DEVELOPMENT OF DIESEL ENGINES COOLING SYSTEM

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DEVELOPMENT OF DIESEL ENGINES COOLING SYSTEM

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Report submitted in partial fulfilment of the requirement for the award of the degree of Bachelor of Mechanical Engineering with Automotive Engineering

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I certify that the project entitled “Development Of Diesel Engines Cooling System” is written by Mohammad Naqib Amirul bin Abdul Rashid. I have examined the final copy of this project and in my opinion; it is fully adequate in terms of scope and quality of the award of the degree of Bachelor of Mechanical Engineering with Automotive. I hereby recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor of Mechanical Engineering with Automotive.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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Dedicated to my beloved parents,
Abdul Rashid Bin Abdullah and Zalena Binti Ahmad,
My fiancée, Nurul Nadia Binti Mat Jalaluddin,
My family, lecturers and friends

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In the name of Allah S.W.T, The Most Merciful and The Most Compassionate.

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ABSTRACT

The current vehicle cooling system is using the water or water mixed with anti-freezing additive usually using ethylene glycol (EG) as the coolant in order to perform cooling process the circulating working fluids through the vehicle radiator. The project is carried out in demonstrating nearly similar condition for the actual condition. In this project, the heat transfer performance of distilled water and TiO_2 nanofluids with varied volume concentration is compared in the similar condition of the actual condition of temperature at radiator inlet, which from 90 °C to 60 °C. In addition, fluid flow rate also varied to compare the effect of different flow rate which 12 and 15 LPM to the heat transfer performance. The project gives the result that nanofluids clearly enhance heat transfer compared to their own base fluid. In the condition given, the best heat transfer enhancement of about 36.6 % compared to the base fluids has been recorded. The result gives the meaning that the typical coolant is could be replaced with nanofluids in order to have thermal transfer enhancement.

ABSTRAK

Sistem pendinginan enjin pada masa kini menggunakan air atau campuran air dengan bahan tambahan anti-pembeku yang biasanya menggunakan "*ethlyne glycol (EG)*" untuk untuk proses penyejukan cecair sistem pendinginan melalui radiator kenderaan. Projek ini dijalankan dalam keadaan yang mirip dengan keadaan sebenar ketika enjin beroperasi. Dalam projek ini, prestasi pemindahan haba air suling dan "*Titanium Dioxide nanofluids*" dibandingkan dimana kepekatan cecair ini diubah-ubah dan suhu perbandingan cecair ini adalah pada saluran kemasukan radiator, dimana pada 90 °C sehinnga 60 °C. Sebagai tambahan, kadar halaju aliran cecair juga diubah pada 12 LPM dan 15 LPM bagi membandingkan kesan perbezaan kadar aliran cecair ini terhadap prestasi pemindahan haba. Projek ini member hasil dimana "*nanofluids*" dengan jelas meningkatkan prestasi pemindahan haba berbanding dengan bendalir asas. Dalam kondisi yang terkawal, peningkatan haba tertinggi kira-kira 36.6 % berbanding dengan bendalir asas telah direkodkan. Hasil ujikaji ini menunjukkan bahawa kegunaan cecair penyejuk yang digunakan pada masa sekarang harus diganti dengan "*nanofluids*" dimana kadar pemindahan haba ditinggatkan berbanding bendalir asas.

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LIST OF SYMBOLS

D_i	Inner diameter of the tube, (*m*)
h	Convective heat transfer coefficient, ($W/m^2.K$)
k	Thermal conductivity, ($W/m.K$)
μ	Dynamic viscosity of the fluid, ($kg/m.s$)
ρ	Density of the fluid, (kg/m^3)
C_p	Specific heat, ($J/kg.K$)
l	Length of the tube, (*m*)
$\dot{m}$	Mass flow rate, (kg/s)
$\dot{Q}_{conv}$	Heat convection rate, (*Watt*)
$\dot{q}_s$	Heat Flux, (*W/m2*)
f	Friction factor
Nu	Nusselt number
Re	Reynolds number
Pr	Prandtl number
ΔP	Pressure difference
T_b	Bulk fluid temperature, (K)
T_s	Surface temperature, (K)
T_w	Wall temperature, (K)
ΔT	Temperature difference
ε	Roughness size, (*m*)
g	Gravitational acceleration, (m/s^2)
¨	Volume concentration of nanofluid
A_s	Surface area, (m^2)

V_{avg}	Average velocity, (m/s)
V	Voltage, (Volt)
I	Current, (Amphere)

LIST OF ABBREVIATIONS

HTC	Heat transfer coefficient
Al	Aluminum
Cu	Copper
Al_2O_3	Aluminum Oxide/Alumina
CuO	Copper Oxide
TiO	Titanium Oxide
SiC	Silicon Carbide
ZrO_2	Zirconia Oxide
LPM	Litre Per Minute
RPM	Revolution Per Minute
HP	Horse Power
HTR	Heat Transfer Rate
SDBS	Sodium Dodecyl Benzene Sulfonate
TDS	Total Dissolved Solids
CTAB	Cetyl trimethylammonium bromide

CHAPTER 1

INTRODUCTION

1.1 Introduction

Although vehicle technology by now was developed with sophisticated, but heat lost and efficiency lost during combustion in engine still become a challenging research theme for researchers all over the world.

Fuel consumption is tidily related to the efficiency of the engine combustion activity. As we know, the internal combustion engine only converts approximately one-third or 30 percent of the fuel energy to mechanical work in make vehicle moving. This is the fact at the present and it is extremely difficult to improve this internal combustion engine.

In this project, the most focusing is on the diesel engine cooling system, in which the diesel engine is operating at a high compression ratios as compared to gasoline engines. In order to ensure the life span of the engine, engine cooling system is necessitate to more efficiently. From the recent innovation and finding in nanotechnology which named nanofluids, improving the heat exchange system is possible with great potential in heat transfer enhancement from these nanofluids.

1.2 Problem Statement

The diesel engine is operating at high compression ratios as compared to gasoline engines. Due to its high compression ratio, the diesel engine produces higher heat when combustion reaction complete in each cycle. In order to afford this higher heat produced, the engine cylinder wall will be ticked that compared to the gasoline engine wall.

The cooling system is aimed to transfer the rejected heat produced from this combustion reaction. The rejected heat is a heat that engine unable to convert to a usefulness of mechanical energy. Thus, the diesel engine is needed to be more efficient to ensure the life span of the engine.

Current design of engine cooling system is normally used radiator, water pump and liquid water as cooling liquid. For this project, the cooling liquid will use water base nanofluids instead of liquid water.

1.3 Objectives

The purpose in the development of the diesel engine cooling system is based on several objectives. Those objectives are:

i. To develop an efficient diesel engine cooling system
ii. To design a new cooling system test rig
iii. To design a new coolant liquid for the cooling system

1.4 Scope

The project scope that categorized is design the diesel engine cooling system, the design and fabricates the test rig (water heater test rig), experimental test, and data analysis. The type of cooling system that will use in this project is vehicle diesel engine cooling system. This cooling system is target to use in Mitsubishi 4D56 diesel engine.

The cooling system will cover starting from the path of the system that circulates from the water pump, the radiator, the thermostat, and the passage inside the engine block and heads. The system will be developed by design the test rig for future real experiment application and TiO_2 nanofluids water based as a coolant instead of ethylene glycol. The parameter that involves is coolant temperature and flow rate which is the temperature at the radiator inlet temperature.

1.5 Thesis Organization

This thesis is divided into 6 chapters and each chapter is devoted to discuss the different issues in the project. Chapter 1 will discuss on introduction to the diesel engine cooling system and briefly in relation to nanofluids. The problem statement, objective and scope will be identified.

Chapter 2 will discuss about all the research and literature review that related to the project. Justification about aqueous alumina nanofluids that used to develop the system will also be discussed. Then, chapter 3 will discuss the approach and framework for the project. It explains about the method that is implemented while designing the system.

Chapter 4 will document all the processes that involve in the development of this project. Generally, this chapter explains about the designed project development. Finally, chapter 5 will discuss about the results and data analysis that had been acquired. The result included result analysis, project limitation and suggestions for project enhancement.

1.6 Project Flow Chart

The project will flow as in Figure 1.1 which the figure shows the process flow of the project with step by step start from the beginning of the project until the end.

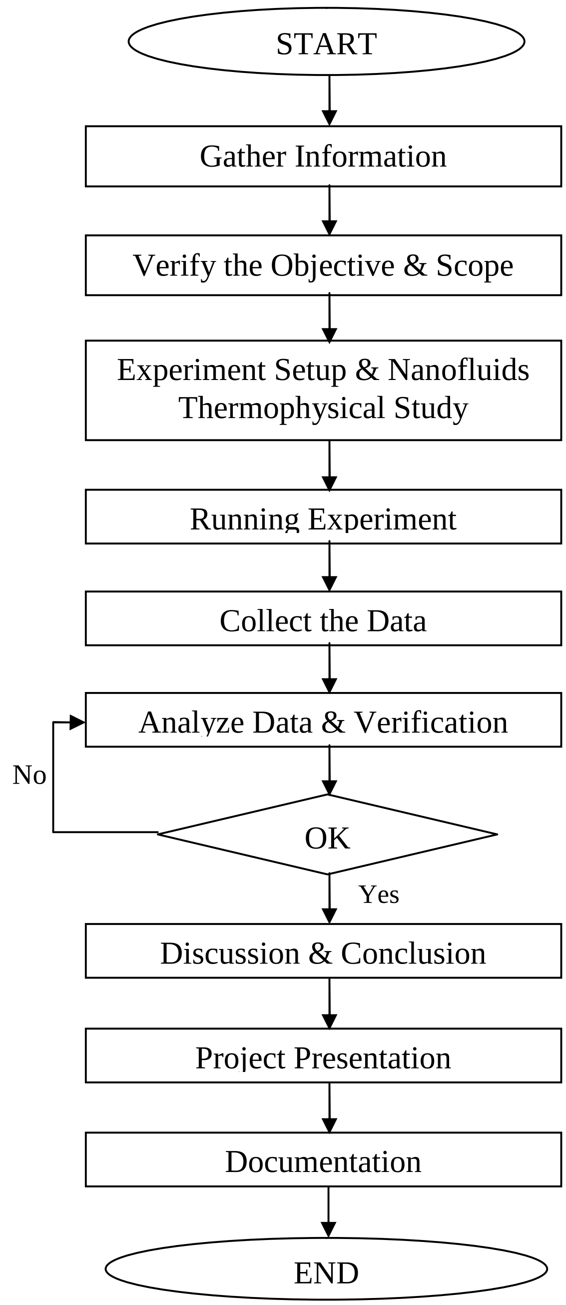

Figure 1.1: Project Flow Chart

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter is very important for any research that will be done. The objective of this chapter two is aimed to present a selected literature review, which is very important for the research. This chapter also describes and explains on the literature review carried out on the system that will be used in developing this experiment research. Besides that, previous research also will be discussed in this section.

In this chapter, manufacturing process of nanofluids and applications nanofluids in industry will be explained. Then, several discussions in heat transfer theory together with dimensionless parameter related to this study organized by chronology to put in preparation for studies next, including effort research showed. Review detailed so that effort research showed could be properly booked to increase for board now literature and to makes sure the scope and direction of effort research are shown. Finally, in this end-of-chapter, the advantages and disadvantages of nanofluid will be enlightened.

2.2 Literature Review

Literature review targets to review the significant points of current research and knowledge on this field. Therefore, the purpose of the literature review is to find, read and analyze the literature or any works or studies related to this system. It is important to well understand about all information to be considered and related before start this experiment research.

For this project, some researchers have been done with knowing and understand about various nanofluids physical and thermal properties through many of experiment. In addition, a few researchers also carried out the experiment using nanofluids with applied to radiator or also called heat exchanger.

2.3 Background

The engines car has produce the high temperature of heat in reaction in the combustion chamber. In order to keep the temperature is in controlled temperature condition, coolant in cooling system is used to transfer the heat that produced from the engines to the ambient air.

In addition to this, the energy that produced in the engines is not all used but the only one-third will used as energy to move the vehicle and the other will used in overcome the friction force in the combustion chamber and others. And also one-third of the wasted energy is going to ambient environment by cooling system as heat dissipated. Increasing the efficiency of cooling system performance will reduce the energy wasted as the same time will increase the capacity of energy can produced with even the same capacity of cooling system that using more efficient cooling system.

The coolant that used in the vehicle is normally either water only or ethylene glycol mixed with water that usually used as typical coolant. This base fluids is known as conventional heat transfer fluids that have characteristic of poor heat transfer performance due to their low thermal conductivities. With compare to the solid metallic such copper, iron and non-metallic material such CuO, alumina, and carbon, nanotubes have much better thermal conductivities than this conventional fluids.

2.4 Nanofluids Innovation

The idea of using metallic particles to enhance the thermal conductivity of fluids is well known from Maxwell in 1881 (Maxwell, 1873), which come from the idea that how much better the coolant will work when mixed to this suspended particles of a conductor in the working fluids. It is well known that metallic material at solid state is having a much higher thermal conductivity than base fluids as look to the Table 2.1.

Table 2.1: Thermal Conductivity (W/m-K) of Various Materials at 300 K unless otherwise noted

Material	Thermal Conductivity
Metallic Solids	
Silver	429
Copper	401
Aluminum	237
Nonmetallic Solids	
Silicon	148
Metallic Liquids	
Sodium (at 644 K)	72.3
Nonmetallic Liquids	
Water	0.613
Engine oil	0.145

Source: Choi and Eastman, 1996

The beginning of the innovation is starting with millimeter and micrometer size solid particles blended into the base fluids. However, this thousand times greater size than nanoparticles that make constrain to the practical application of these nanoparticles which will settle out of the fluids and sink into the pipe or tank quickly.

Even the settling is preventing much with circulating the fluids rapidly, this bigger size of particles will caused the damage to the wall of the pipe, and increase the pressure drop and wearing the pipe thin (Zenghu Han, 2008). The effect also will affect the pump and bearing in the engine damage and wear when applied to the real application.

The changes of the scale from micro to nano sized particles are started by Choi and Eastman in Argonne National Laboratory revisited this field with their nanoscale metallic particle and carbon nanotube suspensions (Choi and Eastman, 1995 and Eastman et al., 1996). Choi and Eastman then have suspended various metal and oxide nanoparticles into several different fluids (Choi et al., 2001). This suspended fluid is then termed as “nanofluids” by Choi and Eastman.

