Biointerface Research in Applied Chemistry
Open-Access Journal (ISSN: 2069-5837)

Article
Volume 13, Issue 3, 2023, 229
https://doi.org/10.33263/BRIAC133.229

Experimental Investigations of Thermophysical Properties and Convective Heat Transfer of Al_2O_3 and CuO Nanofluids in a Copper Tube: Proposing New Correlations

Vinay Singh [1], Munish Gupta [2], Ajay Kumar [3,*], Sunil Luthra [4], Ashwini Kumar [5,*]

1 Chaudhary Ranbir Singh State Institute Of Engineering & Technology, Jhajjar, Haryan, India; theahlawat89@gmail.com (V.S.);
2 Guru Jambheshwar University of Science & Technology; vinaysinghahlawat@gmail.com (M.G.);
3 Department of Mechanical Engineering, School of Engineering and Technology, JECRC University, Jaipur, RJ , India; ajay.kumar30886@gmail.com (A.K.);
4 Chaudhary Ranbir Singh State Institute Of Engineering & Technology, Jhajjar, Haryana, India; sunilluthra1977@gmail.com (S.L.);
5 Shree Guru Govind Singh Tricentenary University , Gurugram, HR, India; aknitjsr08@gmail.com (A.K.);
* Correspondence: ajay.kumar30886@gmail.com (A.K.), aknitjsr08@gmail.com (A.K.);
Scopus Author ID 57221102028

Received: 12.01.2022; Accepted: 10.02.2022; Published: 6.06.2022

Abstract: The performance of the Alumina/water and copper oxide/water nanofluids in a heat exchanger is experimentally investigated for particle weight concentrations ranging from 0.02 wt% to 0.5 wt%. The alumina/water and copper oxide/water nanofluids were prepared using two-step methods in an aqueous solution with 0.01 wt% CTAB (Cetyl Trimethyl Ammonium Bromide) as a surfactant at different concentrations and were characterized using HRTEM (High-Resolution Transmission Electron Microscopy) technique. Laminar forced convective heat transfer analysis using alumina and copper oxide nanoparticles suspended in water in a circular horizontal tube under constant heat flux boundary conditions was performed. The effect of various flow conditions and weight concentrations in the local heat transfer coefficient and pressure drop of both the nanofluids were investigated. Reynolds number varied from 1275 to 2200. Results show that 12.7 & 14.5 % thermal performance enhancement was observed with 0.5 wt% of Al_2O_3 and CuO nanofluids. Maximum, 50.62 % enhancement was observed in the average heat transfer coefficient by Al_2O_3 nanofluids, whereas 52.74 % was observed using CuO nanofluids using 0.5 wt% concentrations of the nanofluids and at Reynolds number of 2200. Correlations were proposed for thermal conductivity, viscosity, and Nusselt number for both the nanofluids with the maximum and minimum deviations of ±9 % and ±10 %, respectively.

Keywords: Al_2O_3 nanofluids; CuO nanofluids; Laminar flow; copper tube; thermal conductivity; viscosity; heat transfer; pressure drop.

© 2022 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

In recent times, heat transfer has played a significant role in highly developed technologies like microelectronics, air conditioning, power generation, mechatronics, food processing, and oil and gas industries [1-7]. The latest trends in advanced semiconductor techniques and ever-increasing customer demands for products with more proficiency have resulted in the development of electronic devices that have miniature size, improved computational speed, better performance, and high power densities [8-12]. Due to these advanced features, thermal management of these electronic devices becomes crucial as the overheating of devices affects the lifetime, reliability, and overall performance, leading to thermal breakdown [13]. Since various remarkable technologies, including thermoelectric cooling, phase change material base cooling, heat pipe, and pump-based cooling, have been done in the last few years, still there are challenging issues in managing the electronic and electrical devices [14]. To perform over the heating effect of electronic devices, dielectric coolants, including fluorocarbons and liquids (silicon-based and aliphatic), possess better heat transfer properties in comparison with the non-dielectric conventional coolants (oils, water & ethylene glycol) [15]. But studies revealed that these cooling materials are not effective and efficient in the case of heat-generating devices [16]. Lower heat transferring capacity remains a limitation for these fluids. So, developing heat transfer fluids that possess better efficiency is the need of the hour to tackle thermal management in these devices [17].

Nikelham *et al*. [18] utilized and stimulated the forced convection of alumina/water nanofluid inside a magnetic field using circular cylinder geometry. Discretization of energy and naviers stokes equations were done using FEM (Finite element method). To examine the thermophysical properties of the nanofluid, an experimental model was used as a function of temperature, volume fraction, and nanoparticle diameter. An increment in Nusselt number was observed with an increase in Reynolds number and magnetic field. Plant *et al*. [19] examine the effect of nanofluid concentration on the possible heat transfer using various heat sinks possessing porous media. Their work includes an experimental and numerical investigation into the effect of aluminum oxide on the system's thermal performance. Using high (1% vol.) nanofluids paired with different channel designs resulted in an average 15 % and a maximum 24 % thermal enhancement. Kumar *et al*. [20] work aims at the preparation of nanofluids using Al_2O_3 nanomaterials as a dispersant in (80:20) solar glycol/water mixture and investigating the thermophysical properties at various volume percentages. The stability of the prepared nanofluids was checked using zeta potential, visual inspection, and UV VIS spectrometer (Ultraviolet-visible spectroscopy). Thermal conductivity was found augmented by 26.36 % at a volume concentration of 0.45 % at a temperature of 30^0C, and viscosity increment was observed by nearly 1.85 times compared to SG–water (Solar Glycol-water) mixture. The confounded associations between nanoparticles of various sizes on the rheological attributes of crossover nanofluids, Al2O3-Cu/W half breed nanofluids with volume parts of 0.3-1.5 vol% were contemplated in the review introduced by Ma *et al*. [21]. Different sizes of Al_2O_3 nanoparticles ranging from 20-50nm and Cu nanoparticles of 50nm were used. Viscosity was found to increase along with an increase in the volume concentration of the nanofluids. Higher viscosity was observed in the Hybrid nanofluids compared to the mono nanofluids. Amjadian *et al*. [22] experimented to understand the effect of several factors like nanofluid concentration, Reynolds number on fluid flow, and heat transfer characteristics for cooling an aluminum disk with constant heat flux. Experiments showed that the heat transfer efficacy of the system increased by 45 % at a concentration of 0.07 % using the Reynolds number of 7330. Uddin *et al*. [23] conducted an experimental study of thermal, flow forms, and local Nusselt number for different appropriate parameters in alumina water nanofluid. Results indicate that increasing the Rayleigh number from 105 to 106 increases the heat transfer rate to 72.78 %. Also, comparing the heat transfer results of the nanofluid having a volume fraction of 0.6 % with base fluid, the heat transfer rate can be increased by 10.42 %.

