EXHAUST GAS CALORIMETER FOR FOUR STROKE GASOLINE ENGINE SIMULATION

MOHD FIRDAUZ BIN A.SAMAD

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SUPERVISOR'S DECLARATION

I hereby declare that I have checked this project and in my opinion, this project is adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Automotive.

Signature:
Name of Supervisor: EN. MOHD FADZIL BIN ABDUL RAHIM
Position: LECTURER OF FACULTY OF MECHANICAL ENGINEERING
Date:

STUDENT'S DECLARATION

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 for award of other degree.

Signature:
Name: MOHD FIRDAUZ BIN A.SAMAD
ID Number: MH06026
Date:

Dedicated to my dearest and beloved parents, family and friends for their everlasting love, guidance and support in the whole journey of my life

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ABSTRACT

This paper investigates about the rate of heat losses from through exhaust gas using exhaust gas calorimeter. A four stroke gasoline engine Magma 4G15 is used as a reference in this study. The engine simulation has been done using one dimensional GT-Power software and the simulation are at the various engine speed. The engine speed is varied for five different cases staring from 1000, 2500, 3000, 4500 and 6000 rpm at wide open throttle. The simulations are conducted with the purpose to test the applicability of exhaust gas calorimeter model in order to quantify the heat losses through exhaust gas. The model considered the calorimeter system components such as water reservoir, pipe for water in and out as a cold fluid and pipe connected from exhaust tail pipe to the calorimeter for the hot fluid. It is important to evaluate energy losses in the engine in order to increase the engine performance. The result showed that the rate of heat losses through the exhaust gas is increased with the increasing of engine speed. This is due to the fact that when the engine speed increase, the throttle opening will also increase in order to allow more mass of air entering the cylinder during combustion. Consequently, the mass of fuel also will be increased and affect the exhaust gas temperature.

ABSTRAK

Kertas ini menyiasat tentang kadar kehilangan haba daripada gas ekzos menggunakan gas ekzos calorimeter. Enjin gasolin 4 lejang, magma 4G15 telah di gunakan sebagai rujukan di dalam kajian ini. Simulasi enjin ini telah dilakukan menggunakan perisian GT-Power dan simulasi dilakukan dengan mempelbagaikan kelajuan enjin. Kelajuan enjin dipelbagaikan di dalam lima kes yang berbeza bermula dari 1000, 2500, 3000, 4500, dan 6000 putaran per minit pada pendikitan maksimum. Simulasi telah dijalankan untuk menguji kebolehan model calorimeter gas ekzos untuk mengukur kadar kehilanagan haba melalui gas ekzos. Model tersebut mengambil kira sistem kalorimeter komponen seperti bekas peyimpan air, paip untuk masukan dan keluaran air sebagai bendalir sejuk serta paip yang disambungkan dari paip ekzos ke kalorimeter untuk bendalir panas. Adalah amat penting untuk menilai kehilangan tenaga di dalam enjin untuk meningkatkan prestasi enjin tersebut. Keputusan menunjukkan tenaga yang terbebas melalui gas ekzos berkadar terus dengan kelajuan enjin.Ini disebabkan apabila kelajuan enjin ditingkatkan,pembukaan pendikit juga akan bertambah untuk membenarkan lebih banyak jisim udara memasuki silinder semasa pembakaran. Seterusnya, jisim minyak juga akan bertambah dan memberi kesan kepada suhu gas ekzos tersebut.

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LIST OF SYMBOLS

C_p	Specific heat
M_a	Mass flow rate of air
m_f	Mass flow rate of fuel
Q	Rate of heat
ΔT	Temperature difference
Q_{HV}	Fuel heating value

LIST OF ABBREVIATIONS

ATDC	After top dead centre
ABDC	After bottom dead centre
BBDC	Before bottom dead centre
BTDC	Before top dead centre
OHV	Overhead valve
SOHC	Single overhead cam
AFR	Air fuel ratio
rpm	revolution per minute

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The engine designer always interested in methods through which engine performance can be improved. So it should be noted that the large proportion of the available energy is lost in a non-usable form such as heat losses. Any method which can be employed to prevent the excessive heat loss and cause this energy to leave the engine is a usable form will tend to increase engine performance. Higher coolant temperatures, for instance, provide a smaller temperature gradient around combustion chamber walls and a reduction in heat loss, but are limited by the possibility of damage to engine parts.

Therefore it can be seen that the cooling system is necessarily designed so that it can remove an enormous fraction of all the energy/power that an internal combustion engine creates, which causes the "overall thermal efficiency" of any conventional automotive engine to have low thermal efficiency, even separate from all the mechanical losses related to the engine's operation. Generally indicate that a conventional internal combustion engine cannot have an overall efficiency of greater than around the low 30% range. There have been some experimental engines designed that have been measured at around 28%, but the most efficient production engines are around 25% and most vehicles on the highways now have engines which have around 21% overall efficiency.(Rajput, 2005).

Nonetheless, the use of higher compression ratios would increase the efficiency of conversion of the energy in the fuel into useful energy (mechanical). Even with such fuels, as pointed out earlier, there appears to be a limit to the advantage in increasing the compression ratio. Another solution would be to reduce the losses between the air cycle and the actual cycle, and thereby increase the proportion of energy which can be mechanically utilized in the engine system.

1.2 PROBLEM STATEMENT

As the heat content of a fuel is transformed into useful work, during the combustion process, many different losses take place. The net useful work delivered by an engine is the result obtained by deducting the total losses from the heat energy input. Thus, it is important to be able to evaluate these various losses of particular interest from the hot gas in the cylinder to the containing surfaces, since these directly affect the indicated power of the engine. Prior of that, a layout of energy balance test rig, especially for the exhaust gas calorimeter using GT Power has been proposed to in this study. The exhaust gas calorimeter is used to quantify the heat losses from the exhaust gas based on the temperature difference between two different fluids.

1.3 OBJECTIVES OF THE STUDY

1. To analyze the heat exhausted by the engine at varying engine speed.
2. To proposed a layout for the exhaust gas calorimeter using GT Power simulation.

