BACHELOR THESIS – ME 141502

ANALYSIS OF INTERNAL FIN USAGE ON THE EXHAUST GAS PIPE OF MAIN ENGINE TO INCREASE THE UTILIZATION OF WASTE HEAT RECOVERY FOR GENERATING ELECTRICITY USING THERMOELECTRIC GENERATOR

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DOUBLE DEGREE PROGRAM
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TUGAS AKHIR – ME 141502

ANALISIS PENGGUNAAN SIRIP INTERNAL PADA PIPA GAS BUANG MAIN ENGINE UNTUK MENINGKATKAN PEMANFAATAN PANAS YANG TERBUANG GUNA MENGHASILKAN LISTRIK MENGGUNAKAN THERMOELECTRIC GENERATOR

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APPROVAL FORM

ANALYSIS OF INTERNAL FIN USAGE ON THE EXHAUST GAS PIPE OF MAIN ENGINE TO INCREASE THE UTILIZATION OF WASTE HEAT RECOVERY FOR GENERATING ELECTRICITY USING THERMOELECTRIC GENERATOR

BACHELOR THESIS

Submitted to Fulfill One of the Requirement
To Obtain a Bachelor Engineering Degree
On
Marine Fluid Machinery and System (MMS) Laboratory
S-1 Program Department of Marine Engineering
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APPROVAL FORM

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ANALYSIS OF INTERNAL FIN USAGE ON THE EXHAUST GAS PIPE OF MAIN ENGINE TO INCREASE THE UTILIZATION OF WASTE HEAT RECOVERY FOR GENERATING ELECTRICITY USING THERMOELECTRIC GENERATOR

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ABSTRACT

Combustion engine is the most widely used engine type as the ship's main engine and auxiliary engine. Combustion engine has 30% - 33% efficiency, which mean the heat energy generated from combustion process, only 30% - 33% are converted into mechanical energy or work. 7% - 10% lost due to frictional force, and for about 60% lost as waste heat at cooling system and exhaust gas. Almost 40% from all of heat energy generated will become waste heat at exhaust gas. Ship's main engine can generate temperature until 300 ^{0}C at the exhaust gas. This waste heat can be reused for the other necessary. The heat from exhaust gas can be transferred by conduction and convection. The heat transfer value of conduction process is influenced by the touch surface area (A). Bigger the touch surface area will result bigger heat transfer value. Touch surface area can be added by using addition of fins. There is a research before, which try to find out the effect of internal fin installation for the thermal performance using simulation software. This research is for developing the previous research, where this research will validate the previous research's result by using calculation and experiment analysis. The experiment is using Kubota RD 85 DI-2S diesel engine, it has 8.5 HP and the maximum RPM is 2200 RPM. From this research, it is known that internal fin installation can increase the heat transfer of the pipe, where the value heat transfer is upset down with the value of thermal resistance. At the same 1.000 RPM, the finned exhaust pipe has 42 K/W thermal resistance, while for the finless pipe is 44 K/W. Besides internal fin installation, the heat transfer also can be increased by increasing the engine RPM. For the finned exhaust pipe, it has 43 K/W thermal resistance at 750 RPM, while at 1000 RPM, it has 42 K/W of heat resistance. From this research also confirming the previous research that thermal performance has directly proportional with the electricity that generated by TEG which is installed at the exhaust gas pipe.

Keywords: finned pipe, exhaust gas, heat transfer, waste heat, energy, electricity, thermoelectric generator, efficient,

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***ANALISIS PENGGUNAAN SIRIP INTERNAL PADA PIPA GAS BUANG* MAIN ENGINE *UNTUK MENINGKATKAN PEMANFAATKAN PANAS YANG TERBUANG GUNA MENGHASILKAN LISTRIK MENGGUNAKAN* THERMOELECTRIC GENERATOR**

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ABSTRAK

Mesin bakar adalah jenis mesin yang paling banyak digunakan sebagai mesin utama dan mesin bantu di kapal. Mesin ini memiliki efisiensi 30% - 33%, yang berarti energi panas yang dihasilkan dari proses pembakaran, hanya 30% - 33% yang diubah menjadi energi atau kerja mekanis. 7% - 10% hilang karena gaya gesekan, dan sekitar 60% hilang sebagai limbah panas di sistem pendingin dan gas buang. Hampir 40% dari semua energi panas yang dihasilkan akan menjadi panas terbuang pada gas buang. Mesin utama kapal dapat menghasilkan suhu hingga 300 ^{0}C dari gas buangnya. Panas limbah ini dapat digunakan kembali untuk keperluan lain. Panas dari gas buang dapat berpindah secara konduksi dan konveksi. Perpindahan panas secara konduksi dipengaruhi oleh luas area bidang sentuh. Area permukaan sentuh yang lebih besar akan menghasilkan nilai perpindahan panas yang lebih besar pula. Area permukaan sentuh dapat ditambahkan dengan menggunakan penambahan sirip. Ada penelitian sebelumnya, yang mencoba untuk mengetahui pengaruh pemasangan sirip internal untuk kinerja termal menggunakan simulasi software. *Dari penelitian itu, diketahui bahwa pemasangan sirip akan meningkatkan nilai perpindahan panas. Penelitian ini untuk mengembangkan penelitian sebelumnya, dimana penelitian ini akan memvalidasi hasil penelitian sebelumnya dengan menggunakan analisis perhitungan dan eksperimen. Penelitian ini menggunakan mesin* diesel *Kubota RD 85 DI-2S, mesin ini memiliki daya 8.5 HP dan RPM maksimal 2200 RPM. Dari penelitian ini diketahui bahwa pemasangan sirip internal dapat meningkatkan perpindahan panas dari pipa, dimana nilai perpindahan panas berbanding terbalik dengan nilai tahanan panas. Pada 1.000 RPM, pipa gas buang bersirip memiliki 42 K / W tahanan panas, sedangkan untuk pipa tanpa sirip adalah 44 K / W. Selain pemasangan sirip internal, perpindahan panas juga dapat ditingkatkan dengan menaikan RPM mesin. Untuk pipa gas buang bersirip, memiliki tahanan panas 43 K / W pada 750 RPM, sedangkan pada 1000 RPM, memiliki 42 K / W tahan panas. Dari penelitian ini juga mengkonfirmasi penelitian sebelumnya bahwa kinerja termal berbanding lurus dengan listrik yang dihasilkan oleh TEG yang dipasang pada pipa gas buang.*

Kata kunci: pipa bersirip, gas buang, perpindahan panas, panas terbuang, energi, kelistrikan, generator termoelektrik, efisien,

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PREFACE

First of all, the writer would like to thank to Allah SWT. for the grace and bless so the writer could finish the Bachelor Thesis successfully. The title of this bachelor thesis is:

"Analysis of Internal Fin Usage On The Exhaust Gas Pipe Of Main Engine To Increase the Utilization of Waste Heat Recovery For Generating Electricity Using Thermoelectric Generator"

As one of the requirement to obtain a bachelor engineering degree on Marine Engineering department faculty of Marine Technology Sepuluh Nopember institute of technology Surabaya.

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Surabaya, 26th of July 2018

The author

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LIST OF SYMBOLS

a_1 : Cross sectional area without fin (m^2)
a_2 : Cross sectional area with fin (m^2)
A : Area (m^2)
A_f : Friction area (m^2)
β : Volume expansion coefficient of exhaust gas (1/K)
C : Expansion Coefficient
Cp : Specific heat (J/kg. K)
d : Inner pipe diameter (mm)
f : Friction factor
g : gravitation (m/s^2)
h : Convection heat transfer coefficient (W/ m^2. K)
H_f : Pressure drop caused by fins friction (kPa)
H_L : Pressure drop caused by fins cross section changing (kPa)
k : Thermal conductivity coefficient (W/ m. ^{0}C)
L : Total equivalent length of pipe (m)
L_c : Fin's length characteristic (m)
M_{air} : Air intake mass rate (kg/s)
M_{fo} : Fuel burned mass rate (kg/s)
N : Number of fin
Nu : Nusselt number
P : Engine power (HP)
$P_{finless}$: Back pressure of finless exhaust gas pipe (kPa)
P_r : Prandtl number
Ps : Backpressure (kPa)
q : Heat transfer (W)
Q : Exhaust gas flow (m^3/minute)
R : Engine RPM (rpm)
Ra : Rayleigh number
Re : Reynold number
Rw : Heat resistance (^{0}C/W)
ρ_{air} : Air density (g/cm^3)
S : Density of gas (m^2/s)
SFOC : Specific fuel oil consumption (gram/HP Hour)
T : Temperature (^{0}C, K)
u_x : Average flow velocity (m/s)
v_c : Cinematic fluid viscosity (m/s^2)
v_d : Dynamic viscosity (N s/m^2)
v_1 : exhaust gas velocity at pipe without fin (m/s)
v_2 : exhaust gas velocity at pipe with fin (m/s)
V : Volume displacement (m^3, cm^3)
x : Thick of wall in the direction of heat transfer (m)

CHAPTER I
INTRODUCTION

I.1 Background

Energy is the most important thing for human life to do every activity. With the increasing number of population causes the energy necessary also increasing every year. It is shown by the increasing amount of total world energy consumption, which are 11.266,7 million tones oil equivalent (TOE) at 2006, 12.455,3 million TOE at 2011 and 13.276,3 million TOE at 2016, with the increasing annual rate of 1.8% for world energy consumption and 3% for Indonesian energy consumption (British Petroleum, 2017). The energy consumption is inversely proportional with the energy reserve, especially for fossil fuels which is the primary energy resource used until now. So, it is necessary to use alternative energy in consuming energy.

One of the biggest consumer energy sector is transportation. Its rank is the third of the biggest consumer energy sector after industry and buildings which spent more than 2,5 billion TOE at 2015 and has been predicted to reach value up to 3 billion TOE at upcoming 2035 (British Petroleum, 2017). The energy consumption by sector is shown at graphic 1.1.

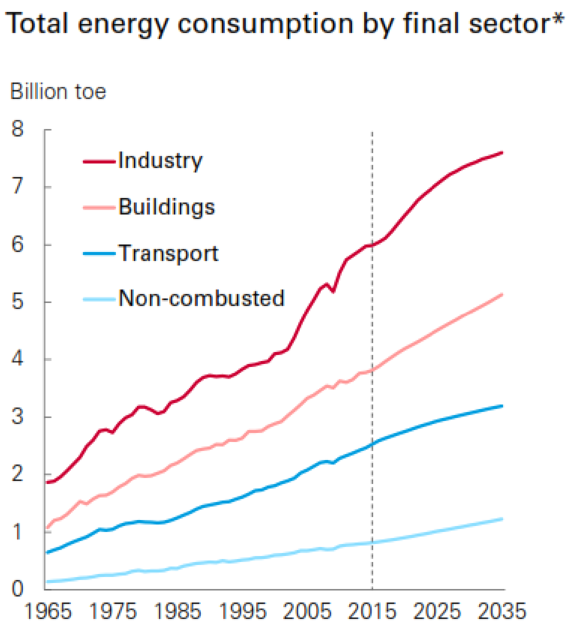


Figure 1.1 Graphic of Total Energy Consumption by Final Sectors (British Petroleum, 2017)

Maritime is the biggest consumer energy in transportation sector. This is because maritime transportation has meet all of it's energy necessary by itself such as mechanical energy and electrical energy in a long operational time. Until now, all of those necessary energy obtained by using combustion engine, especially for diesel engine which is still using fossil fuel as the energy source. Besides maritime sector, diesel engine is also widely used in other sector both on a large and small scale such as at agricultural sector, industrial sector, and building sector.

Diesel engine work by using thermal energy generated from the combustion process of fuel inside the combustion chamber. But, that work is only a fraction of the heat energy generated. Only about 25% of the fuel combustion can be utilized for vehicle operation or engine work, whereas about 40% is lost in the form of waste heat of exhaust gas (Yu & Chau, 2009). The other energy is lost caused by mechanical friction for about 5%, and the other 30% at coolant.

At this time, alternative energy is very important for supporting fossil energy as the main energy source which is used in every activity. One of the potential energy which can be used as alternative energy is derived from the heat discharged by diesel engine at exhaust gas pipe. The temperature of exhaust gas from ship's main engine can reach up to 300 ^{0}C – 400 ^{0}C. That heat energy can be used for another necessary in ship such as oil heater, fuel heater, fresh water generator heater, and water ballast treatment heater. In addition, this heat energy can also convert into electrical energy by using thermoelectric generator.

The utilization of waste heat energy depends heavily on the heat transfer process. Better heat transfer will make bigger percentage of energy gotten. At exhaust gas pipe, heat transfer process can happen in two ways, which are conduction and convection process. But, the most major donating process is conduction. Conduction process is influenced by touch area surface (A), the bigger touch area surface, the better heat transfer itself. The fins installation is an attempt to increase the touch surface area of the fluid contact with the wall of exhaust gas pipe, so as to increase conduction heat transfer (Handoko, 2017).

There are several researches which have discussed about fin utilization on exhaust gas pipe. One of them is a research by Wasis Tri Handoko, entitled "Simulasi Komputasional Kinerja Termal Pipa Gas Buang Bersirip Pada Waste Heat Recovery System Main Engine". This research explains the influence of internal fins installation against thermal performance and back pressure in exhaust gas pipe main engine using computational simulation method. This research confirms that fins installation in exhaust gas pipe able to improve thermal performance for waste heat recovery system and able to increase the heat that absorbed by the exhaust gas pipe. This fins installation also able to increase the backpressure in exhaust gas system, but the back pressure value in this research is still quite small, which is still 1% of main engine's backpressure maximum limit (Handoko, 2017).

In order for better waste heat recovery system of engine exhaust gas can be realized, then it takes a research to get the maximum energy of heat that can be reutilized. By doing experiment for analyzing the heat transfer of finless and finned exhaust gas pipe and change the heat into electrical energy using thermoelectric generator with engine load as the variable.

I.2 Statement of Problems

Based on the description of the background, then the statement of problems to be discussed in this thesis research are:

1. How is the thermal performance of finless and finned exhaust gas pipe of an engine?
2. How is the effect of the engine load against thermal performance of the exhaust pipes?
3. How is the effect of fins installation against the generated electricity from thermoelectric generator?
4. How is the effect of engine load against the generated electricity from thermoelectric generator?

I.3 Research Objectives

The goals to be achieved in this thesis research are:

1. Find out the thermal performance of finless and finned exhaust gas pipe of an engine.
2. Find out the effect of the engine load against thermal performance of the exhaust pipes.
3. Find out the effect of fins installation against the generated electricity from thermoelectric generator.
4. Find out the effect of engine load against the generated electricity from thermoelectric generator.

I.4 Research Benefits

The benefits of this thesis research are:

1. Can develop science especially in the field of heat transfer.
2. Improve the efficiency of fuel consumption by reusing heat waste energy from ship’s main engine combustion product, to meet the necessary energy of other facilities on board.
3. The module can be applicated for people in general who used diesel engine.

I.5 Research Limitations

In this thesis research, there are some limitations which used by the author, there are:

1. This research data is taken from experimental method using prototype and do not discuss the economic analysis of the module.
2. This experiment is using Kubota RD 85 DI-2S single piston 4 strokes diesel engine as exhaust gas producer.
3. The fin’s shape that used is longitudinal fin - rectangular profile.
4. The number of fin which are installed inside the exhaust gas pipe in 10 fins.
5. This experiment is using TEG SP1848-27145 as the thermoelectric generator type for converting the heat into electrical energy.
6. The engine load which is used as the variable control is started from 500 rpm, 750 rpm, and 1000 rpm.

7. This research analyze the transverse heat transfer from exhaust gas to the outside surface of exhaust gas pipe and not analyze the longitudinal heat transfer

CHAPTER II
LITERATURE STUDY

II.1 Combustion Result of Internal Combustion Engine

Diesel engines get energy to work from the fuel burning process inside combustion chamber of the engine. This energy is in the form of heat energy. However, not all of the heat energy of the fuel combustion can be converted to work as engine power. Only about 25% of the energy that can be absorbed as power, the remaining nearly 40% of wasted energy in the exhaust gas (Yu & Chau, 2009). Generally, waste heat can be classified into 3 categorize, which are high, medium, and low temperature ranges. The high temperature range is above 650 °C, medium temperature is between 230 ° C and 650 ° C, and low temperatures below 230 °C (Remeli, Date, Singh, & Akbarzadeh, 2014). Most of the combustion energy on the machine is distributed as a loss, and 70% of the total energy is heat loss. The heat energy distribution of the engine is shown in figure 2.1.

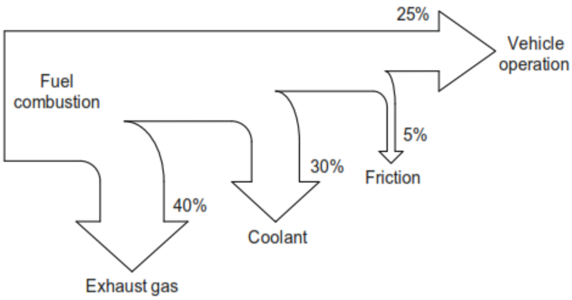


Figure 2.1 Energy Flow Part in Internal Combustion Engine (Yu & Chau, 2009)

The heat energy wasted through the engine exhaust pipe can be reused. One way to reuse that energy is by using heat exchanger. However, the system installation should pay attention to its effect on the machine itself. One of the things to watch out for is the backpressure of the exhaust gas. The average pressure in the exhaust pipe during the exhaust stroke is called the mean exhaust pressure and the atmospheric pressure is called the ambient pressure. The difference between these two pressures is defined as backpressure (Roy, Joardder, & Uddin, 2010). Backpressure is happened because of consisting of the exhaust manifold, roughness of the pipe, junction of exhaust gas pipe, muffler, connecting pipes and fin installation at the exhaust system. Increased exhaust backpressure can have a number of effects on the diesel engine, such as: increased pumping work, reduced intake manifold boost pressure, cylinder scavenging and combustion effects, ad turbocharger problems (Mayer, 2004).

II.2 Exhaust System Backpressure

Backpressure is pressure that opposed the direction of the fluid’s stream itself in confined places such as a pipe. Backpressure can be happened at exhaust gas pipe of an engine, a big backpressure can reduce the engine performance itself, which are decreasing the power, increasing fuel consumption, increasing the temperature and emission of the exhaust gas, and it can reduce the lifetime of engine itself (Caterpillar, 2013).

Backpressure can be caused by pipe size, silencer, internal fin, rain cap, and other exhaust part related components. Excessive backpressure is commonly happened because one or more of the following factors, which are:

1. The diameter of the exhaust gas pipe is too small.
2. Excessive number of the sharp bends at the exhaust system.
3. The exhaust gas pipe is too long.
4. The resistance of the exhaust components such as silencer, internal fin, and rain cap is too high.

A good exhaust system design is an exhaust which has no more than a half of the maximum backpressure allowed by the engine manufacturer or a regulation that followed by the engine user. The Swiss VERT program determined maximum allowance of DPFs to be fitted to a wide variety of equipment (Mayer, 2004). Table 2.1 outlines the VERT recommended back pressure limits for a range of engines sizes. The exhaust pressure for large engines is limited to low values due to valve overlap and high boost pressure considerations.

Table 2.1 VERT Maximum Recommended Exhaust Back Pressure (Mayer, 2004)

Engine Size	Back Pressure Limit
Less than 50 kW	40 kPa
50 - 500 kW	20 kPa
500 kW and above	10 kPa

For machines with large size, the maximum value of backpressure is determined by the engine project guide from its machine manufacturer.

Exhaust backpressure is measured when the engine is operated in full rated load and speed condition. Some engine manufacturer has already put a fitting in the exhaust discharge for measuring the backpressure. If the exhaust gas has not equipped with it. So, the measurement can be done by fitting a pressure tab at the exhaust gas pipe with the following guidelines and picture:

1. Locate the pressure tab in a straight length of exhaust gas pipe.
2. Locate the pressure tab three pipe diameters from any upstream pipe transition.
3. Locate the pressure tab two pipe diameters from any upstream pipe transition.

