International Journal of Engineering Technology and Applied Science
(ISSN: 2395 3853), Vol. 7 Issue 9 September 2021

Analysis of Forced Convection Nanofluid Heat Transfer in The Automotive Cooling System

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Abstract - **The development of high performance thermal systems for heat transfer enhancement has become popular nowadays. A number of works has been performed to gain an understanding of the heat transfer performance for their practical application to heat transfer enhancement. Thus the advent of high heat flow processes has created significant demand for new technologies to enhance heat transfer. Heat transfer performance of liquids is limited by their low thermo-physical properties compared with those of solids. Dispersing solid metallic or non-metallic materials in a base fluid (liquid), such as water, ethylene glycol or glycerol, has become an interesting topic recently. In this paper, the friction factor and forced convection heat transfer of different nano particles dispersed in water in a car radiator was numerically determined. Four different nano fluid volume concentrations (1%, 2%, 3% and 4%) were used, and the resulting thermal properties were evaluated. The Reynolds number and inlet temperature ranged from 10000 to 100000 and from 60 to 90 °C, respectively.**

Keywords- **Nano fluid, Friction factor, Nusselt number, Turbulent Convective Heat Transfer, Car radiator.**

I. INTRODUCTION

A wide variety of industrial processes involve the transfer of heat energy. Throughout any industrial facility, heat must be added, removed, or moved from one process stream to another and it has become a major task for industrial necessity. These processes provide a source for energy recovery and process fluid heating/cooling. The enhancement of heating or cooling in an industrial process may create a saving in energy, reduce process time, raise thermal rating and lengthen the working life of equipment. Some processes are even affected qualitatively by the action of enhanced heat transfer. The development of high performance thermal systems for heat transfer enhancement has become popular nowadays.

A number of work has been performed to gain an understanding of the heat transfer performance for their practical application to heat transfer enhancement. Thus the advent of high heat flow processes has created significant demand for new technologies to enhance heat transfer. Heat transfer performance of liquids is limited by their low thermo-physical properties compared with those of solids. The primary reason behind adding solid particles less type of fluid is called a Nanofluid. Dispersing solid metallic or non-metallic materials in a base fluid (liquid), such as water, ethylene glycol or glycerol, has become an interesting topic recently [1–5]. Base fluids have been used as conventional coolants in automobile radiators for many years; however, these fluids have low thermal conductivities. The low thermal conductivities have thus prompted researchers to search for fluids with higher thermal conductivities than that of conventional coolants. Therefore, Nanofluids have been used instead of the commonly used base fluids [6, 7].Thermal properties of fluids has a major role in temperature controlling applications in every industrial procedures. Heat transfer performance is dependent on thermal conductivity of the fluids. Traditional heat transfer fluids have poor thermal conductivity which makes them less preferred for majority of cooling applications. More research need to be done to decide their applicability for heat transfer applications. The last few decades have witnessed vast research on the new types of heat transfer fluids, namely nano fluids.

A nano fluid is a fluid which contains nanometer-sized solid particles. Nano fluids were introduced by Choi (1995) and they have been proven to provide efficient heat transfer compared to conventional fluids. Detailed reviews on the physical and thermal properties of nano fluids have been reviewed by several authors. Since its first introduction to actual engineering applications, a nanofluid has been successfully applied to enhance heat transfer in many applications such as electronic components, nuclear reactor, building heating and cooling systems, water boiling, and many more.

Said et al. (2019) suggested best practice for analyzing the usage of nanofluids in heat transfer applications is presented, specifically for an actual car radiator. This work investigates the use of aluminum oxide (Al2O3) and titanium dioxide (TiO2) nano particles dispersed in DW and EG at 50:50 volumetric proportions. The choice of these oxide-based nanofluids is motivated by their anti-corrosive properties that are usually not analyzed or discussed in most of the articles.Saxena et al. (2018) focused on the experimental and numerical studies carried out by previous researchers on metallic/non-metallic oxide nano coolant, which are segregated with different nano coolant as CuO, Al2O3, TiO2, and SiO2.

The review focuses on suitable volumetric concentration, sizes of nano particles used by researchers and applications for analysis. This review will be useful for researchers and scholars working in the field of applications of nano technology for enhancement of heat transfer fluid. However, lots of researcher work is still needed in the field of preparation and stability, characterization and applications to overcome the challenges. Wong et al. (2017) focused on presenting the broad range of current and future applications that involve nanofluids, emphasizing their improved heat transfer properties that are controllable and the specific characteristics that these nano fluids possess that make them suitable for such applications.

