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Heat Transfer Augmentation Using CaC_2-Water Nanofluid

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ABSTRACT: *Experimental investigations on heat transfer characteristics, friction factor, and outlet temperature were conducted in a radiator of a vehicle that makes use of calcium carbide-water (CaC_2-H_2O), a novel nanofluid, as a working fluid. The investigations were performed with water (as base fluid) and nanofluid under laminar flow condition. Nanofluid with different nanoparticle volume fraction in the interval* $0.010 \leq \phi \leq 0.050$ *wasconsidered. The results revealed that the heat transfer coefficient and Nusselt number increased with the increase of nanoparticle volume fraction, but the reverse was the case for the friction factor. In the range of the Reynolds number and the volume fraction considered, the convective heat transfer coefficient and Nusselt number of the nanofluid were up to 15% and almost 36%, respectively, higher than that of the base fluid. Furthermore, the outlet temperature of the nanofluid reduced with the increase of nanoparticle volume fraction.*

KEYWORDS: *Heat transfer, nanofluid, volume fraction, base fluid*

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I. INTRODUCTION

Research on heat transfer has been receiving important attention since long time ago andthis has been applied in several areas of engineering,such as radiators, condensers, refrigeration systems, electronics systems, solar systems, etc.[1]. The primary limitation of convective heat transfer in such engineering applications lies in the low thermal conductivity of conventional fluids,such aswater, oil, air, etc. In order to enhance heat transfer, a new technology of fluid known as nanofluids has been developed by suspending metallic or non-metallic nanoparticles in convectionalfluids known as base fluids[2].

Nanoparticles usually have higher thermal conductivity than the base fluids[3]. Nanometer-sized particles do not only prevents sedimentation of the particles, but it also prevents significant increase of pressure drop of the flow [4].An effective transfer of heat necessary to obtain a good thermal performance of a vehicle radiator through its sufficient cooling has been a technical challenge. Therefore, it is apt to look into this challenge.One of the ways to deal with this challenge is to utilise nanofluid as a working fluid. By virtue of a good thermal performance of nanoparticles, they have found applications in various areas, such as solar energy systems, heat exchangers, nuclear energy, heating of building, transportation, nuclear systems, and preservation systems, among others[5].

A lot ofinvestigations have been conducted by different researchers to know the effects of using nanofluid, in lieu of convectional fluids, on heat transfer characteristics.Laminar flow forced convection heat transfer of Al_2O_3/water nanofluid inside a circular tube was investigated experimentally by Heris et al. [6]. The Nusselt number of nanofluids was obtained for different nanoparticle concentrations as well as various Reynolds number. The results indicated there was enhancement of heat transfer due to the presence of nanoparticles in the fluid. Heat transfer coefficient increased with the increase of the concentration of nanoparticles in nanofluid. An experimental investigation on the convective heat transfer characteristics in a tube flow with alumina–water nanofluids was reported by Anoop et al.[7]. It was observed that with an increase of particle concentration and flow rate, the heat transfer coefficient was promoted by between 11% and 25% of that of the base fluid.

A study on the enhanced convective heat transfer of graphene-water nanofluids with a 0.05% volume concentration was examined by Baby and Ramaprabhu[8]. Apart from an enhancement of 16% in Nusselt number that was obtained,an increase of thermal conductivity was also reported.Sundar et al. [9]reportedon convective heat transfer coefficient of magnetite (Fe_3O_4) nanofluids with a volume concentration between 0%

and 0.6% with Reynolds number between 3,000 and 22,000. It was revealed that at 0.6% volume concentration, the heat transfer coefficient and friction factor were enhanced by 30.96% and 10.01%, respectively, compared tothat of the base fluid. The heat transfer coefficient onCuO/water nanofluid investigated under laminar flow in a radiator was increased up to 8% at nanofluidvolume concentration of 0.4 % in comparison with the base fluid. This wasthe submission of Naraki et al. [4]. Usri et al. [10] evaluated the convective heat transfer coefficient of 60:40 water-ethylene glycol based nanofluids. It was found that the heat transfer coefficient of the nanofluidsincreased with an increase of volume concentration of the nanofluid. The heat transfer enhancement of TiO_2nanofluidswas observed to be 33.9 % higher than that of the base liquid of water-ethylene glycol (60:40) mixture at 1.5 % volume concentration.