1.4 SCOPES OF THE STUDY

This model of 4-cylinder gasoline engine is used to determine the heat losses of the engine through the exhaust gas. The heat losses are calculated based on the temperature from the exhaust gas calorimeter. The simulation is carried out at varying engine speed starting from 1000, 2500, 3000, 4500, until 6000 rpm.

The study is based on one dimensional GT-Power engine simulation. All the parameters value in the simulation is based on the carburetted gasoline engine, type Mitsubishi Magma 4G15, 12 valve, 1.5 litre engine with pent-roof combustion chamber.

1.5 FLOW CHART OF THE STUDY

The flow chart of the overall procedure of the study is shown in Figure 1.1

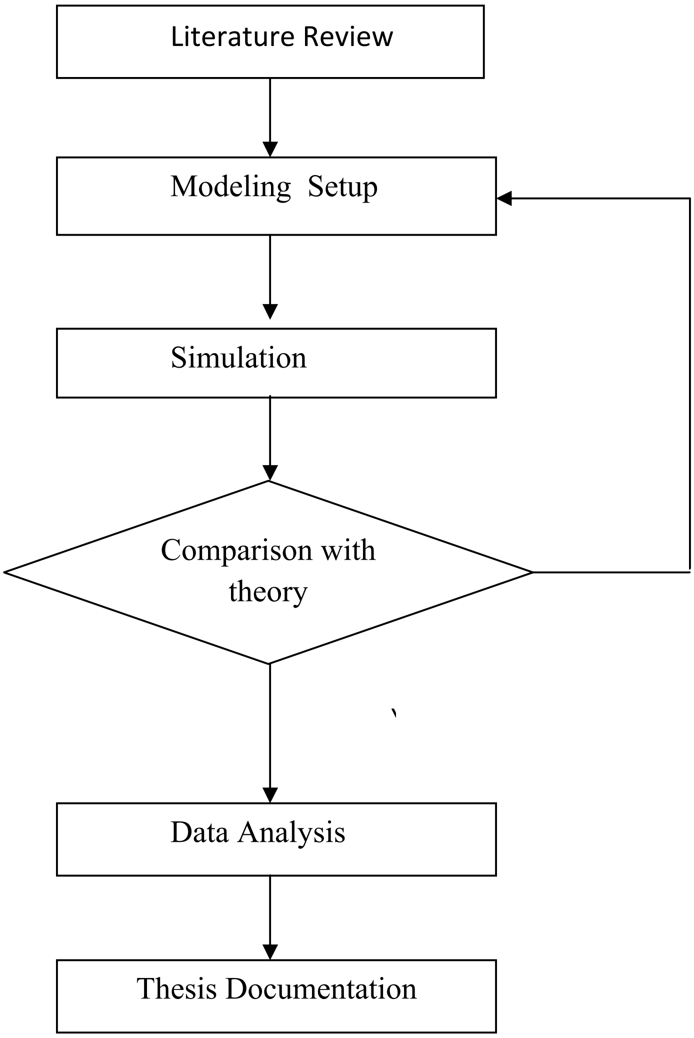

Figure 1.1: Flow chart of the overall procedure of the study

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter presents an overview for type of losses in engine, the important of quantifying exhaust losses, method of quantifying exhaust losses and the expected result.

2.2 ENERGY BALANCE

Energy supplied to an engine is originated from the heat energy of the fuel consumed. However, only a part of this energy is transformed into useful work. The rest of it is either wasted or utilized in special application like turbocharge. The two main parts of the heat not available for work are the heat carried away by the exhaust gases and the cooling medium. Figure 2.1 illustrates the heat balance for spark-ignition engines. (Ganesan, 2003)

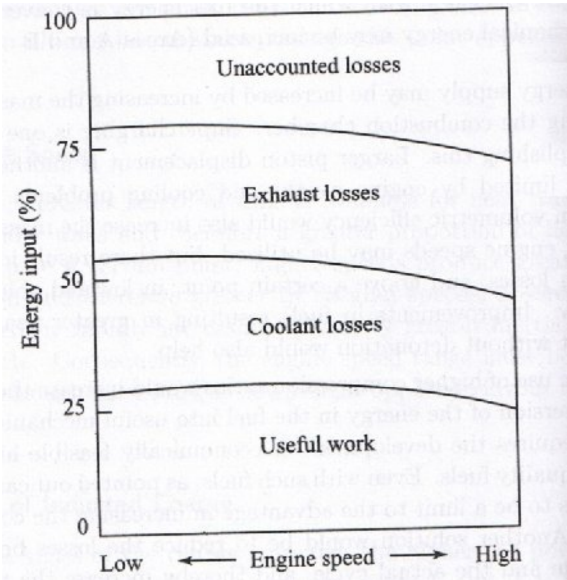

Figure 2.1 Heat Balance Diagram for a Typical SI Engines

Source: Ganesan 2003

To give sufficient data for the preparation of a heat balance sheet, a test should include a method of determining the friction power and the measurement of speed, load, fuel consumption, air consumption, exhaust temperature, rate of flow of cooling water and it's temperature rise while flowing through the water jackets. Besides, the small losses, such as radiation and incomplete combustion, the above enumerated data makes it possible to account for the heat supplied by the fuel and indicated its distribution

Table 2.1 shows a possible energy balance sheet for a cell in which a gasoline engine is developing a steady power output of 100 kW. Note that where fluids(air, water ,exhaust)are concerned, the energy content is referred to an arbitrary zero, the choice of which is unimportant: only the difference between the various energy flow into and out of the cell are taken account

Table 2.1 :Simplified energy flows for a test cell fitted with a hydraulic dynamometer and 100 kW gasoline engine

Energy balance for the engine			
Energy in		Energy out	
Fuel	300kW	Power	100kW
		Exhaust gas	90kW
		Engine cooling water	90kW
		Convection and radiation	20kW
	300kW		300kW

Source: Martyr and Plint 2008

Alternatively there are some commonly used ‘rule of thumb’ calculations available to the cell designer which is known as the ’30-30-30-10 rule’

Table 2.2: Example of 30-30-30-10 rule

Power in via		Power out via	
Fuel	300kW	Dynamometer	30%(90kW)
		Exhaust system	30%(90kW)
		Engine fluids	30%(90kW)
		Convection and radiation	10%(30kW)

Source: Martyr and Plint 2008

2.3 TYPE OF ENGINE LOSSES

There is three major losses accounted in the engine, that is through friction, cooling and exhaust.

