Automotive Radiators: An Experimental Analysis of Hybrid Nanocoolant

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Abstract. A hybrid nanocoolant is a novel type of heat transfer enhancement medium that has the potential to enhance the performance of automotive radiators by improving heat transfer efficiency and heat dissipation. The focus of the present work was to investigate the effect of different hybrid nanocoolant mixing ratios on Reynolds number, Nusselt number, Friction factor, heat transfer coefficient and convective heat transfer on heat transfer performance. Single and its hybrid nanocoolant were tested through a commercial-sized automotive radiator and a scaled-down automotive radiator to determine its laminar convective heat transfer. The nanocoolants are prepared with a fixed volume fraction of 0.01 vol% and for hybrid nanocoolants, different ratios of CNC and CuO nanoparticles are formulated. The studies utilised flow rates of 0.75, 1.00, and 1.25 LPM with a radiator inlet liquid temperature of 80°C. The experimental results show that the Reynolds number, Nusselt Number, heat transfer coefficient and convective heat transfer are proportionally related to the volumetric flow rate, while the friction factor decreases when there is an increase in the flow rate. A scale-down radiator with a low-volume concentration of hybrid nanofluids able to improve the heat transfer efficiency by 92.43% compared to conventional fluids in a commercial-sized car radiator.

1 Introduction

In the industry of automotive engineering, the search for improved thermal management strategies has become a top priority. As internal combustion engines and other vehicle components continue to evolve, the demand for more effective cooling mechanisms continues to increase. Higher cooling rates are necessary as a result of the increased thermal loads driven on by the advancements in automobile technologies. The conventional techniques used to increase the radiator's cooling rates are presently which were previously

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pushed to their maximum limit which include additional fins, microchannels, and turbulators [1,2]. Due to its exceptional capacity for high heat dissipation, reduced pumping power [3,4] and low cost, nanocoolant are a promising alternative to be used in existing automotive cooling medium and system. This paper investigates a novel approach to this problem: the use of nanocoolants in automobile radiators. Using nanofluids, which are engineered colloidal suspensions of nanoparticles in conventional coolants, as the primary focus, this study explores the potential benefits and challenges of integrating nanocoolants into automotive cooling systems. The ultimate objective of this research is to determine the potential and limitations of single and hybrid nanocoolant applied in commercial sized and reduced sized radiator.

2 Material and method

The two-step method proposed by Benedict et al. [5] and Hisham et al. [6] is the preferred procedure for the production of metal oxide nanoparticles, with or without the inclusion of plant-based extracted cellulose nanocrystals (CNC). This approach involves the dispersion of commercially accessible nanopowders into a fluid based on ethylene glycol. Two types of nanoparticles materials used in the present study are Cellulose Nanocrystal (CNC) and Copper Oxide (CuO) in Ethylene Glycol (EG) based fluid.

2.1 Nanocoolant preparation

In this study, the utilisation of Copper Oxide nanoparticles with an average particle size of 40 nm and a purity of 99% (purchased from US Research Nanomaterials Inc.) and CNC nanoparticles with a crystal length ranging from 100-100 nm and a crystal diameter ranging from 9-14 nm (purchased Blue Goose Bio Refinerie Inc) is explored for the preparation of the nanocoolant samples under investigation. The study focuses on the preparation of a nanocoolant with a fixed volume concentration of 0.01vol%, examining the two single nanocoolants (CNC and CuO) and its three hybrid nanocoolants with varying ratios of CNC to CuO at 90:10, 80:20, and 70:30 in ethylene glycol (EG) as the base fluid.

2.2 Experimental setup

This study presents the experimental test rig utilised, as depicted in Fig. 1 and Fig. 2. The study investigates the components of a system, including a storage tank, water pump, heating elements, control system utilising an Arduino programme, flow metre, fan, two automobile radiators of different sizes (standard commercial size and reduced size), a K-type thermocouple, and flow lines. The heating and transfer process of hybrid nanofluids in a water tank is facilitated by a 2000W induction heater, with the Arduino control system automatically opening valves upon reaching the desired temperature, allowing for direct pumping of the nanofluids into the radiator. The material connection of the piping in the studied system should possess minimal heat transfer resistance and high resistance to abrasion caused by nanoparticles in order to facilitate accurate heat transfer measurement. In this study, the temperature measurements at the inlet and outlet of the radiator are obtained using K-Type Thermocouples. The utilisation of eight K-Type thermocouples fixed at the inlet, outlet and walls of the radiator and the subsequent calculation of average temperature readings serve as the basis for analysis.

