Enhancement of Heat Transfer and Pressure Drop Characteristics of Vehicle Radiators with AL2O3/water Nanofluid.

A. Abdelaal [1]

[1]First Automotive and tractors Technology Dpt, Faculty of Technology and Education, Helwan University, 11282 Cairo, Egypt

---

Abstract - *In this study, the thermal performance and pressure drop characteristics of the vehicle radiator are investigated experimentally using nanofluids in Cairo, Egypt's hot, dry climate. Many factors, including working fluid flow rate, working fluid temperature and nanofluid concentrations are examined in this paper. Different nanofluid (Al2O3/water) concentrations of 0.02, 0.05, and 0.1 by volume are investigated. The experiments are conducted for a radiator with a fixed air velocity of 0.6 m/s and working fluid flow rate of 3, 5, 7.5,10 and 12.5 LPM with Reynolds number ranges of 3600≤Re≤22×103. The temperature of working fluid in the reservoir is varied from 80 to 95°C. With specific reference to pure water, the effects of Al2O3/water are evaluated using a Nusselt Number for heat transfer performance and friction factor for pressure drop characteristics. The results show that the Al2O3/water performs better thermally than water. The thermal performance increased as Reynolds number and concentration ratio increased. The results showed that with Reynolds number of 12,500 Nusselt number at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 16%, 10% and 7% respectively. At the same Reynolds number, the friction factor at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 60 %, 54% and 38% respectively. At Reynolds number of 12,500 the friction factor at 95oC is lower than that of 90oC, 85oC and 80oC by 7%, 10% and 18% respectively. At a certain Reynolds number of 12,500 Nusselt number at 95oC is higher than that of 90oC, 85oC and 80oC by 6%, 25% and 37.5% respectively.*

Key Words: vehicle radiators; nanofluid; performance characteristics

1. INTRODUCTION

For nanofluids, Because of its high heat transfer coefficients and ability to accommodate a large heat transfer surface in a short space, cooling radiators are widely employed in several industrial applications. Cars and trucks continually need greater heat rejection because of trends towards stronger outputs. Heat transfer has a direct influence on engine performance, fuel economy, material selection, and emissions. Numerous scholars have examined the thermal efficacy of radiators. W. Yu, et al [1] The following are some advantages of enhanced radiator and heat transfer systems employing nano fluids: smaller components that take up less space under the bonnet and give designers more freedom when it comes to aerodynamic style, lower weight that will increase fuel efficiency, more efficient cooling and lengthen component life Dustin R, et al [2]. Towards the conclusion of the useful life cycle of heat transfer systems, the size-related solid waste disposal issue is lessened. Devendra Vashist et al [3]. % AL2O3 nanoparticles to water increased the thermal conductivity of the Nano fluid by 21.4%. They also improved the viscosity of the liquid by dispersing ultrafine particles K.Y. Leong, et al [4]. An Argonne National Laboratory research team was the first to examine the usage of Nano scale particles. One of the most significant technological issues that many companies, including those in the automotive, electrical, and industrial sectors, must deal with is cooling Hardik V. Patel, et al [5]. The thermal loads created by new technological advancements are rising, necessitating quicker cooling Rashmi Rekha Sahoo, et al [6]. Fins and micro channels, the traditional means for accelerating cooling, have already reached their physical limits Seth Daniel Oduro, et al [7]. To accomplish this high performance cooling, new and creative coolants are therefore urgently needed. S.C. Tzeng, et al [8] Traditional heat transfer fluids, such engine coolants, have relatively poor thermal conductivities W.M. Yan, et al [9]. Industries urgently need to produce heat transfer fluids that are more thermally efficient than those already on the market due to rising worldwide competition A.J. Torregrosa, et al [10]. In certain nations, official organizations like the Environmental Protection Agency are also enforcing stricter standards for pollution and vehicle emissions J.P. Holman et al [11]. The larger heat exchanger/radiator capacity of the new coolants, together with their improved thermal performance, may result in a Reduction in vehicle fuel consumption. A fresh idea is nanofluids W. Duangthongsuk, S. Wongwises [12]. These are heat transfer fluids with nanoparticles suspended in them that were created to handle more difficult cooling difficulties X. Wang, X. Xu [13]. A brand-new category of solid-liquid composites called nanofluids is made up of solid particles with a size of 100 nm or less suspended in heat-transfer fluids including water, ethylene, and propylene glycol Y. Xuan, W. Roetzel [14]. Convective heat transfer has been demonstrated by several studies. Experimental studies the possibility for higher temperature coolants and more heat rejection in vehicle engines is made possible by nanomaterials W. Yu, H. Xie [15]. Just 25% of heat is transformed to usable electricity, while the rest is lost as heat. N. Masoumi, et al [16]. By boosting heat transfer and expanding the heat transfer area, radiator heat transfer may be made better. In order to increase the heat transfer coefficient and the heat transfer rate in the cooling system of the engine radiator and with the use of Nano coolants, Aluminum Oxide (Al2O3) in water was used as a nanofluid M. Kole, et al [17]. In the present study, the performance of the aluminum oxide (Al2O3), where Reynolds number and volume concentrations are raised, Furthermore, compared to concentrations and pure water as a coolant. With a fixed volume fraction, by increasing the pressure of the nanofluid, the radiator pressure drop rises. Experimentation was done on the use of nanofluid as coolants in engines to study heat transfer. Finally, the paper focuses on the performance criteria of the vehicle engine cooling system using Al2O3/H2O, How do a few ratios of Al2O3/H2O affect the heat transfer performance of the vehicle radiator? What impact when different types of nanoparticles are added to water, does the thermal performance change compared with the base fluids? These are some important questions which have been answered along this investigation in addition, to study the effects of key design and operating parameters such as; coolant type, nanofluid concentrations, nanoparticle types, coolant mass flow rate and temperature variations on characteristics of the vehicle radiator. Pumping power, effectiveness, number of transfer units, and performance index are also discussed. Correlations of Nusselt number, effectiveness, and friction factor of the vehicle radiator are also developed.