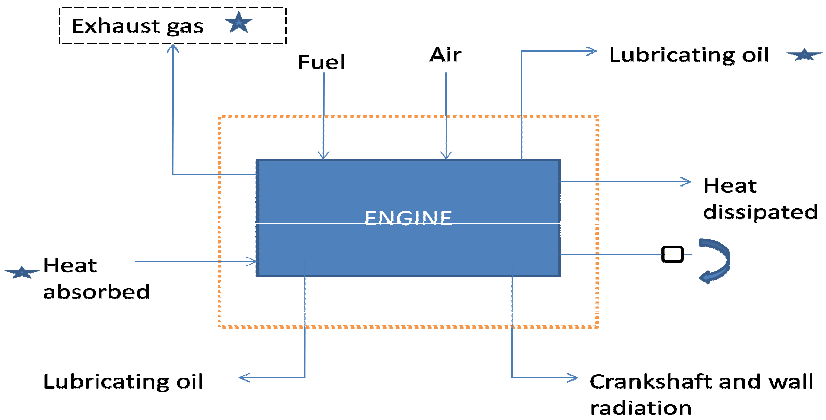

Fig 2.2: External Heat Balance

Source: Ganesan 2003

2.3.1 Friction Losses

A part of the power produced by the engine per cycle is used to draw in the fresh air/fuel charge on the intake stroke, compress it, and pump the burnt remains out on the exhaust stroke. Power is also utilized in overcoming the sliding and rotating friction of the internal mechanical components such as pistons, rings and bearings as well as to drive the engine accessories such as camshaft, distributor and oil pump. These losses are all grouped together under the heading of the friction power. This friction power dissipates useful work as heat into the oil and coolant.(Rajput,2005)

2.3.2 Cooling losses

Heat carried away by lubricating oil and heat lost by radiation reached an amounts of 3 to 5 percent of the total heat supplied. It must be noted that heat carried away by the coolant is a dead loss because not only no useful work can be obtained from it but a part of the engine power is also used to remove this heat. Hence, it is of paramount importance that this loss is kept minimum by the designer.

2.4 EXHAUST LOSSES

Automobile exhaust system refers to a group of independent but interrelated automotive components used to direct the waste exhaust gases out of the combustion chamber of an engine. Based on its design an the exhaust system comprises several different parts such as a cylinder head and exhaust manifold, a turbocharger to enhance engine power, catalytic converters for air pollution reduction, a muffler or a silencer to reduce noise and one or more exhaust pipes.

The important of quantifying this losses is to evaluate the combustion efficiency, which can be measured by analyzing the products of combustion, from the exhaust gases. Combustion efficiency is similar to the heat loss method, but only the heat losses due to the exhaust gases are considered. In reality it is not possible to get a perfect mixture of air and fuel to achieve complete combustion without some amount of excess air.

As excess air is reduced toward the fuel rich side, Incomplete combustion begins to occur, resulting in the formation of carbon monoxide, carbon, smoke and in extreme cases, raw unburned fuel. Incomplete combustion is inefficient, expensive, and frequently unsafe. Therefore, some amount of excess air is required to ensure complete and safe combustion.

However, excess air is also inefficient, as it results in the excess air being heated from ambient air temperatures to exhaust gas temperatures, resulting in a form of heat loss. Therefore while some excess air is required, it is also desirable to minimize the amount of excess air.

2.4.1 Equivalence ratio

One of the parameter that affecting engine heat transfer is fuel equivalence ratio, because a change in fuel-air ratio will change the temperature of the cylinder gases and affect the flame speed. The maximum gas temperature will occur at an equivalence ratio about 1.12 (fuel-air ratio about 0.075).At this equivalence ratio, temperature difference will be maximum. However, from experimental observations the maximum heat rejection is found to occur for a mixture, slightly leaner than this value (Rajput 2005).

2.5 EXHAUST GAS CALORIMETER

In order to quantifying the losses it is easier to used exhaust gas calorimeter, shell and tube type. Shell and tube heat exchangers consist of a series of tubes. One set of these tubes contains the fluid that must be either heated or cooled. The second fluid runs over the tubes that are being heated or cooled so that it can either provide the heat or absorb the heat required. A set of tubes is called the tube bundle and can be made up of several types of tubes: plain, longitudinally finned, etc. Shell and Tube heat exchangers are typically used for high pressure applications (with pressures greater than 30 bar and temperatures greater than 260°C.

This is because the shell and tube heat exchangers are robust due to their shape. There are several thermal design features that are to be taken into account when designing the tubes in the shell and tube heat exchangers, including using a small tube diameter makes the heat exchanger both economical and compact. However, it is more likely for the heat exchanger to foul up faster and the small size makes mechanical cleaning of the fouling difficult.

To prevail over the fouling and cleaning problems, larger tube diameters can be used. Thus to determine the tube diameter, the available space, cost and the fouling nature of the fluids must be considered. Tube length: heat exchangers are usually cheaper when they have a smaller shell diameter and a long tube length.

Thus, typically there is an aim to make the heat exchanger as long as possible. However, there are many limitations for this, including the space available at the site where it is going to be used and the need to ensure that there are tubes available in lengths that are twice the required length (so that the tubes can be withdrawn and replaced)

Also, it has to be remembered that long, thin tubes are difficult to take out and replace. Tube pitch: when designing the tubes, it is practical to ensure that the tube pitch (i.e., the centre-centre distance of adjoining tubes) is not less than 1.25 times the tubes' outside diameter. Tube corrugation: this type of tubes, mainly used for the inner tubes, increases the turbulence of the fluids and the effect is very important in the heat transfer giving a better performance. Tube thickness: The thickness of the wall of the tubes is usually determined to ensure, There is enough room for corrosion, that flow-induced vibration has resistance, and Sometimes the wall thickness is determined by the maximum pressure differential across the wall.