2.5 Types of Nanofluids

Nanofluids are working fluids that dispersed with nanometer-sized particles with the range between 1 to 100 nm. Nanoparticles used in nanofluids have been made from various materials, such as oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, Au), semiconductors (TiO2, SiC), carbon nanotubes, and composite materials such as alloyed nanoparticles $Al_{70}Cu_{30}$ or nanoparticle core polymer shell composites.

In addition to nonmetallic, metallic, and other materials for nanoparticles, completely new materials and structures, such as materials “doped” with molecules in their solid liquid interface structure, may also have desirable characteristics. The common liquid normally used as a base fluid in nanofluid such as water, mineral oil and ethylene glycol. For this project, TiO_2 nanofluids that categorized is semiconductors material is used. There are six types of unit cells of nanofluids which are sphere, cube, hollow cube, slab-cross and column-cross nanoparticles, as we can see in Figure 2.1.

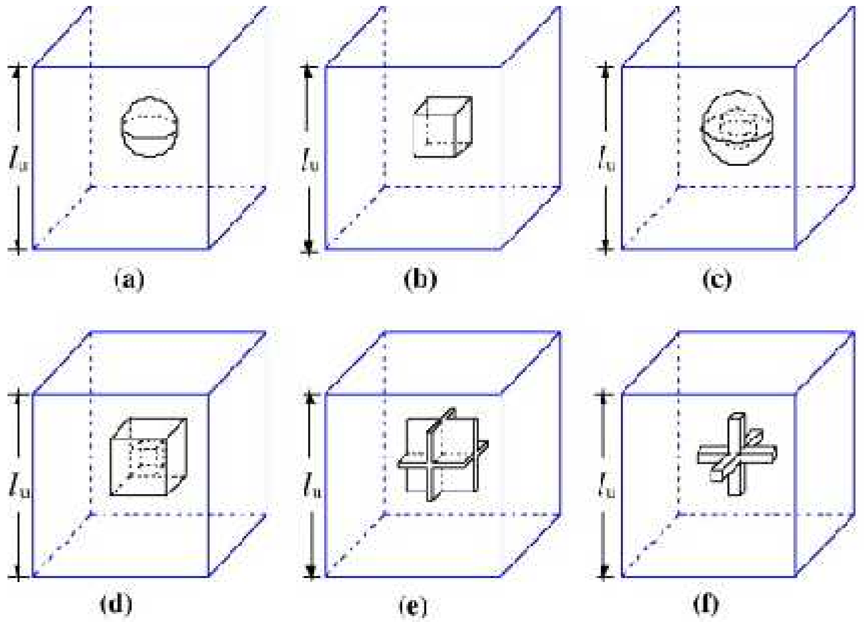

Figure 2.1: Unit Calls for Nanofluids Containing In-line Arrays of Spheres (a), Cubes (b), Hollow Spheres (c), Hollow Cubes (d), Slab-cross Particles (e), and Column-cross Particles (f)

Source: Jing Fan and Liqiu Wang, 2011

2.6 Technique of Nanoparticles Manufacturing

Nowadays, there are several processes in making of metal nanoparticles. The processes are Inert Gas Condensation (IGC), mechanical milling, chemical precipitation, thermal spray, and spray pyrolysis. Alloyed nanoparticles are the newest products that produced Al70Cu30 using ball milling, by Chopkar, et al., (2006).

In ball milling, balls impart a lot of energy to slurry of powder, and in most 9 cases some chemicals are used to cause physical and chemical changes. These nano sized materials are most commonly produced in the form of powders. In powder form, nanoparticles are dispersed in aqueous or organic host liquids for specific applications.

2.6.1 Dispersion of Nanoparticles in Liquids

There are two techniques to produce nanofluids which are single step and two step techniques. The single step techniques is simultaneously makes and disperses the nanoparticles directly into the base fluid and two step techniques starts with nanoparticles produced by one of the physical or chemical synthesis techniques and proceeds to disperse them into a base fluid.

Most of the nanofluids containing oxide nanoparticles and carbon nanotubes are produced by the two step process. In addition, an ultrasonic vibrator or magnetic stirrer was used to sonicate the solution continuously for approximately tenth hours in order to break down agglomeration of the nanoparticles.

2.7 Theory of Heat

Heat is defined as a form of energy that can be transferred from one system to another system as a result of temperature differences. Heat transfers is dealing with determination of the rates of such energy transfers and always occur from the higher temperature to lower temperature and is stop when the two mediums reach the thermal equilibrium condition.

Heat can be transferred in three different modes which are conduction, convection and radiation. All models require the existence of a temperature difference, and all modes from the high temperature medium to a lower one. For nanofluids flowing radiator through a plain tube, it is considered internal flow and heat is transferred by convection mode since it is involved fluid as a medium of heat transfer.

2.7.1 Thermal Conductivity

Thermal conductivity of a material is a measure of ability of material to conduct the heat. It defined as the rate of heat transfer through a unit thickness of the material per unit area per unit temperature difference. As shown in Figure 2.2, a high value for thermal conductivity indicates that the material is a good heat conductor and a low value indicates that the material is a poor heat conductor or insulator.

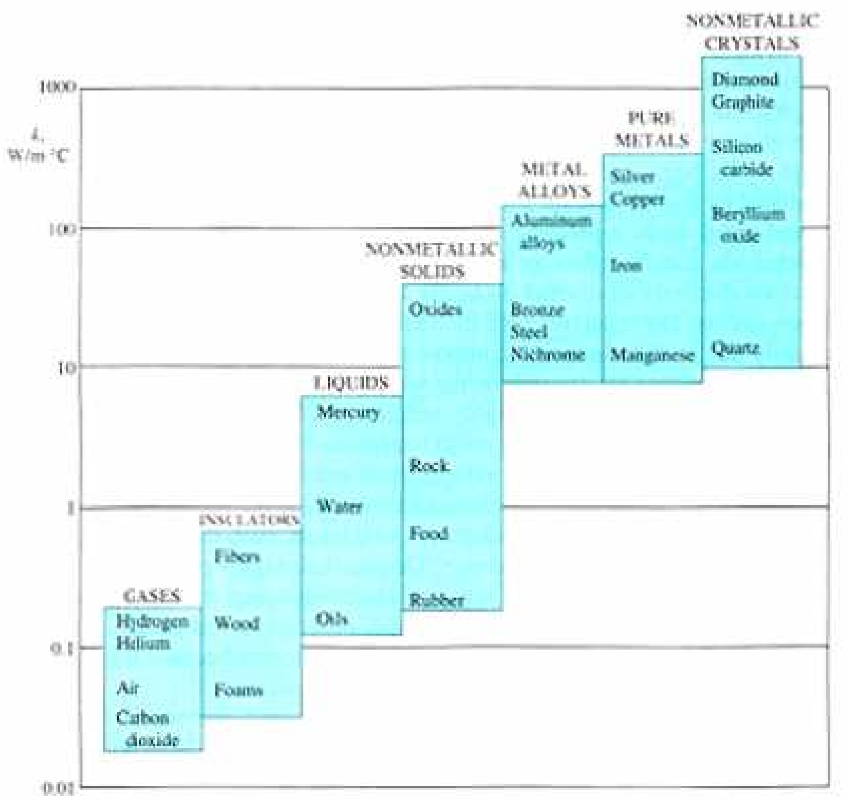

Figure 2.2: The Range of Thermal Conductivity of Various Materials at Room Temperature

Source: Cengel, 2006

Mostly researches on thermal conductivity of nanofluids are obtained at room temperature. The methods that use is hot-wire method and the conventional heat conduction cell method (Choi, 1996 and Lee et al., 1999). Other than this method, the recent published research has using the 3-ω method (Yang and Han, 2006). This 3-ω method is relatively accurate and uses a metal wire suspended in nanofluids.

Investigation on turbulent friction and heat transfer behaviours of dispersed fluids with submicron *γ*-Al_2O_3 (Alumina aqueous) and TiO_2 particles in a circular pipe was carry out through experiments, it shown that the Nusselt number for the dispersed fluids increased with increasing volume concentration as well as Reynolds number. However, when compared under the condition of constant average velocity, it was found that the convective heat transfer coefficient of the dispersed fluid was 12 % smaller than that of pure water. Hence, better selection of particles having higher thermal conductivity and larger size is recommended in order to utilize dispersed fluids as a working medium to enhance heat transfer performance (Pak and Cho 1998).

The experiment that aimed to investigate the thermal conductivity behaviour of dilute nanofluids to measure the thermal conductivity of four oxide nanofluids (Al_2O_3 in water, Al_2O_3 in ethylene glycol, CuO in water, and CuO in ethylene glycol) by a transient hot-wire method was carried out and the results show that nanofluids containing only a small amount of nanoparticles have substantially higher thermal conductivities than the same liquids without nanoparticles (Lee et al. 1999).

For the copper oxide-ethylene glycol (EG) based nanofluids, thermal conductivity can be enhanced by more than 20 % at a volume fraction of 0.04 (4 % by volume). Moreover, in the low-volume fraction range tested (up to 0.05), the thermal conductivity ratios increase almost linearly with volume fraction, but with different rates of increase for each system. The present experimental data also show that the thermal conductivity of nanofluids depends on the thermal conductivities of both the base fluids and particles. As nanofluids using the same nanoparticles, the conductivity ratio increases of ethylene glycol nanofluid systems are always higher than those of water nanofluid systems. For nanofluids using the same liquid, the conductivity ratio of the CuO system is always higher than that of the Al_2O_3 system.

It was proved that the temperature effect of thermal conductivity enhancement in nanofluids (Das et al. 2003). The study shows that a 2 of 4 fold increase in thermal conductivity enhancement of nanofluids can take place over a temperature range of 21 °C to 51 °C. This finding makes nanofluids even more attractive as cooling fluid for devices with high energy density where the cooling fluid is likely to work at a temperature higher than the room temperature. It states that nanofluids containing smaller CuO particles show more enhancement of conductivity with temperature. However the enhancement is considerably increased for nanofluids with Al_2O_3 as well. The study indicate that particle size is an important parameter for the observed behaviour and the usual weighted average type of model for effective thermal conductivity is a poor approximation of the actual enhancement particularly at the higher temperature range.

The effective thermal conductivity of nanofluids was found to significantly increase with the particle volume fraction (Murshed et al., 2008). The proposed models, which consider particle size, interfacial layer, and volume fraction, show good agreement with the experimental results and give better predictions for the thermal conductivity of nanofluids compared to the existing models. Besides the volume fraction of particle, it can also be concluded that particle size, shape, interfacial layer, and temperature also influence the thermal conductivity of nanofluids. The effect of temperature on the enhanced effective thermal conductivity of nanofluids is important for theoretical understanding and needs to be considered for the model development.

In addition, the thermal conductivities of the dilute Al_2O_3–water nanofluids increase almost linearly with the concentration (Lee et al., 2008). Furthermore, the measured thermal conductivities of the Al_2O_3–water nanofluids are consistent in their overall trend with previous data at higher concentrations and agree well with the predicted values by the Jang and Choi model over a very wide concentration range from 0.01 % to 5 % by volume.

Results from the research on the thermal conductivity of nanofluids containing seven sizes of alumina nanoparticles ranging from 8 to 282 nm in diameter indicates that the thermal conductivity enhancement decreases as the particle size decreases below about 50 nm (Beck et al., 2009). The decrease in the thermal conductivity of the nanoparticles was because the particle size becomes small enough to be affected by increased phonon scattering.

Thermal conductivity of TiO_2 nanoparticles in deionized water nanofluids was measured using a 3-ω method for volume fractions ranging from 0.2 % to 3.0 % by volume (Turgut et al. 2009). The data showed that the thermal-conductivity enhancement was in relatively good agreement with the Hamilton–Crosser model. The 3-ω measurement method for thermal conductivity was particularly well adapted as it required small amounts of sample size and was rapid and accurate which uncertainty within 2 %. The measurements showed that there is no dependence related to temperature, the thermal conductivity increased by the same order of magnitude as the base fluid which is water.

Results from experimentally investigated result on the effective thermal conductivity of TiO_2-water nanofluids with varies volume concentrations and temperatures show that the relative thermal conductivity of nanofluids increases with increasing particle volume concentration and slightly decreases with increasing temperature (Duangthongsuk and Wongwises, 2009). It is also seen that the existing correlations for predicting the thermal conductivity of nanofluids gave lower values than the experimental values.

Research on the addition of 0.035 volume fraction of Al_2O_3 nanoparticles in the engine coolant show that enhances the thermal conductivity of the fluid (Kole and Dey, 2010). The enhancement in thermal conductivity of the nanofluid is varied linearly with the volume fraction of the nanoparticles and reaches a maximum of 11.25 % at 80 °C for the nanofluid containing 0.035 volume fraction of Al_2O_3 nanoparticles.

Study on the convective heat transfer performance TiO_2-water nanofluid flowing in a horizontal double tube counter-flow heat exchanger shows the dispersion of the nanoparticles into the base liquid increases the thermal conductivity of the nanofluids, and this augmentation increases with increasing particle concentrations (Duangthongsuk and Wongwises, 2010).

Values of bulk specific heat obtained with CuO nanoparticles from the experiments are found to be in close agreement with the theoretical predictions, at temperatures lower than 225 K for particles up to 50 nm size (Wang et al., 2006). However for temperatures above 225 K, the values from theory predicted a decrease for particle sizes up to 10 nm. The specific heat capacity showed an increasing trend for particles below 10 nm. This research support the study carried by Pak and Cho, 1998 on the variation on specific heat capacity with particle size by the theoretical and experimental observation.

Research on regarding the particles size, the particles larger than 10 nm the quantum effect can be neglected and the specific heat will decrease monotonically with particle size (Wang et al., 2006). For particles which are smaller than 10 nm, the quantum effect will increase the specific heat capacity of the nanoparticles uniformly, and thus create an irregular behaviour for particles of different sizes. This observation is stated to be in conformity with the monotonic decreasing relation proposed by Prasher and Phelan, 1998 for particles larger than 10 nm.

Experimental observation to determine the specific heat of Al_2O_3, ZnO dispersed in Ethylene glycol water mixture in 60:40 ratio and SiO_2 nanoparticles in water indicates a decrease in specific heat of nanofluids with increase in concentration for the three nanoparticles tested (Vajjha and Das, 2009). The specific heat increased with temperature of the nanofluid

Specific heat of SiO_2 nanoparticles with diameters 20, 50 and 100 nm suspended in a 60:40 ethylene glycol and water mixture nanofluids in the concentration range of 0 to 10 % volume carried out and result show the specific heat of the SiO_2 nanofluid decreased with increase in volume concentration. (Namburu et al., 2007). It implies that for higher concentrations of silicon dioxide nanofluid, less heat input is required to increase the temperature of the nanofluid. The specific heat is about 12 % lower than that of the base fluid at 10 % concentration.

