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Improving Heat Transfer Performance of Novel Hybrid Nanofluids in Radiator

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Hybrid nanofluid, Thermal conductivity, Heat transfer, Automobile radiator

Abstract

Nanofluids have budding fluids in the field of heat transfer applications. Hybrid nanofluid is a new emerging class of nanofluids that has nanocomposite dispersed in the base fluid. In this work, synthesis, characterization, and investigation of the heat transfer performance of novel Ag2ZrO3/EG hybrid nanofluid in the field of thermal management have been reported. Silver zirconate (Ag2ZrO3) nanoparticle disseminated in a base fluid (EG) has been used to enhance heat transfer properties in the heat exchanger. The heat transfer performance of the new hybrid Ag2ZrO3/EG nanofluid was studied experimentally at various volume concentrations (0.025, 0.05, 0.075, 0.1, and 0.2%) and temperature range between 35-55oC. Heat transfer coefficient and thermal conductivity enhancement were observed to be 76.37% and 56.2% at 0.2vol. %, which exhibits progressive performance as compared to ZrO2/EG, Al2O3/EG nanofluids. The novel nanofluid shows an excellent replacement potential for advanced fluids used in thermal-based applications.

1. Introduction

Energy is a key aspect of any country's economic growth. Nowadays the biggest challenge for thermal engineers, how to improve heat transfer system thermal efficiency. In this direction, system optimization is a common practice aimed at improving performance with a focus on miniaturization, size reduction, and consequently costs. Improving heat transfer performance leads to saving energy via heat exchangers. The heat exchanger is commonly used in air conditioning, space heating, cooling, power stations, plants of chemicals, plants of petrochemical, natural gas extraction, and wastewater treatment, and many other heat applications [1-2]. A radiator heat exchanger system is used in automobiles to extract heat from the engine’s cooling system. Technological advances in the automotive industry concentrate on improving the fuel efficiency of internal combustion engines. Fuel efficiency is improved by maintaining the engine temperature at an optimal value that involves extraction of engine heat by circulating common fluids around the engine, such as ethylene glycol (EG), water, oil, and a mixture of EG-water [3]. However, the application of conventional fluids as coolants is restricted in their ability to be improved due to their low thermal conductivity. When incorporating nanoparticles, the thermal conductivity of these fluids can be enhanced as these particles have greater thermal conductivity than conventional fluids [4]. A feature of a nanofluid's thermal conductivity is one that directly affects its capacity for heat transmission [5].

Many factors are responsible for the enhancement of thermal conductivity viz. size, shape, and material of the particle, the base fluid, the temperature, the Brownian motion of the nanoparticle, and the aggregation of nanoparticles [6]. As per literature, stability is the main problem in nanofluids because of the escalation in nanoparticle volume concentration which results in rapid sedimentation which could reduce the thermo-physical properties of nanofluids. Therefore, the stability of nanofluids is of considerable importance to preserve their thermo-physical properties after manufacturing for a lengthy period. Need for a more stable nanofluid due to the progression in nanotechnology, Hybrid nanofluid is a new type of nanofluid that has been developed [7]. Hybrid nanofluid is a combination of two nanoparticles suspended as one in a base fluid altogether of these uncommon thermal properties [8]. Metal nitrate, carbides (AIN, SiC), metals (Cu, Ag, Ni, Au), metal oxides (SiO_2, CuO, ZnO, Al_2O_3, TiO_2, MgO, Fe_2O_3), and carbon-based materials (diamond, graphite, CNTs, MWCNTs) are commonly used additives based for enhancing heat transfer performance [9].

Zirconia (ZrO_2) and the zirconia-based nanocomposite have sought the attention of researchers due to its inert chemical makeup, which provides long-term stability and lower production costs [10]. However, zirconia-based nanofluids suffer from low thermal conductivity [10]. Literature reveals that the hybridization of two or more separate nanoparticles could further increase the thermal conductivity of single nanoparticles. Silver nanoparticles are extremely significant, because of their high thermal conductivity of 429 W/mk at a tepid temperature. Thus Ag-based material should be well-suited for heat transfer applications and have ideally strong thermal properties [11]. Literature also reveals that the Ag-based nanocomposites can intensify thermal conductivity for heat transfer application.