2.6 NATURE OF EXHAUST LOSSES

In this simulation, it is presupposed that the heat losses through the exhaust is increased with engine speed. As the engine throttle opening is wide open, the resulted speed is increased. More air is induced to the chamber. Parallely, more fuel is induced to produce rich mixture. As the mixture is burned in the cylinder the exhaust gas temperature will proportionally increased.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

This chapter is focused on the description of simulation setups. Simulation setup describes the engine modeling, in order to determine the heat exhausted using exhaust gas calorimeter.

3.2 ENGINE SPECIFICATION

As for the baseline engine, the 4-cylinder in-line Mitsubishi Magma(4G15) 1.5 liter has been selected. For this simulation, the external cooling system has also been added to overcome the high temperature from the engine.

Table 3.1: Mitsubishi Magma 4G15 engine specification

Parameter	Size and Feature
Valve train type	In-line OHV,SOHC
Number of cylinders and valves per cylinder	4 cylinders with three valves per cylinder(2 intake valves and one exhaust valve)
Combustion chamber type	Pent roof type
Total displacement(cm^3)	1488
Cylinder bore(mm)	75.5
Piston stroke(mm)	82.0
Compression ratio	9.2
Intake valves open/close	15°BTDC/63°ABDC

Table 3.1: Continued

Exhaust valves open/close	57°BBDC/13°ATDC
Lubrication system	Pressure load, full flow filtration
Oil pump type	Trochoid type
Cooling system	Water-cooled force circulation-crankshaft driven water pump
Water pump type	Centrifugal impeller type
Maximum output	66kW@6000rpm
Maximum torque	124 Nm@3000 rpm

Source: Abdul Rahim 2009

This engine has a capacity of 1.5 liter and has been designed with single overhear cam system. For the combustion system, the fuel injection is equipped with electronically controlled multi-point fuel injection and as for each piston, the diameter is 7.55 cm with the length of 8.2 cm.

3.3 GT-POWER ENGINE MODEL

Figure below shows the layout that has been proposed in this simulation

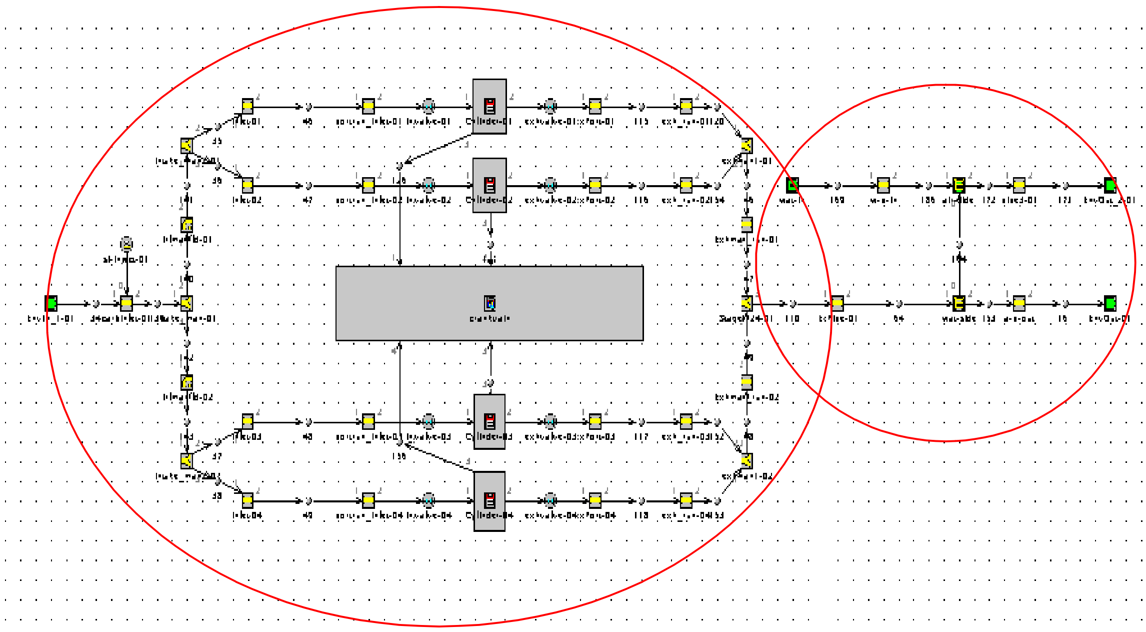

Figure 3.1: Engine model with exhaust gas calorimeter system

Diagram above is consists of two difference system. Basically, the bigger circle represent the whole system of the real engine. Then, the smaller circle represent the exhaust gas calorimeter system that has been proposed in this study using GT-Power simulation.