According to Bigdeli et al. (2016) the role of fundamental heat and mass transfer mechanisms governing thermo-physical properties of nano fluids is reviewed, both from experimental and theoretical point of view. Particular focus is devoted to highlight the advantages of using nano fluids as coolants for automotive heat exchangers, and a number of design guidelines are reported for balancing thermal conductivity and viscosity enhancement in nano fluids. We hope that this review may help further the translation of nano fluid technology from small-scale research laboratories to industrial application in the automotive sector.Sidik et al. (2015) reviewed the application of nano fluids in vehicle engine cooling system. So far, nano particles have been used in engine oil, transmission oil, and radiator coolant to enhance heat transfer removal from vehicle engine.

The heat transfer performance of nano fluids has been reported to perform better compared to pure fluid. This review focused on the experimental and numerical studies by previous researchers and their suggested amount of nanoparticles for optimum performance in vehicle engine cooling system. Finally, the conclusions and important summaries were presented according to the data collected.As seen in these and/or similar works, heat transfer mechanisms in an automotive cooling system could be very complex and this geometry could be appeared in many industrial installation. In this paper, the heat transfer enhancement of turbulent flow through an automobile radiator is evaluated numerically using different nanofluid. The commercial available CFD software, FLUENT© 6.3.26 was used to solve the governing equations of continuity, momentum and energy. The Reynolds numbers based on the hydraulic diameter of the flat tube (Dh) ranged from 10000 to 100000. The nano fluid volume fraction and the inlet temperature are in the range of 1–4% and 60–90 °C respectively. The numerical results are compared with experimental data available in literature.

II. PROBLEM FORMULATION

This study presented an inclusive application of nanofluids for automotive cooling engine vehicles. A vast number of available references showed that nanofluids have a great application prospect in the development of modern engines. For cooling system of radiators, nanoparticles can be dispersed in the fluid to enhance the thermal conductivity of the liquid. In addition, the presence of nanoparticles in radiator will also improve the thermal performance and reduce friction. However, the optimum amount of nano particles still remains unknown. Another method for cooling the automotive engine system is by dispersing nano particles in a conventional coolant radiator. Heat transfer coefficient can be improved up to 50% compared to the original coolant; however, the problem of pressure drop limits the efficiency factor of the cooling system.

For this case, most researchers agree that the optimum performance of cooling system can be achieved at low volume fraction of nano particles (b1%). At the same time, there are still some problems and challenges regarding the mechanisms of heat transfer enhancement and the actual applications on engine vehicle. Current research on nano fluids for engine cooling system is still at its initial stage and needs further development. Therefore in this study the friction factor and forced convection heat transfer of TiO2 nano particles dispersed in water in a car radiator was numerically determined. Four different nano fluid with different volume concentrations (1%, 2%, 3% and 4%) were used, and the resulting thermal properties were evaluated.

III. PHYSICAL MODEL

Fig. 3.1 shows the automobile radiator used in this study, which consists of a flat tube with a length (L=500 mm) and hydraulic diameter (Dh=4.5 mm). The Reynolds number was calculated based on the hydraulic diameter (Dh):

$$D_h = \frac{4 \times Area}{Perimeter}$$

$$D_h = \frac{4 \times [\frac{\pi}{4} d^2 + (D - d) \times d]}{\pi \times d + 2 \times (D - d)}$$

Reynolds number (Re) is determined as:

$$Re_D=\frac{\rho \times D_h \times u}{\mu}$$

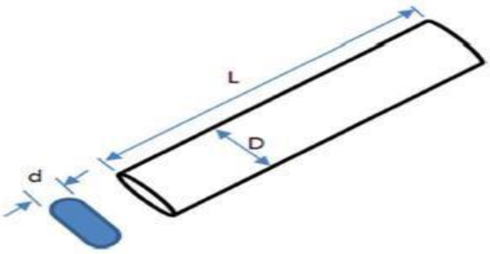


Fig.1. Flat tube of radiator [Hussein et. al. (2017)].