Esfe et al. [12] Correlations have been established to foresee the thermal conductivity of water based (Ag-MgO) hybrid nanofluid according to their volume concentration. Nanofluid thermal conductivity has been improved by an increased volume of nanoparticles. By utilizing silver nanoparticles, Munkhbayar et al. [13] have investigated improving the surface characteristics of CNTs. For the preparation of nanofluids has been used volume concentration and temperature range (0-3% and 15-40ºC). Thermal conductivity was observed to have improved by 14.5% in comparison to the base liquid. Yarmand et al. [14] studied, hybrid nanofluids flowing via a circulatory tube with continuous heating streams, (Ag-graphene nanoplatelets/water) which resulted in an intensification in heat transfer rates and thermophysical properties of the base fluid due to nanoparticle distribution.

Ghozatloo et al. [15] have studied the impact of convective heat transfer coefficient in a shell and tube heat exchanger using the alkaline graphene oxide/H_2O nanofluid, by using different weight concentrations of Graphene nanoparticle 0.025 to 0.1percent. They found to be the heat transfer coefficient increases by 15.3% at 25ºC and 23.9% at 38ºC at the highest concentration.

Zhong et al. [16] nanofluid heat transfer improved in a car heat exchanger (plate-fin oil cooler), using alumina nanofluids with distinct volume fractions was analyzed and the heat transfer was shown to degrade at high-volume nanoparticles fraction compared to water at 5 vol. %. Teng et al. [17] the efficiency of heat dissipation nano coolant MWCNT in a motorcycle radiator has been studied. The maximum enhanced heat exchange of ratio, pumping power, and efficiency factor found that 12.8 percent, 4.9 percent, and 14.1 percent, respectively, compared to a combination of ethylene glycol and water. Tiwari et al. [18] experimental comparison of TiO_2, CeO_2, Al_2O_3, and SiO_2 with base fluid H_2O and the performance of heat transfer through a plate heat exchanger led to the identification of the ideal nanofluid concentration. CeO_2/water shows better performance with comparatively low optimal concentration i. e. 0.75 vol. percentage within studied nanofluids. Ali et al. [19] Performance of the heat transfer performance of automobile radiator using ZnO/H_2O with various volume concentrations 0.01%, 0.08%, 0.2% & 0.3% nanofluid as a coolant. Flow rate varied in a range of 7 to 11 LPM and 17,500 to 27,600 was Reynolds' number range. Enhancement of heat transfer has been obtained 46% as compared to H_2O at 0.2 vol. %. Furthermore, it has been also reported that heat transfer enhancement was decreased beyond 0.2 vol. % of ZnO.

Peyghambarzadeh et al. [20] explored growth in the overall coefficient of heat transfer of nanofluids CuO and Fe_2O_3 with volume fractions of 0.15, 0.4, and 0.65 percent and base fluid water used in the automotive radiator. The coefficient of heat transfer found that 7.5 percent of CuO and 9 percent of Fe_2O_3. Jarrah et al. [21] studied (Ag/water) nanofluids as coolants in a car radiator by using a low volume concentration of nanofluids. It was found to be thermal efficiency up to 30.2 percent more than base fluid (water). Elias et al. [22] nanoparticles of Al_2O_3 dispersed in water and coolant based on ethylene glycol used in vehicle radiators. Enhancement of nanofluids thermal conductivity for more volume concentration 8.3% but decreases specific heat.

Ma et al. [23] analyzed the synergistic mechanism of (Al_2O_3-CuO/W-EG, Al_2O_3-TiO_2/W-EG, and Cu-Al_2O_3/W-EG) with three different hybrid nanofluids for volume concentration 1%. They found that scattering various sizes of nanoparticles to modify the order of fluid molecules around nanoparticles causes a synergistic process of thermal conductivity enhancement, As a result, the solid-liquid contact becomes more compact, and the heat transmission network becomes more appropriate. Hybrid nanofluids exhibit better thermal conductivity than single nanofluids, according to their research. This is owing to their synergistic mechanisms.

