CFD Analysis of Heat Transfer Performance in a Car Radiator with Nanofluids as Coolants

by

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14892

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the requirement for the
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CERTIFICATION OF APPROVAL

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Approved by,

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

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CHONG JIA LING

ABSTRACT

Nanofluids are the new developed thermal fluids with enhanced thermophysical properties which can improve heat transfer performance of various applications. By introducing nanoparticles with high thermal conductivity in the car radiator coolant can enhance the effective thermal conductivity of coolant which improves the performance of cooling system. Alumina, silica and copper oxide nanoparticles with ethylene glycol-water mixture (60:40) have been used in 3-dimentional car radiator simulations to study fluid flow patterns and heat transfer performance. Heat transfer performance for ethylene glycol-water mixture based nanofluids at different nanoparticle concentrations has been studied. Heat transfer coefficients are determined by numerical simulations with varying coolant velocities. It is found that overall heat transfer performance is improved using nanofluids with high effective thermal conductivity. Results display significant increase in heat transfer performance of coolant in car radiator with an increase in the particle loading.

ACKNOWLEDGEMENT

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ABBREVIATIONS AND NOMENCLATURES

A : Area, m^2

bf : Base fluid

C_p : Specific heat capacity, J/kg·K

D_h : Hydraulic diameter

h : Heat Transfer Coefficient, $W/m^2 \cdot K$

k : Thermal conductivity coefficient, W/m·k

L : Length of heat transfer, m

nf : Nanofluid

Nu : Nusselt number, (-)

p : Nanoparticle

Q : Heat Transfer Rate, J/s

Re : Reynolds number, (-)

T : Temperature, K

T_a : Air temperature, K

T_c : Coolant temperature, K

T_f : Fluid temperature, K

T_s : Surface temperature, K

v : Average velocity, m/s

μ : Viscosity, kg/m·s

ρ : Density, kg/m^3

φ : Nanoparticle volume fraction (volumetric concentration), %

Δ : Differential

CHAPTER 1

INTRODUCTION

1.1 Background of Study

A car radiator is a type of heat exchanger and it plays an important role in the cooling system of vehicle. The main function of a car radiator is to transfer the excessive heat from the engine in order to avoid overheating and engine failure. A typical car radiator is as shown in Figure 1. A large amount of heat is produced by advanced automotive internal combustion engines when the air mixture and gasoline is combusted in the combustion chamber. This heat energy forces the piston to be pushed down inside the engine to turn the crankshaft and then generate power to drive vehicle.

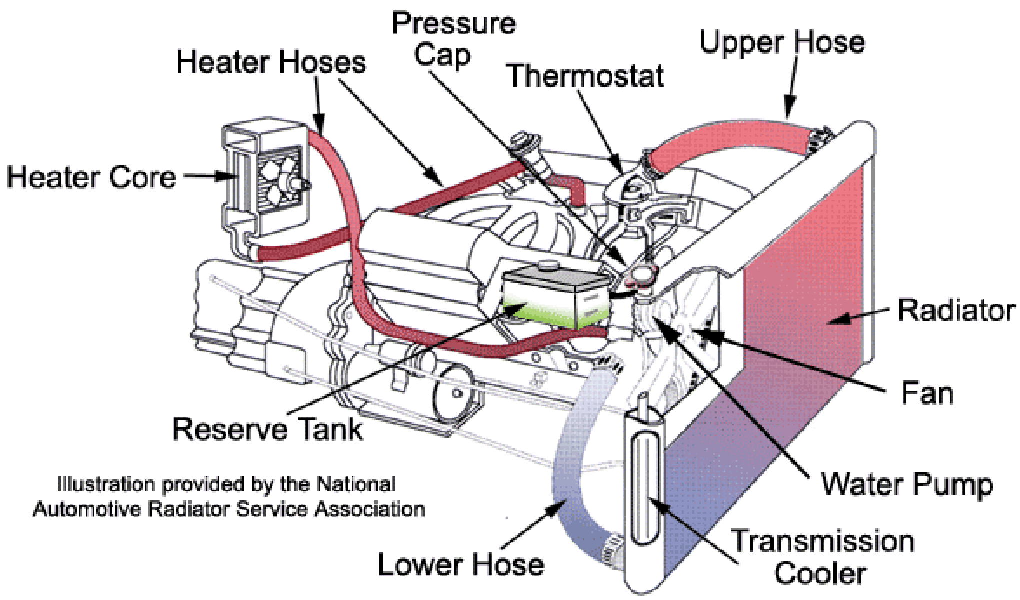


Figure 1 Parts of Car Radiator [1]

There are approximately 1/3 of the thermal energy is used to power the vehicle out of all the heat generated from the combustion of fuel. The next 1/3 of the heat is dissipated to the surrounding through the exhaust system. The remaining 1/3 of the excess heat which trapped in the main component of vehicle such as engine oil, cylinder walls, pistons and valves need to dispose to avoid overheating. Thus, advanced automotive engines normally adopted the most effective liquid cooling system to take care of the heat removal job.

Effective engine cooling is necessary to maintain engine performance, engine life and safety. In a liquid cooling system, the heat produced from the engine cooling and air conditioning process is removed through the circulation of car coolant in the engine cooling jacket to the car radiator as illustrated in Figure 2. The heat from the coolant is then dissipated to the fins of the car radiator and atmosphere when air flow into it through conduction and convection. Cool coolant that flow out from the radiator will then recirculate again in the jacket. The function of the cooling system is not only to carry off the excess heat but also control the temperature of the engine at its operating temperature range which then generate the best performance of the car engine.

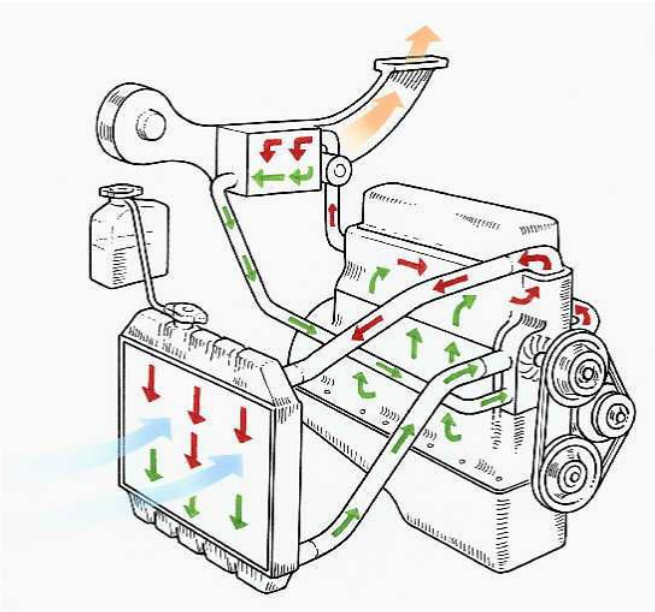


Figure 2 Cooling cycle in the car radiator system [2]

To enhance heat transfer performance of car radiator, a wide range of different fluids and its operating conditions are investigated in different previous studies. These applications would benefit to improve heat transfer properties like the enhanced thermal conductivity of the working fluid. Implementation of such fluids into the existing systems can lead to an improved working efficiency and a better design of the overall system.

Nanofluids, with their improved heat transfer properties, are reliable to be these working fluids. These fluids are beneficial in various industries such as transportation, electronics, medical, manufacturing as well as nuclear engineering due to the enhanced thermophysical properties. Recently, there are many researchers show their interest on nanofluids and evaluate the enhancement of heat transfer capacity. Eastman *et al.* [3], Liu *et al.* [4], Hwang *et al.* [5], Yu *et al.* [6] and Mintsa *et al.* [7] mentioned that nanofluids has potential to enhance thermal quality as compared to conventional coolant. This newly introduced category of nanofluids have unique structures different from conventional solid-liquid mixtures in which nano-sized particles (typically of length 1-100 nm) of metals and non-metals are dispersed. The most utilised coolant now in automobile industry are water and ethylene glycol (EG) which have much lower thermal conductivity than the base fluid that has added with nanoparticles such as silver, copper and iron.

The new breakthrough technology has emerged the needs for more efficient car radiator in automotive industry now-a-days. Over recent years, one of the main scientific research interest is to enhance thermal conductivity of the working fluid. The enhancement of thermal conductivity of nanofluids as coolant in the car radiator application is important to ensure the efficiency of car cooling system. The previous researches investigate the laminar flow of nanofluids flowing in car radiator. However, few study are available on the turbulent flow of nanofluid. The results indicate that it is one of the important factor to improve performance of car radiator. Hence, this study is important to compare the fluid flow (laminar and turbulent) and heat transfer characteristics of a car radiator using 60% ethylene glycol and 40% water by mass (60:40 EG/W) based on different types of nanoparticles as coolants with different volume concentration numerically. Conventional coolant is used for comparison purpose for its thermal and hydraulic performance in car radiator. This analysis can predict the result of heat transfer and thermal conductivity enhancement at the end of project.

1.2 Problem Statement

In order to prevent overheating and failure of engine, cooling is required to remove the excessive heat losses in thermodynamics processes which resulted from heating and friction in the combustion chamber surfaces. Equipment design of a car radiator plays an important role in producing a high efficiency of cooling system and ensuring good performances in engine operation. Various car radiator systems such as shell and tube heat exchangers, double tube heat exchanges and plate heat exchangers are characterised by its high surface area per unit volume for enhanced heat transfer purpose. It should be highlighted that the surface area of car radiator has significant impact on the heat transfer capacity. Large radiator may perform a better heat loss, but will occupy the space under the bonnet. Thus, good selection of coolants to dissipate heat efficiently are prerequisites for maximum engine operation and maintaining its operating temperature within a specific range. By using nanofluids as coolant in car radiator, heat transfer performance can be improved and the size of radiator can be reduced at the same time.

1.3 Objectives

In this study, the Computational Fluid Dynamics (CFD) simulation tool, ANSYS Fluent 15.0 is used to analyse the heat transfer behavior of 3-Dimensional numerical model of car radiator. The main objectives of this study are:

a) To study and compare heat transfer of fluid in car radiator with and without nanoparticles using CFD simulation.

b) To study and compare heat transfer of car radiator with nanofluids as coolants at varying nanoparticles loading.

c) To study and compare heat transfer of car radiator with nanofluids as coolants in various flow regime.

1.4 Scope of Study

This study would be significant for the fundamental of numerical study of nanofluids in car radiator. The focus of this project will be on analysing and comparing the heat transfer of car radiator using nanofluids with different concentration, type of nanoparticles and type of coolant flow.

The heat flow distribution in the car radiator is analyzed under multiple concentration of nanoparticles and also by using the different types of nanoparticles which is copper oxide (CuO), alumina (Al_2O_3) and silicon dioxide (SiO_2). The heat transfer and fluid flow characteristic of different types of flow (turbulent and laminar) will be studied.

CHAPTER 2

LITERATURE REVIEW

2.1 Heat Transfer

Heat transfer is the study of the rates of energy transfer and it is described as a form of energy that can be transferred from one system to another system due to temperature difference [8]. The heat transfer only occur when there is temperature difference and it can be transferred from one body to another body when there is temperature difference as a forcing force between the two bodies. The science of thermodynamic also concern with the total amount of energy changes when a system alter from equilibrium state to other state [9]. There are three different modes of heat transfer which are conduction, convection and radiation. The similarity of all the three modes is that heat is only transferred between two systems when there is temperature difference which is high temperature to low temperature. The differences between conduction and convection are conduction is due to the collisions, diffusions or vibration of the particles in the system whereas convection is the result of heat transfer between conduction and fluid. For radiation, it does not require any medium to occur as radiation can occur in a vacuum state.

In this study, heat transfer is an important factor because car radiator involved heat exchange process. With the theory of heat transfer, the rates of heat transfer to or from a system, heating and cooling time in a heat transfer and variation of temperature can be determined through conducting the CFD simulation with proper assumption.

2.1.1 Conduction

Conduction is the transfer of heat energy within bodies of matter due to temperature difference occurred between them. Conduction involved the transfer of kinetic energy within particles of matter and it take place in solids, liquids and gases. The heat will flow from a body which has higher temperature to lower temperature until steady state is reached. In car radiator, conduction is observed in heat transfer within tubes and fins. The equation to calculate the rate of heat transfer of conduction is stated as below:

$$Q_{conduction} = \frac{kA\Delta T}{L} \tag{1}$$

Where k is the conductivity of material ($Wm^{-1}K^{-1}$), A is the cross-sectional surface area (m^2), ΔT is the temperature difference between two ends (K) and L is the length of heat transfer between two ends (m) [10].

2.1.2 Convection

Convection involved two elements in heat transfer which are solid and adjacent moving fluid. At constant pressure, the density is inversely proportional to the temperature, the adjacent air to the hot surface becomes hotter and buoyant as its density decreases [9]. The cooler fluid will then replace the hotter fluid and form a fluid circulation. The heat from the coolant is transfer to the tube wall and when the air flow across the car radiator, the heat will be carried off through convection. The Newton's law of cooling can be applied here in order to know the rate of heat exchange between the two systems which is as shown in equation (2):

$$Q_{convection} = hA(T_s - T_f) \tag{2}$$

At which T_f is the temperature of fluid, A is the surface area, T_s is the temperature of the surface object and h is the convection heat transfer coefficient.

2.1.2.1 Mode of Convection

a) **Natural Convection:** Heat transfer is caused by the motion of fluid and on a solid surface as shown in Figure 3. This phenomena involves fluid circulation as the fluid will move upward when it gets warm and decreases in density, the cooler fluid which is denser will sink and replace the hot fluid due to buoyancy forces.

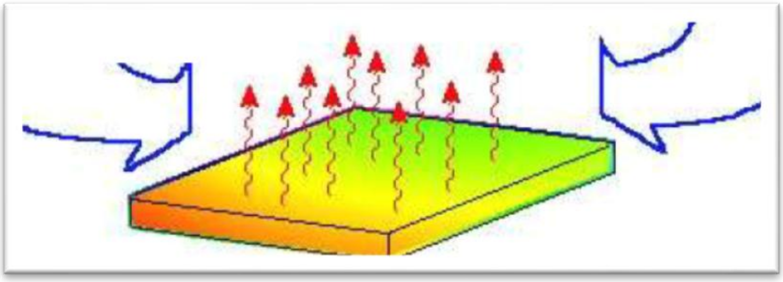


Figure 3 The Cooling of a Hot Plate by Natural Convection [9]

b) **Forced Convection:** The fluid flow to the surface through external forces such as pump and fan. The rate of heat transfer is enhanced due to the rapid movement of air flow over a hot plate as shown in Figure 4. Higher flow rate of forced convection than natural convection has shown higher heat transfer rate in forced convection than natural convection. The heat transfer of car radiator in this study is forced convection because the hot coolant is pumped into the car radiator to remove the excess heat.

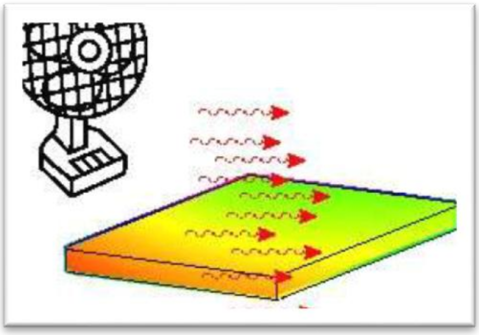


Figure 4 The Cooling of a Hot Plate by Forced Convection [9]

2.1.2.2 Heat Transfer Coefficient

In convection, heat transfer coefficient depends on the characteristic in the boundary layer of fluid. According to the equation 3, it is influenced by the motion of fluid, surface geometry, and an assortment of fluid thermodynamic and transport properties [9]. The relationship of heat transfer coefficient in a car radiator between Nusselt number, fluid conductivity and diameter of tube is stated as below:

$$\mathrm{h} = \frac{Nuk}{D_h} \tag{3}$$

Where Nu is the Nusselt number (dimensionless), k is the conductivity of fluid ($Wm^{-1}K^{-1}$), D_h is the hydraulic diameter of tube (m). The relationship clearly shows that heat transfer coefficient of convection is directly proportional to Nusselt number and fluid conductivity but inversely proportional to the diameter of tube. It can be predicted in this study that the change of Nusselt number will influence the value of heat transfer coefficient and also influence the rate of heat transfer directly.