IV. GOVERNING EQUATIONS

Using infinitesimal (less than 100 nm) solid particles, the single-phase approach can be used, and thus, the single-phase approach was adopted for nanofluid modeling. The thermal properties of the nano fluid can be estimated by the equations below:

$$\rho_{nf}=\left(\frac{\phi}{100}\right)\rho_p+\left(1-\frac{\phi}{100}\right)\rho_f$$

$$C_{nf}=\frac{\frac{\phi}{100}(\rho C)_p+(1-\frac{\phi}{100})(\rho C)_f}{\rho_{nf}}$$

$$k_{nf}=(1+3\Phi)k_f$$

$$\mu_{nf}=(1+2.5\Phi)\mu_f$$

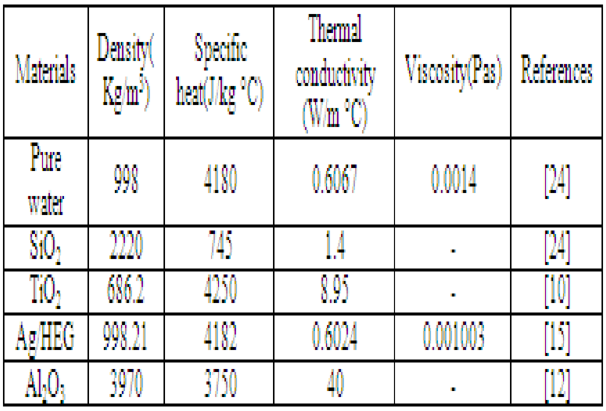
where ρ, C, k and μ are the density, specific heat capacity, thermal conductivity and viscosity, respectively, and the subscripts, nf, f,and p, represent the nanofluid, fluid and solid properties, respectively. For all assumptions, the dimensional governing equations at steady state are the continuity, momentum and energy equations [16]:

$$\nabla \cdot V=0$$

$$V_x\frac{\partial V_z}{\partial x}+V_y\frac{\partial V_z}{\partial y}+V_z\frac{\partial V_z}{\partial z}=-\frac{1}{\rho}\frac{\partial P}{\partial z}+\upsilon\frac{\partial^2 V_z}{\partial z^2}+g_z$$

$$V_x\frac{\partial T}{\partial x}+V_y\frac{\partial T}{\partial y}+V_z\frac{\partial T}{\partial z}=\alpha\frac{\partial^2 T}{\partial z^2}$$

Table I: Thermal property of nano particle and base fluids.



Materials	Density(Kg/m^3)	Specific heat(J/kg °C)	Thermal conductivity (W/m °C)	Viscosity(Pas)	References
Pure water	998	4180	0.6067	0.0014	[24]
SiO_2	2220	745	1.4	.	[24]
TiO_2	686.2	4250	8.95	.	[10]
Ag/HEG	998.21	4182	0.6024	0.001003	[15]
Al_2O_3	3970	3750	40	.	[12]

V. FEM MODELLING

The geometry was created in Ansys workbench Design modeller.Working fluid is flowing in the automobile radiator. For creating the fluid zone the extrude option in the design modeler is used. For using extrude option and a sketch is required. The profile is created in XY plane. The profile here is a flat tube. The path here is a straight line along the Z-axis. The profile is created in the XYplane. The flat tubeis generated by giving profile using extrude option. In the detailsthe type is changed to fluid from solid.

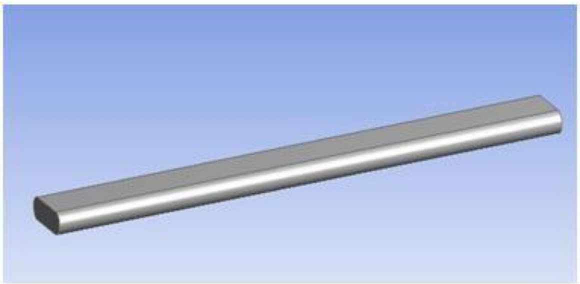


Fig.2. Fluid domain.

The geometry should be made sweep able before generating mesh .We can check whether a body is sweep able or not by right clicking on the mesh then go to show option and in that go to sweep able bodies then it will show the sweep able bodies in green colour. The size of the mesh can be adjusted under the sizing option which is available in details of mesh. We can adjust the min size, max face size and max size to adjust the size of the mesh and the number of elements of the mesh. Mesh was created using tetrahedron cells with nodes 19375 and element 16478.

Fig.3. Image of geometry which is meshed fully.

The boundary condition of the present model consists of 3 parts which are velocity inlet, pressure outlet, and wall. The inlet fluid has a temperature of (27 °C) with corresponding velocity to definite Reynolds numbers in the axial direction. The fluid velocity on the wall is zero that represents no-slip boundary condition and it is of constant temperature of (100 °C). Last but not the least, the pressure outlet value has been considered as zero.