Recently, it was discovered that addition of graphene nanoparticles to water increased the thermal conductivity and the heat transfer coefficient by 10.3% and 14.2%, respectively. This was the results of the research on heat transfer coefficient of graphene-water nanofluid in a flow through a circular pipe which was examined experimentally by Akhavan-Zanjani[11].Noghrehabadi and Pourrajab et al.[12] explained that increasing the particle volume fraction of γ-Al_2O_3 nanoparticles from 0% (base fluid) to 0.9% yielded a 16.8% increase of convective heat transfer coefficient.Dhaiban[13] studied the flow and heat transfer characteristics of Al_2O_3-water nanofluids with a volume concentration between 1% and 4%. The findings of the study revealed that at Reynolds number of 7100 and particles volume fraction of 4%, the enhancement of heat transfer coefficient was 13.5%.

Just of recent,Aghabozorg et al.[14] in their work onhorizontal shell and tube heat exchanger operating with Fe_2O_3-CNT magnetic nanofluidsindicated that a higher heat transfer coefficient can be obtained from the nanofluidcompared to water. It was clear from their results that the heat transfer coefficient of the nanofluidfor laminar flow at volume concentration of 0.1% and 0.2%were enhanced by 13.54% and 34.02%, respectively in comparison with water.Trinh and Xu [15] experimentally considered the convective flow and heat transfer characteristics of ethanol/polyalphaolefinnanoemulsion flowing through circular minichannel. Ethanol/PAO nanoemulsion was used as the working fluid to study the effect of ethanol nanodroplets on its convective flow and heat transfer characteristics. It was found that using ethanol/PAO nanoemulsion fluids can improve convective heat transfer compared to that of pure PAO.

It is obvious from the literature review presented above that some researches have been carried out on heat transfer characteristics using different types of nanofluid as working fluids. As at present, there is no research that has been carried out on use of calcium carbide-water (CaC_2-H_2O) as a nanofluid. This gap motivated this work. Therefore, in this paper,heat transfer characteristics, friction factor, and outlet temperature of a novel nanofluidin a radiator of a vehicle were explored experimentally under laminar flow.

II. THERMOPHYSICAL PROPERTIES OF NANOFLUID

In order to be able to evaluate the heat transfer and flow characteristics ofthe nanofluid, it is necessary to determine its thermophysical properties, such as density, specific heat capacity, viscosity and thermal conductivity. Because of the different correlations for nanaofluids' properties which have been developed by different researchers, the particular correlations which were adopted in this work have been made known.

Xuan and Roetzel[16] presented an expression commonly used to determine the specific heat of nanofluids as a function of nanoparticle volume fraction (ϕ) as

$$(\rho c_p)_{nf} = \phi(\rho c_p)_p + (1-\phi)(\rho c_p)_f \tag{1}$$

where $(\rho c_p)_{nf}$,$(\rho c_p)_p$, and $(\rho c_p)_f$ are the heat capacitance of the nanofluid, nanoparticles and base fluid, respectively.

Wen and Deng [17] introduced the nanofluid density (ρ_{nf})as

$$\rho_{nf} = \phi\rho_p + (1-\phi)\rho_f \tag{2}$$

where$\rho_p$andρ_f and are the density ($\mathrm{kg/m^3}$) of the nanoparticleand base fluid, respectively.

In the present work, the formula introduced by Corcione[18] was used to calculate the dynamic viscosity ($\mathrm{Ns/m^2}$) of the nanofluid as

$$\mu_{nf} = \left[1 - 34.87\left(\frac{d_p}{0.1\left(\frac{6M_f}{N_f\pi\rho_f}\right)^{1/3}}\right)^{-0.3}\phi^{1.03}\right]\mu_f \tag{3}$$

where μ_{nf} ,μ_f, d_p, M_f, and N_f arethe dynamic viscosity of the nanofluid, dynamic viscosity of the base fluid, diameter of the nanoparticle, molecular weight of the base fluid, and Avogadro constant of the base fluid, respectively.

