EXPERIMENTAL STUDY OF NANOFLUIDS AS A COOLANT FOR IMPROVED THERMAL PERFORMANCE OF AN AUTOMOBILE RADIATOR

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ABSTRACT :
In this experimental study the thermal (heat transfer) performance of mono TiO_2, ZnO, MWCNT nanofluids, and a hybrid TiO_2+ZnO+MWCNT nanofluid as a coolant within a car radiator were investigated. The nanofluids were synthesized via a two-step approach. This involved dispersing nanoparticles at a 0.1% vol. fraction into a base fluid, which was an equal parts of water and ethylene glycol. Nanofluid testing was conducted in laminar flow, with the flow rate adjusted between 4 to 12 LPM while maintaining a constant inlet temperature of 70°C. The findings showed that, in comparison to the base fluid, nanofluids improve the rate of heat transfer. The MWCNT nanofluid exhibited the highest heat transfer enhancement, followed by the hybrid nanofluid.
Keywords: Heat transfer, automobile radiator, heat transfer coefficient, nanofluid, Nusselt number.

INTRODUCTION:
In different types of industrial applications, like solar collectors, electronics, automobiles, heat exchangers, power plants, refrigeration and air conditioning heat transfer is crucial [1]. Several of heat transfer fluids, such as air, ethylene glycol (EG), water, oils, are used to transport heat energy depending on the requirements of the specific application. But, these ordinary fluids have limited potential to transport heat. To develop smaller and more effective systems, fluids with higher thermal conductivity than ordinary fluids are needed. Consequently, scientists are focusing their research on augmenting the heat transfer in multiple industrial devices to increase thermal performance.
In recent years, the automotive sector has been expanding rapidly, which has generated demand for superior engine thermal performance. Engine performance is improved by increasing the heat transfer rate, either through the addition of fins to the engine surface or by utilizing forced convection via a coolant. However, these techniques have reached their limits in improving heat transfer rates. An automobile radiator is a heat exchanger used to remove unwanted heat from the engine and provide cooling. It consists of flat tubes with fins provided around them. A significant amount of heat is produced while the engine is operating, and only 60% of this heat is utilized to generate power. Traditional coolants is mixture of water and an antifreeze agent (i.e., ethylene glycol), are used in automobile radiators, but they are less efficient at removing this excess heat. Therefore, this additional heat increases the engine temperature, resulting in increased fuel consumption and a reduced lifespan of engine components.
Due to technological advancements in nanotechnology, a new class of coolant, namely nano-coolant, is finding applications by replacing conventional coolants in radiators. Choi [2] coined the term "nanofluid" in the year 1995. Typically, nanofluids are prepared by dispersing very ultra-small particles, called nanoparticles, whose size is less than 100nm, in a suitable base fluid. When compared to traditional fluids, nanofluids have improved heat transfer rates and outstanding thermal characteristics. Many researchers have used nanofluids as coolants in automobile radiators.
An Al_2O_3 water-EG based coolant for a car radiator was experimentally examined for its heat transfer capability by Dattatray Subhedar [3], who found that a 0.2% vol. fraction enhanced heat transfer by 30%. Adnan Topuz [4] found similar results using an Al_2O_3-water-ethylene glycol mixture, observing a 15% rise in the rate of heat transfer over the base fluid. Muhammad Qasim [5] improved automobile cooling performance by 41%, with 47% increase in pressure drop. Ashutosh