In the present work, a new hybrid Ag_2ZrO_3 (Silver zirconate) is synthesized by the microwave-assisted process and Ag_2ZrO_3/EG nanofluid's thermal conductivity has been investigated for the first time at different volume concentrations and temperatures. To the best of our knowledge, there has been no study published on the performance of heat transfer in the heat exchanger (automobile radiator) of these hybrid (Ag_2ZrO_3/EG) nanofluids. Silver zirconate nanofluid was found to be remarkable thermal conductivity and coefficient of heat transfer at varied volume concentrations (0.025, 0.05, 0.075, 0.1 and 0.2%) and temperatures ranging from 35^{o}C to 55^{o}C.

2. Materials and Methods

2.1. Characterization and preparation

The synthesis of a silver modified Zirconia nanocomposite (Silver Zirconate). Ag_2ZrO_3 was developed with the aid of the microwave process. The crystallinity and phase pureness of the synthesised Ag_2ZrO_3 were assessed using an X-ray diffractometer (Bruker AXS D8 advance). XRD pattern (Fig. 1a) of the silver zirconate shows extraordinary crystallinity with sharp peaks at 2θ = 27.331°, 30.952°, 45.759°, 54.385°, 57.027°, 67.048, 74.076° and 76.366°, which is in good agreement with previously reported XRD pattern [24]. The diffraction pattern of silver zirconate neither follows the Zirconium oxide (ZrO_2) [25] nor silver oxide (AgO) [26], but it has a certain resemblance with the diffraction pattern of Na_2ZrO_3 [27].

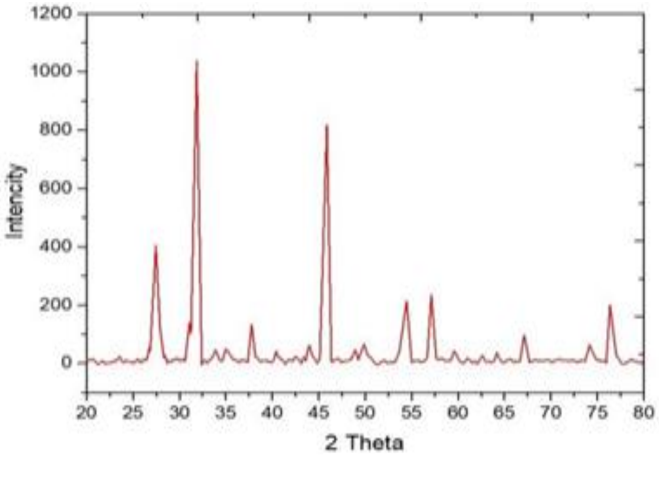

Figure 1 (a) XRD images of Ag_2ZrO_3 nanoparticles

Model – JEOL 6380A has been utilized for Scanning Electron Microscope (SEM), and transmission electron microscope (TEM) using a (Philips CM200 instrument) for identification of microstructures. For the identification of microstructures. Both SEM and TEM image (Figure 1b, c) impart the presence of spherical Ag_2ZrO_3 nanoparticles with an average particle size in the range of 10 to 50 nm. Fig.1c reveals the polycrystalline nature of the synthesized Ag_2ZrO_3 nanoparticles.