The proper maintenance and preparation of the apparatus, including cleaning, refilling, and rerunning with ethylene glycol, is essential before introducing a new mixture of nanofluids. The utilisation and testing of each mixture of nanocoolant/ethylene glycol will be conducted once the system reaches a steady state. In this study, the inlet temperature of the coolant is maintained at 80°C for all the experiment and the flow rate is varied at 0.75, 1.00 and 1.25 LPM.

Fig. 1. Test rig of reduced size radiator.

Fig. 2. Test rig of standard commercial size radiator (cs).

2.3 Numerical parameter

In the present heat transfer analysis, the equations below are taken into consideration. Equation (1) which determined the Reynolds Number (Re) and Equation (2) to calculate the Nusselt number (Nu). The experimental values of friction factor were calculated using for laminar flow with $N_{Re} \leq 2000$. The friction factor, f as in Equation (3) for laminar flow is calculated using eq. which was correlated by Darcy-Weisbach. The heat transfer coefficient can be evaluated by Equation (4). The geometrical characteristic of the reduce sized radiator are listed in Table 1.

$$Re = \frac{\rho D_h u}{\mu} \tag{1}$$

$$Nu = \frac{h_{exp} D_h}{k} \tag{2}$$

$$F = \frac{64}{Re} \tag{3}$$

$$h_{exp} = \frac{\dot{m}C_p(T_{in} - T_{out})}{A_s(T_b - T_s)} \tag{4}$$

Table 1. Geometrical characteristics of the reduce size radiator.

Feature	**Notation**	**Configuration**
Radiator length	l_{rad}	123 mm
Radiator height	h_{rad}	320 mm
Radiator width	w_{rad}	36 mm
Tube length	l_{tube}	2.2 mm
Tube height	h_{tube}	25 mm
Tube width	w_{tube}	2 mm
Tube hydraulic diameter	D_{htube}	3.73x10^{-3} m
Number of tubes	n_{tube}	16
The cross-sectional area of each tube	A_c	3.542 mm
The surface area of each tube	A_s	11570 mm^2
Weight	W	800 g

3 Results and discussion

The experiments were conducted by varying volume concentrations and flow rate, control entry temperatures, and utilising two different sizes of radiator. This study experimental investigate the Reynolds Number, Nusselt Number and friction factor of a low concentration single and hybrid nanocoolant of CNC and CuO. The findings obtained from the current study are presented as follows.

3.1 Friction factor

The effect of nanoparticle flow rate on the friction factor is shown in Figure 3, the friction factor decreased with the increase of flow rate. Similar results have been documented in various studies for laminar conditions [7-9]. It can be seen that the friction factor value distribution for all nanocoolant in commercial size and down scale size are almost equally equivalent. The highest friction factor was EG for both radiators. A larger friction factor leads to a greater pressure drop across the radiator, which makes the fluid work harder to move through the radiator. The fluid flow rate may be reduced as a result, which may lower the radiator's ability to transmit heat and its general efficiency. The friction factor for reduced size and commercial size radiator are found to be equal.

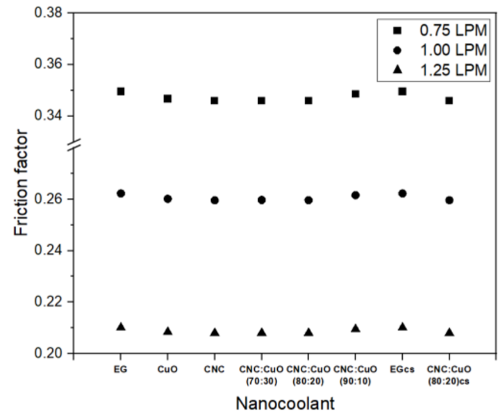
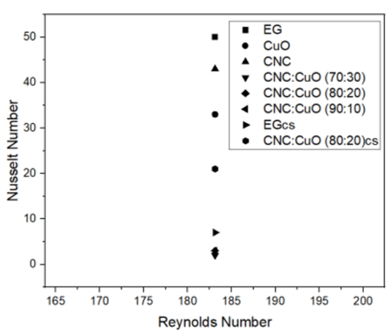


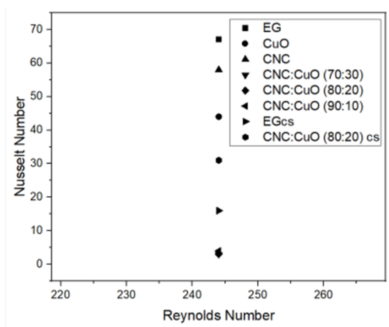
Fig. 3. Friction factor of nanocoolant at 0.75,1.00 and 1.25 LPM.