3.4 CALORIMETER MODEL

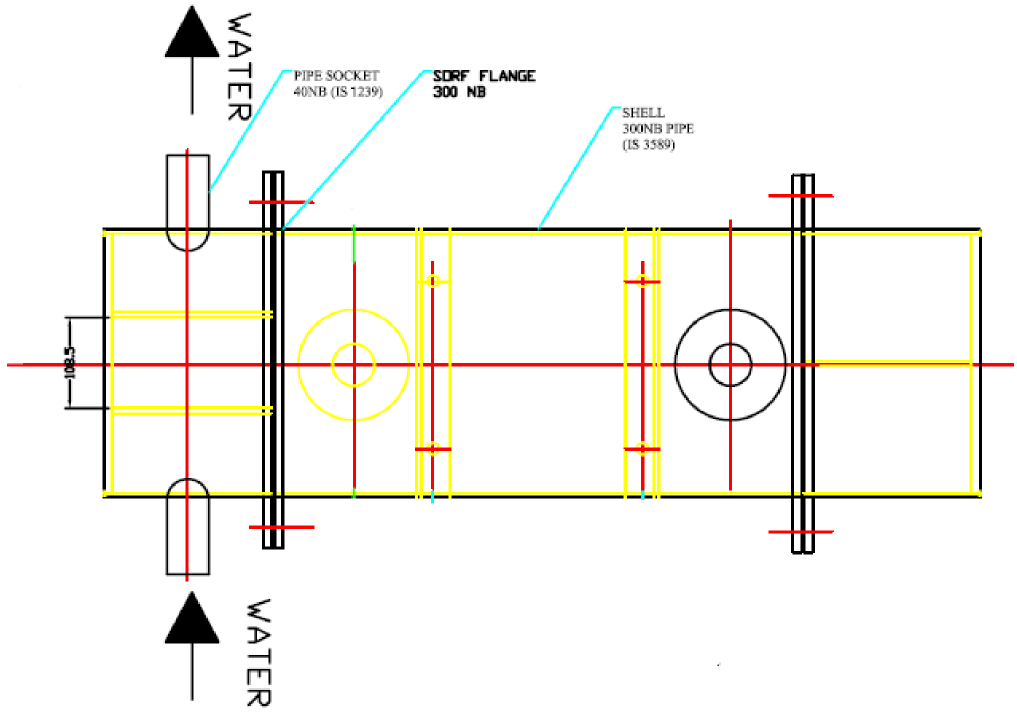

Figure 3.2: Exhaust gas calorimeter(cold fluid)

Source: Kuithho(2008)

Figure 3.2 shows the cross section of the cross flow type of exhaust gas calorimeter for water flow. The water will enter the calorimeter and then passing a tube. In this calorimeter, it has 16 tubes that will prevent the water from mixing with the gas and also to make sure that the heat transfer is occurred between those two different fluids.

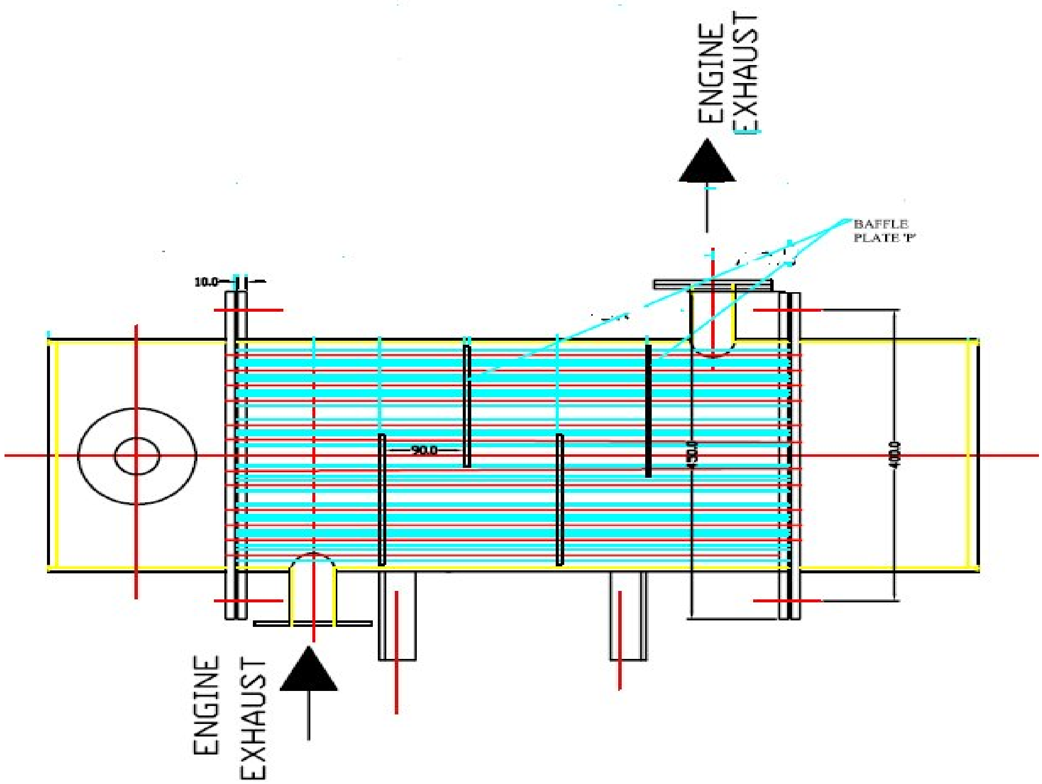

Figure 3.3: Exhaust gas calorimeter(hot fluid)

Source: Kuithho(2008)

Figure 3.2 shows the cross section of the cross flow type of exhaust gas calorimeter for gas flow. The function of the baffle plate is for the heat transfer favorable flow pattern for the medium in the shell and at the same time provide the necessary support for the tube bundle placed in the shell.