Kakaç and Pramuanjaroenkij[19]proposed an empirical correlation for the thermal conductivityof nanofluid as

$$\frac{k_{nf}}{k_f} = 1 + 4.4Re_p^{0.4}Pr^{0.66}\left(\frac{T_{nf}}{T_{fr}}\right)^{10}\left(\frac{k_p}{k_f}\right)^{0.03}\phi^{0.66} \quad (4)$$

where k_{nf}, k_f, and k_p are the thermal conductivity ($\mathrm{W/m.K}$) of the nanofluid, base fluid , and nanoparticles respectively; T_{nf} and T_{fr} arenanofluid temperature (K) and the freezing point (K) of the base liquid,respectively; Re_P is the Reynolds number of the nanoparticle.

The thermophysicalproperties the base fluid (water) and the nanoparticle (calcium carbide) are shown below in Table 1.

Table 1: Thermophysical properties of water (H_2O) and calcium carbide (CaC_2) at 27°C

Thermophysical properties	H_2O [20]	CaC_2[21]
Specific heat capacity, $C_p/\mathrm{kJ/kg.K}$	4.179	0.971
Density, $\rho/(\mathrm{kg/m^3})$	996.6	2220
Dynamic viscosity, $\mu/(\mathrm{Ns/m^2})$	0.000855	0.001
Thermal conductivity, $k/\mathrm{W/m.K}$	0.613	40

III. PREPARATION OF CALCIUM CARBIDE-WATER NANOFLUID

The nanofluid has to be prepared before applying it to conduct the experiments. Calcium carbide nanoparticle was obtained by using apulverizer and a ball mill (Spex - 8000M, Wolf Laboratories Ltd, UK) to grind a lump of calcium carbide into a powdery form,and then sieved it with a sieve shaker (BST/MSS-4, Bionics Scientific Technologies (P) Ltd. India) to obtain the nanoparticle. The nanometer-sized particle was confirmed with a particle analyser (Mastersizer 3000, Malvern Instruments Limited, UK). The nanofluid was prepared by mixing the nanoparticle (CaC_2) with the base fluid (water). In order to prevent sedimentation of the nanoparticle, some quantity of oleic acid was added to the base fluid prior to the mixing. Specific quantities of the CaC_2 nanoparticles were mixed with water to preparethe nanofluidof variousnanoparticle volume fractionsof 0.01, 0.02, 0.038, and 0.05.

IV. EXPERIMENTATION

The schematic diagram of the components of the experimental system is shown in Fig. 1. It included a 0.0395m^3- capacity metallic reservoir with a 1500 W-heater (Flange immersion, YanchengHongtai Alloy Electric Apparatus Co. Ltd., China) which was used to represent an engine. The reservoir contained the nanofluid which was heated by the heater. The nanofluid flowed through a flow line. The fluid was conveyed to the vehicle radiator via a 50 litre/minute pump (Interdab JET- 100M, China) with an accuracy of ±0.12litre/minute. A fan (Fanafrik S-06, Marc & Mei Nig. Ltd., Nigeria) was placed close to the face of the radiator to supply air current to cool it. The flow velocity was adjusted means of a valve (Type RH-S, AZ-Armaturen South Africa (Pty) Ltd., South Africa) while the flow rate of the fluid was measured with a flow meter (LZM-15Z, Sichuan Vacorda Instruments Manufacturing Co., Ltd., China) with an accuracy of ±0.1litre/minute.