2.1.2.3 Reynolds number

Reynolds number is a dimensionless number which provides the ratio of inertial forces to viscous forces. These two forces can quantify the importance of them in a given flow condition. Basically, Reynolds number is affected by fluid flow velocity, viscosity and dimension of fluid boundary and the relationship as stated below:

$$\mathrm{Re} = \frac{\rho v D_h}{\mu} \tag{4}$$

Where ρ is the density of fluid (kgm^{-3}), v is the velocity of fluid flow (ms^{-1}), μ is the dynamic viscosity (Nsm^{-2}) and D_h is the diameter of the tube in car radiator (m). From equation above, velocity of the flow is directly proportional to the Reynolds number. In this study, both laminar flow and turbulent flow are considered and calculated by varying Reynolds number and velocity of the fluid.

2.2 Computational Fluid Dynamics (CFD)

CFD is a numerical study to investigate the fluid flow behaviour and its heat transfer phenomena in a 3-Dimensional or a 2-Dimensional space numerically. The method that applies to solve and analyse problem is by discretising the geometry into several small volumes and the algorithm is solved for the temperature and velocity profile. Discretization of the geometry into smaller volumes is called mesh generation and the size of the mesh can influence the accuracy of the solution. Energy equation, momentum equation (Navier stokes equation) and the continuity equation are used to solve the problem.

CFD simulation can use to perform analysis over the car radiator with nanofluids as coolants. Thus, ANSYS Fluent 15.0 is used to study the fluid flow behaviour of nanofluids in car radiator. Previously, there are extensive works have done on the analysis of heat transfer performance of car radiator using various simulation tools.

2.2 Relevant Work

The conventional coolants such as water, ethylene glycol (EG) and water used in car radiator to dissipate excess heat is restricted as an energy-efficient heat transfer fluid due to its low thermal conductivity characteristic. Hence, the thermal conductivity of coolant is a primary factor on heat transfer coefficient between coolant and heat transfer surface which are fins and tube. Numerous research have been performed to enhance the thermal conductivity of conventional coolant fluid by suspending nanoparticle materials with nanometres (nm) size in the range of 1 to 100 nm in liquids which is also known as "nanofluids". The idea of nanofluids is a term introduced by Choi and Eastman [3] to study the new developed of nanotechnology working fluid that has a higher thermal properties compare to other conventional coolant or base fluids. According to Das *et al.* [10], Trisaksri and Wongwises [11] and Wang and Mujumdar [12] have concluded the research completed at this area. The literature review specifies that the size, shape, and volume fraction of the nanoparticles as well as on the type of the nanoparticles and of the base fluid is used to characterise the properties of nanofluid. They have summarized that that the thermal conductivity of the nanofluid is higher than its base fluid [13, 14].

Researchers have claimed that nanofluids technology has potential to improve the heat transfer performance of car radiator as nanoparticles have higher thermal conductivity than conventional heat transfer fluid as shown in Figure 5. Leong *et al.* [16] found out that there are approximately 18.7% reduces at the frontal area of a car by adding 2% of copper nanoparticles into the coolant. This is because the high thermal characteristics of nanofluids generates the better heat performance, reduce fuel consumption and consequently lower the operating costs.

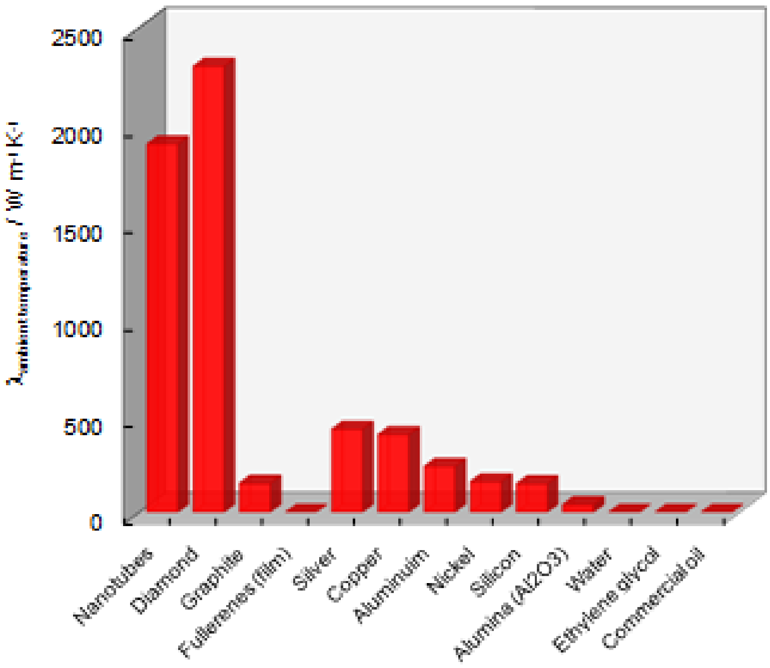


Figure 5 Thermal conductivity of typical material [15]

Xie *et al.* [17] conducted an experimental study on the thermal conductivity behaviour of Al_2O_3 nanoparticle in water, oil, and EG. They recorded an enhancement of the thermal conductivities of the suspensions when nanoparticles is added into base fluids. It is proven that thermal conductivity ratios increases with the volume fraction of nanoparticles but reduces with increasing thermal conductivity of the base fluid.

Eastman *et al.* [18] have investigated the effectiveness of thermal conductivity of nanofluid consisting of Cu, CuO and Al_2O_3 nanometer-sized particles dispersed in EG and base fluid. The experimental result indicates that nanofluid consisting of nanometer-sized particles dispersed in EG has a much higher effective thermal conductivity than pure EG. An increment of 40% of thermal conductivity of EG is found for a nanofluid consisting 0.3% of Cu nanoparticle in EG basefluid as compared to other nanofluids with the same particle loading. It is determined that Cu/EG nanofluids have been recorded to show outstanding thermal conductivity improvement compared to other nanofluids containing oxide particles.

Farajollahi *et al.* [19] pointed out in their experimental work that base fluid consisting of nanoparticle results in significant improvement of heat transfer. They examined the capability of heat transfer of water basefluid consisting Al_2O_3 and TiO_2 nanoparticles for turbulent flow by investigating its convective heat transfer coefficient and Nusselt number. Peclet number, volume fraction of nanoparticles and type of nanoparticles play an important role in the enhancement of heat transfer. Different nanofluids have different optimum nanoparticle concentration. In comparison, Al_2O_3-H_2O nanofluid are able to transfer more heat at higher nanoparticle concentrations, whereas at a certain Peclet number, TiO_2-H_2O nanofluid possess better heat transfer characteristic at its optimum nanoparticle loading than Al_2O_3-H_2O nanofluid.

Vajjha *et al.* [20] conducted a 3D numerical study of laminar flow and forced convective heat transfer of Al_2O_3 and CuO nanofluids in EG in the flat tubes of an automobile radiator. They stated heat transfer enhanced better in nanofluid over the base fluid. This paper developed the new correlations for viscosity and thermal conductivity of nanofluids as a function of particle loading and temperature. The result observed that nanofluid generated a remarkable enhancement of heat transfer coefficient along the flat tubes compared to the base fluid. They presented convective heat transfer coefficient and the local and the average friction factor increase with particle loading of the nanofluids and Reynolds numbers.

Besides the thermophysical properties of basefluid, the type of flow across the tube influence the heat transfer behaviour of nanofluids. Pantzali *et al.* [21] performed experimental study on result of performance of in a commercial herringbone-type plate heat exchanger (PHE) by adding a 4% volume concentration of CuO in water as a coolant. They compared several of flow (laminar and turbulent) of nanofluid in the heat exchanger and found that the turbulence flow of nanofluid is favourable if there is an increase in its thermal conductivity and significant increase in viscosity. Or else, it is beneficial to work in laminar conditions with a need to control the instability of the nanoparticle suspension.

Maiga *et al.* [22] performed numerical study of Al_2O_3 nanofluid in laminar flow along the circular tubes and between parallel disks. They reported increase in heat transfer characteristic particle volume concentration and Reynolds numbers from 250 to 1000. However, there is a drastic adverse effect on wall shear stress compared to the basefluid. They observed irrelevant effect on the heat transfer enhancement with the flow between the disks.

According to Patel *et al.* [23], the temperature profile and flow behaviour prediction of radiator played a dominant role for designer. Computational Fluid Dynamics (CFD) can be used to study the performance of the radiator at the early stage. The solving of mathematical equations and numerical analysis is very useful for studying the chemical reaction, heat transfer and fluid flow. Pressure distribution, temperature gradients and flow parameters can be resolved in a shorter time and lower cost as experimental work is eliminated. Sulaiman *et al.* [24] had carried out CFD modeling simulation of air flow distribution from the automotive radiator fan. The model of the fan geometries are developed and the result showed that the design of the fan blade was inappropriate and the error of average outlet air velocity is 12.5%. Authors inferred that the CFD simulation is an effective tool to enhance the performance of car radiator as the result obtained is a useful information for further investigation

After a comprehensive study of the existing literature, it is clear that nanofluids have potential to use as coolant in car radiator due to the excellent heat transfer performance. CFD analysis is a useful tool to study thermal performance of different coolant in car radiator. This project will study the heat transfer performance of a car radiator using ethylene glycol and water mixture (60:40 wt %) of Al_2O_3, CuO and SiO_2 nanofluids as coolants at various concentrations (1 vol %, 3 vol % and 5 vol %) using ANSYS Fluent 15.0. The thermal characteristics of nanofluids operated in car radiator will be compared with 0 vol % ethylene glycol and water mixture (60:40 wt %). The effect of concentration in volume fraction of nanoparticles and the type of flow on the thermal conductivity will be analysed. Al_2O_3, CuO and SiO_2 nanoparticles are selected in this research.

2.3 Governing Equation

The problem under investigation is a three-dimensional steady and forced convection flow of nanofluids flowing inside a flat tube having width of 0.025 m, height of 0.0015 m, and length of 0.105 m. The nanofluids are assumed to be in single phase, incompressible and enter the flat tube with uniform axial velocity and temperature. The single phase model equations include the equation of continuity, momentum equation and energy equation (ANSYS Fluent 15.0). The continuity and momentum equations are used to calculate velocity vector. The energy equation is used to calculate temperature distribution and wall heat transfer coefficient. The equation for conservation of mass or continuity equation can be written as follows:

2.3.1 Mass Conservation Equation

The equation for conservation of mass, or continuity equation, can be written as follows:

$$\frac{\partial \rho}{\partial t} + \nabla(\rho \vec{v}) = s_m \tag{5}$$

Equation (5) is the general form of the mass conservation equation, and is valid for both incompressible compressible flows. The source S_m is the mass added to the continuous phase from the dispersed second phase (e.g., due to vaporization of liquid droplets) and any user-defined sources.

2.3.2 Momentum Conservation Equation

Conservation of momentum in an inertial (non-accelerating) reference frame is described by:

$$\frac{\partial}{\partial t}(\rho\, \vec{v}) + \nabla(\rho\, \vec{v}\, \vec{v}) = -\nabla \mathrm{p} + \nabla(\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \tag{6}$$

Where p is the static pressure, is the stress tensor, and $\rho \vec{g}$ and $\vec{F}$ are the gravitational body force and external body forces (e.g., that arise from interaction with the dispersed phase), respectively. F also contains other model dependent source terms such as porous-media and user-defined sources.

2.3.3 Energy equation

ANSYS FLUENT solves the energy equation in the following form:

$$\frac{\partial}{\partial t}(\rho E) + \nabla(\vec{v}\,(\rho E + p)) = \nabla\left(K_{eff} \nabla \mathrm{T} - \sum_j h_j \vec{J_J} + (\,\bar{\bar{\tau}}_{eff}\, \vec{v}) \right) + S_h \tag{7}$$

Where K_{eff} is the effective conductivity, and $\vec{J_J}$ is the diffusion flux of species J. The first three terms on the right-hand side of Equation represent energy transfer due to conduction, species diffusion, and viscous dissipation, respectively. S_h includes the heat of chemical reaction, and any other volumetric heat sources.

CHAPTER 3

METHODOLOGY

3.1 Research Methodology

The goal of this research is to investigate the heat transfer in the car radiator using nanofluids as coolant. Various nanofluids are taken into consideration: Alumina (Al_2O_3), Copper oxide (CuO) and Silica (SiO_2). Heat transfer performances of car radiator using ethylene glycol/water (60:40) basefluid are analysed with varying nanoparticles concentration which are 1 vol%, 3 vol%, and 5 vol%. The project will be studied numerically by using ANSYS Fluent 15.0 to formulate a 3-Dimensional numerical model which can be used to analyze the behavior of fluid flow in car radiator and heat transfer of car radiator in different type of coolant flow. The nanofluids as coolant are studied at different Reynolds's number conditions for coolant (laminar and turbulent), $100 \leq Re \leq 10000$.

The selected design parameters are first inserted in Design Modeler to create a three-dimensional model of various geometric shaped solid fins. This design will be meshed using four distinctly different size meshes depending on different surface and part of car radiator. These mesh sizes are ranged from coarse to fine. The boundary conditions will be inserted based on the selected nanofluid as well as type of flow. The selected model will set to run until convergence is achieved. This procedure will be followed for each of the nanofluid, nanoparticle concentration and flow regime.

3.2 Overview of CFD ANSYS Simulation

The process flow diagram below describes the procedure followed to perform CFD simulations from initial stage to the end of the study. The sequence of steps followed in solving the problem is presented in a flowchart as shown in the Figure 6.

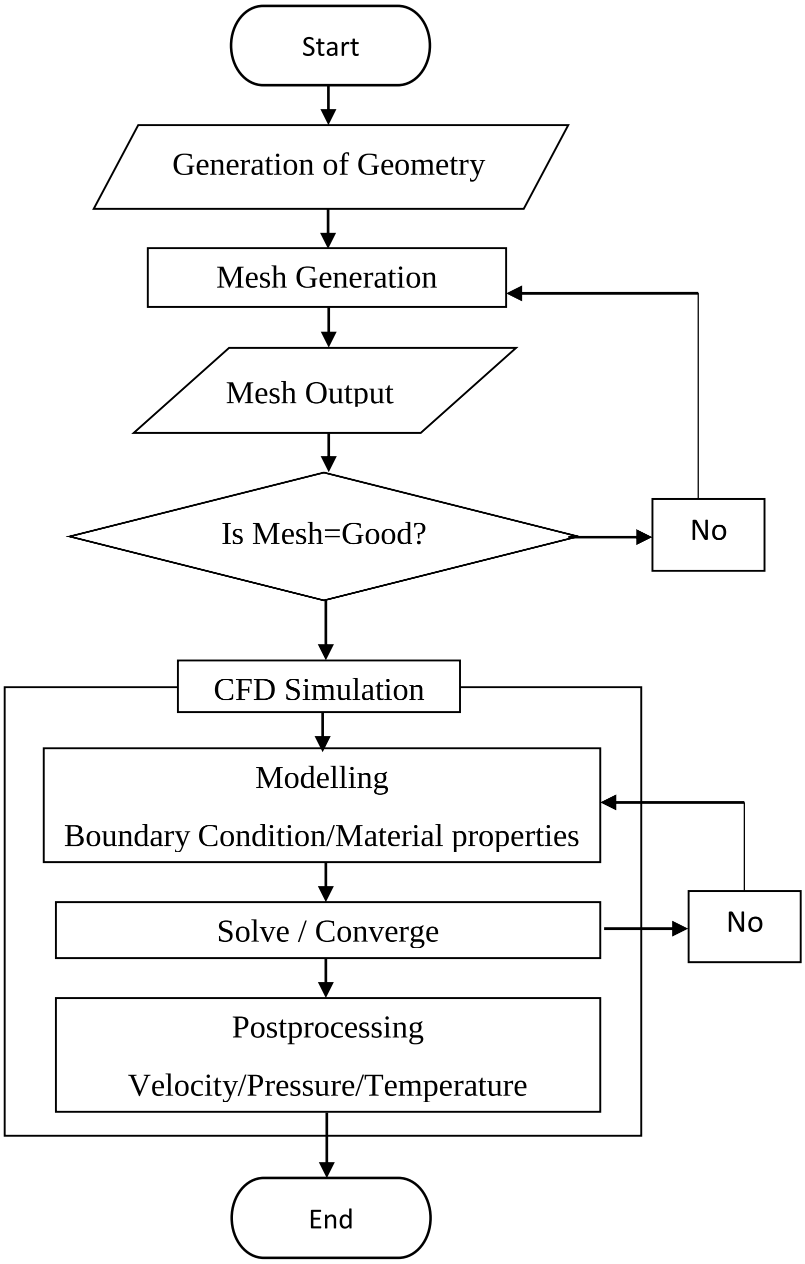


Figure 6 Flowchart of CFD ANSYS Simulation

3.2.1 Geometry Modeling

A 3-Dimensional model of a radiator which consist of air flow duct serpentine finned-tube exchanger as shown in Figure 7 is considered for analysis purpose. The detail measurement of the radiator are summarised in Table 1. In this study, only one part of radiator with dimension is constructed which consist of one long rectangular tube and 25 fins attached at the both side of the tube as shown in Figure 8. Air flow domain is constructed to consider the air flow across the car radiator when the car is moving. The same geometry and dimension will be used throughout the simulation for all the nanofluids. The tube is set to fluid and the fins of car radiator are set to solid. The object will be imported to mesh after the geometry is completed.