2.8 Convection

Convection is mode of energy transfer between a solid surface and the adjacent liquid or gas that is in motion and it involves the combined effects of conduction and fluid motion. The faster liquid motion, the greater the convection heat transfers. Convection is strongly depends on the fluid properties such as dynamic viscosity, thermal conductivity, density, specific heat and fluid velocity.

The heat transfer process that involve in change of phase of a fluid are also considered to be convection because of the fluid motion induced during the process, such as the rise of the vapor bubbles during boiling or the fall of the liquid droplets during condensations. The rate of heat transfer in the convection is observed to be proportional to the temperature difference and is expressed by Newton's law of cooling in Eq. 2.1.

$$Q_{conv} = hA_s \Delta T_{avg} = hA_s \left(T_s - T_{\infty}\right) \tag{2.1}$$

Where, *h* is convection heat transfer coefficient in W/m².K, *A* is surface area, T_s is surface temperature and T_∞ is ambient temperature.

The value of heat transfer coefficient, *h* is not a property of the fluid and it is experimentally determined parameter whose value depends on all variables influencing convection such as the surface geometry, the nature of fluids motion, and the properties of the fluid and bulk fluid velocity. The typical value of *h* is given in Table 2.2.

Table 2.2: Typical Value of Convection Heat Transfer Coefficient

Type of Convection	***h*, W/m^2.°C**
Free convection of gases	2-25
Free convection of liquids	10-1,000
Forced convection of gases	25-250
Forced convection of liquid	50-20,000
Boiling and condensation	2500-100,000

Source: Cengel (2006)

Convection is divided by two ways which is forced convection and natural convection or also known as free convection. Natural convection occurs by nature without any motion in the air and due to the rise of the warmer air near the surface and the fall of the cool air to fill its place. Forced convection will be explained in the next sub chapter.

2.8.1 Forced Convection

Forced convection is caused by fluid flow is force over the surface by external means such as pump, fan or blower. There are two main situations of forced convection which is external forced convection and internal forced convection. External forced convection normally occur when the fluid flow over a surface such as a plate, a wire and pipe. However, internal forced convection occurs in pipe or duct. Internal forced convection will briefly explain in the next sub-chapter.

2.8.2 Internal Forced Convection

The terms pipe, duct and conduit are usually refer to the internal flows and descriptive phrase for pipes (circular cross section), duct (noncircular cross section), and tubes (are referring to smaller diameter size). Most of the fluids an especially liquid is transported in circular tubes since it can withstand large pressure differences between the inside and outside without undergoing significant distortion. Nanocircular pipes are usually used in applications such as cooling and heating systems of building where the pressure difference is relatively small

2.8.3 Average Velocity and Temperature

In internal flow, the fluid velocity in a tube changes from zero at the surface because of no-slip condition to the maximum at the tube center as shown in Figure 2.1. Therefore, it is convenient to work with average velocity or mean velocity, which remains constant for incompressible flow when the cross sectional area of the tube is constant. The value of average velocity is obtained from conservation of mass principle as Eq. 2.2 below.

$$\dot{m} = \rho V_{avg} A_c = \int_{A_c} \rho u(r) dA_c \qquad (2.2)$$

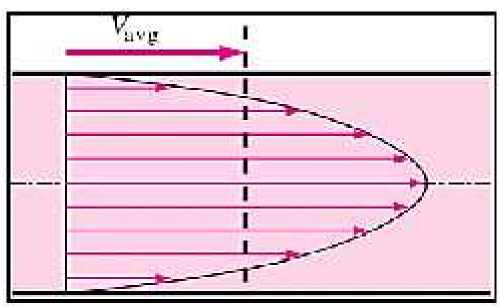

Figure 2.3: Average Velocity for Fully Develop Flow

Source: Cengel (2006)

2.9 Engineering Parameter

Common practice in engineering studies to nanodimensionalize the governing equations and combines the variables, which group together into dimensionless number in order to reduce the number of total variables. It also to standardize the result obtains from various experimental with different parameter used. Thus, dimensionless is the best method to make a comparison between other researchers' results.

2.9.1 Heat Transfer Coefficient (HTC)

Heat transfer performance is a better indicator than the effective thermal conductivity for nanofluid used in industry. Heat transfer coefficient is indicated by h and the value is depends on the type of the fluid gas or liquid, the properties of the flow and temperature of the flow. The value of HTC can be obtained by applying the equation of Nusselt number as shown in Equation 2.3 through 2.6 with respect to the properties of the flow either fully developed laminar or turbulent flow and surface roughness of the tube wall.

Normally, the internal pipe flow convection coefficient of nanofluids was measured experimentally. Nanofluid was diluted to various volume fractions and particles size for convection heat transfer coefficient study. The high volume fraction results in the high viscosity of the fluid and a tendency for the nanoparticles to stick on the walls of tubing and containers. It also requires large pumping power. Therefore, the highest concentration of the testing fluid has been limited since higher costs for nanoparticles.

2.9.2 Nusselt Number (*Nu*)

The Nusselt number is named after Wilhelm Nusselt, who make significant contributions to convective heat transfer in the first half of the twentieth century and it's viewed as the dimensionless convection heat transfer coefficient. Nusselt number also defined as the ratio of heat transfer by convection and conduction across the same fluid.

The larger the Nusselt number, the more effective the convection. In convection studies, it common practices to nondimensionalize the heat transfer coefficient, with the Nusselt number defined as Eq. 2.3.

$$\mathrm{Nu} = \frac{h_{exp} d_{hy}}{k} \tag{2.3}$$

Where *k* is the thermal conductivity of the fluid, *h* is heat transfer coefficient of the fluid and *D* is the diameter of the tube.

Another alternative to obtain Nusselt number is given by Gnielinski Equation, as given in Eq. 2.4 and valid in the range of 2300< $Re < 5 \times 10^6$ and 0.5 < Pr < 2000.

$$\mathrm{Nu} = \frac{\left(\frac{f}{2}\right)(\mathrm{Re} - 1000)\,\mathrm{Pr}}{1 + 12.7\left(\frac{f}{2}\right)^{0.5}\left(\mathrm{Pr}^{\frac{2}{3}-1}\right)} \tag{2.4}$$

.

Where friction factor, *f* can be determined from the first Petukhov equation as given in Eq. 2.5,

$$f = (1.58 \ln \mathrm{Re} - 3.82)^{-2} \tag{2.5}$$

For fully developed turbulent flow in smooth tubes, Dittus-Boelter equation (Dittus and Boelter, 1930) shown in Eq. 2.6 is obtained to improve the accuracy from the Colburn equation.

$$\mathrm{Nu} = 0.023\mathrm{Re}^{0.8}\mathrm{Pr}^{n} = \begin{Bmatrix} \mathrm{Re} > 10{,}000, & n = 0.4\ \textit{heating} \\ 0.7 \leq \mathrm{Pr} \leq 160, & \mathrm{n} = 0.3\ \text{cooling} \end{Bmatrix} \tag{2.6}$$

2.9.3 Reynolds Number (*Re*)

Osborn Reynolds discovered in 1880s that the flow regime depends mainly on the ratio of the inertia forces to viscous forces as shown in Equation 2.7. This ratio is called the Reynolds number which is dimensionless quantity.

$$Re = \frac{InertiaForces}{ViscousForces} = \frac{V_{avg}D}{v} = \frac{\rho V_{avg}D}{\mu} \tag{2.7}$$

Where *D* is diameter of the tubes, ρ is density of the fluid, ν is kinematic viscosity, and μ is dynamic viscosity of the fluid.

From the derivation of Eq. 2.23, Reynolds number also can express as shown in Eq.2.8.

$$Re = \frac{4\dot{m}}{\pi D \mu} \tag{2.8}$$

2.10 Specific Heat

The specific heat is defined as the energy required raising the temperature of a unit mass of a substance by one degree (Figure 2.4). In general, this energy will depend on how the process is executed. In thermodynamics, specific heat is interested in two kinds of specific heats: specific heats at constant volume, C_v and specific heat at constant pressure, C_p.

Physically, the specific heat at constant volume C_v can be viewed as the energy required to raise the temperature of the unit mass of a substance by one degree as the volume is maintained constant.

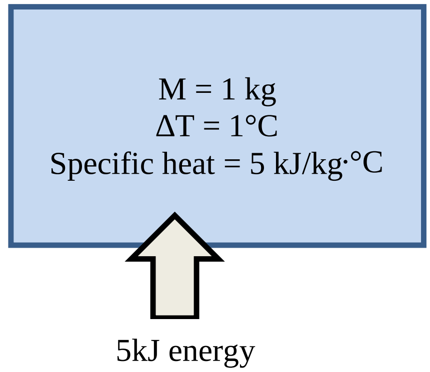

Figure 2.4: Image of specific heat

2.11 Previous Study on Heat Transfer Coefficients

Study that investigate on the thermal conductivity behaviour of dilute nanofluids, the thermal conductivity of four oxide nanofluids (Al_2O_3 in water, Al_2O_3 in ethylene glycol, CuO in water, and CuO in ethylene glycol) was measured by a transient hot-wire method show the results show that nanofluids, containing only a small amount of nanoparticles, have substantially higher thermal conductivities than the same liquids without nanoparticles (Lee et al. 1999).

Thermal conductivity ratios increase almost linearly with volume fraction, but with different rates of increase for each system. It also shows that the thermal conductivity of nanofluids depends on the thermal conductivities of both the base fluids and particles. For nanofluids using the same nanoparticles, the conductivity ratio increases of ethylene glycol nanofluid systems are always higher than those of water nanofluid systems. For nanofluids using the same liquid, the conductivity ratio of the CuO water based nanofluids system is always higher than that of the Al_2O_3 water based nanofluids system.

Research on the effective thermal conductivities of fluids with Al_2O_3 and CuO nanoparticles dispersed in water, vacuum pump fluid, engine oil, and ethylene glycol shows that the thermal conductivities of nanoparticle–fluid mixtures increase relative to those of the base fluids and a possible relation between the thermal conductivity increase and the particle size which is the thermal conductivity of nanoparticle–fluid mixtures increases with decreasing the particle size (Wang et al., 1999). The thermal conductivity increase also depends on the dispersion technique. By using existing models for computing the effective thermal conductivity of a mixture, it is found that thermal conductivities computed by theoretical models are much lower than the measured data, indicating the deficiencies of the existing models in describing heat transfer at the nanometer scale in fluids. It appears that the thermal conductivity of nanoparticle fluid mixtures is dependent on the microscopic motion and the particle structure. Any new models of thermal conductivity of liquids suspended with nanometer-size particles should include the microscopic motion and structure-dependent behaviour that are closely related to the size and surface properties of the particles. This correlation correctly takes the main factors of affecting heat transfer of the nanofluid into account. On the other hand, the friction factor for the dilute nanofluids consisting of water and Cu-nanoparticles is approximately the same as that of water. The nanofluid with the low volume fraction of the suspended nanoparticles incurs almost no extra penalty of pump power.

The result of research was done on the convective heat transfer of CuO water based and Al_2O_3 water based nanofluids and the experiment were carried out for the laminar flow regime under constant wall temperature boundary condition shows that for the nanofluids systems, the heat transfer coefficient was increase with the increasing of the nanoparticles concentrations and the Al_2O_3 water based nanofluids shows more enhancements compared with CuO water based nanofluids (Heris et al., 2006). The optimum concentration also can be found for the most enhancements available. It shows that heat transfer enhancement by nanofluid depends on several factors including increment of thermal conductivity, nanoparticles chaotic movements, fluctuations and interactions.

Moreover, the research shows a significant enhancement of heat transfer of nanofluids particularly in the entrance region, which agree reasonably well with the experimental results which is suggested that the convective heat transfer coefficient is more affected by the thermal conductivity than that by the viscosity and the Brownian force, the lift force and the thermophoretic force play very small role (He et al. 2009). This increase in heat transfer rate over prediction is a favourable result for nanofluid heat transfer enhancement. The pumping power penalty of the SiC water based nanofluid was shown to be less than that of an Al_2O_3 water based nanofluid of comparable particle concentration. The two nanofluids were compared using a figure of the merit consisting of the ratio of heat transfer enhancement to pumping power increase. The merit parameter was 0.8 for the SiC water based nanofluid compared to 0.6 for the Al_2O_3 water based nanofluid, which is favourable to the SiC water base nanofluid for applications that are pumping power sensitive. Heat transfer rates on the basis of constant velocity showed 7 % lower results for the SiC water based nanofluid than its base fluid water. However, these results are above those reported for Al_2O_3 water based nanofluids with comparable particle concentrations. Based on the study, it is shown that the Darcy friction factor of Al_2O_3 water based nanofluids experimentally measured in this paper has a good agreement with theoretical results from the friction factor correlation for the single-phase flow. The study clearly presented that the nanoparticles suspended in water enhance the convective heat transfer coefficient in the thermally fully developed regime, despite low volume fraction between 0.01 % volume and 0.3 % volume Especially, the heat transfer coefficient of Al_2O_3 water based nanofluids is increased by 8 % volume at 0.3 % volume under the fixed Reynolds number compared with that of pure water and the enhancement of the heat transfer coefficient is larger than that of the effective thermal conductivity at the same volume concentration. Also, the convective heat transfer coefficient of water-based Al_2O_3 nanofluids is increased with volume fraction of Al_2O_3 nanoparticles. It is shown that the flattening of velocity profile is a possible mechanism of the convective heat transfer enhancement, which cannot be explained by an increase in the thermal conductivity of nanofluids alone. The study on the Nusselt number estimated with the equation of Gnielinski's valid for single phase fluid predicts values which are lower by 13.4 % for 0.6 % for Fe_3O_4 nanofluid under similar operating conditions. Enhancement of heat transfer coefficient in a plain tube with 0.6% volume concentration of Fe_3O_4 nanofluid is 20.99 % and 30.96 % for Reynolds number of 3000 and 22,000 respectively compared to water. The Nusselt number estimated with Pak and Cho equation valid for Al_2O_3 and TiO_2 under predicts by 7.12% for 0.6% Fe_3O_4 nanofluid under same Reynolds number, in the similar way the Nusselt number estimated with of Xuan and Li equation valid for Cu nanofluid under predicts by 13.20 % compared to the data of 0.6 % Fe_3O_4 nanofluid under same Reynolds number. The enhancement of friction factor in a plain tube with 0.6 % volume concentration of Fe_3O_4 nanofluid when compared to water is 1.09 times and 1.10 times for Reynolds number of 3000 and 22, 000 respectively (Sundar et al. 2011).

