Comparative Study of Cooling Performance of Automobile Radiator Using Al_2O_3-Water and Carbon Nanotube-Water Nanofluid

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In the present study, the forced convective heat transfer performance of two different nanofluids, namely, Al_2O_3-water and CNT-water has been studied experimentally in an automobile radiator. Four different concentrations of nanofluid in the range of 0.15–1 vol. % were prepared by the additions nanoparticles into the water as base fluid. The coolant flow rate is varied in the range of 2 l/min–5 l/min. Nanocoolants exhibit enormous change in the heat transfer compared with the pure water. The heat transfer performance of CNT-water nanofluid was found to be better than Al_2O_3-water nanocoolant. Furthermore, the Nusselt number is found to increase with the increase in the nanoparticle concentration and nanofluid velocity. [DOI: 10.1115/1.4026971]

Keywords: Al_2O_3-water, CNT-water, nanofluids, forced convection, thermal performance

Introduction

Usually single phase fluids such as water, engine oil, and ethylene glycol (EG) possess poor thermal properties. This problem can be overcome by dispersing small particles with high thermal conductivity in these conventional fluids. Earlier studies associated with the dispersion of micrometer sized particles exhibited problems with dispersion and flow. Later on, Choi [1] developed nanoparticles and reported an enhancement in thermal conductivity with the dispersion of nanoparticles in conventional heat transfer fluids. The fluids that contain nanosize particles are termed as *nanofluids*. These fluids found to possess substantially higher thermal conductivities compared to the base fluids. Because of their improved thermal properties, nanofluids are used in various applications such as micro-electronics, transportation, manufacturing, and bioengineering.

An effective thermal management system is needed to improve the thermal efficiency of heavy vehicle engines. In general, the ethylene glycol and water mixture is used as an automotive coolant in the radiator of automobile engines. These fluids have poor heat transfer performance compared to water because of lower thermal conductivity. Choi [2] reported the limitations of the existing cooling system as follows:

- Liquid-side: traditional coolants and oils have inherently poor heat transfer properties.
- Air-side: fin designs have been already adopted in order to increase the heat transfer coefficient in the air side.

In view of this, new technique is needed to improve the existing cooling performance of heavy vehicle engines. Most of the automobiles utilize a heat exchanger device, termed as radiator, to remove the heat from the cooling jacket of the engine. The radiator is a part of the cooling system of the engine. It may be noted that the addition of nanoparticles to the standard engine coolant may improve the cooling performance of automotive radiator and heavy-duty engine. This improvement in heat removal rate by utilizing nanofluids could reduce the size of the cooling system resulting in increase in the fuel economy. In addition, the smaller size could reduce the drag and leading to lesser fuel consumption. Several researchers utilized nanofluids in the automobile radiator and elaborated below.

Kulkarni et al. [3] studied the application of Al_2O_3-water nanofluids in diesel electric generator as a jacket coolant and observed a reduction in cogeneration efficiency. This is due to the decrease in specific heat, which influences the waste heat recovery from the engine. However, the efficiency of waste heat recovery heat exchanger with nanofluid increased because of its superior convective heat transfer coefficient. Vajjha et al. [4] numerically studied the laminar flow and heat transfer behavior of two different nanofluids, namely, Al_2O_3 and CuO in the ethylene glycol/water mixture by circulating the fluid through the flat tubes of an automobile radiator. The nanofluids exhibited considerable improvement in heat transfer over the base fluid. Peyghambarzadeh et al. [5] used Al_2O_3-water nanofluids in the car radiator and determined the tube side heat transfer coefficient. The heat transfer coefficient is determined for different volume concentration of nanofluid in the range of 0.1–1%, mass flow rate of 2–5 l/min and inlet temperature in the range of 37–49 °C. The heat transfer enhancement was found to be 45% higher compared to pure water for turbulent flow condition. Leong et al. [6] reported the application of ethylene glycol based copper nanofluids in an automobile cooling system. With the addition of 2% copper particles in a base fluid, the heat transfer enhancement is found to be 3.8%. Peyghambarzadeh et al. [7] used various fluids, namely, pure water, pure ethylene glycol and their binary mixtures with Al_2O_3 nanoparticles and observed that nanofluids improve the cooling performance of the car radiator. The heat transfer enhancement in nanofluids was found to be 40% higher compared to the base fluid. Naraki et al. [8] obtained the overall heat transfer coefficient of CuO-water nanofluids under a laminar flow regime in a car radiator through experimental investigation. The overall heat transfer coefficient was found to decrease with the increasing nanofluid inlet temperature from 50 to 80 °C. For the 0.4% volume concentration, nanofluid exhibited the increase in the overall heat transfer coefficient up to 8% compared to water.