2.EXPERIMENTAL SET-UP AND INSTRUMENTATION

The thermal performance of vehicle radiator is investigated using the test apparatus as shown schematically and graphically in Fig. 1 and Fig. 2, respectively. Experimental setup is consisting of 0.5 m3 insulated water tank which is provided with 1.5 kW immersed electric water heater (regulated by thermostat) and agitator. 0.5 Hp water centrifugal pump for working fluid circulation. Vehicle radiator, fin and tube heat exchanger type provided with DC fan supplied by battery. Dimensional data and geometrical characteristics for vehicle radiator are indicated in table (1 and 2), respectively. In addition to piping network with required ball valves that connecting different parts of the system. Volume flow rates are measured by using floating flow meters with an accuracy of ±0.5 LPM. A mercury U- tube manometer is connected to the inlet and outlet of the radiator for pressure drop measurements. The temperatures are measured by *13* type – K calibrated thermocouples are placed in different point in the system. Volume flow rates are measured by using floating flow meters with an accuracy of ±0.5 LPM. The hot wire anemometer is used to obtain the average air velocity with an accuracy of ±0.1 m/s, which were 0.6 m/s and constant during all experiments.

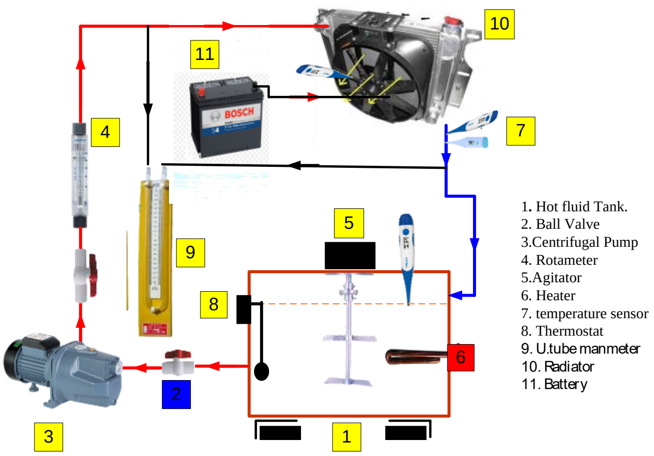

Fig -1: Schematic diagram of the experimental setup

Fig -2: Graphical view of the experimental setup

Table -1: Dimensions of the vehicle radiator

Geometrical characteristics	Radiator configuration
Radiator core dimension, (mm^3	400x500x67
Tube dimension, (mm^2)	12×2
Tube length, Ltu, (mm)	500
Tube thickness, δtu, (mm)	0.02
Number of tubes, Ntu	36
Number of fins, Nf	399
Number of rows, Nr	4
Number of column, Nc	37
Tube cross section	Rectangular
Tubes arrangement	Staggered
Tube material	Aluminum

Table -2: Geometrical characteristics of the fin design parameters

Geometrical characteristics	Fin configuration
Fin length, *Lf*, (mm)	500
Fin depth, *Wf*, (mm)	67
Fin pitch, *λf*, (mm)	2.5
Fin thickness, *δf*, (mm)	0.12
Number of fins, *Nf*	399
Transverse pitch,	9.7
α(mm)	4
Staggered offset, *β*(mm)	Copper
Fin material	Flat fin
Fin pattern	

Table -3: Matrix of the experimental inlet conditions

Variables/Unit	Range
Hot fluid inlet temperature (T_{wf}),°C	50:90 °C $\pm$ 0.5
Fluid flow rate ($\dot{m}_{wf}$)kg/s	0.05:0.1
Air inlet velocity (v_a), m/s	0.6 Const.
Al_2O_3, (φ), % Vol.	0.02–0.05-0.1

2.*1*. Measurements uncertainties and accuracy

The error analysis method of estimating uncertainty in experimental results has been presented by Kline and McClintock, which described. The method is based on a careful specification of the uncertainties in the various primary experimental measurements [*18–19*].The dependent variable (R) is illustrated as a function of the independent variables x1, x2, x3, ..., xn; thus: R=R (x1, x2, x3, ..., xn). Let Ur the uncertainty in the result and u1, u2, u3… UN is the uncertainties in the independent variables. Therefore, the uncertainty in the result is given by [*20*]:

$$W_R = \left[\left(\frac{\partial R}{\partial X_1} W_1\right)^2 + \left(\frac{\partial R}{\partial X_2} W_2\right)^2 + \left(\frac{\partial R}{\partial X_n} W_n\right)^2\right]^{\frac{1}{2}} \quad (1)$$

The accuracy and uncertainty of the instruments and measurement Parameters are given in Table 4.

