiesel exhibited a lower Reynolds number than the other two hybrid nanodiesels due to higher flame propagation. The lowering Reynolds number indicates reduced turbulence during fuel combustion inside the cylinder. References [2, 5, 22, 37, 40-42]are used to validate the results.

Figure 3.3(b) displays a typical trend of Prandtl number vs mass fraction for each tested fuel type. The Prandtl number decreases as the number of nanoparticles in diesel mixes increases. Gr+Al2O3 hybrid nanodiesel has a lower Prandtl number than the other two hybrid nanodiesels because it has a higher effective thermal conductivity and a lower specific heat. The Prandtl number is an intrinsic property of fluids. Fluids with high thermal conductivity and free-flowing properties are known to have small Prandtl values, which makes them an attractive choice for heat-conducting fluids. References [[2, 5, 22, 37, 40-42] are used to verify the results.

Table 6 demonstrates how Nusselt number and Convective heat transfer coefficient are affected by the mass fraction of hybrid nanoparticles and surfactants

Hybrid nanoparticles mass in (mg)	Mass of surfactant (mg)	Nusselt number of hybrid nano-diesel			Heat transfer coefficient of hybrid nano-diesel (W/m2K)		
		Diesel+CuO+ Al2O3	Diesel+Gr+ CuO	Diesel+Al2O3 +Gr	Diesel+CuO+ Al2O3	Diesel+Gr+ CuO	Diesel+Al2O3 +Gr
200	300	183.60	184.86	180.15	333	354	340
160	259	182.91	183.98	179.86	324	345	331
102	200	182.63	183.50	178.70	310	331	319

44	140	179.51	181.24	174.25	291	317	306
5	100	167.23	167.23	167.23	281	306	296

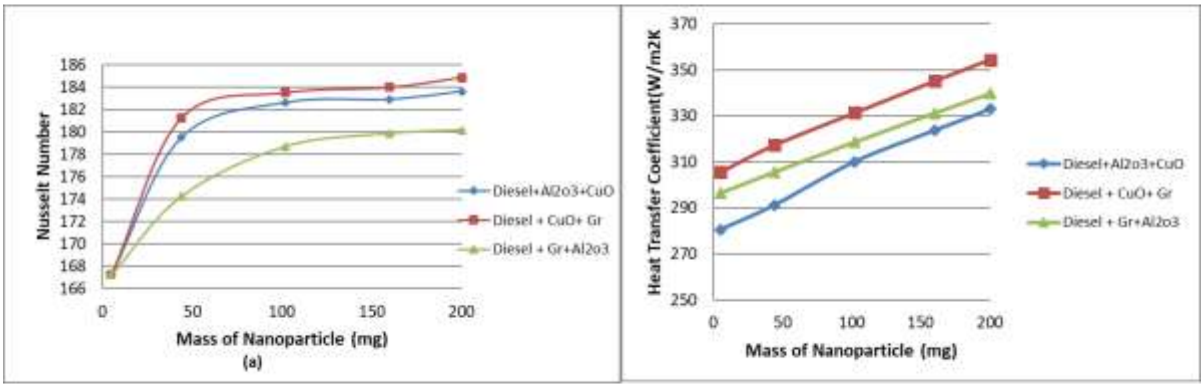

Figure 3.4 Comparison of experimental Nusselt number & Heat transfer coefficient of different hybrid nano-diesel

According to experimental findings, the Nusselt number enhanced as the nanoparticle volume concentration of hybrid nanoparticles and Reynolds number increased. When nanoparticles were added to the parent fluid, the Nusselt number increased by 7% to 15.56%. Furthermore, for Reynolds numbers 5359 and 5370, the improvements in heat transmission were seen at volume concentrations of 14.67% and 21.10%, respectively. Additionally, the molecular Brownian movement, the thermo-physical characteristics of the hybrid nanoparticles, and the broad surface range are responsible for the improvement in the Nusselt number for hybrid CuO+ Gr nanofluids. As a result, the ability of CuO+ Gr nanofluid to transmit heat also improved. The attractive qualities of high thermal conductivity nanofluids, as opposed to diesel, may be credited with the improvement in the Nusselt number. The heat transfer coefficient for CuO-Gr/diesel hybrid nanofluids has shown a significant growth. Because copper and graphene nanoparticles are added to hybrid nanofluids, their thermal transport properties are improved.