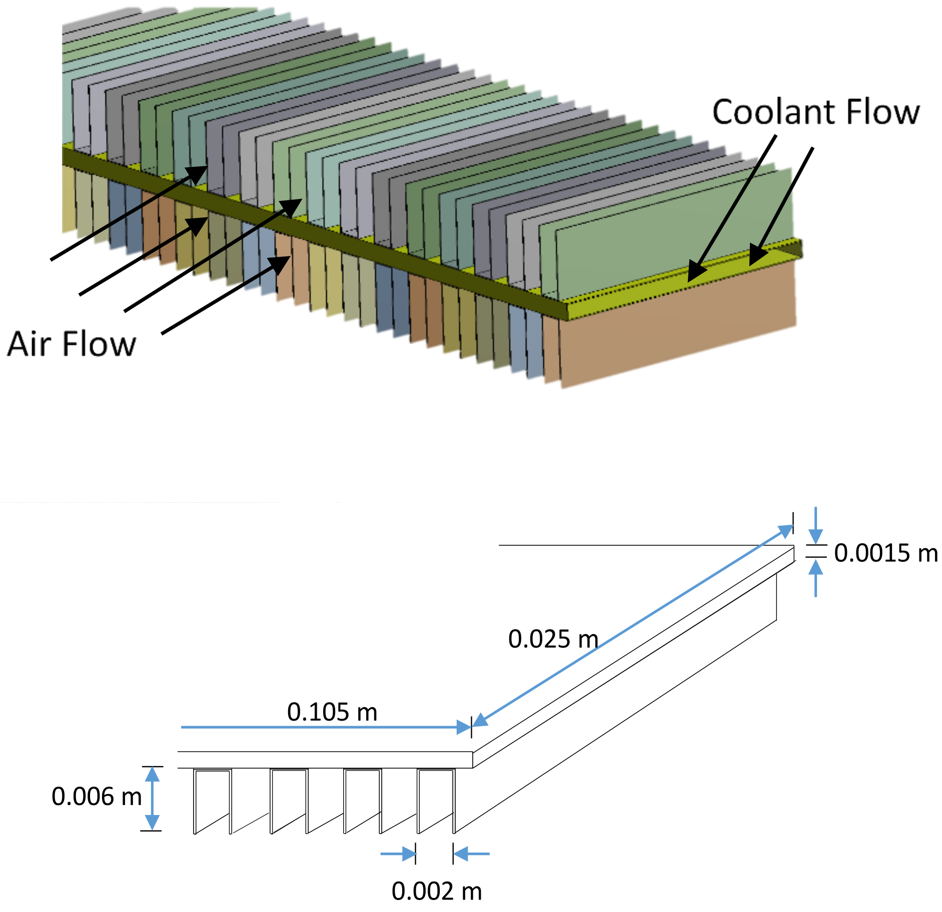


Figure 7 Car Radiator Model under Consideration with Dimensions

Table 1 Core geometry of flat tubes, continuous fins, and operating conditions of a radiator

Number	Description	Dimension
1	Tube height	0.0015 m
2	Tube length	0.105 m
3	Tube width	0.025 m
4	Fin height	0.006 m
5	Fin width	0.025 m
6	Fin Thickness	0.0001 m
7	Distance between fins	0.002 m
8	Number of fins	25
9	Air side hydraulic diameter, D_h	0.0247 m
10	Coolant side hydraulic diameter, D_h	0.04038 m
11	Air Temperature (T_a)	303 K
12	Coolant Temperature (T_c)	363 K
13	Material	Aluminum

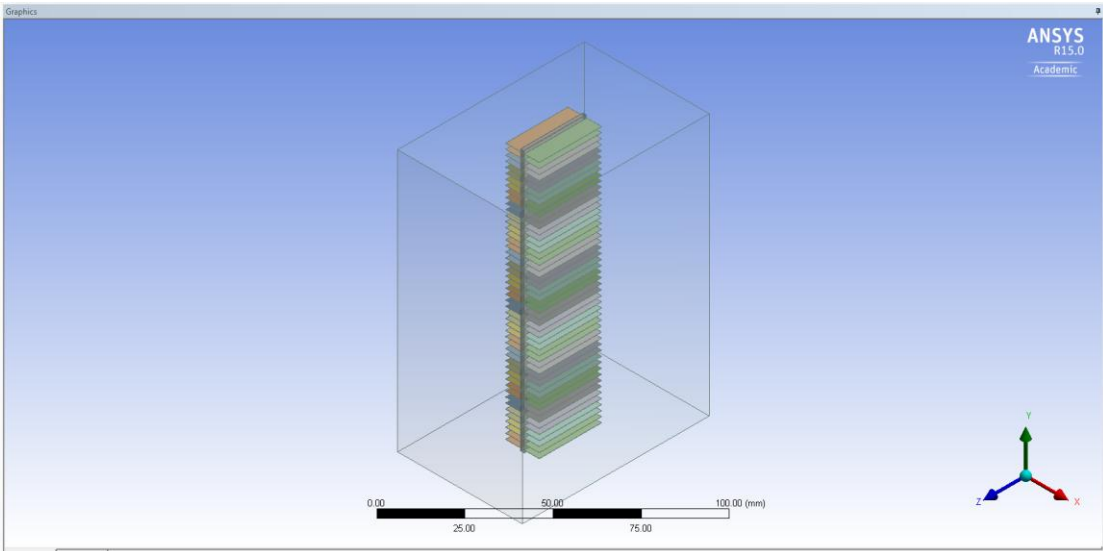


Figure 8 Geometry Modeling Using Design Modeler

3.2.2 Mesh Generation

Mesh is defined as the open spaces in a net or network. Good quality of mesh is important for rapid convergence, accurate result and shorter time taken to generate mesh. The project is started with automatic meshing method available in ANSYS mesh cell to analyse its quality. In this study, constant body size of meshing of 0.003 m is set for air domain and 0.0004 m is set for tube and fins as shown in Figure 9. Finer mesh quality at the complicated region such as fins is applied for a better result. The number of elements for the geometry at the final mesh is 314 728. Several testing has been conducted in order to generate the best mesh size. The same mesh size is used for all simulation. After the meshes have been developed, inlet and outlet faces of car radiator and air domain have been assigned and named for further analysis in FLUENT.

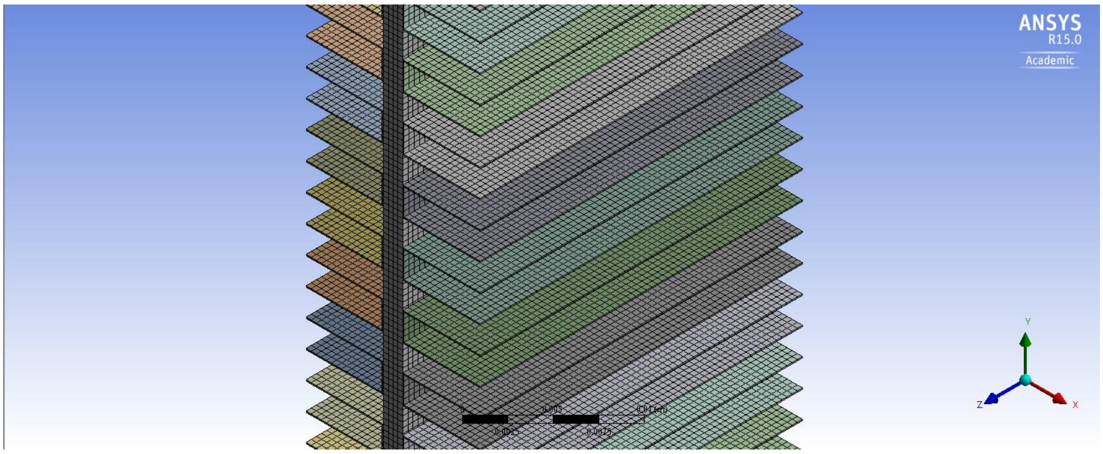


Figure 9 Geometry of Meshing

A variety of mesh quality metrics can be analysed in order to determine the mesh quality generated. In this study, skewness and orthogonal quality and smoothness have significant importance to evaluate the quality of the mesh. The maximum skewness obtain is 0.984737 as shown in Figure 10. By referring to Table 2, it is in the range excellent quality of meshing.

Minimum cell orthogonality is an important indicator of mesh quality. As mentioned in the ANSYS User's Guide, the values for orthogonality can vary between 0 and 1 with lower values indicating poorer quality cells. The minimum orthogonality should not be below 0.01 with the average value significantly larger. For the orthogonal quality as shown in Figure 11, the minimum value obtain is 3.083291 and considered an acceptable quality of mesh.

Statistics	
Nodes	392579
Elements	314728
Mesh Metric	Skewness
Min	7.93309573065739E-05
Max	0.984737320499386
Average	0.327295859027155
Standard Deviation	0.24807343228197

Figure 10 Skewness

Table 2 Skewness Ranges and Cell Quality

Value of Skewness	**Cell Quality**
0	degenerate
< 0.02	bad (sliver)
0.25 - 0.02	poor
0.5 - 0.25	fair
0.75 - 0.5	good
0.75 - 1	excellent
1	equilateral

Statistics	
Nodes	392579
Elements	314728
Mesh Metric	Orthogonal Quality
Min	3.08329103308893E-02
Max	0.999999992208235
Average	0.784494144946148
Standard Deviation	0.215309542747477

Figure 11 Orthogonal quality

3.2.3 Setup Physics

After the mesh is completed, the geometry model must be checked before proceeding to setup in ANSYS Fluent 15.0. The procedure of the general setup is as shown below.

3.2.3.1 General

In general setup, pressure based, absolute velocity formulation, steady and 3D double precision are initialised for this study as shown in Figure 12. Pressure based is selected as the flow of nanofluids is incompressible flow.

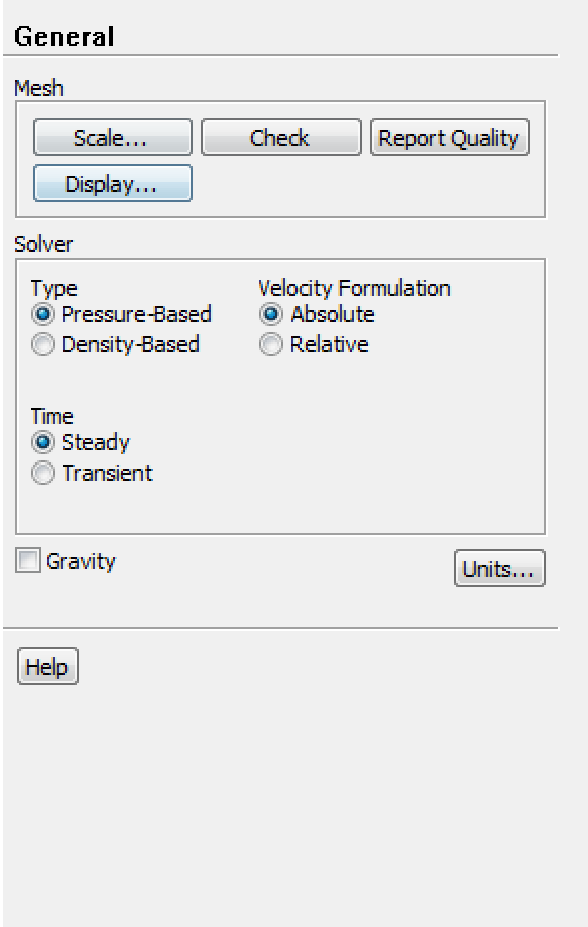


Figure 12 General Setup

3.2.3.2 Models

In this study, heat transfer is investigated and thus energy equation is enabled (Figure 13). Laminar flow is assumed and setup when the flow is in the range of $100 < Re < 1000$ as shown in Figure 14. Whereas, Standard κ-ε turbulent model is used with enhanced wall treatment for turbulent modelling when the flow is in the range of $5000 < Re < 10000$ which is turbulent flow as described in Figure 15.

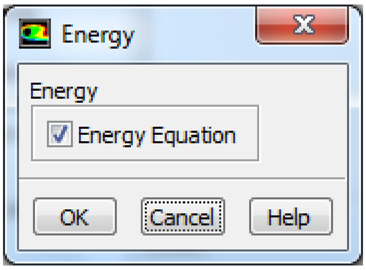


Figure 13 General Setup

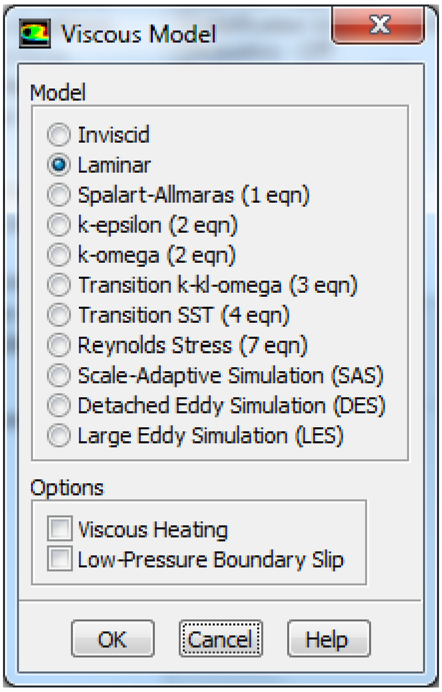


Figure 14 Laminar Model Setup

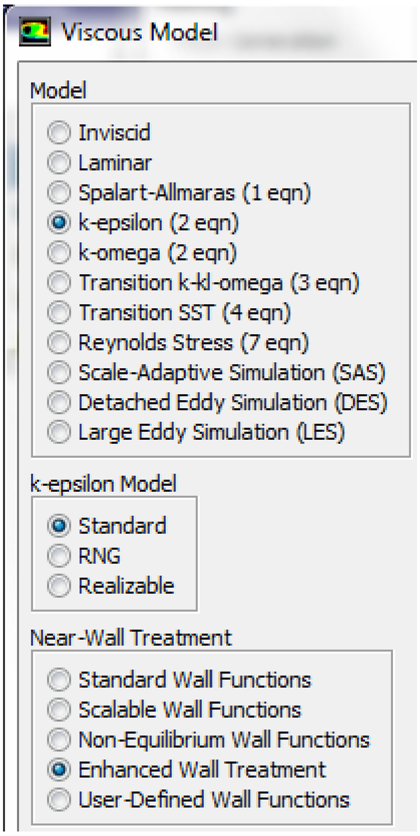


Figure 15 Turbulent Model Setup

3.2.3.3 Materials

There are two kind of bodies in this geometry which are solid and fluid. Solid is defined for the fins part and the material is aluminum. Whereas, fluid is referring to the coolant in the tube and air flow across the flow domain. All the properties can be extracted from the FLUENT database except the thermophysical properties of nanofluids and basefluid as the properties are highly dependent on temperature.

Determination of thermophysical properties

Nanofluids

Nanofluids Al_2O_3, CuO and SiO_2 are investigated in this study. The properties of nanoparticles are shown in Table 3 below:

Table 3 Properties of nanoparticles [25]

Type of material	**Density (kg/m^3)**	**Specific heat (J/kg K)**	**Thermal conductivity (W/m K)**
Al_2O_3 (45 nm)	3600	765	36
CuO (29 nm)	6500	533	17.65
SiO_2 (20 nm)	2220	745	1.4

The thermophysical properties of all types of nanofluids as coolants are strongly dependent on the temperature and type of nanoparticle. It is noticed that the density, thermal conductivity, and dynamic viscosity seems to be higher than the base fluid. The thermal conductivity of each nanofluids are assumed to be constant because the variation of the thermal conductivity with temperature is relatively small. On the other hand, the specific heat of nanofluids appear significantly lower than the base fluid. The thermophysical properties of nanofluids flow in tube are calculated using the following equation (8–10), accordingly at below. The values of constants A_1 and A_2 are shown in Table 4.

$$\text{Density: } \rho_{nf} = (1-\varphi)\,\rho_{bf} + \rho_p\varphi \quad (8)$$

$$\text{Specific heat: } C_{pnf} = \frac{\varphi\,\rho_p C_{pp} + (1-\varphi)\,\rho_{bf} C_{bf}}{\rho_{nf}} \quad (9)$$

$$\text{Viscosity: } \frac{\mu_{nf}}{\mu_{bf}} = A_1 e^{(A_2\varphi)} \quad (10)$$

Table 4 Constant of the viscosity correlation for different nanofluids

Nanoparticles	**A_1**	**A_2**
Al2O3 (45 nm)	0.983	12.959
CuO (29 nm)	0.9197	22.8539
SiO2 (20 nm)	1.092	5.954

Basefluid Properties

To find the thermophysical properties of nanofluid, the information for the properties of base fluid is required. The properties basefluid (60:40 EG/W) is obtained from ASHRAE Handbook [26]. The values of properties also varies with temperature and the relation of this effect is given in the equation (11-14) below:

Density: $$\rho_{bf} = -0.0024T^2 + 0.963T + 1009.8 \quad (11)$$

Viscosity: $$\mu_{bf} = A_4 e^{\frac{B_4}{T}} \quad (12)$$

Where $A_4 = 0.555 \times 10^{-3}$; $B_4 = 2664$

Thermal conductivity: $$k_{bf} = -3 \times 10^{-6}T^2 + 0.0025T + 0.1057 \quad (13)$$

Specific Heat: $$C_{pbf} = 4.2483T + 1882.4 \quad (14)$$

The above equations are valid within the temperature range of $293\text{ K} \ll T \ll 363\text{ K}$.