Four K-type thermocouples (WXE-2016, Yueqing Zhejia Electronic Co., Ltd. China) were placed on the surface of the radiator to measure its surface temperature, while another K-type thermocouple was placed at each of the inlet and outlet of the radiator to measure its inlet temperature and outlet temperature, respectively. The values of temperature were measured by digital multimeters (Fluke 115, Fluke Corporation, USA) with an accuracy of ±0.1°C. A pressure gauge (ADT681, Additel Corporation, USA) with an accuracy of ±2.5 mbar was placed at each of the inlet and outlet of the radiator to measure its inlet pressure and outlet pressure, respectively. The experiment was repeated four timesto make its data accurate and reliable.

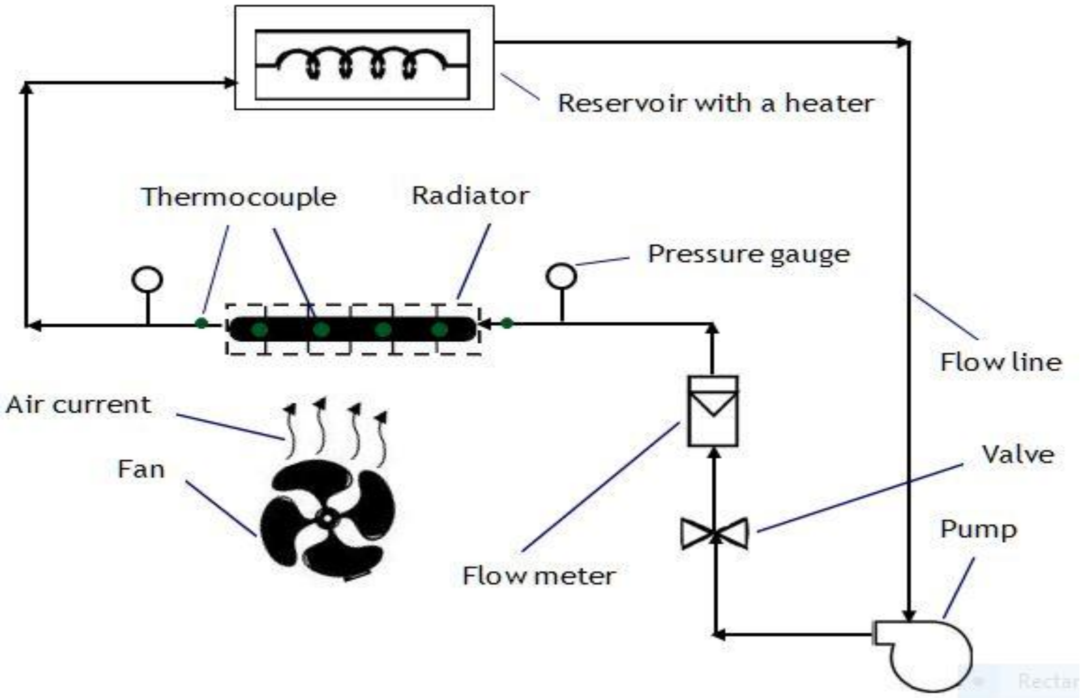

Fig. 1:Schematic diagram of components of the experimental system

V. HEAT TRANSFER CALCULATION

The Nusselt number (Nu) was obtained from the fundamental equation of Newton's law of cooling provided by Incropera et al. [20] as

$$Q = hA_s(T_b - T_s) = hA_s\left(\frac{T_i + T_o}{2} - T_s\right) \quad (5)$$

where$Q$, h, A_s, T_b,T_s, T_i,and T_o are the heat transfer rate ($\mathrm{W/m^2}$), heat transfer coefficient ($\mathrm{W/m^2.K}$), surface area of tube ($\mathrm{m^2}$), bulk temperature (K), surface temperature of tube (K), fluid inlet temperature (K), and fluid outlet temperature (K), respectively.
Since the four thermocouples were used to measure the surface temperature of tube, then the mean temperature was taken as