Akhavan *et al*. [24] studied thermo rheological properties and heat transfer behavior of copper oxide- heat transfer oil and observed a maximum 32 % enhancement in Nusselt number using 1.5 % CuO nanoparticles. Heris *et al*. [25] conducted an experimental study to examine the convective heat transfer using alumina/water nanofluid in a horizontal tube. Convective heat transfer was found to be increased by about 40 % using a mass concentration of 2.5 and a Peclet number value of 6000. Relocation, motion, and collision were considered the fundamental variables behind heat move upgrades. An experimental study on pressure drop and heat transfer characteristics using CuO- based oil nanofluid in helical coil geometry was performed by Hashemi *et al*. [26]. Reports stated the 30 % enhancement in heat transfer and 18 % increase in the pressure drop. Kannaiyan *et al*. [27] were the first to study the thermophysical properties of cupric oxide and alumina nanoparticles hybrids using water/water EG (Ethylyn glycol)-based fluids with different fractions and temperatures. Almost 25 % improvement in warm conductivity was noticed utilizing the half-breed nanofluids at a temperature of 70°C.

Although numerous experimental and theoretical research articles have been published by several researchers in the last decade regarding the synthesis of different nanofluids, thermophysical properties of nanofluids, heat transfer with different boundary conditions, but still systematic and organized studies are required. Some articles regarding methods of synthesis of Al_2O_3/water and CuO/water nanofluids and their thermal analysis in heat transfer equipment/heat exchangers have been published. However, a number of works have been going on the thermal and thermohydrailic performance of such nanofluids but are limited to the analysis of physical behaviors. So there is a need for an investigation regarding heat transfer analysis using these Al_2O_3/water and CuO/water nanofluids using constant heat flux boundary conditions and the development of correlations for such properties of these nanofluids. In this context, fluids having outstanding heat transfer capabilities, i.e., nanofluids, were developed. The current work depends on heat move examination involving consistent hotness transition limit conditions in a round tube utilizing alumina/water and CuO/water nanofluids. These fluids proved to be the potential to remove the heat from the cooling systems. Various advanced properties, i.e., enhanced thermal conductivity, Thermophoresis, and Brownian motion, make nanofluids a potential to use in several electronic and heat transfer processes. The objective of the present study also includes synthesizing stable nanofluids and further examining the thermophysical properties and the heat transfer properties of the stabilized Al_2O_3/Water CuO/Water nanofluids. This study deals with the investigation of different factors influencing the thermophysical properties of Al_2O_3/Water, CuO/Water nanofluids, the effect of increasing weight fraction, thermal benefits of utilizing water-based aluminum oxide and copper oxide nanofluids, and the development of new correlations for estimating thermal conductivity, viscosity, and the Nusselt number using constant heat flux condition, for which no experimental investigation has been reported previously in the literature. The novelty of this work is based on extracting the experimental data for the prepared nanofluids and presenting new correlations for Nusselt number and thermophysical properties for a circular tube.

2. Materials and Methods

2.1. Nanofluids preparation and stability.

In the present experimental study, Al_2O_3 and CuO solutions were used in different weight proportions ranging from 0.02, 0.05, 0.1, 0.2, and 0.5 wt% concentrations. The average particle size from 10 mm to 30 mm was used in the experiments. The synthesis method of the nanofluids has been demonstrated in previous research [28]. To ensure the proper mixing, a magnetic stirrer and a bath and probe sonicator were used. However, CTAB (Cetyl Trimethyl Ammonium Bromide) surfactant was also used to prevent the solution from any kind of agglomeration or sedimentation. Surfactant ensures the stability of the solution for some days. The solutions were kept for about two months to check sedimentation.

2.2. Characterization techniques.

Characterization techniques involve different tests, including HRTEM (High-Resolution Transmission Electron Microscopy), EDS (Energy-Dispersive X-ray Spectroscopy), and UV Spectroscopy. These tests are useful in understanding the nanopowders' complete physical structure and morphology. The respective transmission electron microscopy images of copper oxide nanopowder samples have been found during the experimentation, as shown in Figure 1. Results for various characterization techniques have been shown in [28] and [29].

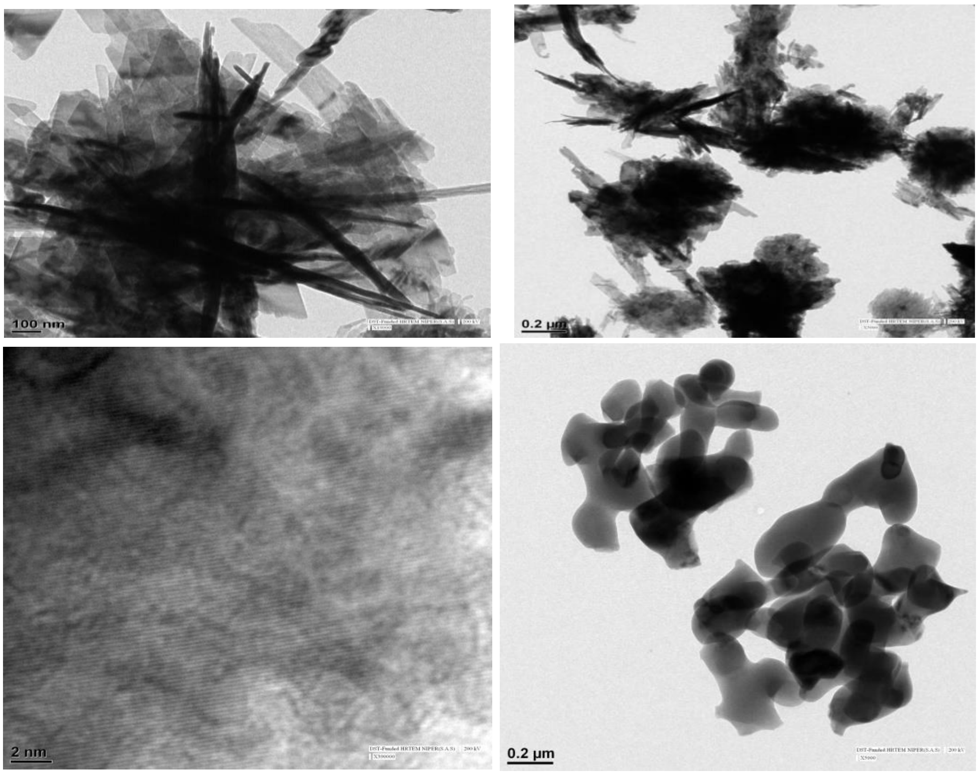


Figure 1. Transmission electron microscopy images of Copper Oxide nanopowder samples.

3. Results and Discussion

3.1. Thermophysical properties.

3.1.1. Thermal conductivity.

The measurements for thermal conductivity were carried out using KD2 Pro (Decagon Instruments). First, the accuracy of the results was checked using the distilled water samples. Experimental research was carried out three times, and the average value was determined for taking as reference. Thermal conductivity for both the nanofluids was measured from 30°C to 80°C temperature range. For validating the thermal conductivity results, a comparison was made with the Ramires *et al*. [30] and data book results (a handbook for thermal conductivity is there to check the thermal conductivity value of different substances and mixtures). Comparison with the results has already been shown in [31].