In the equation (11-14), the subscripts p, b and nf refer to the particles, basefluid, and nanofluid respectively. φ is volume fraction of the nanoparticle added to the basefluid.

Figure 16 presents the material setup for the fins of car radiator in Fluent. Since the material of fins is aluminum and the properties is available in Fluent database, the properties is used for all simulations. For air domain, the setup is shown in Figure 17. The air properties is chosen from the Fluent database.

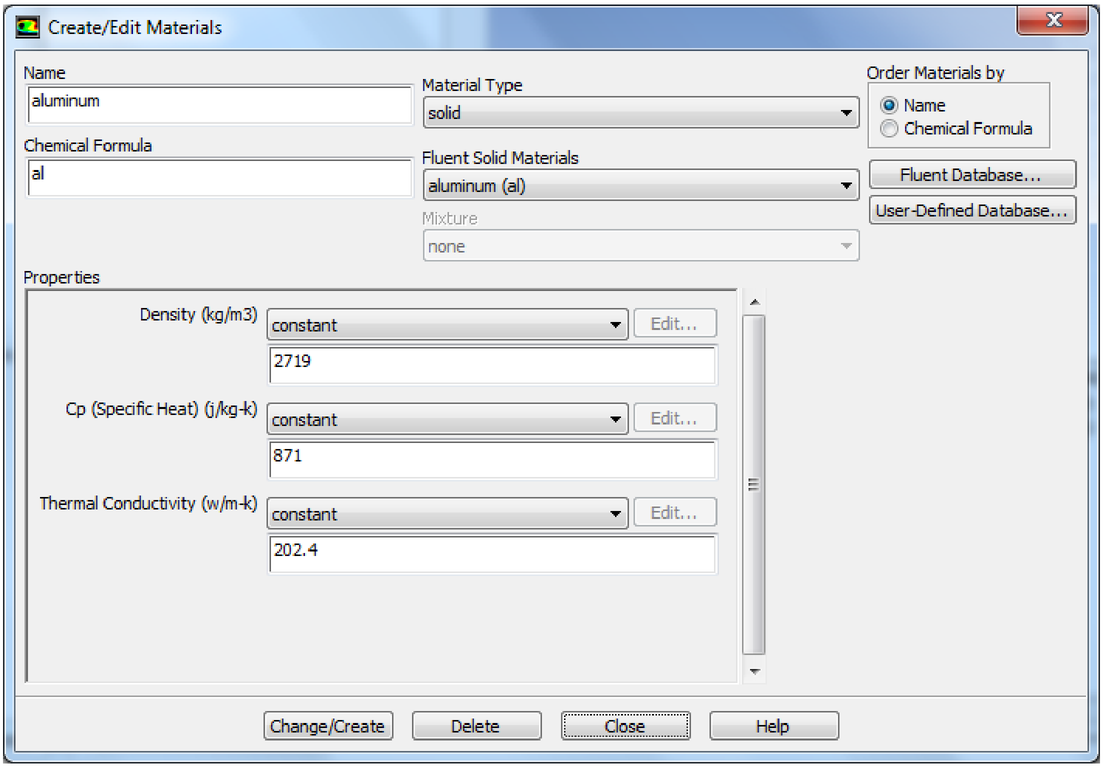


Figure 16 Material Setup for fins

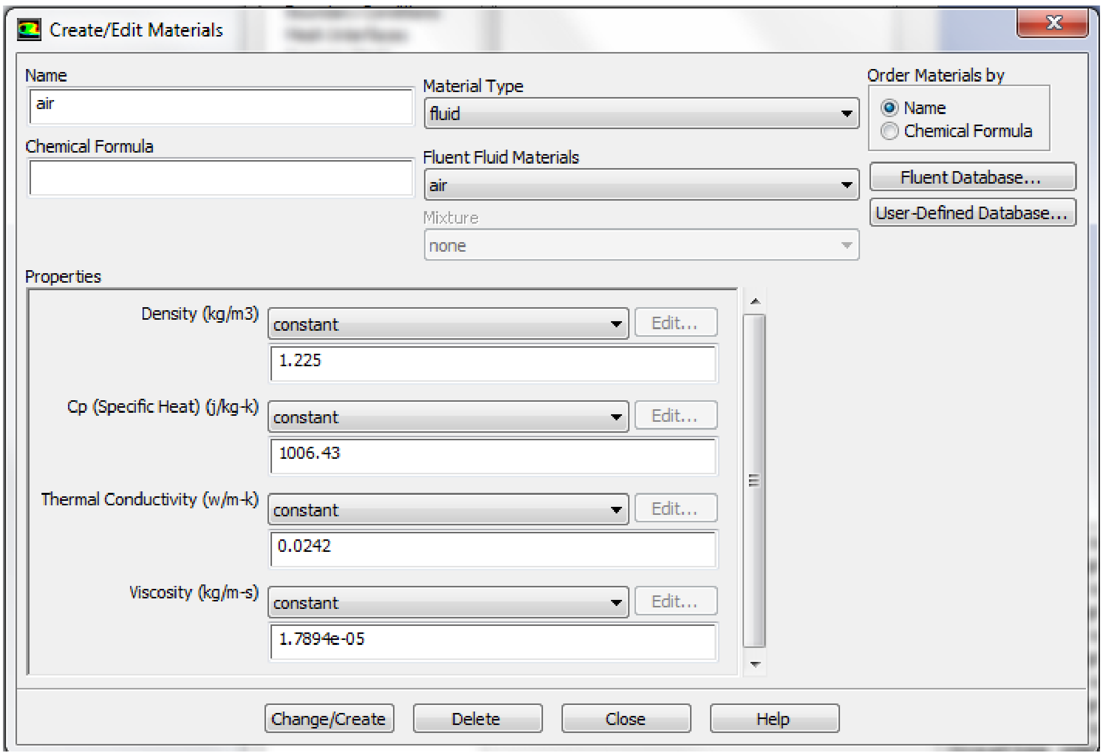


Figure 17 Material Setup for air domain

Due to the reason that the properties of nanofluids and basefluid is varied with temperature. Polynomial function for the properties of density, specific heat and viscosity need to be developed and set up for accurate result.

3.2.3.4 Boundary Condition

Numerical calculations are performed in both laminar and turbulent flow regimes based on 60:40 EG/W from a volumetric concentration of 0 % to 5 % for Al_2O_3, CuO, and SiO_2 nanoparticles. Uniform axial velocity and temperature are given at the inlet of radiator. For this study, the inlet velocity is determined by the Reynolds number of the flow. The Reynolds number at the inlet flow of coolant was varied from 100 to 1000 for laminar flow and from 5000 to 10000 for turbulent flow, whereas the inlet velocity of air is constant at 4.4 m/s. The inlet velocity for coolants are identified and calculated using the formula below

$$u_{in} = \frac{Re\mu}{\rho D_h} \tag{15}$$

The inlet temperature of coolant and air has been taken as 90°C (363 K) and 30°C (303 K), respectively. All along the fin and tube wall, a no-slip boundary condition is imposed for velocity. At the outlet section of the tube and air domain, pressure outlet boundary condition is adopted.

3.2.4 Solution

Method of calculation, references value, number of iteration and calculation is determined in this step.

3.2.4.1 Solution Method

For laminar flow which is illustrated in Figure 18, the solution method used is Semi-Implicit Method for Pressure Linked Equations-Consistent (SIMPLEC) scheme for better result. In spatial discretization, least square cell based gradient is used with standard pressure, first order upwind momentum and energy for performing the CFD simulations over the car radiator geometry. Then the solution is initialized and the number of iteration is set to 1000 for the solution to converge.

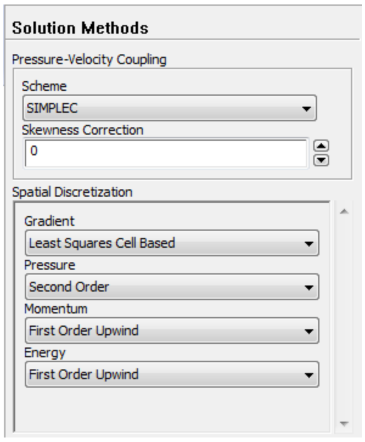


Figure 18 Laminar Solution Method

The absolute criteria in continuity, x-velocity, y-velocity and z-velocity in residual equation is set to 1e-05 and energy to 1e-07 in order to increase the accuracy of result as shown in Figure 19.

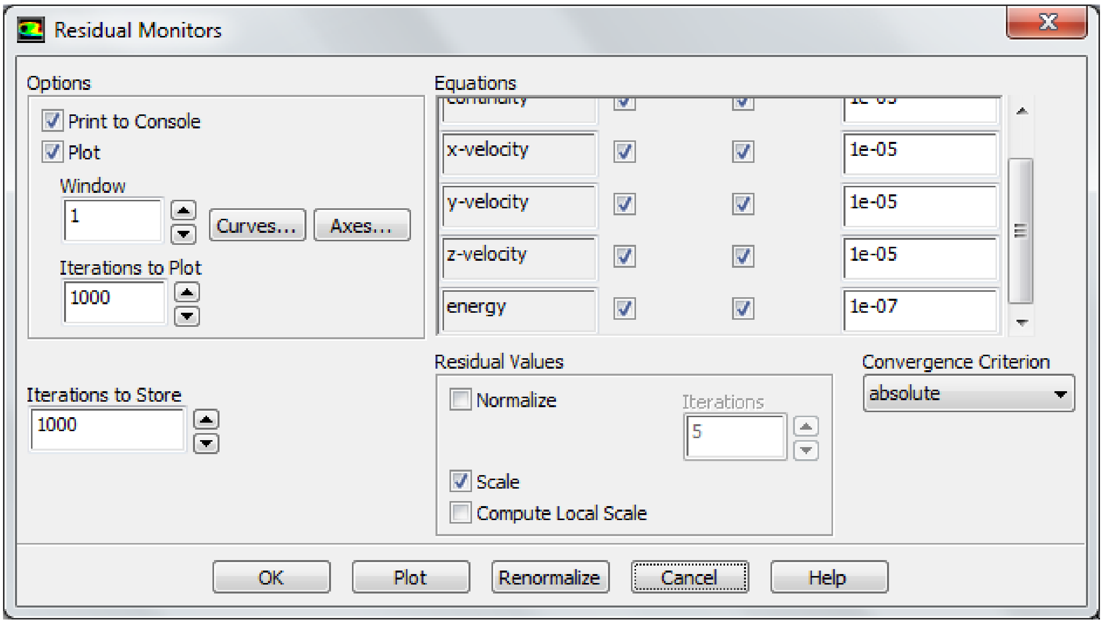


Figure 19 Residual Convergence

For turbulence condition as shown in Figure 20, Coupled scheme for turbulent flow are used as algorithms. In spatial discretization, least square cell based gradient is used with standard pressure, second order upwind momentum and energy, first order upwind turbulent kinetic energy and dissipation rate for the simulation. The absolute criteria in continuity, x-velocity, y-velocity, z-velocity, kinetic and epsilon in residual equation is set to 1e-05 while for energy is set to 1e-07.

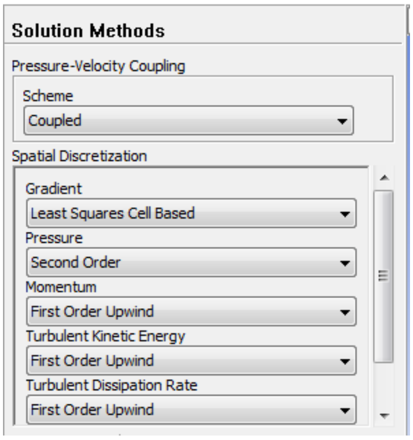


Figure 20 Turbulent Solution Method

3.2.4.2 Solution Initialization

Standard Initialization is set for solution initialization in both turbulent and laminar condition of flow as shown in Figure 21. The simulation is then run after the solution has been initialised.

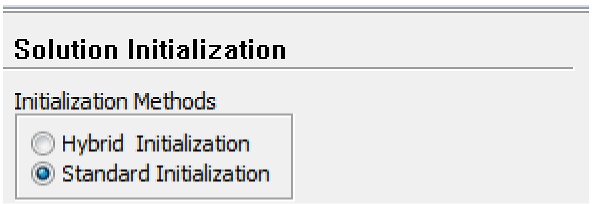


Figure 21 Solution Initialization

3.2.5 Results

CFD post processor is launched to verify the results calculated in form of graphical result such as temperature profile, velocity profile, graphs for heat transfer coefficient with Reynolds number, graphs for Nusselt number with Reynolds number, graphs for heat transfer coefficient along the tube (Z) with Reynolds number. The data and information that used to plot the graphs is exported to excel for further analysis and calculation purpose.

3.2.5.1 Contours of Temperature

Iso-surface is created at z = 0.025 m and the temperature contour of the forced convection varies with flow rate and nanoparticles are shown using CFD post after every simulation and calculation is converged (Figure 22).