$$T_s = \frac{T_1 + T_2 + T_3 + T_4}{4} \quad (6)$$

The heat transfer rate (Q) was obtained from the relation

$$Q = \dot{m}C_p(T_i - T_o) \quad (7)$$

The Nusselt number was expressed mathematically as

$$Nu = \frac{h.D_H}{k} \quad (8)$$

Combining Eqs(5) and (7), Nusselt number (Nu) was obtained from the relation

$$Nu = \frac{\dot{m}C_p(T_i - T_o)}{nA_s(T_b - T_s)}.\frac{D_H}{k} \quad (9)$$

In Eq.(9), $\dot{m}$, C_p, n, D_H, and k are the mass flow rate (kg/s), specific heat capacity (kJ/kg.K), number of radiator tubes, hydraulic diameter of the radiator tube (m), and thermal conductivity ($\mathrm{W/m.K}$), respectively.
The Reynolds number (Re) and friction factor (f) were calculated from the following relations in Eq. (10)and (11), respectively[22]:

$$Re = \frac{\rho.D_H}{\mu}.\frac{\dot{V}}{n.A_c} \quad (10)$$

$$f = 0.316Re^{-1/4} \quad (11)$$

where$\dot{V}$ (m^3/s) is the volumetric flow rate and A_c (m^2) is the cross sectional area, A_c (m^2) of the radiator tube.

VI. RESULTS AND DISCUSSIONS

VI.1 Effect of nanoparticle volume fraction on convective heat transfer coefficient

Fig. 2 below depicts the heat transfer coefficient of thenanofluid as a function of the nanoparticle volume fraction. It is revealed in the figure that the heat transfer coefficient of the nanofluidwas higher than that of the base fluid. The reason adduced for this, as provided by Vajjha et al. [23], was that the nanoparticles created a larger surface area for interaction between the nanoparticles and the base fluid. This did not only increase the collision between the nanoparticle and the wall of the radiator tubes, but it also increased the intensity of heat transfer. Quantitatively, the heat transfer coefficient of the nanofluid with nanoparticle volume fraction of 0.01, 0.02, 0.038, and 0.05 were 1.05, 1.09, 1.12 and 1.15, respectively, times that of the base fluid.