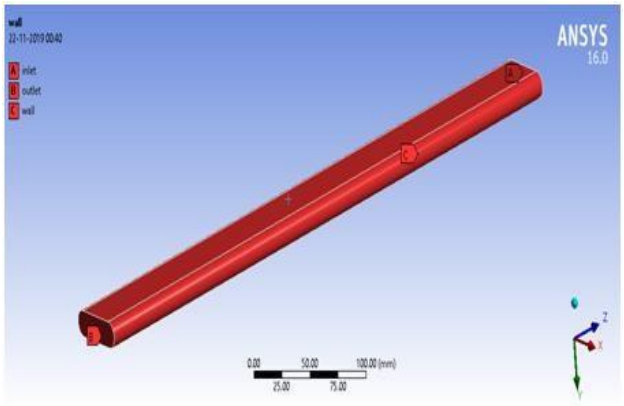


Fig.4.Various boundary conditions in domain.

VI. DATA PROCESSING

FLUENT evaluates the Nusselt number as follows
The outlet air temperature $T_{out}$was calculated as a mass average temperature atthe outlet position of the calculation domain.

$$T_{out} = \frac{\int T\rho\bar{u}.d\bar{A}}{\int \rho\bar{u}.d\bar{A}} = \frac{\sum_{i=1}^{n} T_i \rho_i \bar{u}_i .\bar{A}_i}{\sum_{i=1}^{n} \rho_i \bar{u}_i \bar{A}_i}$$

The dimensionless number for air-side heat transfer in the finned-tube bank wasdefined and calculated depending on the Reynolds number and geometric parameters.For many cases the Nusselt number and Stanton number are used toexpress the heat transfer coefficient and the characteristic length is not the same.
In here the Nu number was used as

$$Nu = \frac{hd}{k_a}$$

The static pressure at the inlet and outlet of the computational domain were evaluated as

$$p_{in,out} = \frac{\int p d\bar{A}}{\int d\bar{A}} = \frac{\sum_{i=1}^{n} p_i \bar{A}_i}{\sum_{i=1}^{n} \bar{A}_i}$$

VII. RESULTS AND DISCUSSION

Figure 6 illustrated temperature profiles at different Reynolds number.Furthermore theminimum temperature is 300 K and 333 K at Reynolds numberis 10000for TiO2.

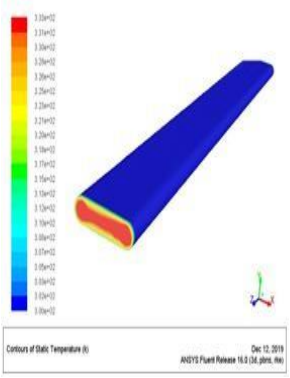


Fig.5. Contour of temperature at Reynolds number.

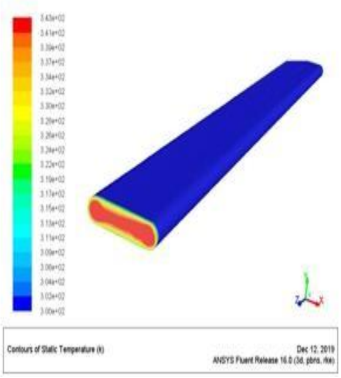


Fig.6. Contour of temperature at Reynolds number.

(Re = 10000) for TiO2(Re = 10000) for Ag/HEG

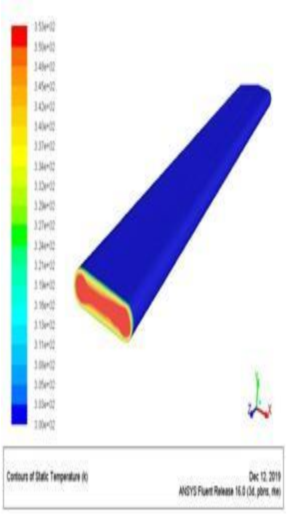


Fig.7. Contour of temperature at Reynolds number.

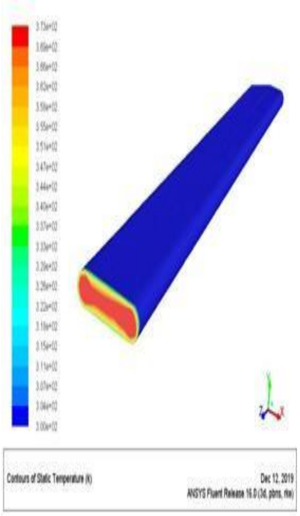
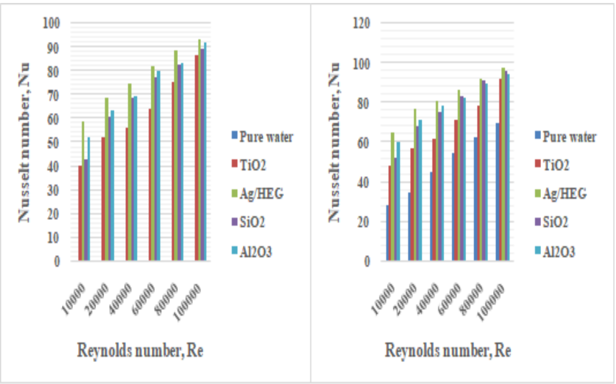