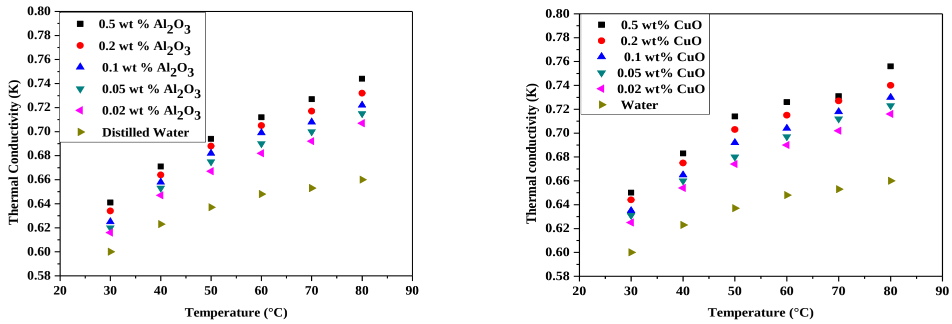
Aluminum oxide nanofluids showed an increasing drift in the thermal conductivity with temperature and weight concentration. Aluminum oxide nanofluids with 0.02 wt% showed 2.8% enhancements in the thermal conductivity at 30°C and 7.2 % at 80°C in comparison with the distilled water. Similarly, 3.4% and 8.3% enhancements in the thermal conductivity were achieved by 0.05 wt% alumina nanofluids at 30°C and 80°C, respectively. This value increases up to 4.1 % and 9.4 % in the case of 0.1wt % nanofluids at 30°C and 80°C. However, at the same temperature, an increment of 5.6 % and 10.9 % was observed in the nanofluids with 0.2 wt%. The highest increment observed by alumina nanofluids was 12.7 % at 80°C in comparison with the distilled water.

The highest increasing trend can be observed using the copper oxide nanofluids. CuO nanofluids with 0.02 wt% increased 4.2 % and 8.5 % at 30°C and 80°C, respectively. This value goes higher on increasing concentration. Highest enhancement was observed at 80°C was 9.6 % (0.05 wt%), 10.6 % (0.1 wt%), 12 % (0.2 wt%) and 14.5 % (0.5 wt%) of nanofluids.

The prime reasons behind the increased thermal conductivity of the nanofluids are liquid layering at the interface of liquid and particle, Brownian motion of the particles, heat transfer mode in nanoparticles, and nanoparticles clustering effect [32,33].

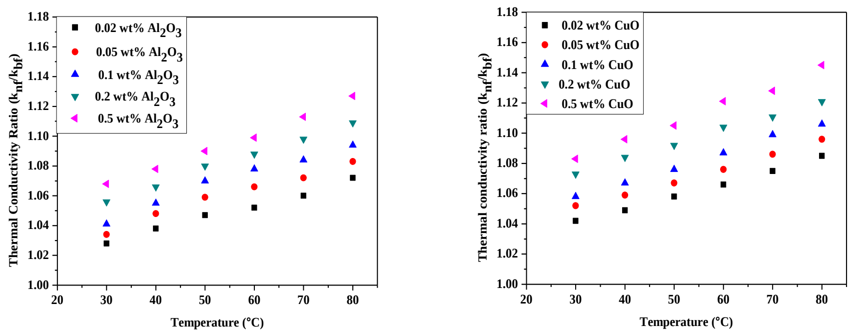
3.1.1.1. Thermal conductivity ratio.

It is defined as the ratio between the nanofluid's thermal conductivity with respect to the thermal conductivity of the base fluid, distilled water.



(a) (b)

Figure 2. Thermal conductivity of (a) Al_2O_3 and (b) CuO nanofluids.



(a) (b)

Figure 3. (a) Thermal conductivity ratio graphs of Aluminum oxide and (b) copper oxide nanofluids (water).

The present study deals with the thermal conductivity of both Al_2O_3 and CuO nanofluids at different concentrations (up to 0.5 wt%) and temperatures ranging from 30°C to

80°C, as shown in Figure 2 (a-b). The graphical representation of the percentage enhancement of thermal conductivity ratios for nanofluids at various weight concentrations regarding distilled water at the same temperatures is shown in Figures 3 (a-b). Here, the thermal conductivity increased with particle concentration and with temperature.

3.1.2. Viscosity.

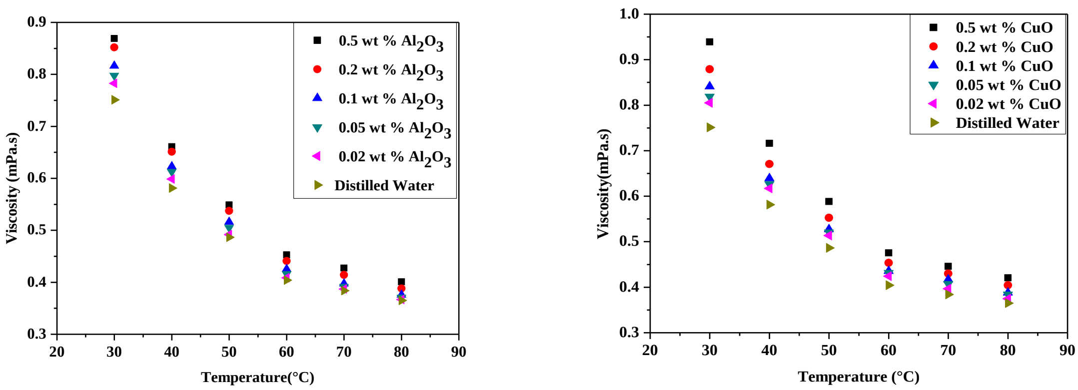
In a similar manner, the viscosity of nanofluids was measured after validating with the existing literature. Once the literature results were validated, nanofluids samples with different weight concentrations for both the nanofluids were measured.

The results show the increasing trend in viscosity of the nanofluids with an increase in the weight concentration. This can be explained as because the increase in concentration directly influences the internal shear stress of the fluid [34]. Further, the results show that the viscosity shows decrement with the increase in the temperature. This is because adhesion forces between particles and molecules become weak [35].

The highest increasing trend was observed using the copper oxide nanofluids. CuO nanofluids with 0.02 wt% increased 7.2 % and 2.7 % at 30°C and 80°C, respectively. This value goes higher on increasing concentration. Highest increment observed at 30°C was 9 % (with 0.05 wt%), 12 % (with 0.1 wt%,), 17 % (with 0.2 wt%) and 25 % (with 0.5 wt% concentrations) of nanofluids. (See Figure 4 (a)).

Aluminum oxide nanofluids with 0.02 wt% showed a 4.2 % increase in the viscosity at 30 °C in comparison with the distilled water. Similarly, a 6.2% increment in the viscosity was achieved by 0.05 wt% aluminum oxide nanofluids at 30°C. This value increases up to 8.7 % in the case of 0.1 wt% nanofluids at 30°C. An increment of 13.4 % was observed in the nanofluids with 0.2 wt% at the same temperature. The highest value of viscosity observed by aluminum oxide nanofluids was 15.7 % at 30°C and 9.9 % at 80°C in comparison with the distilled water. (See Figure 4 (b)). Also, it has been found that viscosity decreases with an increase in temperature and is found to increase with an increase in particle concentration.

At the temperature range of 30^0C to 70^0C, the thermal conductivity increases along with the temperature rise. The prime reasons behind the increased thermal conductivity of the nanofluids temperature range of 30^0C to 70^0C are the Brownian motion of the particles and liquid layering at the interface of liquid and particle.