2.12 Cooling Systems

The concept of cooling system for diesel engine and gasoline engine are same. There are differences in engine operational parameter such as compression ratio that it can generate. Due to the project aim, which is to develop the vehicle's diesel engine cooling system instead of other application of diesel engine, cooling system is the main system to be research in the vehicle's system.

For vehicle's engine cooling system, there are several components that get together:

i. Radiator
ii. Radiator cap
iii. Passage inside
iv. Thermostat
v. Water pump
vi. Engine coolant

There also have another several components such plumbing, that connecting between radiator and engine, transmission cooler, and heater core but above components is the main component in the system. The detail function of each component will be described in following section each.

2.12.1 Radiator

The radiator is heat exchangers. The engine power rating determines the size of radiator required by a diesel engine. The radiator is positioned in front of the vehicle. Inside the radiator, the coolant will flow from the top of the radiator to the bottom of the radiator, and then will circulate into the engine again. Vehicle speed and ambient temperatures determine the radiator's efficiency as a heat exchanger. With radiator, the fun is attached together to help the coolant temperature lower.

Figure 2.5: Radiator used in the experiment

2.12.2 Radiator Cap

Radiator is usually equipped with a pressure cap whose function it is to maintain a fixed operating pressure while the engine is running. This cap is additionally equipped with a vacuum valve to admit surge tank coolant or air into the cooling circuit which is upper radiator tank when the engine is shut down and the coolant contracts.

Radiator caps allow sealed cooling systems to be safely pressurized. For each 7 kPa above the atmospheric pressure, coolant boil point is raised by 1.67 °C at sea level; for every 304.8 m of elevation, the boil point decreases by 0.5 °C. System pressures are more typical they range between 50 kPa and 100 kPa.

2.12.3 Passage inside

The passage inside the engine block and heads are the passages of coolant to circulate the cooling system. There are various numbers around the engine block and heads to control the temperature around area stated. This parts is very important in ensure the engine life span as well other components.

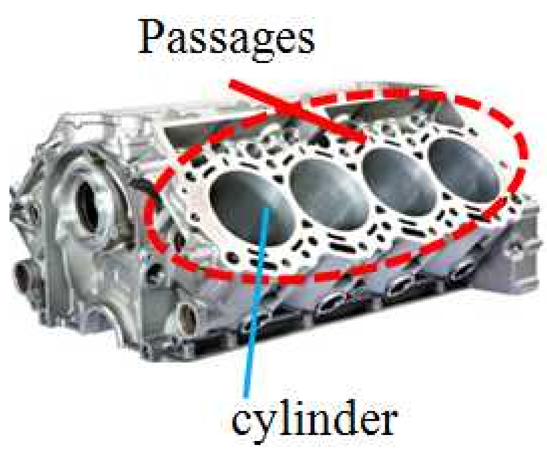

Figure 2.6: The passages around the engine block's cylinder

2.12.4 Thermostat

Thermostat function as a type of automatic valve that senses changes in engine temperature and regulate coolant flow to maintain an optimum engine-operating temperature. The cooling system thermostat is normally located either in the coolant manifold or in a housing attached to the coolant manifolds.

This small device is functioned by block the coolant flow when the engine is in cool condition until the engine is warmed up and reaches the set temperature usually at 95 °C, this device will let the coolant flow through the water jacket to cool down the engine in order to control the engine block temperature. When the engine block temperature is not in control, the engine blocks may have cracks and engine will wear that cause the engine life span is shorten.

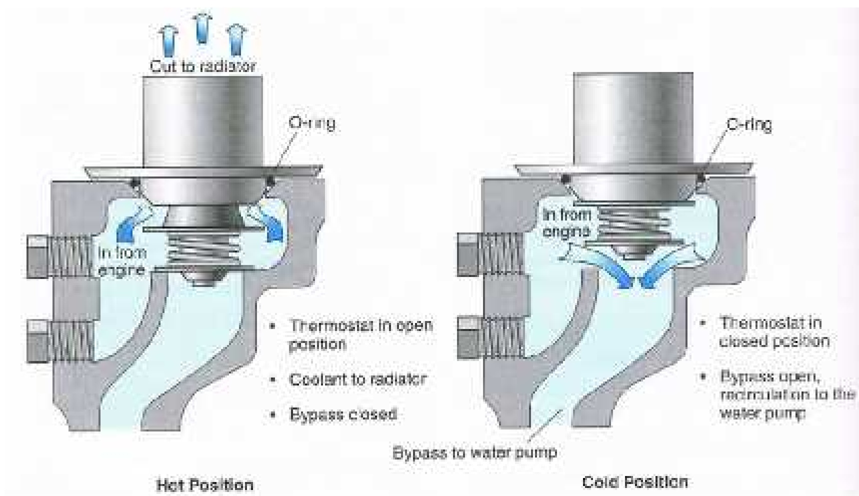

Figure 2.7: Thermostat

Source: Sean, 2009

2.12.5 Water pump

Water pumps are usually centrifugal pumps type that driven directly by a gear or by belts. When the engine rotates the coolant pump, an impeller is driven within the housing, creating low pressure as its inlet, usually located at or close to the center of the impeller.

The impeller vanes throws the coolant outward and centrifugal force accelerates it into the spiraled pump housing and out toward the out toward the pump outlet. Due to the cooling system pressure at the inlet to the coolant pump is at its lowest because of low-pressure pull of impeller at inlet, system boiling always occurs at this location first.

This will very rapidly accelerate the overheating condition as the pump impeller will be acting on vapor. Coolant pumps are the main reason that engine coolant should have some lubricating damage when the coolant total dissolved solids (TDS) levels are high.

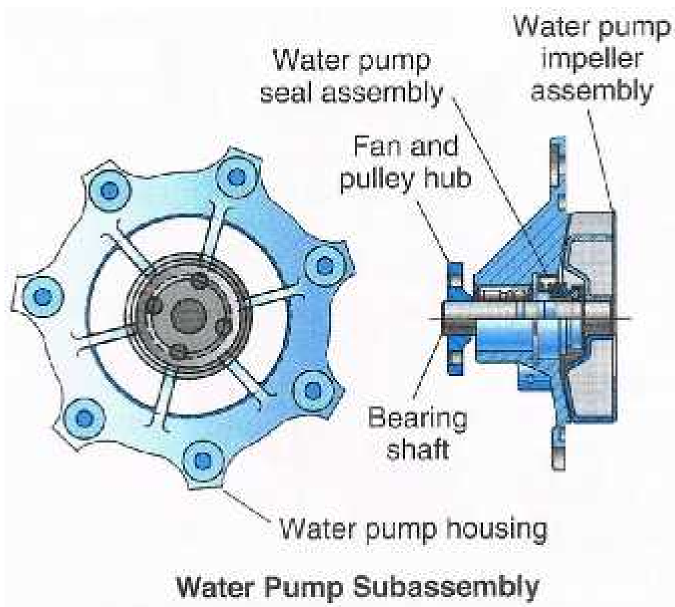

Figure 2.8: Water pump

Source: Sean, 2009

2.12.6 Engine Coolant

Almost vehicle engines use a mixture of ethylene glycol (EG) or propylene glycol (PG) plus water as coolant or a premix of carboxylate, EG-based extended life coolant (ELC). Typical coolant is either use only water or ethylene glycol mixed water with 50:50 partially. A properly formulated diesel engine coolant is always made up of the correct proportions of water, antifreeze, and supplemental coolant additives. For this project, the coolant will use is TiO_2 nanofluids based water with various concentrations.

Figure 2.9: Ethylene glycol used in the typical coolant

2.13 Application of Nanofluids

Nanofluids are used in aimed to using that superior properties characteristic in heat transfer performance and high conductivity. Many of the applications are to make the coolant transfer heat with quicker and many with compare to same capacity of base fluids. As this project using nanofluids to coolant in vehicle cooling system, nanofluids is good in used to transfer higher temperature heat to lower temperature and purpose to transfer heat as much better than conventional fluids used.

Furthermore, the normal coolant operating temperature can be increased since nanofluids have obtained a higher boiling point, which is desirable for maintaining single phase coolant flow. Thus, this heat transfer fluids play an important role for cooling applications in many industries including manufacturing, transportation, energy, and electronics. Nanofluids can be used to improve heat transfer and energy efficiency in a variety of thermal systems, including the important applications of vehicle cooling.

In the biomedical fields, nanofluids are also used to producing effective cooling around the surgical region and thereby enhancing the patient's chance of survival and reducing the risk of organ damage. In a contrasting application to cooling, nanofluids could be used to produce a higher temperature around tumors to kill cancerous cells without affecting nearby healthy cells (Jordan, et al., 1999).

In the renewable energy industry, nanofluids could be employed to enhanced heat transfer from solar collectors to storage tanks and increase the energy density. Nanofluid coolants also have potential application in major process industries, such as materials, chemical, food and drink, oil and gas, paper and printing, and textiles.

2.14 Advantages and Disadvantages of Nanofluids

This superior in heat transfer characteristic working fluids is found to have a great advantages in heat transport, it is approved by previous researchers during evaluate their thermal performance. However, it also has disadvantages discovered in nanofluids. Advantages and disadvantages of nanofluids are explained in the next subchapter.

2.14.1 Advantages

Nanofluids have great advantages which can be followed from the properties of metallic or non-metallic particles that are added to base fluids. Most of nanofluids have been studying about the experiments of thermal conductivity and mechanisms of heat transfer enhancement and reported that heat transfer performance and their thermal conductivity is increased compared to common fluids.

In application of cooling system, it can reduce the size, weight and cost of thermal apparatus. For example, the application of nanofluids in engine cooling system, the circulated nanofluids removed the heat from the engine efficiently which make the cooling system could reduced in size which is using the smaller and lighter radiators. This turn to the benefit for almost every aspect of vehicle performance especially increased in energy optimization and leads to increase in fuel economy.

Numerous advantages of nanofluids such as no clogging, no stationary bed in a flow through a tube and low pressure drop when particles sizes close to the nanoscale or even nanosize have been found by previous researchers.

2.14.2 Disadvantages

Even the disadvantage of usage of nanofluids in practical application is still in research to prevent them, the main trouble facts from the research is the erosion and clogging in the pipe or tank will occur with a certain concentration of nanofluids. Some of the researchers claimed that there is no erosion when nanofluid flowing through a tube but in case of improper in the process of nanofluid preparation, it will result the agglomeration in the system.

When it occurred, it is important to consider the surface erosion caused by the flowing fluid as well as effects of particle settling and agglomeration. The effects of agglomeration and settling need serious attention. The dispersion and suspension of nanoparticles in a fluid pose a difficult colloidal chemistry problem, and considerable work remains to be done if the two-step process is ever to develop into large scale production. In addition to that, the disadvantages of nanofluids are the challenge in producing process of nanoparticles since the early innovation of this fluid.

2.15 Conclusion of Literature Review

The application of nanofluids have a bright future to be used as an effective heat transfer fluids and have greater potential for heat transfer enhancement and are highly suited to application in practical heat transfer processes. This is an opportunity for engineers to develop highly compact and effective heat transfer equipment.

Several published articles show that the heat transfer coefficient of nanofluids is much higher than that of the base fluid and gives little or no penalty in pressure drop. Therefore, further research on convective heat transfer of nanofluids and more theoretical and experimental research works are needed in order to clearly understand and accurately predict the trend for heat transfer enhancement.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In this section, every project development includes discussion of the methodology used where are methodology is use as the solution tree to the project. Methodology is a set of guidelines, standards and processes that is involved and followed explicitly in order to produce a product or software. In this study the methods is consist of the compatibility development process. By having the proper project methodology, the project is able to be complete within the given time.

3.2 Apparatus used

The diesel engine cooling system experimental simulation is tested with using TiO_2 (titanium dioxide) nanofluids water based and distilled water. The coolant temperature on radiator inlet and outlet will be measured and recorded using thermocouple type-K and every second of increase and decrease the temperature will recorded by Pico TC-08 Thermocouple Data Logger.

Furthermore, the coolant flow rate will be measure by Blue-White F-1000 Digi-Meter paddle wheel type flow rate meter. Water pump or circulating pump is using centrifugal type water pump in order to circulate the fluid flow. To complete the connection between the radiators with piping system, the high thermal resistance silicon radiator hose is used. In addition, infrared thermometer is used to take the radiator surface temperature.

3.3 Research Flowchart

The flowchart of this research starts with experiment set up which is include the design of the test rig, making of the test rig stand, radiator leaking check, radiator fan power supply system, preparation of instruments for measurement, and preparation of nanofluids. Next, the test rig is checked by test running experiment, and the stability of test rig is ensured.

After the test running, the experiment starts with distilled water severally as experiment control and to check the consistency of result. The experiment continued with varied concentration of TiO_2 nanofluids water based, with varying the flow rate. The experiment data then will record and analysed.