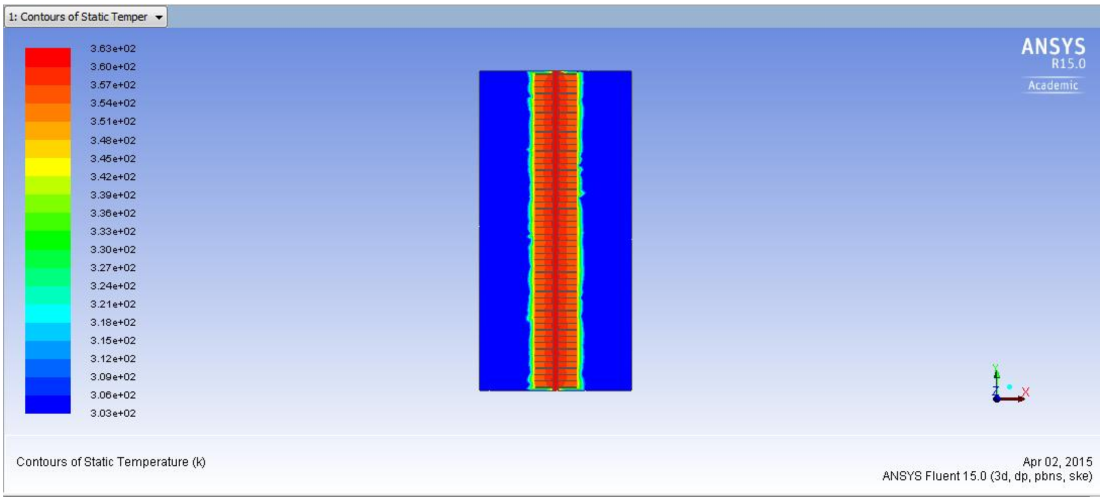
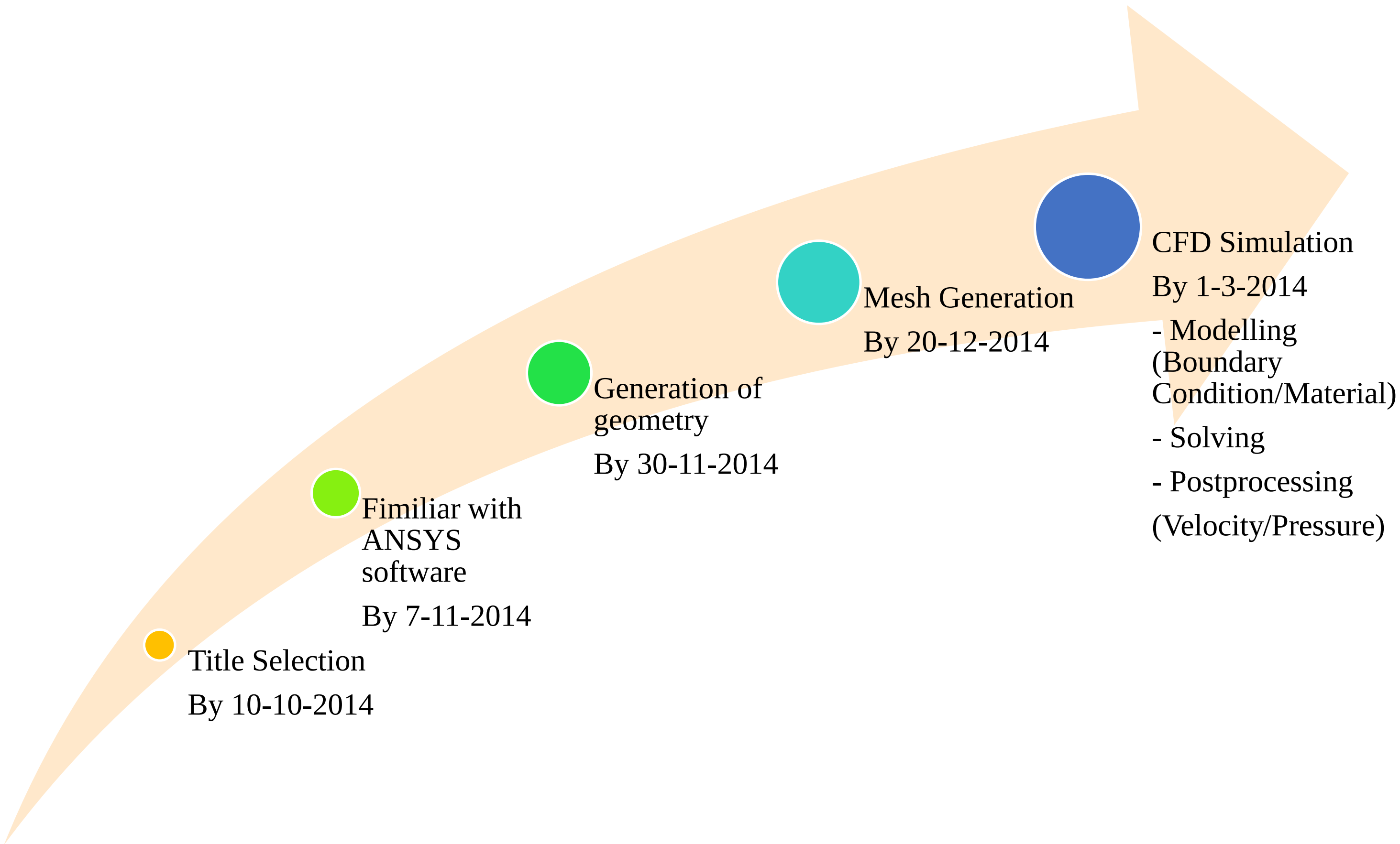


Figure 22 Temperature Contour

3.3 Key Milestone



3.4 Gantt Chart

No	Task	Week (Final Year Project I)														Week (Final Year Project II)													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of Project Topic	■	■																										
2	Preliminary Research Work			■	■	■																							
3	Submission of Extended Proposal						■																						
3	Proposal Defence						■																						
4	Preparation of Extended Proposal									■																			
5	Submission of Interim Draft Report													■															
6	Submission of Interim Report														■														
7	Project Work Continues															■	■	■	■	■	■								
8	Submission of Progress Report																					■							
9	Pre-SEDEX																								■				
10	Submission of Draft Final Report																									■			
11	Submission of Dissertation (soft bound)																										■		
12	Submission of Technical Paper																										■		
13	Viva																											■	
14	Submission of Project Dissertation (Hard Bound)																												■

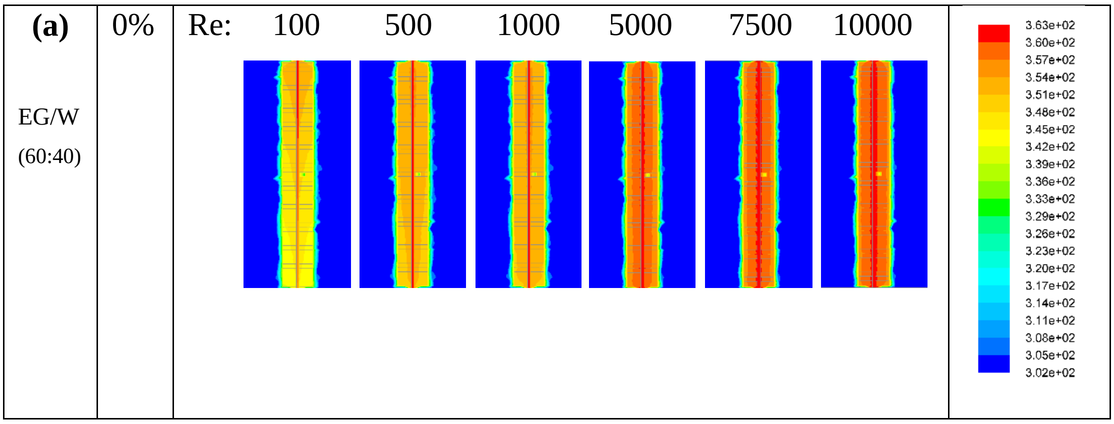
CHAPTER 4

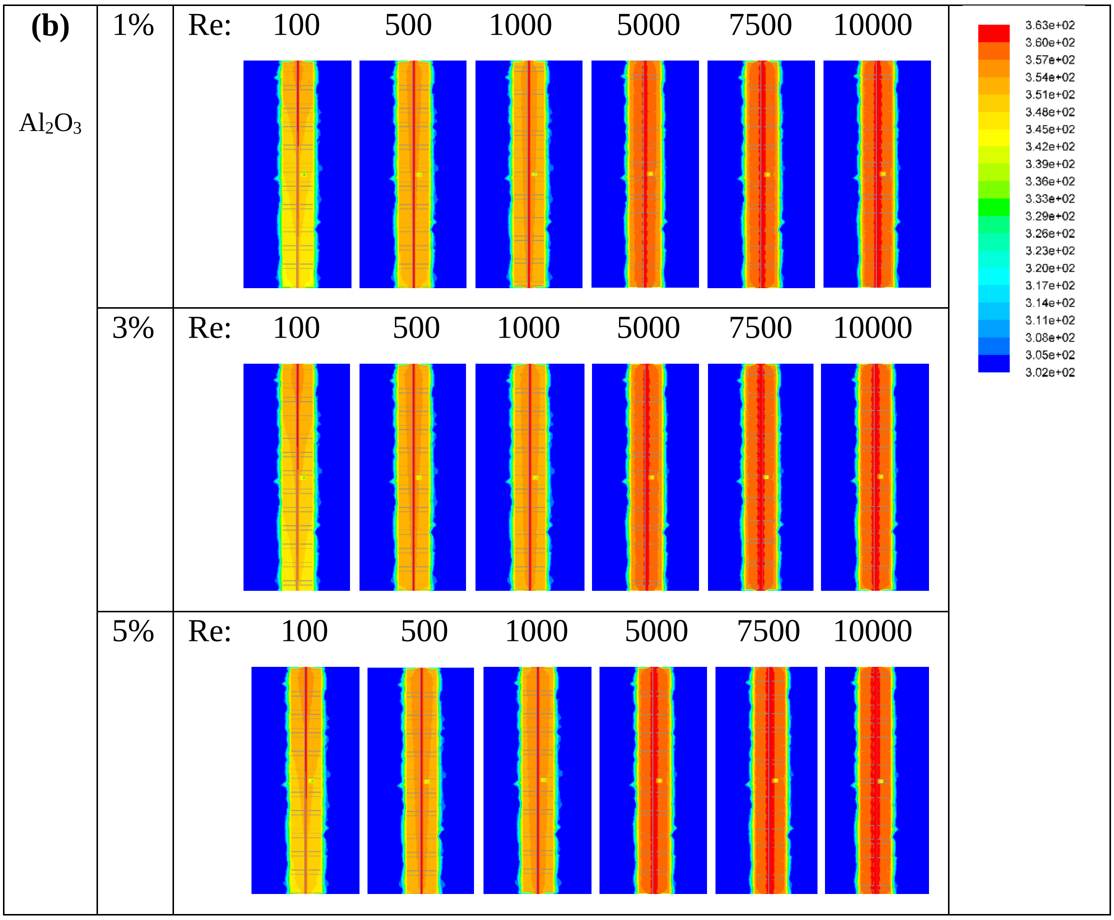
RESULT AND DISCUSSION

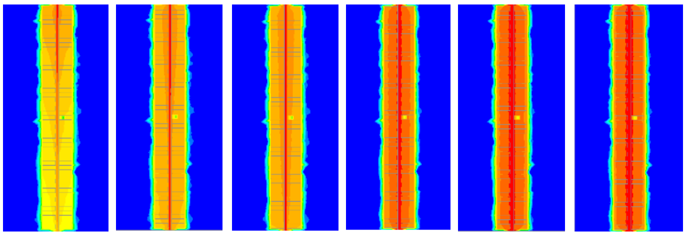
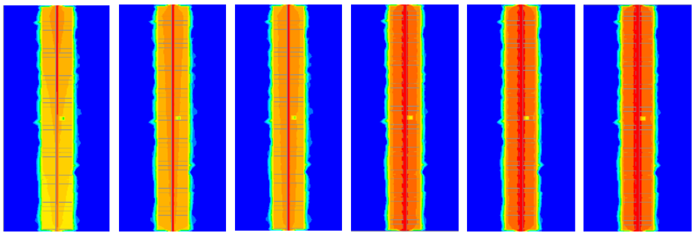
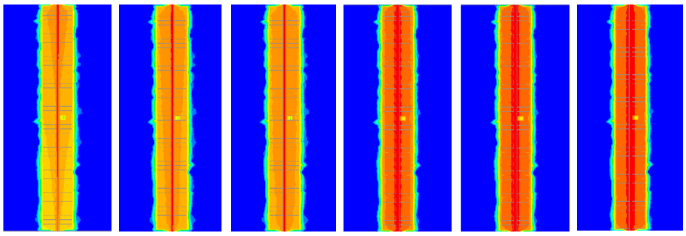
The enhancement of thermal conductivity of nanofluids is one of the important requirement for car radiator application for the car radiator to operate efficiently. It is important to analyse the effect of flow condition of coolants in car radiator in the heat transfer performance. In this study, both type of fluid flow (laminar and turbulent) and heat transfer characteristics of a car radiator using 60% ethylene glycol and 40% water by mass (60:40 EG/W) based on different types of nanoparticles including Al_2O_3, CuO, and SiO_2 as coolants with different volume concentration (1 vol %, 3 vol % and 5 vol %) are investigated numerically. Conventional coolant is used for comparison purpose for its thermal and hydraulic performance in car radiator. The expected result such as temperature contour, heat transfer coefficient variation, Nusselt number as function of Reynolds number and heat transfer coefficient along the tube are presented to demonstrate the effects of using different types and volume concentration of nanofluids on these parameters. The result can be served for designing an effective and efficient car radiator in the future.

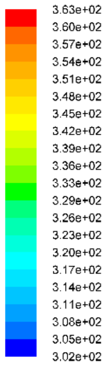
4.1 Effect of Temperature on Heat Transfer Characteristics

Table 5 presents the effect of temperature contour on heat transfer characteristic for different nanoparticle, different concentration and type of flow. Reasonable temperature distribution is obtained and simulated for all the nanoparticles including Al_2O_3, CuO, and SiO_2 as coolant. The temperature of coolant is drop from higher inlet temperature to lower outlet temperature due to the loss of heat from the coolant to the tube wall and fins through conduction and convection. Higher temperature is observed at the upper section of the radiator of car radiator as compared to the bottom section of car radiator due to the reason of coolant flow from the inlet to the outlet of car radiator and the forced convection induced by the air and coolant.


(a)
EG/W
(60:40)
0%
Re: 100 500 1000 5000 7500 10000
3.63e+02
3.60e+02
3.57e+02
3.54e+02
3.51e+02
3.48e+02
3.45e+02
3.42e+02
3.39e+02
3.36e+02
3.33e+02
3.29e+02
3.26e+02
3.23e+02
3.20e+02
3.17e+02
3.14e+02
3.11e+02
3.08e+02
3.05e+02
3.02e+02


(b)
Al_2O_3
1%
Re: 100 500 1000 5000 7500 10000
3%
Re: 100 500 1000 5000 7500 10000
5%
Re: 100 500 1000 5000 7500 10000
3.63e+02
3.60e+02
3.57e+02
3.54e+02
3.51e+02
3.48e+02
3.45e+02
3.42e+02
3.39e+02
3.36e+02
3.33e+02
3.29e+02
3.26e+02
3.23e+02
3.20e+02
3.17e+02
3.14e+02
3.11e+02
3.08e+02
3.05e+02
3.02e+02

(c) CuO	1%	Re: 100 500 1000 5000 7500 10000 	
	3%	Re: 100 500 1000 5000 7500 10000 	
	5%	Re: 100 500 1000 5000 7500 10000 	



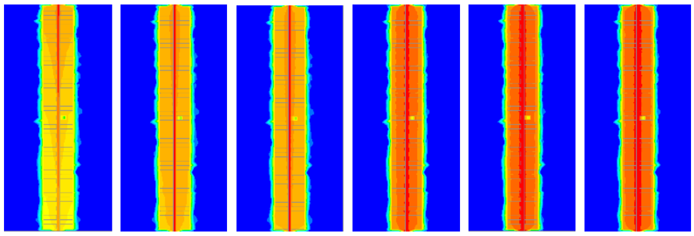
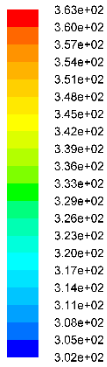
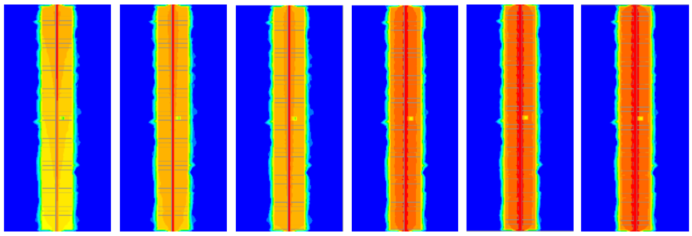
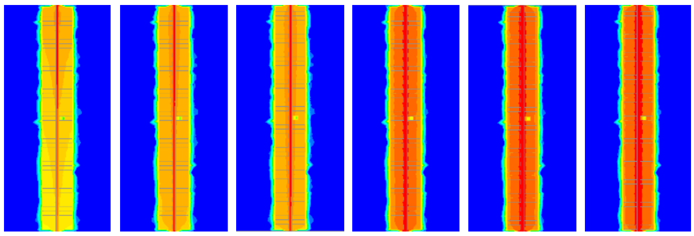
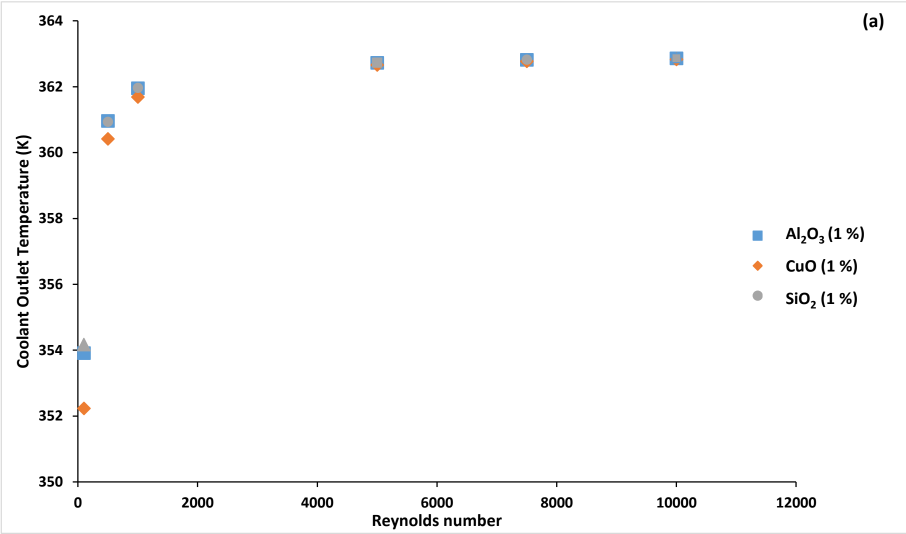
(d) SiO_2	1%	Re: 100 500 1000 5000 7500 10000 	
	3%	Re: 100 500 1000 5000 7500 10000 	
	5%	Re: 100 500 1000 5000 7500 10000 	

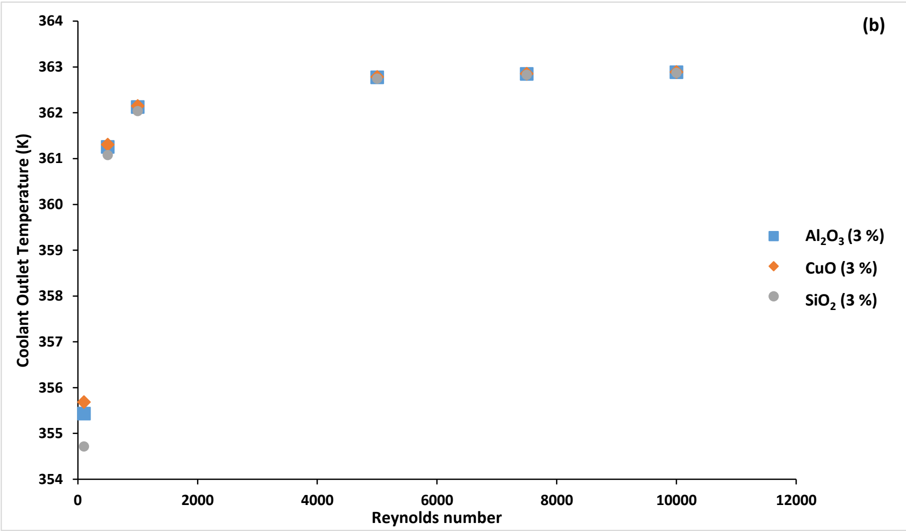
Table 5 Contours of Temperature on the Iso-Surface at z=0.025 (a) EG/W (b) Al_2O_3 (c) CuO and (d) SiO_2

From the table above, there are obvious difference in the temperature contour between laminar and turbulent flow. The range of drop in temperature varies from 1 K-10 K depending on the flow condition of coolants.