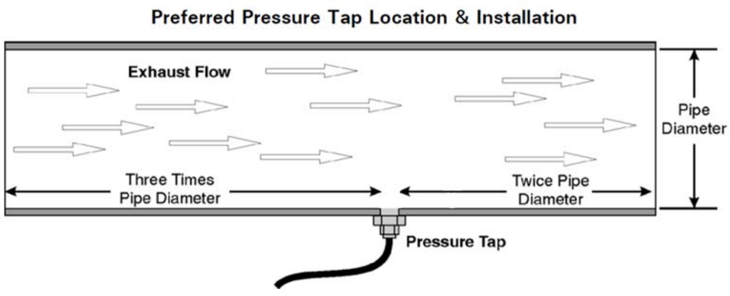


Figure 2.2 Preferred Pressure Tab Location (Caterpillar, 2013)

To calculate backpressure of an exhaust gas system can be done by using the following formula:

$$P = \frac{L\ x\ S\ x\ Q^2\ x\ 3.6\ x\ 10^6}{D^5} + Ps \quad [2.1]$$

Where:

P : Backpressure (kPa)
L : Total equivalent length of pipe (m)
Q : Exhaust gas flow (m^3/minute)
D : Inside diameter of pipe (mm)
S : Density of gas (kg/m^3)
Ps : Pressure drop of silencer/internal fin/rain cap (kPa)

To obtain the equivalent length of straight exhaust gas pipe for various elbow, it can use the following formula option:

For standard elbow (elbow radius = pipe diameter)

$$L = \frac{33D}{X}$$

For long elbow (elbow radius = 1.5 pipe diameter)

$$L = \frac{20D}{X}$$

For 45^0 elbow

$$L = \frac{15D}{X}$$

For square elbow

$$L = \frac{66D}{X}$$

Where, X = 1000 mm

II.3 Heat Energy Transfer

Heat is defined in physics as the transfer of thermal energy across well-defined limits around the thermodynamic system. Heat transfer is a science which is used for predicting the possible energy that transferred through a body caused by temperature difference. Heat transfer is a process function, therefore, the amount of heat transferred in the thermodynamic process that alters the state of the system depends on how the process occurs, not just the difference between the initial and final state of the process. Heat is the most converted form of energy as another energy, moving heat is the result of temperature differences. The theory of heat transfer is used to analyze the energy transfer and the rate of energy transfer (Holman & Jasjfi, 1997).

There are three modes of heat transfer: conduction, convection, and radiation. Any energy exchange between bodies occurs through one of these modes or a combination of them. Conduction is the transfer of heat through solids that do not participate in displacement. That is, the heat transfer in a substance is not accompanied by the displacement of the particles. Convection is a type of heat transfer which is transferred the heat through fluid. Radiation does not require a medium for transferring heat; this mode uses the electromagnetic radiation emitted by an object for exchanging heat

(Incropea & Witt, 1990). From the three modes above, the most dominant method of heat transfer is conduction and convection.

II.3.1 Conduction Heat Transfer

Temperature gradient that exist in a body will cause energy transfer process from the high temperature region to the low temperature region in its body itself, which is called by conduction. The energy transfer rate per unit area in conduction heat transfer is proportional to the normal temperature gradient (Holman & Jasjfi, 1997). The rate value of heat transfer by conduction can be formulated by equation 2.2

$$q_x = -kA\frac{\partial T}{\partial x} \quad [2.2]$$

Equation 2.2 is called Fourier's law, where q_x is the heat transfer rate and $\partial T/\partial x$ is the temperature gradient in the direction of the heat flow. The positive constant k is called the thermal conductivity of the material, and the minus sign as a sign that the heat flows from high temperature to a lower temperature. The value of thermal conductivity for some metals material is shown on table 2.2.

Table 2.2 Thermal Conductivity Value of Various Metal Materials at 0 ^{0}C (Holman & Jasjfi, 1997)

Material	**Thermal Conductivity**	
	W/m. ^{0}C	**Btu/h. ft. ^{0}F**
Silver (Pure)	410	237
Copper (Pure)	385	223
Alumunium (Pure)	202	117
Nickel (Pure)	93	54
Iron (Pure)	73	42
Carbon steel, 1% C	43	25
Lead (Pure)	35	20.3
Chrome-nickel steel (18% Cr, 8% Ni)	16.3	9.4

II.3.2 Convection Heat Transfer

Convection heat transfer is happened caused by the fluid flow which has different temperature. Convection uses the motion of fluids to transfer heat. In a typical convective heat transfer, a hot surface heats the surrounding fluid, which is then carried away by fluid movement (Incropea & Witt, 1990). The warm fluid is replaced by cooler fluid, which can draw more heat away from the surface. In this heat transfer mode, area surface also influences the total value of heat transfer rate. To express the overall effect of convection, we use Newton's law of cooling as shown on equation 2.3

$$q = hA\,(T_{\omega} - T_{\infty}) \qquad [2.3]$$

The heat-transfer rate is related to the overall temperature difference between the wall and fluid and the surface area (A). The quantity h is called the convection heat transfer coefficient. An analytical calculation of h may be made for some systems. For complex situations it must be determined experimentally. The heat-transfer coefficient is sometimes called the film conductance because of its relation to the conduction process in the thin stationary layer of fluid at the wall surface (Holman & Jasjfi, 1997). The value of thermal conductivity for some metals material is shown on table 2.3.

Table 2.3 Approximate Values of Convection Heat Transfer Coefficients (Holman & Jasjfi, 1997)

Mode	**Film Conductance**	
	$W/m^2.\ ^0C$	**$Btu/h.\ ft^2.\ ^0F$**
Across 2.5 cm air gap evacuated to a pressure of 10-6 atm and subjected to		
$\Delta T = 100\ ^0C - 30\ ^0C$	0.087	0.015
Free convection, $\Delta T = 30\ ^0C$		
Vertical plate 0.3 m [1 ft.] high in air	4.5	0.79
Horizontal cylinder, 5 cm diameter, in air	6.5	1.14
Horizontal cylinder, 2 cm diameter, in water	890	157
Heat transfer across 1.5 cm vertical air gap with $\Delta T = 60\ ^0C$	2.64	0.46
Fine wire in air, d = 0.02 mm, DT = 55 ^0C	490	86
Forced convection		
Airflow at 2 m/s over 0.2 m square plate	12	2.1
Airflow at 35 m/s over 0.75 m square plate	75	13.2
Airflow at Mach number = 3, p = 1/20 atm, $T\infty = 40\ ^0C$, across 0.2 m square plate	56	9.9
Air at 2 atm flowing in 2.5 cm diameter tube at 10 m/s	65	11.4
Water at 0.5 kg/s flowing in 2.5 cm diameter tube	3500	616
Airflow across 5 cm diameter cylinder with velocity of 50 m/s	180	32
Liquid bismuth at 4.5 kg/s and 420 ^0C in 5.0 cm diameter tube	3410	600
Airflow at 50 m/s across fine wire, d = 0.04 mm	3850	678

Mode	Film Conductance	
	W/m^2. ^{0}C	Btu/h. ft^2. ^{0}F
Boiling water		
In a pool or container	2500 - 35000	440 - 6200
Flowing in a tube	5000 - 100000	880 - 17600
Condensation of water vapor, 1 atm		
Vertical surfaces	4000 - 11300	700 - 2000
Outside horizontal tubes	9500 - 25000	1700 - 4400
Dropwise condensation	170000 - 290000	30000 - 50000

II.3.3 Radiation Heat Transfer

In radiation heat transfer, heat is transferred through regions where a perfect vacuum exists. The mechanism in this case is electromagnetic radiation. Electromagnetic radiation is propagated as a result of temperature difference, this is called thermal radiation. (Holman & Jasjfi, 1997).

Anybody with temperature above 0 Kelvin emits radiation. The type of radiation emitted is determined largely by the temperature of the body. Most "hot" objects emit infrared radiation. Hotter objects, such as the sun at ~ 5800 K, emits more energetic radiation including visible and UV (Incropea & Witt, 1990). The amount of radiation emitted by an object is given in equation 2.4

$$q = \sigma A T^4 \qquad [2.4]$$

Where A is the surface area, T is the temperature of the body, and σ is the proportionality constant and is called the Stefan-Boltzmann constant with the value of 5.669 x 10^{-8} W/m^2. K. Equation 2.4 is called the Stefan-Boltzmann law of thermal radiation and it applies only to blackbodies (Holman & Jasjfi, 1997).

II.3.4 Heat Transfer at Tube

The heat transfer in the exhaust gas pipe system is a force convection heat transfer. Convection heat transfer is caused by fluid movement against a surface that has different temperature with the fluid itself. Force convection is a convection heat transfer process where the movement fluid is not caused by natural causes like temperature and pressure difference.

The fluid flow in the exhaust gas pipe system is strongly influenced by power and engine rpm, so the flow form is very influential on the movement of this convection. The flow form can be determined through the Renault number:

Laminar flow, if Re < 2 x 10^3
Turbulence flow, if Re > 10^4

The value of Renault number can be determined by using the following formula:

$$Re = \frac{u_x\, d}{v}$$ [2.5]

Where:

Re : Reynold number
u_x : Average flow velocity (m/s)
d : Inner pipe diameter (m)
v : Cinematic fluid viscosity (m^2/s)

The convection that happen at tube is closely related to the temperature difference, the flow rate of the mass, and the flow form. The overall magnitude of the heat transfer can be determined using the following formula:

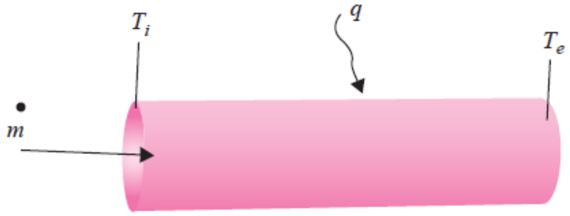


Figure 2.3 Overall heat transfer process at pipe (Holman & Jasjfi, 1997)

$$q = m\, C_p\, \Delta T_b$$ [2.6]

Where:

q : Overall heat transfer (W)
m : Mass flowrate (m)
C_p : Fluid specific heat (W/m. K)
ΔT_b : Temperature changes (^{0}C, K)

When the cross-section is not in circle form, then the hydraulic diameter is used to determine the Nuselt number and Renault number, the value of the hydraulic diameter is $D_h = \frac{4A}{p}$ where A is the cross-sectional area and P is the circumference of the fluid area.

II.4 Heat Spreading

Heat spreading is the heat movement pattern from the higher temperature side to the lower temperature side of an object. Heat spreader is most often simply a plate made from copper or other materials which have high thermal conductivity. Heat spreading resistance is influencing the value of heat transfer. Bigger heat spreading resistance will makes lower heat transfer rate value.

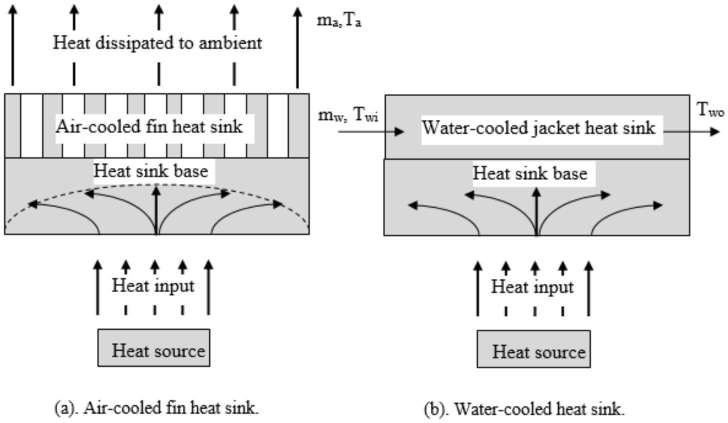


Figure 2.4 Thermal Cooling with Air-Cooled and Water-Cooled Jacket Heat Sink (Seng, Tan, & Lai, 2017)

Different type of heat transfer mode will affect different heat spreading. From figure 2.4, the heat spreading resistance occurs at the bottom of the fin heat sink (FHS) if the heat source is smaller than the base of the heat sink. Heat spreading effect increasing with larger different in sizes between source and sink. There are several ways for decreasing the heat spreading resistance, there increasing the base thickness of FHS, make the fins higher, or use more expensive highly conductive materials (Seng, Tan, & Lai, 2017).

II.5 Fin

Fin is a thin component or appendage attached to a larger body or structure. Fins typically functioned as foils that produce lift or thrust, fin is also a form of effort to improve convection and conduction heat transfer. Fins utilization for increasing the heat transfer rate has already applied in various equipment such as: Air cooled I.C. engines, refrigeration condenser tubes, electric transformers, reciprocating air compressors, semiconductor devices, and automobile radiator (Sachdeva, 2009).

Fin can influence conduction and convection mode because the heat transfer from the fluid to the fins takes by convection, while the fins occur by conduction. Principally, heat transfer is strongly influenced by surface area, and fins installation is to increase the surface area for getting better heat transfer rate. The efficiency of the fin is the ratio of actual heat transferred with the heat that would be transferred if entire fin area were at base temperature (Holman & Jasjfi, 1997). There are several types of fin based on its shape, which are:

1. Longitudinal fin
   a. Longitudinal fin – Rectangular profile
   b. Longitudinal fin – Trapezoidal profile
   c. Longitudinal fin – Concave parabolic profile
2. Radial fin
   a. Radial fin – Rectangular profile
   b. Radial fin – Triangular profile
3. Pin fin

a. Pin fin – Cylindrical profile
b. Pin fin – Tapered profile
c. Pin fin – Concave parabolic profile

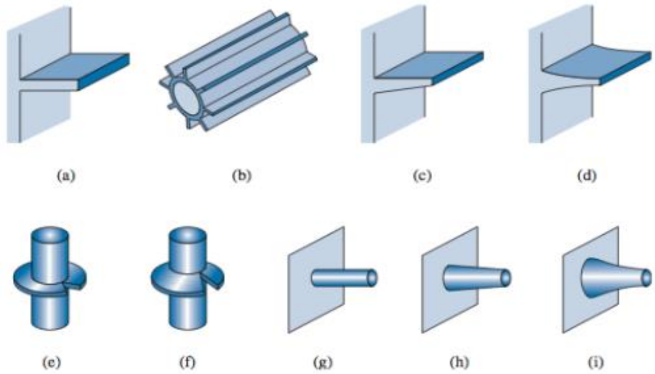


Figure 2.5 Types of Fin Based on Its Shape (Sachdeva, 2009)
(a) Longitudinal – Rectangular (b) Longitudinal – Rectangular (c) Rectangular – Trapezoidal (d) Longitudinal – Concave parabolic (e) Radial – Rectangular (f) Radial – Triangular (g) Pin – Cylindrical (h) Pin – Tapered (i) Pin – Concave parabolic

The heat transfer process that occurs in the fin and transmitted to the pipe surface is the convection and conduction process. T value of heat that transferred can be determined using energy balance formula, which is:

Energy in = Energy out + Convection loss

Energy in $= q_x = -kA\frac{\partial T}{\partial x}$ [2.7]

Energy out $= q_x + d_x = -kA(\frac{\partial T}{\partial x} + \frac{\partial^2 T}{\partial x^2}\, d_x)$ [2.8]

Convection loss $= hPd_x\,(T - T_\infty)$ [2.9]

II.6 Thermal Resistance at Fin and Surface Combination

Every material has thermal resistance against heat. For determining the value of energy that moved to outer surface of the pipe, its need to determine the pipe wall thermal performance.

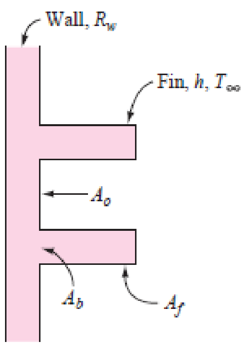


Figure 2.6 Fin (Holman & Jasjfi, 1997)

To find the value of conduction thermal resistance that work at finned pipe wall can be done by using the following formula:

$$Rw = \frac{\Delta x}{kA} \qquad [2.10]$$

Where:

Rw : Conduction Heat resistance (^{0}C/W)
Δx : Thick of wall in the direction of heat transfer (m)
k : Thermal conductivity coefficient (W/ m. ^{0}C)
A : Sectional area perpendicular to the direction of heat transfer (m^2)

The value of A in this formula is using A_0 for finless area and using A_b for finned area. While for convection thermal resistance can be determined by using the following formula:

$$Rw = \frac{1}{hA} \qquad [2.11]$$

Where:

Rw : Convection Heat resistance (^{0}C/W)
h : Convection heat transfer coefficient (W/ m^2. K)
A : Sectional area perpendicular to the direction of heat transfer (m^2)

Where, to determine the value of heat that transferred can be done with the following formula:

$$q = \frac{T_1 - T_2}{R_w} \qquad [2.12]$$

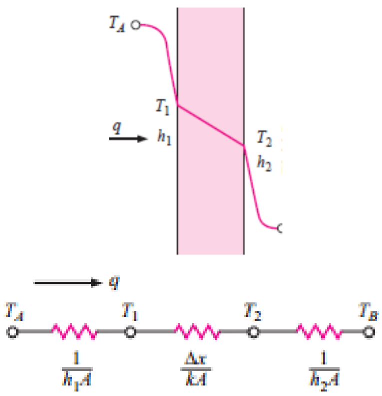


Figure 2.7 Overall process (Holman & Jasjfi, 1997)

To determine the overall heat transfer process that occur in a system, can be done by dividing the system temperature difference with the total thermal resistance $= \frac{\Delta x}{Rw}$. This formula can be translated into the following formula:

$$q = \frac{T_A - T_B}{\frac{1}{h_1A} + \frac{\Delta x}{kA} + \frac{1}{h_2A}} \qquad [2.13]$$

II.7 Thermoelectric Generator

Thermoelectric generator (TEG) is all solid-state devices that convert heat difference between its surfaces to be electrical energy. TEG works without any moving part inside, so it is completely silent when it is being operated. (Snyder, 2008). Although TEG has low efficiency, but it has several good points because it is compact, simple, quiet operation, and has inexpensive price.

TEG produces electrical power from heat flow across a temperature gradient between the hot surface and the cold surface. It works on the principle of the Seebeck effect, when the junction formed by joining two dissimilar current carrying conductors are maintained at different temperatures, an electro motive force is generated in the circuit. The current carrying conductors are known as thermoelectric elements and the couple formed out of the two current carrying conductors is known as thermoelectric couple (Karri, 2011).

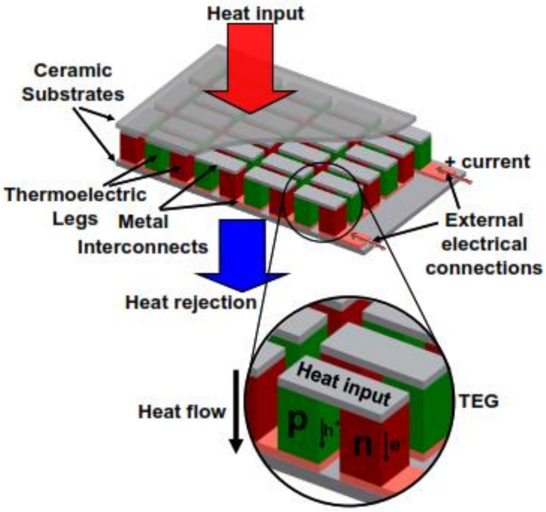


Figure 2.8 Components of a Thermoelectric Module (Karri, 2011)

The module of TEG is a matrix of semiconductor thermoelectric couples that are connected electrically in series and thermally in parallel. Figure 2.8 shows the main components of TEG, which are: (1) thermoelectric elements (legs), (2) ceramic substrates, (3) metal interconnects, and (4) External electrical connections (Karri, 2011).

Even relatively inefficient, TEG can be competitive for small use, such as waste heat sources. TEG can extract waste heat from the exhaust then deliver DC electrical power to charge the battery. BMW is one of car manufacturer who has the conceptual design of thermoelectric generator which producing electricity from waste heat in the engine exhaust. By installing that TEG in the car, the load on the engine is reduced and makes improving on fuel efficiency by as much as 10% (Snyder, 2008).

Figure 2.9 Conceptual Design of TEG Producing Electricity from Waste Heat in Exhaust (Copyright BMW) (Snyder, 2008)

II.8 Previous Researches

There are some previous studies which have discussed about waste heat recovery from the main engine exhaust gas and it is converted into electrical energy using thermoelectric, there are:

1. Teguh Julianto, entitled "*Pemanfaatan Perbedaan Temperatur Pada Main Engine Cooling System Sebagai Energi Alternatif untuk Pembangkit Listrik di Kapal"*. Final proect research, Sepuluh Nopember Institute of Technology Surabaya. 2016.