3.5 COMPONENTS OF CALORIMETER MODEL

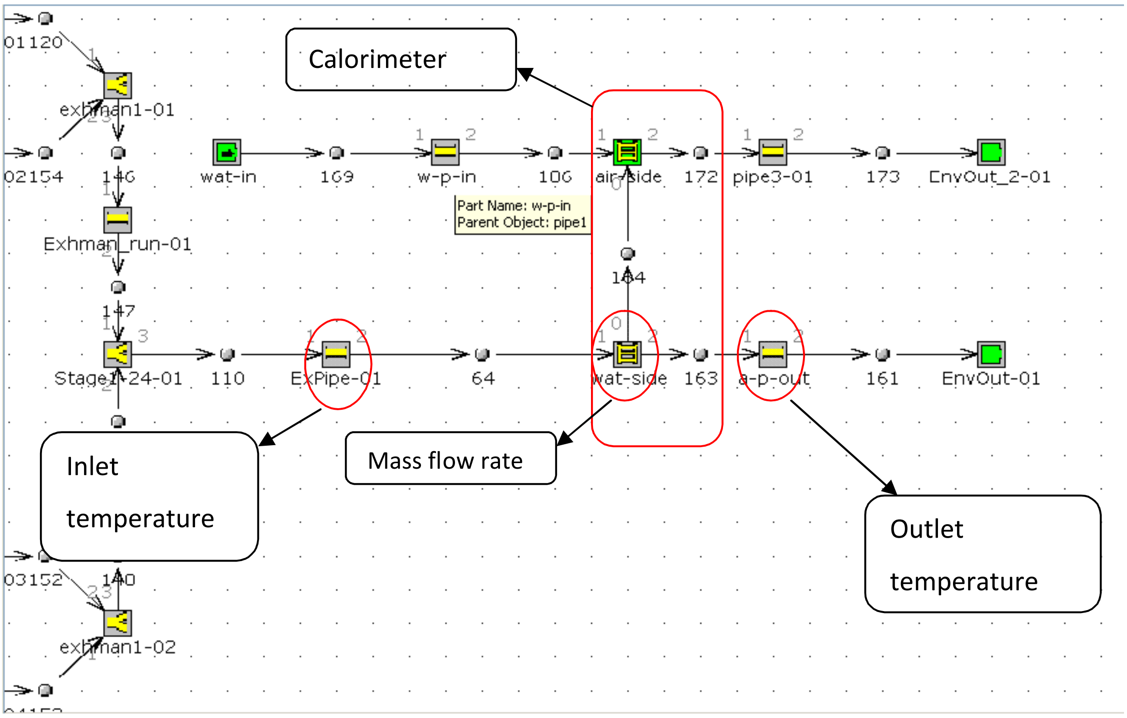

Figure 3.4: Exhaust gas calorimeter system

Figure 3.4 shows the components of exhaust gas calorimeter model in GT-Power simulation. The mass flow rate data is taken from wat-side component, while for the calculation of heat losses, the temperature difference is evaluated between inlet and outlet temperature from exhaust gas.

Table 3.2: Description of calorimeter components

Component	Representative/Function
Wat-in	Water reservoir
Pipe3-01	Pipe connection from calorimeter
EnVout_2-01/ EnVout-01	Describes end environment boundary conditions of pressure, temperature, and composition
ExPipe-01	Pipe connection from engine exhaust to the calorimeter
a-p-out	Pipe connection from the air side of calorimeter

Table 3.2 describes the function of the components of calorimeter model.pipe3-01 is a pipe for cold fluid out from the air-side component while w-p-in is a pipe for cold fluid entered the calorimeter. As for hot fluid,Expipe-01 and a-p-out represent the connection from the exhaust tail pipe to the calorimeter(hot fluid in) and hot fluid out respectively.

3.6 CALCULATION OF POWER LOSSES

Example of calculation of power losses for case one(1000 rpm)

$$\mathbf{Q= m_1C_p\Delta T} \qquad (3.1)$$

Where;

Rate of work, Q # In order to calculate the power from the heat exchanger in Figure 3.4, the exhaust gas was assumed to be ideal gas and assume that the heat is 100% absorbed by water on water side of calorimeter

Mass flow rate, $m_1 =$ 0.0109 kg/s

#the value taken based on figure 3.4

Specific heat, $C_p =$ 1022.116 kJ/kg

C_p is obtained by interpolation on table A-15 after finding t_{avg}

$T_{avg} =$ (716.579K-341.34K)/2

= 528.959K

Temperature difference, ΔT= 716.579K-341.34K

= 375.239K

So, Q= 0.0109(1022.116)(375.239)

= 4.18 kW

3.7 CALCULATION OF PERCENTAGE OF POWER LOSSES

Example calculation of percentage of power losses for case one(1000 rpm)

$$\%P = Q/(m_f * Q_{HV}) \quad (3.2)$$

Where;

Percentage of power, losses, %P

Rate of work, Q= 4.18 kW

Fuel flow rate, m_f = 6.9257 x10^-4

#obtained directly from the result of simulation

Fuel heating value, Q_{HV} = 42500 kJ/kg

%P=[4.18/(6.9257 x10^-4)]*100%

= 14.20%

CHAPTER 4

RESULTS AND DISSCUSSION

4.1 INTRODUCTION

In this chapter, the results are further discussed on engine simulation that has been run using GT-Power software. The results consists of variation of inlet and outlet temperature, energy losses, and percentage of energy losses from the exhaust using exhaust gas calorimeter with varying engine speed. The simulation using five different cases starting from 1000,2500,3000,4500 until 6000 rpm.

4.2 CALORIMETER INLET AND OUTLET TEMPERATURE DIFFERENCE

Table 4.1: Data of temperature at inlet and outlet of exhaust gas calorimeter

Engine speed(rpm)	Temperature(K)		
	inlet	outlet	ΔT
1000	716.579	341.34	375.239
2500	881.849	483.657	398.192
3000	917.534	443.367	474.167
4500	951.829	402.942	548.887
6000	996.703	364.733	631.97

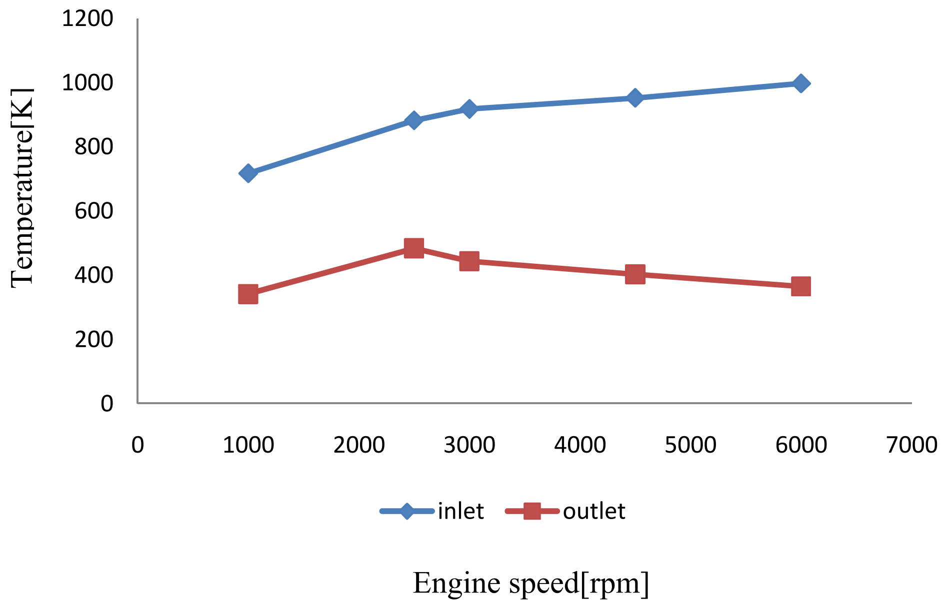

Figure 4.1: Inlet and outlet temperature vs engine speed graph

As shown by the figure 4.1, it is obvious that the temperature variations of inlet increased proportionally with the engine speed, while the outlet temperature is decreasing as the engine speed increased. Parallely, the temperature differences also increased with the engine speeds. The inlet temperature is taken directly from the exhaust, before the calorimeter and for the outlet temperature, right after the calorimeter. In this simulation since the cold fluid was circulated by a mechanical water pump, the mass flow and heat transfer rate are dependent on the engine speed and cooling methods. Thus, temperatures differences have increased as the engine speeds are increased. Outlet temperature at1000 rpm is slightly lower because at low rpm, the gas velocity develops after the combustion is lower and consequently producing low temperature through the exhaust.