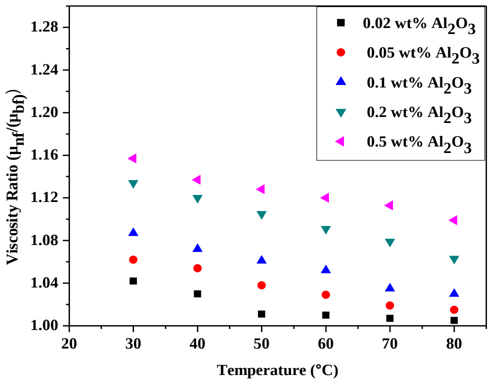
(a) (b)

Figure 4. (a) Viscosity of Aluminum oxide and (b) copper oxide nanofluids.

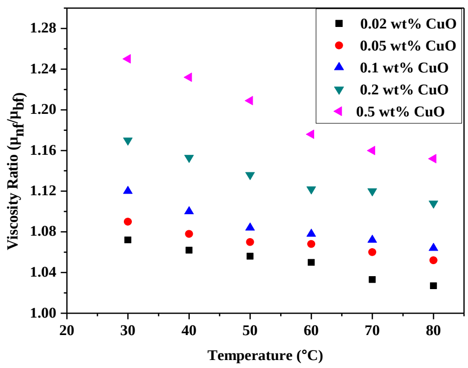
Also, here, the prime reason for not taking maximum temperature beyond 80^0C for better conductivity is that at temperatures above 80^0C, the water/liquid in the nanofluids starts evaporating, i.e., changes from a liquid state to a vapor state. The base fluid used in the study is water; the complete liquid evaporates at higher temperatures, and only solid nanoparticles are left down in the sample.

3.1.2.1. Viscosity ratio.

The viscosity ratio of Aluminum oxide and Copper oxide nanofluids concerning base fluid, i.e., distilled water, was calculated—the percentage increment of relative viscosity of both nanofluids viz. Aluminum oxide and Copper oxide nanofluids having different concentrations and at different temperatures concerning distilled water have been graphically represented by Figures 5 (a-b).



(a)



(b)

Figure 5. (a-b). Viscosity ratio graphs of Aluminum oxide and copper oxide nanofluids in the temperature range (30°C to 80°C) concerning water.

3.1.3. Correlations (proposed) for thermophysical properties.

Based on the present experimental results, correlations have been developed separately for nanofluids to predict thermal conductivity and viscosity. These correlations have been developed using the regressions analysis method for the predicted data for the present work.

The correlation developed for thermal conductivity of aluminum oxide (Al_2O_3/DI water) (Al_2O_3/Deionized water) nanofluid is as under:

$$K_{(Al_2O_3)} = 0.39929 \times (T)^{0.143375} \times (\psi)^{0.13716} \quad (1)$$

In the same way, the correlation developed for copper oxide (CuO/DI water) nanofluids is

$$K_{(CuO)} = 0.41104 \times (T)^{0.1404} \times (\psi)^{0.01523} \quad (2)$$

Where K_{Al2O3} = Thermal conductivity of Al_2O_3/DI water nanofluid,
K_{CuO} is the thermal conductivity of CuO/DI water nanofluids, and ψ is the weight concentration of the nanofluids.

Similarly, Correlations were also developed for the viscosity of both nanofluids by using the regression analysis method.

For alumina nanofluid:

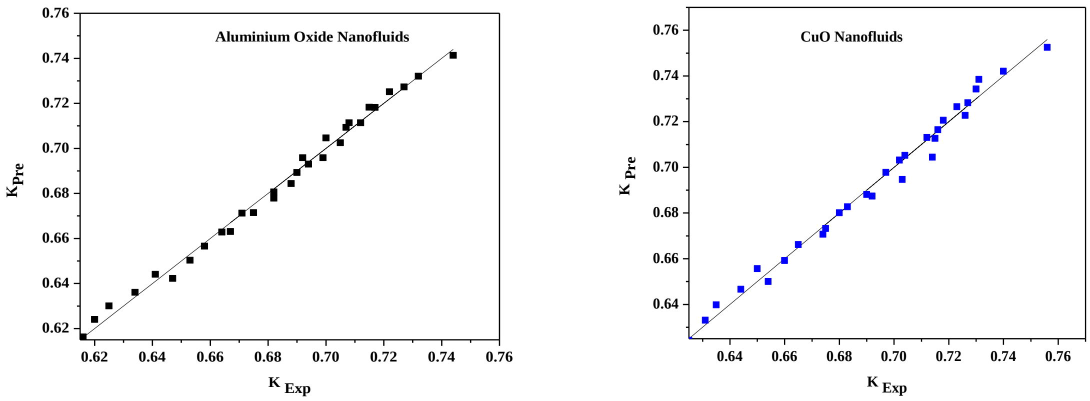
$$\mu_{(Al_2O_3)} = 13.51 \times (T)^{-0.80941} \times (\psi)^{0.032944} \quad (3)$$

In the same way, the correlation developed for the viscosity of the copper oxide nanofluids is

$$\mu_{(CuO)} = 14.43 \times (T)^{-0.8121} \times (\psi)^{0.04083} \tag{4}$$

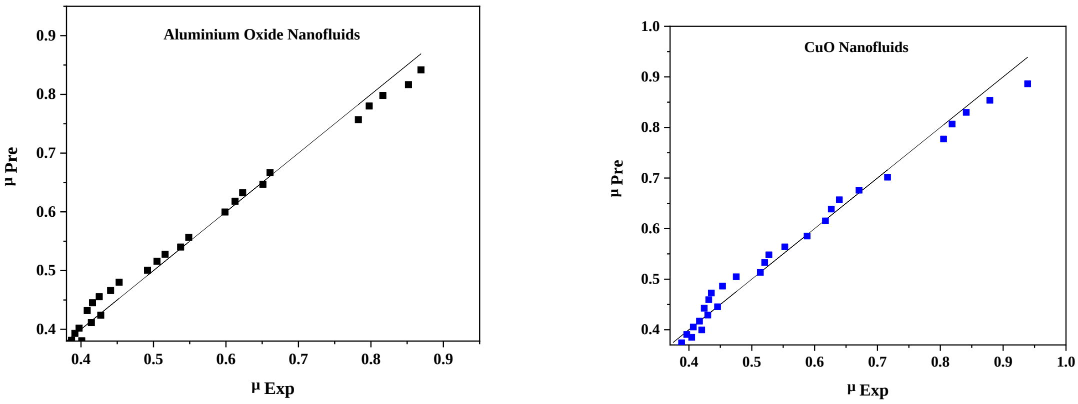
Where, $\mu_{Al_2O_3}$ is the viscosity of aluminum oxide (Al_2O_3/DI water) nanofluid and μ_{CuO} is the viscosity of copper oxide (CuO/DI water) nanofluids.

Based on the above-derived correlations for thermal conductivity and viscosity properties of aluminum oxide and copper oxide nanofluids, deviation graphs have been plotted to show the proper and acceptable deviation range between the experimental and predicted values. It has been shown in Figures 6 (a-b) and 7 (a-b) for the respective values of thermal conductivity and viscosities of aluminum oxide and copper oxide nanofluids. And the maximum and minimum deviations between the experimental and predicted ones have been found in the range of ± 10 % for both the respective studies, which is within the acceptable range.



(a) (b)

Figure 6. Predicted value Vs. Experimental value graph of thermal conductivity results for (a) Aluminum Oxide/water and (b) Copper Oxide nanofluids.