   This research uses experimental method by using conversion box which utilizes an opposite direction of water with high temperatures and lower temperatures that pass the two thermoelectric generator surfaces. The electric power generated from 12 thermoelectric pieces in the circuit is just 40 watts dc, this is because the heat transfer is not all absorbed by thermoelectric, and the heat absorbed by the conversion box is not taken into calculation (Julianto, 2016).

   In this research, the author has utilized thermoelectric generator for generating electricity from waste energy in one of system in ship, but the author still has not utilized fin for the heat exchanger, both on the hot side and cold side of thermoelectric generator, so there is no attempt to obtain greater heat from the heat sources to gain bigger power electricity.

2. Muhammad Fajrul Rahman, entitled "*Analisa Penggunaan Thermoelectric Sebagai Sumber Arus Listrik Pada Impressed Current Cathodic Protection (ICCP) Pada Pelat Lambung Kapal"*. Technical Journal ITS volume 4 No. 1. 2016.

   This research uses experimental method for converting heat from exhaust gas of main engine into electrical energy using a thermoelectric generator. This electrical energy will be used as a cathodic protection of force current method (Impresse Current Cathodic Protection). This research is using heat sink to enlarge the heat transfer value obtained from the exhaust gas to the thermoelectric generator. The results of data circulation in the research showed on table 2.4

Table 2.4 Results of Circulatory Experiment (Rahman, 2015)

No	S (m)	Debit (l/min)	Hs (^{0}C)	Cs (^{0}C)	ΔT (^{0}C)	Current (A)	Voltage (V)	Power (Watt)
1	0.2	240	72	30	42	0.13	1.36	0.1768
2	0.2	420	112	31	81	0.19	2.15	0.4085
3	0.15	240	98	31	67	0.18	1.74	0.3132
4	0.15	420	129	31	98	0.24	2.83	0.6792
5	0.1	420	107	30	77	0.19	2.16	0.4104
6	0.1	456	156	32	124	0.3	3.72	1.116
7	0.05	492	132	32	100	0.23	2.67	0.6141
8	0.05	528	183	35	148	0.34	4.43	1.5062

In this research, the author has utilized thermoelectric generator for generating electricity from waste heat energy of engine's exhaust gas. The author also has used heat sink (fin) to maximize the heat transfer process. But, the heat sink is just installed at the cool side of the thermoelectric generator, so it just can increase the value rate of the heat release at the cool side of TEG. So, the side of TEG still haven't a maximum heat from the exhaust gas pipe.

3. Ahmet Caglar, entitled "*The Effect of Fin Design Parameter on The Heat Transfer Enhancement in The Adsorbent Bed of a Thermal Wave Cycle*". Applied Thermal Engineering Volume 104. 2016. Page 386-393

Heat transfer and mass transfer model 2 Dimensions can be used to analyze finned and finless tube type adsorbent bed for thermal wave adsorption cooling cycle. That analyzation shows a significant enhancement in heat transfer value. Such that finned tube installation, the temperature of the adsorbent in the finned tube adsorbent bed is at almost 47.8 K higher than that in the finless tube. Increasing the thickness 2 times just can increase the temperature for about 2-3 K which mean it has not a significant effect on heat transfer process. Increasing the radius will decrease the temperature for about 10-17 K, while increasing the number of fins can increase the heat transfer significantly (Caglar, 2016).

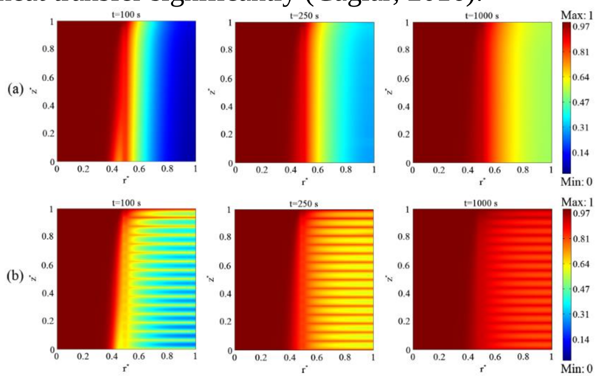


Figure 2.10 Dimensionless Temperature Distribution Inside the Adsorbent Bed with (a) Finless Tube and (b) Finned Tube (Caglar, 2016)

This research is using simulation method for analyzing the thermal performance of fin utilization in pipe. It uses 4 variables for analyzing the thermal performance, there are fin geometry, fin thickness, fin radius, and number of fins, but it doesn't use fin's length as the variable yet. Although this research is simulated for general cases, not in specific one such as on exhaust gas pipe of engine, but, this research has proven that fins installation on pipe can increase the heat transfer rate that pipe.

4. Wasis Tri Handoko, entitled *"Simulasi Komputasional Kinerja Termal Pipa Gas Buang Bersirip Pada Waste Heat Recovery System Main Engine".* Final project research, Sepuluh Nopember Institute of Technology Surabaya. 2017.

This research uses computational method by using Ansys Fluent software for analyzing the thermal performance of internal finned pipe in exhaust gas pipe of an engine. One of the effect of internal fins installation in engine exhaust system is backpressure which can influence the performance of the engine. Backpressure value that exceeds the limit from the engine manufacture will decrease engine performance and decrease the life time of the engine itself (Handoko, 2017). From the simulation result, obtained the pressure value in exhaust pipe which is shown on table 2.5

Table 2.5 Pressure of Exhaust Gas in Pipe (Handoko, 2017)

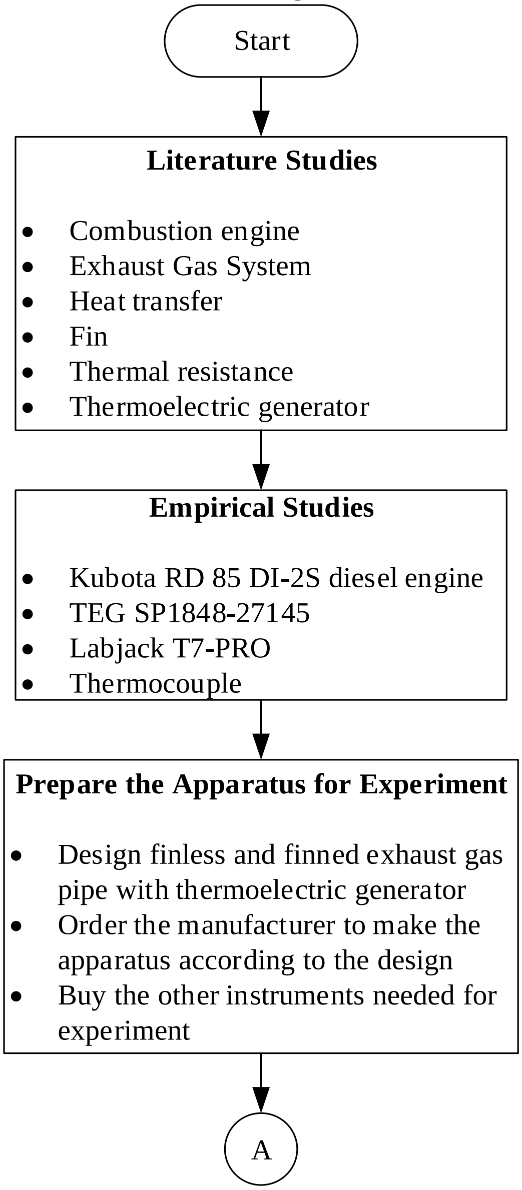
Power Rate	**Pressure (Pa)**					
	Fin		**Transition**		**Tengah**	
	Inlet	**Outlet**	**Inlet**	**Outlet**	**Inlet**	**Outlet**
100	578.5	65.8	493	151.3	407.6	407.6
90	577.9	65.11	492.4	236	407	407
80	577.9	65.11	492.4	236	407	407
70	577.9	65.11	492.4	150.6	407	407
60	577.9	65.11	492.4	150.6	407	407
50	577.9	65.11	492.4	236	407	407

This research is using computational simulation method for analyzing the thermal performance of fin utilization in pipe. It uses longitudinal- rectangular profile fin for the analyzation. This simulation has proven that internal fin installation is able to increase the heat transfer between exhaust gas and exhaust gas pipe. In addition, this research also has proven that fin installation has small effect in increasing backpressure, which is less than 1% from the maximum pressure drop limit of the engine. But, this research is fully using computational simulation method, so it is necessary for doing the validation and improvement by using experimental method to get better analyzation about the thermal performance of finned exhaust gas pipe in main engine.

CHAPTER III
METHODOLOGY

III.1 Methodology Flow Chart

Research method is a reference that is used in research implementation. Generally, research methods are the stages and processes that are used to achieve the goal of thesis research. The flow of this research as shown in Figure 3.1



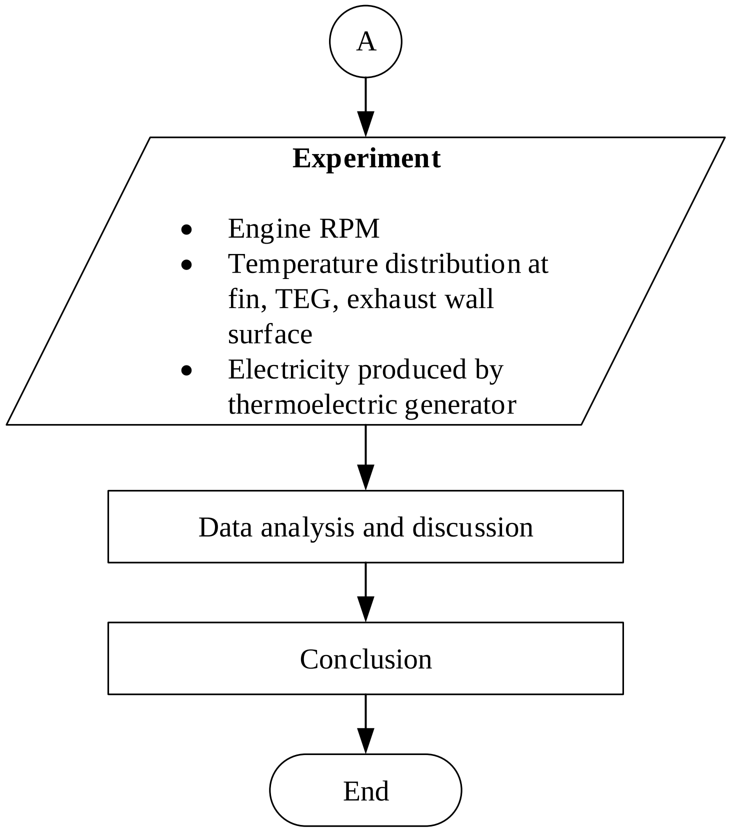


Figure 3.1 Research Flow Diagram

III.2 Definition of Methodology Flow Chart

1. Literature Studies

Literature studies was conducted to obtain supporting theories and references on the thesis research. Supporting references include books, journals, papers, seminar and official website proceedings related to energy, heat transfer, heat spreading, diesel engine, waste heat utilization, fin, thermoelectric generator and electrical circuit. Literature studies is discussing about the characteristics of the heat distribution of internal combustion engine results especially on heat characteristics at the exhaust gas. This process also learns about heat transfer, especially regarding conduction and convention heat transfer along with the heat spread. It is hoped that the result of this process is obtained the right foundation to determine the maximum heat transfer rate in waste heat recovery system.

2. Empirical Studies

This process is a preliminary analysis of a study of the research already studied in the literature study. From the results of this empirical study will obtain the design parameters used to design the exhaust pipe system design. In this process, the author will find out several data which are:

1. Dimension of exhaust gas port of Kubota RD 85 DI-2S single piston 4 strokes diesel engine.
2. Exhaust gas temperature rate of Kubota RD 85 DI-2S single piston 4 strokes diesel engine at 500 rpm, 750 rpm, and 1000 rpm.
3. Specification of TEG SP1848-27145
4. Manufacturer for makes finless and finned exhaust gas pipe with thermoelectric generator installation place
5. The right setting for Lab Jack T-7 Pro as the temperature data logger using software from Kipling.
6. The right way to use thermocouple wire type, stainless type, and exhaust gas type.

In addition, empirical study process also done to get the design parameters for getting research variables that will be used in this bachelor thesis research, these variables include:

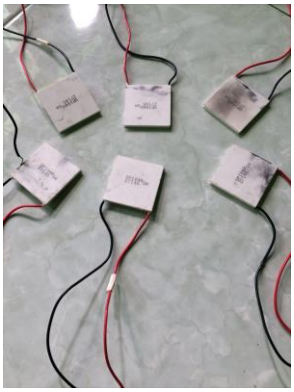
Control variables : Experiment time and reference temperature.
Independent variables : Fin installation, engine load operation, and experiment duration.
Dependent variables : Thermal performance and electric power generated from thermoelectric generator.

3. Prepare the Apparatus for Experiment

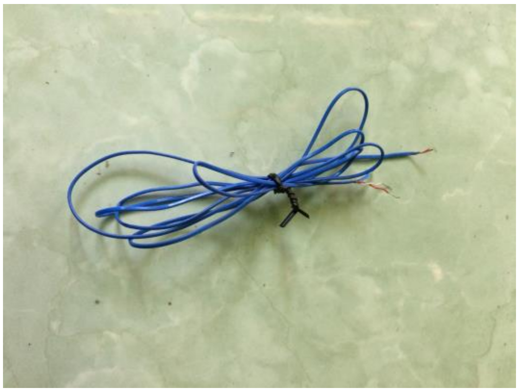
Preparing the apparatus for doing the experiment, this process consists of preparing the required materials in the experimental process as well as the equipment required in the data retrieval of the experimental results. In this process also will be done a planning of the design using the reference of the initial design parameters from the results of empirical studies. After designing the finless and finned exhaust gas pipe, in this process also will be looked out the workshop for making the exhaust gas pipe in accordance with the design that has been planned. The apparatus which need to be prepared for doing the experiment are:

Table 3.1 The Requirement Apparatuses

No.	Name	Picture
1.	Finless exhaust gas pipe	 

2.	Finned exhaust gas pipe	
3.	Thermoelectric generator (TEG SP1848-27145)	
4.	Kubota RD 85 DI-2S single piston 4 strokes diesel engine	

5.	Diesel fuel (High speed diesel fuel)	
6.	Polyurethane foam as heat shield for insulation	 
7.	Alumunium Foil	

8.	Thermocouple wire type	
9.	Thermocouple stainless type	
10.	Thermocouple exhaust gas type (EGT)	

11.	Tachometer digital	
12.	Multimeter digital	
13.	Stopwatch	

14.	Extension cable	

4. Experiment

Data retrieval in this thesis research is done by doing experiment. This experiment is done to get data about thermal performance and power electricity generated by thermoelectric generator between using finless and finned exhaust gas pipe. The experiment results are the difference amount of heat energy that is transferred and power electric generated with variating of engine load by measuring the engine RPM. The experiment procedure that will be done in this research is shown on experiment flow diagram at figure 3.2

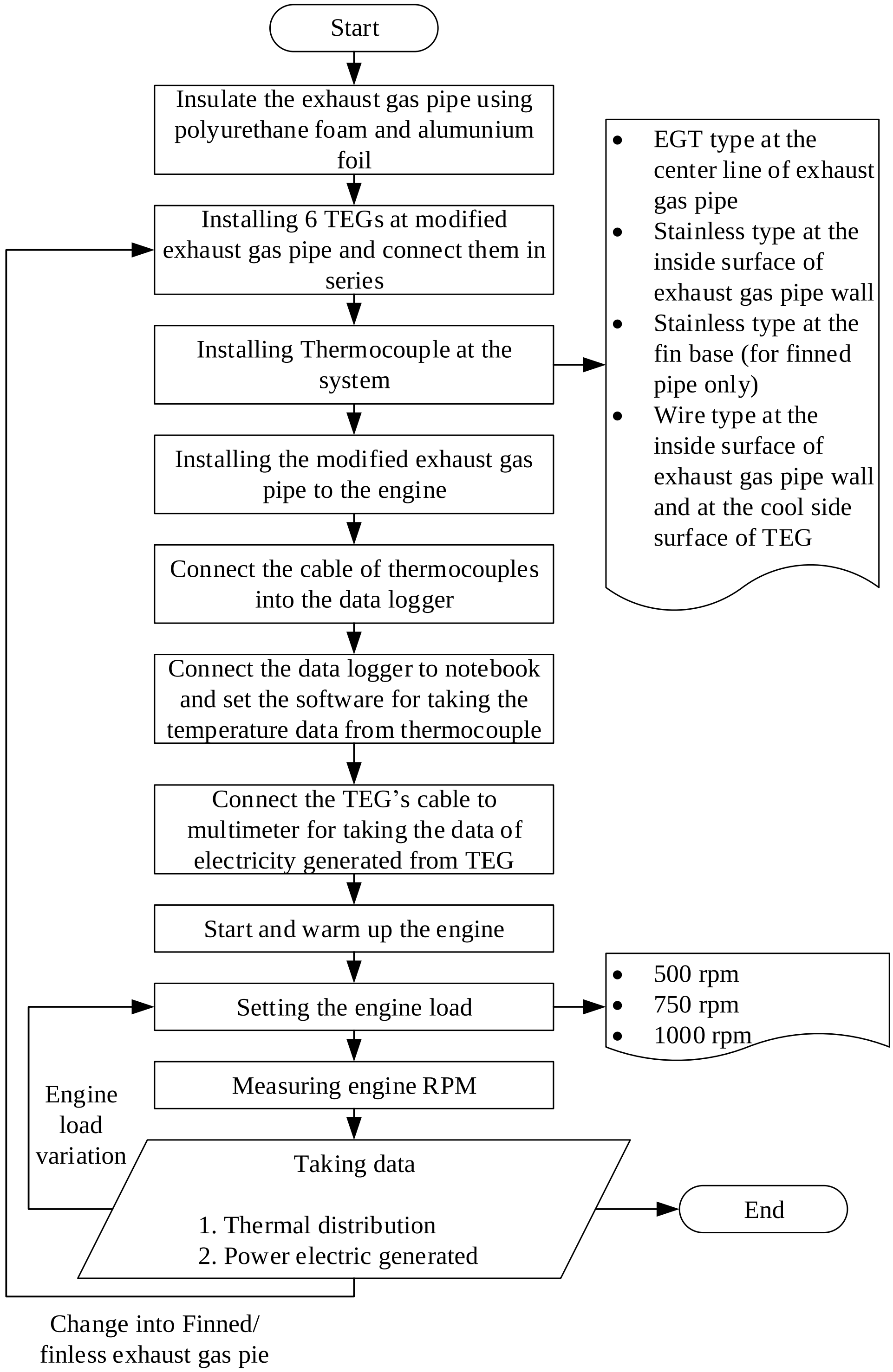


Figure 3.2 Experiment Flow Diagram

1. Insulate the exhaust gas pipe using polyurethane foam. This is done to reduce the heat transfer through radiation from the outside surface of the exhaust gas pipe to the atmosphere for making the calculation analysis easier. Because, in this bachelor thesis, the author wants to focus on the effect of internal fin installation where on that process only focusses on conduction and convection heat transfer processes.
2. Continue to insulate the exhaust gas pipe using alumunium foil. This is done by the author to make better heat insulation for the exhaust gas pipe, where the first layer is using polyurethane foam, and the second layer is using alumunium foil. For the alumunium foil itself, the author wraps the exhaust gas pipe with it in two layers.

Figure 3.3 Heat Insulation Using Alumunium Foil for the Exhaust Gas Pipe

3. Clean the heat insulation of the exhaust gas pipe for the thermoelectric generator's placess, which are by cutting the alumunium foil and clean the polyurethane foam from the exhaust gas pipe surface. This is done to eliminate the heat resistance from the exhaust gas pipe surface to thermoelectric generators, so the thermoelectric generators will have directly contact with the exhaust gas pipe surface and can take more heat from it.

Figure 3.4 Heat Insulation Cleaning

4. Install 6 TEGs at the outside surface of the exhaust gas pipe , then connect each of them in series circuit, this is done by the author because the author want to get the total value of the voltage generated by 6 Thermoelectric generators SP1848-27145.