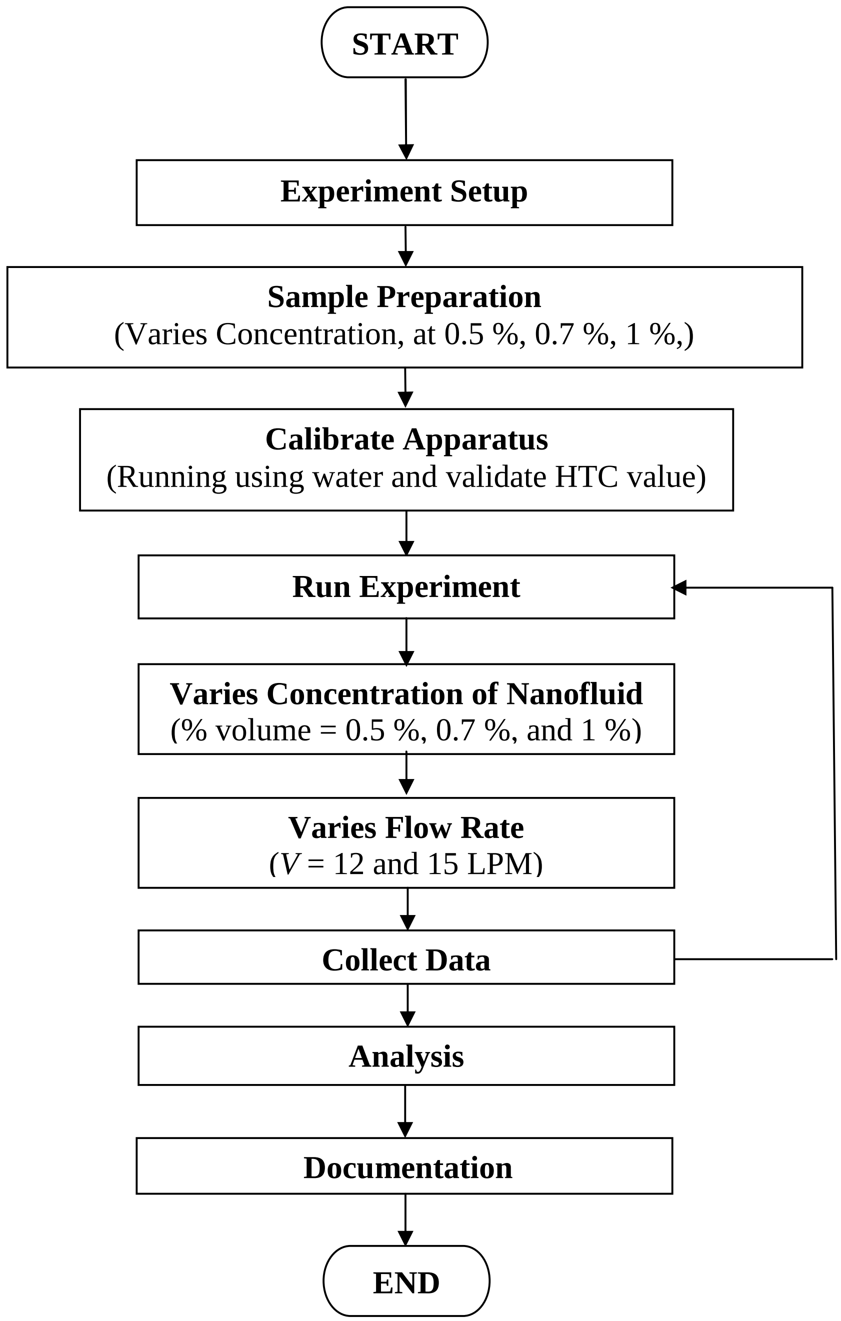

Figure 3.1: Flowcharts for the Experiment

3.4 TiO_2 (Titanium Dioxide Aqueous) Nanofluids as Coolant

For the nanofluids used, the parameter of concentration and flow rate will be varied. For the concentration: 0 % volume (distilled water), 0.5 % volume, 0.7 % volume , 1.0 % volume, and flow rate will vary with 12 LPM and 15 LPM.

Figure 3.2: TiO_2 (Titanium Dioxide) Nanofluids

3.5 SAMPLE PREPARATION

Nanofluids are term which is the two-phase mixture that consists of nanoparticles that disperse in working fluids. In produce this two-phase mixture fluid; there are two processes used which is single-step and two-step process. However, most of nanofluids that consist of oxide nanoparticles and carbon nanotube are produce by the two step techniques.

For this experiment, the TiO_2 nanofluids procured from Sigma-Aldrich are prepared to desired concentration by dilution process. The nanofluids are subjected to mechanical homogenization.

3.5.1 One Step Process of Nanofluid Dilution

Nanofluids procured supplied from Sigma-Aldrich listed in Table 3.1 are available in percent weight concentration, ω . This percent weight concentration ω is converted into volume percent ¤ with by using Eq. 3.1 by taking the nanoparticle density as given in Table 3.2. The volume of distilled water to be added, ΔV for attaining a desired concentration ¤ $_2$ can be estimated with Eq. 3.2 with the initial values of the volume of nanofluids, *V* and concentration of nanofluids, φ that known before dilution.

$$\theta = \frac{\omega\rho_W}{\left(1-\frac{\omega}{100}\right)\rho_P + \frac{\omega}{100}\rho_W}\times 100 \qquad (3.1)$$

Where, $\omega = \left[\frac{m_V}{\left(m_V + m_W\right)}\right]\times 100$

$$V = \left(V_2 - V_1\right) = V_1\left(\frac{\varphi_1}{\varphi_2} - 1\right) \qquad (3.2)$$

Table 3.1: Properties of nanofluids supplied by Sigma-Aldrich

Type of Nanofluid	**Diameter (nm)**	**Weight Concentration, μ (%)**	**Volume Concentration (%) estimated with Eq. (3.1)**
TiO2	150	35	11.42

Table 3.2: Physical properties of nano materials

Nanoparticle	Thermal Conductivity, W/m K	Density, kg/m^3	Specific heat, J/ kg K	Reference
TiO_2	8.4	4175	692	Pak and Cho, 1998

3.5.2 Two Step Process of Nanofluid Preparation

Nanoparticles procured from Sigma-Aldrich and listed in Table 3.1 are of different sizes and materials. Measured quantity of nanoparticles is added to a pre-determined volume of distilled water. The mass of particles required to obtain a desired volume concentration in a fixed mass of 100 grams of water can be estimated from Eq. 3.3 (Azmi et al., 2010), using the nanoparticle density listed in Table 3.2

$$\theta = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\frac{m_p}{\rho_p} + \frac{100}{\rho_w}\right)} \times 100 \qquad (3.3)$$

The pH of nanofluid is affected by the type of material dispersed, surfactant used and concentration. Occasionally small quantities of surfactants such as Cetyl trimethylammonium bromide (CTAB), Sodium Dodecyl Benzene Sulfonate (SDBS), Tween 80, Oleic acid, others are used to achieve homogenous dispersion of the particles. The mixture applied with mechanical mixing for a period of 60 min 30. The dispersion stability is observed through visual view. Nanofluids which are stable for a minimum duration of one week are tested for their thermo-physical properties.

The concentration of the nanofluids in volume percentage, φ can be approximated with Eq. 3.4 (Azmi et al., 2010),

$$\theta = \frac{\left(\frac{m_p}{\rho_p}\right)}{\left(\frac{m_p}{\rho_p} + \frac{m_w}{\rho_w}\right)} \times 100 \qquad (3.4)$$

Figure 3.3: Nanofluid Prepared by Two Step Method

TiO_2 nanofluids procured from Sigma-Aldrich are prepared to desired concentration by dilution process. The nanofluids are subjected to mechanical homogenization and their properties such as thermal conductivity and viscosity determined after observing for dispersion stability.

TIO_2 nanofluids were supplied by US Research Nanomaterials, Inc. and distilled water is used to prepare the nanofluid. SDBS is weighing 10 % from the mass of nanoparticles and used as dispersant to stabilize the nanoparticles in the base fluid.

Nanoparticles are added after the dispersant is mixed with water around tenth minutes. The mixture is stirred with magnetic stirrer continuously for 10 hours. The desired volume concentrations used in this study are 0.5 % volume, 0.7 % volume, and 1.0 % volume.

Table 3.3: Calculated Volume Water Addition to Nanofluids

Former nanofluids volume percent concentration (¤),%	Desired volume percent concentration (¤), %	Volume of distilled water (ΔV), ml	Volume of distilled water to be add (ΔV), ml
1	0.7	2000.00	357.14
0.7	0.5	2357.14	1010.20

3.6 Evaluation of Nanofluids Properties

3.6.1 Properties of Water

The thermo-physical properties of water such as thermal conductivity, viscosity, density and specific heat are required for the determination of nanofluids convection heat transfer coefficients. The properties are estimated at different temperatures using the regression equations given in Table 3.4, which deviate not more than 2.8%. specific heat equation is derived by Kravchenko, 1966.

Table 3.4: Properties of Water Applicable in the Range $5 \le T_w \le 100$ °C

Property	**Equation for water**
Density	$\rho_w = 1000 \times \left[1.0 - \frac{(T_w - 4.0)^2}{119000 + 1365 \times T_w - 4 \times (T_w)^2} \right]$ $\pm 0.07\%$
Viscosity	$\mu_w = 0.00169 - 4.25263e-5 \times T_w + 4.9255e-7 \times (T_w)^2$ $- 2.0993504e-9 \times (T_w)^3$ $\pm 2.75\%$
Thermal conductivity	$K_w = 0.56112 + 0.00193 \times T_w - 2.60152749e-6 \times (T_w)^2$ $- 6.08803e-8 \times (T_w)^3$ $\pm 1.4\%$
Specific heat	$C_w = 4217.629 - 3.20888 \times T_w + 0.09503 \times (T_w)^2 - 0.00132 \times (T_w)^3$ $+ 9.415e-6 \times (T_w)^4 - 2.5479e-8 \times (T_w)^5$ $\pm 2.46\%$

3.6.2 Thermal Conductivity and Viscosity of Nanofluid

$$K_{nf} = K_w \left[0.8938 \left(1 + \frac{\phi}{100}\right)^{1.37} \left(1 + \frac{T_{nf}}{70}\right)^{0.2777} \left(1 + \frac{d_p}{150}\right)^{-0.0336} \left(\frac{\rho_p}{\rho_w}\right)^{0.01737} \right] \quad (3.5)$$

$$\frac{\mu_{nf}}{\mu_w} = C_1 \left\{ \left(1 + \frac{\phi}{100}\right)^{11.3} \left(1 + \frac{T_{nf}}{70}\right)^{-0.038} \left(1 + \frac{d_p}{170}\right)^{-0.061} \right\} \quad (3.6)$$

Equation 3.6 use $C_1 = 1.4$ for SiC and $C_1 = 1.0$ for metal and metal oxide nanofluids in base liquid water.

3.6.3 Specific Heat and Density of Nanofluid

Specific heat capacity of CuO EG based nanofluid at different volume concentrations have compared through experiments with Eq. 3.7 and 3.8 (Zhou et al., 2010). The experimental values decreased from 2550 to 2450 J/kg K with an increase in volume concentration from 0.1 % volume to 0.6 % volume. The experimental values are higher than the values calculated with Eq. 3.7 and 3.8 developed on the law of mixtures.

$$C_{nf} = \frac{(1-\phi)(\rho C)_w + \phi (\rho C)_p}{(1-\phi)\rho_w + \phi \rho_p} \tag{3.7}$$

$$C_{nf} = \phi C_p + (1-\phi) C_w \tag{3.8}$$

However, the variation of heat capacities with volume concentration is observed to be constant. The effect of particle size has no significant influence due to large heat capacity of the base fluid according to Zhou et al., 2010. Based on the observations of Wang et al., 2006 and Zhou et al., 2010, it can be concluded that the heat capacity of particle varies while that of nanofluid remains constant at different particle sizes.

The nanofluid specific heat at any concentration can be estimated from the relation valid for homogeneous mixtures given by Eq. 3.7 and 3.8. The values of specific heat estimated with Eq. 3.8 are in agreement with Eq. 3.7 in the low volume concentration.

It was supported by the investigations of Zhou et al., 2008 that the values estimated with Eq. 3.9 deviate at higher volume concentrations. Hence, Eq. 3.7 is used to determine the specific heat of nanofluids. The equation for the estimation of nanofluids density that given by Pak and Cho, 1998 is used and given as,

$$\rho_{nf} = \phi \rho_p + (1-\phi)\rho_w \tag{3.9}$$

3.7 Experiment set up

The schematic experiment set up as follow:

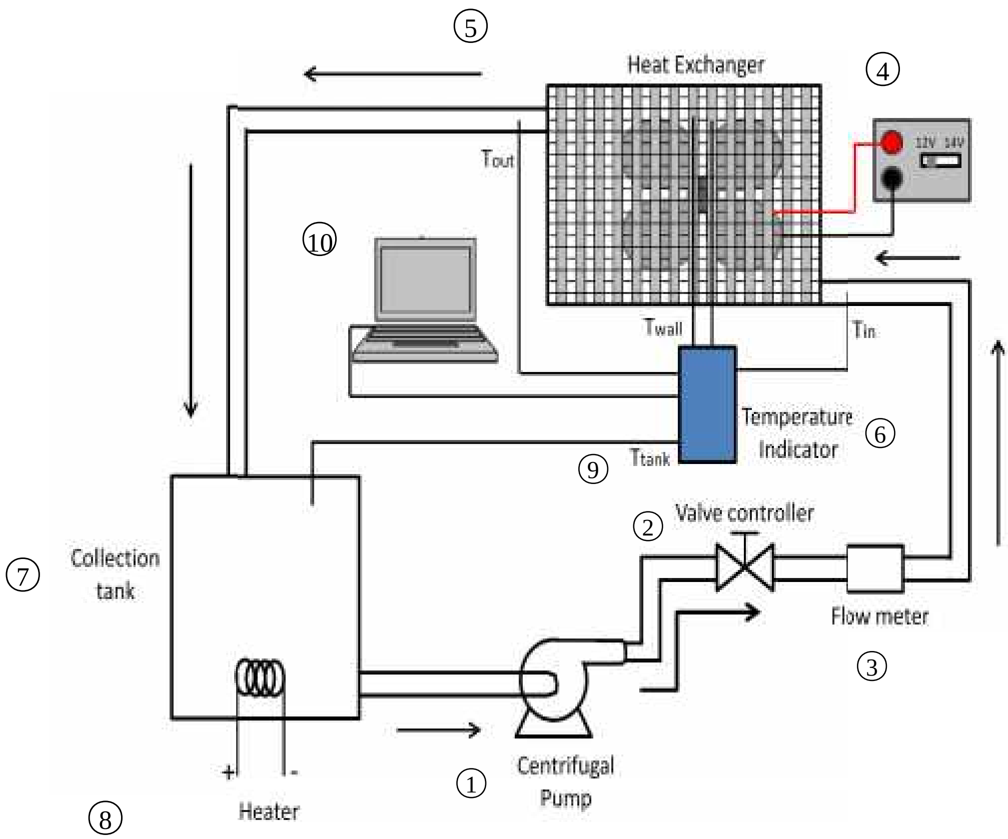

Figure 3.4: Schematic diagram of experiment set up

Description:-

1. Circulating Pump
2. Valve controller
3. Flow rate meter
4. 12V DC power supply
5. Radiator
6. Data logger
7. Collection tank

8. Electric water heater
9. Thermocouple K-type
10. Personal Computer

Table 3.5: Summarize Function for Each Apparatus

Apparatus	**Function**
Circulating Pump	To force nanofluid flow through the system
Valve controller	To regulate the liquid speed into desired velocity
Flow rate meter	To measure a flow rate flow through a test section
12V DC power supply	Current source of radiator fan
Radiator	To cool the liquid that through it
Data logger	To record and transfer the temperature reading data to the personal computer
Collecting Tank	Stored fluid in steady state condition to supplied to the pump
Electric water heater	To supply heat for entire test section
Thermocouples (K-type)	To measure temperature at located position
Personal Computer	To save the data that transferred from data logger

3.8 Experiment Apparatus

3.8.1 Circulating Pump

The circulating pump is used in order to have a forced water flow through a system, on account of this experiment is about force convection. Since this experiment designed with close circuit and the amount of power required to overcome the friction inside the piping system is less than other pipe system, this type of pump is very appropriate. An electric motor with capacity of 0.5 HP is used to drive the circulation pump with inside blade rotation speed 2185 RPM. Figure 3.5 shows the circulating pump used in this experiment with electric motor.