4.3 POWER LOSSES THROUGH EXHAUST

Table 4.2: Values of power losses through the exhaust

Engine speed(rpm)	Power losses(kW)
1000	4.18
2500	12.33
3000	19.05
4500	33.458
6000	49.017

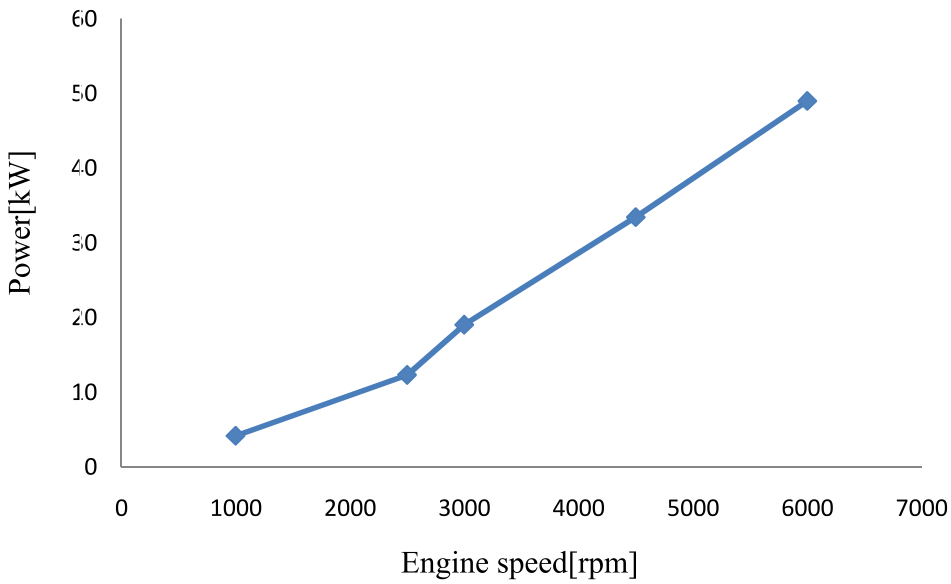

Figure 4.2: Power losses vs engine speed graph

Graph 4.2 presents power losses are increased proportionally with the engine speed. On the first graph it has been discussed that the temperature also increased with the engine speed. Basically, with increased in engine speed, the combustion in the chamber become faster, thus resulting in increased of gas pressure and peak burned gas temperature.

4.4 PERCENTAGE OF POWER LOSSES FROM EXHAUST

Table 4.3: Percentage of power losses from the exhaust

Engine speed(rpm)	Power losses(%)
1000	14.20
2500	15.21
3000	17.2
4500	18.11
6000	24.11

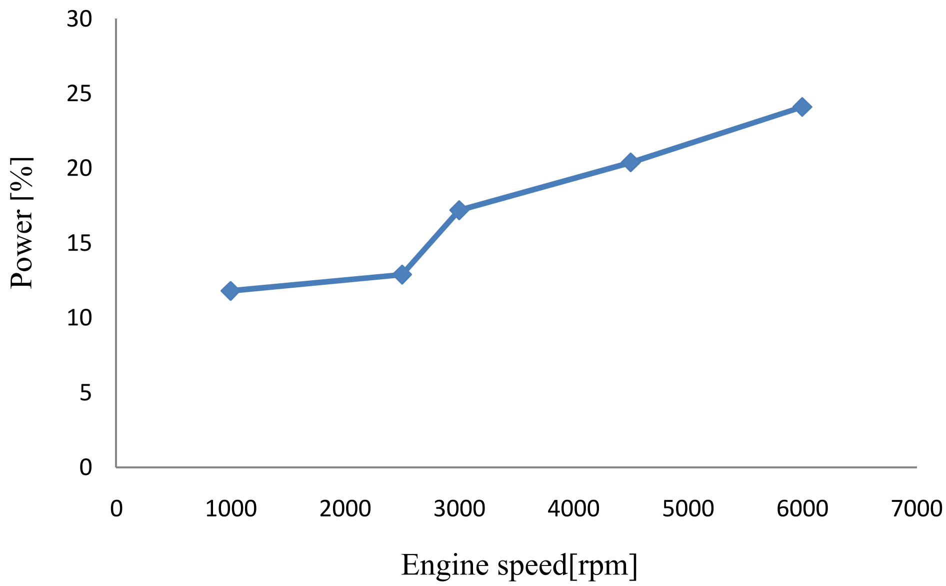

Figure 4.3: Percentage of power losses vs engine speed graphs

From figure 4.3, it shows that the percentage of power losses is gradually increased from 1000 rpm to 4500.But, after 4000 rpm, the percentage is increased rapidly. Thus it is not economical for this type of engine to be run beyond that speed because during peak power operation the engine requires a richer mixture.

Mixture burning rate is strongly influenced by engine speed. The burning rate throughout the combustion process increased almost, though not quite, as rapidly as engine speed. Additionally, at a given engine speed, increasing in-cylinder gas velocities will also increases the burning rate, thus increasing the exhaust temperature. Besides that, the idea of the calculation of percentage is to calculate the fraction between power losses over the power provided by the fuel itself.