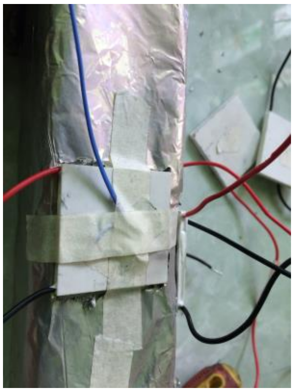


Figure 3.5 TEG Installation at Exhaust Gas Pipe

5. Install thermocouple needed to the system for measuring the value of temperature of the system. For this experiment, the author uses 4 thermocouple for finless exhaust gas pipe and five thermocouples for finned exhaust gas pipe using 3 types of thermocouple, which are installed at:
    a. Center line of exhaust gas port for measuring the temperature of the exhaust gas itself. For this, the author uses thermocouple exhaust gas type which has higher working temperature range then the other type.

Figure 3.6 Thermocouple EGT Installation

    b. Inside surface of exhaust gas pipe. For this, the author uses thermocouple stainless type. By knowing the temperature at this point, the author will know the convection heat transfer from the exhaust gas to the exhaust gas pipe.
    c. Fin. For this, the author uses thermocouple stainless type (for finned exhaust gas only). By knowing the temperature at this point, the author will know the conduction heat transfer from fin’s peak to inside surface of exhaust gas pipe.
    d. Outside surface of exhaust gas pipe. For this, the author uses thermocouple wire type because it has easier installation then the other type and its working temperature range appropriate with the actual temperature at this point. By knowing the temperature at this point, the author will know the

conduction heat transfer at the exhaust gas pipe from inside surface to outside surface.

e. Cool surface of thermoelectric generator. For this, the author uses thermocouple wire type. By knowing the temperature at this point, the author will know the heat transfer and the heat resistance of thermoelectric generator SP1848-27145. Besides that, the author also knows the temperature difference between the hot side and the cool side for calculating the voltage and current which can be generated by thermoelectric generators theoretically based on its spesification and compere the calculation result with the actual voltage and current generated.

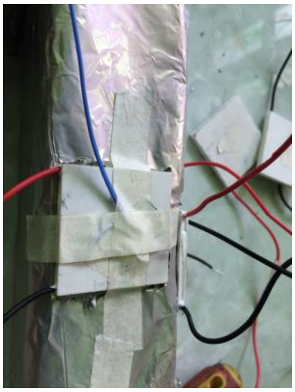


Figure 3.7 Thermocouple EGT Installation

6. After all of the instruments required has been installed at the exhaust gas pipe, then the exhaust gas pipe is installed to the engine. This is done after installing all of the instrument to make the installation easier, because it will be more difficult if the author installs the instruments after the exhaust gas pipe has been installed to the engine caused by lack of space during the instruments installation.
7. Connect the cable of thermocouple to data logger (Lab Jack T-7 Pro).

Figure 3.8 The Thermocouple Has Been Connected To Data Logger

8. Connect the data logger to notebook that has been turned on before. From the notebook, open the software from Kipling for setting the data logger. Where, for this experiment, the things that set by the author are:

a. Choose how we will connect the data logger to notebook. For Lab Jack T-7 Pro has 2 options, which are by using wireless and also USB. For this experiment, the author chooses USB mode for connect it to notebook.

Figure 3.9 Option for Connecting the Data Logger to Notebook

b. Set the analog input of the data logger. Which input channels that will be used for the experiment, then choose what instrument or sensor which is connected to that channel. For this experiment, the author use type K thermocouple.

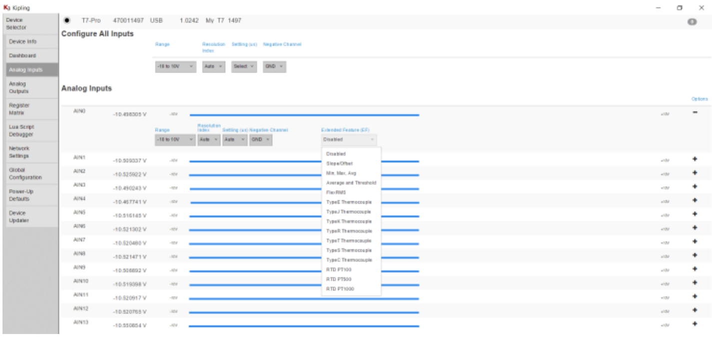


Figure 3.10 Election of Instrument That Will Be Used

c. Set the negative channel that will be used for that channel, then choose the metric or unit which is desired to read is it kelvin or Celsius degree. For CJC Modbus Address means that the experiment will use external terminal screw, external sensor, or not. For this experiment, the author doesn't use both of external terminal screw and external sensor, so the author choose "T7 Screw Terminal (AIN0-3)" for CJC Modbus Address.

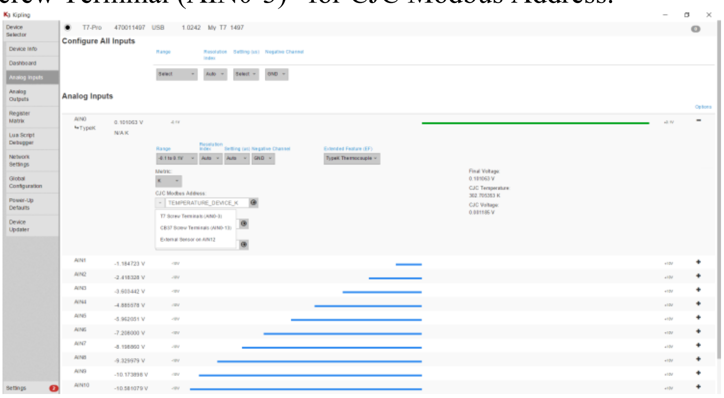


Figure 3.11 Setting the Data Logger

d. Do the step a – c for the other channel that also will be used for the experiment.
e. Close Kipling software.
f. Open software “LJ Log M” for setting the appearance data which are gotten by the thermocouple through data logger.

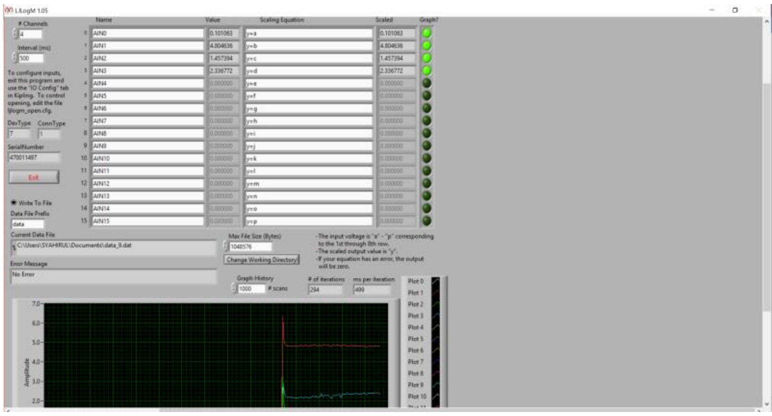


Figure 3.12 Software LJ Log M Appearance

g. Set the number of channels that will be used. Number of channel means that how many channels that will be showed in the graphic.
h. Choose graph option to turn on and of the graphic appearance for each channels.
i. Set the time interval for reading the data through data logger.
j. Add “_EF_READ_A” at the column name to change the graphic from voltage into temperature.

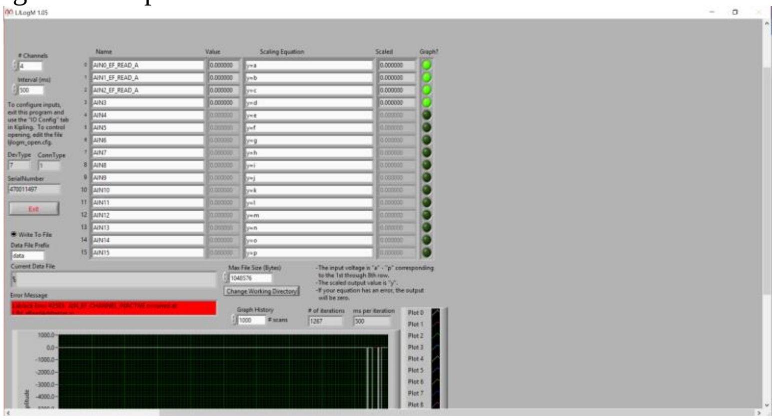


Figure 3.13 Set the Graphic into Temperature Graphic from Voltage Graphic

9. Connect the positive and the negative cable from TEG’s circuit to multimeter for reading the voltage that will be generated by the thermoelectric generators.

Figure 3.14 Connect TEG's Circuit to Multimeter

10. Ensure that the diesel fuel is enough while doing the experiment.
11. Start to operate the engine.
12. Setting the engine load at 500 rpm.
13. Measure the engine rpm using tacho meter.
14. Wait for about 2 minutes, this is done for warming up the diesel engine. Because when the diesel engine is started in the first time, the rpm will be unstable for a while
15. Take the data of thermal distribution in several point, which are:
    a. Thermoelectric generator
    b. Inner wall of exhaust gas pipe's wall
    c. Outer wall of exhaust gas pipe's wall
    d. Fin (Finned exhaust gas type)
    e. Exhaust gas

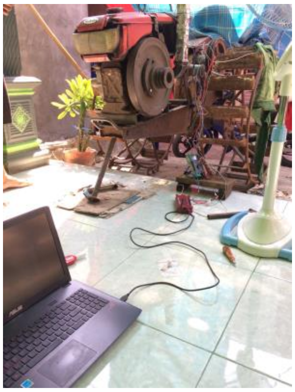


Figure 3.15 Do the Experiment and Take the Data

16. Take the data of voltage and current generated from thermoelectric generator
17. Repeat the step number 6 – 10 using 750 rpm and 1000 rpm engine
18. Repeat the step number 1 – 17 using Finned exhaust gas pipe

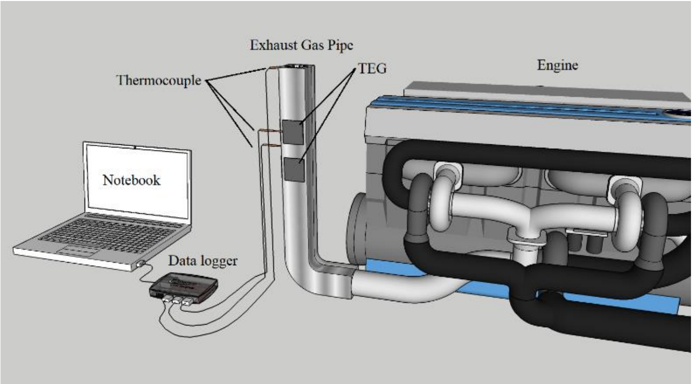


Figure 3.16 Schematic overview of the experiment

5. Data analysis and discussion

Data analysis and discussion based on data of experiment results, data of thermal performance and power electricity generated in evaluation and if not appropriate then process will be repeat from planning the design. The data success parameter is higher heat flow rate which resulting big power electricity when using finned exhaust gas pipe than using finless exhaust gas pipe, if it is not achieved then the data is evaluated. In addition, the other parameter engine performance, if there is high decreasing engine performance, then the data will be evaluated. All data will be analyzed to get maximum results to be able to draw as conclusions.

6. Conclusion

The conclusion of this thesis research refers to the relationship between experiment results data with the purpose of this study. So, the conclusion will summarize the effect of internal fin fitting on waste heat recovery system at main engine.

CHAPTER IV
PROTOTYPE DESIGN

IV.1 General

The method that used in this research is to prove experimentally that internal longitudinal fin installation in exhaust gas system will increase the heat transfer ability of the exhaust gas pipe by scaling the design from the previous research and making it real. For achieving it, in this chapter will be explained about the empirical data of engine Kubota RD 85 DI-2S and TEG SP1848-27145, the exhaust gas pipe design, the overview of the system how the author will do the experiment, and also the calculation of backpressure that can be generated by the exhaust gas pipe if it is installed to the engine.

IV.2 Empirical Data

Before doing the experiment and calculation analysis about thermal performance at finless and internal finned exhaust gas pipe and also the electricity which can be generated from them using thermoelectric generator. So, it is required the data which is used to support the first calculation analysis and also used as the design parameter for internal finned exhaust gas pipe. That data includes the engine spesification and Thermoelectric Generator spesification.

IV.2.1 Engine Spesification

The data about exhaust gas system that used is based on the small diesel engine exhaust gas system. The diesel engine that used in this research is Kubota RD 85 DI-2S. Based on the engine specifications. Then obtained data as follows:

- Motor model : 4-stroke diesel engine
- Air sucking : Natural
- Number of cylinder : 1
- Diameter x stroke long : (88 x 84) mm
- Stroke volume : 510 cc
- SFOC : 170 gr/HP hour
- Max Power : 8.5 HP
- Max RPM : 2200
- Exhaust gas manifold : 3 cm x 2.5 cm

IV.2.2 Thermoelectric Generator Spesification

Figure 4.1 TEG SP1848-27145

On this research, the waste heat recovery that the author takes from the exhaust gas pipe will be converted into electrical energy using thermoelectric generator. On this research, the type of thermoelectric generator that used by the author is SP1848-27145 with the specification as follows:

- Size : 40 mm x 40 mm x 3.4 mm
- Maximum temperature : 150 ^{0}C
- Electricity generated based on the temperature difference

Table 4.1 Electricity Generated Based on Temperature Difference

Δ*T* (^{0}C)	**Voltage (V)**	**Current (mA)**	**Power (Watt)**
20	0.97	225	0.22
40	1.8	368	0.66
60	2.4	469	1.13
80	3.6	558	2.01
100	4.8	669	3.21

The data of electricity generated based on temperature difference for TEG SP1848-27145 can be shown on figure 4.1 and 4.2 bellow:

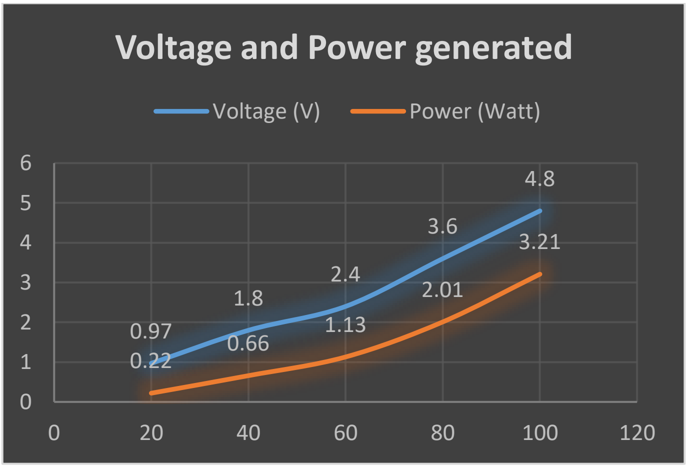


Figure 4.2 Graphic of Voltage and Power Generated Against Temperature Difference

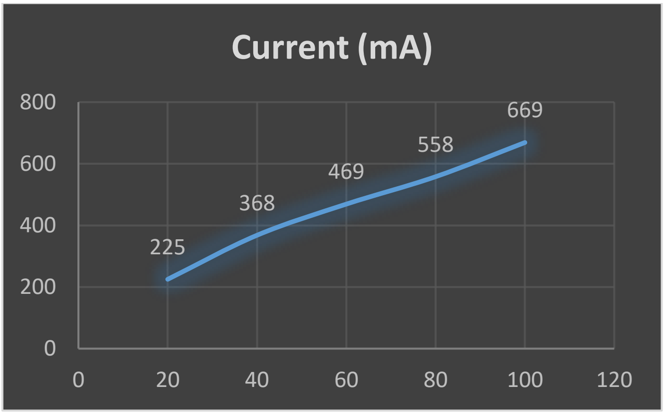


Figure 4.3 Graphic of Current Generated Based on Temperature Difference

For this experiment, to gain more electricity which can be generated from thermoelectric generator with the same temperature difference, the author strings up 6 TEGs in series, so they can generate more voltage. By stringing up six thermoelectric generators in series, the voltage which can be generated can be shown on table 4.2 as follows:

Table 4.2 Electricity Generated By 6 TEG in series Based on Temperature Difference

Δ*T* (^{0}C)	**Voltage (V)**	**Current (mA)**	**Power (Watt)**
20	5.82	225	1.31
40	10.8	368	3.97
60	14.4	469	6.75
80	21.6	558	12.05
100	28.8	669	19.27

IV.2 Prototype Design of Engine Exhaust Heat Utilization System

The stage for designing the exhaust gas pipe in this research starts from observing the module design from previous research.

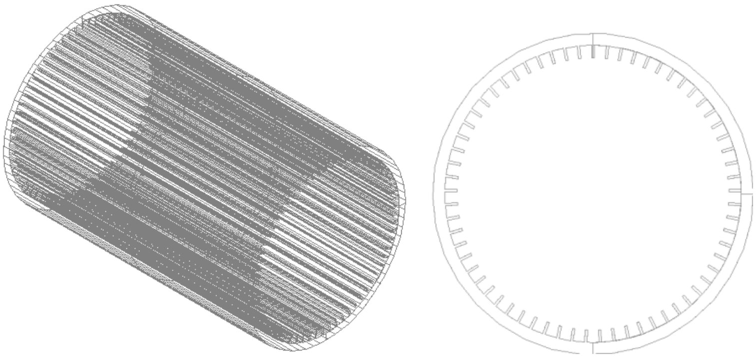


Figure 4.4 Exhaust Gas Pipe Design from Previous Research (Handoko, 2017)

From the previous design, the author plans the exhaust gas pipe based on several parameters and considerations for this experiment, there are:

1. The diameter of exhaust gas pipe is bigger than the size of exhaust gas manifold of the engine that used for the experiment. This is done to avoid the increased back pressure if the diameter of the exhaust gas is smaller than the exhaust gas manifold of the engine.
2. The diameter of exhaust gas pipe is not exceed the mooring boundary at the engine manifold so the exhaust gas pipe can be installed properly at the engine.
3. The value of backpressure which can be generated by the exhaust gas pipe design is not more than 50% of the maximum backpressure limit for the engine that used for the experiment because if the backpressure is bigger than 50% of the maximum limit given by the engine manufacturer, it can cause damage to the machine and reduce its lifetime.
4. The shape profile and the number of fins are token based on the ease of manufacture in small workshop.
5. The shape profile of the exhaust gas pipe is chosen based on the ease of install the instrumentation (TEG) for doing the experiment.

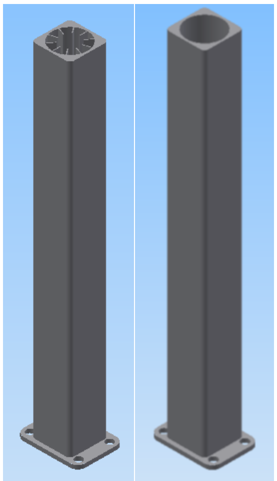


Figure 4.4 Exhaust Gas Pipe Design

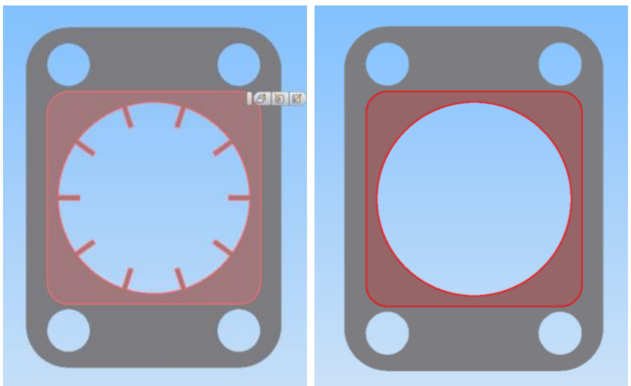


Figure 4.5 Cross Section of Internally Finned and finless Exhaust Gas Pipe

This exhaust gas pipe was designed with inner diameter 45 mm, more than the size of engine exhaust gas manifold of Kubota RD 85 DI-2S which is 30 mm x 20 mm, this is done to prevent bigger pressure drop on the finned exhaust gas pipe which can makes bigger backpressure to the engine. The thickness of the exhaust gas pipe is 2.5 mm. this design using internal fin to add the touch surface area between the exhaust gas and the exhaust gas pipe. The number of fins which is installed is 10 fins with the length is 5 mm and the thickness is 1 mm along the exhaust gas pipe. For this design, the author choose rectangle profile for the fin to make the manufacturer easier for making the exhaust gas pipe. On the outer side, the exhaust gas pipe design has rectangle profile, this was chosen by the author to make easier installation for the thermoelectric generator which has flat shape.