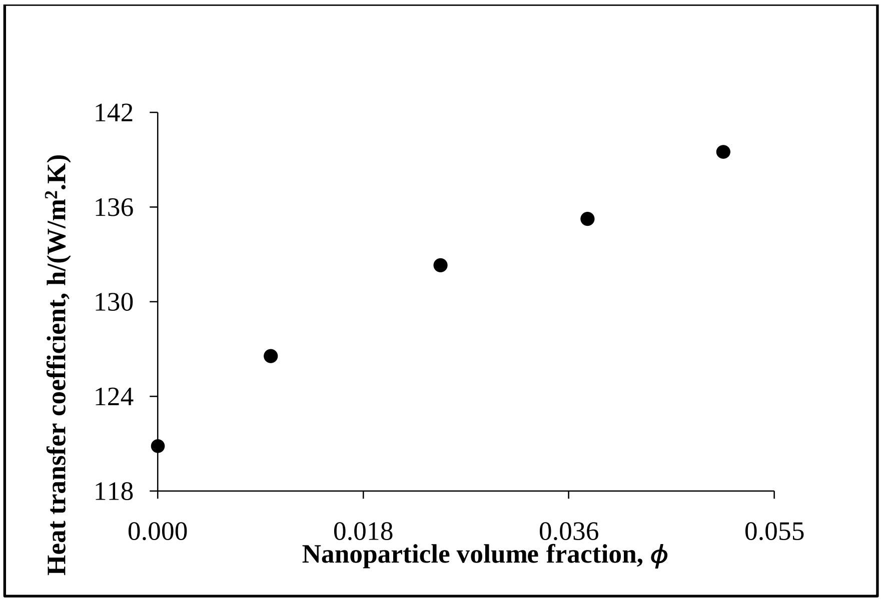

Fig. 2: Heat transfer coefficient at various nanoparticle volume fraction

VI.2Effect of nanoparticle volume fraction on Nusselt number

The Nusselt number at different nanoparticle volume fraction and Reynolds number isplotted in Fig. 3.Evidently, the Nusselt number increased with the increase of nanoparticle volume fraction. The Nusselt number of the nanofluid with nanoparticle volume fraction of 0.01, 0.02, 0.038, and 0.05 were almost 7-10%, 15%, 24-28%, and 33-36%,respectively, higher than that of the base fluid.In the observation ofMadhesh et al. [24], the increase ofNusselt number was because as the volume fraction of the nanoparticle increased, chaotic motion of the particles increased the exchange of energy between the wall of the radiator's tubes and the fluid, and consequently augmented the Nusselt number. In addition, it is observed that the Nusselt number also increased with an increase of Reynolds number. This is because the momentum of the fluid overcame its viscous force as the Reynolds number increased.

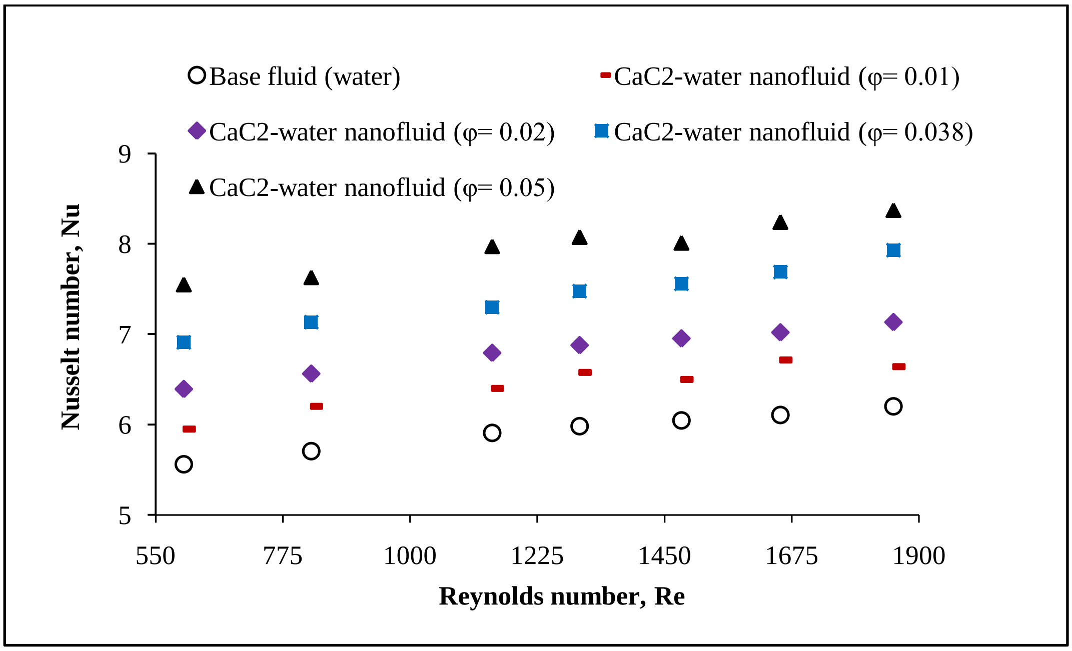

Fig. 3:Nusselt number at various nanoparticle volume fraction and Reynolds number

VI.3 Effect of nanoparticle volume fractions on friction factor

In order to investigate the flow characteristics of the nanofluid, the pressure drop (ΔP) of the CaC_2-H_2O nanofluidsand that of the base fluid was determined experimentally. The relationship between the Darcy friction factor (f) and the pressure drop can be expressed mathematically[20]as

$$f = \frac{-(\Delta P/dx)D_H}{\rho u^2/2} \qquad (12)$$

where$u$isthe fluidvelocity.