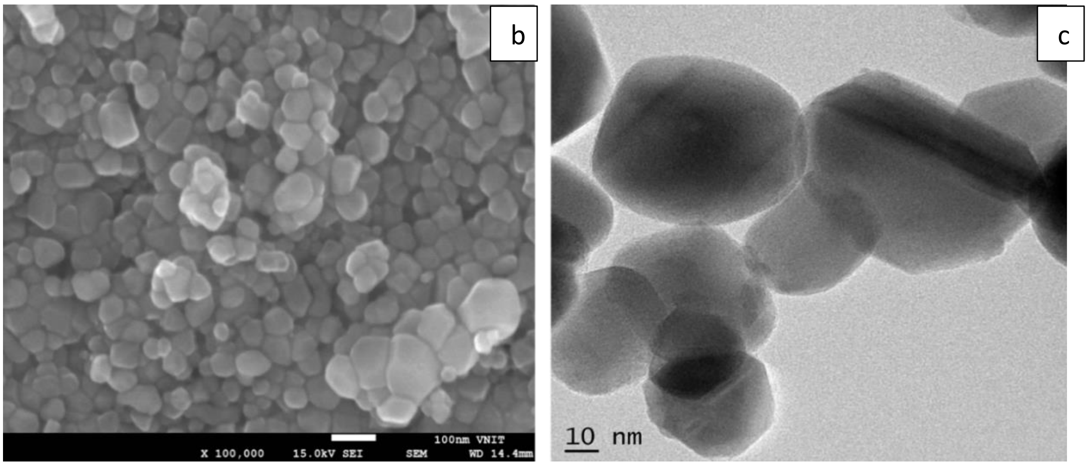

Figure 1 (b) SEM and (c) TEM images of Ag_2ZrO_3 nanoparticles

The morphological examination of the synthesized Ag_2ZrO_3 nanoparticles reveals the presence of small pores that serve as the sites for better heat exchange, thus imparting enhanced thermal conductivity.

The two-step method is the one that is most frequently utilized in the literature to create nanofluids. The current study uses two-step techniques to transfer heat. This process should be cost-effective for large-scale production. To measure the precise equilibrium of the nanoparticles to be used at five different volume concentrations of nanofluids, 0.025, 0.05, 0.075, 0.1, and 0.2 percent, the following equations were estimated and re-evaluated. [28].

$$\%\,\text{Volume concentration} = \left[\frac{\frac{W_{np}}{\rho_{np}}}{\frac{W_{np}}{\rho_{np}} + \frac{W_f}{\rho_f}}\right]$$

Ethylene glycol was used as the base fluid for the preparation of nanofluid because of its common usage and superior quality to have a proper mixture. Nanoparticle used in this experiment is (ZrO_2, Al_2O_3, and hybrid Ag_2ZrO_3) uses with base fluid ethylene glycol. Nanofluid prepared with a volume concentrations of 0.025%, 0.05 %, 0.075 %, 0.1 % and 0.2% of nanoparticles with EG used in the automobile radiator. Different inlet temperature were used 35°C, 40°C, 45°C, 50°C, 55°C, and 60°C. The radiators' inlet and outlet, temperatures were recorded for measurement of bulk temperature. The tube wall temperatures were recorded using eight thermocouples connected to the radiator's surface. Cooling flow rate kept constant 60LPH. A probe ultrasonicator was utilized for the sonication interaction and an electronic gauging machine for estimating the amount of nanoparticles needed for the distinctive volume parts of nanofluid. By embracing a two-step strategy for nanofluid arrangement, nanoparticles were vibrated utilizing a probe ultrasonicator. Prior to the experimentation, all thermocouples, the temperature recorder, and the Rota meter were aligned.

3. Results and Discussion

In the current study, the thermal conductivity, viscosity, and heat transfer coefficient of Ag_2ZrO_3/EG, ZrO_2/EG, and Al_2O_3/EG nanofluids were assessed with varied volume concentrations of nanoparticles (0.025, 0.05, 0.075, 0.1 and 0.2%) and temperatures ranging from 35°C to 55°C. Experimentally, the heat transfer coefficient of Ag_2ZrO_3/EG, ZrO_2/EG, and Al_2O_3/EG nanofluids in an automotive radiator were studied. Experiments have been carried out with varied volume concentrations (0.025, 0.05, 0.075, 0.1 and 0.2%), inlet temperature (35 to 55°C), and constant flow rate 60LPH.