To study the influence of coolant Reynolds number on the channel performance, different coolant velocity for different nanoparticles at various concentrations are invetigated numerically. The lowest coolant outlet temperature is reported for the lowest inlet velocity or lowest Reynolds number for 1 vol %, 3 vol % and 5 vol % concentration.

Figures 23 shows the effect of coolant Reynolds number on coolant outlet temperatures respectively. With increase in coolant Reynolds number, coolant outlet temperature increases. This may be attributed to the lesser residence time for coolant to transfer heat to the air. Similar result had been found in previous work [27].





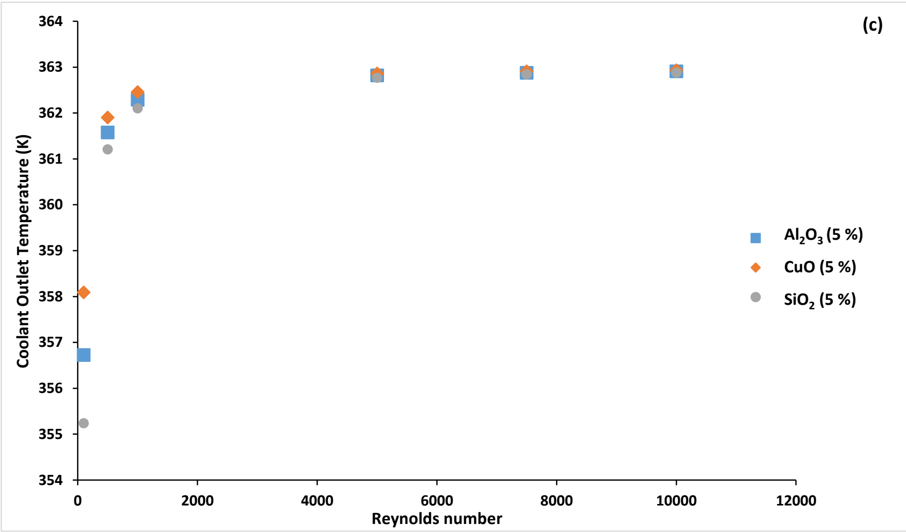


Figure 23 Effect of Coolant Reynolds Number Variation on Coolant Outlet Temperature (a) 1 vol % (b) 2 vol % and (c) 3 vol %

In Figure 24, the decrease in temperature along the length of the tube when the coolant flow in the tube is illustrated. The plot specifically shows the bulk fluid temperature which is the coolant temperature and the wall temperatures for 1 vol% of Al_2O_3 nanofluid along the tube. We can infer that for all the simulations, the temperature difference between the wall and the coolant becomes almost constant after changing over the (small) developing flow region. This implies that the flow is fully developed and the heat coming in from the wall is increasing with the local fluid temperatures linearly.

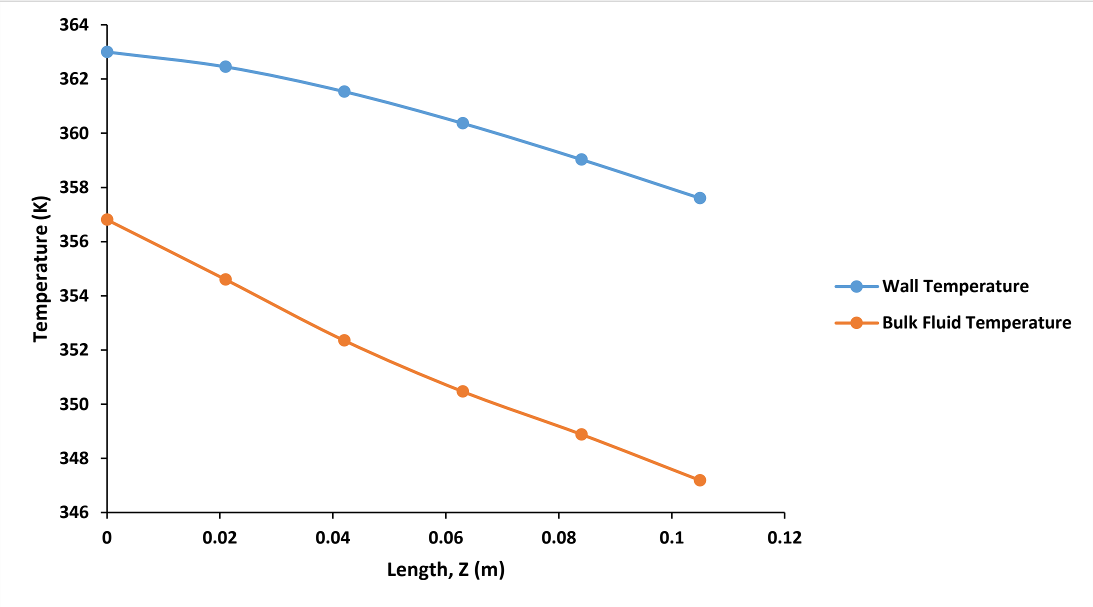


Figure 24 Wall temperature and bulk fluid temperature along the length of tube of Al_2O_3 in 1 vol %

The air that flow across the car radiator also resulted in the increase of air temperature from the inlet temperature of 303 K to a higher temperature due to convection phenomena. The temperature contour in Figure 25 shown that the area behind the car radiator when the air is flow in front of the car radiator has higher temperature.

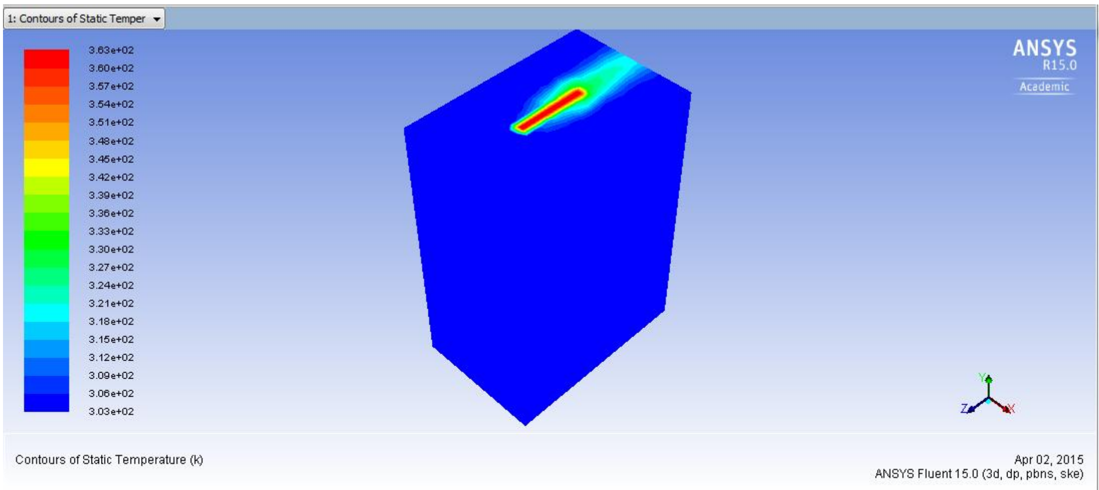


Figure 25 Temperature Contour of Air Domain

For the effect of coolant Reynolds number on air outlet temperatures as illustrated in Figure 26, it is observed the air outlet temperature increases with the increase of Reynolds number. The higher the velocity of the fluid the higher the rate of heat transfer and thus the higher the air outlet temperature. This result can be seen for all type of nanoparticles and concentration of nanoparticles.

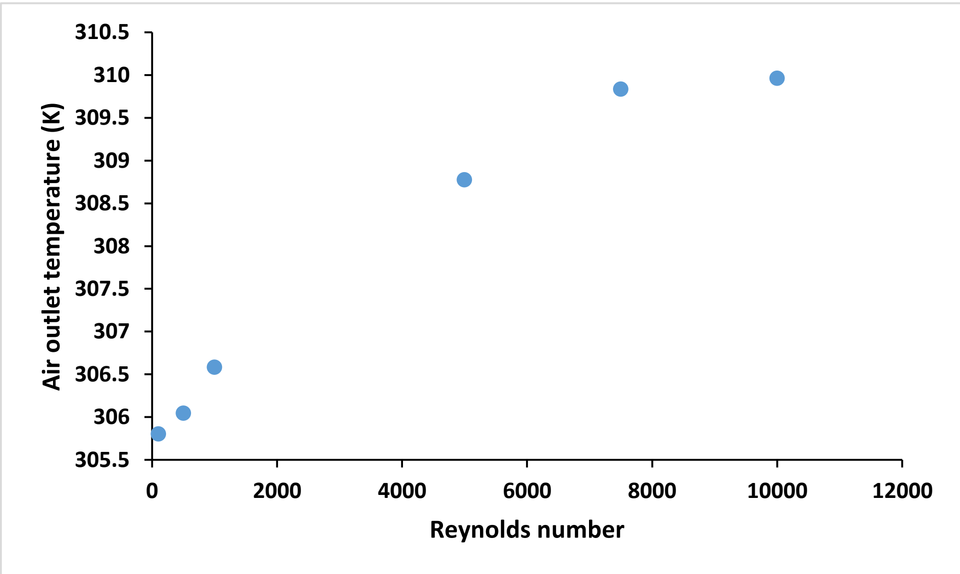
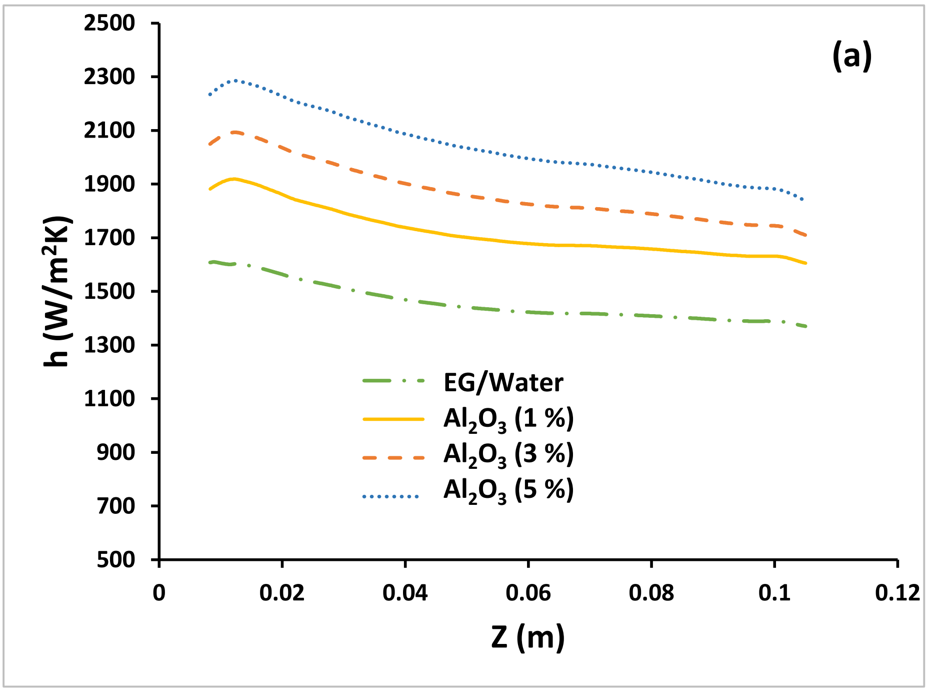


Figure 26 Effect of Coolant Reynolds Number Variation on Air Outlet Temperature of Al_2O_3 in 1 vol %

4.2 Convective Heat Transfer of Nanofluids

The heat transfer capability of using different types of nanofluids in a radiator is studied. Figure 27 shows the variation of a local heat transfer coefficient along the tube length for various particle concentrations of Al_2O_3, CuO, and SiO_2 nanoparticles at laminar flow. As the wall temperature and outside condition are same, the amount of heat loss by coolant is nearly constant for different flow rates, hence the moving average graphs of local heat transfer coefficient along the duct length is plotted. The first few points are not considered due to variation of temperature at the entry region. The heat transfer coefficient appear to be extremely large at Z=0 m since the inlet velocity was kept constant at constant laminar flow (Re = 100) and the thermal boundary layer's thickness is assumed to be zero at the inlet of the tube. The result reported that heat transfer coefficient reduces gradually until the fully developed region is reached and the constant values is obtained. This result is comparable with the results achieved by Vajjha *et al.* [18] and and Gunnasegaran *et al.* [27]. As shown in Figure 27, there are difference in heat transfer coefficient among all the nanofluids selected in this study. The significant outcome is that all types of nanofluids are able to improve heat transfer in car radiator better than pure EG/Water.