Table -4: Accuracies and estimated uncertainties of measurements

Instruments/Parameter	Unit	Accuracy	Uncertainty
Flow meter Digital	L/min	0.5%	–
type	°C	0.1%	–
thermocouples	mm	0.1%	–
U-tube	m	0.01%	–
manometer	/	0.1%	–
Hot wire velocity	s	–	±2.11
anemometer	g	–	±2.76
Weighing	m	–	±2.33
balance	–	–	±1.86
Reynolds	–	–	±1.77
number	–		
friction factor	–		
Nusselt	–		
number			
Number of			
transfer units			
Performance index			

2.*2*. Nanofluid preparation and properties

2.*2*.1. Preparation steps of nanofluids

The Al2O3 is the only nanoparticle employed in this experiment. Obtain the Al2O3 nanoparticles by adding nanoparticles in a certain concentration to a base fluid [AL2O3/water] with various weight mixing ratios, the nanofluids are created [*21*]. During around 15 to 20 minutes, a mechanical stirrer is employed to produce a homogeneous solution for each nanofluid concentration. After that, the solution is run through ultrasonic machinery for a period of around 4-6 hours to disperse any sediment agglomerations [*22*]. Following, the hot water tank is filled with various nanofluid samples that have been subjected to various scientific testing [*23*]. By utilizing an agitator motor in the heating tank, nanofluids are continuously flipped while being employed as a homogeneous solution [*24–25*]. For Al2O3, the nanofluid concentrations are set at particle volume concentrations of 0.02, 0.05, and 0.1%. Volume concentration ratio, Table 5.

$$\Phi\,(\%) = \frac{\text{Volumeofnanoparticle}\,(V_{np})}{\text{Volumeofnanofluid}\,(V_{np} + V_{bf})} \times 100 \quad (2)$$

2.*2*.2. Nanofluid physical properties

In accordance with certain ratios, the Al2O3 nanoparticles are disseminated in a base fluid (water or both). The system-wide distribution of the nanoparticles is uniform and well-sprayed in the mixture [*26–27*]. Several formulae have been proposed to calculate the density, specific heat capacity, and thermal conductivity of the nanofluid as the following

$$\rho_{nf} = \rho_{np}\left(\varphi\right) + \rho_{bf}\left(1-\varphi\right) \quad (3)$$

$$Cp_{nf} = \frac{(\rho Cp)_{np}\left(\varphi\right) + (\rho Cp)_{bf}\left(1-\varphi\right)}{(\varphi)\rho_{np} + \rho_{bf}\left(1-\varphi\right)} \quad (4)$$

$$k_{nf} = k_{bf}\left(1+8.733\varphi\right) \quad (5)$$

$$\mu_{nf} = \mu_{bf}.\exp\left(\frac{(5.989\varphi)}{(0.278-\varphi)}\right) \quad (6)$$

Where Ø the weight concentration of nanofluid /water.

Table -5: the physical properties of water and AL2O3 nano-particles

Specification	ρ (kg/m³)	C_p (J/kg.K)	K (W/m.K)	μ (pa.s)
Water	1000	4180	0.60	$1.003x10^3$
AL_2O_3	3890	773	36	-

AL2O3 nano-particles have average diameter of 55 nm Fig.3 [*29–30*], which are checked with transmission electron microscopy (TEM).

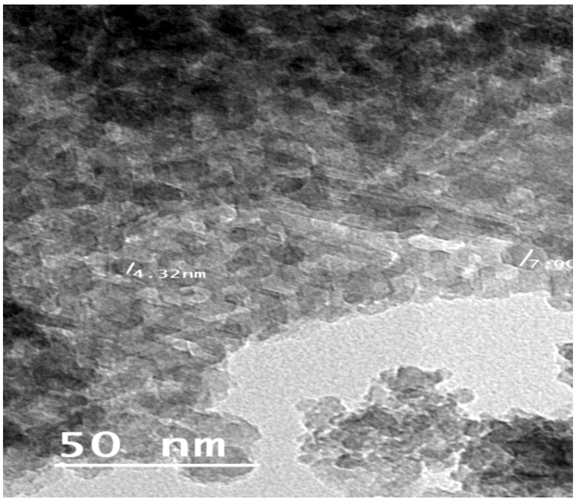

Fig -3: TEM image for AL2O3 nano-particles

3. Data analysis

The following pre assumptions have been taken into consideration when recording the experimental test findings in order to study and evaluate the performance of a vehicle engine cooling system under various designing and operating conditions:

- Steady flow of coolant and air.
- The test section's radiator insulates all of the heat that is rejected from the coolant.
- The mean fluid temperature was used to determine the properties.

The working fluid side heat transfer rate can be calculated as [*31*]:

$Qwf = m_{wf} . c_{wf}$ (Twfi _Twfo) (7)

By applying Newton's cooling law on the working fluid side, the

The method described below has been used to calculate forced convection

As follows for working fluid flow side heat transfer [*32*]:

$Qwf = h_{wf}$. As. ΔTLMTD (8)

Where hwf is the typical radiator coolant side heat transfer coefficient, as well as the radiator's interior heat transfer surface area,

And ΔTLMTD is the difference in mean temperature between the coolant and air sides.