Kumar [6] used water-EG-based nanofluids made from Al_2O_3, ZnO, and CuO nanoparticles to examine heat transfer in a vehicle radiator. The coefficient of heat transfer were found to increase by 42.5%, 51.5% and 47.4% respectively. S.M. Peyghambarzadeh [7] evaluated car radiator heat transfer with CuO and Fe_2O_3 based nanofluids using various concentrations, coolant flow rates (Re 50-1000), and inlet temperatures (50-80 °C), indicating an enhancement of the total coefficient of heat transfer by 9% over the water. This improvement was more significant with increased nanoparticle concentrations and fluid/air velocities but decreased with higher nanofluid inlet temperatures. Altay Arbak [8] experimentally determined that a CuO-ZnO hybrid nanofluid increase the heat transfer rate by 40%. Divereddi Sandhya [9] used an equal amount of water and EG as the base coolant in an experiment utilizing TiO_2 nanofluid. When compared to the mixture of water+EG, and according to their result 37% increase in rate of heat transfer. They also concluded that the heat transfer accelerates with increasing fluid flow. The impact of incorporating MWCNT based nanofluid into a car engine system was examined by Beriache Mohamed [10]. They found that utilization of a 0.5% vol. fraction of nanoparticles showed a 196.3% rise in heat transfer coefficient. In an investigation by Adman M. Hussein [11], TiO_2 and SiO_2 nanoparticles dispersed in water at a vol. fraction of 1-2.5% were used to improve heat transmission in a vehicle radiator during laminar flow. The study showed that TiO_2 nanoparticles boosted effectiveness by 24% and heat transfer by 20%. Similarly, SiO_2 nanoparticles improved effectiveness by 29.5% and heat transfer by 32%. Senthil Ramalingam [12] used Al_2O_3 and SiC nanoparticles for the preparation of a hybrid nanofluid in vehicle radiator. Based on the findings of the experiment, an improvement in Nusselt number of 8.98% for a 0.4% vol. fraction and 23.6% for a 0.8% vol. fraction of milled nanoparticles. A study by Rashmi Rekha Sahoo [13] that used a hybrid nanofluid containing Al_2O_3, CNT, and graphene nanoparticles having different type shapes as a coolant in a radiator. According to the results, the heat transfer rate increased by 18.45%, the performance index decreased by 18.75%, and the pressure drop increased by 25%. C. Selvem [14] commented that the addition of graphene nanoplatelets to a water-ethylene glycol coolant boosts a car radiator's heat transfer by up to 104%, but this effect is less pronounced at higher coolant temperatures. Although the nanofluid increases pressure drop, the nanofluid flow rate influences this increase more significantly than the amount of graphene added. Akshay Joshi [15] experimentally and numerically demonstrated that a Graphene Amine nano-coolant significantly enhances heat transfer in car radiators across various temperatures and flow rates, outperforming conventional coolants. The nano-coolant achieved a highest heat transfer augmentation of 154.3% at the highest tested conditions, with predicted and experimental thermal properties showing good agreement. Ravinder Kumar [16] work demonstrated that a CuO/SiO_2 hybrid nanofluid in ethylene glycol enhances car engine cooling across nanoparticle concentrations of 0.1% - 0.5%. The nanofluid boosted thermal conductivity by 6.5% and significantly improved heat transfer, with a 48.24% increase in the Nusselt number. Higher nanoparticle loading enhanced performance due to increased turbulence, while specific heat reduced. Li [17] experimentally investigated SiC-MWCNT-EG hybrid nanofluids as a coolant for automobile engines, focusing on enhancement in heat transfer. The hybrid nanofluid showed a 32.01% greater thermal conductivity at a 0.4% vol. fraction and enhancement in convective heat transfer by 26% in comparison with pure EG. The hybrid nanofluid behaves as a Newtonian, and its viscosity is directly proportional vol. fraction and inversely proportional temperature.

The application of nanoparticles in nanofluids for enhancing heat transfer in automobile radiators is well-supported by existing literature. This research work focuses on the heat transfer using mono TiO_2, ZnO, MWCNT nanofluid, and hybrid TiO_2+ZnO+MWCNT nanofluid in a radiator designed to simulate the cooling system of Maruti Wagon R, a vehicle operating in the hot climate of India. The experiment was conducted to assess the coefficient of heat transfer & Nusselt number under laminar flow. This was done using a 0.1% nanoparticle vol. fraction, at variable flow rates (4–12 LPM) and a fixed inlet temperature of 70°C.

NANOFLUID PREPARATION:
This study utilized a nanofluid containing 0.1% vol. fraction of nanoparticles, prepared by combining equal parts water and ethylene glycol**.** Four nanofluid samples were prepared, consisting of three individual mono nanofluids (TiO_2, ZnO, and F-MWCNT) and one hybrid nanofluid (TiO_2 + ZnO + F-MWCNT). In order to prepare mono and hybrid nanofluid, the quantity of base fluid and nanoparticles needed is determined using equations 1 and 2 [18].

$$\emptyset = \frac{(\frac{m}{\rho})_{np}}{(\frac{m}{\rho})_{np} + (\frac{m}{\rho})_{H2O} + (\frac{m}{\rho})_{EG}} * 100 \quad (1)$$

$$\emptyset = \frac{(\frac{m}{\rho})_{TiO} + (\frac{m}{\rho})_{ZnO} + (\frac{m}{\rho})_{MWCNT}}{(\frac{m}{\rho})_{TiO2} + (\frac{m}{\rho})_{ZnO} + (\frac{m}{\rho})_{MWCNT} + (\frac{m}{\rho})_{H2O} + (\frac{m}{\rho})_{EG}} * 100 \quad (2)$$

Nanofluid was prepared by using two step method. After adding the necessary quantity of nanoparticles to the base fluid, the ultrasonication process is run for 80 minutes to ensure that the nanoparticles are uniformly distributed and that the nanofluid is stable [19].