Challenges & Application of Hybrid Nanofluids:

Although there has been a lot of study on hybrid nanofluids in recent years and on nanofluids during the past ten years, the findings about their behavior, features, and performances are still somewhat lacking. Following that, additional study is required to precisely assess the effects of particle size and shape, appropriate particle scattering and sedimentation, particle grouping, surfactant impacts, nanofluid temperatures, and appropriate experimental methods and procedures[2, 43]. Certain researchers have addressed some of these issues in part[2, 43]. The production of homogeneous suspensions are still a specialized test due to the extraordinarily solid Vander-Waals interactions[9, 44]. One of the most important requirements for nanofluid applications is frequently the long-term stability of nanoparticle dispersion [40, 45–47]. A reasonable correlation exists between the increase in thermal conductivity and the stability of nanofluids; the more the dispersion conduct, the greater the thermal conductivity of nanofluids [48].

It was discovered that fresh nanofluids had somewhat greater thermal conductivities than nanofluids that had been accumulated over a two-month period. This might be as a result of nanoparticles' decreasing dispersion stability with time. When stored for specific amounts of time, nanoparticles may have a tendency to aggregate. [27] looked at how the stability of Al2O3 nanofluid changed over time. It was discovered that compared to fresh nanofluids, nanofluids stored for 30 days showed some signs of settling. It showed that the thermal performance of nanofluids might deteriorate with time. Particle settling needs to be carefully examined since it may result in cooling section blockage. Nanofluid manufacture, according to[27], has only been carried out on a small scale in laboratories. The near future will be impacted by high prices, which will also restrict its potential for broad use. Costs will probably stay high until industrial methods enable mass manufacture of suspensions and related nanoparticles. The influences of base fluids, liquid-solid interfaces, and nanoparticles on the thermal conductivity of nanofluids have all been the subject of numerous experimental research in recent years[3].

Since many years ago, researchers have studied the many applications of nanofluids and nanolubricants, and more recently, a large number of review papers have been published that span business, industrial, and transportation purposes[2, 39, 45]. There are many different application areas, including refrigeration systems, automobile industry, solar energy, and electronic component cooling. In line with its industrial uses, hybrid nanofluids and hybrid nanolubricants are an important new type of nanofluid that are still in the experimental stage[2]. Hybrid nanofluids and hybrid nanolubricants are expected to be used for similar applications with improved performance[31].

3. Conclusion

These nanofluids—Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO—were examined in this work. Nanoparticle and surfactant mass increased from 5 to 200 mg and 100 to 300 mg, respectively. Investigations were done into how various aspects of heat transport are impacted by temperature and mass concentration. The preparation process and the factors affecting the hybrid nanofluid's performance have both been described in full detail. The thermal characteristics of hybrid nanofluid, in contrast, were shown to be greater in this experimental study than those of base fluid and fluid containing single nanoparticles, respectively. Furthermore, it was demonstrated that the characteristics of hybrid nanofluids change as temperature and particle volume fraction increase. Although the synthesis and temperature characteristics of hybrid nanofluids are the focus of this study, further research is required for a complete understanding the fluid's characteristics. Further experimental study is required to identify the optimum approach that will perform the best for each hybrid nanofluid synthesis since different processes yield different outcomes. There is a list of the conclusions.

- At different mass fractions, pure diesel demonstrated maximum thermal conductivity gains of 29.5%, 25%, and 16.2% compared to diesel+CuO+Gr, diesel+Gr+Al2O3, and diesel+Al2O3+CuO. The capacity of the nanodiesel to transmit heat is revealed by improvements in thermal conductivity.
- Diesel+CuO+Gr, Diesel+Gr+Al2O3, and Diesel+Al2O3+CuO showed lower specific heats than pure diesel at different mass fractions of 5%, 4.2%, and 3.5%, respectively.
- As can be observed, a nanofluid's viscosity falls as temperature rises. Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO at various mass fractions had the biggest reductions in surface tension when compared to pure diesel, at 15%, 10%, and 3.5%, respectively.
- the viscosity of Diesel+Gr+Al2O3, Diesel+CuO+Gr, and Diesel+Al2O3+CuO decreased the most viscosity when compared to pure diesel at various mass fractions, by 10%, 5.5%, and 4.5%, respectively. The viscosity of Diesel+Gr+Al2O3 is lower than that of the other two hybrid nanodiesels as a result of the maximal dispersion of Gr+Al2O3 with diesel. The reduction in viscosity suggests that the specific Diesel+Gr+Al2O3 hybrid nanodiesel has a greater capacity for heat transmission.
- The Nusselt number increased with the rise in hybrid nanoparticle volume concentration and Reynolds number, according to experimental results. The Nusselt number improved by a range of 7% to 15.56%. Furthermore, for Reynolds numbers 5359 and 5370, the improvements in heat transmission were seen at volume concentrations of 14.67% and 21.10%, respectively.