Dimensionless group parameters of working fluid flow side; (Re_{wf}),

(Nu_{wf}) and (Pr_{wf}) are provided in turn by the correlations [*33*]:

$$Re_{wf} = \frac{\rho_{wf}.v.\ D_{hy}}{\mu} \quad (9)$$

$$Nu_{wf} = \frac{h_{wf}.D_{hy}}{K_{wf}} \quad (10)$$

$$Pr_{wf} = \frac{CP_{wf}.\mu_{wf}}{K_{wf}} \quad (11)$$

Where (Dhy) according to K. Goudarzi and H. Jamali is the hydraulic diameter of the radiator tubes, and the following equation is found as [*34*]:

$$\mathrm{Dhy} = \left(\frac{4.V_{Ra}}{\pi.H_{Ra}}\right)^{1/2} \quad (12)$$

Where the volume of the radiator tubes can be calculated by [*35*]:

VRa = Ntu .Atu. LRa (13)

The Darcy friction factor for radiator tubes is calculated by Darcy-

Weisbach equation as [*36*]:

$$F_{wf} = \frac{2\,\Delta P_{wf}.D_{hy}}{\rho_{wf}.n_{tu}.L_{tu}.v^2{}_{wf}} \quad (14)$$

4. Results and discussion

4.1. Validation of the experimental results

The most applied equation of Gnielinski is compared with the data of the present research as*:*

For the purpose of assessing the reliability and accuracy of the experimental design, it is necessary to validate one of the results using diverse data from open literature [38-37]. Furthermore, a theoretical comparison should be made between the results and three distinct empirical correlations that are widely recognized. This comparison should consider the degree of compatibility between the empirical equations used for establishing boundaries and the ongoing investigation. [*39-40*].

To compare the outcomes with the current data, the following renowned empirical equation proposed by V. Gnielinski [*44*]: The correlation is limited for a range of 2300≤Re≤5×106 and
0.5 < Pr < 2000.

$$\mathrm{Nuwf} = \frac{\left(\frac{f}{2}\right).(Re_{wf}-1000).Pr_{wf}}{1+12.7.\left(\frac{f}{2}\right)^{0.5}.\left(Pr^{\frac{2}{3}}\right)} \qquad (15)$$

The correlation is limited for a range of 2300≤Re≤5×106 and 0.5 < Pr < 2000.

The friction factor in the region of turbulent flow is validated using the more well-known Petukhov correlation as [*41-43*]:

$$f = \left(1.82 lnRe_{wf} - 1.64\right)^{-2} \qquad (16)$$

The correlation is applicable within the range of 3000≤Re≤5×106. Chart -2 demonstrates the consistent results of friction factors obtained from the current experiments using pure water, along with the results from V. Gnielinski [44] and Petukhov [45]. The comparison reveals a strong agreement between the findings. The deviations between the present study and V. Gnielinski [44] amount to 6%, while the deviations with Petukhov [45] are found to be 4%.

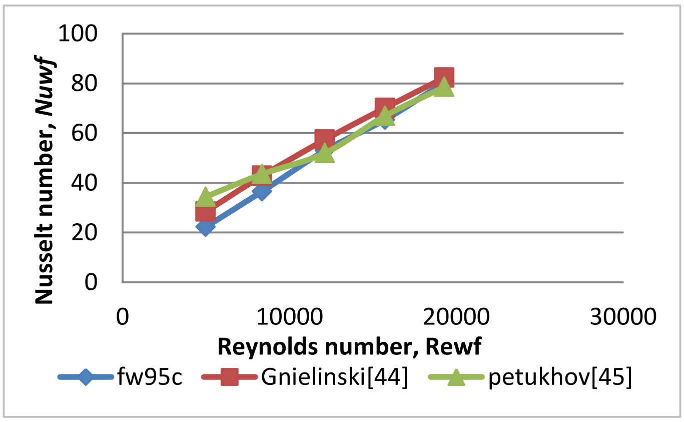

Chart -1: Comparison of the present experimental data for pure water at *95* °C with the V. Gnielinski [*44*], Petukhov [*45*].

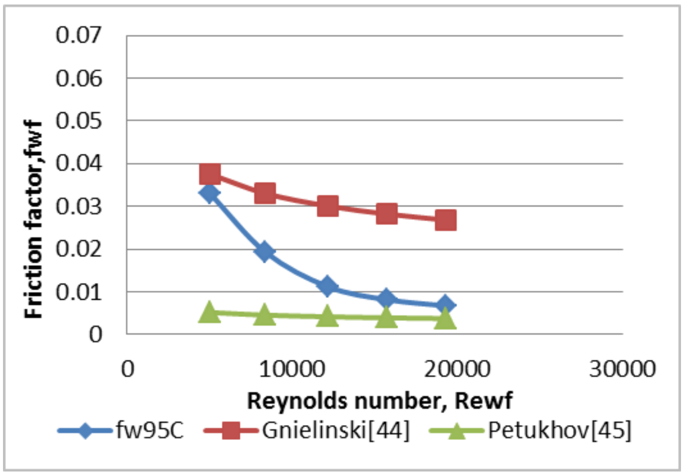

Chart -2: Results of friction factor of the present experimental data with pure Water and V. Gnielinski [*44*], Petukhov [*45*].

4.2. Effect of nanofluid concentration

The experiment is conducted at constant air speeds of 0.6 m/s with concentration ratios of 0.02, 0.05, and 0.1% vol. compared to pure water. Chart -4 shows how the working fluid friction factor (fwf) varies for pure water and Al2O3/water as a function of the Reynolds number (Rewf). Based nanofluids with constant VA=0.6 m/s with concentration of 0.1% vol at inlet working fluid temperatures of 95 °C. As seen from the figure the radiator tubes' friction factor is decreasing when the Reynolds number increases in all cases. By considering the fundamental Darcy equation, it is evident that changes in velocity have an impact on the friction factor. Specifically, the square of velocity signifies that higher fluid velocities tend to result in lower friction factors, establishing an inverse relationship between velocity and friction factor. At certain Reynolds number of 12,500 the friction factor at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 60 %, 54% and 38% respectively.

