COMPUTATIONAL SIMULATION OF ENGINE COOLING SYSTEM PERFORMANCE OF A COMMERCIAL CAR

by

Chen Tien Hao

22616

Dissertation submitted in partial fulfilment of

the requirements for the

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With Honours

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Universiti Teknologi PETRONAS

32610 Seri Iskandar

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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Approved by,

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(Dr Mior Azman b Meor Said)

UNIVERSITI TEKNOLOGI PETRONAS
BANDAR SERI ISKANDAR, PERAK
January 2020

CERTIFICATION OF ORIGINALITY

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

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(CHEN TIEN HAO)

ABSTRACT

Engine cooling system one of the important parts for a vehicle which it responsible is to maintain the engine temperature to work at an optimum temperature. Heat transfer coefficient of engine coolant is an important aspect in the performance of engine cooling system. This paper analyses on the simulation of coolant performance in an engine cooling system by using different concentration (0.1%, 0.25% and 0.5%) MWCNT nanoparticles in water/ethylene glycol based multi-walled carbon nanotubes (MWCNT) and lastly comparison between the base coolant which is ethylene glycol + water. As many researchers had proved that nanofluid's heat transfer properties had improved compared to base coolant. In furtherance to analyse the performance, the nanofluid was simulated in engine cooling systems of Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10 using Simulink software. Flowing of liquid in the system had been controlled in the rage of 2, 3 and 4L/min. Thermodynamics and physical law were used to derive the mathematical equation to implement into the Simulink model. The simulation results revealed that the heat transfer coefficient was increased as the concentration of nanofluid increased. In addition, Reynolds number was increased when the flow rate of nanofluid in the tube increased. As comparison between Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10, the flow rate used in Yamaha engine cooling system should lowered because due to the tube inside the engine cooling system, higher flowrate caused turbulence flow in the tube which it is not recommended.

ACKNOWLEDGEMENT

I would like to take this opportunity to that my research supervisor, Dr Mior Azman b Meor Said for his patient guidance and dedicated involvement in every step throughout the process. He has showed me different ways and methods to complete different tasks and provide me with knowledge in relevant topics of my studies. Additionally, I also want to express my gratitude to my parents and friends who gave me physical and technical support to complete the project. I am ever grateful to have them with me for the past eight months. Without their support and understanding, this paper would never be accomplished. This dissertation stands as a testament to all your unconditional love and encouragement.

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CHAPTER 1

INTRODUCTION

1.1 Background Study

In the past decades, vehicle engine performance had been rapidly developed. Every manufacturer competing each other in producing highly efficient engine at low cost in order to meets customer demands [1]. An efficiency engine does not only base on the performance but also fair for less emission and better fuel economy. The engine performance can influence by many systems such as fuel ignition system, emission system, cooling system and so on. A commercial car is where a car fitted with internal combustion engine to carry a small number of people. It is normally powered using petrol or diesel as the combustion fuel. Internal combustion engine is a machine to convert chemical energy which is the fuel into mechanical energy. During the combustion, the internal combustion engine burning the fuel with air inside the engine and therefore thermal energy is then created to drive a piston. There is about 70% of vitality in the fuel is change over into heat where the engine cooling system comes in to take on the job on cooling down. The cooling rate of radiator in engine cooling system is one of the parameters that will influence the performance.

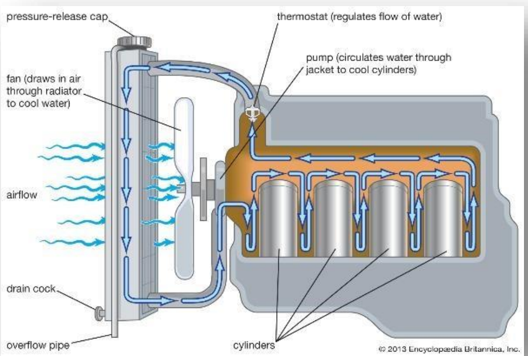

Figure 1.1: Engine Cooling System

There are two types of engine cooling system in the market which is the aircooled and water-cooled types. Air cooled engine allows heat to distributed to the surrounding by large surface area. The fins are covering around the engine block which can allows the heat from the engine release through the fins, giving the powertrain of staying cool under load. Air cooled has its benefits, the weight of the engine cooling system can be reduced due to the lack of coolant and radiator needed for the system. Furthermore, the maintenance was almost non-existed with the less components for the engine cooling system. This air-cooled engine cooling system is suitable for small capacity engines due to the heat the engine produced is low. As to accommodate higher performance of a car, a higher efficient engine cooling system needed for the car, so here comes the innovation of water-cooled engine cooling system.

When the car started, the engine will heat up to working temperature as quickly as possible. As when it reaches the optimum temperature, the cooling system will kick in to prevent the temperature to go higher. The wasted heat produced from the combustion is transferred from a closed loop water pumped through the entire engine to the atmosphere by using a radiator. Engine cooling system takes care of excess heat produced during the combustion of engine operation as engine does not like excess amount of heat. As water heat capacity is higher than air, therefore it can remove heat more quickly from the engine. However, engine coolant with low thermal conductivity can limits the cooling efficiency of a car radiator. Ideally, a coolant must have high thermal capacity, low viscosity, not toxic, and not corrosive to the engine cooling system. A 100% pure water is not recommended to use as a coolant as water freezes at 0℃, hence, just in case it's snowing, the water freeze in the engine can cause bad damage to it. Damages can cause cracks in the radiator, cylinder and block. But even in a hot climate, water can still damage the engine cooling system because water consists of minerals and it tends to build up in the radiator and cause corrosion to the engine cooling system or the build-up minerals clogged up the system.

Ethylene glycol is a commercial coolant which widely used in automotive and manufacturing industry. It acts as a coolant to reduce overheating in hot climate and keep the car engine from freezing in the cold climate. Ethylene glycol is normally mixed with water. A standard mixture is about 50% ethylene glycol and 50% water. The mixture of these two liquids increases the boiling point from the initial 100℃ to 105℃.

Nanofluid is a carrier liquid such as water or ethylene glycol dispersed with nanoparticles. The nanoparticles dispersed into the carrier liquid changes the fluid flow and the heat transfer characteristics too. Multi-walled carbon nanotubes (MWCNT) is one of the strongest materials known to human. It has unique structure and electrical properties that make it the possible to apply into various applications. Ideally, MWCNT is consists of layers of graphene that form a tube shape.

In this research, Simulink is a simulation platform of MATLAB. Simulink provides an interactive, graphical environment for modelling, simulating and analysing of the dynamic systems. Simulink allows graphical user interface (GUI) for building models as block diagrams in the modelling system. User can deliver an fully operational model that would otherwise require hours to work in the laboratory. Furthermore, by using simulation, it saves down a lot of cost in building the actual prototype and might having a lot of mistakes in the design too. Simulink encourages user to try things out by changing the parameters and immediately see what the results is and suitable for exploration.

1.2 Problem Statement

Car manufacturers had reached their limits on increasing the efficiency by increasing the number of fins onto the radiator. If they were to increase the number of fins onto to the radiator to provide greater heat transfer area to enhance the air convective heat transfer coefficient, the radiator size will need to be increase and causes the weight of the engine cooling system to increase also. This makes them difficult to maintain the engine cooling size in compact. In addition, a weighty engine cooling system will decrease the efficiency of the car performance although the enlarge size of radiator improve the efficiency. Accordingly, there is a need of new and imaginative heat transfer fluids to improve heat transfer rate in a vehicle radiator. Furthermore, the commercial coolant, ethylene glycol and water mixture exhibit very low thermal conductivity. With the development of nanotechnology, Nanofluids as the new generation heat transfer fluids has been found that they offer higher thermal conductivity. Nanofluid also has better heat transfer coefficient compare to commercial coolant but the research and simulation on the nanofluid are lacking. Lack of research on this topic did not provide any simulation answer or validate to some of the experimental results. Experimental result needs more time to compute but simulation is better and more efficient to optimize a system. Analysis and comparison studies with different concentrations of nanofluids will be done to achieve the best result for engine cooling system performance.

1.3 Objectives

The purpose of this research study is to simulate an engine cooling system by using different concentration of nanofluid. The main objectives of this study are as follows:

i. Perform computational simulation with nanofluid in engine cooling system.
ii. Compare engine cooling system performance with nanofluid and commercial coolant.
iii. Perform optimization studies on which concentrations of nanofluid properties will give the best result of performance from engine cooling systems.

1.4 Scope of Study

The research will be conducting simulation using MATLAB – Simulink instead of using other simulation software because I am having some basic knowledge of using MATLAB which I had already learned them during the previous classes. During the simulation, the parameters of intake temperature will be set at 40℃ and the flowrate of coolant is set from 2L / min - 4L / min with 1L / min of interval. While for the engine cooling system, the study will only focus on using Perodua Kelisa 1000cc. Every parameter needed are based on this type of engine cooling system. The concentration of MWCNT to be inserted into ethylene glycol is 0.1%, 0.25% and 0.5% for the simulation. All the result concludes after the simulation will be using heat transfer coefficient as the main comparison value. At the end of the research, validation and verification of the results is needed to be compute by comparing the simulation results with the experimental results from research paper [1].