The exhaust gas pipe will be made from aluminum as the material because this material has a big thermal conductivity than other material. Besides that, this material also easier to found at small manufacturer. This design also will be made by using casting metal method to prevent welding which can reduce the thermal conductivity of the exhaust gas pipe itself.

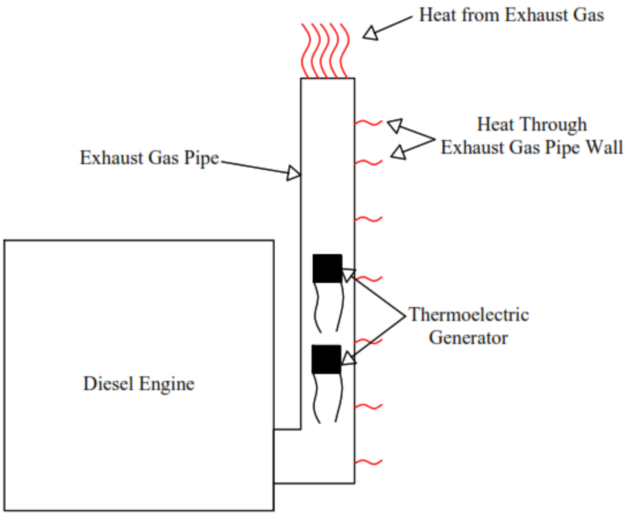


Figure 4.6 Schematic Diagram of Engine Exhaust Heat Utilization

From the schematic diagram above, the thermoelectric generators just need to be sticked at the outside surface of exhaust gas pipe, then those thermoelectric generator will produce electricity because of its temperature difference between its hot surface and its cool surface.

IV.3 Backpressure Calculation

The mathematic calculation is done using the equation which has been discussed on chapter 2. This calculation process is done to determine the value of backpressure which is generated, where it can be caused by friction and also the internal finned exhaust gas pipe of the engine.

To determine and confirm that the design has not reach 50% of the maximum backpressure limit, the backpressure calculation will be done using the data when the engine is operated in maximum power with the following equation:

IV.3.1 Finless Exhaust Gas Pipe Backpressure

$$P = (\frac{L\ x\ S\ x\ Q^2\ x\ 3.6\ x\ 10^6}{D^5}) + (Ps)$$

$$P = (P_{finless}) + (H_L + H_f)$$

(Caterpillar, 2013)

Where:

P	: Back pressure (kPa)
L	: Total Equivalent Length of pipe (m)
Q	: Exhaust gas flow (m^3/min)
D	: Inside diameter of pipe (mm)
Ps	: Pressure drop of silencer/raincap/fin (kPa)
$P_{finless}$	: Back pressure of finless exhaust gas pipe (kPa)
H_L	: Pressure drop caused by fins cross section changing (kPa)
H_f	: Pressure drop caused by fins friction (kPa)

- **Total Equivalent Length of Pipe (L)**

  $L = L_1 + L_2 + L_3$

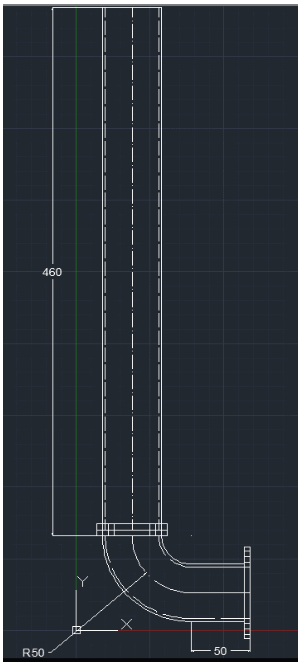


Figure 4.7 Side view of Exhaust Gas Pipe

$L_1 = 460\ mm$

$= 0.46\ m$

***Equivalent of Length Straight Pipe**

a. For standard elbow (elbow radius = pipe diameter)

$$L = \frac{33\ D}{X}$$

b. For long elbow

$$L = \frac{20\ D}{X}$$

c. 45^0 elbow

$$L = \frac{15\ D}{X}$$

d. Square elbow

$$L = \frac{66\ D}{X}$$

Where, X = 1000 mm or 12 in.

(Caterpillar, 2013)

$$L_2 = \frac{33\ D}{X} = \frac{33\ x\ 45}{1000}$$

$= 1.485\ mm$

$= 0.001485\ m$

$L_3 = 50\ mm$

$= 0.05\ m$

$L = L_1 + L_2 + L_3 = 0.46 + 0.001485 + 0.05$

$= 0.511485\ m$

- **Total Exhaust Gas Flowrate (Q)**

$$Q = V\ x\ \frac{R}{2}\ x\ C$$

(Donaldson Company Inc., 2015)

Where:

Q : Exhaust gas flow (cm^3/s)

V : Volume displacement of combustion chamber (cm^3)

R : Engine RPM (rpm)

C : Expansion Coefficient

$$= \frac{(T+460)}{540} = \frac{(418.86+460)}{540}$$

$= 1.62752$

T : Exhaust gas temperature (K)

$$Q = 510\ x\ \frac{2200}{2}\ x\ 1.62752 = 913038 \frac{cm^3}{minute}$$

$$= 0.91304 \frac{m^3}{minute}$$

$$= 0.01522 \frac{m^3}{s}$$

- **Air Intake Mass Rate (M_{air})**

$$M_{air} = V\ x\ \frac{R}{2}\ x\ \rho$$

Where:

M_{air} : Air intake mass rate (kg/s)
V : Volume displacement of combustion chamber (cm^3)
R : Engine RPM (rpm)
ρ_{air} : Air density (g/cm^3)
$= 0.00116\ g/cm^3$

$$M_{air} = 510\ x\ \frac{2200}{2}\ x\ 0.00116 = 652.387 \frac{g}{minute}$$

$$= 0.01087\ kg/s$$

- **Fuel Mass Rate (M_{fo})**

$$M_{fo} = SFOC\ x\ P$$

Where:
M_{fo} : Fuel burned mass rate (kg/s)
SFOC : Specific fuel oil consumption (gram/HP Hour)
P : Engine power (HP)

$$M_{fo} = 170\ x\ 8.5\ = 1445 \frac{g}{hour}$$

$$= 0.0004\ kg/s$$

- **Density of Exhaust Gas (S)**

$$S = \frac{M_{rate}}{V_{rate}} = \frac{(M_{air} +\ M_{fo})}{Q}$$

Where:

S : Density of gas (kg/m^3)
M_{air} : Air intake mass rate (kg/s)
M_{fo} : Fuel burned mass rate (kg/s)
Q : Exhaust gas flow (cm^3/s)

$$S = \frac{(0.01087 + 0.0004)}{0.01522}$$
$$= 0.7409\ kg/m^3$$

- **Pipe Inside Diameter (S)**

$$D = 45\ mm$$

- **Finless Exhaust Gas Pipe Backpressure (P)**

$$P = \frac{L\ x\ S\ x\ Q^2\ x\ 3.6\ x\ 10^6}{D^5}$$
$$= \frac{0.511485\ x\ 0.7409\ x\ 0.91304^2\ x\ 3.6\ x\ 10^6}{45^5}$$
$$= 0.00616\ kPa$$

IV.3.2 Pressure Drop Caused By Cross Section Changing (H_L)

$$H_L = \frac{(\frac{a_1}{a_2} - 1)^2\ x\ {v_1}^2}{2g}$$

Where:
H_L : Pressure drop caused by fins cross section changing (kPa)
a_1 : Cross sectional area without fin (m^2)

$$= \pi\ \left(\frac{1}{2}\ x\ D\right)^2 == \ 3.14\ \left(\frac{1}{2}\ x\ 45\right)^2$$
$$= 1589.63\ mm^2$$
$$= 0.00159\ m^2$$

a_2 : Cross sectional area with fin (m^2)

$$= 1540.39\ mm^2$$
$$= 0.00154\ m^2$$

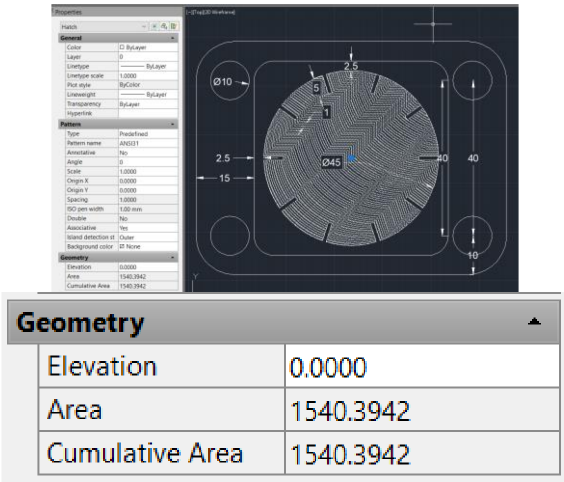


Figure 4.8 Cross section view of Internally Finned Gas Pipe

v_1 : exhaust gas velocity at pipe without fin (m/s)

$$= \frac{Q}{a_1} = \frac{0.01522}{0.00159}$$

$$= 9.57289\ m/s$$

g : gravitation (m/s^2)

$$= 9.81\ m/s^2$$

$$H_L = \frac{(\frac{0.00159}{0.00154} - 1)^2\ x\ 9.57289^2}{2\ x\ 9.81^2}$$

$$= 0.00477\ m\ Exhaust\ Gas$$

$$= 0.00477\ x\ 0.00727\ kPa$$

$$= 0.0000345\ kPa$$

IV.3.3 Pressure Drop Caused By Fin's Friction (H_f)

$$H_f = \frac{f\ x\ A_f\ x\ {v_2}^2}{a_2\ x\ 2\ x\ g}$$

Where:

H_f : Pressure drop caused by fins friction (kPa)
f : Friction factor
A_f : Friction area (m^2)
v_2 : exhaust gas velocity at pipe with fin (m/s)
a_2 : Cross sectional area with fin (m^2)
g : gravitation (m/s^2)

- **Cinematic viscosity (V_c)**

$$V_c = \frac{V_d}{S}$$

Where:

V_c : Cinematic viscosity (m^2/s)
V_d : Dynamic viscosity ($N\ s/m^2$)
$= 22.2359\ x\ 10^{-6}\ N.s/m^2$ (www.pipeflowcalculations.com, 2018)
S : Density of gas (kg/m^3)

$$V_c = \frac{22.2359\ x\ 10^{-6}}{0.7409}$$
$$= 0.000030012\ m^2/s$$

- **Reynold Number (Re)**

$$Re = \frac{v_2\ x\ D}{V_c}$$

Where:

Re : Reynold number
v_2 : Exhaust gas velocity at pipe with fin (m/s)
$$= \frac{Q}{a_2} = \frac{0.01522}{0.00154}$$
$$= 10.6818\ m/s$$
D : Inside pipe diameter (m)
V_c : Cinematic viscosity (m^2/s)

$$Re = \frac{22.2359 x\ 0.045}{0.000036535}$$
$$= 14812.4$$

- **Friction Factor (f)**

$$f = 0.02 + (\frac{0.0005}{D})$$

Where:

f : Friction factor
D : Pipe inside Diameter (mm)

$$f = 0.02 + (\frac{0.0005}{D})$$
$$= 0.03111$$

- **Friction Area (A_f)**

$$A_f = 2\ x\ p\ x\ l\ x\ N$$

Where:

A_f : Friction area (m^2)
p : Fin length (m)
l : Fin width (m)
N : Number of fin

$$A_f = 2\ x\ 0.46\ x\ 0.0005\ x\ 10$$
$$= 0.0046\ m^2$$

- **Pressure Drop Caused By Fin Friction (H_f)**

$$H_f = 2\ x\ p\ x\ l\ x\ N$$

Where:

A_f : Friction area (m^2)
p : Fin length (m)
l : Fin width (m)
N : Number of fin

$$H_f = \frac{0.03111\ x\ 0.0046\ x\ 9.87886^2}{0.00154\ x\ 2\ x\ 9.81} = 0.11099\ m\ exhaust\ gas$$
$$= 0.46212\ x\ 0.00673\ kPa$$
$$= 0.00336\ kPa$$

IV.3.4 Finned Exhaust Gas Pipe Backpressure

$$P_{finned} = P_{finless} + H_L + H_f$$
$$= 0.00616 + 0.0000345 + 0.00956$$
$$= 0.00956\ kPa$$

From the calculation above, can be concluded that the exhaust gas pipe which has been designed by the author in this research will not reach 50% of the maximum backpressure limit of the engine if the author installs it to the engine although that engine is operated on maximum load or maximum RPM. By using the same formula for finding the value of backpressure like the calculation above, the author can gets the value of backpressure of the engine for some rpm variable which are shown on table 4.3

Table 4.3 Backpressure Generated by Exhaust Gas Pipe Installation

RPM	Load (%)	Exhaust Gas Flow Rate (m^3/s)	Exhaust Gas Temperature (^0C)	Reynold Number	Backpressure (kPa)
500	22.73	0.003371043	123.64	3936.31	0.00053940
750	34.09	0.003461112	126.35	5599.80	0.000792019
1000	45.45	0.006786101	129.23	7243.58	0.00201994
2200	100.00	0.015217298	145.86	14812.36	0.00955676

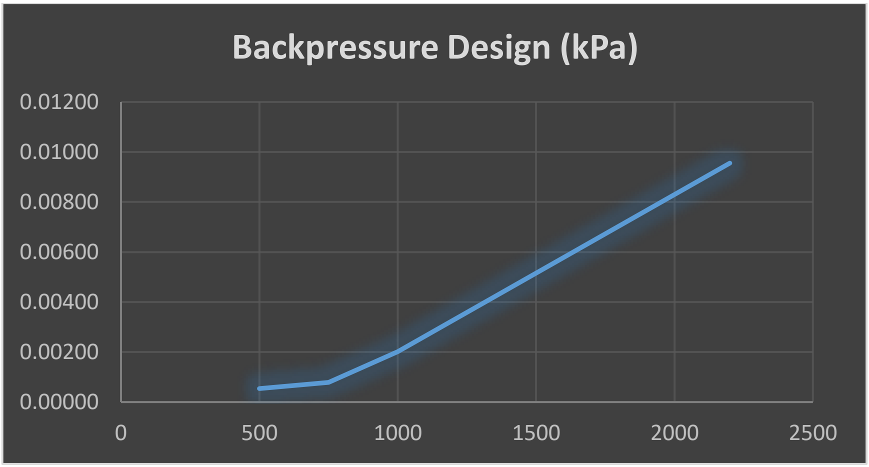


Figure 4.9 Graphic of Backpressure Generated Against RPM

Figure 4.9 shows that the increasing of engine RPM will affect the increasing of backpressure generated. It happened because the increasing of engine RPM will makes the exhaust flowrate also increasing. It makes the velocity of the exhaust gas also increasing, where velocity is one of the main factors, which influence the backpressure.

From the data that shown on table 4.3, it shows that the exhaust gas pipe design is safe for the engine and will not decrease the engine lifetime significantly, because it is still far below the exhaust gas backpressure limit which is 40.000 kPa.

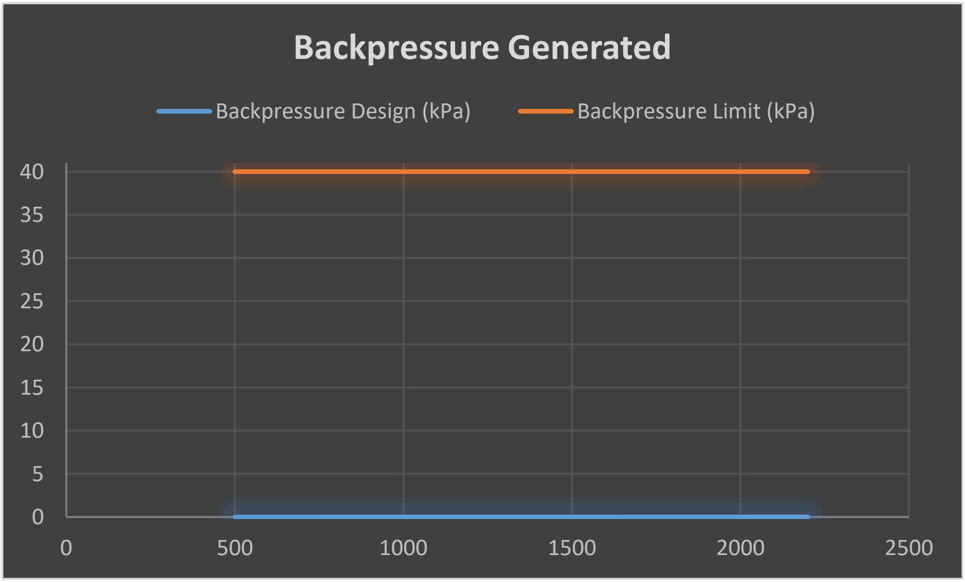


Figure 4.10 Graphic of Backpressure Generated by Exhaust Gas Pipe Design

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CHAPTER V
ANALYSIS AND DISCUSSION

V.1 General

In this chapter will be explained about the data analysis and the discussion about the result of exhaust gas waste heat utilization experiment using finless and finned exhaust gas pipe on diesel engine. The results of this research are expected to validate the results of the previous research which shows that internal longitudinal fin installation on pipe will increase the heat transfer value of the pipe itself by using software for simulation method. This data analysis is gotten from the experiment result by measuring the temperature of the exhaust gas pipe at several points when the engine is being operated using thermocouples and compere the temperature data obtained between when the engine is installed with finless exhaust gas pipe and when the engine is installed with internal longitudinal finned exhaust gas pipe. Besides temperature data, in this experiment also will be measured the value of voltage that can be generated by thermoelectric generators which have been installed to the exhaust gas pipe. In this chapter also will be found out the value of heat transfer at the exhaust gas pipe wall by using analytical calculation for comparing the experiment data with the theoretical data. From this analysis and discussion will be known whether the internal longitudinal installation can increase the heat transfer value at exhaust gas pipe of an engine or not.