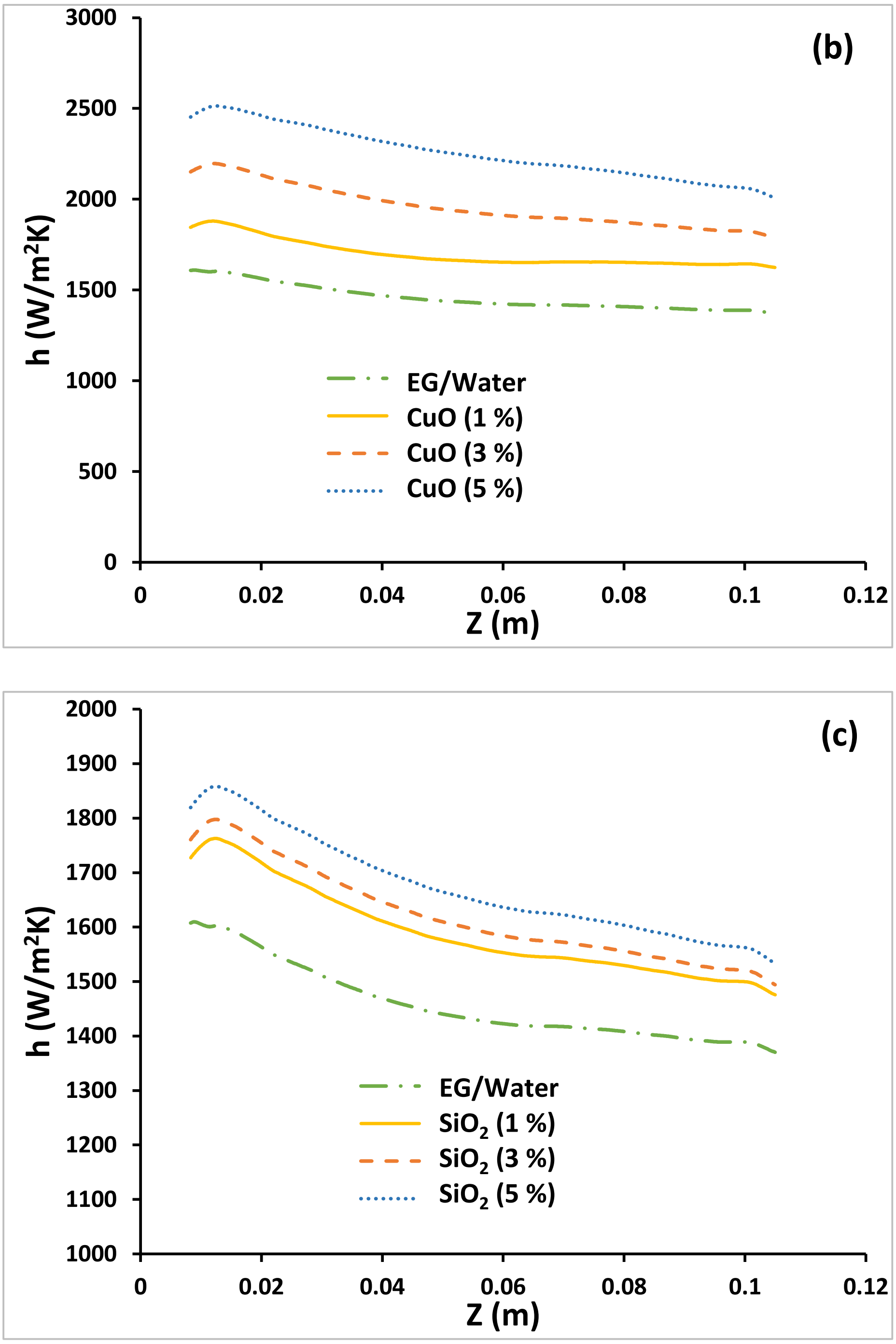
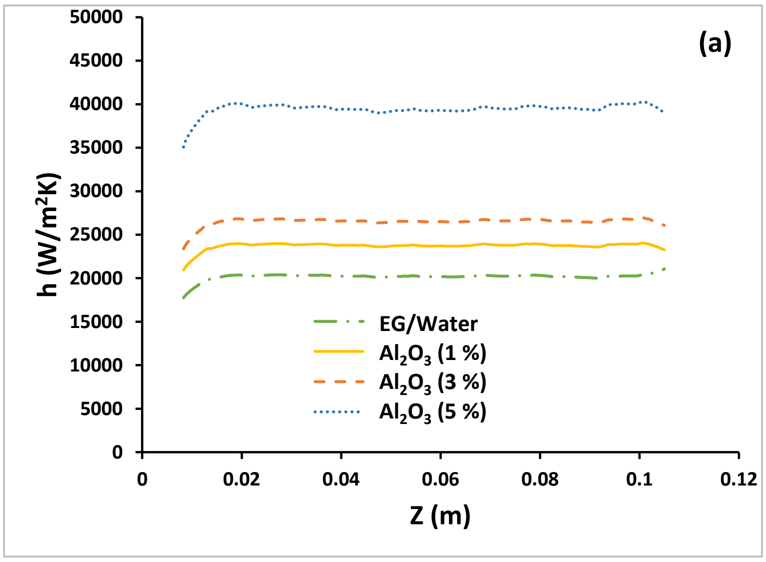
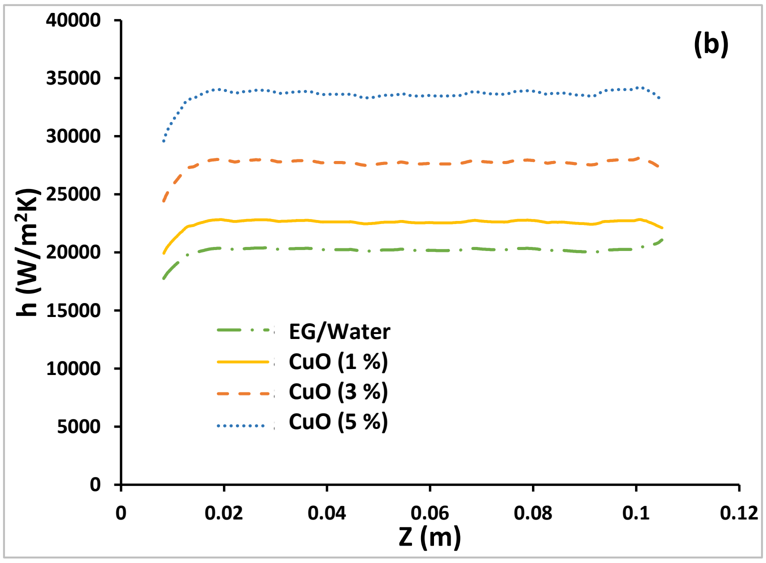


Figure 27 Variation of Heat Transfer Coefficient along the Tube Length for Various Nanofluids i.e. (a) Al_2O_3 (b) CuO and (c) SiO_2 in Laminar Flow (Re = 100).

Local heat transfer coefficient has been studied at turbulent flow at different Reynolds numbers i.e. 5000, 7500 and 10000 for different nanofluids. The variation of heat transfer coefficient along the duct length for various nanofluid coolants with turbulent flow for Re = 7500 is shown in Figure 28. It is observed that local heat transfer coefficient in the coolant side is higher near the fins due to enhancement in the heat transfer by fins. However, high local heat transfer coefficient is predicted at turbulent flow conditions than laminar flow conditions.

Addition of nanoparticles with different particle loading in coolant has significant importance towards efficient heat transfer. It is observed that all types of nanoparticles with high thermal conductivity increases heat transfer coefficient. The results demonstrate that replacing ordinary coolant with nanofluid gives high heat transfer rate along the duct. Heat transfer coefficient is found to be increased by the increase in nanoparticle concentration in ethylene glycol-water mixture at fixed Reynolds number. It can be seen from Figure 27 and Figure 28 that concentration of alumina, copper oxide and silica at 5 vol % shows higher heat transfer coefficient than the base-fluid alone.





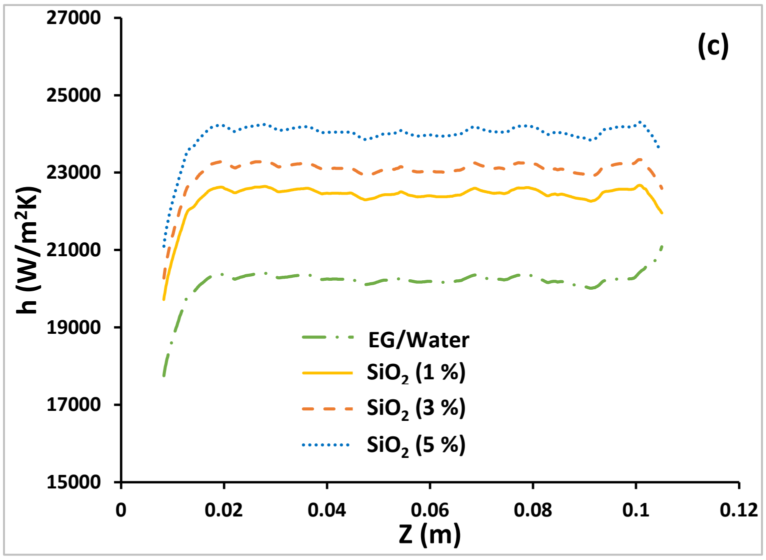


Figure 28 Variation of Heat Transfer Coefficient along the Duct Length for Various Nanofluids (a) Al_2O_3 (b) Cuo and (c) Sio_2 in Turbulent Flow for Re = 7500

4.3 Influence of Coolant Reynolds Number on Average Heat Transfer Coefficient and Average Nusselt Number

4.3.1 Average Heat Transfer Coefficient

The thermal performance of radiator is influenced by the coolant Reynolds number. It plays a vital role in controlling the temperature of engine to avoid overcooled or overheated. The coolant Reynolds number and air Reynolds number is controlled to ensure that the radiator is operating at optimum temperature. To control the coolant Reynolds number, coolant pump and thermostat is required in engine [16].

Figure 29 presents the effect of coolant Reynolds number in determining the radiator's thermal performance at a constant air inlet velocity of 4.4 m/s. At the coolant side, it is observed that the average heat transfer coefficient was increased with Reynolds number.

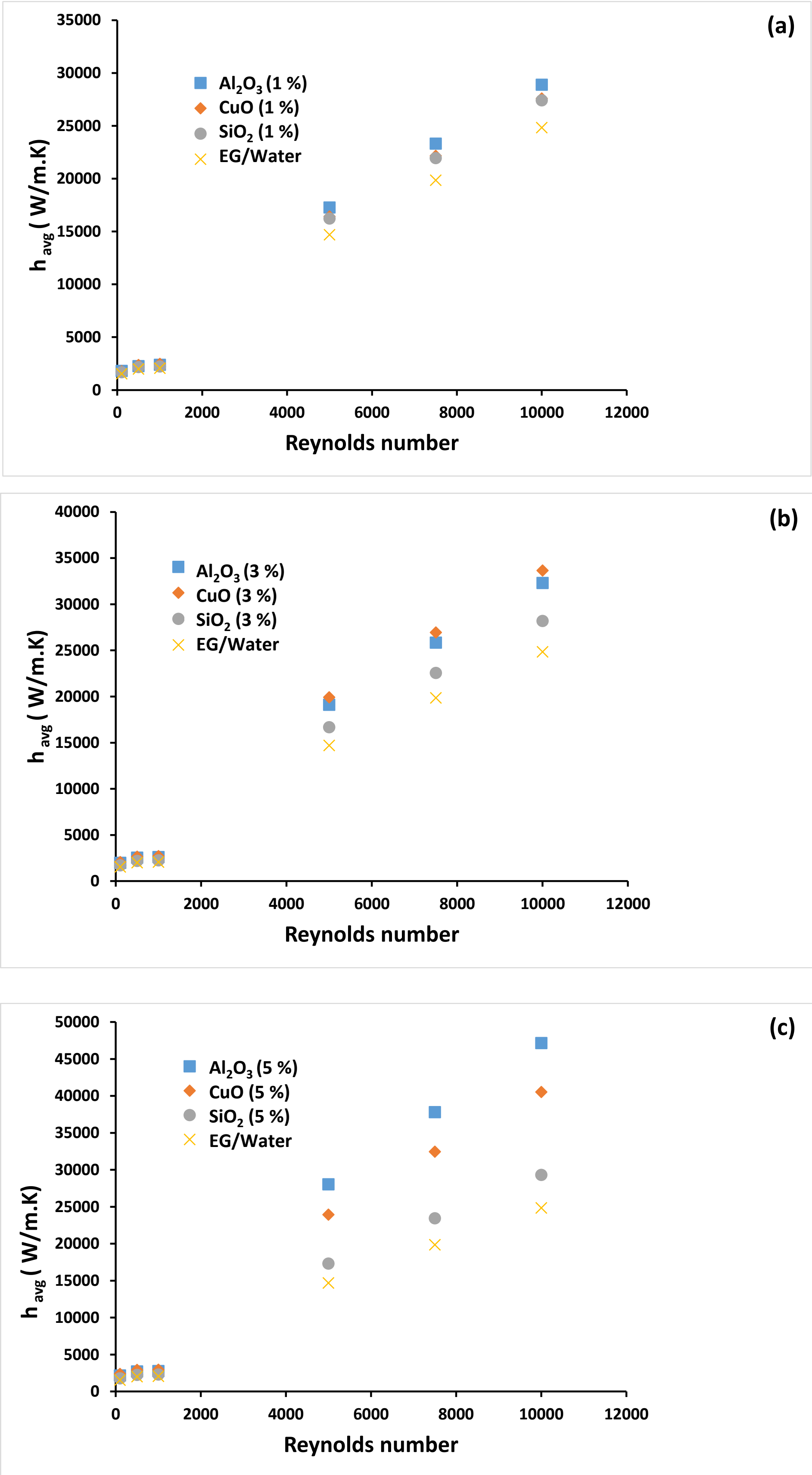


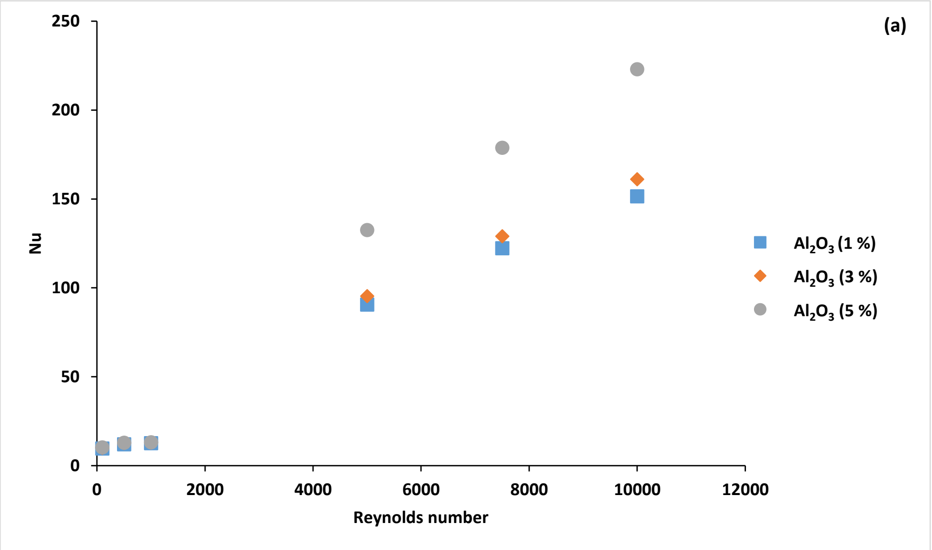
Figure 29 Variation of Average Coolant Heat Transfer Coefficient with the Coolant Reynolds Number at Different Nanoparticle Concentrations in Ethylene Glycol-Water Mixture i.e. (a) 1 Vol % (b) 3 Vol % and (c) 5 Vol %

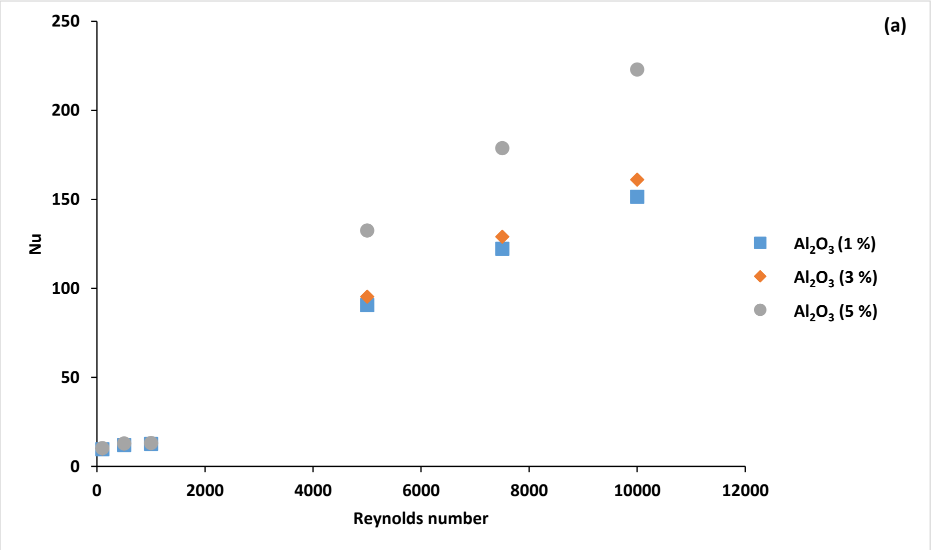
The improvement for the average heat transfer coefficient during laminar flow conditions (100 – 1000) for 3 vol % alumina, copper oxide and silica based nanofluids is estimated to be about 27.28 %, 32.97 % and 10.23 % respectively. When coolant Reynolds number is increased from 5000 to 10000, the percentage increase in average heat transfer coefficient in EG/Water mixture with 3 vol % of alumina, copper oxide and silica is found to be about 30.07 %, 35.55 % and 13.50 % respectively. Copper oxide based nanofluids exhibits high thermal performance than alumina and silica during laminar and turbulent flow conditions due to high thermal conductivity. However, under certain conditions of turbulent flow, alumina based nanofluids showed better average heat transfer coefficient than copper oxide based nanofluids. Similar trends are found in few studies by Heris *et al.* [29, 30].