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Carbon nanotubes (CNTs) have a higher thermal conductivity, higher aspect ratio, lower specific gravity, and larger specific surface area (SSA) and lower thermal resistance compared to CuO-water, Al_2O_3-water nanofluid [9]. Because of their excellent thermal properties, CNTs reported an enormous enhancement in heat transfer [10–14]. Assael et al. [10] prepared MWCNT nanofluid with the addition of 0.1 wt. % of sodium dodecyl sulfate to strengthen the suspension. For a volume concentration of 0.6%, MWCNTs in water as a base fluid showed the maximum enhancement in thermal conductivity by 38%. Hwang et al. [11] compared the thermal conductivity of various nanofluids, namely, MWCNT-water, CuO-water, SiO_2-water, and CuO-EG nanofluids. For 1.0 vol. %, MWCNT-water nanofluid exhibited the highest enhancement in thermal conductivity and found to be 11.3%. Phuoc et al. [12] prepared MWCNT-water nanofluid for various concentrations of chitosan as a dispersant (0.1, 0.2, and 0.5 wt. %). For the 0.5 wt. %–3 wt. % MWCNTs, the enhancement in the thermal conductivity of MWCNT-water was found to be 2.3–13%. Ding et al. [13] reported the heat transfer performance of MWCNT-water nanofluids with a CNTs concentration of 0.5 wt. % in a horizontal tube. The authors obtained maximum enhancement in heat transfer of 350% for $Re = 800$. The enhancement in heat transfer is due to particle rearrangement, shear-induced thermal conduction and reduction of the thermal boundary layer by nanoparticles, and the highest aspect ratio of MWCNTs. The forced convective heat transfer performance of aqueous-based nanofluids using TiO_2, CNT, and titanate nanotube has been reported by Ding et al. [14].

It is evident that most of the studies utilize Al_2O_3-water and CuO-water nanofluids in the automobile radiator in order to estimate the heat transfer performance. In view of this, an attempt has been made to study the thermal performance of automobile radiator using CNT-water nanofluid as a coolant. In addition, the performance of automobile radiator with Al_2O_3-water nanofluid as a coolant has also been studied in the present investigation. The comparison of thermal performance for nanofluids CNT-water and Al_2O_3-water has been reported in the present investigation.

Nanofluid Preparation

Multiwalled carbon nanotubes and alumina were received from the M/S Nanoshel LLC (USA). The physical properties of CNT and Al_2O_3 nanoparticles are listed in Tables 1 and 2. CNT nanofluids with different nanoparticle concentration ($\phi = 0.15\%$, 0.45%, 0.60%, and 1%) were prepared by the functionalization acid treatment method [15–20]. According to this method, simple acid treatment gives good stability in water to carbon nanotubes suspension. This was caused by a hydrophobic-to-hydrophilic conversion of the surface nature due to the generation of a hydroxyl group. In this procedure, CNTs were immersed in a mixture of H_2SO_4/HNO_3 (3:1) at room temperature. Later on, CNT were treated in an ultrasound bath (USBT-9.0 L Ultrasonic Cleanser, 200W, Rico Scientific Industries, India) for 2 h and upheld for 15 h followed by the addition of chloridric acid. Subsequently, this solution was neutralized with ammonium hydroxide and filtered with a 0.22 mm cellulose acetate membrane. The CNTs were washed several times using de-ionized water until the

Table 1 Geometrical specification and characteristics of multiwalled carbon nanotubes

Material	Multiwalled carbon nanotubes
Appearance	black
Purity	>99.5%
Diameter	20–30 nm
Length	3–8 μm
Specific surface area	90–350 m^2/g
density	3.250 g/cm^3