(a) (b)

Figure 7. Predicted value Vs. Experimental value graph of viscosity results for (a) Aluminum Oxide/water and (b) Copper Oxide/water nanofluids.

3.2. Heat transfer results.

The complete description of the experimental setup, data validation, and validation test with water has already been explained in [31].

To examine the convective heat transfer of the Al_2O_3 and CuO nanofluids, experiments were carried out in circular tubes using different weight concentrations of both nanofluids. Figure 8(a-d) demonstrates the local heat transfer using aluminum oxide nanofluids in different weight concentrations ranging from 0.02 to 0.5 wt% at four fixed values of Reynolds number. A laminar flow regime was used in the experimental study. The highest enhancement rate was observed at the inlet or entrance of the test section. But as we approached the length of the tube, a noticeable reduction in the heat transfer enhancement occurred. The real phenomenon behind this reduction is the boundary layer theory. As the value of thermal resistance remains less at the test section entrance, higher values of heat transfer can be observed at the entrance region of the test section. But on the axial movement of the test section, the development of the thermal boundary layer occurs, resulting in the thermal resistance increment. This thermal resistance increment further leads to the decrement of the heat transfer coefficient. Experimental results clearly state that heat transfer enhances the nanofluids, and better outcomes can be attained with increased weight concentrations of the nanofluids. Maximum enhancement in convective heat transfer coefficient obtained for 0.5 wt.% of nanofluid enhanced in the rate of 45.79 %, 48.14 %, 49.92 %, and 50.62 % for Re = 1275, 1500, 1875, and 2200 respectively concerning the base fluid.

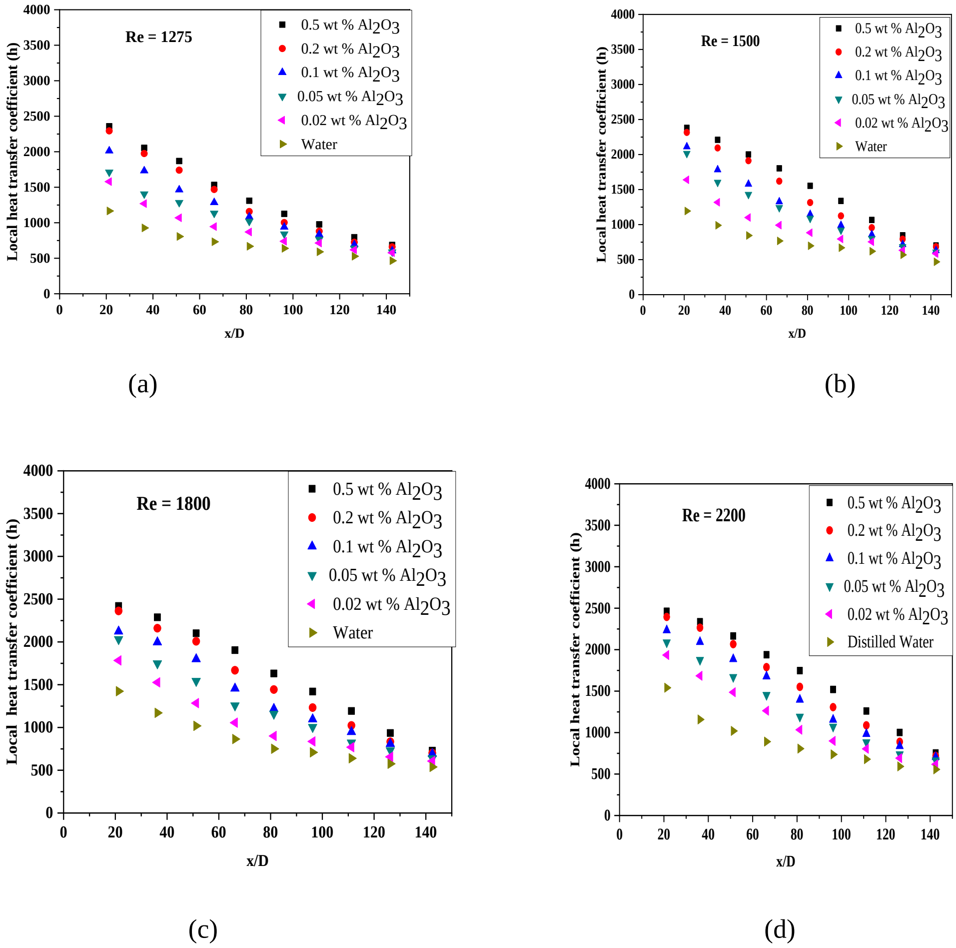
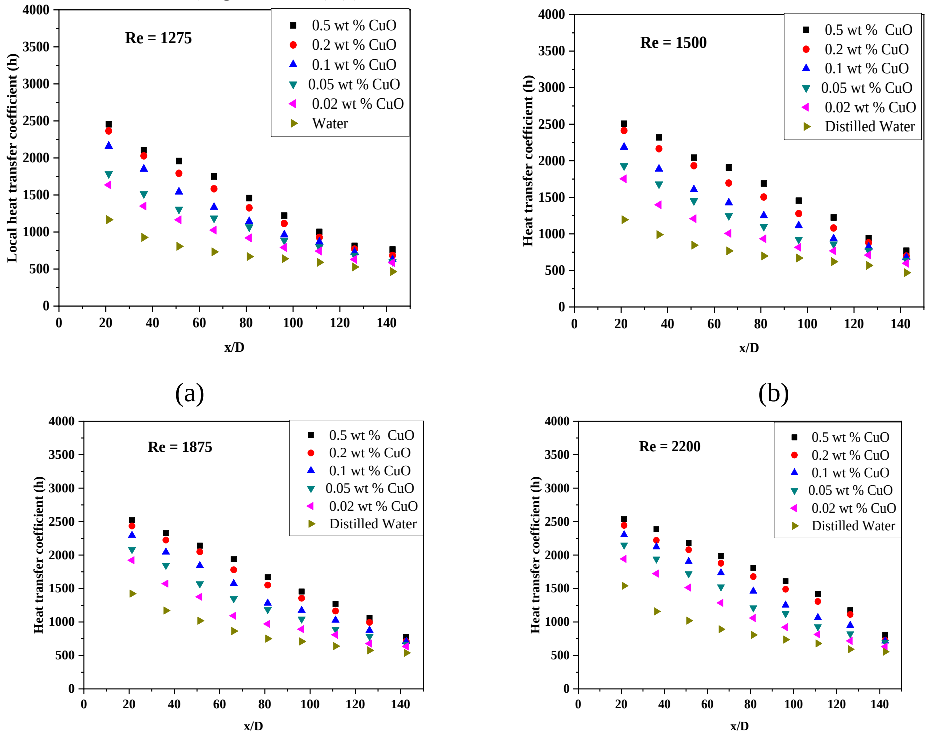


Figure 8. Convective Heat transfer (local) (a-d) for aluminum oxide nanofluid along the test section length at different weight concentrations.