4.3.2 Average Nusselt Number

As illustrated in Figure 30, the Nusselt number for the nanofluid as a function of different Reynolds number and volume concentration of nanoparticles are investigated. The figure shows the Nusselt number increased uniformly with Reynolds number and concentration loading of nanoparticles. This is due to the changes in thermophysical properties of nanofluid when there is a slight increase in nanoparticles which caused the density, thermal conductivity, and viscosity increased and the slightly decreasing in the specific heat. In order to ensure improvement in heat transfer in nanofluid, the Brownian motion of the nanoparticles plays a vital role. The nanoparticles move randomly in the fluid and resulting in the decrease of the boundary layer thickness and thus enhancing the heat transfer from wall to the bulk fluid.

Results show that the heat transfer coefficient and Nusselt number can be enhanced by adding nanoparticles to the base fluid. Enhancement of heat transfer by the nanofluid may be resulted from two aspects. First, the incremented particles concentration which increase the thermal conductivity of the mixture. Second, chaotic movement of ultrafine particles accelerates the energy exchange between the fluid and the wall of the car radiator. However, it should be noted that increasing the particles concentration raises the fluid viscosity and consequently decreases the overall heat transfer behavior. But the results shown in Figures 29 and 30 indicate that increasing in particles concentration raises the heat transfer coefficient and Nusselt number respectively. This is due to the fact that the change in the thermal conductivity is more effective than the change in the fluid viscosity on heat transfer enhancement of nanofluid at higher concentration.





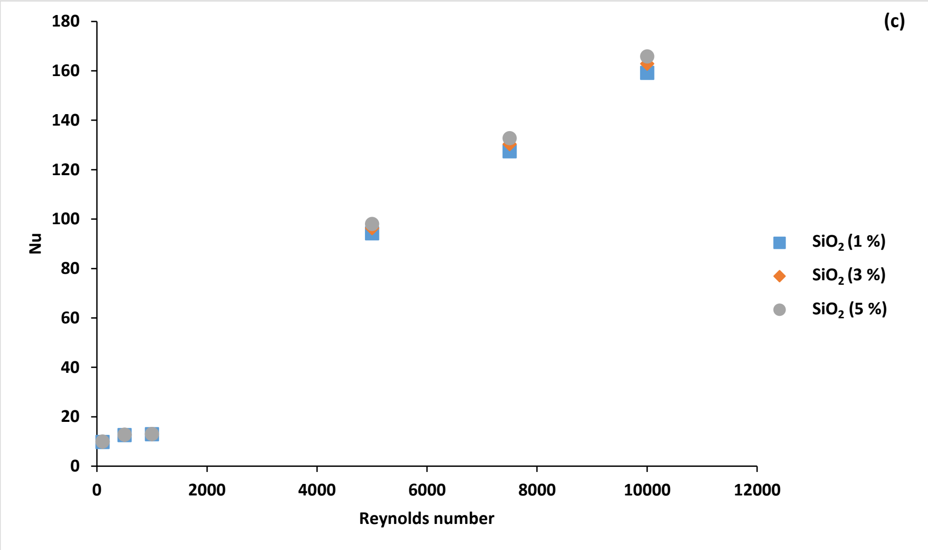


Figure 30 Variation of Nusselt Number with the Coolant Reynolds Number at Different Nanoparticle Concentrations in Ethylene Glycol-Water Mixture i.e. (a) 1 vol % (b) 3 vol % and (c) 5 vol %

4.4 Correlation development for Nusselt number

The Nusselt number for the nanofluid as a function of Reynolds number and volume concentration of nanoparticles are investigated. The Nusselt number is found to be increased uniformly with Reynolds number and concentration of nanoparticles. The Nusselt number and Prandtl number are significantly influenced by the thermophysical properties of the coolant nanofluid i.e. density, viscosity, thermal conductivity and specific heat capacity. Correlations are developed for Nusselt number (Nu) in terms of Reynolds number and particle concentration (ϕ_p) for laminar and turbulent flow conditions. It is found that Prandtl number has negligible effect on the Nusselt number in case of laminar and turbulent flow conditions due to low temperature difference. The correlation are given as

For laminar flow

$$Nu = 1.53 + \mathrm{Re}(0.0178 - 5\times10^{-7}\,\mathrm{Re} + 1.112\varphi_p) \quad (16)$$

$$100 \le \mathrm{Re} \le 1000$$

$$0.01 \le \varphi_p(Vol\ \ fr.) \le 0.05$$

For turbulent flow (17)

$$Nu = 8.65 + \text{Re}(0.0119 - 8\times10^{-6}\,\text{Re} + 0.0107\varphi_p)$$
$$5000 \le \text{Re} \le 10000$$
$$0.01 \le \varphi_p (Vol\ \ fr.) \le 0.05$$

Performance of correlation for Nusselt number is shown in Figure 31 for laminar and turbulent flow conditions. The presented correlation for laminar flow exhibits 1.79 % average absolute deviation (AAD) and the sum of squared errors (SSE) is found to be 2.58. The correlation shows ±7.5 % mean absolute error. The AAD of the Nusselt number correlation for turbulent flow is found to be 6.81 % and all the data points are in agreement within ±20 of mean absolute error.

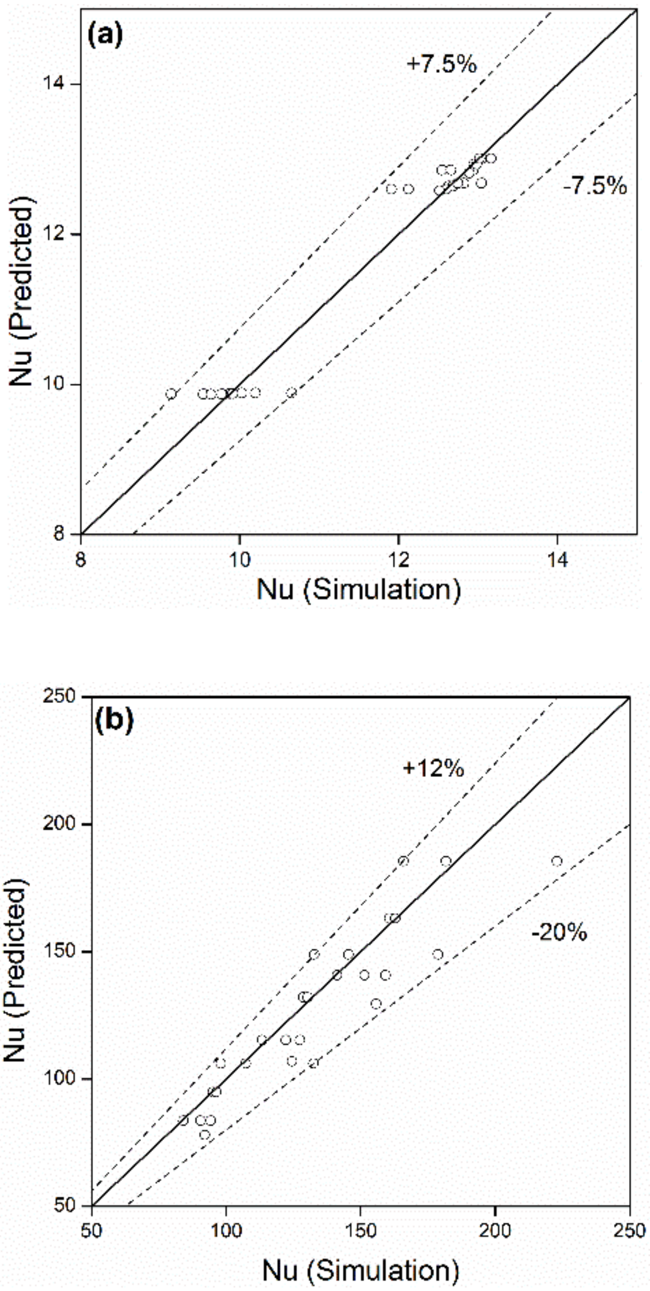


Figure 31 Performance of Correlation for Predicting Nusselt Number at (a) Laminar Flow Conditions and (b) Turbulent Flow Conditions.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The heat transfer characteristic of ethylene glycol-based of SiO_2, Al_2O_3 and CuO nanofluids were numerically investigated in laminar and turbulent flow regimes in a car radiator using ANSYS Fluent 15.0. A 3D geometry of car radiator were developed and heat transfer performance of a car radiator using ethylene glycol and water mixture (60:40 wt %) of Al_2O_3, CuO and ZnO nanofluids as coolants at various concentrations (1 vol %, 3 vol % and 5 vol %) were discussed. To calculate the nanofluid viscosity, specific heat as a function of temperature and nanoparticle volume concentration, new correlations from previous literature review were used. The Nusselt numbers for both flow condition at different coolant Reynolds number and nanoparticle concentrations with the same air Reynolds number was compared and studied. The effects of the temperature contour on heat transfer for different nanoparticle, different concentration and type of flow of nanofluids are considered in this work. The correlations are developed for Nusselt number as a function of Reynolds number and particle concentration. As presented in the result and discussion, the following conclusion can be determined:

i. Local heat transfer coefficient decreases gradually with distance along the duct until the fully developed region is reached in laminar flow conditions.
ii. The thermal performance of car radiator using nanofluid or EG/Water coolant is enhanced with coolant Reynolds number and nanoparticle concentrations.
iii. The overall heat transfer coefficient increases slightly with enhancing coolant Reynolds number and nanoparticle concentrations

iv. Copper oxide and alumina based nanofluids showed higher thermal efficiency than silica based nanofluids in laminar and turbulent flow conditions.

v. Nanofluid is reliable to be a new developed coolant for a car cooling system when the size of the car radiator is an important factor.

5.2 Recommendations

The project provides a foundation for the fluid flow analysis of a car radiator with nanofluids. With the limited time, the results obtained were found to be satisfactory. It is clearly observed that heat transfer can be enhanced by using nanofluid with higher nanofluid concentration. When compared to conventional coolant (EG/Water), rate of heat transfer is greater when nanofluid is used as coolant on same radiator model. By this it can be concluded that the size of the radiator can be reduced by using nanofluid as coolant.

A continued study in various aspects towards a better design of the radiator and different types of nanofluids are suggested below:

- To study different type of nanoparticles other than the nanoparticles in this study and compare the different of their thermal performance in the radiator
- Optimizing the dimensions of the car radiator and type of fins for heat transfer analysis purpose.

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APPENDICES

Type of Nanofluid	Conc.	k (W/m·k)	Coolant Velocity (m/s)	Coolant Density (kg/m^3)	Coolant Mass Flowrate (kg/s)	Tc $_{in}$-Tc $_{out}$ (K)	Cp (J/kg·K)	Q(W)	Tb-Tw (K)	hc (W/m^2·K)	Nu
Al_2O_3	1%	0.471428648	0.069	1073.321	0.002	9.087	3395.169	73.428	7.245	1821.327	9.543
			0.344	1069.817	0.012	2.036	3442.392	83.149	6.573	2273.298	11.911
			0.688	1069.271	0.024	1.047	3449.638	85.638	6.425	2394.956	12.548
			3.439	1068.754	0.119	0.139	3456.484	56.999	0.709	14452.262	75.721
			5.159	1068.705	0.178	0.028	3457.129	17.494	0.194	16174.622	84.745
			6.878	1068.754	0.237	0.139	3456.484	113.999	0.046	442152.492	2316.611
	3%	0.495194448	0.085	1123.671	0.003	7.566	3255.148	75.985	6.896	1979.880	10.373
			0.426	1120.780	0.015	1.745	3293.051	88.427	6.270	2534.077	13.277
			0.852	1120.305	0.031	0.874	3299.200	88.668	6.134	2597.430	13.609
			4.258	1119.878	0.154	0.112	3304.702	57.156	0.636	16147.756	84.604
			6.388	1119.840	0.231	0.023	3305.198	17.448	0.174	18030.644	94.470
			8.517	1119.878	0.308	0.112	3304.702	114.313	0.046	443706.645	2324.754
	5%	0.522407115	0.106	1174.138	0.004	6.274	3125.743	78.446	6.534	2157.440	11.304
			0.528	1171.731	0.020	1.425	3156.509	89.760	5.947	2712.001	14.209
			1.057	1171.346	0.040	0.710	3161.375	89.557	5.829	2760.624	14.464
			5.283	1171.006	0.199	0.091	3165.674	57.197	0.436	23578.081	123.535

			7.925	1170.975	0.299	0.018	3166.056	17.515	0.156	20130.673	105.473
			10.567	1171.006	0.399	0.091	3165.674	114.393	0.046	442822.975	2320.124
CuO	1%	0.482728894	0.069	1103.055	0.002	10.771	2693.132	71.391	7.183	1786.041	9.358
			0.346	1099.106	0.012	2.586	2708.406	85.866	6.512	2369.601	12.415
			0.692	1098.414	0.025	1.312	2711.008	87.168	6.331	2474.186	12.963
			3.460	1097.768	0.122	0.172	2713.417	57.032	0.743	13802.121	72.315
			5.190	1097.708	0.184	0.034	2713.638	17.097	0.204	15063.893	78.926
			6.920	1097.701	0.245	0.017	2713.666	11.564	0.116	17985.560	94.233
	3%	0.517398304	0.100	1210.545	0.004	7.311	2697.806	76.685	6.655	2070.637	10.849
			0.498	1207.750	0.019	1.691	2708.590	88.835	6.034	2645.602	13.861
			0.996	1207.290	0.039	0.847	2710.329	89.042	5.899	2712.176	14.210
			4.981	1206.877	0.194	0.109	2711.884	57.150	0.610	16826.844	88.162
			7.472	1206.839	0.291	0.021	2712.025	16.557	0.161	18457.875	96.708
			9.962	1206.834	0.388	0.010	2712.043	10.397	0.086	21639.626	113.379
	5%	0.550865392	0.145	1318.502	0.006	4.910	2700.661	81.483	6.161	2376.562	12.452
			0.723	1316.560	0.031	1.098	2708.170	91.214	5.634	2909.088	15.242
			1.445	1316.259	0.061	0.544	2709.316	90.475	5.538	2935.809	15.382
			7.227	1315.996	0.307	0.068	2710.314	56.715	0.503	20263.833	106.170
			10.841	1315.973	0.460	0.014	2710.401	16.855	0.134	22636.452	118.601

			14.455	1315.970	0.613	0.007	2710.412	11.519	0.075	27498.546	144.076
SiO_2	1%	0.425333577	0.072	1059.455	0.002	8.830	3372.247	73.386	7.836	1682.985	8.818
			0.361	1056.037	0.012	2.062	3418.312	86.593	7.171	2170.041	11.370
			0.722	1055.466	0.025	1.035	3425.892	87.059	7.020	2228.374	11.675
			3.608	1054.952	0.123	0.136	3432.696	57.124	0.749	13709.825	71.831
			5.412	1054.904	0.184	0.028	3433.322	17.491	0.206	15279.540	80.056
			7.215	1054.952	0.245	0.136	3432.696	114.247	0.749	27419.649	143.662
	3%	0.427494115	0.080	1082.654	0.003	8.284	3227.299	74.248	7.777	1715.450	8.988
			0.398	1079.478	0.014	1.923	3269.009	87.025	7.123	2195.362	11.502
			0.796	1078.954	0.028	0.963	3275.802	87.299	6.980	2247.363	11.775
			3.978	1078.484	0.138	0.126	3281.863	57.107	0.728	14092.915	73.838
			5.968	1078.441	0.207	0.026	3282.418	17.483	0.200	15747.005	82.505
			7.957	1078.484	0.277	0.126	3281.863	114.214	0.728	28185.830	147.677
	5%	0.436274848	0.088	1105.866	0.003	7.763	3094.514	75.188	7.628	1771.141	9.280
			0.439	1102.925	0.016	1.791	3132.238	87.538	6.986	2251.709	11.798
			0.878	1102.445	0.031	0.895	3138.323	87.658	6.850	2299.478	12.048
			4.389	1102.017	0.156	0.116	3143.729	57.110	0.700	14650.229	76.758
			6.584	1101.977	0.234	0.024	3144.221	17.504	0.192	16401.920	85.936
			8.779	1102.017	0.312	0.116	3143.729	114.219	0.700	29300.458	153.517

EG/Water	0%	0.394133	0.063	1048.274	0.002	9.913	3395.690	71.595	8.365	1538.048	8.058
			0.315	1044.442	0.011	2.356	3417.291	85.305	7.675	1997.273	10.464
			0.629	1043.788	0.021	1.187	3420.895	86.008	7.512	2057.437	10.780
			3.147	1043.194	0.106	0.158	3424.151	57.117	0.827	12404.449	64.992
			4.720	1043.138	0.159	0.032	3424.455	17.470	0.228	13785.393	72.227
			6.293	1043.194	0.212	0.158	3424.151	114.233	0.827	24808.899	129.984