Table 2 Geometrical specifications and characteristics of Al_2O_3 nanoparticles

Material	Alumina
Appearance	White powder
Purity	99.99%
Diameter	<100 nm
pH value	6.6
Specific surface area	15–20 m^2/g
Specific Density	3.428 g/cm^3
Crystal form	alpha

pH adjusted to 5.5, When a surface suffers oxidation, chemical elements are adsorbed, forming functional groups. These groups are either positive or negatively charged. In this case, hydroxyl and carboxylic groups are inserted on the nanotubes surface; these groups are equally charged [21]. The presence of same-sized charged particles on the surface of CNTs enables the CNTs to repel from each other, keeping the solution dispersed form. Here, Al_2O_3-water nanofluids were prepared with different nanoparticle concentration ($\phi = 0.15\%$, 0.45%, 0.60%, and 1%) by simply dispersing specified amounts of nanoparticles in de-ionized water without any surfactant. To make the nanofluid more stable and remain more dispersed in water, ultrasonic vibrator was used. Sonication was done for 1 h continuously to obtain a more stable and evenly dispersed nanoparticle suspension.

The volume concentration is evaluated from the following relation in percentage:

$$\phi = \frac{\text{Volume of nanoparticle}}{\text{Volume of nanoparticle} + \text{Volume of base fluid}} \times 100 \quad (1)$$

$$\phi = \left[\frac{\frac{W_s}{\rho_s}}{\frac{W_s}{\rho_s} + \frac{W_{bf}}{\rho_{bf}}}\right] \times 100 \quad (2)$$

Experimental Test Facility

The schematic view of the test facility developed to study the heat transfer performance of the Al_2O_3 and CNT nanofluid in an automobile radiator is shown in Fig. 1. The test facility consists of the test section, ac-power supply, coolant supply system, cooling, and instrumentation scheme for measuring the temperature. An

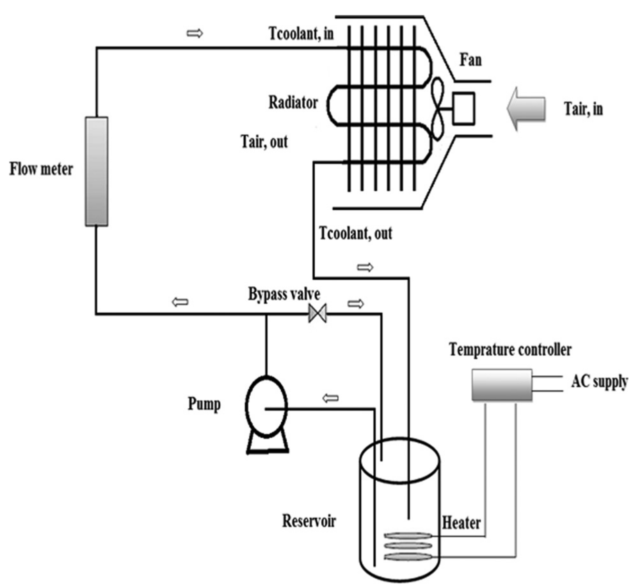

Fig. 1 Schematic diagram of the test facility

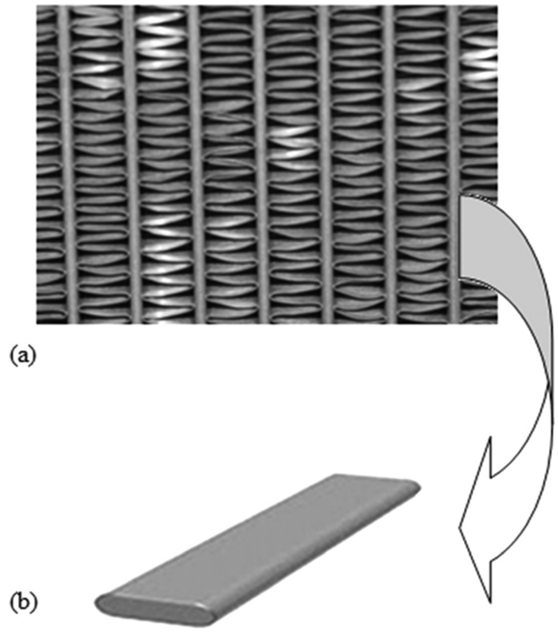

Fig. 2 (*a*) The fin and flat tube of the automobile radiator and (*b*) stadium-shape of the radiator flat tube