3.1. *Thermal conductivity and viscosity*

A KD2 Pro thermal properties analyzer (Decagon Devices, USA) has been used to measure the thermal conductivity of nanofluids. Using this instrument, thermal conductivity, resistivity, diffusivity, volumetric specific heat capacity, and single-needle sensors are used to detect thermal conductivity and resistivity, respectively. It employs the transient hot-wire method of operation. This instrument has ±5.0% accuracy. Data acquisition was triplicated to increase precision and a median value has been determined for analysis. As shown in figures 2, 3, and 4, the thermal conductivity of Ag_2ZrO_3/EG, ZrO_2/EG, and Al_2O_3/EG nanofluids was assessed at temperatures between 35 and 55^{o}C and with varied volume concentrations of nanoparticles (0.025, 0.05, 0.075, 0.1, and 0.2 percent). As their volume concentration and temperature increase, it illustrates that nanofluids increase thermal conductivity. At temperatures between 35 and 55 degrees Celsius, Ag_2ZrO_3, ZrO_2, and Al_2O_3 nanoparticles were added to ethylene glycol, in varying volume concentrations (i.e. 0.025, 0.05, 0.075, 0.1, and 0.2 percent). First, it was determined that ethylene glycol had a thermal conductivity of 0.24 W/m K.

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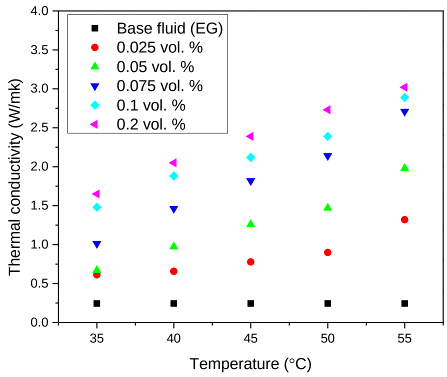

Figure 2 Ag_2ZrO_3/EG nanofluid's thermal conductivity at various temperatures

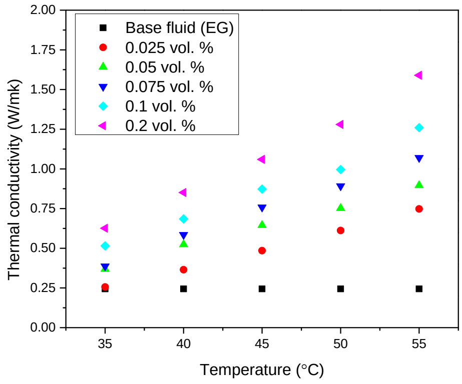

Figure 3 Al_2O_3/EG nanofluid's thermal conductivity at various temperatures

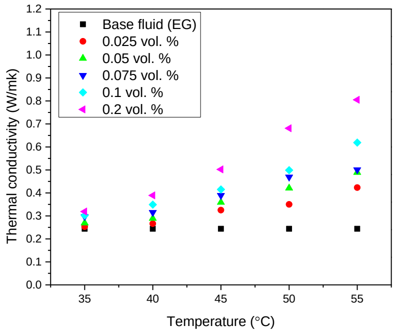

Figure 4 ZrO_2/EG nanofluid's thermal conductivity at various temperatures

Five distinct volume concentrations (0.025, 0.05, 0.075, 0.1 and 0.2 percent) and temperatures (35, 40, 45, 50 and 55ºC) were used to evaluate the impact of nanofluid's thermal conductivity. As the volume concentration, and temperature increase, it demonstrates an improvement in thermal conductivity. Figure 5 shows the Ag_2ZrO_3/EG, ZrO_2/EG, and Al_2O_3/EG nanofluids' thermal conductivity at various volume concentrations. The increased volume of nanoparticles in base fluids has undoubtedly improved the thermal conductivity of every nanofluid. Similar incidents had previously been observed for various nanofluids [25–26].

The volume concentration of nanoparticles in the base fluid, the type and morphology of the nanoparticles, the kind of basic fluid, the temperature of the base fluid, and the production process are some of the factors that affect the nanofluid's thermal conductivity.