CHAPTER 2

LITERATURE REVIEW

2.1 Engine cooling system

The best automotive design for performance, fuel consumption, safety, etc has always involve in strong competition among the automotive industry. Engines do convert chemical energy into mechanical energy by combusting the fuel in order to turn the wheels. But not all the combusted energy converted into mechanical energy, as only about 30% of fuel converted to mechanical energy. The remaining 35% of heat generated has lost to the engine cooling system and another 35% is losses through the exhaust [2]. Heisler [3] had said that the 30% of heat generated during the combustion had transferred to the cylinder head and bore.

2.2 Types of Engine Cooling System

To run the engine smoothly with optimum performance, the engine needs to be cooled, this is where the engine cooling system being created from using air-cooled till the current liquid-cooled engine cooling system. The current most popular engine cooling system being used is liquid – cooled typed as it provides stable performance during high speed or in traffic jams. Heat exchanger in the liquid – cooled engine cooling system is named as radiator. The radiator removes excess heat produce from the engine by circulate the coolant through it. Amrutkar and Patil[4] said that the factors like air flow, coolant flow, fin density, air inlet temperature and coolant properties will affect the cooling performance of the entire system. The **Figure 2.1** shows the liquid – cooled engine cooling system while **Figure 2.2** shows the air – cooled engine cooling system.

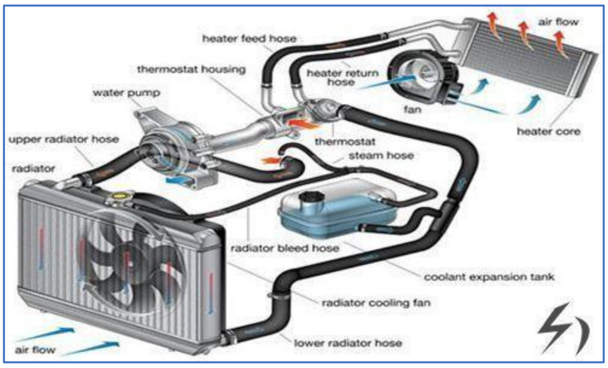

Figure 2.1: Liquid-cooled Engine Cooling System

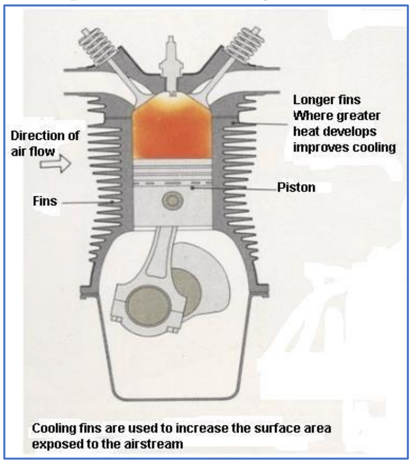

Figure 2.2: Air-cooled Engine Cooling System

2.3 Development of Nanofluid

Choi [5] said that nanofluids are develop for energy efficiency as to reduce the size and weight of cooling system by 10% and increase the fuel efficiency by 5%. Furthermore, higher engine loading like engine running at higher RPM will also cause the engine to get hot quickly, resulting the coolant temperature to rise. A smaller engine cooling system can improve the weight and subsequently the fuel economy. A larger radiator positioned to sits at the front part of engine to boost the cooling effect but in resultant increasing the aerodynamic drag and fuel consumption too. Bhatt, Patel and Vashi [6] mentioned in Nanofluids: A New Generation Coolants, that the utilization of nanofluids as coolants would take into consideration for smaller size and better positioning of the radiators as the efficiency of Nanofluids is better than current commercial coolant. Peyghambarzadeh [7] used aluminium oxide based water nanofluid in the engine cooling system to determine the tube side heat transfer coefficient while it was determined using different volume concentrations of nanofluid between the range of 0.1% to 1%, mass flow rate of the coolant was at 2 – 5L / min, and the temperature of the inlet is at the range of 37℃ to 49℃.

2.4 Carbon Nanotubes Nanofluid

There are many researchers reported that carbon nanotubes can contribute high thermal conductivity, aspect ratio, specific surface area and lower specific surface area, specific gravity and thermal resistance compared to normal nanofluid. Ding et.al. [8] said the multi-walled carbon nanotubes had an enhancement in heat transfer of 350%. They found out that high concentration of nanofluid will cause uneven distribution of nanoparticles which cannot give better performance. A 14.1% of increment had found by Teng and Yu [9] from the performance MWCNT nanofluid. Nanofluids thermal conductivity are based on the particles volume fraction and thermal conductivity of base fluid and particles. Eventually, Mintsa [10] found out that small particle size can improve thermal conductivity at the same concentration of nanofluid. With the help of the creation of nanofluid, the temperature of the engine can be maintained at a lower stage which then helping the performance and fuel consumption of the engine to improve as the load to the radiator is smaller than before said by Gade.K, Navale.M, Shelar.P [11]. **Figure 2.3** shows the structure of Multi-Walled Carbon Nanotubes.

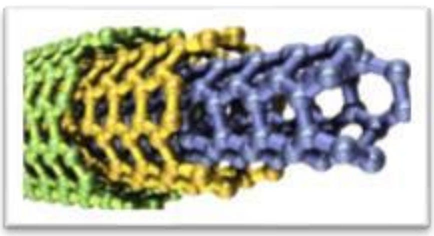

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Figure 2.3: Multi-Walled Carbon Nanotubes Structure

2.5 Performance of Nanofluid

Furthermore, Amrutkar.P.S and Patil.S.S [4], 2013 said that nanofluid based coolant can increase the performance of engine cooling system compared to commercial coolant which is the ethylene glycol + water, mixture of 50% / 50%. As the thermal performance of the nanofluid is increase, therefore, it has a higher thermal conductivity where it requires lesser power compared to the same radiator which using ethylene glycol as coolant. With a proper selection of nanofluid, it had been proved to step up the heat transfer of engine cooling system by a proper selection of size, material, shape, and base fluid type, which is also having outstanding performance than our usual commercial coolant. Nanofluid does not only benefit on heat transfer but some of them has high dispersion stability, which means they can help in reducing pump size or entire size of the cooling system, reducing particle clogging and having adjustable properties.

One of the researchers, Choi [5] has proved that engine cooling system efficiency can be improve by using nanofluid as coolant for the engine cooling system. Nanoparticles are solid size particles which are in nano-meter sizing. Nanoparticles are inserted to the base heat transfer fluid for better thermal conductivity. It was discovered that nanofluids are having much higher temperature dependent thermal conductivity at low particle concentrations than conventional radiator coolants without nanoparticles. Besides Choi, there are many more researchers out there proved that nanofluids have significantly better heat transfer properties than base water coolant. The effect of temperature, particle size and volume fraction can enhance thermal conductivity of the water based nanofluids of copper oxide and alumina as stated by a researcher, Azmi [12]. As from what the author said, the smaller the molecule size, the greater the effective thermal conductivity of the nanofluids at the similar volume fraction.

2.6 Disadvantages of Nanofluid

Nanofluid is not all about advantages only, it has disadvantages which it is costly and stability. The production cost of nanofluid is higher because the production methods require sophisticated and modern equipment. Moreover, the production of nanofluids are difficult and complex which makes the cost of production increases [6]. The base fluid contains other ions and reaction products which make it difficult to separate from the fluids. While another difficulty met during the manufacture of nanofluid is the nanoparticle has the tendency to agglomerate into a bigger particle. To encounter this, base fluid with the nanoparticles are added with particle dispersion additives which this exercise can change the surface properties of particles, but preparation of this way may contain unacceptable levels of impurities. Nanofluids does need a basic criterion of long-term stability for its nanoparticles dispersion as its stability have great corresponding relationship with the improvement of thermal conductivity. Eastman [13] found out that fresh nanofluids at the first few days has a slightly better thermal conductivity than the nanofluids that stored for 2 months. Nanofluids may tend to degrade when kept for significant stretch of time.

2.7 Stability of Nanofluid

Stability of nanofluid is part of the concern where the nanofluid still cannot be commercialize [14]. Nanofluid has poor stability because of the interaction between itself and between it itself and the liquid it surrounds with. The particles surface has attractive force from Van der Waals causes the particles to attract each other into framing groups or agglomerations of particles and separate from the base liquid and settle at the base because of force of gravitational. While another force is the electrical twofold layer appalling power which will in general separate the particles from one another by means of steric and electrostatic shock mechanism. Stability is important factor in order to commercialize the nanofluids as it conserves its thermophysical properties when the shelf-life of the product extend. To get a stable nanofluid, the electrical twofold layer appalling power ought to outperform the Van der Waals appealing powers.

2.8 Nanofluid in Perodua Kelisa 1000cc Engine Cooling System

From the paper [1], it had done an experimental test to evaluate the heat transfer coefficient and thermal performance of Perodua Kelisa 1000cc engine cooling system using ethylene glycol + water based MWCNT coolant. The experiment started with the preparation and evaluation of nanofluid with different concentration of MWCNT. This experiment requires various physical properties of the nanofluid such as density, thermal conductivity, viscosity, and specific heat. The experiment runs with test facility which consists of a coolant tank, Perodua Kelisa 1000cc engine cooling system, pump, fan and instrumentation for measuring the temperature. The engine cooling system consists of 33 finned tubes made of aluminium. Each of the tube is in 137mm length, 15.5mm width and 1.8mm height. The coolant is flowing through 33 tubes with different flow rates of 6, 4 and 2L/min. The heat transfer coefficient was 307.05 W/m^2K for 0.1% volume concentration of nanofluid while at 0.25% volume concentration, the results had gone up to 569.69 W/m^2K and at 0.5% volume concentration, the results showed at 717.47 W/m^2K.