automobile radiator which is a cross flow heat exchanger is selected as a test section for the present investigation. The radiator consists of 30 serpentine finned tubes with stadium shape made of Aluminum. Each tube is of 310 mm length, 20 mm width, and 3 mm height (Figs. 2(*a*) and 2(*b*)). The total effective heat transfer area of the tube and fins are 0.445 m^2. The closed storage tank of 15 l capacity is used to store coolant. A centrifugal pump is used to supply coolant from the storage tank to the inlet of the test section. The outlet supply from the test section is sent back to the storage tank and used to recirculate through the test section. The flow rate of the nanofluid is controlled by using bypass valve arrangement and the remaining fluid is sent back to the storage tank. A calibrated flow meter was used to measure the liquid flow rate with the precision of 0.1 l/min. An electrical power supply (220 V, 15 A, ac) is provided to the heating elements (2 kW, 4 Nos.) in order to heat the coolant in the storage tank. For all the test runs, the inlet temperature is maintained at a constant temperature of 90 °C. The temperature of the coolant is maintained constant with the help of a temperature controller. Eight calibrated RTD PT100 type temperature sensors with an accuracy of ±0.1 °C are mounted on the test section to measure outside wall temperature. Three calibrated RTD PT100 type temperature sensors are located at inlet and outlet of the test section to measure the temperature of the working fluid, while the other one is used to measure the inlet air temperature. In addition, one RTD PT100 type temperature sensor was used to measure the temperature of coolant in the storage tank; subsequently the required temperature in the feeding tank is maintained by controlling the power supply to the heating element. The temperatures were measured by using a data acquisition system (34972 A, Agilent Technologies). A fan that provides constant air supply is used to cool the coolant through the radiator. A thermal properties analyzer (KD-2 Pro, Decagon Devices, USA) with an accuracy of ±5.0% and viscosity meter (LVDVII+ PRO, Brookfield Digital Viscometer, USA) with an accuracy of ±1.0% were used to measure the thermal conductivity and viscosity of the nanocoolant at various volume fractions and sample temperatures. Tests were performed at ambient temperature 35 ± 1 °C with a relative humidity of 65% ± 5%. An error analysis is made to estimate the errors associated in various parameters following the procedure by Cole-man and Steele method [22] and ANSI/ASME standard [23]. The individual uncertainties associated with various parameters such as: flow rate, wall and fluid temperatures, voltage and current were evaluated to calculate the total uncertainty in Nusselt number on the basis of 95% confidence level. A maximum uncertainty in Reynolds number and Nusselt number were found to be ±3% and ±5%, respectively.

Data Reduction

The following procedure was followed to obtain the heat transfer coefficient and corresponding Nusselt number.

According to Newton's cooling law, one can write

$$Q = hA\Delta T = hA(T_b - T_w) \tag{3}$$

where, A is surface area of tube. Here, T_b is bulk temperature and is assumed to be the average values of inlet and outlet temperature of the fluid moving through the radiator

$$T_b = \frac{T_{in} + T_{out}}{2} \tag{4}$$

where, T_{in} and T_{out} are inlet and outlet temperatures, respectively

$$T_w = \frac{T_1 + T_2 + \cdots + T_8}{8} \tag{5}$$

Here, T_w is the average wall temperature of the tube and T_1–T_8 denote the temperature of tube wall at various longitudinal and transverse locations of the radiator.

Heat transfer rate can be calculated as

$$Q = mC_P\Delta T = mC_P(T_{in} - T_{out}) \tag{6}$$

where, m is mass flow rate and C_p specific heat capacity of the fluid.

Utilizing Eqs. (3) and (6), one can obtain

$$\mathrm{Nu}_{exp} = \frac{hd_{hy}}{k} \tag{7}$$

where, Nu is the average Nusselt number for the radiator, k is thermal conductivity of fluid, and d_{hy} is hydraulic diameter of the tube. It may be noted that all the physical properties are measured at the bulk temperature of the fluid.

Results and Discussion

Tests were performed with water, CNT-water and Al_2O_3-water nanofluid with varied range of concentration (0.15%, 0.45%, 0.60%, and 1% by volume). In this study, tests were performed at ambient temperature 35 ± 1 °C with a relative humidity of 65% ± 5%. The inlet temperature of the coolant is maintained at 90 °C for all the test runs and the flow rate is varied between 2 and 5 l/min. The observation obtained from the present investigation is summarized below.