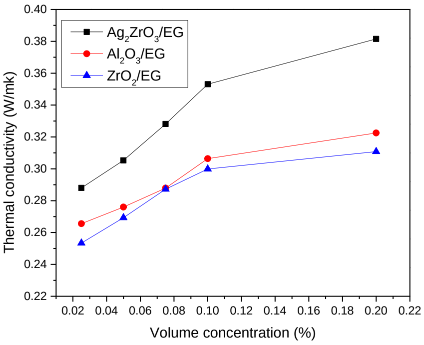

Figure 5 Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG nanofluid's thermal conductivity at various volume concentrations.

The following equation was used to calculate the improved thermal conductivity of nanofluids [29].

$$\text{Thermal conductivity enhancement } (\%) = \left[\frac{K_{nf} - K_f}{K_f}\right] \times 100$$

Figure 6 shows Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG, thermal conductivity enhancement at different volume concentrations. Maximum enhancement of thermal conductivity of Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG, nanofluids was recorded at 0.2% volume concentration 56.2%, 32.17%, and 27.37% compared with the ethylene glycol (base fluid).

When compared to ZrO2/EG and Al_2O_3/EG nanofluids, Ag_2ZrO_3/EG demonstrates a significant increase in thermal conductivity of 56.2 percent at 0.2vol. %, indicating superior performance. The novel nanofluid shows an excellent replacement potential for advanced fluids used in thermal-based applications.

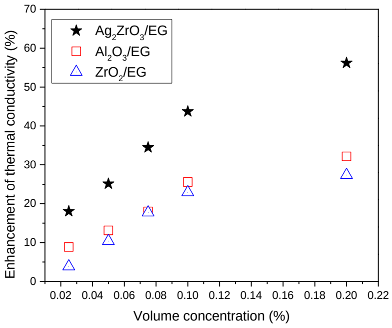

Figure 6 Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG nanofluid's thermal conductivity enhancement at different volume concentrations.

Brownian mobility and particle collisions between base fluid nanoparticles have improved thermal conductivity. Large nanoparticle surface areas per unit volume, which enable greater heat transmission between solid particles and base fluids, are the cause of the energy system's high thermal efficiency. In this experiment, viscosity was measured using a Redwood viscometer. These viscometers permit the passage of a predetermined volume of fluid through a capillary tube with specific diameters under predetermined circumstances, and the flow rate at a specific temperature is monitored. Figure 7 illustrates the experimental viscosities of Ag_2ZrO_3/EG, ZrO_2/EG, Al_2O_3/EG nanofluids, and ethylene glycol (base fluid).

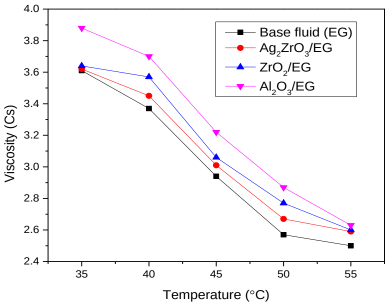

Figure 7 The viscosity of Ag_2ZrO_3/EG, ZrO_2/EG, and Al_2O_3/EG nanofluids at different temperature

It was found that Nanofluid viscosities are more than ethylene glycol (base fluid). Extreme viscosity enhancement was observed to be at 55ºC. The slightest viscosity enhancement was observed to be at 35ºC. It has been found that the viscosity of nanofluid decreases as temperature rises.

3.2. *Heat transfer coefficient*

The test part consisted of a typical car radiator, and the effects of the operating circumstances on its heat transfer ability were examined. The quantity of nanoparticles added to the base fluid influences heat transfer enhancement.

The thermal conductivity, Nusselt number, heat transfer coefficient, and rate of heat transfer of nanofluids were all used to evaluate their heat transfer capabilities. The Nusselt number rises in proportion to the Reynolds number, according to the findings.