Chart -3 demonstrates the relationship between the Nusselt number and the Reynolds number for several fluids, including pure water and Al2O3/water nanofluids, at inlet temperature of 95oC. Nusselt number for all concentrations increases as the Reynolds number rises. This is while the heat transfer is directly dependent on the thermal conductivity which increases by increasing of nanofluid concentrations. At certain Reynolds number of 12,500 Nusselt number at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 16%, 10% and 7% respectively. The variation of overall heat transfer coefficient with volume flow rate of working fluid at different working fluid concentration and 95oC indicated in Chart -5. As indicated, the overall heat transfer coefficient increases as volume flow rate increases for all working fluids concentrations pure water. At working fluid flow rate of 7.5 LPM, overall heat transfer coefficient at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 35 %, 25% and 16% respectively.

Chart -6 indicates the relation of Number of heat transfer units vs. volume flow rate for different nanofluid concentration and 95oC. Number of heat transfer unit's rises corresponding to rising in volume flow rate that due to the increasing of overall heat transfer coefficient. At working fluid flow rate of 7.5 LPM, overall heat transfer coefficient at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 37%, 17% and 8% respectively.

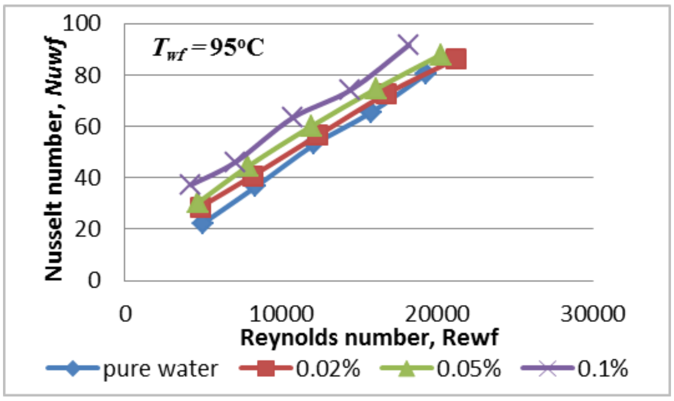

Chart -3: Variation between Nusselt numbers versus Reynolds number for different nanofluid concentration

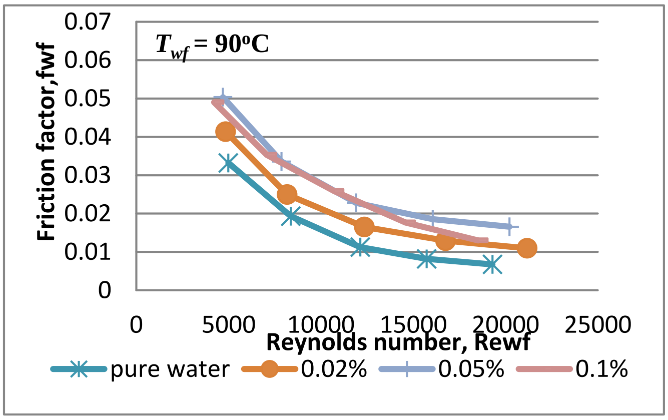

Chart -4: Variation between friction factors versus Reynolds number for different nanofluid concentration

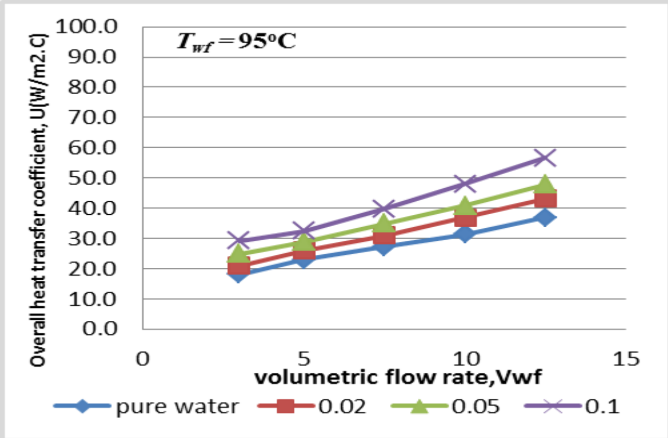

Chart -5: Overall heat transfer coefficient vs. volume flow rate for different nanofluid concentration

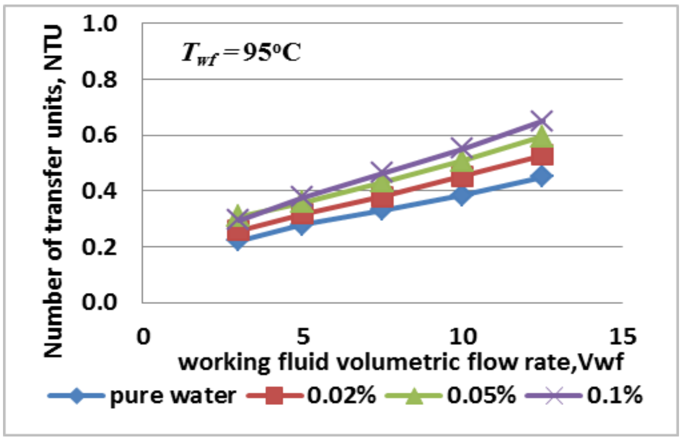

Chart -6: Number of heat transfer units vs. volume flow rate for different nanofluid concentration