2.9 Simulation Software

A good simulation tool can reduce in a lot aspect on development of these complex system such as the time and the expenses cost. MATLAB Simulink simulation system is broadly utilize in automotive industry as it can efficiently co-simulate with vehicle simulation programs and applicable to evaluate various control algorithms [15]. MATLAB Simulink is a graphical based programming for modelling or simulation.

2.10 Summary

To conclude the literature review, engine cooling system had been revised thoroughly on its theory and performance analysis. The challenges to make the engine cooling system performance increases lies on many factors, with one of the main contributors –nanofluid. As from the studies and experimental results that have been done from the past papers, there are few types of nanofluids that have met all the criteria on the working coolant selection. The chosen nanofluid for the future simulation will be 0.1%, 0.25% and 0.5% MWCNT nanofluids. These coolants were chosen mainly based on the properties and the past experimental results of the fluids. Besides that, the analysis had been done during the experimental research to the nanofluids and they were proven to be reliable candidates. Furthermore, nanofluid working stability should be improve so that it will not degrade over time. The experimental paper [1] will be using as reference for the research project

CHAPTER 3

METHODOLOGY

3.1 Flowchart of Research Project

Based on the objective at Chapter 1, this project mainly focusses on the simulation study of the engine cooling system performance using different concentrations of nanofluid. After the end of the simulation, analyse and validation on the performance of the nanofluid require by comparing the result with experimental results. The vital approach of this project is shown via research planning flowchart shown in **Figure 3.1**.

3.1.1 Phase I

During the first phase, the focus of the research will be on the detailed study on the literature review and the selection of nanofluid as working coolant on engine cooling system. Furthermore, more exploration on the research paper and simulation examples for comparison and review.

3.1.2 Phase II

In the phase II, the modelling of the engine cooling system will be design. After the designation of modelling, the model designed will be running on simulation with different concentration of nanofluid that has been chosen at phase I.

3.1.3 Phase III

Simulation results are being validate and compare with experimental result from literature review. If all the nanofluid failed from validation, the modelling system will be revised, and amendment will be made. In the end, the simulation results will be analysed and conclude the project on which concentration of nanofluid has the best performance in the engine cooling system.

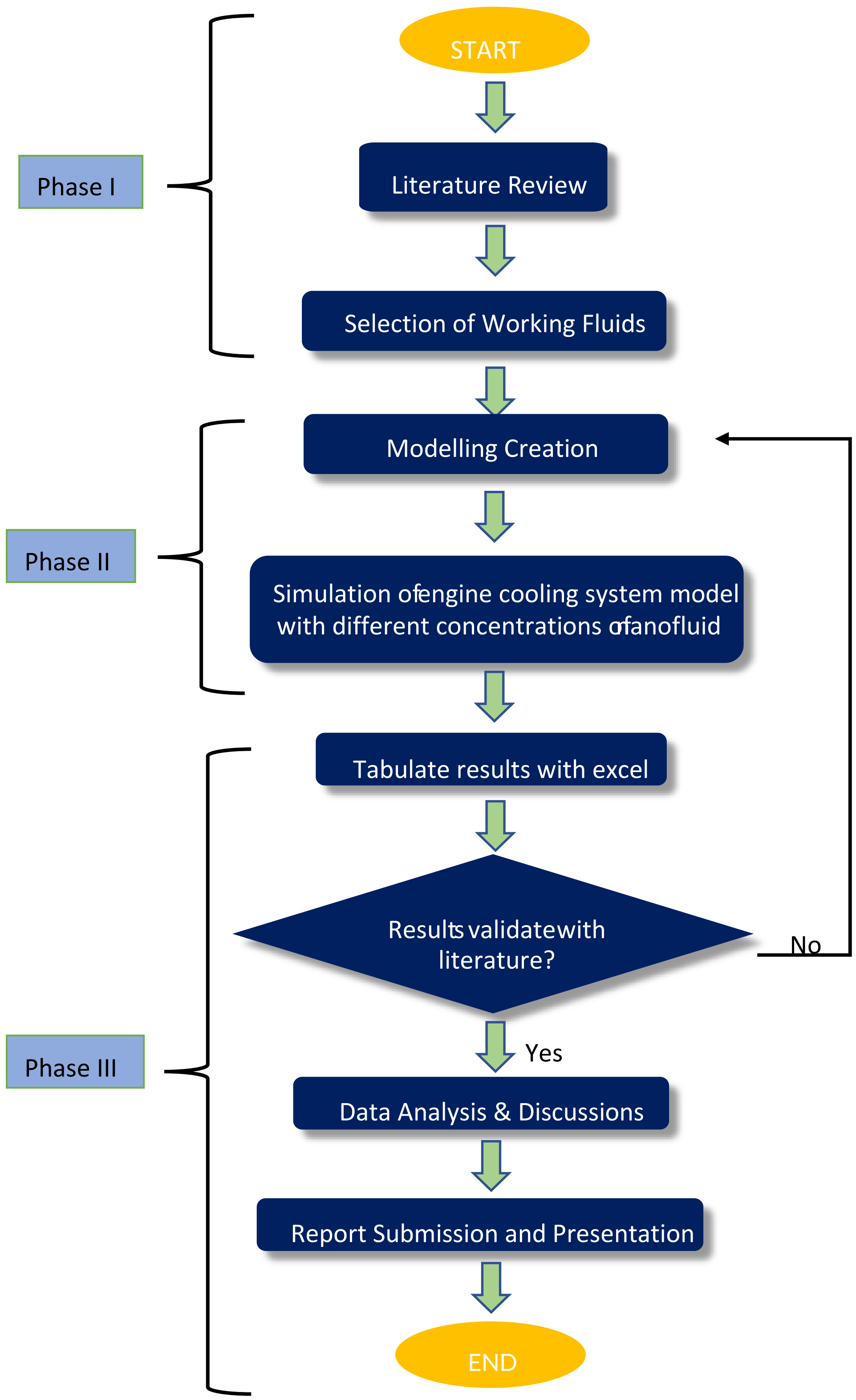

Figure 3.1: Project Flow Chart

3.2 Key Milestones

Milestone of a project is a task in a duration that shows an important achievement in a project. It is a project management to make sure on the important events are achieved within the time frame. The progress of the project can be kept track by listing a few major tasks together with its desired timeframe to complete. The key milestones for this project are shown in **Table 3.1**.

Colour Code	Key Milestone for FYP I (September 2019 - December 2019)
	Literature study and selection of coolant types and concentration
	Set the validation for simulation result
Colour Code	Key Milestone for FYP II (January 2020 - May 2020)
	Simulation of engine cooling system with different concentration of nanofluid
	Result analysis and interpretation on each concentration nanofluid

Table 3.1: Key Milestones

3.3 Gantt Chart for FYP I and FYP II

Gantt chart acts a guideline and target for completion of the research project within the two semesters. Each task has been allocated with duration throughout the 28 weeks given duration. The **Table 3.2** shows the Gantt chart and the allocation timeline for each project activities.

Colour Code	Key Milestone for FYP I (September 2019 - December 2019)
	Literature study and selection of coolant types and concentration
	Set the validation for simulation result
Colour Code	Key Milestone for FYP II (January 2020 - May 2020)
	Simulation of engine cooling system with different concentration of nanofluid
	Result analysis and interpretation on each concentration nanofluid

Table 3.1: Key Milestones

Project Activities	FYP I (September 2019 - December 2019)													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research on Project Title & Data Gathering														
Literature Review														
Selection of coolant types for engine cooling system from literature														
Set the validation for simulation result														
Understand basic operation and functionality of simulation software														

Project Activities	FYP II (January 2020 - May 2020)													
Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Literature Review														
Validation of the modelling system														
Simulation of the model with selected coolant														
Result gathering and analysis on each coolant														
Tabulate and result discussion on the performance														

Table 3.2: Gantt Chart

3.4 Simulation Modelling System

Simulation in Simulink using simple symbol to simulate a mathematical model which can speak to a physical framework. All the models in Simulink are presented as block diagrams. Then the mathematical equations of an engine cooling system are serving as the basic for a Simulink model is extract from physical laws. Each component in the engine cooling system is designed with mathematical sub-models and then all are amassed together into an engine cooling system model. The modelling is based on Yamaha 5CA-E2460-10 engine cooling system. As mentioned earlier, Simulink is a block diagram-based simulation environment in which causality must be decide by user in offline condition. For many systems this is satisfactory such as control system algorithms however descriptions in closed network form such liquid channel work or electric circuits must have the governing equations resolved offline and meticulously entered.

3.5 Radiator represents in Simulink

Responsibility of the radiator is for the heat exchange from engine coolant to the air. The radiator is made of aluminium where it has a pipe that circulates the coolant. The fins on the radiator use to enlarge the surface area for the heat exchange. The coolant will remove heat from the combustion chamber and engine block. The coolant will start circulating, when the engine reaches its working temperature, by going through the radiator to cool the engine. The working temperature of engine is between 90℃ - 100℃.

3.6 Heat Transfer Equations inside Radiator

A temperature difference between two or more mediums cause heat transfer occurs. Heat transfer occurs in from three scenario, which is conduction, radiation, and convection. Convection and conduction remove the build-up heat that is produced during the combustion in the engine. During the heat being transferred to the coolant, conduction and convection also occurs. These two processes explain the cooling effect of ambient air flowing and its interaction with the radiator core to redistribute generated heat from the system to the passing airflow. The symbols used in the design of radiator model in Simulink are given in **Table 3.3** below.