Figure 3.5: Circulating Pump with Electric Motor

3.8.2 Flow Rate Meter

This digital flow rate meter is paddlewheel type flow rate meter. Applicable maximum pressure is 20.7 bar at 20.7 °C and maximum temperature is up to 93 °C. The range of flow rate that this flow rate meter can measure is 7 to 70 LPM. The accuracy is about 2% for full scale. Flow rate meter is placed after circulating pump and valve controller to measure the volumetric flow rate of the fluid flow through the tube.

Figure 3.6: Flow Rate Meter

3.8.3 Data logger

The data logger is used to record the temperature and transfer the data to the personal computer. For this project, TC-08 Thermocouple Data Logger from Pico technology is used. The range of temperature that can be measured is from -270 °C to 1370 °C.

Figure 3.7: TC-08 Thermocouple Data Logger

Source: Pico Technology

3.8.4 12V DC Power Supply

In the real application, radiator fan is using car battery to rotate the blade for cooling the coolant circulates in the cooling system. In order to have an electric power supply to radiator fan, 12V unregulated direct current power supply from Teletron is used in this project. Positive and negative radiator fan wire is connected to the DC power supply and 12V of voltage is chosen.

Figure 3.8: Unrated DC Power Supply

3.8.5 Thermocouples

Three thermocouples K- type is provided to the test section in this experiment as shown in Figure 3.9 which the location placed is at inlet of radiator, the outlet of radiator, and in the collecting tank. All these thermocouples have 0.1 °C resolution and need to calibrate before fixing them at the specified locations.

Figure 3.9: Thermocouples Placed at Three Locations

3.8.6 Radiator

The radiator is made to remove the heat by radiation and convection process of fluids through it. The fluids temperature at high temperature will decrease to lower temperature which radiator will emit the heat to surrounding space through fin in real application for vehicle cooling system.

The radiator also called as heat exchanger. As fluids circulate through the tubes in the radiator, the coolant transfers its heat to the tubes which the heat then transferred to the fins that are lodged between each row of tubes. The heat that transferred to fins then released the heat to the ambient air. Fins are used to significantly increase the contact surface of the tubes to the air which will increase the heat exchange efficiency. The radiator flat tube sized 38 cm x 38 cm x 0.5 cm, and tube sized 1.2 cm x 0.15 cm and the radiator is louvered fin-and-tube type, with 42 rectangular vertical tubes with stadium-shaped cross section (Figure 3.11).

Figure 3.10: Typical vehicle radiators used in experiment

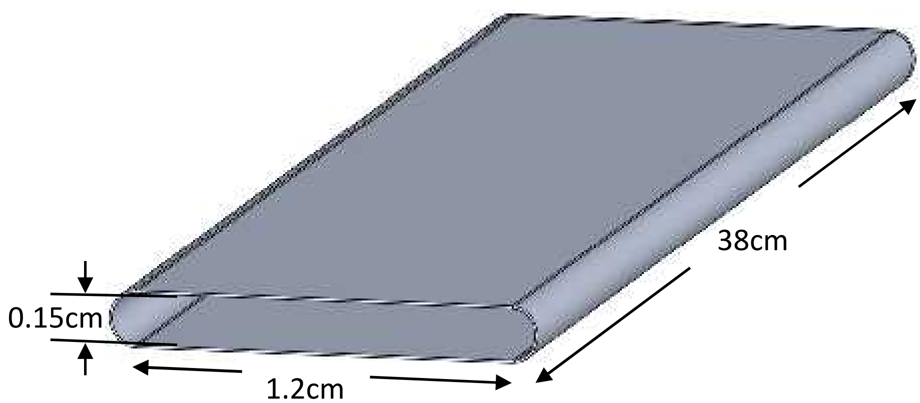

Figure 3.11: Schematic and dimesion of the radiator flat tube

3.8.7 Radiator Fan

Fluid that was flowing through a radiator is cooled with radiator fan and ambient air flow towards the radiator. This radiator fan has the maximum rotation speed of 9489.1 RPM and the experiment is held with the fan is at maximum rotation. The electric source is using 12V unrated direct current power supply.

Figure 3.12: Radiator fan used in experiment

3.8.8 Control Valve

In this experiment, the parameters are including the flow rate of the fluids. This valve controller used to limit the flow through it to control the flow rate, and placed after the circulation pump to control the flow rate of the fluids going out of the pump. Figure 3.13 have shown the valve that was used in this experiment as the control valve.

Figure 3.13: Control valve

3.8.9 Infrared Thermometer

The surface temperature of the radiator inside tube is measured by infrared thermometer, as a thermocouple's size is unfit in between the fin to attach to the radiator tube. The minimum of temperature that can be measure is negative 18 °C and maximum temperatue is 1450 °C. The surface temperature reading is recorded from inlet temperature is 90 °C to 60 °C,with interval 5 °C.

Figure 3.14: Infrared Thermometer

3.9 Running Experiment

The experiment in the beginning conduct with distilled water as an experiment control and check for result consistency. The experiment then proceeds with nanofluids using different concentration and flow rate. In the analysis intended for estimation of convective heat transfer coefficient (HTC) ,the assumption is made which is there is no loss to surrounding space and Newton's convective law is applicable to nanofluids in the nanofluids range tested.

Fluids that will used in the experiment which are distilled water and prepared sample of nanofluids (TiO_2 dilute by water as a based fluid) in volume concentration of 0.5 % volume, 0.7 % volume, and 1.0 % volume is set. The running experiment stage as follow:-

1. Distilled water is filled in the collecting tank
2. Power supply is on to operate the heaters
3. Circulating pump is on to force the flow through the test section.
4. Control valve is operated based on desired flow rate with estimate from flow rate meter apparatus.
5. Temperature T_{in}, T_{out}, and $T_{s,}$ and volume flow rate is noted when inlet radiator temperature is constant at 92 °C and start to record the reading of temperature with on the power supply of radiator fan at the same time.
6. The temperature is recorded by time until inlet radiator temperature is 60 °C.
7. Step 1 to 6 is start with flow rate at 12 and repeat at 15 LPM after done with 12 LPM.
8. When the experiment completed for sample one, collecting tank, test section need to flask before placed the other sample to make sure no nanofluids sample one is left inside.
9. The experiment is repeated for nanofluids with concentration of 0.5 % volume, 0.7 % volume, and 1 % volume.

3.10 Data Analysis

The data from the experiment are analyzed using circumstances equation to get the heat transfer rate, Q and HTC value of the nanofluids sample. Analysis flow to determine HTC from experiment data have shown in the next sub chapter.

3.10.1 Desired Reynolds Number

Based on the assumptions state from previous section, condition of the experiment is assumed:

I. There is no heat loss to environment.

II. Newton's convective law is applicable to nanofluids in the nanofluid range tested.

Mass flow rate is measured from flow rate meter during experiment conducted and calculated from product of density and volume flow rate.

3.10.2 Calculation of Experimental Heat Transfer Coefficient

To determine heat transfer coefficient (HTC) of experiment and Nusselt number, the following equation is used. According to Newton's law of cooling law, heat transfer is obtained from Eq. 3.10.

$$Q = hA\Delta T = hA\left(T_b - T_s\right) \tag{3.10}$$

h is heat transfer coefficient, A is area, T_b is bulk temperature, T_s is tube wall surface temperature.

Plus, heat transfer rate can be calculated with Eq. 3.11.

$$\dot{Q} = \dot{m}C_p\Delta T = \dot{m}C_p\left(T_{in} - T_{out}\right) \tag{3.11}$$

$$h = \frac{QA}{\left(T_s - T_b\right)} \tag{3.12}$$

h is heat transfer coefficient, *A* is tube heat transfer surface area.
For the tube heat transfer surface area,

$$A = Pl \tag{3.13}$$

P is the wetted perimeter of the cross-section and l for tube length for one tube. Nusselt numbers is calculated using the equation;

$$Nu = \frac{h_{exp} d_{hy}}{k} \tag{2.3}$$

Nu is average Nusselt number for the whole radiator, $\dot{m}$ is mass flow rate of fluid which is the product of density and volume flow rate of fluid, Cp is fluid specific heat capacity, A is peripheral area of radiator tubes, T_{in} and T_{out} are inlet and outlet radiator temperatures, T_b is bulk temperature which was assumed to be the average values of inlet and outlet temperature of the fluid that circulate through the radiator (Eq. 3.15), and T_s is tube wall temperature. In this equation, k is fluid thermal conductivity and d_{hy} is hydraulic diameter of the tube. The hydraulic diameter, d_{hy}, is a commonly used term when handling flow in noncircular tubes and channels.

$$D_h = \frac{4A}{p} \tag{3.14}$$

Using this term one can calculate many things in the same way as for a round tube, which is A is the cross sectional area and P is the wetted perimeter of the cross-section.

It should also be mentioned that all the physical properties were calculated at fluid bulk temperature.

$$T_b = \frac{T_{in} - T_{out}}{2} \tag{3.15}$$

3.10.3 Experimental Nusselt Number

Experiment Nusselt number is calculate from Eq. 2.3.

$$Nu = \frac{h_{exp} d_{hy}}{k} \tag{2.3}$$

Significant of Nusselt number to the heat transfer, when Nusselt number is higher, it represents very good heat transfer in convection situation. Since heat transfer coefficient, *h* is nominator in Nusselt number equation thus, high value of HTC represent very good heat transfer.

3.11 Experiment Parameter

There are two types of parameter in this experiment which is constant parameter and manipulated. There are three constant parameters which are,

1. Type of nanofluid (TiO_2 nanofluids water based).
2. Temperature inlet, T_i (92 ^oC)
3. Total tube area (7.26 cm^2)

And for the manipulated parameter there were two which are,

1. Volume concentration (0.5 % volume, 0.7 % volume, and 1.0 % volume)
2. Flow rate (12 to 15 LPM)

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter will present the experiment analysis result from the beginning until the end of the experiment. All evaluated data then being calculated then present as non-dimensionless result and graph. It then being discuss with the relationship of enhancement heat transfer when different nanofluids volume concentration were used with comparing two different flow rate.

In this study, water, and TiO_2 nanofluids water based with 0.5 % volume, 0.7 % volume and 1.0 % volume concentration are tested in experiment apparatus set up as Figure 3.4. The purpose of testing water is to verify the difference in heat transfer rate and heat transfer coefficient comparing among the fluids. The thermo physical properties needed for data analysis are specific heat, density, fluid thermal conductivity, hydraulic diameter of the tube, and thermal conductivity. These properties are temperature dependent and vary with the type and volume concentrations.

4.2 Nanofluids Heat Transfer Performance

4.2.1 Comparison of Water and Nanofluids Heat Transfer Rate (HTR)

The heat transfer rate is calculated to measure the heat that transferred or heat exchanged from radiator inlet to outlet in this project. This parameter is one of the significant values to measure the heat transfer performance. The heat transfer rate is calculated using Equation 3.2.

$$Q = hA\Delta T = hA\left(T_b - T_s\right) \quad (3.10)$$

To obtain the tube heat transfer surface area,

$$A = Pl \quad (3.13)$$

P is the wetted perimeter of the cross-section and l for tube length for one tube. The tube schematic and dimension is on Figure 3.11.

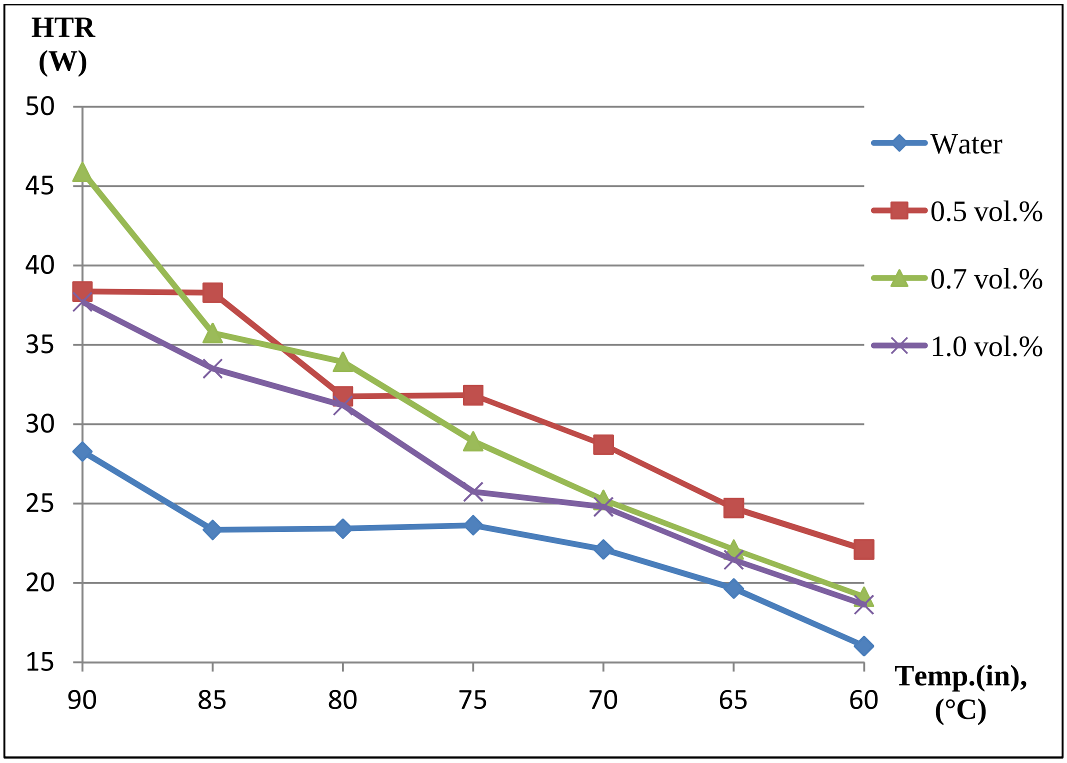

Figure 4.1: Comparison heat transfer rate with temperature inlet for 12 LPM

Figure show the comparison of heat transfer rate with temperature inlet for 12 LPM with varied nanofluids concentration with water. With flow rate at 12 LPM, the difference in heat transfer for various fluids is clearly observed than that flow at flow rate of 15 LPM (Figure 4.2). The higher heat transfer among the various fluids at 15 LPM flow rate, nanofluids 1.0 % volume is observed to have lower average heat transfer rate than nanofluids 0.5 and 0.7 % volume. Water is clearly having lower heat transfer rate below the nanofluids 0.5 % volume, 0.7 % volume, 1.0 % volume. It shows that the nanofluids heat transfer rate is higher than water in concentration of 0.5 %, 0.7 %, and 1.0 % nanofluids. Te highest in heat transfer rate difference is 61.6 % between nanofluids with concentration of 0.7 % and water at 90 °C, and followed by the difference 61.0 % between 0.5 % nanofluids with water at 85 °C. The average of increased HTR value after 75 °C is about 26.9% between the largest HTR difference for 0.5 % nanofluids and water. The trend of this heat transfer rate is decreasing with linear.