4.3 Effect of working fluid inlet temperature

In order to perform the impact of temperature variation on the heat transfer and pressure drop characteristics, the tests are conducted at working fluid inlet temperatures of 80, 85, 90, and 95 °C with 0.1% AL2O3/water nanofluid concentration. Chart -8 shows the relation between friction factor and Reynolds number at 0.1% AL2O3/water nanofluid concentration and different working fluid inlet temperature. The results reported that the friction factor decreases with increasing of Reynolds number. Additionally, as temperature and fluid velocity increase, the viscosity of the fluid decreases at a greater rate than the decrease in fluid density. Consequently, this results in the development of a thinner boundary layer. At certain Reynolds number of 12,500 the friction factor at 95oC is lower than that of 90oC, 85oC and 80oC by 7%, 10% and 18% respectively. The relationship between Nusselt number and Reynolds number is depicted in Chart -7. It is observed that Nusselt number increases as the Reynolds number increases. At a certain Reynolds number of 12,500 Nusselt number at 95oC is higher than that of 90oC, 85oC and 80oC by 6%, 25% and 37.5% respectively. On the other side the overall heat transfer coefficient increased as working fluid volume flow rate increased which can be seen in Chart -9. At a certain volume flow rate of 7.5 LPM overall heat transfer coefficient at 95oC is higher than that of 90oC, 85oC and 80oC by 5%, 25% and 30% respectively. Chart -10 performs the variation of the number of heat transfer units and working fluid volume flow rates. As performed in the figure, the number of heat transfer unit's increases with increasing of working fluid volume flow rates. At a certain volume flow rate of 7.5 LPM the number of heat transfer units at 95oC is higher than that of 90oC, 85oC and 80oC by 9%, 13.6% and 20% respectively.

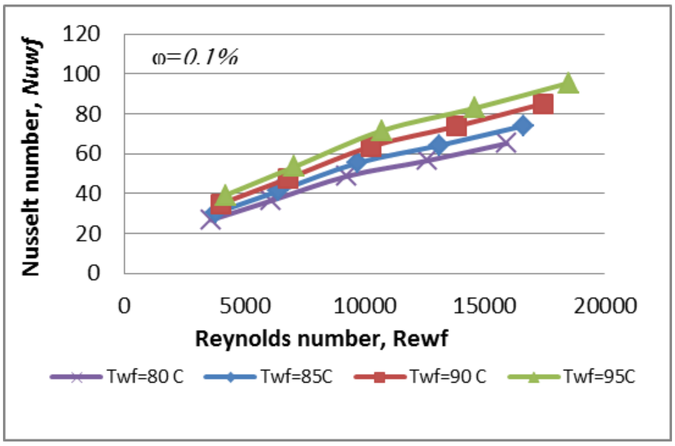

Chart -7: The Nusselt numbers versus number for different inlet working fluid Temperature

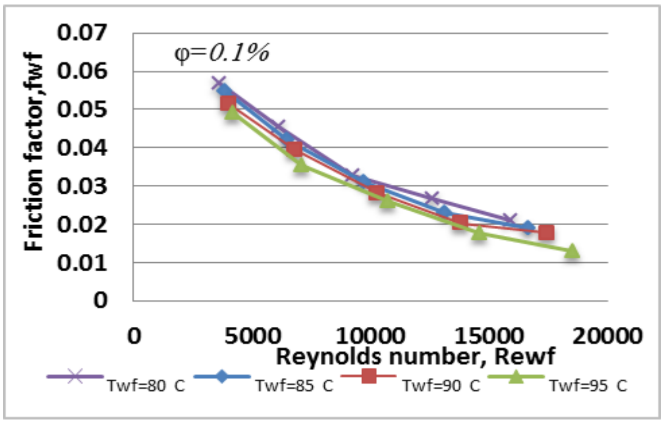

Chart -8: Variation between friction factor versus Reynolds number for different Inlet working fluid temperature

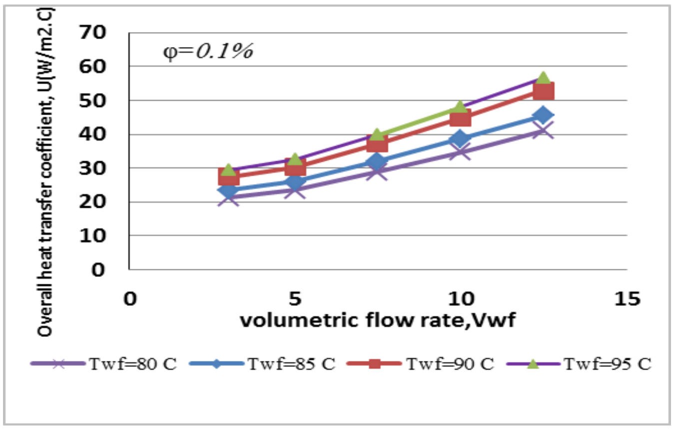

Chart -9: The impact of nanoparticle volume concentrations at T= 95 0c on the convective heat transfer coefficient

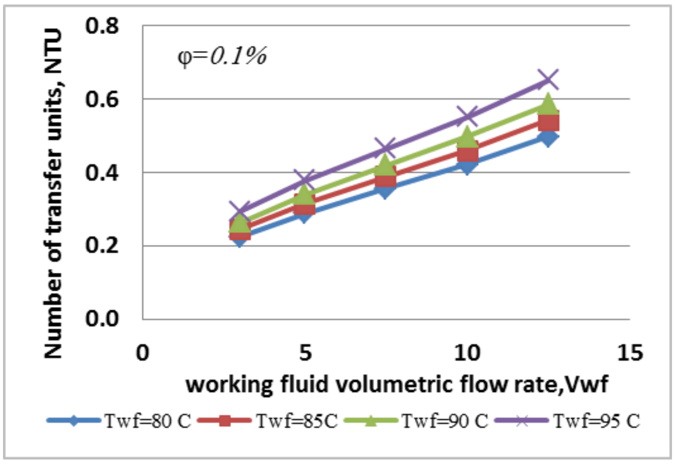

Chart -10: Nusselt number vs. Reynolds number variation for concentrations based water and nanofluid