Symbol	Description	Units
C_p	Specific heat capacity	Jk/(gK)
m	Mass of coolant	kg
$\dot{m}$	Coolant mass flow rate	Kg/s
Q_{c-s}	Convection heat transfer rate from the coolant to inner wall	W/s
Q_{s-s}	Conduction heat transfer rate through the radiator wall	W/s
Q_{s-a}	Conduction heat transfer rate from the radiator wall to the air	W/s
Q_{total}	Total heat transfer rate from the coolant to the air	W/s
T_i	Engine coolant temperature	K
T_o	Coolant outside temperature	K
T_s	Outside air temperature	K
U	Heat transfer coefficient	$W/(m^2K)$
A_t	Cross section area of radiator tube	m^2
A_r	Area of the radiator	m_2

Table 3.3: Symbols used in the design of radiator model

The heat loss in the engine cooling system as the temperature difference between the intake and exhaust point, where the exhaust temperature is assumed to be the same as the engine coolant temperature. The total heat transfer rate,

Q_{total} is calculated by Equation 1.

$$Q_{total} = \dot{m}\, Cp(T_i - To) \text{- } \mathbf{Eq.1}$$

where the coolant mass flow rate is $\dot{m}$, Cp is the specific heat capacity, T_i is engine coolant temperature and T_o is temperature of radiator outlet.

Convection occurs when heat energy is transfer from a surface to moving fluid at various temperatures. The heat transfer per unit surface through convection was first depicted by Newton and the connection is known as the Newton's Law of Cooling.

Q_{c-s} is convection heat transfer rate from the coolant to inner wall and is given by,

$$Q_{c-s} = UA_r (T_o - T_s)\text{,- } \mathbf{Eq.2}$$

Where U is heat transfer coefficient, A_r is area of radiator and T_s is outside air temperature.

Heat energy transferred between the two surfaces having different temperatures is known as conduction. The amount of heat transferred between the walls of the radiator tube is very small and therefore neglected.

Q_{s-s} is heat loss rate by conduction through the radiator wall and is given by,

$$Q_{s-s} \approx 0.\text{- } \mathbf{Eq.3}$$

For the time interval dt, heat transferred out of radiator surface is equal to decrease in energy through the radiator surface. The relation between the heat transferred to outside air and the temperature decrease is given by,

$$dQ = m\, C_p\, dT_o \text{ , or } \frac{dQ}{dt} = m\, C_p \frac{dT_o}{dt},$$

where dT_o is the change in temperature of the coolant from the outlet of the radiator.

Q_{s-a} is conduction heat transfer rate from the radiator wall to the air and computed by,

$$Q_{s-a} = m\, C_p \frac{dT_o}{dt}.\text{-}\ \textbf{Eq.4}$$

Using the law of energy balance, the following equation is obtained,

$$Q_{total} = Q_{c-s} + Q_{s-s} + Q_{s-a}.\text{-}\ \textbf{Eq.5}$$

After putting the equations (1), (2), (3) and (4) into equation (5) and solving we have,

$$\dot{m}\, Cp(T_i - To) = UAr(To - Ts) + m\, C_p \frac{dT_o}{dt}.\text{-}$$

Eq.6 By rearranging the equation (6), we have,

$$m\, C_p \frac{dT_o}{dt} = \dot{m}\, Cp(T_i - To) + UAr(To - Ts),$$

And further rearranging, we get,

$$\frac{dTo}{dt} = \{\dot{m}\, Cp(T_i - To) + UAr(To - Ts))\} / \, m\, C_p - \textbf{Eq.7}$$

3.7 Fan represents in Simulink

Heat transfer coefficient is when heat flow between an object and its surrounding environment as states by Newton's Law of cooling. Qn is the heat transfer rate and can be written as Equation 8.

$$Q = hA(Ts - To)\text{-}\ \textbf{Eq.8}$$

where h is the heat transfer coefficient, A is the surface cross sectional area, Ts is ambient air temperature while coolant temperature, To.

The change in energy with the change in air temperature is given by Q_T are according to first law of thermodynamics. It is net heat flow to the outside air, joules/s and given by,

$$Q_T = \rho C_v v \frac{d(T_s - T_o)}{dt}, \text{ - } \mathbf{Eq.9}$$

Where ρ is air density (kg/m^3), C_v is specific heat of air (kJ/kgC) and V is air volume (m^3).

For the case where the net heat flow is zero, Newton's Law of Cooling and the First Law of Thermodynamics, equation (8) and (9), can be equated and given by,

$$hA(Ts - To) = \rho C_v v \frac{d(T_s - T_o)}{dt}, \text{ - } \mathbf{Eq.10}$$

The solution of the above equation is given by,

$$\ln(To - Ts) = -\frac{t}{\tau} + C, -\mathbf{Eq.\ 11}$$

Where ln(.) is the natural logarithm function and

$$\tau = \frac{(\rho C_v v)}{hA},$$

Where τ is the time constant. The constant C can be found by putting time t equal to 0 in equation (11).

$$C = \ln(T_i - T_s), \text{- } \mathbf{Eq.12}$$

Where T_i is initial coolant temperature, when t is 0.

Substitute equation (12) into (11),

$$\frac{To - Ts}{T_i - Ts} = \exp\left(-\frac{t}{\tau}\right). \text{- } \mathbf{Eq.13}$$

After solving equation (13) for T, following equation is obtained,

$$T_o = Ts - (Ts - Ti)\{\exp\left[\frac{-h * A}{\dot{m}\, C_v}\right]\}, \text{ - } \mathbf{Eq.14}$$

Where $\dot{m}$ is air mass flow rate.

3.8 Electric Water Pump represents in Simulink

Electric water pump is a combination of electric motor and a water pump which both connected to the same axis, and a speed control device. There are several concepts that were considered to drive the water pump.

1) Switched reluctance motor: It is a kind of stepper engine that runs by reluctance torque. It is much cheaper because its design is not as complex as the other design and three – phase winding type would also provide a 'limp home' facility with one phase disabled.
2) Brushless DC motor: It is also known as BLDC motor. It is a synchronous motor which can provide high torque over a tremendous speed range. BLDC motor is reliable since it does not have any brushes to wear out and supplant. Comparing to switched reluctance, this type of motor runs silently under every speed condition, with refined response time due to high torque and low rotor inertia.

In the simulation, BLDC motor is chosen to rotate the coolant to circulate them inside the cooling system. The coolant flow velocity is always depending on the angular velocity of pump's impeller rotation which is driven by the DC motor. The velocity is given by the relation w*r, where w is the angular velocity of impeller rotation and r is the radius of the impeller. For the design of the pump in this simulation, the angular velocity and radius of impeller is set to be 400 rad/s and 0.001 m respectively. Hence, this gives the coolant flow velocity equal to 4 m/s.

3.9 Modelling DC Motor

DC motor is utilized as a plant to the control system. There are strategies that can used to control the speed of an independently energized DC motor. The popular strategy here is armature voltage control which has a preferred position of holding most extreme torque capacity while the other technique of field flux control will diminish greatest torque ability. Symbols used in the design of dc motor are given in **Table 3.4.**

Symbol	**Description**	**Value**
k_m	Torque constant	0.0502 Nm/A
R_m	Terminal resistance	10.6 ohm
L_m	Terminal inductance	0.82 mH
J_{eq}	Total moment of inertia	2.21 x 10^{-5} kg m^2

Table 3.4: Symbols used in the design of dc motor

The transfer function of dc motor is given by the Eq.15,

$$G(s) = Pv\underline{dot}(s) = L\_\_\_\_\_\_ mJeqs2 + kRmmJeqs + k2m,$$

Eq.15

Where k_m is torque constant, R_m is terminal resistance, $L_m$is terminal inductance and J_{eq} is total moment of inertia. After some approximations,

$$G(s) = \frac{k_{m-1}}{(R_m J_{eq} k_{m-1})S + 1}$$

This gives,

$$G(s) = \tau s\_\_\_\_ K + 1,$$ **-Eq.16**

Where K is k_m^{-1} and τ is $R_m J_{eq} k_m^{-1}$.

By putting the parameter value from **Table 3.4** in equation 16, we have,

K= 19.9 rad/Vs, τ= 0.0929s.

Therefore, the transfer function of the DC motor is given by,

$$G(s) = \frac{19.9}{0.0929s + 1}$$

This design the DC motor of the electric pump inside a car, it is assumed that the same dc motor is used in ELEC 360 labs at University of Victoria.

3.10 Modelling of PI controller

In order to construct a zero steady state error, fast-transient response to a step command, short settling time and low overshoot, control objectives must be target on the transient behaviour of the system. It is likewise alluring to make the system less sensitive to disturbance. Proportional-Integral-Derivative (PID) control is the most popular controller in the businesses. This plan offers essential structure as well as robust performance. For DC motor drive purpose, the utilization of two term controller so called PI controller is enough for best performance. The utilization of derivative term for motor drive which equipped with DC/DC converter is unnecessary as certain signals will have discontinuities or ripple that would result in spikes when differentiated.