The friction factor at various nanoparticle volume fraction and Reynolds number is represented graphically inFig. 4. As shown in the figure, the friction factor decreased with the increase ofReynolds number.The reason provided for this by Oni and Paul [25] was that athigher Reynolds number, the momentum of the flow was higher and therefore the flow resistance betweenthe fluid and the wall of the tubes of the radiatorwas reduced.It is obvious from the figure that the friction factor reduced as the nanoparticle volume concentrationincreasedfrom 0.01 to 0.05. The friction factor of the nanofluid with nanoparticle volume concentration of 0.01, 0.02, 0.038, and 0.05were1.01-1.03, 1.01-1.04, 1.02-1.04, and 1.01-1.03times, respectively, that of the base fluid. This shows that the difference in the values of the friction factor of the base fluid and those of the nanofluid of various nanoparticle volume fraction at various Reynolds number was not significant.

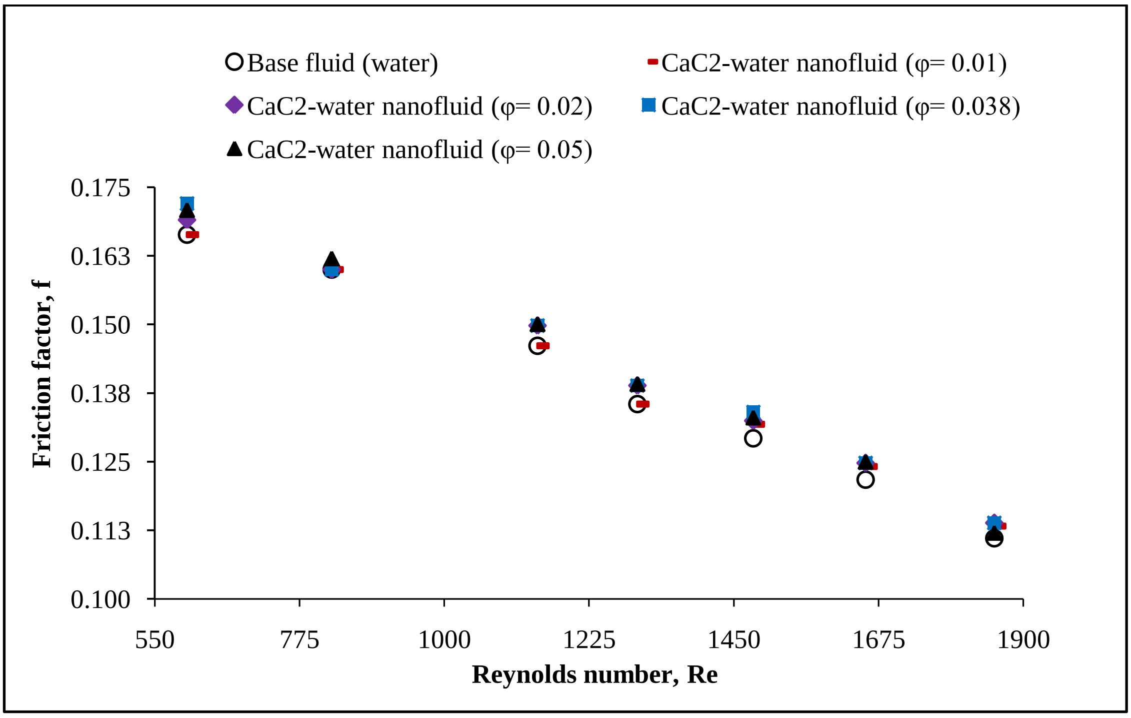

Fig. 4: Friction factor at various nanoparticle volume fraction and Reynolds number

VI.4Effect of nanoparticle volume fraction on outlet temperature

The effect of the nanoparticle volume fraction on the outlet temperature of the working fluids is shown in Fig. 5. It can be observed from the figure that the fluid outlet temperature (T_o) decreased with theincreaseof nanoparticle volume fraction (ϕ). The outlet temperature decreased with the increase of Reynolds number (Re). At $Re = 600$, $T_o$decreased from 70°C to 52°C for an increase ofϕ from 0.00 (base fluid) to 0.05, respectively.At$Re = 1855$, T_o decreased from 64°C to 42°C for the same increase ofnanoparticle volume fraction from 0.00 (base fluid) to 0.05, respectively. Hence, it is reasonable to submit that an effective heat transfer necessary to obtain a good thermal performance ina vehicle radiator through its sufficient coolingwas achieved withthenanofluid.