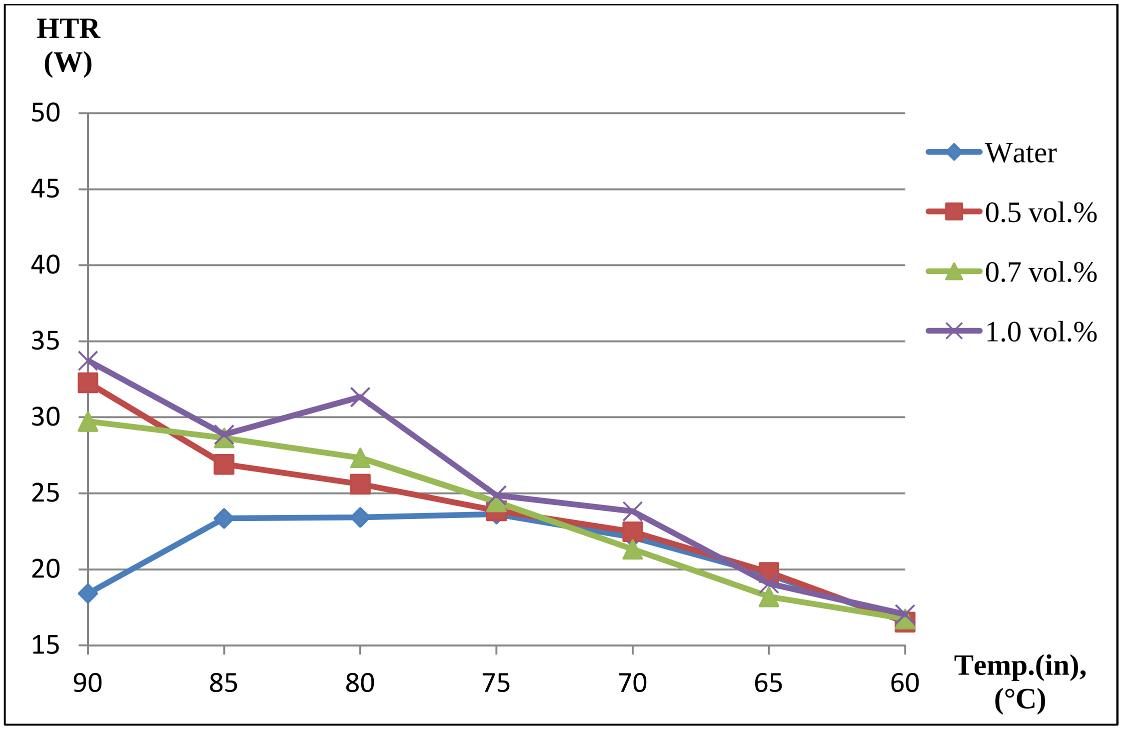

Figure 4.2: Comparison heat transfer rate with temperature inlet for 15 LPM

Heat transfer rate is having no significant difference for varied fluids. Among the fluids compared, the highest rate of heat transfer is nanofluids 1.0 % volume of TiO_2 with water based, follow by 0.7 % volume and 0.5 % volume nanofluids. As compare to water, these nanofluids have higher heat transfer rate from high temperature as 90 °C to 75 °C.

After temperature 75 °C to 60 °C, the heat transfer of water seems to higher slightly than nanofluids 0.5 % volume and 0.7 % volume. The value of heat transfer rate is significantly affected by difference in temperature inlet and outlet of radiator as the value of mass flow rate is constant and value difference in specific heat low with temperature. As this value in temperature difference is high, the heat transfer rate will high. The trend of the heat transfer rate line is also decrease linearly as heat transfer rate line with 12 LPM flow rate.

4.2.2 Comparison of Temperature at Radiator Outlet Differences

Temperature outlet is observed to analyze the difference for varied flow rate, which are 12 LPM and 15 LPM. The figure below is temperature outlet against time for each fluid with two different in flow rate, 12 LPM and 15 LPM.

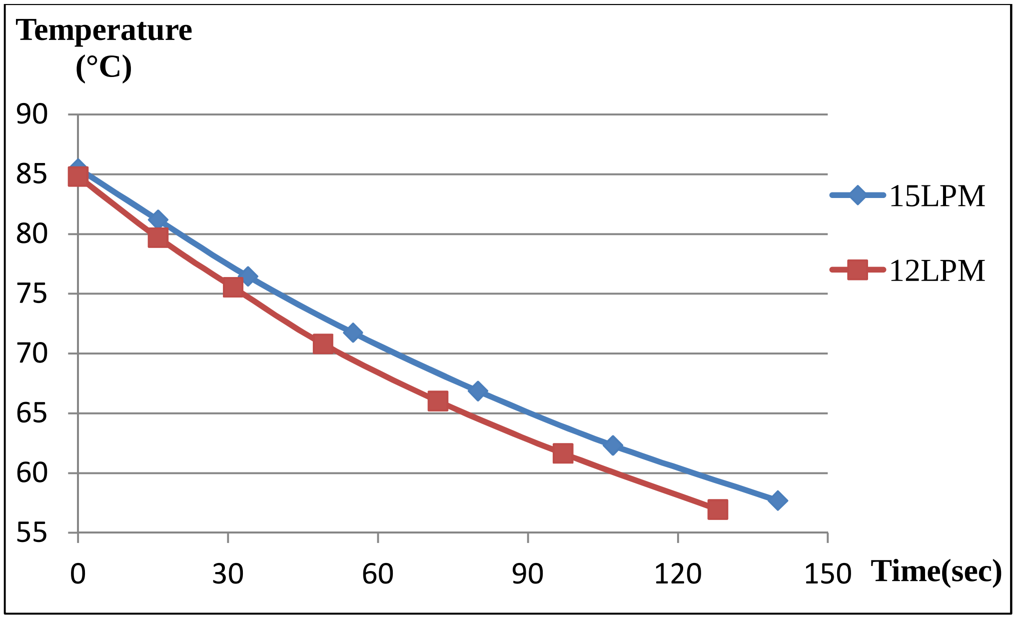

Figure 4.3: Temperature outlet at radiator for 0.5 % volume nanofluids with different flow rate

This graph has clear difference in temperature outlet between 12 LPM and 15 LPM flow rate. At last point of outlet temperature, the outlet temperature is lower for flow rate at 12 LPM and time taken to reach that point is less than outlet temperature for flow rate at 15 LPM.

It will means for this range of flow rate, the fact is, fluids with 0.5 % volume TiO_2 nanofluids is cooled early and slightly lower than that same fluids with 15 LPM flow rate. The difference at last point of the outlet temperature is 0.75 °C and difference in time is 12 second.

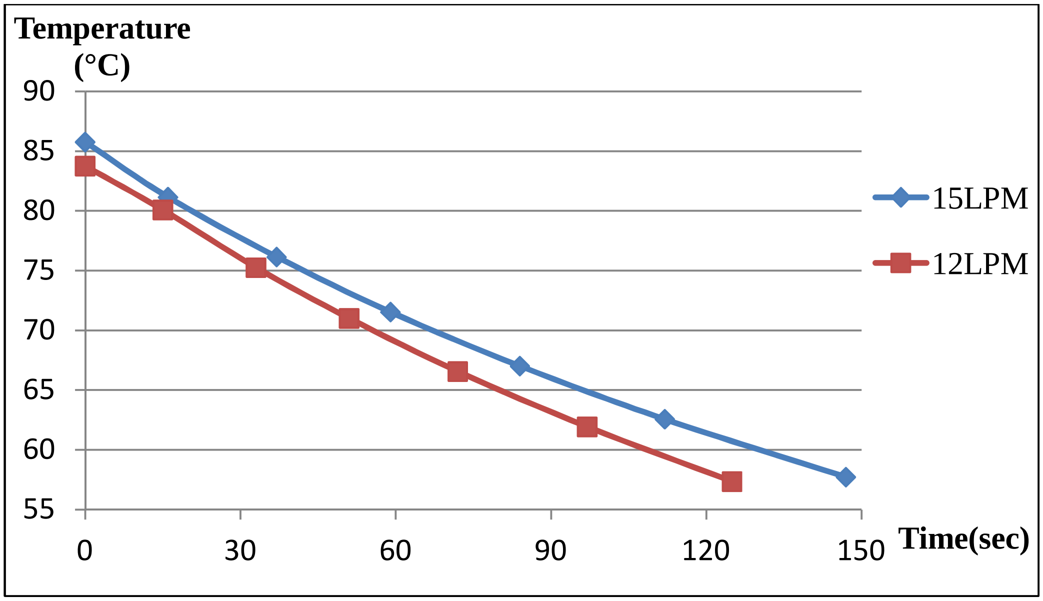

Figure 4.4: Temperature outlet at radiator for 0.7 % volume nanofluids with different flow rate

As previous graph for 0.5 % volume nanofluids TiO2, this 0.7 % volume nanofluid TiO_2 also have clear difference in temperature outlet between 12 LPM and 15 LPM flow rate. There are slightly differences with 0.5 % volume nanofluids which is at first point of outlet temperature is clearly different for 12 LPM and 15 LPM flow rate. This graph also show that, the outlet temperature is lower for flow rate at 12 LPM and time taken to reach that point is less than outlet temperature for flow rate at 15 LPM. It will show that for this range of flow rate, fluids with 0.7 % volume TiO_2 nanofluids is cooled early than those same fluids with 15 LPM flow rate and almost same temperature outlet. The difference at last point of the outlet temperature is 0.38 °C and difference in time is faster than previous case, which is 22 second.

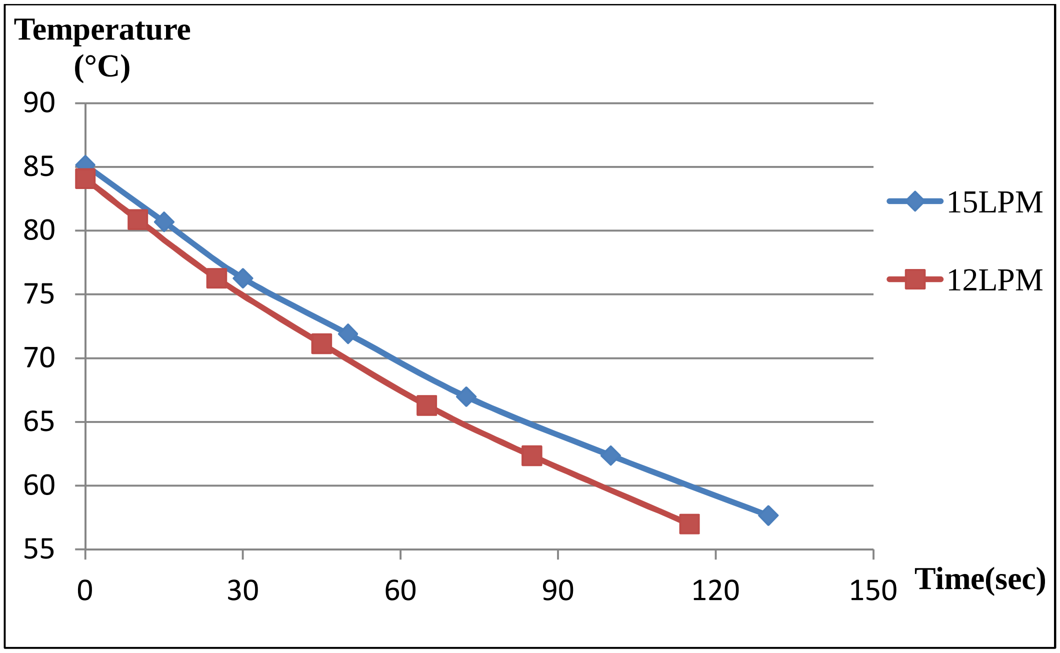

Figure 4.5: Temperature outlet at radiator for 1.0 % volume nanofluids with different flow rate

Same as previous graph 0.5 % volume and 0.7 % volume nanofluids TiO2 (Figure 4.3 and 4.3), this 1.0 % volume nanofluids TiO_2 also have clear difference in temperature outlet between 12 LPM and 15 LPM flow rate. There are same as previous outlet temperature against time graph for 0.5 % volume (Figure 4.3), at first point of outlet temperature is slightly same and no clear difference in outlet temperature for 12 LPM and 15 LPM flow rate. The difference in temperature for first point of outlet temperature is 1.07 °C.

This graph show that, ,the outlet temperature is lower at last point of outlet temperature for flow rate at 12 LPM and time taken to reach that point is less than outlet temperature for flow rate at 15 LPM. It give the meaning that for this range of flow rate, fluids with 1.0 % volume TiO_2 nanofluids is cooled early than that same fluids with 15 LPM and almost same temperature outlet. The difference at last point of the outlet temperature is 0.67 °C and difference in time is slower than previous case, which is 15 second.