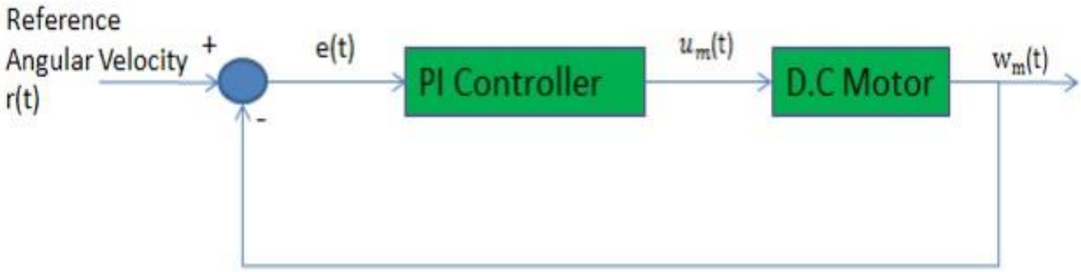

Figure 3.2: Speed control of DC Motor

From **Figure 3.2,** the error signal is given by,

$$e(t)=r(t)-W_m(t)$$

The control signal is given by,

$$U_m(t)=k_p(r(t) - w_m(t)) + k_i\int_0^t (r(\tau) - w_m(\tau))d\,\tau,$$

Where r(t) is reference signal, $w_m(t)$ is output angular velocity, k_p is proportional gain and k_i is integral gain.

Ziegler and Nichols proposed rules for deciding estimations of the proportional gain k_p, integral time T_i, and the derivative time T_d dependent on transient response characteristics of a given plant. For the Ziegler-Nichols Frequency Response Method, the critical gain, k_{pc}, and the critical period T_{pc} have to be resolved first by setting the T_i and T_d equal to 0. Increment the estimation of k_p from 0 to a critical value at which the yield first exhibits sustained oscillation. The **Table 3.5** below shows Ziegler Nichols controller gains obtained in ELEC 360 lab session at University of Victoria.

Description	Symbol	In-Lab Result	Units
Properties of PI Control			
Critical Proportional gain	k_{pc}	0.4	V.s/rad
Critical period of k_{pc}	T_{pc}	0.09	S
Ziegler-Nichols Design			

Proportional gain	k_p	0.16	V.s/rad
Integral gain	k_i	2.22	V/rad

Table 3.5: Ziegler-Nichols Controller Gains

Therefore, the transfer function of the PI controller is given by,

$$G_{PI}(s) = 0.16 + (2.22/s)$$

3.11 Calculation of Heat Transfer Coefficient

To acquire heat transfer coefficient and comparing Nusselt number, it is required from Newton Cooling Law,

$$Q=hA(Tb-Ts),$$

Where h is heat transfer coefficient, Q is heat transfer rate and A is area of the tube. Tb is bulk temperature while Ts is the wall temperature. Ts is determined from different longitudinal and transverse areas of the radiator. Tb is thought to be average values of the inlet and outlet temperatures of the nanofluid through the radiator.

$$Tb = \frac{Tin + Tout}{2}$$

The heat transfer rate can be calculated as

$$Q = \dot{m}\, C_P(Tin - Tout)$$

Where $\dot{m}$ is mass flow rate and C_P is specific heat capacity of the nanofluid.

The heat transfer coefficient h is obtained as follows.

$$h = \frac{\dot{m}\, C_P(Tin - Tout)}{nA(Tb - Ts)}$$

where n is number of radiator's tube.

Nusselt number can be obtained from the equation,

$$Nu = \frac{hDh}{\lambda}$$

Where Dh is hydraulic diameter of the tube which is calculated from

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

The D and d are the width and height of the radiator tube.

The average fluid velocity u can be calculated by the following.

$$u = \frac{\dot{v}}{nA}$$

Where $\dot{v}$ is volumetric flow rate of the nanofluid flow through the radiator. Reynolds number of the nanofluid flow, Re can be calculate from

$$Re = \frac{\rho u Dh}{\mu}$$

Where ρ is density and μ is dynamic viscosity of the nanofluid.

3.12 Conclusion of Modelling

Simulink models of engine cooling components like radiator, fan, sensors are developed by using thermodynamic laws, Newton's law of cooling and other mathematical equations. These component models are assembled together to form an engine cooling system model. Each engine cooling components has their ability to maintain the engine working temperature.

3.13 Parameters of Engine Cooling Systems

Radiator	Perodua Kelisa 1000cc	5CA-E2460-10, Yamaha
Structure	Finned – Tube	Finned – Tube
Materials	Aluminium	Aluminium
Tube Number	33	16
Cross Sectional Area of each tube (mm^2)	0.006227	0.02969
Front Area (m^2)	0.1564	0.0293

Table 3.6: Engine cooling systems parameters

3.14 Parameters for modelling

Volume Concentration	Base coolant (Ethylene glycol + water)	0.1 % MWCNT	0.25 % MWCNT	0.5 % MWCNT
Inlet Temperature ℃	92	86	84	83
Outlet Temperature ℃	99	92	92	90
Bulk Temperature ℃	90.5	88.5	88	86.5
Surface Temperature ℃	91	72	72	72
k	0.3736	1.3313	1.9926	3.9667
Cp	0.88	4.6	4.55	4.16
ρ	1030	1270	1600	2150
μ	0.00226	0.003250	0.004225	0.005850

Table 3.7: Modelling parameters

3.15 Validation and Verification of simulation model

Results had obtained after the simulation. Validation and verification of simulation models needed to be conducted after the development of simulation model to produce an exact and valid model. Simulation models are never precisely mirroring this present reality framework. So, every model ought to be confirmed and approved to the degree required for the models proposed application. Verification of model is the process to confirm that it is accurately actualized to the theoretical model as it needs to match the specifications and assumptions. The objective of verification of modelling is to ensure that the implementation of model is correct. There is various way to verify them, such as examine the model output with various of input parameters. Moreover, validation checks keep an eye on the precision of the modelling representation of the genuine system. The validation results should be in an agreeable scope of the exactness predictable with the proposed application. Validation of the results should have an enough suitable date to assemble a theoretical model. All the data should come from a reliable source. The validation test should consist of comparing inputs and yields from the framework viable for a similar arrangement of information conditions.

The validation and verification is referred to and set as a validation model. The engine cooling system used in this study came from Perodua Kelisa 1000cc [1]. The study utilized MWCNT nanofluid with 0.1%, 0.25%, 0.5% concentrations and 50%/50% Ethylene glycol + water. The experimental result is listed in **Table 3.8, Figure 3.3,** and **Figure 3.4** for the validation purposes. The result of the simulation performance analysis of the nanofluid can be compared with the experimental result from **Table 3.8** by setting a tolerance limit below 10%.

Liquid	Heat Transfer Coefficient (W/m^2K)	Enhancement Percentage (%)	Reynolds Number (Re)	Enhancement Percentage (%)
Ethylene Glycol/Water	225.5	-	430	105.3
0.1% MWCNT	307.05	26.8	-	
0.25% MWCNT	569.69	135.3	-	
0.5% MWCNT	717.47	196.3	1440	

Table 3.8: Experimental result [1]

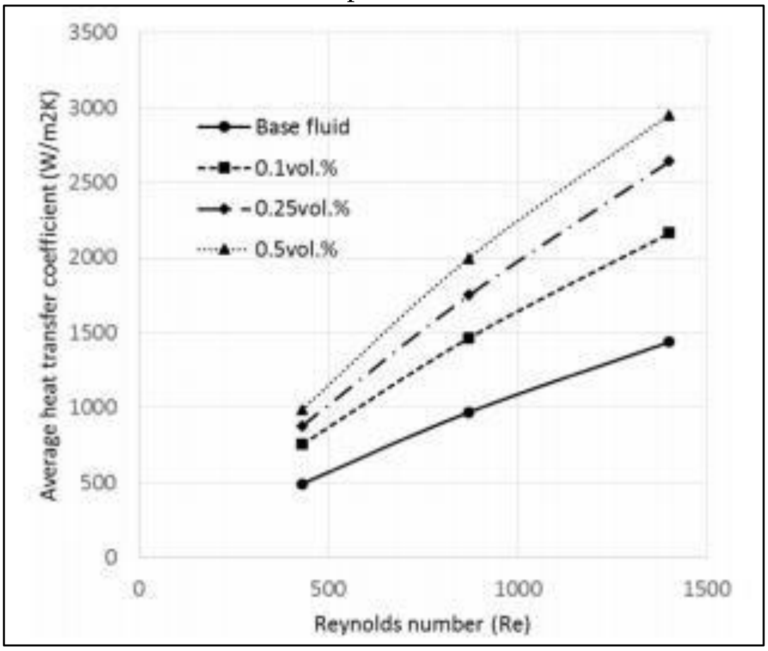

Figure 3.3: Heat Transfer Coefficient vs Reynolds Number [1]

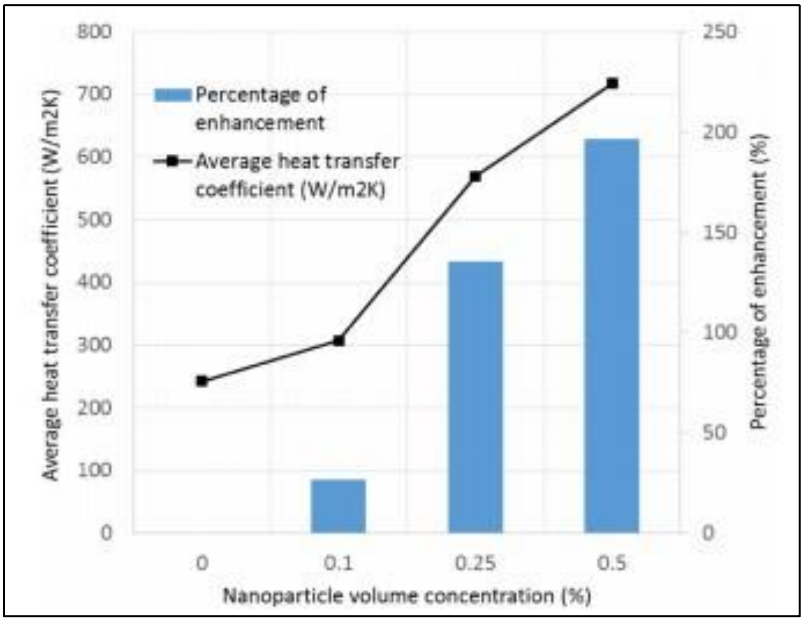

Figure 3.4: Heat Transfer Coefficient vs Concentration[1]

3.16 Facilities

From our simulation methodology, it is requiring using a simulation software which is MATLAB – Simulink. This Simulink software require a minimum of 4GB ram to run the simulation and 20 GB of disk space to accommodate the installation. While a minimum of 5GB of disk space is needed to keep the temporary data. Due to my personal laptop does not meet the minimum requirement of the specification needed, so I will need to use the computer from computer lab at UTP Academic Block 17 Room 5.