EXPERIMENTAL SETUP:

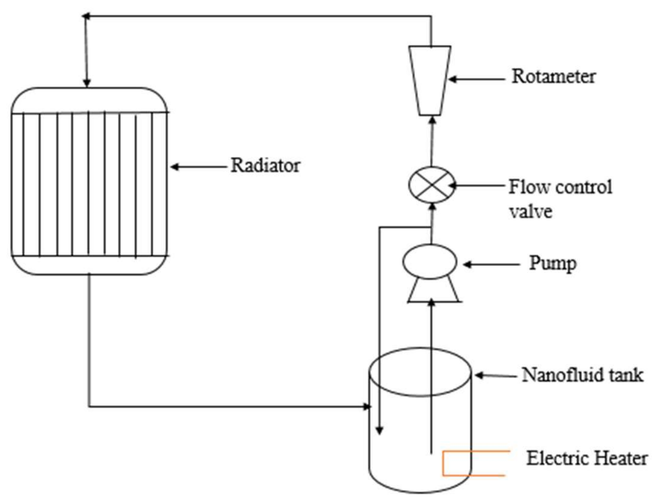

Figure 1: Schematic diagram of experimental setup

The setup, shown in figure 1, was designed to examine the heat transfer properties of an aluminum car radiator, consist of 32 vertical tubes, employed a closed-loop system for nanofluid circulation. The test rig was initially calibrated using pure water as a coolant. The experimentally determined Nusselt number values for water flow within the radiator tubes were calculated and subsequently validated by comparison with the established Shah-London correlation for laminar flow, to verify the test setup's accuracy and reliability. A nanofluid storage tank, equipped with a 2 kW electrical immersion heater, served to simulate the heat generated by an internal combustion engine, while keeping the nanofluid inlet temperature constant at 70°C. A flow control valve located downstream of the pump allowed the flow rate to be adjusted between 4 to 12 LPM. A rotameter accurately measured the flow rate through the radiator. Six Type-K thermocouples were attached to the outer surface of the radiator core at various points to record the temperature distribution across the heat radiator, thereby allowing for the measurement of heat exchange within the radiator. Two thermocouples were placed at the radiator's entry and exit to precisely measure the nanofluid's temperature change. This temperature difference is used for determining the heat transfer from the nanofluid to the surrounding air.

RESULT AND DISCUSSION:

Heat transfer using nanofluid:

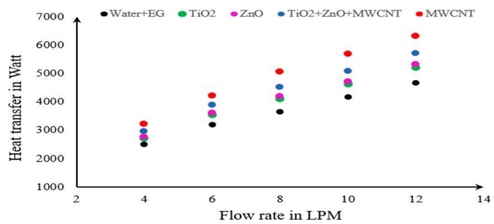

Figure 2: Heat transfer vs. flow rate

Figure 2 shows how the heat transfer by different nanofluids varies with flow rate, in comparison to a water+EG mixture. The patterns show that heat transfer rises with increasing flow rate for all fluids. Higher flow rates enhance heat transfer from a fluid to a radiator tube by increasing turbulence and thinning the thermal boundary layer, thereby increasing convective heat transfer. However, the key observation is that all the nanofluids demonstrate higher heat transfer rates than the mixture of water+EG across the entire range of flow rates tested. The MWCNT nanofluid continuously shows its superior heat transfer capability among all nanofluids, followed by the hybrid TiO_2+ZnO+MWCNT nanofluid, then ZnO, and finally TiO_2, which still outperforms the base fluid but to a lesser extent than the others. Multiple factors contribute to the improved heat transmission seen with nanofluids when nanoparticles are added to the base fluid. A primary reason for enhanced heat transfer in nanofluids is the presence of nanoparticles. Their excellent thermal conductivity directly increases the overall thermal conductivity of the nanofluid, leading to a more efficient transfer of heat. Another factor is that nanoparticles can disturb the laminar flow close to the heat transfer surface, thereby promoting turbulence even when Reynolds numbers are low. Better mixing of fluid layers reduces the thermal boundary layer's thickness and, therefore, a higher heat transfer rate. Thirdly, nanoparticles can facilitate energy transport through mechanisms like Brownian motion.In case of MWCNT nanofluid exhibiting the highest heat transfer, their unique one-dimensional structure, higher aspect ratio of nanoparticles and exceptionally high thermal conductivity play a crucial role. The interconnected network formed by these nanotubes within the base fluid can create efficient pathways for heat conduction. The hybrid nanofluid, incorporating MWCNTs along with TiO_2 and ZnO nanoparticles, also shows substantial enhancement, likely benefiting from the synergistic effects of the different nanoparticles, potentially leading to improved dispersion stability, and heat transfer enhancement. Additionally, TiO_2 and ZnO nanofluids also augmented heat transfer because of the improved thermal properties compared to the water+EG mixture, but their performance is less than that of the MWCNT-based nanofluids, suggesting that the high aspect ratio and thermal conductivity of MWCNTs are useful for enhancing heat transfer.

NUSSELT NUMBER ENHANCEMENT USING NANOFLUID :

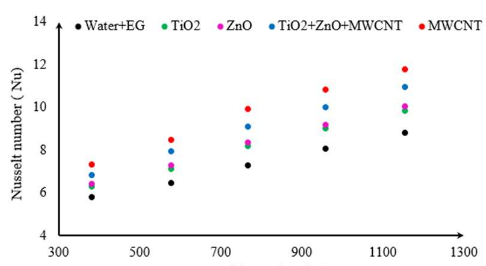

Figure 3: Nusselt number variation with Reynolds number

The Nusselt number (Nu) is a dimensionless quantity that is crucial in the field of heat transfer, particularly in convection. Figure 3 illustrates the improvement in Nusselt number (Nu), in an automobile radiator achieved through the utilization of various nanofluids compared to mixture of Water+EG across a range of Reynolds numbers (Re), which is directly proportional to flow rate. As the Reynolds number increases, indicating higher fluid velocities within the radiator, a consistent trend of improved heat transfer is observed for all fluids. However, the nanofluids showing a significantly superior performance compared to the mixture of water+EG across the entire range of flow rates investigated. At lower Reynolds numbers, each nanofluid demonstrated improved heat transfer, with MWCNT providing the most significant increase in the Nusselt number, followed in descending order by the hybrid nanofluid, ZnO, and then TiO_2. This suggests that even at lower flow rates, the inclusion of nanoparticles, particularly MWCNTs because of their excellent thermal conductivity and unique structure, significantly improves the heat transfer within the radiator. At a higher Reynolds number of 1155, TiO_2, ZnO, TiO_2+ZnO+MWCNT, and MWCNT-based nanofluids show 11.76%, 13.94%, 24.14%, and 33.61% enhancement in Nusselt number, respectively. For all fluids the Nusselt number increases with rising Reynolds number, due to increased turbulence and convective mixing. The implications of these findings for automobile radiator applications are significant. The adoption of nanofluids as coolants can lead to more effective heat removal from the engine, this could lead to smaller, lighter radiator designs**,** better fuel efficiency**,** and enhanced engine performance and lifespan.

CONCLUSIONS:

Key findings from this experimental works are:

- For automobile radiator applications, nanofluids show higher heat transfer rates & Nusselt number when compared to a mixture of water+EG.
- Higher flow rate leads to enhanced heat transfer across all fluids, including both nanofluids and the mixture of water+EG.
- Among the nanofluids tested, MWCNT nanofluid showed the highest increase in Nusselt number of 33.61%.
- Hybrid TiO_2+ZnO+MWCNT nanofluids also show 24.14% increment in Nusselt number, indicating a synergistic effect of combining various types of nanoparticles.
- The augmentation of heat transfer when using nanofluids is due to factors like enhanced thermal conductivity, disruption of laminar flow leading to increased turbulence, and enhanced energy transport.
- The study indicates that employing nanofluids in automobile radiators can enhance heat dissipation, enabling the design of smaller and lighter radiators and enhancing engine performance and fuel efficiency.

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