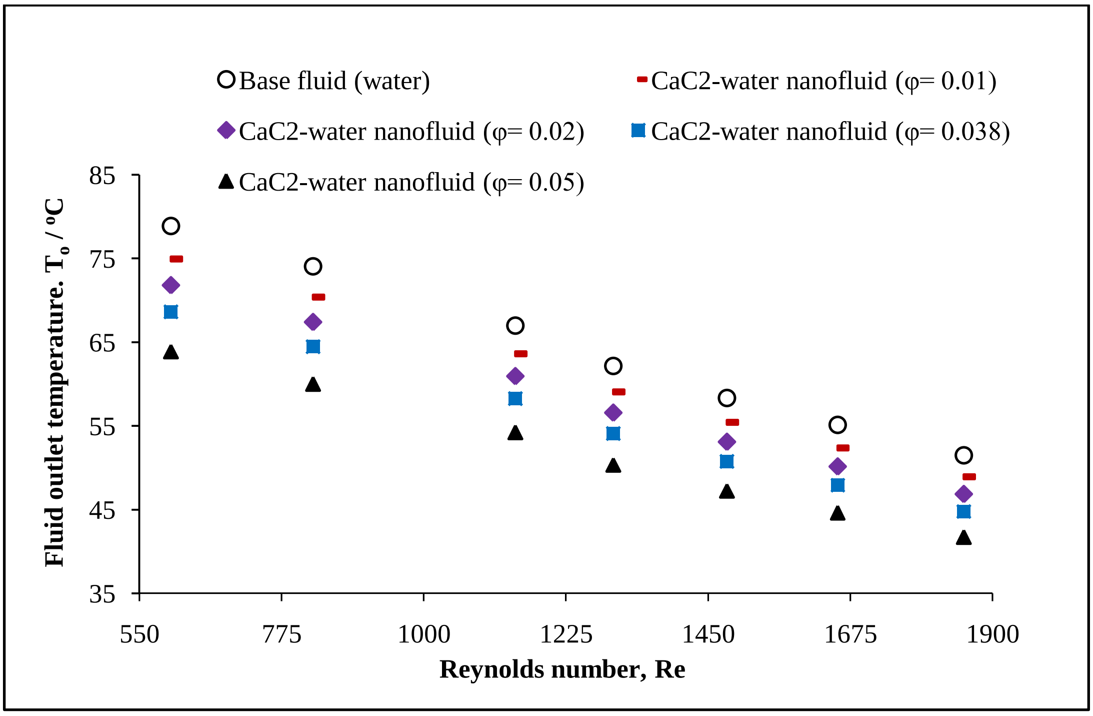

Fig. 5: Effect of nanoparticle volume fraction on fluid outlet temperature

VII. CONCLUSION

In the present work, the heat transfer characteristics, friction factor, and outlet temperature in a vehicle radiator making use of a novel nanofluid with different nanoparticle volume fraction in the interval $0.010 \leq \phi \leq 0.050$ under laminar flow with Reynolds number in the range of 600 - 1855was examined experimentally. The convective heat transfer coefficient and Nusselt number increased with the increase of nanoparticle volume fraction (ϕ), with the maximum values obtained at $\phi = 0.050$.The convective heat transfer coefficient and theNusselt number of the nanofluid were up to 15% and almost 36%, respectively, higher than that of the base fluid. The friction factor diminishes as ϕ and *Re* increased, but the effect was not significant in comparison with the base fluid. The interpretation of this is that heat transfer enhancement with nanofluid is possible with insignificant penalty in pressure drop.At$Re = 1855$, the outlet temperature of the nanofluid reduced from 52°C for $\phi = 0$ (base fluid) to 42°C for $\phi = 0.05$. This means that an effective heat transfer necessary to obtain a good thermal performance in a vehicle radiator through its sufficient cooling was achieved with the novel nanofluid.

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