V.2 Heat Transfer Analytical Calculation

To analyze and determine the value of heat transfer theoretically at finned exhaust gas pipe using calculation analysis, the author calculates it using the following equation and stage:

V.2.1 Convection Heat Transfer Coefficient (h)

- **Prandtl Number (Pr)**

$$P_r = \frac{V_D\ x\ Cp}{k}$$

Where:

P_r : Prandtl number

V_d : Dynamic viscosity (N s/m^2)

= 0.000021 (m^2/s) @ 396.642 K for flue gas

Cp : Specific heat (J/kg. K)

$= 1080.23 \frac{J}{kg}.K$ @ 396.642 K for flue gas

k : Thermal conductivity (W/m. K)

$= 0.01746 \frac{W}{m} K$ @ 396.642 K for flue gas

$$P_r = \frac{0.000021\ x\ 1080.23}{0.01746}$$
$$= 1.31910658$$

- **Rayleigh Number (Ra)**

$$Ra = \frac{g\ x\ \beta\ x\ (T_\infty - T_s) x\ Lc^3\ x\ Pr}{V_c^{\ 2}}$$

Where:

Ra : Rayleigh number
g : Gravitation (m^2/s)
β : Volume expansion coefficient of exhaust gas (1/K)
$= (T_\infty + 460)/540$
$= \frac{396.642 + 460}{540}$
$= 1.58637\ 1/K$
T_∞ : Exhaust gas temperature (K)
$= 396.642\ K$
T_s : Fin's surface temperature (K)
$= 350.355\ K$
L_c : Fin's length characteristic (m)
$= l + \left(\frac{t}{2}\right)$
$= 0.005 + \left(\frac{0.001}{2}\right)$
$= 0.0055\ m$
  l : Width of fin (m)
  t : Thick of fin (m)
P_r : Prandtl number
V_c : Cinematic viscosity (m^2/s)
= 0.000025 (m^2/s) @ 396.642 K for flue gas

$$Ra = \frac{9.81\ x\ 1.58637\ x\ (396.642 - 350.355)\ x\ 0.0055^3\ x\ 1.31910658}{0.000025^2}$$

$$= 252568.9816$$

- **Nusselt Number (Nu)**

$$Nu = 0.023\ x\ Re^{0.8}\ x\ Pr^n$$

Where:

Nu : Nusselt number
Re : Reynold number
= 3936.310808 @ 396.642 K for flue gas
P_r : Prandtl number
n : Position of tube and fluid
= 0.4 if the fluid is being heated by the wall
= 0.3 if the fluid is being cooled by the wall

$Nu = 0.023\ x\ Re^{0.8}\ x\ Pr^{n}$

$= 0.023\ x\ 3936.31^{0.8}\ x\ 1.31910658^{0.3}$

$= 18.788$

- **Convection Coefficient (h)**

$$h = \frac{Nu\ x\ k}{Lc}$$

Where:

h : Convection heat transfer coefficient of the fluid ($W/m^2\ K$)
Nu : Nusselt number
k : Thermal conductivity of exhaust gas (W/m. K)
Lc : Fin’s length characteristic (m)

$$h = \frac{18.79\ x\ 0.01746}{0.0055}$$

$= 59.6373\ W/m^2K$

V.2.2 Convection Heat Transfer at Fin’s Longitudinal Cross Section

$q_1 = h\ x\ A\ x\ (T_\infty - T_s)$

Where:

q_1 : Convection Heat transferred at fin's longitudinal cross section (W)
h : Convection heat transfer coefficient of exhaust gas ($W/m^2\ K$)
A : Fin's longitudinal cross section (m^2)

$= n\ x\ ((2\ x\ p\ x\ l) + (p\ x\ t)$

$= 10\ x\ ((2\ x\ 0.45\ x\ 0.005) + (0.45\ x\ 0.001)$

$= 0.0495\ m^2$

n: Number of fin (m)
p: Length of fin (m)
l: Width of fin (m)
t: Thick of fin (m)

T_∞ : Exhaust gas temperature (K)

$= 396.642\ K$

T_s : Inner exhaust gas pipe surface temperature (K)

$= 353.047\ K$

$q_1 = 59.64\ x\ 0.0495\ x\ (396.64 - 353.05)$

$= 128.69\ W$

V.2.3 Convection Heat Transfer at Fin’s Transvers Cross Section

$q_2 = h\ x\ P\ x\ L\ x\ (T_\infty - T_s)$

Where:

q_2 : Convection Heat transferred at fin's transvers cross section (W)

h : Convection heat transfer coefficient of exhaust gas (W/m^2 K)
P : Circumference of transverse cross section (m^2)

$$= (\pi \ x \ D) + n \ x \ (2 \ x \ l)$$

$$= (3.14 \ x \ 0.045) + 10 \ x \ (2 \ x \ 0.005)$$

$$= 0.2413 \ m$$

D : Pipe inner diameter (m)
n : number of fin
l : Width of fin (m)

L : Length of pipe (m)
T_∞ : Exhaust gas temperature (K)
$= 396.64 \ K$
T_s : Inner Exhaust gas pipe surface temperature (K)
$= 353.05 \ K$

$$q_2 = 59.63 \ x \ 0.2413 \ \ x \ (396.64 - \ 353.05)$$

$$= 282.307 \ W$$

V.2.4 Heat Balance

$$q_{cond} = q_1 + \ q_2$$

Where:

q_{cond} : Conduction heat transferred at fin's transvers cross section (W)
q_1 : Convection Heat transferred at fin's longitudinal cross section (W)
q_2 : Convection Heat transferred at fin's transvers cross section (W)

$$q_{cond} = 128.694 + 282.307$$

$$= 411 \ W$$

V.2.5 Fin's Base Temperature

$$q_{cond} = -k \ x \ A \ x \ \left(T_{pick} - \ T_{base}\right) / \ dx$$

$$T_{base} = \ T_{pick} - \frac{(q_{cond} \ x \ dx)}{k \ x \ A}$$

Where:

T_{base} : Temperature at fin's base (^{0}C)
T_{pick} : Temperature at fin's pick (^{0}C)
$= 77.36 \ C$
q_{cond} : Conduction heat transferred at fin's transvers cross section (W)
dx : Thick of fin in the direction of heat propagation (m)
k : Thermal conductivity coefficient of Alumunium (W/m ^{0}C)
= 202 (W/m ^{0}C)
A : Sectional area perpendicular to the direction of heat flow (m^2)

$$= p \ x \ l$$

$$= 0.45 \ x \ 0.001$$

$= 0.00045\ m^2$

$$T_{base} = 77.36 - \frac{(411\ x\ 0.005)}{202\ x\ 0.0045}$$

$= 75.09\ C$

V.2.6 Outer Exhaust Gas Pipe Surface Temperature

$$q_{cond} = -k\ x\ A\ x\ (T_{in} - T_{out})/\ dx$$

$$T_{out} = T_{in} - \frac{(q_{cond}\ x\ dx)}{k\ x\ A}$$

Where:

T_{out} : Temperature at outside surface of exhaust pipe (^{0}C)
T_{in} : Temperature at inside surface of exhaust pipe (^{0}C)
$= 75.09\ C$
q_{cond} : Conduction heat transferred(W)
dx : Thick of pipe in the direction of heat propagation (m)
k : Thermal conductivity coefficient of Alumunium (W/m ^{0}C)
= 202 (W/m ^{0}C)
A : Sectional area perpendicular to the direction of heat flow (m^2)

$= (\pi\ x\ D)$

$= (3.14\ x\ 0.045)$

$= 0.1413\ m^2$

$$T_{base} = 77.36 - \frac{(411\ x\ 0.01)}{202\ x\ 0.1413}$$

$= 74.95\ C$

From the calculation above, can be concluded that, theoretically, internal fins installation at exhaust gas pipe for the same load or engine RPM will increase the heat transfer from the exhaust gas. By using the same formula for finding the value of the exhaust gas convection coefficient, heat transfer, and outside surface of exhaust gas pipe temperature like as the calculation above, the author can gets the value of them for some rpm variable when using finless exhaust gas pipe and when using internal dinned exhaust gas pipe which are shown on table 5.1

Table 5.1 Heat Transfer on Exhaust Gas Pipe

Fin	RPM	Exhaust Gas Temperature (^{0}C)	Nu	H (W/m^2.K)	Outside surface of Exhaust Pipe T. (^{0}C)
No	500	123.36	18.32	58.14	74.81
	750	125.60	24.37	77.36	75.24
	1000	128.46	29.94	95.03	75.64

Fin	RPM	Exhaust Gas Temperature (^{0}C)	Nu	H (W/m^2.K)	Outside surface of Exhaust Pipe T. (^{0}C)
Yes	500	123.64	18.79	59.64	74.95
	750	126.35	24.95	79.21	77.24
	1000	129.23	30.72	97.51	77.60

From the data shown on table 5.1, the highest temperature at outside surface of the exhaust gas pipe is gained at 1.000 RPM with finned exhaust gas pipe installed. Where at the same RPM, the temperature at the outside of finned exhaust gas pipe has higher temperature than at finless exhaust gas pipe. Besides that, the increasing of engine RPM also affect the increasing of exhaust gas temperature and the value of convection heat coefficient (H), and make the outside surface of the exhaust gas pipe also higher.

V.3 Thermal Performance Data Experiment

The temperature data is taken by using some thermocouples which have been integrated to notebook by using data logger (T7 Lab jack Pro). The experiment is done two times, the first experiment is using finless exhaust gas pipe and the second experiment is using internal finned exhaust gas pipe. For each experiment is done 3 times with different engine RPM as the variable which are 500 RPM, 750 RPM, and 1000 RPM. On this experiment, there are 4 points which is used as the reference for finding out the thermal performance on exhaust gas pipe, which are at the center of exhaust gas pipe for measuring the exhaust gas temperature, inside wall of exhaust gas pipe, outside wall of exhaust gas pipe, and the cool side surface of the thermoelectric generator. But, for the experiment which uses finned exhaust gas pipe, there is one addition point which will be measured, it is at the fin surface. From the experiment, the author obtains data as follows.

V.3.1 500 Engine RPM with Finless Exhaust Gas Pipe

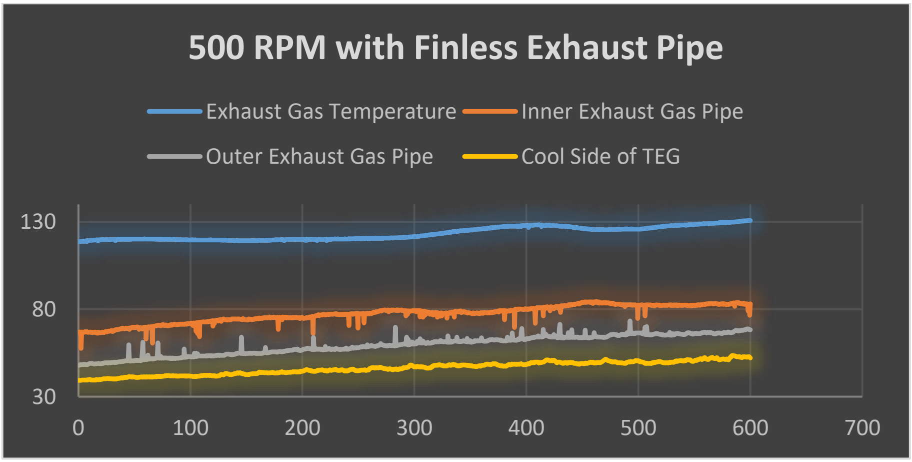

Figure 5.1 Graphic of thermal performance at 500 RPM with finless pipe

From figure 5.1 above, can be concluded that the experiment for finding out the thermal performance on 500 RPM engine using finless exhaust gas pipe has higher temperature over time in 4 points of measurement. From figure 5.1, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point. The temperature is decreasing again at the outside wall point, and the last is at the cool side of TEG point which has the lowest temperature. From the measurement, the author takes the average value for each point, there are:

a. Exhaust gas temperature : 123.36 ^{0}C
b. Inside wall temperature : 77.29 ^{0}C
c. Outside wall temperature : 59.49 ^{0}C
d. Cool side of TEG temperature : 46.34 ^{0}C

V.3.2 750 Engine RPM with Finless Exhaust Gas Pipe

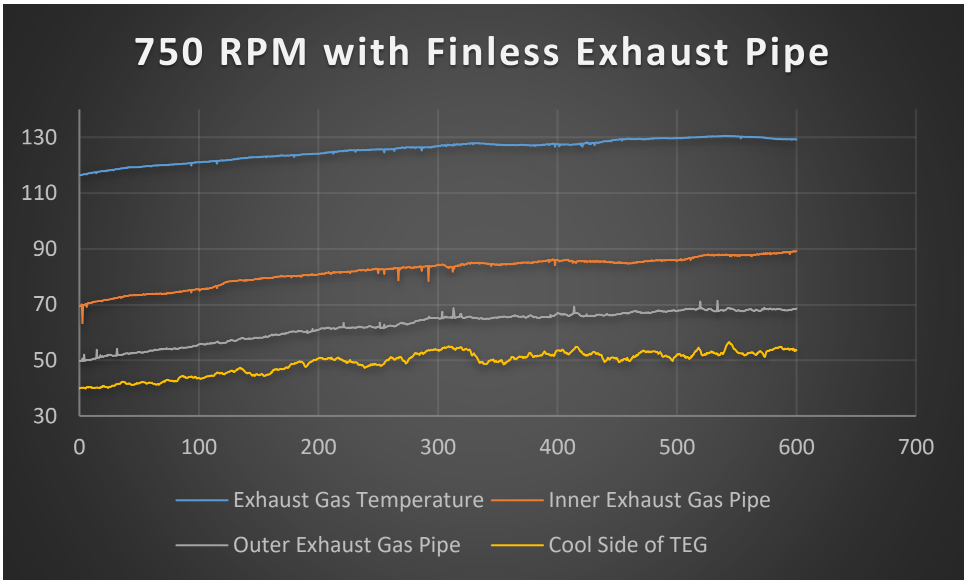

Figure 5.2 Graphic of thermal performance at 750 RPM with finless pipe

From figure 5.2 above, can be concluded that the experiment for finding out the thermal performance on 750 RPM engine using finless exhaust gas pipe has higher temperature over time in 4 points of measurement. From figure 5.2, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point. The temperature is decreasing again at the outside wall point, and the last is at the cool side of TEG point which has the lowest temperature. From the measurement, the author takes the average value for each point, there are:

a. Exhaust gas temperature : 125.6 ^{0}C
b. Inside wall temperature : 82.04 ^{0}C
c. Outside wall temperature : 62.35 ^{0}C
d. Cool side of TEG temperature : 49.21 ^{0}C

V.3.3 1000 Engine RPM with Finless Exhaust Gas Pipe

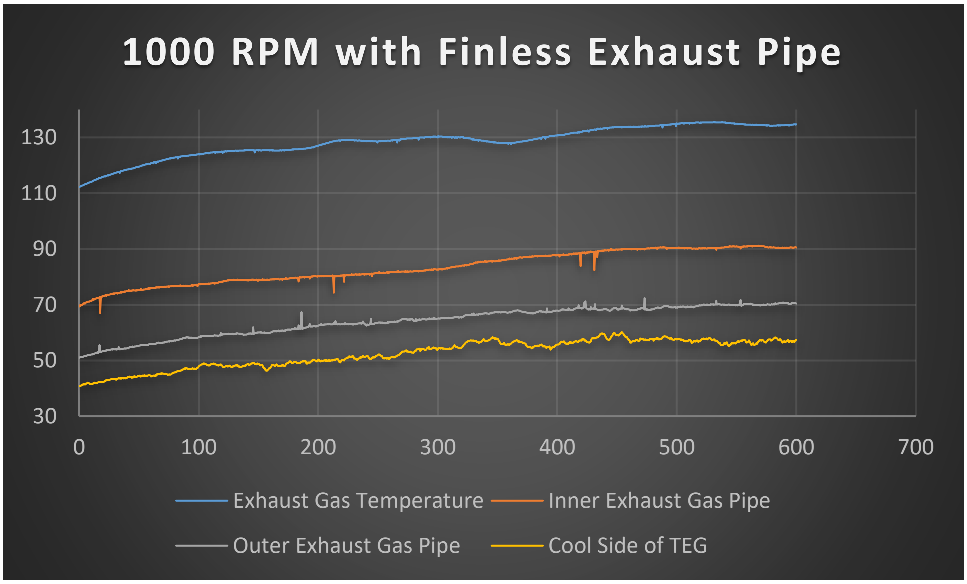

Figure 5.3 Graphic of thermal performance at 1000 RPM with finless pipe

From figure 5.3 above, can be concluded that the experiment for finding out the thermal performance on 1000 RPM engine using finless exhaust gas pipe has higher temperature over time in 4 points of measurement. From figure 5.3, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point. The temperature is decreasing again at the outside wall point, and the last is at the cool side of TEG point which has the lowest temperature. From the measurement, the author takes the average value for each point, there are:

a. Exhaust gas temperature : 128.46 ^{0}C
b. Inside wall temperature : 83.42 ^{0}C
c. Outside wall temperature : 64.07 ^{0}C
d. Cool side of TEG temperature : 52.49 ^{0}C

V.3.4 500 Engine RPM with Finned Exhaust Gas Pipe

From figure 5.4 below, can be concluded that the experiment for finding out the thermal performance on 500 RPM engine using finned exhaust gas pipe has higher temperature over time in 5 points of measurement. From figure 5.4, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point, the temperature is decreasing again at the fin surface point, at outside wall point, and the last is at the cool side of TEG point which has the lowest temperature.

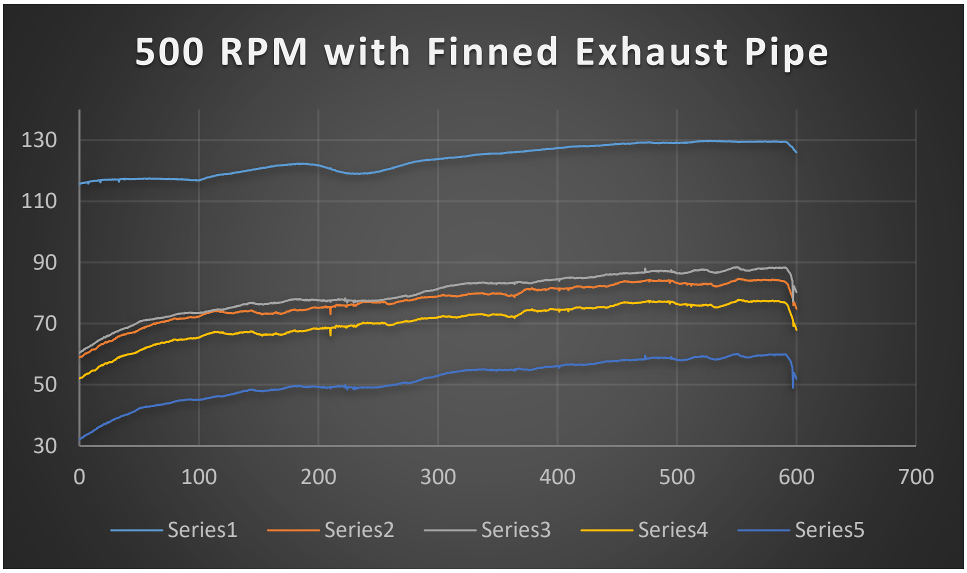

Figure 5.4 Graphic of thermal performance at 500 RPM with finned pipe

From the measurement, the author takes the average value for each point of the measurement, there are:

a. Exhaust gas temperature : 123.64 ^{0}C
b. Inside wall temperature : 80.31 ^{0}C
c. Fin temperature : 74.84 ^{0}C
d. Outside wall temperature : 67.97 ^{0}C
e. Cool side of TEG temperature : 51.94 ^{0}C

V.3.5 750 Engine RPM with Finned Exhaust Gas Pipe

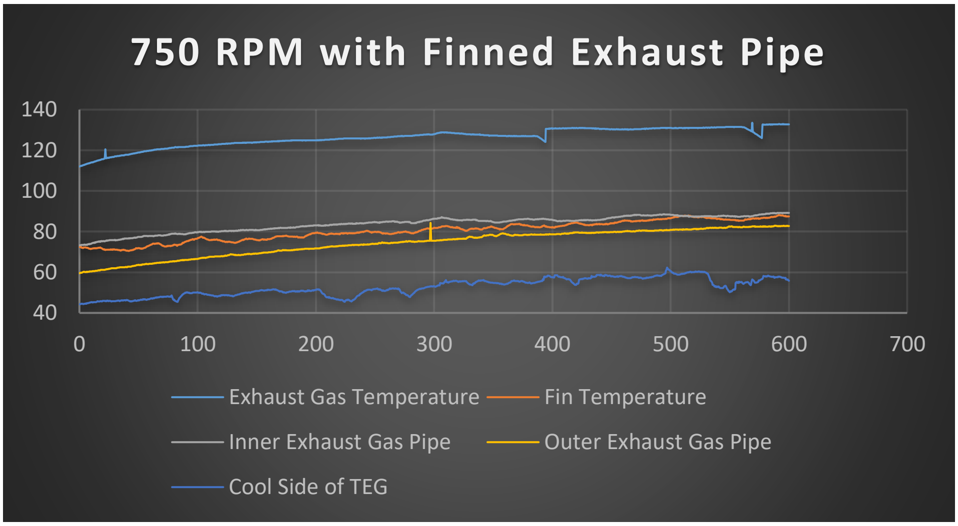

Figure 5.5 Graphic of thermal performance at 750 RPM with finned pipe

From figure 5.5 above, can be concluded that the experiment for finding out the thermal performance on 750 RPM engine using finned exhaust gas pipe has higher temperature over time in 5 points of measurement. From figure 5.5, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point, the temperature is decreasing again at the fin surface point, at outside wall point, and the last is at the cool side of TEG point which has the lowest temperature. From the measurement, the author takes the average value for each point of the measurement, there are:

a. Exhaust gas temperature : 126.35 ^{0}C
b. Inside wall temperature : 83.79 ^{0}C
c. Fin temperature : 80.36 ^{0}C
d. Outside wall temperature : 74.35 ^{0}C
e. Cool side of TEG temperature : 52.68 ^{0}C

V.3.6 1000 Engine RPM with Finned Exhaust Gas Pipe

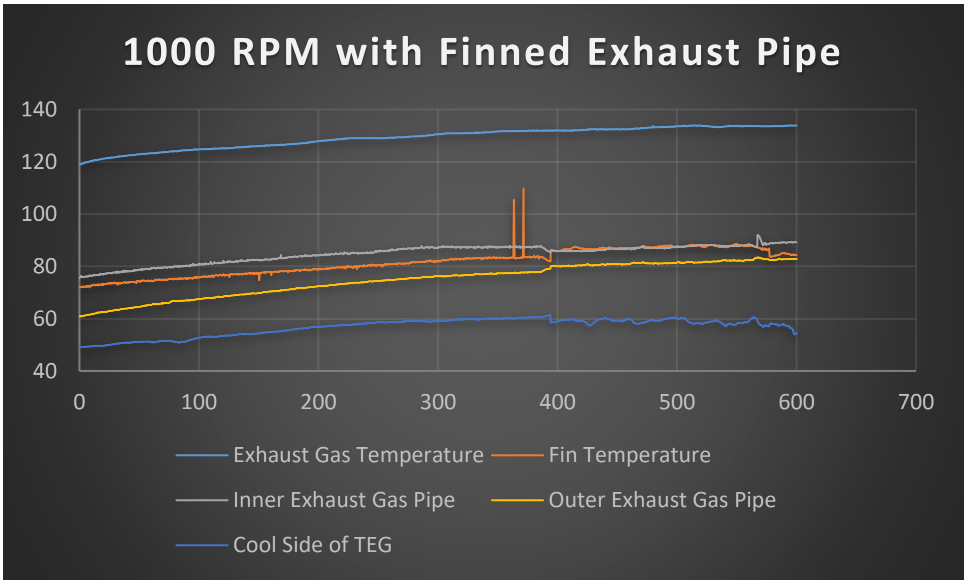

Figure 5.6 Graphic of thermal performance at 1000 RPM with finned pipe

From figure 5.6 above, can be concluded that the experiment for finding out the thermal performance on 1000 RPM engine using finned exhaust gas pipe has higher temperature over time in 5 points of measurement. From figure 5.6, the data shows that the higher temperature of the exhaust gas pipe is on the exhaust gas itself. Getting sideways, the temperature is going down, start from the exhaust gas, the temperature decreases at the inside wall point, the temperature is decreasing again at the fin surface point, at outside wall point, and the last is at the cool side of TEG point which has the lowest temperature. From the measurement, the author takes the average value for each point of the measurement, there are:

a. Exhaust gas temperature : 129.23 ^{0}C
b. Inside wall temperature : 84.83 ^{0}C
c. Fin temperature : 81.60 ^{0}C
d. Outside wall temperature : 74.88 ^{0}C
e. Cool side of TEG temperature : 56.86 ^{0}C

V.4 Thermal Performance Analysis Depend on RPM

On this analysis, the author try to find out the effect of engine RPM to the thermal performance of the exhaust gas pipe. From the experiment, obtained data as the figure bellow.