Thermal Conductivity and Viscosity of Measurement. Figures 3(*a*) and 3(*b*) demonstrate the experimentally measured value of thermal conductivity of CNT-water and Al_2O_3-water nanofluids. The thermal conductivity of nanofluids increases with the fluid temperature and the viscosity is found to decrease with temperature. At higher fluid temperature, the Brownian motion of nanoparticles intensifies, consequently the microconvection increases resulting in an enhancement of the thermal conductivity of nanofluids. The enhancement in the thermal conductivity with temperature for CNT-water nanofluid is shown in Fig. 3(*a*). This shows that at 60 °C, the effective thermal conductivity of CNT-water nanofluids increases by 12% and 38% for 0.15% and 0.60% volume concentration, respectively. Earlier, various authors [10,24] reported similar observations during their experimental

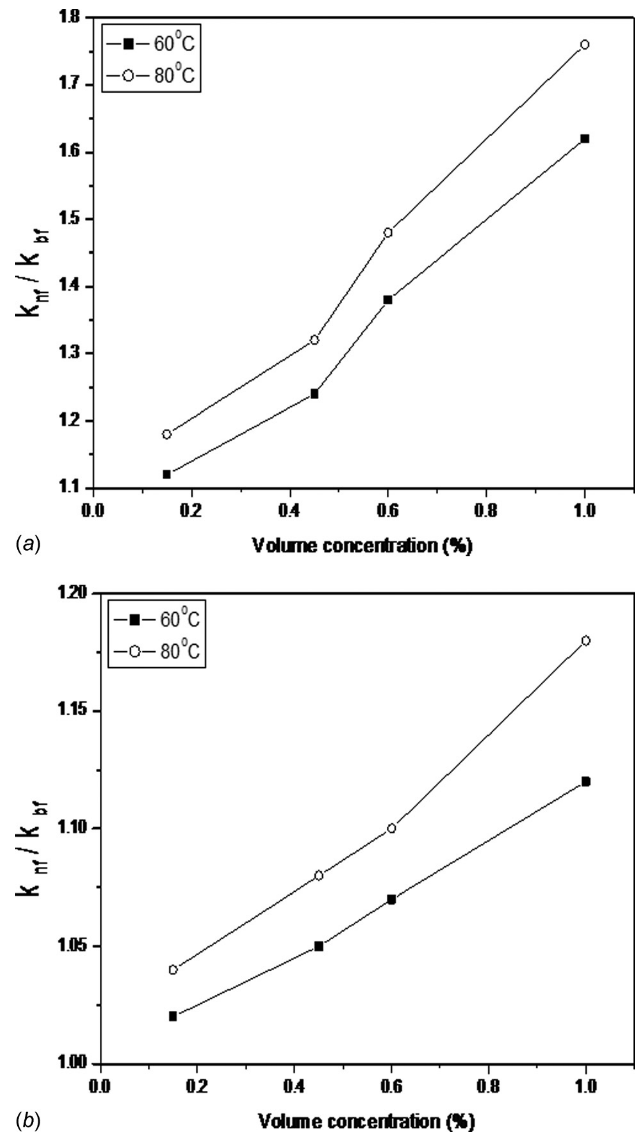

Fig. 3 Variation of thermal conductivity ratio with temperature for nanofluid with different volume concentrations (*a*) CNT-water nanofluid and (*b*) Al_2O_3-water nanofluid

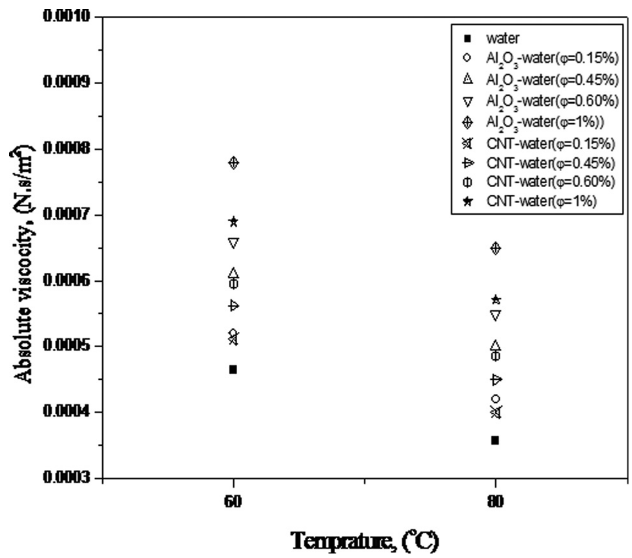

Fig. 4 Variation of absolute viscosity with temperature at different volume concentration