CHAPTER 4

RESULT AND DISCUSSION

4.1 Introduction

The aim of this chapter is to analyse and interpret the obtained results from the simulation results. Simulation was done with MATLAB Simulink and the simulation model had been done and shown in **Figure 4.1**.

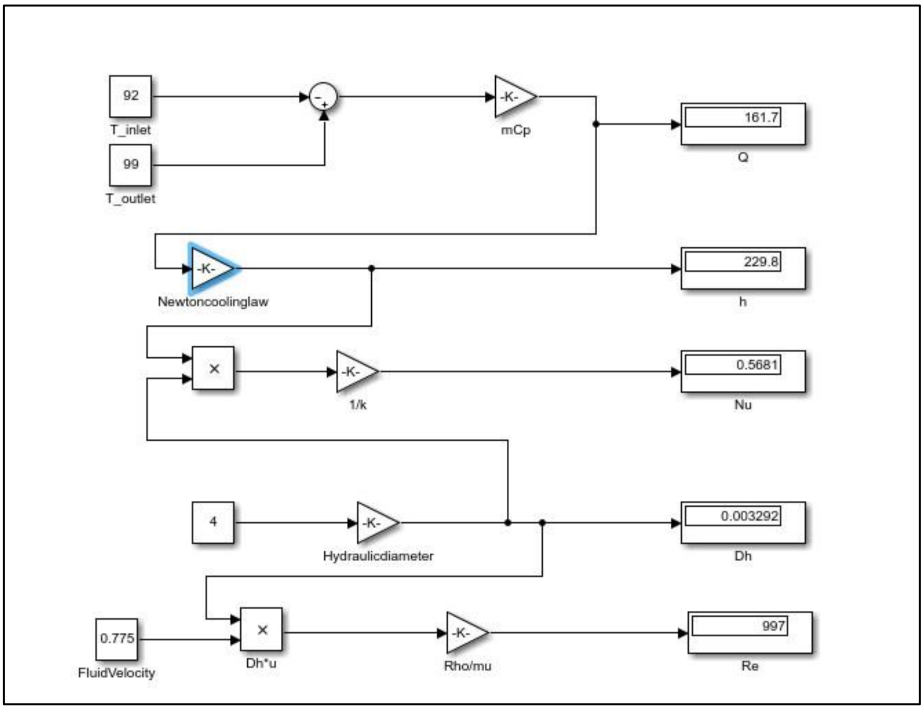

Figure 4.1: Simulation Model in Simulink

4.2 Validation and Assumption

To validate the experimental model, average Nusselt number for Reynolds number was contrasted and relationships for various concentrations of nanoparticles. Hydraulic diameter, Dh, is used as the characteristic length in calculation of Reynolds and Nusselt number. Nusselt number result will be affect by heat transfer coefficient. As the Nusselt number goes larger, the more effective the convection. Moreover, Reynolds number is affected by fluid velocity as the higher the volumetric flow rate, the higher the Reynolds number. Furthermore, the model validation is comparing the heat transfer rate from both simulation and experiment model.

4.3 Comparison between Experimental and Simulation Results

The experimental result had been retrieved from the paper [1]. However, the experimental project was done in a lab. It will be more efficient if the experiment is done on a running vehicle as the air velocity and engine performance from vary rpm may affect the result of the project. Therefore, simulation method has been done in order to find the differences between the experimental method and simulation method. The software has been used to determine the heat transfer coefficient of engine cooling system which is MATLAB Simulink. The simulation result is shown as in **Table 4.1**. Comparison of simulation and experimental result are tabulated in the **Table 4.2**. From the comparison of both results, the percentage difference for the heat transfer coefficient is less than 10%, therefore, this had been proved that the experimental result is reliable.

Volume Concentration	**Base Coolant (Ethylene Glycol + water)**	**0.1 % MWCNT**	**0.25 % MWCNT**	**0.5 % MWCNT**
Heat Transfer Coefficient, h, (W/m^2K)	229.8	328.4	582.4	690.3
Heat Transfer Rate, Q	161.7	873.3	1456	1565

Nusselt Number, Nu	0.5681	0.8118	0.9625	0.5729
Hydraulic Diameter, D_h	0.003292	0.003292	0.003292	0.003292
Reynolds Number, Re	1163	997	966.2	937.7
Fluid Velocity, u	0.775	0.775	0.775	0.775

Table 4.1: Simulation Result with fixed velocity of fluid, 4 L / min

<table>
<tr><th colspan="5">Experimental Result</th></tr>
<tr><th>Liquid</th><th>Heat Transfer Coefficient (W/m²K)</th><th>Enhancement Percentage (%)</th><th>Reynolds Number (Re)</th><th>Enhancement Percentage (%)</th></tr>
<tr><td>Ethylene Glycol + Water (50/50)</td><td>225.5</td><td>-</td><td>430</td><td rowspan="4">105.3</td></tr>
<tr><td>0.1% MWCNT</td><td>307.05</td><td>26.8</td><td>-</td></tr>
<tr><td>0.25% MWCNT</td><td>569.69</td><td>135.3</td><td>-</td></tr>
<tr><td>0.5% MWCNT</td><td>717.47</td><td>196.3</td><td>1440</td></tr>
<tr><th colspan="5">Simulation Result</th></tr>
</table>

Liquid	Heat Transfer Coefficient (W/m^2K)	Tolerance Percentage (%)	Reynolds Number (Re)	Enhancement Percentage (%)
Ethylene Glycol + Water (50/50)	229.8	1.87	1163	-
0.1% MWCNT	328.4	6.50	997	
0.25% MWCNT	582.4	2.18	966.2	
0.5% MWCNT	690.3	3.79	937.7	

Table 4.2: Comparison of experimental result and simulation result

4.4 Effect of Nanofluid Volume Concentration

The research on this simulation was intended to validate the measured heat transfer coefficient of base coolant, Ethylene glycol + water in a 1:1 ratio. Furthermore, 0.1%, 0.25% and 0.5% concentration of MWCNT had the simulation done by using the engine cooling system of Perodua Kelisa 1000cc. The result retrieved from the heat transfer coefficient according to the volume concentrations of nanofluids. The results had validated that the volume concentration of the nanofluid can increase the heat transfer coefficient. The heat transfer coefficient of the base coolant ethylene glycol and water was 229.80 W/m^2K while 0.1% volume concentration MWCNT had 328.4 W/m^2K for the heat transfer coefficient. The results value had been increased up to 582.4 W/m^2K at the point when the volume concentration of nanofluid managed to 0.25%. Crashes among nanoparticles and radiator tube wall were radically expanded when the volume concentration had been increased. The increment of volume concentration with motion of Brownian in the nanoparticles resulted an increase in the heat transfer coefficient and the reason why the results showed 690.3 W/m^{2}K of heat transfer coefficient for 0.5% volume concentration of nanofluid.

Heat transfer coefficient percentage enhancement for diverse volume concentrations of nanofluids compared to regular coolant, the ethylene glycol + water is shown in **Table 4.1**. The percentage difference is found to be 1.87%, 6.50%, 2.18% and 3.79% for base coolant, 0.1%, 0.25%, and 0.5% nanofluid volume concentration respectively.