5. CONCLUSIONS

The performance of heat transmission and pressure drop characteristics of a vehicle engine radiator are examined in the current study under Cairo, Egypt's climatic circumstances. Across a broad range of coolant Reynolds numbers of *3600*–Rewf–*22*000, many parameters are tested. Effects of hot fluid temperature, fluid mass flow rate, nanomaterial type, nanoparticle concentration ratio. Discussions included Nusselt number, friction factor, and number of heat transfer unit's. The following summarises the key conclusions:

Higher Reynolds number and concentrations of nanomaterials improve the heat transfer characteristics of the vehicle radiator.

Pressure drop characteristics increased as Reynolds number increased due to higher friction rates.

At certain Reynolds number of 12,500 the friction factor at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 60 %, 54% and 38% respectively.

With Reynolds number of 12,500 Nusselt number at concentration of 0.1%, 0.05% and 0.02% is higher than pure water by 16%, 10% and 7% respectively.

At Reynolds number of 12,500 the friction factor at 95oC is lower than that of 90oC, 85oC and 80oC by 7%, 10% and 18% respectively.

At a certain Reynolds number of 12,500 Nusselt number at 95oC is higher than that of 90oC, 85oC and 80oC by 6%, 25% and 37.5% respectively.

At a certain volume flow rate of 7.5 LPM overall heat transfer coefficient at 95oC is higher than that of 90oC, 85oC and 80oC by 5%, 25% and 30% respectively.

REFERENCES

[1] W. Yu, D. M. France, S. U. S. Choi, J. L. Routbort, Review and Assessment of Nanofluid Technology for Transportation and Other Applications (No. ANL/ESD/07-9). Energy System Division, Argonne National Laboratory, Argonne, 200.

[2] Dustin R. Ray, Debendra K. Das, Superior performance of nanofluids in an Automotive radiator, J. Thermal Sci. Eng. Appl. 6 (2014) 1–16.

[3] Devendra Vashist, Sunny Bhatia, Ashish Kalra, Some studies on the performance of Automotive radiator at higher coolant temperature, J. Basic Appl. Eng. Res. 1(2014) 41–46.

[4] K.Y. Leong, R. Saidur, S.N. Kazi, A.H. Mamun, Performance investigation of an Automotive car radiator operated with nanofluid-based coolants (nanofluid as a Coolant in a radiator), Appl. Therm. Eng. 30 (2010) 2685–2692.

[5] Hardik V. Patel, Dattatraya G. Subhedar, Dr. Bharat Ramani, and Numerical Investigation of Performance for Car Radiator Oval Tube Materials Today: Proceedings, vol. 4, (2017), pp. 9384–9389.

[6] Rashmi Rekha Sahoo, Pradyumna Ghosh, Jahar Sarkar, Performance comparison of Various coolants for louvered fin tube automotive radiator, Therm. Sci. 21 (2017) 2871–2881.

[7] Seth Daniel Oduro, Joshua Ampofo, Effect of radiator fins blockage by clay soil on The engine cooling temperature, Int. J. Eng. Technol. 6 (2012) 1002–1010.

[8] S.C. Tzeng, C.W. Lin, K.D. Huang, Heat transfer enhancement of nanofluids in rotary blade coupling of four-wheel-drive vehicles, Acta Mech. 179 (2005) 11–23.

[9] W.M. Yan, P.J. Sheen, Heat transfer and friction characteristics of fin and tube heat Exchangers, Int. J. Heat Mass Transf. 43 (2000) 1651–1659.

[10] A.J. Torregrosa, A. Broatch, P. Olmeda, C. Romero, Assessment of the influence of Different cooling system configurations on engine warm-up, emissions and fuel Consumption, Int. J. Automot. Technol. 9 (2008) 447–458.

[11] J.P. Holman, Experimental Methods for Engineers, 7th edn, McGraw-Hill, New York, 2001.

[12] W. Duangthongsuk, S. Wongwises, Effect of thermophysical properties models on the predicting of the convective heat transfer coefficient for low concentrationnanofluid, Int. Commun. Heat Mass Transf. 35 (2008) 1320–1326.

[13] X. Wang, X. Xu, Thermal conductivity of nanoparticle-fluid mixture, J.Thermophys. Heat Transf. 13 (1999) 7.

[14] Y. Xuan, W. Roetzel, Conceptions for heat transfer correlation of nanofuids, Int. J. Heat Mass Transf. 43 (2000) 7.

[15] W. Yu, H. Xie, A review on nanofluids: preparation, stability mechanisms, and Applications, Nanomater. (2012) 1.

[16] N. Masoumi, N. Sohrabi, A. Behzadmehr, A new model for calculating the effective Viscosity of nanofluids, J. Phys. D. Appl. Phys. 42 (2009) 491–501.

[17] M. Kole, T.K. Dey, Viscosity of alumina nanoparticles dispersed in car engine Coolant, Exp. Thermal Fluid Sci. 34 (2010) 677–683.

[18] M.M. Elias, I.M. Mahbubul, R. Saidur, M.R. Sohel, I.M. Shahrul,S.S. Khaleduzzaman, S. Sadeghipour, Experimental investigation on the thermophysical properties of Al2O3 nanoparticles suspended in car radiator coolant, Int.Commun. Heat Mass Transf. 54 (2014) 48–53.