Declaration of Competing Interest:
The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability Statement:
The raw/processed data cannot be shared at this time as it is also part of ongoing research.

4. References

1. Adamu, I.M., N.A.C. Sidik, and M.M.J.J.o.A.R.i.A.M. Jamil, Preparation methods and thermal performance of hybrid nanofluids. 2020. **66**(1): p. 7-16.
2. Babar, H. and H.M.J.J.o.M.L. Ali, Towards hybrid nanofluids: preparation, thermophysical properties, applications, and challenges. 2019. **281**: p. 598-633.
3. Harun, M.A., et al., Recent review on preparation method, mixing ratio, and heat transfer application using hybrid nanofluid. 2022. **95**(1): p. 44-53.
4. Bhattad, A., et al., Review on Mono and Hybrid Nanofluids: Preparation, Properties, Investigation, and Applications in IC Engines and Heat Transfer. 2023. **16**(7): p. 3189.
5. Mercan, H., Thermophysical and rheological properties of hybrid nanofluids, in Hybrid Nanofluids for Convection Heat Transfer. 2020, Elsevier. p. 101-142.
6. Mercan, H., A. Çelen, and T. Taner, Thermophysical and rheological properties of unitary and hybrid nanofluids, in Advances in Nanofluid Heat Transfer. 2022, Elsevier. p. 95-129.
7. Sundar, L.S., et al., Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor–a review. 2017. **68**: p. 185-198.

8. Naddaf, A., S.J.J.o.T.A. Zeinali Heris, and Calorimetry, Density and rheological properties of different nanofluids based on diesel oil at different mass concentrations: an experimental study. 2019. **135**: p. 1229-1242.
9. Said, Z., et al., Synthesis, stability, density, viscosity of ethylene glycol-based ternary hybrid nanofluids: Experimental investigations and model-prediction using modern machine learning techniques. 2022. **400**: p. 117190.
10. Kazemi, I., et al., Improving the thermal conductivity of water by adding mono & hybrid nano-additives containing graphene and silica: A comparative experimental study. 2020. **116**: p. 104648.
11. Naddaf, A., S.Z.J.I.C.i.H. Heris, and M. Transfer, Experimental study on thermal conductivity and electrical conductivity of diesel oil-based nanofluids of graphene nanoplatelets and carbon nanotubes. 2018. **95**: p. 116-122.
12. Rostami, S., A.A. Nadooshan, and A.J.P.T. Raisi, An experimental study on the thermal conductivity of new antifreeze containing copper oxide and graphene oxide nano-additives. 2019. **345**: p. 658-667.
13. Sajid, M.U., H.M.J.I.J.o.H. Ali, and M. Transfer, Thermal conductivity of hybrid nanofluids: a critical review. 2018. **126**: p. 211-234.
14. Yalçın, G., et al., Measurement of thermal conductivity and viscosity of ZnO–SiO 2 hybrid nanofluids. 2021: p. 1-17.
15. Ağbulut, Ü., et al., Synthesis of graphene oxide nanoparticles and the influences of their usage as fuel additives on CI engine behaviors. 2022. **244**: p. 122603.
16. Awais, M., et al., Synthesis, heat transport mechanisms and thermophysical properties of nanofluids: A critical overview. 2021. **10**: p. 100086.
17. Mehta, B., et al., Synthesis, stability, thermophysical properties and heat transfer applications of nanofluid– a review. 2022: p. 120034.
18. Jamil, F. and H.M. Ali, Applications of hybrid nanofluids in different fields, in Hybrid nanofluids for convection heat transfer. 2020, Elsevier. p. 215-254.
19. Nagarajan, A., et al., Preparation methods and thermal performance of hybrid nanofluids. 2018. **3**(6): p. 42-47.
20. Sidik, N.A.C., I.M. Adamu, and M.M.J.J.o.A.R.i.M.S. Jamil, Preparation methods and thermal performance of hybrid nanofluids. 2019. **56**(1): p. 1-10.
21. Gupta, N., S.M. Gupta, and S.J.M.T.P. Sharma, Preparation of stable metal/COOH-MWCNT hybrid nanofluid. 2021. **36**: p. 649-656.
22. Kanti, P., et al., Synthesis, characterization, stability, and thermal properties of graphene oxide based hybrid nanofluids for thermal applications: Experimental approach. 2022. **128**: p. 109265.
23. Abdel-Rehim, A.A. and S.Y. Akl, An experimental investigation of the effect of aluminum oxide (Al2O3) nanoparticles as fuel additive on the performance and emissions of a diesel engine. 2016.
24. Asokan, N., et al., Experimental investigation on the thermal performance of compact heat exchanger and the rheological properties of low concentration mono and hybrid nanofluids containing Al2O3 and CuO nanoparticles. 2020. **20**: p. 100727.
25. Hussein, A.M.J.E.T. and F. Science, Thermal performance and thermal properties of hybrid nanofluid laminar flow in a double pipe heat exchanger. 2017. **88**: p. 37-45.
26. Hormozi, F., et al., An experimental investigation on the effects of surfactants on the thermal performance of hybrid nanofluids in helical coil heat exchangers. 2016. **78**: p. 271-276.
27. Xian, H.W., et al., Impact of different surfactants and ultrasonication time on the stability and thermophysical properties of hybrid nanofluids. 2020. **110**: p. 104389.
28. Ghanbari, M., et al., Effect of alumina nanoparticles as additive with diesel–biodiesel blends on performance and emission characteristic of a six-cylinder diesel engine using response surface methodology (RSM). 2021. **11**: p. 100091.
29. Ağbulut, Ü., et al., Effects of high-dosage copper oxide nanoparticles addition in diesel fuel on engine characteristics. 2021. **229**: p. 120611.
30. Chinnasamy, C., et al., Environmental effects of adding aluminum oxide nano-additives on diesel engine fueled with pyrolyzed biomass oil– diesel blends. 2018. **40**(22): p. 2735-2744.
31. Cuce, P.M., et al., Effect of using hybrid nanofluids as a coolant on the thermal performance of portable thermoelectric refrigerators. 2022. **53**: p. 102685.
32. Dhahad, H., et al., Effect of aluminum oxide nanoparticles fuel additives on the performance and emissions of diesel engine. 2017. **35**(9 Part A): p. 956-960.
33. Dinesha, P., S. Kumar, and M.A.J.B.R.J. Rosen, Effects of particle size of cerium oxide nanoparticles on the combustion behavior and exhaust emissions of a diesel engine powered by biodiesel/diesel blend. 2021. **8**(2): p. 1374.