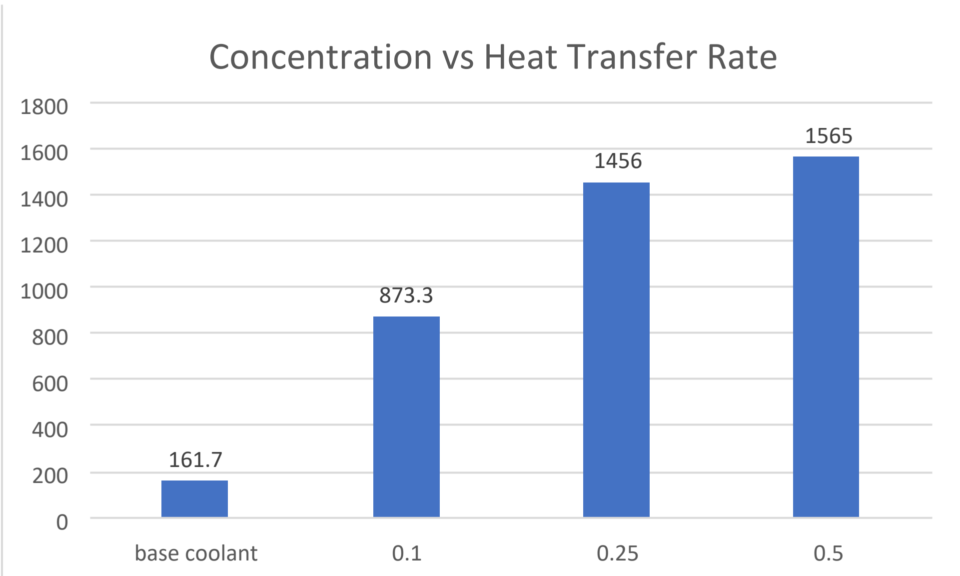

Figure 4.2: Concentration of Nanofluid vs Heat Transfer Rate

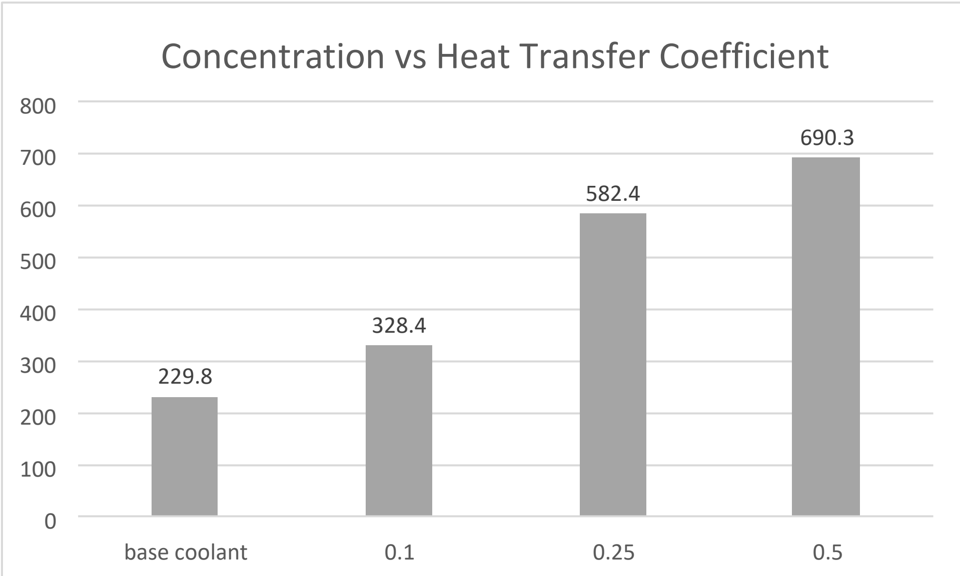

Figure 4.3: Concentration of Nanofluid vs Heat Transfer Coefficient

From the trend of both graphs, **Figure 4.2** and **Figure 4.3**, the higher concentration of MWCNT nanofluid gives better heat transfer rate and heat transfer coefficient, which both aspects are important criteria for a coolant. The simulations 3 different concentrations of MWCNT nanofluid. The lowest concentration nanofluid which was the 0.1% of MWCNT gave about 81% of increment in the heat transfer rate compared to the base coolant, ethylene glycol + water. While the heat transfer coefficient, it had about 30% of increment from the base coolant.

4.5 The Effect of Reynolds Number

The Reynolds number were affected by the flow rate of nanofluid. From the

Reynolds number equation, $Re = \frac{\rho u D_h}{\mu}$, u is fluid velocity where it is calculate using

volumetric flow rate. Flow rate will change from 2L / min to 4L / min with 1L / min interval for different concentration of MWCNT nanofluid. The results were not affected the value Dh as the value Dh is a fixed value. To conclude that the higher the Reynolds number, the higher the flow rate of fluid flow in the system. The graph of the Reynolds number vs flowrate had been tabulated in **Figure 4.4.**

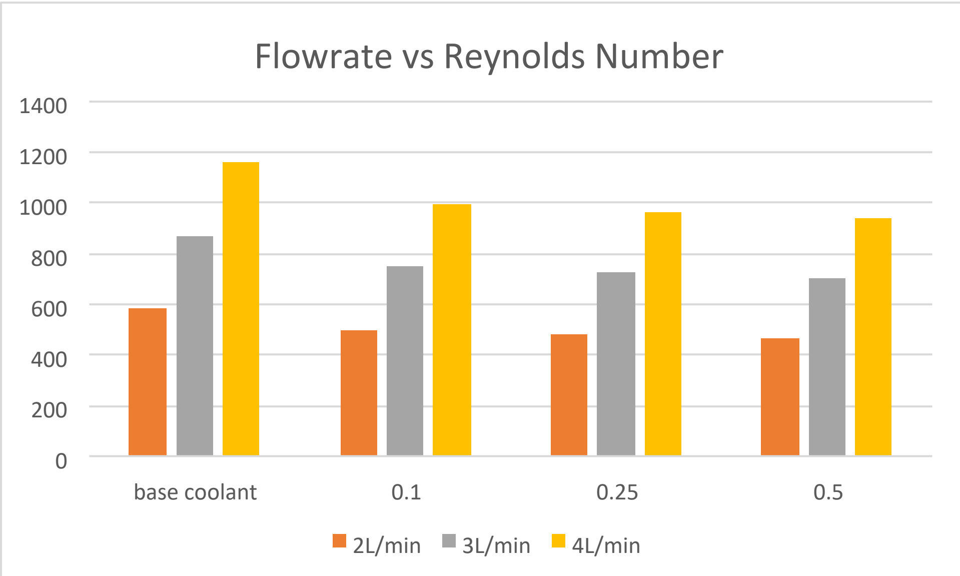

Figure 4.4: Graph of Flowrate vs Reynolds Number of 2, 3 and 4L/min

As reading from the trend of the graph in **Figure 4.4**, it shown that the higher the flowrate, the higher the Reynolds number. Furthermore, comparing the base coolant and nanofluid with MWCNT, the base coolant has higher laminar flow which characterized by high momentum diffusion. Base coolant, ethylene glycol + water has higher Reynolds number because its viscosity is lower comparing to nanofluid.

4.6 Simulation Results using Yamaha 5CA-E2460-10 engine cooling system

Yamaha 5CA-E2460-10 engine cooling system is smaller and more compact than Perodua Kelisa 1000cc engine cooling system as it is use in motorcycle. This radiator has 16 tubes and the tube size is 210mm x 27mm x 1.5mm (LxWxH). The fluid velocity of this simulation is only running in 4L /

min. The heat transfer rate of nanofluid was higher compared to Perodua Kelisa 1000cc as the size of the tube is larger. The larger the surface area of the tube, the larger the area for the heat dissipated from the nanofluid. The heat transfer rate using base coolant which is ethylene glycol + water (50%/50%) is 612.8 W/m^2K, 0.1% of MWCNT is 1806 W/m^2K, 0.25% is at 3106 W/m^2K, and 0.5% is at 3819 W/m^2K. As for the Reynolds number, the difference is 10 times higher than in Perodua Kelisa 1000cc. The results are 11200 for base coolant, 0.1% at 9600, 0.25% at 9303, and 0.5% at 9029. From here, the simulation is not suitable to be run in 4 L / min as it created turbulence flow in the tube.

4.7 Comparison of Heat Transfer Coefficient results in Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10 engine cooling system

From the results obtained from the simulations for both engine cooling system in Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10, the trend of the results based on the Figure 4.5 showed that the higher the concentration of nanofluid running in the engine cooling system, the higher the heat transfer coefficient. There were about 83.9% of increment in heat transfer coefficient in 0.5% nanofluid using in Yamaha engine cooling system compared to the base coolant which are commercialize in the market now. While Perodua Kelisa 1000cc engine cooling system had an increment of 67% of heat transfer coefficient in 0.5% nanafluid from the base coolant.

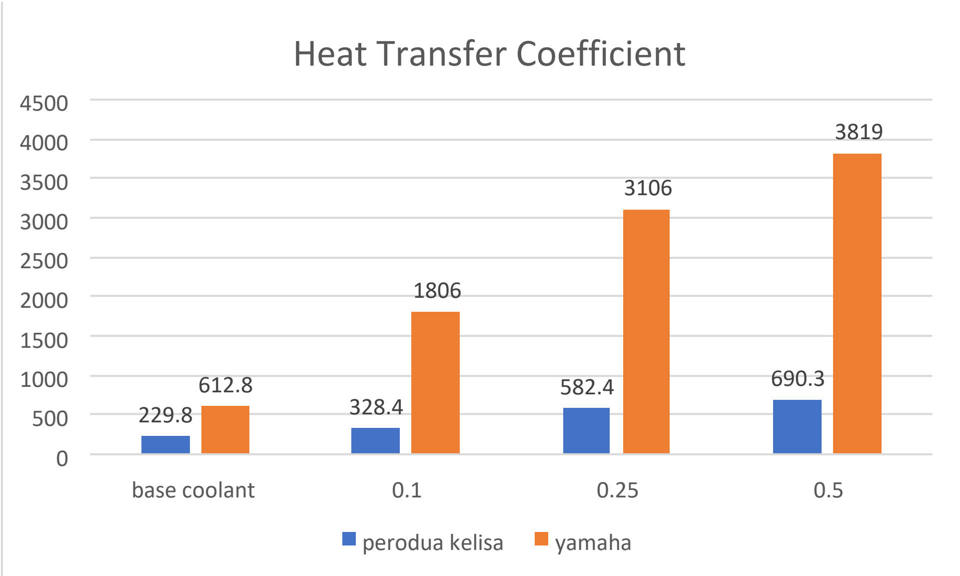

Figure 4.5: Heat Transfer Coefficient of Perodua Kelisa 1000cc and Yamaha 5CAE2460-10