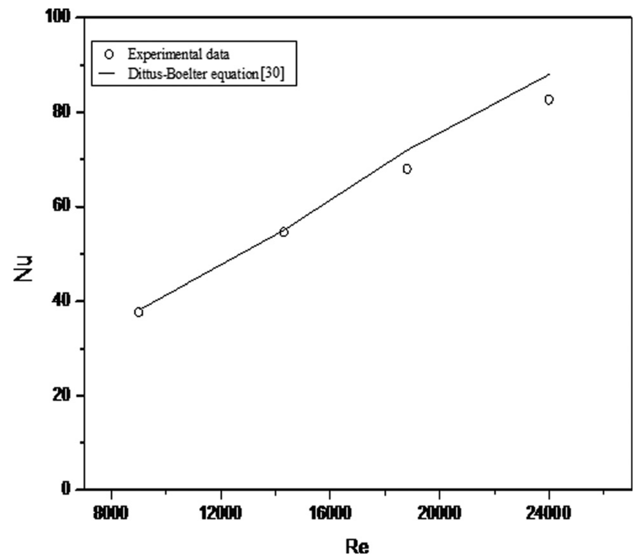

Fig. 5 Variation of Nusselt number of pure water with existing correlations

investigation. Figure 3(*b*) depicts the enhancement in the thermal conductivity with temperature for Al_2O_3-water nanofluid. For 1% vol. concentration and 60 °C fluid temperature, Al_2O_3-water nanofluid exhibit 12% enhancement in thermal conductivity compared to water. Similar observations have been made by previous researchers [25–27]. The absolute viscosities of nanofluid at different volume concentrations and temperatures are estimated by using a viscosity meter (LVDV-II+ PRO, Brookfield Digital Viscometer, and USA). Repeated tests are conducted with water and nanofluid to test the reliability of the values. The values of viscosity are found to be in excellent agreement with the values available in literature. Figure 4 shows the test data for viscosity of CNT-water, Al_2O_3-water nanofluid and water. It can be observed from these figures that the absolute viscosity of nanofluid increases with particle volume concentration and are in close agreement with the values reported by earlier researchers [28,29].

Heat Transfer Study. The test facility was evaluated for the accuracy and reliability of measurement by conducting test runs with water as coolant in the automobile radiator. The results obtained from the experimental investigation were compared with the empirical correlation suggested by Dittus Boelter [30]. Figure 5 shows the variation of the Nusselt number with Reynolds number. The experimental results exhibited good agreement with Dittus Boelter equation [30]. The results show that the Nusselt number increases with the increase in the Reynolds number. The experimental results show average deviation of 6% from theoretical results

$$\mathrm{Nu} = 0.0236\,\mathrm{Re}^{0.8}\,\mathrm{Pr}^{0.3} \tag{8}$$

where, $0.6 \le \mathrm{Pr} \le 160$, $\mathrm{Re} \ge 10000$

Figure 6 shows the variation in Nusselt number with different coolant flow rate of various nanofluids (CNT-water and Al_2O_3-water) at 0.15% volume concentration. While, the variation in Nusselt number with different coolant flow of various nanofluids (CNT-water and Al_2O_3-water) at 1% volume concentration is shown in Fig. 7. It is observed that the Nusselt number increases with the increase in the coolant flow rate, thereby increases the heat transfer (Figs. 3 and 4). This may be due to the fact that the enhanced thermal conductivity of nanofluids increases the heat transfer performance. CNT-water nanofluid was found to exhibit