Similarly, Figures 9 (a-d) depict the convective heat transfer coefficient variation of copper oxide nanofluids at four fixed values of Reynolds numbers. Maximum enhancement in convective heat transfer coefficient (HTC) obtained for 0.5 wt.% of nanofluid enhanced in the rate of 49.13 %, 50.69 %, 51.69 % and 52.74 % for Re = 1275, 1500, 1875 and 2200 respectively in comparison with base fluid. Finally, it was found that heat transfer increases with an increase in the weight concentration of the nanofluids.

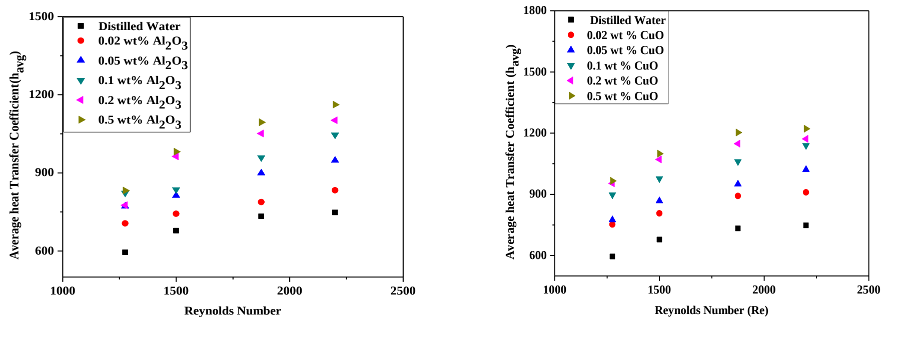
3.2.1. Average heat transfer coefficient.

Heat transfer variations for distilled water and both the nanofluids for all the five weight concentrations in terms of Reynolds number have been depicted in figures 10(a) and (b). The value found increasing along with the rise in nanoparticle concentration and increment of Reynolds number. Figure 10(a) shows that the highest convective heat transfer co-efficient enhances by 55.33% for 0.5 % weight concentration in the case of alumina/water nanofluids at the Highest Reynolds number. Similarly, CuO/water nanofluids showed a maximum percentage enhancement of 63.68% at the highest weight concentration at Re = 2200 compared to base fluid, i.e., water (figure 10(b)).



(c) (d)

Figure 9. Convective Heat transfer (local) (a-d) for copper oxide nanofluid at different weight concentrations.



(a) (b)

Figure 10. Convective Heat Transfer Coefficient variations using (a) Alumina/water nanofluid and (b) copper oxide-water nanofluid.

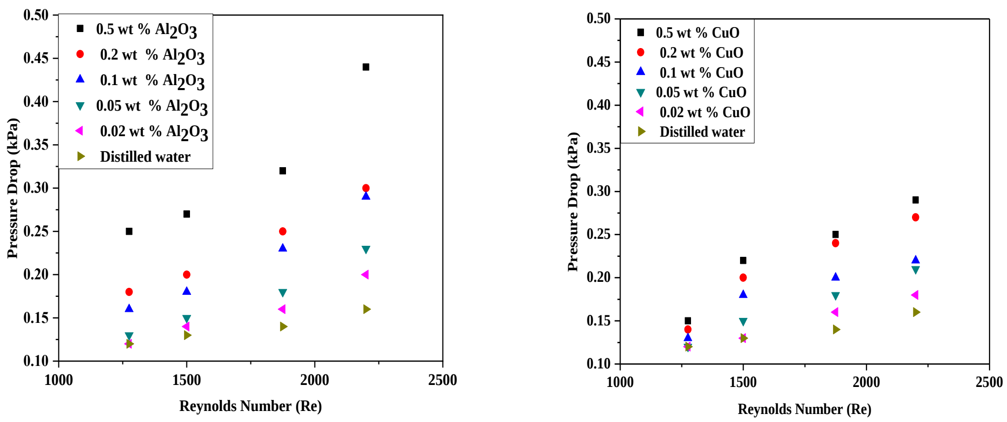
With the addition of the nanoparticles in the base fluid, i.e., distilled water, an increment in the thermal conductivity can be observed. This change further leads to considerable augmentation in the average heat transfer coefficient. Moreover, the chaotic motion happening in the nanoparticles helps improve the rate of energy exchange, resulting in fluid temperature adjoining the copper tube. Hence, the temperature gradient increases near the wall of the tube. This enables the enhancement of heat transfer using nanofluids compared to distilled water.

3.3. Pressure drop results.

Figure 11(a) shows the variation in the measurements of pressure drop at different values of Reynolds number by using different aluminum oxide nanoparticles weight fractions. It is observed that an increment in pressure drop occurs as the weight fraction of nanoparticles increases because of the increase in the viscosity of the nanofluid. It can be clearly observed that using 0.5 wt% aluminum oxide nanofluids, pressure drop was found to be about 63.63 % more at Reynolds number of 2200 compared to the base fluid. This increment becomes 56.85 at Re =1875, 53.25 % at Re = 1500 and 52 % at Re = 1275 respectively. Similarly, pressure drop characteristics of the different weight concentrations of the CuO nanofluids are shown in figure 11(b). It can be observed from the figure that pressure drop using the highest weight concentration with copper oxide nanofluids is about 44.824 % higher at Reynolds number of 2200 in comparison with the base fluid. This increment becomes 44 at Re =1875, 40.25% at Re = 1500 and 20 % at Reynolds number 1275 respectively.

3.4. Nusselt number correlations.

After several studies, correlations were developed separately for each nanofluid inside a tube under laminar flow conditions. Correlations are a function of wt. Fraction of nanoparticles, Prandtl number, and Reynolds number. Nonlinear regression analysis was done to develop the correlations.



(a) (b)

Figure 11. Pressure drop variations at different concentrations using (a) Aluminium oxide and (b) Copper Oxide nanofluids at different values of Reynolds number

In the case of Aluminum oxide nanofluids,

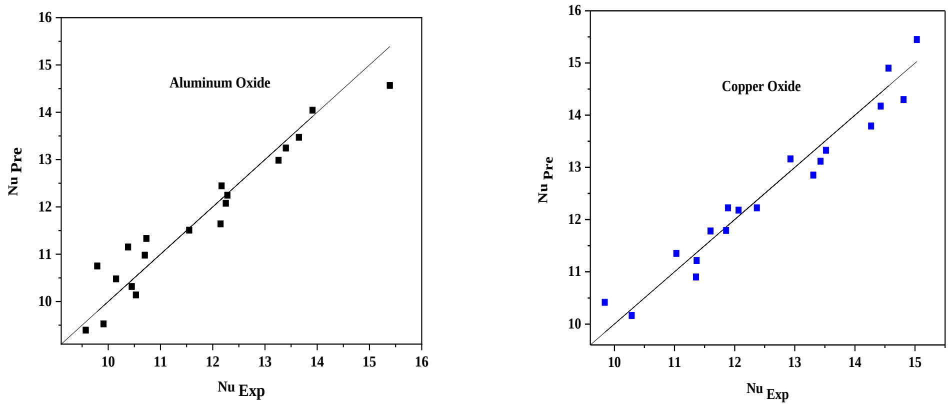
$$Nu_{(Al_2O_3)} = 0.3297 \times (\mathrm{Re})^{0.386} \times (\mathrm{Pr})^{0.679} \times (\psi)^{0.1334} \quad (5)$$

For Copper oxide nanofluids,

$$Nu_{(CuO)} = 1.46 \times (\mathrm{Re})^{0.326} \times (\mathrm{Pr})^{-0.179} \times (\psi)^{0.0536} \quad (6)$$

The above correlations hold their validity for 2200 ≥ Re ≥ 1275, 5.06 ≥ Pr ≥ 3.6 and 0.5 % ≥ ψ ≥ 0.02 % for the working fluids used in this study.