4.8 Comparing Reynolds Number in Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10 engine cooling system

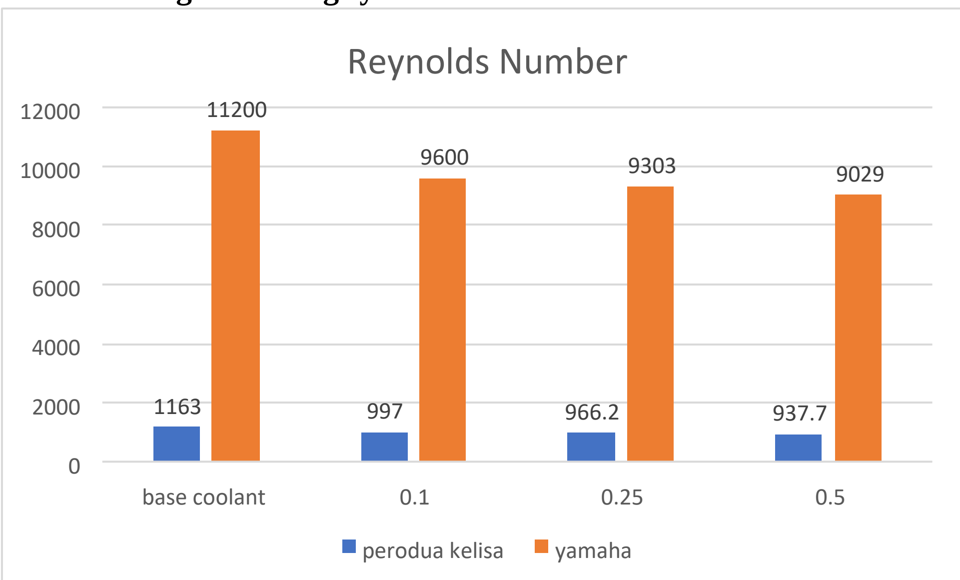

Figure 4.6: Reynolds Number Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10

Thru the trend of the graph from the Figure 4.6, Reynolds number of Perodua Kelisa 1000cc vs Yamaha 5CA-E2460-10 engine cooling system had about 10 times differences. These results were only obtained from the simulation with the condition of fluid flow was at 4 L / min. Yamaha engine cooling system was running in turbulent flow as the fluid in Perodua Kelisa 1000cc engine cooling system was running in laminar flow. The laminar flow results obtained by the Perodua Kelisa 1000cc engine cooling system was working fine. But the turbulence flow in the Yamaha engine cooling system was probably caused by smaller tube size of the radiator and furthermore, the fluid was flowing at a high velocity. From the **Figure 4.7**, the graph from the figure showed that the Reynolds number range was between 3387-4200, depending on the concentration of the nanofluid and base coolant when the fluid velocity was lowered to 1.5 L / min. Due to the smaller size of the tube in the engine cooling system of Yamaha 5CA-E2460-10, it caused turbulent when the fluid was flowing fast.

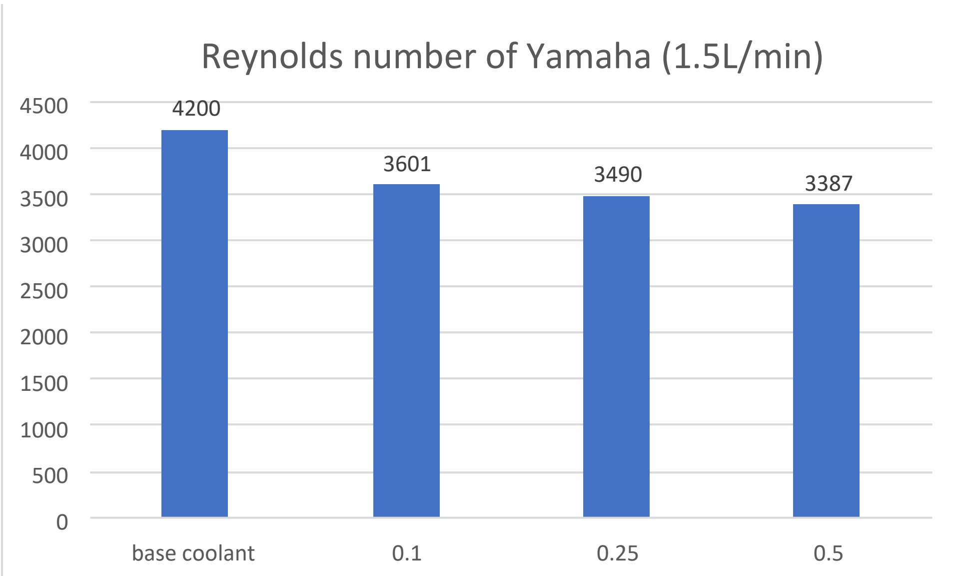

Figure 4.7: Reynolds number of coolant with velocity of 1.5L/min flowing in Yamaha 5CA-E2460-10

4.9 Summary of Results and Discussions

After the analysis done from the simulation results, it gathered the results of heat transfer coefficient can be improved with increment of nanofluid, but it did increase the viscosity too. Therefore, 0.1% concentration of nanofluid had been chosen to be the most suitable coolant for engine cooling system with not much affect on the liquid viscosity. From the comparison of both engine cooling system, Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10, nanofluid was performing well in both the engine cooling systems, but liquid velocity should be adjusted accordingly to avoid turbulent flow in the tube.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

In the automotive industry, engine cooling system efficiency is important to keep the engine to work in the working temperature instead of overheating it. The study on computational simulation on car engine cooling system performance is important step to find out the efficiency of engine cooling system by using nanofluid as coolant. In the current research on engine cooling system, not much work has been done to find out the effectiveness of the nanofluid. The objective of this research is to study by using simulation to validate the results got from experimental. Furthermore, the efficiency of nanofluid had compared with the commercial coolant which is the ethylene glycol + water solution.

5.1 Conclusion

In this research, nanofluid was studied to understand how it works and how it can improve the efficiency. The first part of this study was implemented by setting up the modelling for simulation which include of various equation including, Newton Cooling Law, bulk temperature, heat transfer rate, Nusselt number, hydraulic diameter, average fluid velocity and Reynolds number. The simulation method was implemented in order to validate the outcomes of the experimental method. The simulation method by using Simulink was performed to ensure that simulation software is the valid tool to measure the performance of engine cooling system. The comparison between both methods was done and it was found that the result of this project is validated and can be prove the nanofluid is efficiency enough to work in the engine cooling system.

The simulation was also done with Yamaha 5CA-E2460-10 engine cooling system which is a motorcycle engine cooling system.

Simulation modelling and simulation was done with different concentrations of nanofluid as mentioned before. The simulation results had been verified with experimental result taken from literature review as a benchmark to guarantee the perfection of the simulation. After the verification done, the simulation was further improved to study on the heat transfer coefficient of the nanofluid. The heat transfer coefficient was improved as the concentration of the nanofluid increase. But when the nanofluid concentration increase, the viscosity of the nanofluid was also increase, so to conclude the study on this topic, 0.1% concentration of MWCNT nanofluid was the most suitable nanofluid to be use as a coolant solution as the heat transfer coefficient was improve compared to the base coolant and the viscosity was only slightly higher than base coolant. Furthermore, the comparison of results between nanofluid used in Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10, as the engine cooling system of Yamaha is smaller, hence the tube was also smaller than Perodua Kelisa 1000cc's. The
Reynolds number of Perodua Kelisa 1000cc was about 900, but in Yamaha's was about 9000, it was 10 times different. And both the liquid velocity was set at steady state
4L/min. Another simulation of Yamaha's engine cooling system was done with velocity flowing at 1.5L/min, the Reynolds number was then decrease to about 4000, which was in the range of laminar flow.

The simulation analysis was carried out using Simulink with engine cooling system from Perodua Kelisa 1000cc and Yamaha 5CA-E2460-10, the summaries from the research had been made:

a) The validation of water/ethylene glycol MWCNT nanofluid is highly proven as the result of heat transfer coefficient had increased.

b) Reynolds number was proved to be in laminar flow range, no turbulent flow in the tube. Furthermore, the higher the concentrations of nanofluid, the better the heat transfer coefficient but viscosity will increase as well. To conclude the performance of nanofluid, 0.1% concentration of nanofluid is the most suitable coolant for engine coolant system as the heat transfer coefficient is improve over the commercial coolant but the viscosity is not much affected.
c) 4L/min of liquid flow was suitable to be using in Perodua Kelisa 1000cc but not in Yamaha 5CA-E2460-10 as turbulent flow occurs in smaller tube.

5.2 Recommendation

An important discovering during the simulation for Reynolds number can be highly affect the flow of the fluid in the tube. The limitation of this research is that it could not get as much thermophysical data from online resources as not much research had been done for nanofluid. This can be research for future works where the nanofluid should be done experimentally to retrieve all the thermophysical data to apply on non-steady state simulation.

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