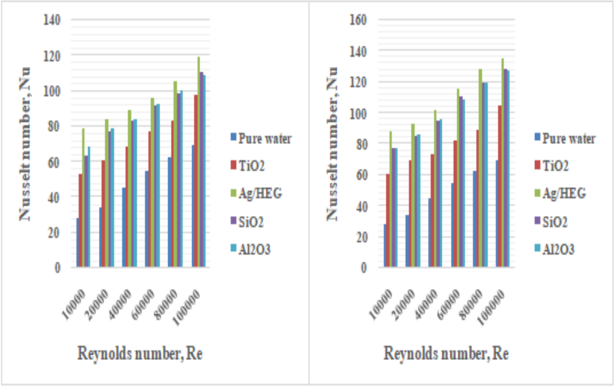
Fig.8. Contour of temperature at Reynolds number.

(Re = 10000) for SiO2(Re = 10000) for Al2O3
Fig.9, shows Nusselt number at different Reynolds number and different nanofluid volume concentration.



1% nano concentration
(a)

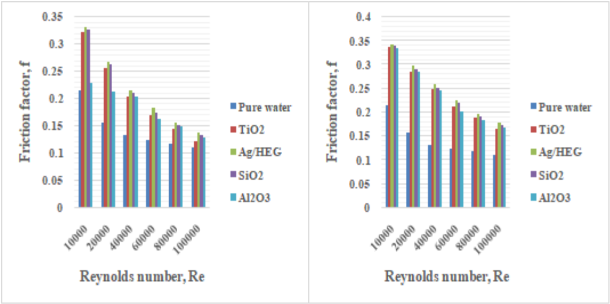
2% nano concentration
(b)



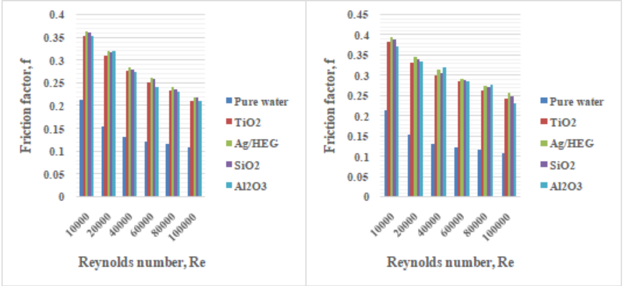
3% nano concentration (c) 4% nano concentration (d)

Fig.10. Overall comparison of effect of nano fluid concentration on Nusselt number.

From the above figure, the Nusselt number increases with increasing of Reynolds number at 1%, 2%, 3% and 4% nanofluid volume concentration of different nano fluids. The deviation is approximately 41.16%, 107.25%, 52.18% and 83.42% when adding the nano particles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017).



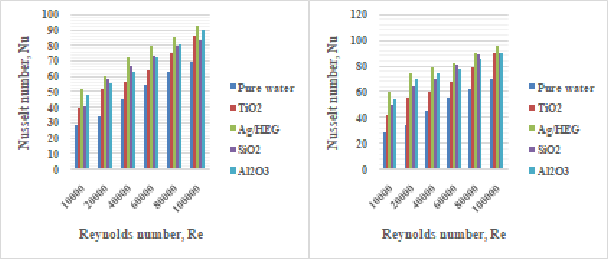
1% nano concentration (a) 2% nano concentration (b)



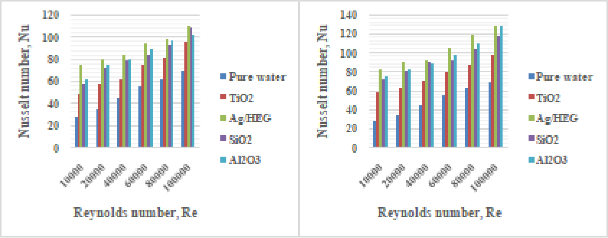
3% nano concentration (c) 4% nano concentration (d)

Fig.11. Overall comparison of effect of nano fluid concentration on friction factor.