The assessment of current experimental values and those values calculated by the present correlations have been drawn in figures 14(a) and (b) for aluminum oxide and copper oxide nanofluids, respectively. Figures 12(a) and (b) clearly show the deviation in the measured data falling within the ± 9 % from the present correlation for the Nusselt number.



(a) (b)

Figure 12. Graphical comparisons between the experimental values and those computed by correlations for (a) Alumina /water nanofluids and (b) Copper Oxide nanofluids.

4. Conclusions

Characterization techniques supported the nanometric size of the nanoparticles. While experimenting with aluminum oxide nanofluids, the highest 12.7 % increment in thermal conductivity was observed, while copper oxide nanofluids showed a 14.5 % increment at 80°C when compared with the distilled water. When the viscosity was considered, aluminum oxide nanofluids showed a maximum 15.7 % increment, while copper oxide nanofluids showed a 25 % increment at 30°C when compared with the distilled water. Using aluminum oxide nanofluids, the highest 50.62 % augmentation in average convective heat transfer coefficient was obtained for 0.5 wt.% of nanofluid enhanced at Reynolds number = 2200 with axial position (x/D= 21.25). Copper oxide nanofluids showed maximum enhancement with 52.74 %. The pressure drop penalty was found to be 56.85 % in the case of aluminum oxide nanoparticles at Reynolds number 2200. A minimum pressure drop penalty was observed with copper oxide nanofluids at 44.824 %. Correlations were developed for thermophysical properties and Nusselt number for Al_2O_3/water and CuO/water nanofluids. The maximum and minimum deviations between the experimental and predicted ones have been found in the range of ± 10 % for both the respective studies of thermal conductivities and viscosities of aluminum oxide and copper oxide nanofluids, which is within the acceptable range. The deviation in the measured data falls within the ± 9 % from the present correlation for the Nusselt number.

Although this research investigated heat transfer performance by the nanofluids, additional work is equally important and necessary. Further work that would greatly complement this work would be the investigation of both these nanofluids to provide available means of heat transfer enhancement in the industrial sector, including electronics, solar collectors and automotive sector, defense, etc., such that commercialization of the work could be carried out.

Funding

The author Munish Gupta thanks UGC, Government of India, for the Grant provided under Major Research Project vide Sanction Letter No. 43-445/2014/(SR) dated: 30.09.2015 and acknowledges the Grant received under DST PURSE vide Letter No. CIL/2017/364 dated 22/06/2017.

Acknowledgments

The authors thanks Dr Sandeep Kumar and Dr. Neeraj Dilbaghi, Department of Bio and nanotechnology, for providing the technical support and lab facilities.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. Singh, V.; Gupta, M. Heat transfer augmentation in a tube using nanofluids under constant heat flux boundary condition: a review. *Energy Conversion And Management* **2016**, *123*, 290-307, https://doi.org/10.1016/j.enconman.2016.06.035.
2. Mittal, A. Recent advances in using a silica nanofluid for enhanced oil recovery. *Materials Today: Proceedings* **2021**, In Press, https://doi.org/10.1016/j.matpr.2021.11.050.
3. Gupta, M.; Singh, V.; Kumar, R.; Said, Z. A review on thermophysical properties of nanofluids and heat transfer applications. *Renewable And Sustainable Energy Reviews* **2017**, *74*, 638-670, https://doi.org/10.1016/j.rser.2017.02.073.
4. Sivalingam, V.; Kumar, P.G.; Prabakaran, R.; Sun, J.; Velraj, R.; Kim, S.C. An automotive radiator with multi-walled carbon-based nanofluids: A study on heat transfer optimization using MCDM techniques. *Case Studies In Thermal Engineering* **2021**, *29*, https://doi.org/10.1016/j.csite.2021.101724.
5. Tarafdar, A.; Sirohi, R.; Negi, T.; Singh, S.; Badgujar, P.C.; Shahi, N.C.; Pandey, A. Nanofluid research advances: Preparation, characteristics and applications in food processing. *Food Research International* **2021**, *150*, https://doi.org/10.1016/j.foodres.2021.110751.
6. Singh, V.; Kumar, A.; Kumar, K.; Gupta, M. Synthesis and Stability of Al_2O_3/Water Nanofluids. In: *Advances in Materials and Mechanical Engineering*. 1st ed.; Pandey, C.; Goyat, V.; Goel, S. Eds.; Lecture Notes in Mechanical Engineering, Springer: Singapore, Volume 1, pp. 3-11, **2021**; https://doi.org/10.1007/978-981-16-0673-1_1
7. Khoramian, R.; Kharrat, R.; Golshokooh, S. The development of novel nanofluid for enhanced oil recovery application. *Fuel* **2021**, *311*, https://doi.org/10.1016/j.fuel.2021.122558.
8. Prado, J.I.; Vallejo, J.P.; Lugo, L. A new relationship on transport properties of nanofluids. Evidence with novel magnesium oxide based n-tetradecane nanodispersions. *Powder Technology* **2021,** *397*, https://doi.org/10.1016/j.powtec.2021.117082.
9. Khaleduzzaman, S.S.; Sohel, M.R.; Saidur, R.; Mahbubul, I.M.; Shahrul, I.M.; Akash, B.A.; Selvaraj, J. Energy and exergy analysis of alumina–water nanofluid for an electronic liquid cooling system. *International Communications In Heat And Mass Transfer* **2014**, *57*, 118-127, https://doi.org/10.1016/j.icheatmasstransfer.2014.07.015.
10. Mahian, O.; Bellos, E.; Markides, C.N.; Taylor, R.A.; Alagumalai, A.; Yang, L.; Wongwises, S. Recent advances in using nanofluids in renewable energy systems and the environmental implications of their uptake. *Nano Energy* **2021**, *86*, https://doi.org/10.1016/j.nanoen.2021.106069.
11. Pavía, M.; Alajami, K.; Estellé, P.; Desforges, A.; Vigolo, B. A critical review on thermal conductivity enhancement of graphene-based nanofluids. *Advances In Colloid And Interface Science* **2021**, *294*, https://doi.org/10.1016/j.cis.2021.102452.
12. Gupta, S.K.; Verma, H.; Yadav, N. A review on recent development of nanofluid utilization in shell & tube heat exchanger for saving of energy. *Materials Today: Proceedings* **2021**, In Press, https://doi.org/10.1016/j.matpr.2021.09.455.
13. Tang, Z.; Qi, C.; Tian, Z.; Chen, L. Thermal management of electronic components based on new wave bio-inspired structures and nanofluids. *International Communications In Heat And Mass Transfer* **2022**, *131*, https://doi.org/10.1016/j.icheatmasstransfer.2021.105840.
14. Selvaraj, V.; Krishnan, H. Synthesis of graphene encased alumina and its application as nanofluid for cooling of heat-generating electronic devices. *Powder Technology* **2020**, *363*, 665-675, https://doi.org/10.1016/j.powtec.2020.01.050.