3.2 Reynolds and Nusselt Number

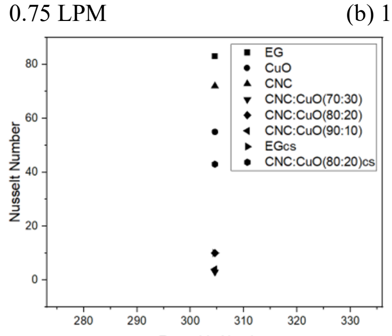
The dimensionless parameters of Reynolds number and Nusselt number are presented in Fig. 4.



(a) 0.75 LPM



(b) 1.00 LPM



(c)1.25 LPM

Fig. 4. The effect of flow rate on Re and Nu number.

Fig. 4 illustrates the influence of various flow rate on Re and Nu number for the nanocoolants at 0.75, 1.00 and 1.25 LPM. An increase of 66% is observed in Re as the flow rate increases from 0.75 to 1.00 LPM for all nanocoolant including the base fluid. Nu number increased as the flow rate increase, and this is consistent with the published research findings [8,10]. The highest values of Nusselt number found at pure EG followed by single CNC nanocoolant and hybrid nanocoolant of ratio 80:20 for commercial size radiator. The improvement in Nu is caused by an increase in attributes including density, thermal conductivity, and heat transport caused by the addition of nanoparticles in water and random collisions of nanoparticles.

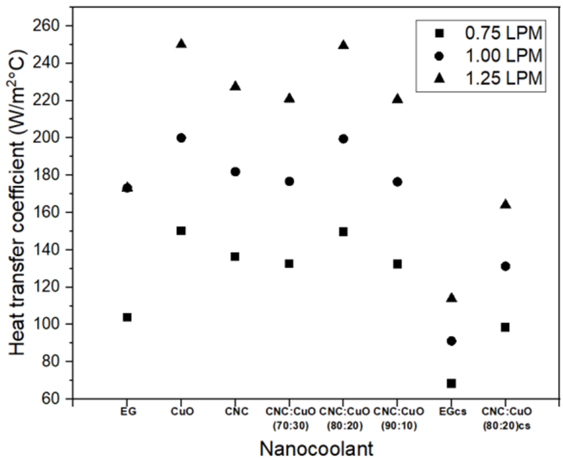


Fig. 5. Variation of heat transfer coeffifceint with flow rate for Single and Hybrid Nanocoolant.

Fig. 5 shows the relationship between the heat transfer coefficient and the flow rate of nano coolants. The highest heat transfer coefficient was observed at a flow rate of 1.25 LPM, where the CuO nano coolant exhibited a heat transfer coefficient of 250.05 W/m^{o}C. In comparison, the hybrid coolant with an 80:20 ratio achieved a slightly lower value of 249.4 W/m^{o}C. The heat transfer coefficient values for the 80:20 ratio at flow rates of 0.75 LPM and 1.00 LPM were determined to be 149.64 W/m^{o}C and 199.52 W/m^{o}C, respectively. In a similar manner, the heat transfer coefficient values for CuO were determined to be 150.03 W/m^{o}C and 250 W/m^{o}C at the same flow rate. The study of heat transfer properties for individual CuO and its hybrid material, with a composition ratio of 80:20, demonstrates a significant improvement in the heat transfer coefficient with increasing flow rate. This observed trend remains consistent to all nano coolants under investigation. Heat transfer coefficient enhancement for base fluid in reduced size radiator compared to the commercial size is 51%, 90% and 52% at 0.75LPM, 1.00 LPM and 1.25LPM respectively.

4 Conclusion

This paper provides a discussion of the Reynolds and Nusselt Numbers, friction factor and heat transfer coefficient in relation to the heat transfer performance of two distinct sizes of an automotive radiator. The findings of this study indicate that the impact of using a hybrid coolant consisting of CNC and CuO nanoparticles is particularly significant when operating at low Nusselt numbers in a reduced siza of an automotive radiator. The heat transfer rate of a single CuO nanocoolant exhibited a significant enhancement of 139.92%. Similarly, a hybrid nanocoolant with an 80:20 ratio for both radiator demonstrated heat transfer rate enhancements of 92.43% and 75.15% at a flow rate of 0.75 LPM, exceeding the performance of other hybrid nanocoolants.

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