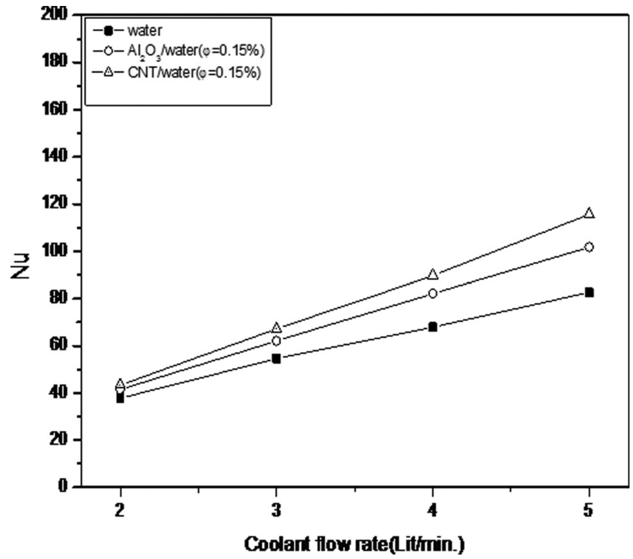

Fig. 6 Comparison of Nusselt number variation for nanocoolant at 0.15 vol. %

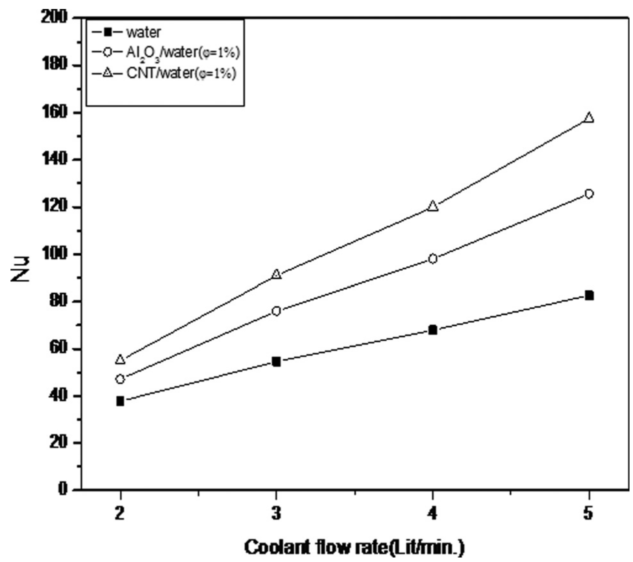

Fig. 7 Comparison of Nusselt number variation for nanocoolant at 1 vol. %

enormous heat transfer performance compared to Al_2O_3-water nanofluid for any value of coolant flow rate and nanoparticle concentration. Compared to water, CNT-water nanofluid (1% by volume) exhibited 45.87%, 66.64%, 76.55%, and 90.76% increase in the Nusselt number at flow rates 2 l/min, 3 l/min, 4 l/min, and 5 l/min, respectively. On the contrary, Al_2O_3-water nanofluid (1% by volume) exhibited 24.66%, 39.17%, 44.18%, and 52.03% increase in the Nusselt number at coolant flow rates 2 l/min, 3 l/min, 4 l/min, and 5 l/min, respectively, compared to the results with water as a coolant. The increase in the Nusselt number of CNT-water nanofluid (0.15% by volume) compared to water was found to be 15.30%, 22.09%, 32.18%, and 39.95% for the flow rates of 2 l/min, 3 l/min, 4 l/min, and 5 l/min, respectively. While, Al_2O_3-water nanofluid (0.15% by volume) exhibited 10.21%, 13.63%, 20.83%, and 23.07% enhancement in Nusselt number at coolant flow rate 2 l/min, 3 l/min, 4 l/min, and 5 l/min, respectively, compared to the pure water. Compared to water, the maximum enhancement in Nusselt number for CNT-water and Al_2O_3-water nanofluid are found to be 90.76% and 52.03%,

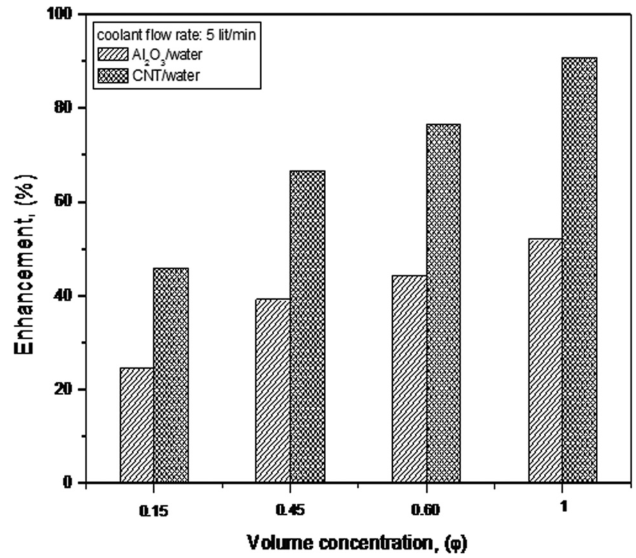

Fig. 8 Variation of thermal performance for different nanoparticle concentration

respectively. The experimental result shows that CNT-water nanofluid gives enormous enhancement in heat transfer compared to the Al_2O_3-water nanofluid. CNT nanoparticles of 20–30 nm diameter, 3–8 μm length and Al_2O_3 nanoparticles with 100 nm length are used in the present experimental investigation. CNTs have higher thermal conductivity, higher aspect ratio, lower specific gravity, large SSA and lower thermal resistance compared to Al_2O_3-water nanofluid. The higher thermal conductivity and larger SSA of CNT nanoparticles compared to Al_2O_3 nanoparticles play an important role for the better heat transfer enhancement of CNT-water nanofluid [15,18]. Therefore, greater enhancement is shown by CNT-water compared to Al_2O_3-water nanofluid.