15. Gupta, M.; Singh, V.; Kumar, S.; Kumar, S.; Dilbaghi, N., Said, Z. Up to date review on the synthesis and thermophysical properties of hybrid nanofluids. *Journal Of Cleaner Production* **2018,** *190*, 169-192, https://doi.org/10.1016/j.jclepro.2018.04.146.
16. Adun, H.; Kavaz, D.; Dagbasi, M. Review of ternary hybrid nanofluid: Synthesis, stability, thermophysical properties, heat transfer applications, and environmental effects. *Journal Of Cleaner Production* **2021,** *328*, https://doi.org/10.1016/j.jclepro.2021.129525.
17. Vallejo, J.P., Prado, J.I.; Lugo, L. Hybrid or mono nanofluids for convective heat transfer applications. A critical review of experimental research. *Applied Thermal Engineering* **2021**, *203*, https://doi.org/10.1016/j.applthermaleng.2021.117926.
18. Nikelham, A.; Enjilela, V.; Vaziri, N.; Moziraji, Z.P. The effects of magnetic-field direction and magnitude on forced convection of aluminum oxide–water nanofluid over a circular cylinder. *International Journal Of Thermal Sciences* **2021**, *173*, https://doi.org/10.1016/j.ijthermalsci.2021.107398.
19. Plant, R.D.; Saghir, M.Z. Numerical and experimental investigation of high concentration aqueous alumina nanofluids in a two and three channel heat exchanger. *International Journal of Thermofluids* **2021,** *9*, https://doi.org/10.1016/j.ijft.2020.100055.
20. Kumar, P.G.; Sakthivadivel, D.; Thangapandian, N.; Salman, M.; Thakur, A.K.; Sathyamurthy, R.; Kim, S.C. Effects of ultasonication and surfactant on the thermal and electrical conductivity of water–solar glycol mixture based Al_2O_3 nanofluids for solar-thermal applications. *Sustainable Energy Technologies And Assessments* **2021,** *47*, https://doi.org/10.1016/j.seta.2021.101371.
21. Ma, M.Y.; Zhai, Y.L.; Li, Z.H.; Yao, P.T.; Wang, H. Particle size-dependent rheological behavior and mechanism of Al2O3-Cu/W hybrid nanofluids. *Journal Of Molecular Liquids* **2021**, *335*, https://doi.org/10.1016/j.molliq.2021.116297.
22. Amjadian, M.; Safarzadeh, H.; Bahiraei, M.; Nazari, S.; Jaberi, B. Heat transfer characteristics of impinging jet on a hot surface with constant heat flux using Cu_2O–water nanofluid: An experimental study. *International Communications In Heat And Mass Transfer* **2020**, *112*, https://doi.org/10.1016/j.icheatmasstransfer.2020.104509.
23. Arifuzzaman, M.; Uddin, M.J. Convective flow of alumina–water nanofluid in a square vessel in presence of the exothermic chemical reaction and hydromagnetic field. *Results In Engineering* **2021**, *10*, https://doi.org/10.1016/j.rineng.2021.100226.
24. Akhavan-Behabadi, M.A.; Hekmatipour, F.; Mirhabibi, S.M.; Sajadi, B. Experimental investigation of thermal–rheological properties and heat transfer behavior of the heat transfer oil–copper oxide (HTO–CuO) nanofluid in smooth tubes. *Experimental Thermal And Fluid Science* **2015**, *68*, 681-688, https://doi.org/10.1016/j.expthermflusci.2015.07.008.
25. Heris, S.Z.; Esfahany, M.N.; Etemad, S.G. Experimental investigation of convective heat transfer of Al2O3/water nanofluid in circular tube. *International Journal Of Heat And Fluid Flow* **2007**, *28*, 203-210, https://doi.org/10.1016/j.ijheatfluidflow.2006.05.001.
26. Hashemi, S.M.; Akhavan-Behabadi, M.A. An empirical study on heat transfer and pressure drop characteristics of CuO–base oil nanofluid flow in a horizontal helically coiled tube under constant heat flux. *International Communications In Heat And Mass Transfer* **2012**, *39*, 144-151, https://doi.org/10.1016/j.icheatmasstransfer.2011.09.002.
27. Kannaiyan, S.; Boobalan, C.; Umasankaran, A.; Ravirajan, A.; Sathyan, S.; Thomas, T. Comparison of experimental and calculated thermophysical properties of alumina/cupric oxide hybrid nanofluids. *Journal Of Molecular Liquids* **2017**, *244*, 469-477, https://doi.org/10.1016/j.molliq.2017.09.035.
28. Gupta, M.; Singh, V.; Katyal, P. Synthesis and structural characterization of Al_2O_3 nanofluids. *Materials Today: Proceedings* **2018**, *5*, 27989-27997, https://doi.org/10.1016/j.matpr.2018.10.039.
29. Singh, V.; Gupta, M.; Kumar, A. Investigating the morphology and thermophysical properties of Al_2O_3 and CuO nanofluids. In: IOP Conference Series: Materials Science and Engineering, International Conference on Advances in Materiala and Manufacturing Applications, Bengaluru, India, 18 August 2018; Kumar, V.G.B.; Pramod, R.; Eds.; IOP Conference Series: Materials Science and Engineering: IOP Publishing **2019**, *577*, https://doi.org/10.0.4.64/1757-899X/577/1/012052/meta.
30. Ramires, M.L.; Nieto de Castro, C.A.; Nagasaka, Y.; Nagashima, A.; Assael, M.J.; Wakeham, W.A. Standard reference data for the thermal conductivity of water. *Journal Of Physical And Chemical Reference Data* **1995**, *24*, 1377-1381, https://doi.org/10.1063/1.555963.
31. Gupta, M.; Singh, V.; Said, Z. Heat transfer analysis using zinc Ferrite/water (Hybrid) nanofluids in a circular tube: An experimental investigation and development of new correlations for thermophysical and heat transfer properties. *Sustainable Energy Technologies And Assessments* **2020**, *39*, https://doi.org/10.1016/j.seta.2020.100720.
32. Jang, S.P.; Choi, S.U. Role of Brownian motion in the enhanced thermal conductivity of nanofluids. *Applied physics letters* **2004**, *84*, 4316-4318, https://doi.org/10.1063/1.1756684.
33. Prasher, R. Brownian-motion-based convective-conductive model for the thermal conductivity of nanofluids. In ASME 2005 Summer Heat Transfer Conference collocated with the ASME 2005 Pacific Rim Technical Conference and Exhibition on Integration and Packaging of MEMS, NEMS, and Electronic Systems, *American Society Of Mechanical Engineers* **2005,** 343-353, https://doi.org/10.1115/HT2005-72048.

34. Williams, W.; Buongiorno, J.; Hu, L.W. Experimental investigation of turbulent convective heat transfer and pressure loss of alumina/water and zirconia/water nanoparticle colloids (nanofluids) in horizontal tubes. *Journal Of Heat Transfer* **2008,** *130*, https://doi.org/10.1115/1.2818775.
35. Kole, M.; Dey, T.K. Enhanced thermophysical properties of copper nanoparticles dispersed in gear oil. *Applied Thermal Engineering* **2013,** *56*, 45-53, https://doi.org/10.1016/j.applthermaleng.2013.03.022.