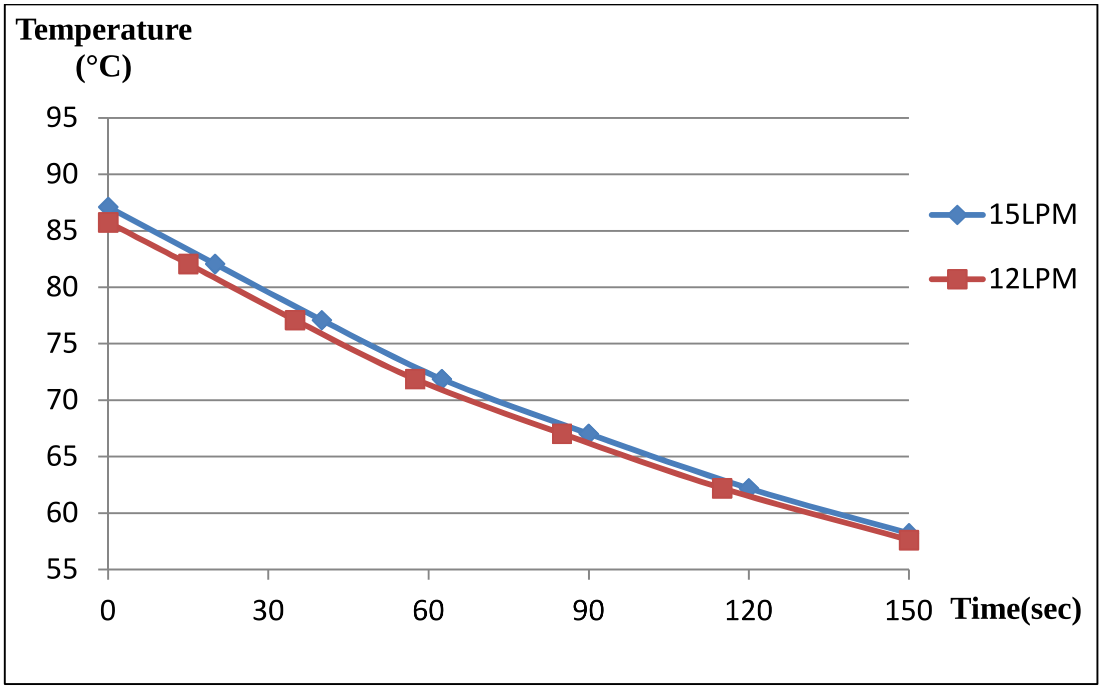

Figure 4.6: Temperature outlet at radiator for water with different flow rate

Different from previous graph for 0.5 % volume, 0.7 % volume, and 1.0 % volume nanofluids TiO2 (Figure 4.3, 4.3, and 4.4), this graph for temperature outlet against time for water is have slightly difference in temperature outlet between 12 LPM and 15 LPM (Figure 4.6). There are same as previous outlet temperature against time graph for 0.5 % volume and 1.0 % volume (Figure 4.3 and 4.5), at first point of outlet temperature is slightly same and no clear difference in outlet temperature for 12 LPM and 15 LPM. The difference in temperature for first point of outlet temperature is 1.36°C.

Similar with previous graph (Figure 4.3, 4.4, 4.5), at last point of outlet temperature, the outlet temperature is slightly lower for flow rate at 12 LPM but time taken to reach that point is same as outlet temperature for flow rate at 15 LPM. It give the meaning that for 12 LPM flow rate, no significant finding for difference in temperature cooled that same fluids with 15 LPM flow rate and almost same temperature outlet. The difference at last point of the outlet temperature is 0.61 °C and no difference in time.

4.2.3 Nusselt Number

Result of Nusselt number obtained with same Reynold number at inlet temperature 85 °C and 80 °C with varied nanofluids concentration and water is compared.

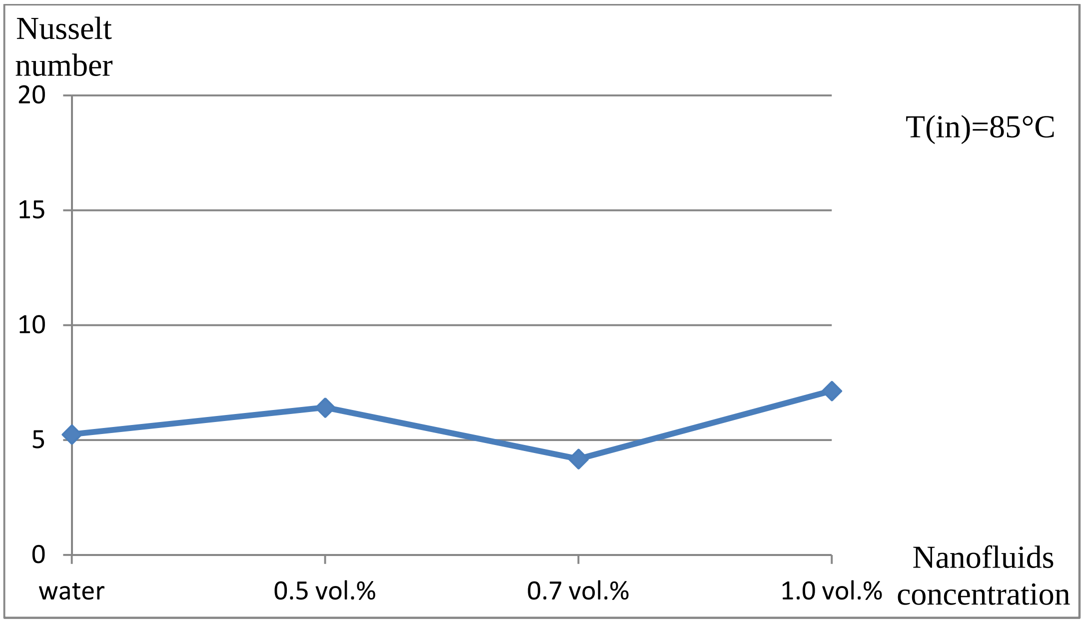

Figure 4.7: Comparison of Various Concentrations of Nanofluids and Water Nusselt Number with Re Number at 1820 for Temperature Inlet at 85 °C

Figure 4.7 shows Nusselt number increase comparing water to 0.5 % volume nanofluids but decrease at 0.7 % volume nanofluids and increase again at 1.0 % volume. It indicates that, at certain concentration of nanofluids such 0.7 % volume nanofluids in this project case will have lower HTC than water.

Nanofluids with 1.0 % volume TiO_2 have highest HTC than other concentration of nanofluids and water. When the operating temperature is 85 ^{o}C, the enhancement in nanofluid HTC for 0.5 % volume and 1.0 % volume concentration respectively is 22.2 %, 36.1 % while for 0.7 % volume nanofluids decrease 20.3 % when compared to distilled water at Reynolds number of 1820.

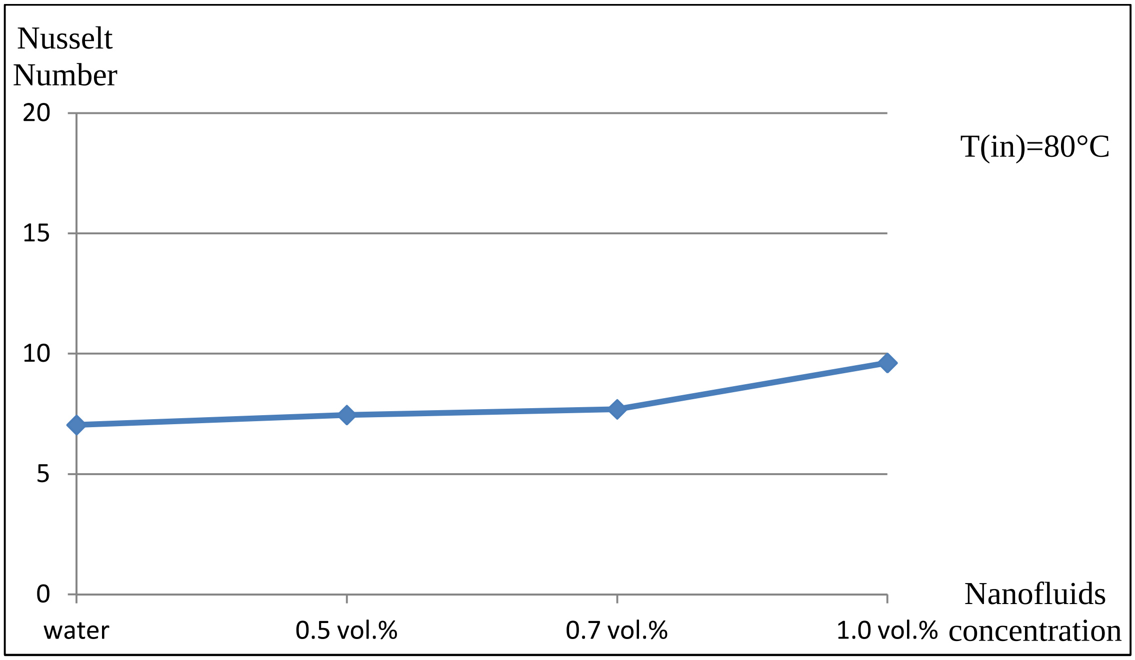

Figure 4.8: Comparison of Various Concentrations of Nanofluids and Water Nusselt Number with Re Number 2220 at Temperature Inlet 80 °C

Figure 4.8 show Nusselt number increase comparing water to 0.5 % volume and 0.7 % volume nanofluids but decrease at 1.0 % volume nanofluids. Compare to Figure 4.7, decrease in operating temperature will increase the Re number. For HTC value, nanofluids with 1.0 % volume have higher HTC than other nanofluids and water, which water have lowest HTC than other varied concentration nanofluids.

When the operating temperature is 80 ^{o}C, the enhancement in nanofluid HTC for 0.5, 0.7 and 1.0% concentration respectively is 5.9 %, 9.3 % and 36.6 % when compared to distilled water at Reynolds number of 2220.

CHAPTER 5

CONCLUSION

5.1 Introduction

In this last chapter, the project experiment is briefly concluded and summarized. The recommendation and future work also suggested for further project under the similar fields and scope.

5.1 Prominent Points of Thermo Physical Properties

The following conclusions are made from the analysis undertaken with TiO_2 nanofluids with water as the base fluid. The significant observations from the experimental analysis on thermal conductivity of nanofluids with different temperatures and concentration can be listed as:

(i) The thermal conductivity increases with volume concentration with condition applied

(ii) The heat transfer coefficient is higher for lower flow rate for applied condition

(iii) The thermal conductivity of metal and metal oxide nanofluids dispersed in water can be estimated using Eq. 3.15 and 3.16 respectively for concentration ¤ ≤ 3.7 % and $20 \leq d_p \leq 150$.

(iv) Prove that nanofluids have a better HTC than water used in car radiator and record the best increased in HTC up to 36.6 % with applied condition

(v) The mixture equation can be used for the estimation of specific heat and density of nanofluids from Eq. 3.8 and 3.10 respectively

(vi) The property relations could predict a decrease in heat transfer coefficients as observed by Pak and Cho, 1998 and Duangthongsuk and Wongwises, 2010 at certain operating conditions.

(vii) The proposed correlations of thermal conductivity given by Eq. 3.15 predict heat transfer coefficients obtained by various investigators with water based TiO_2 nanofluid satisfactorily.

(viii) The concentration, temperature and particle size are be considered simultaneously for evaluating the nanofluid thermal conductivity and viscosity.

5.2 Recommendation and Future Works

From the experiment that done, I suggest the future work and recommendation for the next further project:

(i) Experiments are to be conducted at different type of nanofluids to be compared to this coolant using TiO_2 nanofluids.

(ii) Experiments are to be conduct at controlled temperatures to have more constant readings of data.

(iii) Experiments are to be conducted at more various flow rates to have more various Re number.

(iv) Heat transfer coefficients are to be determined experimentally at different type of nanofluids and concentrations.

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APPENDIX A1

Experiment setup

APPENDIX A2

Experiment setup (Cont.)

APPENDIX B1

Device and equipments used

Radiator

Radiator Fan

Thermocouple 1

APPENDIX B2

Device and equipments used (Cont.)

Thermocouple 2

12V DC power supply

Water pump

APPENDIX B3

Device and equipments used (Cont.)

Flow meter

Valve controller

Data logger

APPENDIXES B4

Device and equipments used (Cont.)

Infrared thermometer

APPENDIX C1

Experiment stand making

APPENDIX C2

Experiment stand making (Cont.)

APPENDIX D1

Specification of device (flow meter)

Manufacturer	Blue-White Industry
Model	f-1000 Electric Flowmeter
Type of flow rate meter	Paddle wheel flow meter
Minimum flow rate	1.51 LPM
Maximum flow rate	30,3000.00 LPM
Type of display	LCD display
Power source	Battery (2 battery Alkaline AA)
Maximum pressure	20.7 bar at 20.7 °C
Maximum temperature	93 °C

Source: Blue-White Ltd

APPENDIX D2

Specification of device (Pico USB TC-08 thermocouple data logger)

Number of channels (per TC-08)	8
Conversion time	100 ms (thermocouple and cold junction compensation)
Temperature accuracy	Sum of ± 0.2 % of reading and ±0.5 °C
Voltage accuracy	Sum of ± 0.2 % of reading and ±10 µV
Overload protection	± 30 V
Maximum common mode voltage	± 7.5 V
Input impedence	2 MΩ
Input range (voltage)	±70 mV
Thermocouple types supported	B, E, J, K, N, R, S, T

Source: Pico Technology

TC-08 Resolution

Thermocouple type	**Overall range (°C)**	**0.1 °C resolution**	**0.025 °C resolution**
B	20 to 1820	150 to 1820	600 to 1820
E	-270 to 910	-270 to 910	-260 to 910
J	-210 to 1200	-210 to 1200	-210 to 1200
K	-270 to 1370	-270 to 1370	-250 to 1370
N	-270 to 1300	-260 to 1300	-230 to 1300
R	-50 to 1760	-50 to 1760	20 to 1760
S	-50 to 1760	-50 to 1760	20 to 1760
T	-270 to 400	-270 to 400	-250 to 400

Source: Pico Technology

APPENDIX E1

Gantt chart PSM 1

ACTIVITIES	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Meet with supervisor brief introduction with FYP 1	■	■													
Finalize objectives, Scope and Problem statement		■	■												
Literature Review				■	■	■	■	■	■	■	■	■	■	■	
Chapter 1					■	■									
Chapter 2							■	■	■	■	■	■	■		
Chapter 3									■	■	■	■	■	■	
Test Rig preparation											■	■	■	■	
Apparatus Preparation														■	
FYP 1 presentation															■

APPENDIX E2
Gantt Chart PSM 2

ACTIVITIES	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7	Week 8	Week 9	Week 10	Week 11	Week 12	Week 13	Week 14	Week 15
Meet with supervisor brief introduction with FYP 2	■	■													
Apparatus preparation		■	■	■	■										
Test rig preparation				■	■	■	■								
Nanofluids preparations					■	■	■								
Experiment (nanofluids)							■	■	■	■	■				
Data analysis									■	■	■	■			
Chapter 4 : Results & discussions											■	■	■	■	
Chapter 5 : Conclusion														■	
FYP 2 presentation															■