4.5 PLOT RLT FLOW(WALL TEMPERATURE)

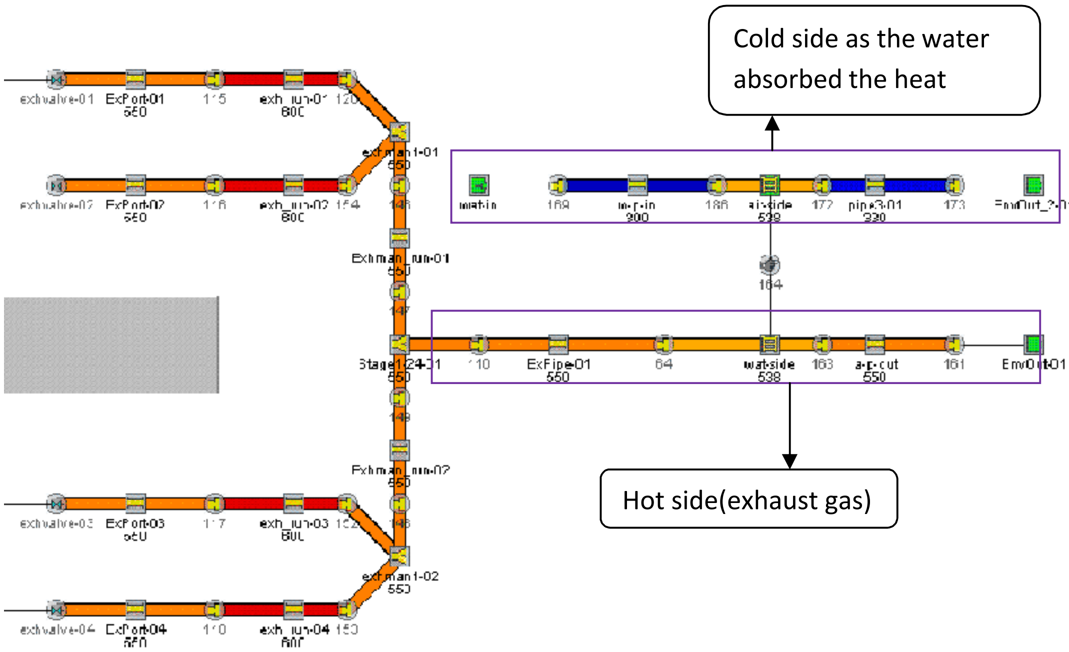

Figure 4.4: RLT viewer on GT-Power

From the RLT viewer for 1000 rpm, it shows that the maximum wall temperature was 600K and the minimum temperature recorded was 300K.Besides that, from the color schemes, it is obvious that the heat transfer occurred between two fluids on the air side components. Thus the simulation was succeed.

4.6 PLOT m_a+m_f VERSUS POWER LOSSES

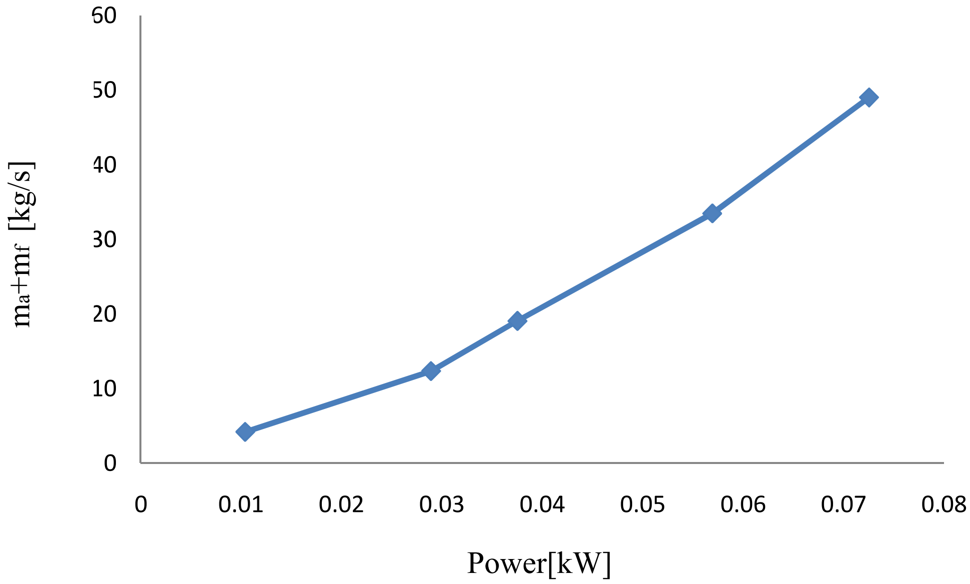

Figure 4.5: Total mass and fuel flow rate vs power losses graph

From the graph, it shows that total of mass and fuel flow rate is increased proportionally with the power losses through the exhaust. In this simulation, it is noted that the engine is operating at slightly leaner than stoichiometric condition (best economy for the fuel). Moreover, the power outputs of the engine increases with speed due to more number of cycles are executed per unit time. It should be noted that the air consumption will continue to increase with increased engine speed until some point is reached where the charge per cylinder per stroke decreases very rapidly than the number of strokes per unit time is increasing. Increase in air consumption means that increased quantities of fuel can be added per unit time consequently increasing the power output.(Ganesan 2003).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

The power exhausted by the engine at varying speed has been studied using one - dimensional GT-Power simulation based on magma 4G15 gasoline engine. The engine speed is selected from 1000, 2500, 3000, 4500 and 6000 rpm. Those ranges of speed are selected because it is represent operational speed available for a vehicle. In this study it has been show that the engine speed is proportional with the rate of heat losses through the exhaust. Increasing load increases the mass and temperature in the blowdown pulse. Increasing speed raises the gas temperature throughout the exhaust process. These effects are the results of the variations in the relative importance of heat transfer in the cylinder and heat transfer to the exhaust valve and port. Lastly, the time available for heat transfer, which depends on engine speed and exhaust gas flow rate, is the most critical factor in the heat transfer engine study.

5.2 RECOMMENDATIONS

For continuing this project or further research, some of the recommendations had been made and should consider for better analysis and accuracy results. Firstly, it is important to validate the results with the experimental results. For this study also, it is best to include the study of the exhaust gas calorimeter itself for better understanding in heat transfer using heat exchanger in order to calculate the heat transfer between two different fluids. Lastly, it is best to further the research to evaluate other losses in the engine in order to understand the nature of the engine.

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