The friction factor at different Reynolds number and nanofluid volume concentration is shown in Fig. 11.It appears that the friction factor decreases with increasing in Reynolds number and different nanofluid volume concentration. The deviation in increment of friction is approximately 50.23%, 53.95%, 52.55% and 60.46% when adding the nano particles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017).Likewise, Fig. 12 demonstrates the effect to finletradiator temperature on Nusselt number. The highest values of Nusselt number found when Ag/HEG was used for all inlet temperatures. This refers to high heat transfer from the radiat or when high in let temperature would apply. The deviation is approximately 41.16%, 83.95%, 41.97% and 69.66% when adding the nanoparticles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017). Also among the different nano fluids Ag/HEG accounted for maximum heat transfer.

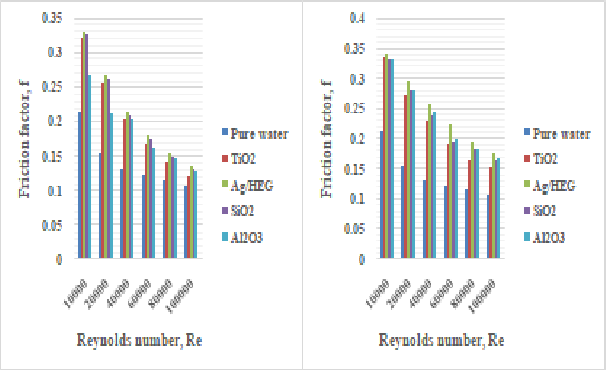


60°C wall temperature (a) 70°C wall temperature (b)



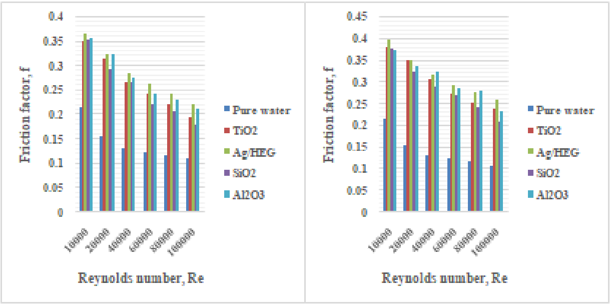
80°C wall temperature (c) 90°C wall temperature (d)

Fig.12. Overall comparison of effect of the wall temperature on Nusselt number.



60°C wall temperature (a) 70°C wall temperature (b)

Fig.13, shows the friction factor at different inlet wall temperatures.



80°C wall temperature
(c)

90°C wall temperature
(d)

Fig.13. Overall comparison of effect of the wall temperature on friction factor.

It appears that the friction factor decreases with increasing in Reynolds number and different nanofluid volume concentration. The deviation in increment of friction is approximately 50.23%, 53.95%, 52.55% and 60.46% when adding the nanoparticles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017).

VIII. CONCLUSION

The following conclusion can be drawn from following studies:

1. The friction factor and forced convection heat transfer enhancement of different nano particles suspended in water were determined.
2. Significant increases in friction factor and heat transfer enhancement were observed when nano particles at different volume concentrations were added to the base fluid.
3. The simulation results showed that the friction factor and Nusselt number behavior of the nano fluids were highly dependent on the volume concentration, inlet temperature and Reynolds number.
4. The results revealed that the nano fluid (Ag/HEG) with highest concentration of volume 4%has the highest friction factor at all Reynolds numbers.
5. The highest values of Nusselt number found when Ag/HEG was used for all inlet temperatures. This referstohighheattransferfromtheradiatorwhenhighinlet temperaturewouldapply.The deviation is approximately 41.16%, 83.95%, 41.97% and 69.66% when adding the nano particles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017).
6. Friction factor decreases with increasing in Reynolds number and different nano fluid volume concentration. The deviation in increment of friction is approximately 50.23%, 53.95%, 52.55% and 60.46% when adding the nano particles (TiO2, Ag/HEG, SiO2 and Al2O3) on base fluid (pure water) (Hussein et. al. 2014), Zainal et. al. (2016), (Hussein et. al. 2017).
7. This solution provides promising ways for engineers to develop highly compact heat exchangers and automobile radiators. When adding nano particles to the base fluid, such as water, the potential enhancement of car engine cooling rates could entail more engine heat being removed or a reduction in size of the cooling system.
8. Smaller cooling systems would lead to smaller and lighter radiators, which would benefit almost every aspect of car performance and increase fuel economy.

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