Figure 8 depicts the percentage of enhancement in Nusselt number for two different nanofluids namely, CNT-water and Al_2O_3-water for different nanoparticle concentration ($\phi = 0.15\%$, 0.45%, 0.60%, and 1%) compared with water. The percentage in heat transfer enhancement can be evaluated by

$$\text{Percentage Enhancement} = \frac{\mathrm{Nu_{nf}} - \mathrm{Nu_{bf}}}{\mathrm{Nu_{bf}}} \tag{9}$$

It can be seen from Fig. 8 that with the increase in nanoparticle concentration, the percentage enhancement in heat transfer increases for both CNT-water and Al_2O_3-water nanofluid. The nanoparticle concentration results in an increase in the effective thermal conductivity. Besides, the heat transfer enhancement is associated with the collision among nanoparticles and between the nanoparticles and the tube wall of the automobile radiator. This leads to an increase in the Brownian motion and the energy exchange rate of nanoparticles. The effective thermal conductivity, Brownian motion of nanoparticles, particle migration increases with the increase in the nanoparticle concentration resulting in an increase in heat transfer. The heat transfer enhancement of Al_2O_3-water nanofluid at nanoparticle concentration 0.15%, 0.45%, 0.60%, and 1% are found to be 23.07%, 33.12%, 40.38%, and 52.03%, respectively, compared with water. While, the enhancement in heat transfer for CNT-water nanofluid is found to be 39.95%, 57.32%, 69.42%, and 90.76% for the nanoparticle concentration of 0.15%, 0.45%, 0.60%, and 1%, respectively, compared with water. The increase in heat transfer leads to higher thermal performance because of higher heat transfer coefficients obtained by utilizing nanofluid in automobile radiator compared to water as a coolant. The increase in heat transfer rate causes an improvement in cooling performance of the automotive engine.

Conclusion

In the present experimental study, the heat transfer performance of automobile radiator has been estimated by using two different water based nanofluids (CNT and Al_2O_3) at various coolant flow rates and nanoparticle concentration. The conclusions of the study are elaborated below:

(1) The nanocoolants found to enhance the thermal performance of the automobile radiator.
(2) The maximum heat transfer performance for 1.0 vol. % nanoparticle concentration were found to be 90.76% and 52.03% higher for CNT-water and Al_2O_3-water, respectively, compared with water.
(3) With the increase in the coolant flow rate, the heat transfer performance increases for various coolants, namely, water, CNT-water and Al_2O_3-water.
(4) The CNT-water nanofluid exhibited enormous enhancement in heat transfer compared to the Al_2O_3-water nanofluid. This may be due to the fact that carbon nanotubes offer a high thermal conductivity, high aspect ratio, low specific gravity, and large SSA and low thermal resistance as compared Al_2O_3-water nanofluid.
(5) The effective thermal conductivity of both CNT-water and Al_2O_3-water nanocoolant increases with the increase in nanoparticles concentration, consequently, increases the cooling performance in automobile radiator.

Nomenclature

A = peripheral area (m^2)
C_p = specific heat (J/kg K)
d_{hy} = hydraulic diameter (m)
h = heat transfer coefficient (W/m^2 K)
k = thermal conductivity (W/m K)
$\dot{m}$ = mass flow rate (kg/s)
Nu = average Nusselt number
Pr = Prandtl number
Q = heat transfer rate (W)
Re = Reynolds number
T = temperature (K)
W = weight of nanoparticle (kg)

Greek Symbols

μ = viscosity (kg/m s)
ρ = density of nanoparticle (kg/m^3)
φ = volume fraction

Subscripts

b = bulk
bf = basefluid
exp. = experimental
in = in
nf = nanofluid
out = out
s = nanoparticle
w = wall

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