It's worth noting that mixing nanoparticles into base fluid can effectively remove heat from an automotive radiator. This advancement in heat transfer could lead to a reduction in the size of radiators in automotive engines, resulting in better fuel economy. As nanoparticle concentration grows, so does the effective thermal conductivity. Furthermore, the heat transfer improvement is linked to nanoparticle collisions as well as nanoparticles colliding with the automotive radiator's tube wall. This leads to an increase in the energy exchange rate and Brownian motion of nanoparticles. Particle migration, Brownian motion of nanoparticles, and effective thermal conductivity all rise as a result increasing heat transmission. Figure 8 shows Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG nanofluid’s enhancement of heat transfer coefficient at different volume concentrations. Maximum enhancement of average heat transfer coefficient for volume concentration (0.2%) was recorded 76.37%, 37.12%, and 28.97% for Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG nanofluids compared with the ethylene glycol (base fluid).

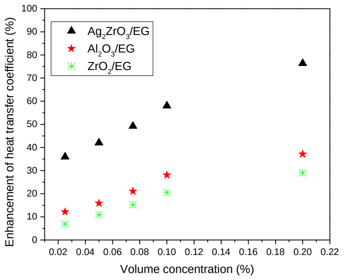

Figure 8 Ag_2ZrO_3, Al_2O_3, and ZrO_2 nanofluid’s enhancement of heat transfer coefficient at different volume concentrations.

The test facility's accuracy and measurement dependability were evaluated by conducting tests utilizing ethylene glycol as a coolant in the car radiator. The results of the experimental inquiry were compared with the proposed empirical correlation by Dittus and Boelter [30].

$$Nu = 0.023Re^{0.8} * Pr^{0.3}$$

The Nusselt number changes in relation to the Reynolds number, as seen in Figure 9. Good agreement was found between the experimental findings and the Dittus and Boelter equation. The findings indicate that as the Reynolds number rises, the Nusselt number also does. The experimental results show an average 5 percent deviation from the expected results.

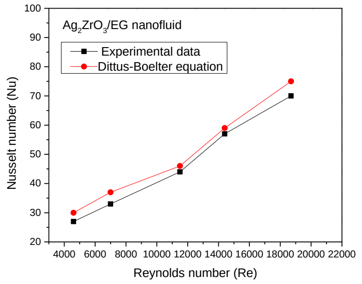

Figure 9 Validation of experimental Nusselt no. with standard correlations

4. Conclusion

In this work, improving the heat transfer performance of novel hybrid nanofluid in the automobile radiator has been investigated. The use of novel silver modified zirconia nanocomposite (Ag_2ZrO_3) was successfully synthesized by microwave process. The thermal conductivity was calculated using a KD2 Pro thermal property analyzer, and the viscosity of the nanofluids was measured using a Redwood viscometer. The test part consisted of a typical car radiator, and the effects of the operating circumstances on its heat transfer ability were examined. Maximum enhancement of thermal conductivity of Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG, nanofluids was recorded at 0.2% volume concentration 56.2%, 32.17%, and 27.37% compared with the ethylene glycol (base fluid). It demonstrates that temperature and volume concentration have an impact on the increase in thermal conductivity of nanofluids. According to measurements of viscosities, nanofluid viscosity decreases as temperature increases. Maximum enhancement of average heat transfer coefficient for the highest concentration (0.2 vol. %) was recorded 76.37%, 37.12%, and 28.97% for Ag_2ZrO_3/EG, Al_2O_3/EG, and ZrO_2/EG nanofluids compared with the ethylene glycol (base fluid). Significant enhancement in the thermal conductivity and average heat transfer coefficient of Ag_2ZrO_3/EG was observed which exhibits higher performance as compared to ZrO_2/EG, Al_2O_3/EG nanofluids. The novel nanofluid shows an excellent replacement potential for advanced fluids used in thermal-based applications. In this direction, system optimization is a common practice aimed at improving performance with a focus on miniaturization, size reduction, and consequently costs. Improving heat transfer performance leads to saving energy via automobile radiator.

5. Acknowledgements

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6. Conflicts of Interest

The authors declare no conflict of interest.

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