34. Elipey, M.K., et al. Dispersion effect of Al2O3 nanoparticles in diesel and hemp biodiesel blend on the engine parameters of a diesel engine. in AIP Conference Proceedings. 2022. AIP Publishing LLC.
35. El-Seesy, A.I., et al., Investigation the effect of adding graphene oxide into diesel/higher alcohols blends on a diesel engine performance. 2020. **17**(3): p. 233-253.
36. Elsaid, K., et al., Thermophysical properties of graphene-based nanofluids. 2021. **10**: p. 100073.
37. Tahat, M.S. and A.C. Benim. Experimental analysis on thermophysical properties of Al2O3/CuO hybrid nano fluid with its effects on flat plate solar collector. in Defect and diffusion forum. 2017. Trans Tech Publ.
38. Wanatasanappan, V.V., M. Rezman, and M.Z.J.N. Abdullah, Thermophysical Properties of Vegetable Oil-Based Hybrid Nanofluids Containing Al2O3-TiO2 Nanoparticles as Insulation Oil for Power Transformers. 2022. **12**(20): p. 3621.
39. Benedict, F., et al., Thermal performance of hybrid-inspired coolant for radiator application. 2020. **10**(6): p. 1100.
40. Eshgarf, H., et al., A review on the properties, preparation, models and stability of hybrid nanofluids to optimize energy consumption. 2021. **144**: p. 1959-1983.
41. Nabil, M., et al., Thermo-physical properties of hybrid nanofluids and hybrid nanolubricants: a comprehensive review on performance. 2017. **83**: p. 30-39.
42. Nadooshan, A.A., H. Eshgarf, and M.J.J.o.M.L. Afrand, Measuring the viscosity of Fe3O4-MWCNTs/EG hybrid nanofluid for evaluation of thermal efficiency: Newtonian and non-Newtonian behavior. 2018. **253**: p. 169-177.
43. Kegl, T., et al., Nanomaterials as fuel additives in diesel engines: A review of current state, opportunities, and challenges. 2021. **83**: p. 100897.
44. Mousavi, S.B., S.Z. Heris, and P.J.F. Estellé, Viscosity, tribological and physicochemical features of ZnO and MoS2 diesel oil-based nanofluids: An experimental study. 2021. **293**: p. 120481.
45. Kegl, T., et al., Nanomaterials for environmental application. 2020: Springer.