[19] T.V.R. Sekhar, Gopal Nandan, Ravi Prakash, Marisamy Muthuraman, Investigations On viscosity and thermal conductivity of cobalt oxide-water nanofluid, Mater. Today 5 ((2018) 6176–6182.

[20] R.R. Sahoo, P. Ghosh, J. Sarkar, Performance comparison of various coolants for Louvered fin automotive radiator, Therm. Sci. 21 (2017) 2871–2881.

[21] F.W. Dittus, L.M.K. Boelter, Heat Transfer in Automobile Radiators of Tubular Type, University of California Press, Berkeley, CA, 1930, pp. 13–18.

[22] F.M. White, Fluid Mechanics, fourth ed., McGraw-Hill, Inc, New York, 2001.

[23]OlietC,OlivaA,CastroJ,SegarraCDP.Parametricstudiesonautomotiveradiators.ApplThermEng2007; 27:2033–43.

[24]LeeS,ChoiSUS,LiS,EastmanJ.Measuringthermalconductivityoffluidscontainingoxide nanoparticles.JHeatTransf1999; 121(2):280–9.

[25]PeyghambarzadehSM,HashemabadiSH,JamnaniMS,HoseiniSM.Improvingthecooling performanceofautomobileradiatorwithAl2O3/waternanofluid.ApplThermEng2011; 31:1833–8.

[26] ParkKW, PakHY. Flow and heat transfer characteristics in flat tubes of a radiator.Numer Heat Transf2002; 41:19–40.

[27] LeongKY,SaidurR,KaziSN,MamunAM.Performance investigation of an automotive car adiatoroperated with nanofluid based coolants (nano fluid as a coolant in a radiator).ApplThermEng2010; 30:2685–92.

[28] HwangKS, JangSP, ChoiS US. Flow and convective heat transfer characteristics of water basedAl2O3nanofluidsinfullydevelopedlaminarflowregime.IntJHeatMassTransf2009; 52:193–9.

[29] MaigaS,PalmSJ,NguyenCT,RoyG,GalanisN. Heat transfer enhancement by using nano fluids in forced convection flows.IntJ Heat Fluid Flow 2005; 26(4):530–46.

[30] HusseinAM, BakarRA, KadirgamaK ,SharmaKV. Experimental measurements of nanofluids thermal properties.IntJAutomMechEng2013; 7:850–64.

[31] XieWY,YangL,LifeiC.Discussion on the thermal conductivity enhancement of nano fluids Huaqing.NanoscaleResLett2011; 6:1–12.

[32] SyamSundar L, Sharma KV. An experimental study on heat transfer and friction factor of Al2O3nanofluid.Journal of Mechanical Engineering and Sciences.1 (2011) 99-112.

[33] SyamSundar L, Sharma KV. Laminar Convective Heat transfer and friction factor of Al2O3nanofluid in circular tube fitted with twisted tape inserts. International Journal of Automotive and Mechanical Engineering. 3(2011)265-78

[34] Yogeswaran M, Kadirgama K, Rahman MM, Devarajan R. International Journal of Automotive and Mechanical Engineering. 11(2015)2272-81.

[35] S. P. Jang and S. U. S. Choi, “Effects of various parameters on nanofluid thermal conductivity,” Journal of Heat Transfer, vol. 129, no. 5, pp. 617–623, 2007.

[36] Hammad, Et Al.'' An experimental study on the effect of diameter on thermal conductivity and dynamic viscosity of Fe/water nanofluids '' Research Paper in Akade’miai Kiado´, Budapest, December 2014.

[37] I. Gherasim, G. Roy, C. T. Nguyen, and D. Vo-Ngoc, “Experimental Investigation of nanofluids in confined laminar radial flows,” International Journal of Thermal Sciences, vol. 48, no. 8, pp. 1486–1493, 2009.

[38] S. M. Peyghambarzadeh, S. H. Hashemabadi, M. S. Jamnani, and S.M.Hoseini, “Improving the cooling performance of automobile radiator with Al2O3/water nanofluid,” Applied Thermal Engineering, vol. 31, no. 10, pp. 1833–1838, 2011.

[39] T.H. Tsai, L. S. Kuo, P. H. Chen, and C. T. Yang, “Thermal conductivity Of nanofluid with magnetic nanoparticles,” Progress In Electromagnetics Research Symposium, vol. 5, no. 3, pp. 231–234, 2009.

[40] Das SK, Choi SUS, Yu W, Pradeep T. Nanofluids—science and technology. Wiley- Interscience; 2008.

[41] Xuan Y, Li Q. Heat transfer enhancement of nanofluids. International Journal of Heat and Fluid Flow 2000; 21:58–64.

[42] C Kannan,Jaysingh T Raja, 2014. “An Experimental study on the influence of operating parameters on the heat transfer characterstics of an automotive Radiator with Nanofluids”

[43] Adnan M. Hussein, R. A. Bakar, K. Kadirgama, 2014. Study of forced convection nanofluid heat transfer in the automotive cooling system. International Journal of Thermal Engineering 2, 50–61

[44] V. Gnielinski, New equations for heat and mass transfer in the turbulent flow in Pipes and channels, NASA STI/Recon Technical Report a 75 (1975) 22–28.

[45] Betukhov B, Heat transfer and friction in turbulent pipe flow with variable physical Properties, Adv. Heat Tran. 6 (1970) 503–564.