V.4.1 Thermal Performance against Engine RPM at Inside Wall of Finless Exhaust Pipe

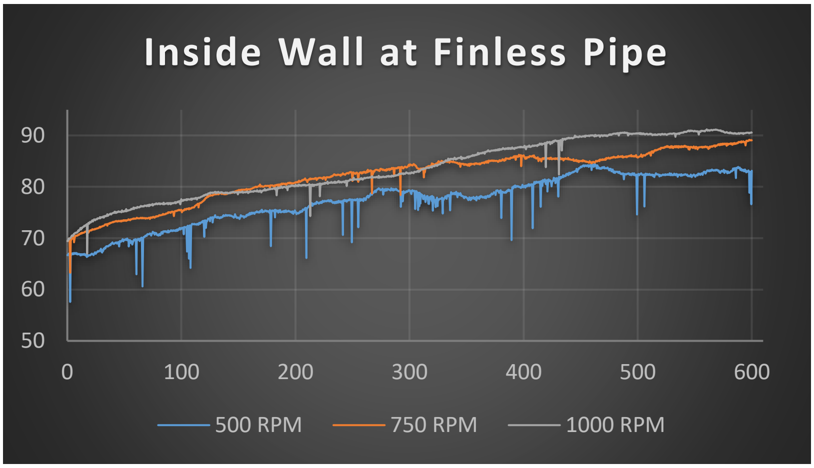

Figure 5.7 Graphic of thermal performance vs RPM at inside wall of finless pipe

Figure 5.7 shows that at the same point, which is at the inside wall of the exhaust gas pipe, that bigger engine RPM will generate bigger heat. From figure 5.7 also obtained the data of the average temperature at inside wall of the exhaust gas pipe as follows:

a. 500 RPM : 77.28 ^{0}C
b. 750 RPM : 82.04 ^{0}C
c. 1000 RPM : 83.42 ^{0}C

V.4.2 Thermal Performance against Engine RPM at Outside Wall of Finless Exhaust Pipe

Figure 5.8 below shows that at the same point, which is at the outside wall of the exhaust gas pipe that bigger engine RPM will generate bigger heat. From figure 5.8 also obtained the data of the average temperature at inside wall of the exhaust gas pipe as follows:

a. 500 RPM : 59.49 ^{0}C
b. 750 RPM : 62.35 ^{0}C
c. 1000 RPM : 64.07 ^{0}C

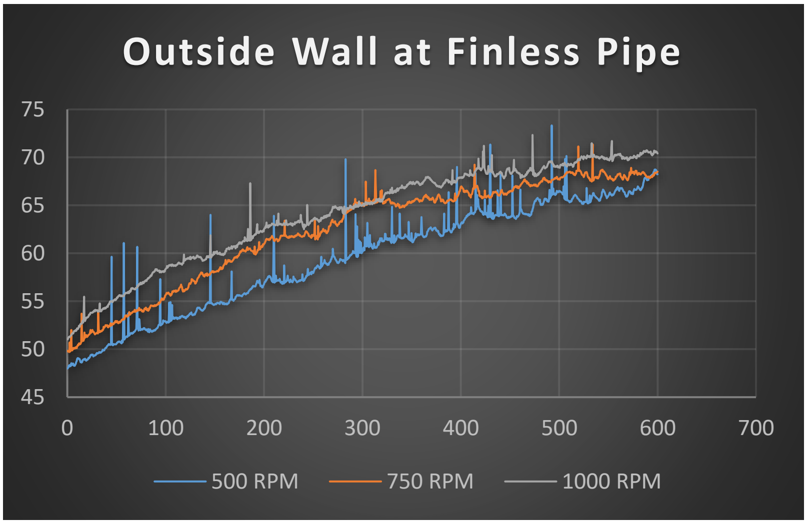

Figure 5.8 Graphic of thermal performance vs RPM at outside wall of finless pipe

V.4.3 Thermal Performance against Engine RPM at Inside Wall of Finned Exhaust Pipe

Figure 5.9 shows that at the same point, which is at the inside wall of finned exhaust gas pipe that bigger engine RPM will generate bigger heat. From figure 5.9 also obtained the data of the average temperature at inside wall of finned exhaust gas pipe as follows:

a. 500 RPM : 80.05 ^{0}C
b. 750 RPM : 83.79 ^{0}C
c. 1000 RPM : 84.83 ^{0}C

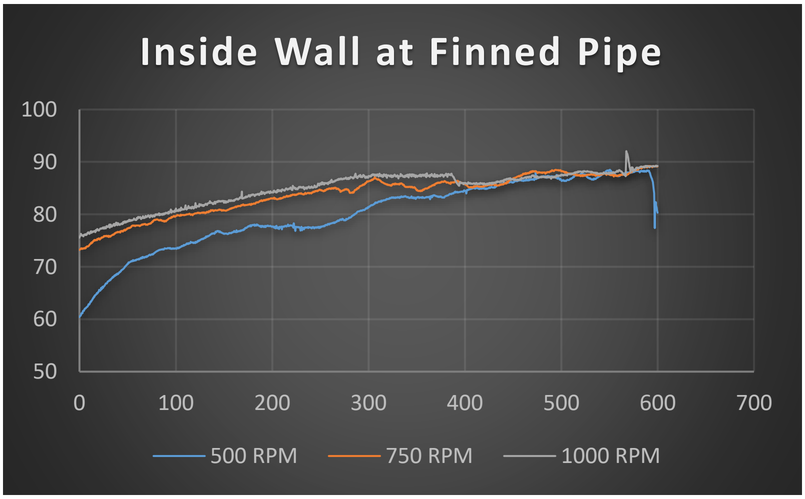

Figure 5.9 Graphic of thermal performance vs RPM at inside wall of finned pipe

V.4.4 Thermal Performance against Engine RPM at Fin Surface of Finned Exhaust Pipe

Figure 5.10 shows that at the same point, which is at the fin surface of finned exhaust gas pipe that bigger engine RPM will generate bigger heat. From figure 5.10 also obtained the data of the average temperature at fin surface of finned exhaust gas pipe as follows:

a. 500 RPM : 77.36 ^{0}C
b. 750 RPM : 80.36 ^{0}C
c. 1000 RPM : 81.60 ^{0}C

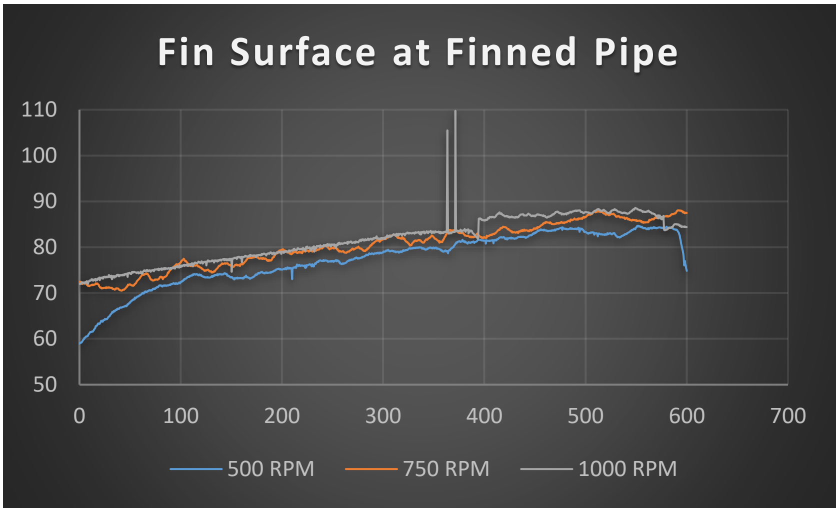

Figure 5.10 Graphic of thermal performance vs RPM at fin surface of finned pipe

V.4.5 Thermal Performance against Engine RPM at Outside Wall of Finned Exhaust Pipe

Figure 5.11 shows that at the same point, which is at outside wall of finned exhaust gas pipe that bigger engine RPM will generate bigger heat. From figure 5.11 also obtained the data of the average temperature at outside wall of finned exhaust gas pipe as follows:

a. 500 RPM : 70.49 ^{0}C
b. 750 RPM : 74.35 ^{0}C
c. 1000 RPM : 74.88 ^{0}C

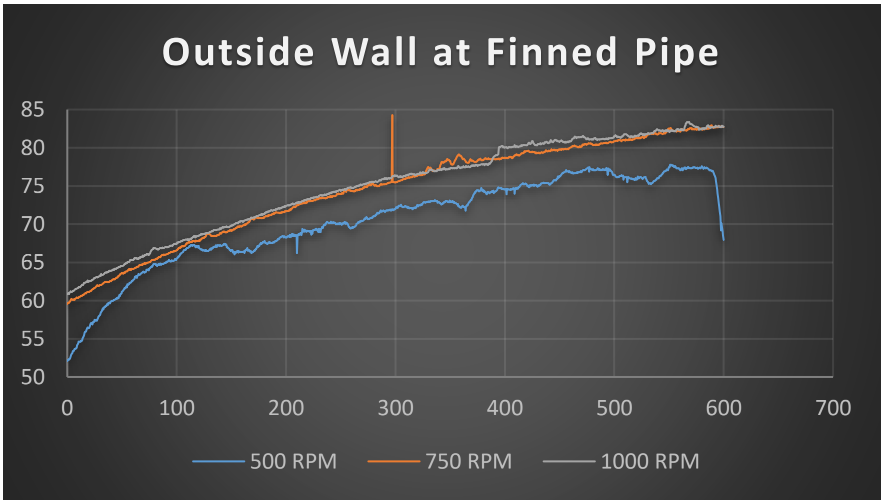

Figure 5.11 Graphic of thermal performance vs RPM at outside wall of finned pipe

V.5 Thermal Performance Analysis Depend on Internal Fin Utilization

On this analysis, the author try to find out the effect of internal fin utilization to the thermal performance of the exhaust gas pipe. From the experiment, obtained data as the figure bellow.

V.5.1 Thermal Performance in Inside Wall against Fin Utilization at 500 RPM

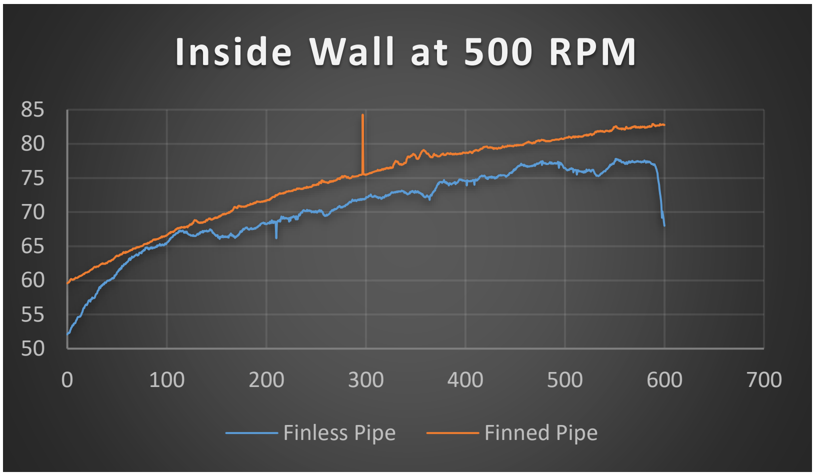

Figure 5.12 Graphic of thermal performance vs fin utilization at 500 RPM

Figure 5.12 shows that at the same point, which is at the inside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.12 also obtained the data of the average temperature at inside wall of the exhaust gas pipe as follows:

a. Finless pipe : 70.49 ^{0}C
b. Finned pipe : 74.35 ^{0}C

V.5.2 Thermal Performance in Inside Wall against Fin Utilization at 750 RPM

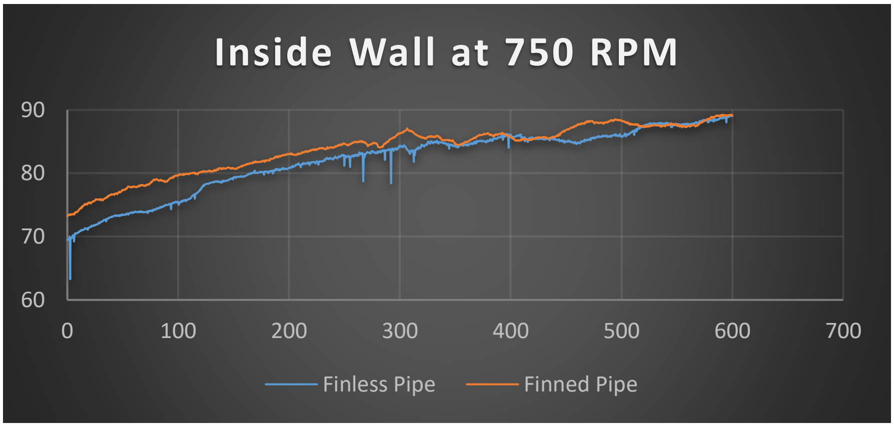

Figure 5.13 Graphic of thermal performance vs fin utilization at 750 RPM

Figure 5.13 shows that at the same point, which is at the inside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.13 also obtained the data of the average temperature at inside wall of the exhaust gas pipe as follows:

a. Finless pipe : 82.04 ^{0}C
b. Finned pipe : 83.79 ^{0}C

V.5.3 Thermal Performance in Inside Wall against Fin Utilization at 1000 RPM

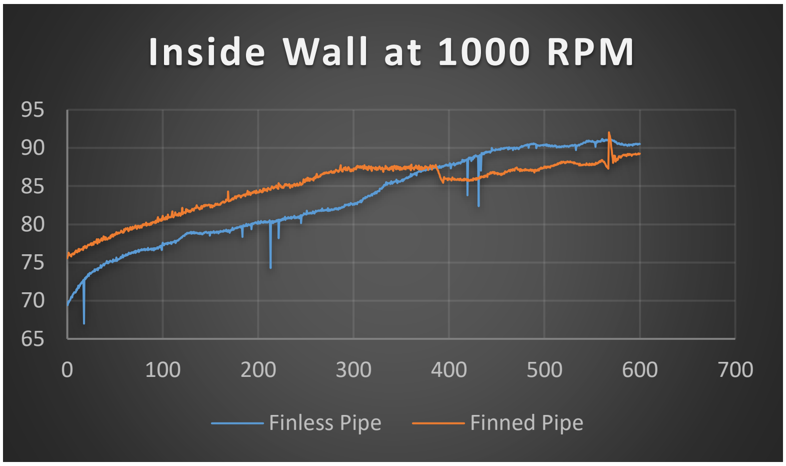

Figure 5.14 Graphic of thermal performance fin utilization at 1000 RPM

Figure 5.14 shows that at the same point, which is at the inside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.14 also obtained the data of the average temperature at inside wall of the exhaust gas pipe as follows:

a. Finless pipe : 83.42 ^{0}C
b. Finned pipe : 84.83 ^{0}C

V.5.4 Thermal Performance in outside Wall against Fin Utilization at 500 RPM

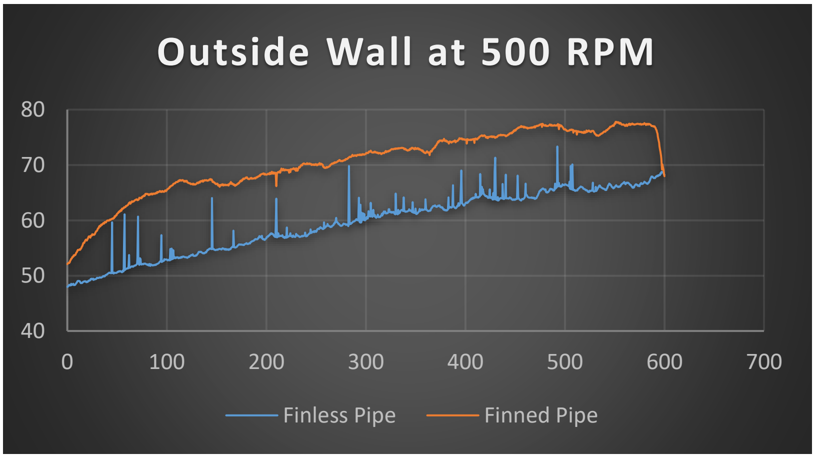

Figure 5.15 Graphic of thermal performance vs fin utilization at 500 RPM

Figure 5.15 shows that at the same point, which is at the outside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.15 also obtained the data of the average temperature at outside wall of the exhaust gas pipe as follows:

a. Finless pipe : 59.49 ^{0}C
b. Finned pipe : 70.49 ^{0}C

V.5.5 Thermal Performance in outside Wall against Fin Utilization at 750 RPM

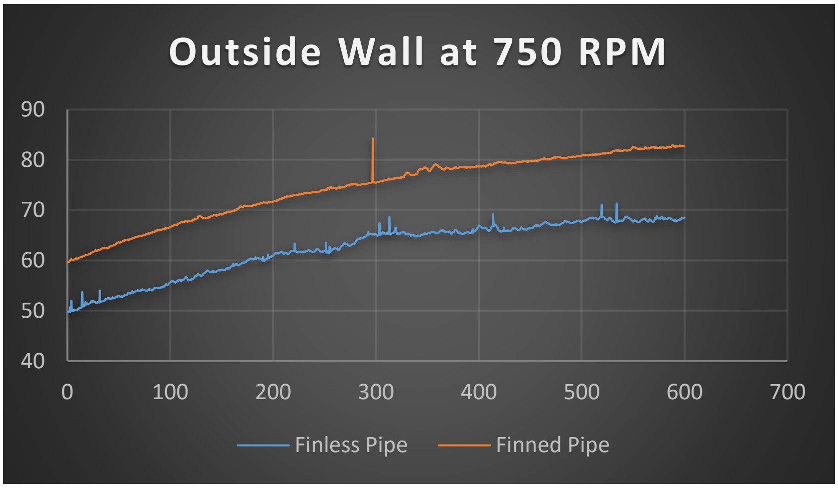

Figure 5.16 Graphic of thermal performance vs fin utilization at 750 RPM

Figure 5.16 shows that at the same point, which is at the outside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.16 also obtained the data of the average temperature at outside wall of the exhaust gas pipe as follows:

a. Finless pipe : 62.35 ^{0}C
b. Finned pipe : 74.35 ^{0}C

V.5.6 Thermal Performance in outside Wall against Fin Utilization at 1000 RPM

Figure 5.17 shows that at the same point, which is at the outside wall of the exhaust gas pipe, that internal fin installation can generate bigger heat transfer. From figure 5.16 also obtained the data of the average temperature at outside wall of the exhaust gas pipe as follows:

c. Finless pipe : 64.07 ^{0}C
d. Finned pipe : 74.88 ^{0}C

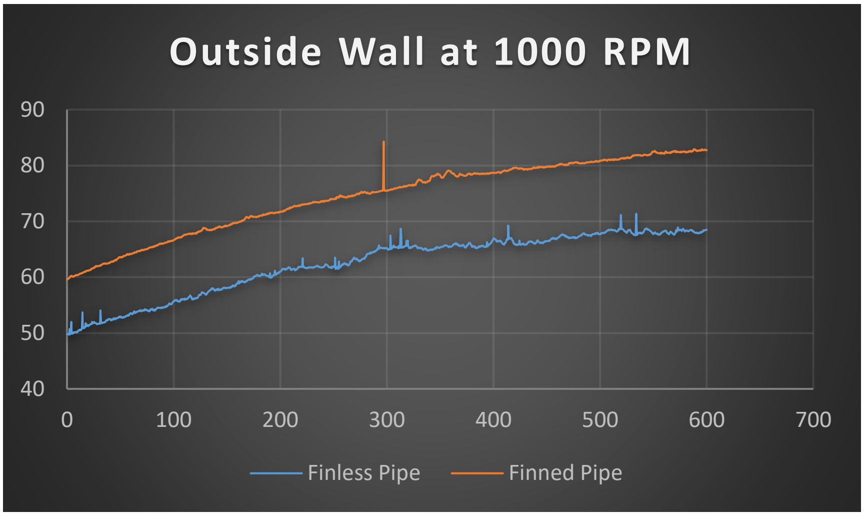

Figure 5.17 Graphic of thermal performance vs fin utilization at 1000 RPM

V.6 Thermal Resistance Analysis

From all of the temperature data that have been analyzed at the previous subchapter, it can be determined the value of heat transfer as the following table.

Table 5.2 Heat transfer Resistance

Fin	RPM	q	T Exhaust	T Wall In	T Wall Out	R_{conv}	R_{cond}	R_{tot}
No	500	423.46	123.3563	77.28579	59.4976002	46.07	0.042	46
	750	532.78	125.6015	82.03899	49.2065861	44.56	0.062	45
	1000	676.71	128.4593	83.41622	83.4162199	44.04	0.00	44
Yes	500	430.43	123.6416	80.04695	70.4904543	43.59	0.022	44
	750	532.85	126.3531	83.7998	74.3521472	42.55	0.018	43
	1000	684.47	129.234	86.8298	76.8774536	42.4	0.015	42

From the table above, the author can conclude that thermal resistance is influenced by engine RPM. Bigger engine RPM which is set will makes the heat resistance smaller. Besides engine RPM, heat resistance is also can be influenced by fins installation. Table 5.2 shows that internal fins installation can reduce the heat transfer or can increase the heat transfer rate of a thing.

V.7 Thermal Performance of TEG SP1848-27145

TEG SP1848-27145 is made from ceramic material, it is because the principle working of TEG is changing the temperature difference between the hot side surface and the cool side surface to be electrical energy. The lower conductivity thermal of TEG's material, the bigger temperature difference is happened, and bigger temperature difference will result bigger electricity produced by it, because of that generally, TEG is made from ceramic where, ceramic has low thermal conductivity. But, with a fairly thin of TEG SP1848-27145, it causes the heat resistance is small and the temperature difference is also small.

In this research, the author measures the temperature of the hot side of TEG and also the outside surface of exhaust gas pipe by using assumption that the cool side of TEG has the same temperature with outside surface of exhaust gas pipe. The measurement is don to find out the temperature difference between the cool side and the hot side of TEG against engine RPM when using finless exhaust gas pipe and also finned exhaust gas pipe. From the measurement, the authors get the data on table 5.5 below.

Table 5.3 Average Temperature Difference at Thermoelectric Generator

No.	Fin	RPM	Temperature Difference (^{0}C)
1	Finless	500	12.50
2		750	12.75
3		1000	13.32
4	Finned	500	18.81
5		750	19.50
6		1000	19.82

From table 5.5, can be concluded that the increasing of engine RPM makes the temperature difference of TEG also increasing. Other than that, internal fin installation also affects the increasing of temperature difference at TEG.

The effect of fins installation against the temperature difference is shown at figure 5.18, figure 5.19, and figure 5.20. While for the effect of engine RPM against the temperature difference is shown at figure 5.21 and figure 5.22

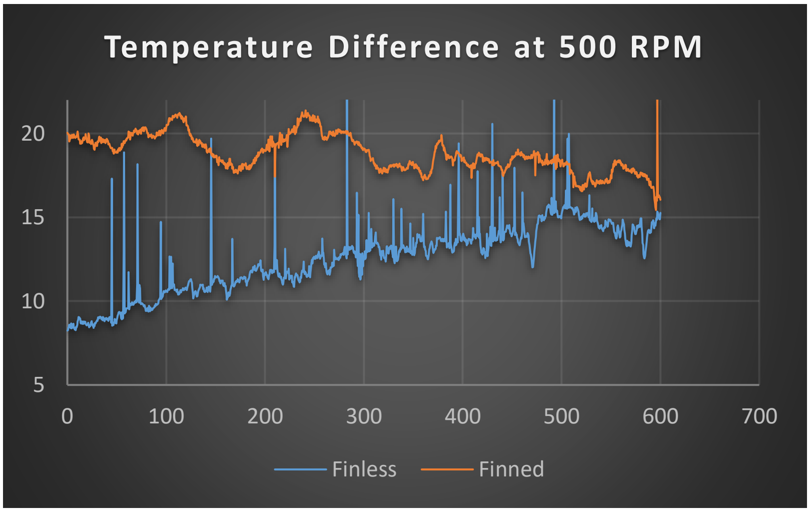

Figure 5.18 TEG’s temperature difference against fins installation at 500 RPM

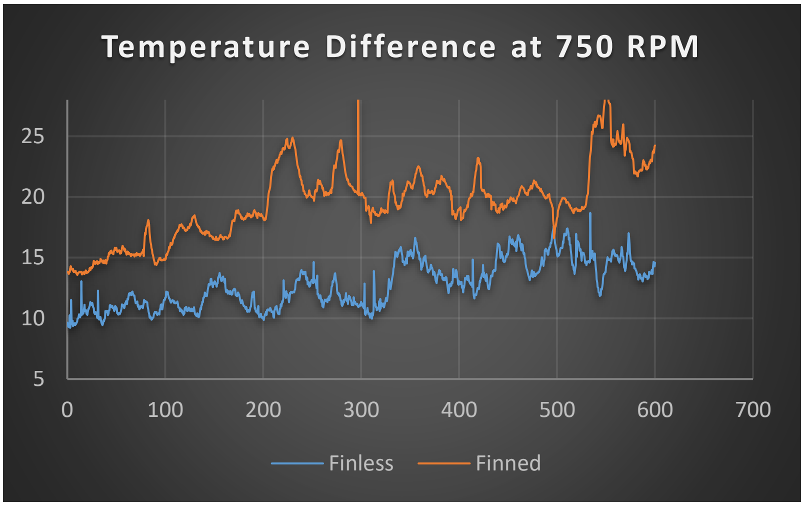

Figure 5.19 TEG's temperature difference against fins installation at 750 RPM

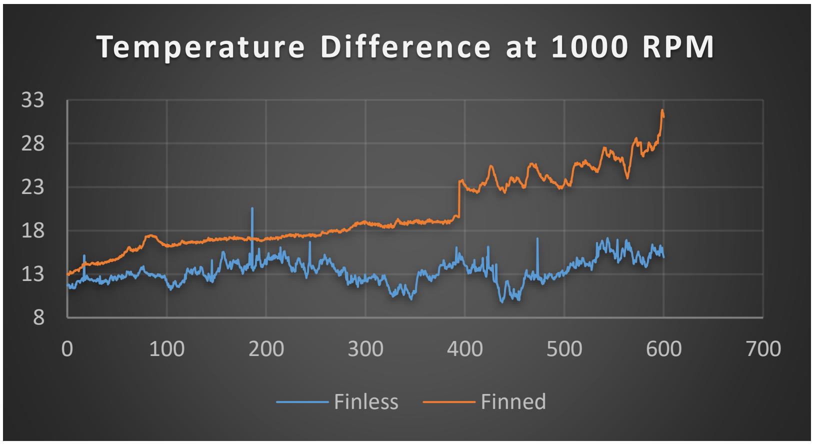

Figure 5.20 TEG's temperature difference against fins installation at 1000 RPM

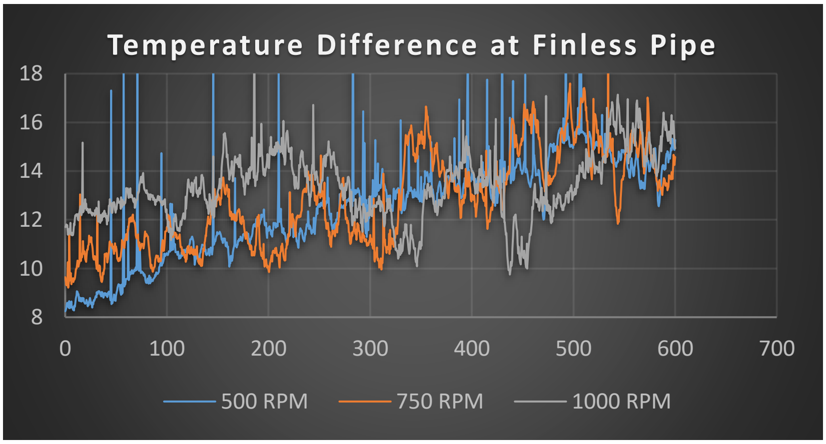

Figure 5.21 TEG's temperature difference against engine RPM at finless pipe

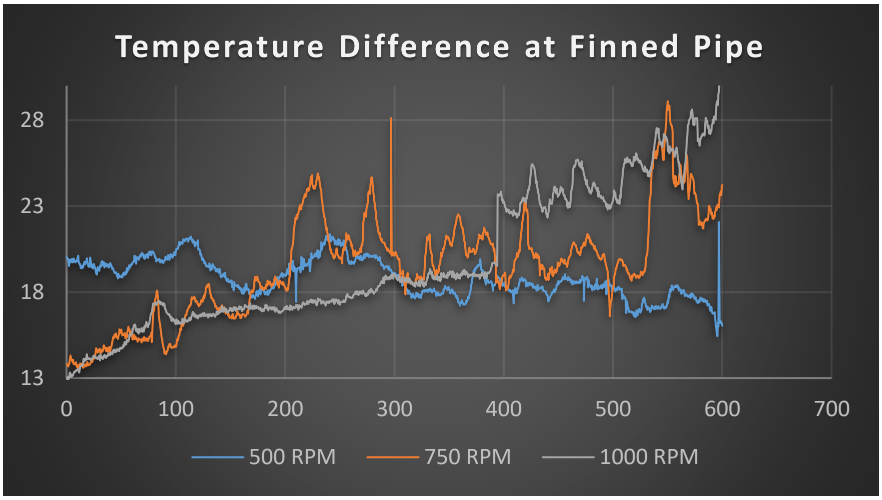

Figure 5.22 TEG's temperature difference against engine RPM at finned pipe

The fins installation also effect the temperature difference fin installation will increase the heat which is transferred to thermoelectric generator at its hot side surface. Although the cool side of thermoelectric generator is also increasing along with the increasing of engine RPM or internal fin installation, but the temperature increasing at hot side of thermoelectric generator is higher than the temperature increasing at its cool side, so it will make the temperature difference between them is also increasing.

V.8 Electricity Generated

For the electricity, in this research the author measures the voltage and the current that generated by thermoelectric generators during the engine operation. The voltage and the current which are generated by six thermoelectric generators that connected in series is measured manually by using digital multimeter. The data is taken each 30 seconds for 10 minutes during the engine operation. From the measurement, the author gets the data on table 5.4 for the voltage generated by thermoelectric generator with engine RPM as variation when using finless exhaust gas pipe and finned exhaust gas pipe.

Table 5.4 Voltage Generated by Thermoelectric Generator

Time (s)	Voltage Generated (mV)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
30	735	986	1095	834	1019	1206
60	833	1062	1202	963	1097	1286
90	891	1164	1293	1058	1176	1337
120	954	1217	1373	1139	1250	1407
150	1007	1230	1464	1197	1278	1481
180	1070	1265	1536	1236	1335	1526
210	1113	1307	1553	1280	1392	1595
240	1145	1427	1623	1353	1446	1644

Time (s)	Voltage Generated (mV)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
270	1173	1463	1655	1362	1478	1725
300	1241	1401	1587	1385	1503	1754
330	1263	1470	1622	1410	1532	1799
360	1290	1581	1613	1460	1632	1847
390	1334	1644	1767	1506	1679	1898
420	1337	1677	1808	1455	1703	1943
450	1385	1701	1812	1581	1742	1968
480	1463	1718	1875	1605	1763	1986
510	1457	1736	1910	1670	1761	2001
540	1494	1781	1943	1671	1790	1989
570	1506	1802	1973	1679	1779	2018
600	1527	1826	2066	1646	1781	2051

For the electricity, the author also measures the current, which is generated by thermoelectric generator manually using digital multimeter. As in voltage data retrieval, the current data also token every 30 seconds during 10 minutes. From the current measurement, which is generated by thermoelectric generator during the engine operation, the data are shown on table 5.5

Table 5.5 Current Generated by Thermoelectric Generator

Time (s)	Current Generated (mV)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
30	24.47	25.44	26.37	28.04	27.19	27.09
60	28.29	29.47	30.35	31.83	31.03	31.09
90	30.41	30.96	32.22	34.06	32.93	33.61
120	33.32	33.37	34.72	36.59	36.03	35.85
150	35.65	36.46	36.63	38.30	37.85	37.96
180	37.86	37.58	39.06	40.61	40.61	40.34
210	42.33	38.61	41.35	42.08	42.79	42.04
240	40.66	41.98	41.58	43.92	43.91	43.27
270	42.60	42.32	42.77	44.86	44.96	44.49
300	44.71	43.88	44.78	47.30	47.48	47.28
330	47.32	45.43	44.52	47.94	48.47	48.10
360	47.98	47.80	47.04	48.71	49.61	49.12

Time (s)	Current Generated (mV)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
390	48.37	48.27	49.20	50.62	51.14	50.97
420	48.37	48.09	48.76	50.87	51.47	51.47
450	50.87	51.55	48.26	52.70	52.89	53.34
480	54.19	53.57	52.41	55.57	56.09	56.35
510	54.36	55.07	53.38	55.20	55.65	56.14
540	55.21	54.73	55.96	56.37	57.55	57.49
570	54.84	55.42	55.44	57.05	58.01	57.92
600	56.83	56.45	56.65	57.19	58.83	58.43

From voltage data on table 5.4 and current data on table 5.5, the author can calculate the power that generated by thermoelectric generator by multiplying the voltage and the current at the same time. From this, the author get data of power generated which are shown on table 5.6

Table 5.6 Power Generated by Thermoelectric Generator

Time (s)	Actual Power Generated (mW)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
30	17.99	25.09	28.88	23.38	27.70	32.67
60	23.57	31.30	36.48	30.65	34.04	39.98
90	27.10	36.04	41.66	36.03	38.73	44.94
120	31.79	40.61	47.67	41.68	45.04	50.44
150	35.90	44.84	53.63	45.85	48.38	56.22
180	40.52	47.53	60.00	50.19	54.22	61.56
210	47.11	50.47	64.22	53.87	59.57	67.05
240	46.56	59.91	67.48	59.43	63.49	71.14
270	49.97	61.91	70.78	61.10	66.45	76.75
300	55.48	61.47	71.07	65.51	71.37	82.93
330	59.77	66.78	72.21	67.60	74.25	86.53
360	61.89	75.58	75.88	71.12	80.96	90.72
390	64.52	79.35	86.94	76.23	85.87	96.74
420	64.67	80.65	88.15	74.02	87.65	100.01
450	70.45	87.68	87.45	83.32	92.13	104.97
480	79.28	92.03	98.28	89.19	98.88	111.91

Time (s)	Actual Power Generated (mW)					
	Finless Pipe			Finned Pipe		
	500 RPM	750 RPM	1000 RPM	500 RPM	750 RPM	1000 RPM
510	79.21	95.61	101.96	92.18	98.00	112.33
540	82.48	97.47	108.73	94.20	103.01	114.35
570	82.59	99.87	109.39	95.79	103.20	116.88
600	86.78	103.08	117.04	94.14	104.77	119.83

V.9 Voltage Generated Analysis Depend On Engine RPM

On this analysis, the author try to find out the effect of engine RPM to the power generated by thermoelectric generators

Figure 5.18 shows that at the same position and pipe where the thermoelectric generators are installed, that engine RPM can increase the power generated by them. From figure 5.18 also obtained the data of the average power generated from 6 thermoelectric generators which is installed at finless pipe as follows:

a. 500 RPM : 55.38 mW
b. 750 RPM : 66.86 mW
c. 1000 RPM : 74.39 mW

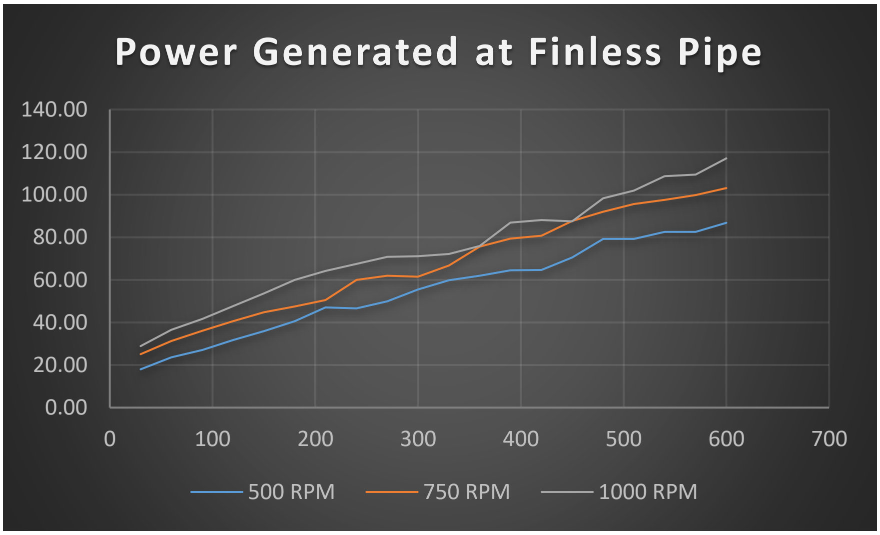

Figure 5.23 Graphic of power generated at finless pipe

Figure 5.23 shows that at the same position and pipe where the thermoelectric generators are installed, that engine RPM can increase the power generated by them. From figure 5.24 also obtained the data of the average power generated from 6 thermoelectric generators which is installed at finned pipe as follows:

a. 500 RPM : 65.27 mW
b. 750 RPM : 71.89 mW
c. 1000 RPM : 81.90 mW

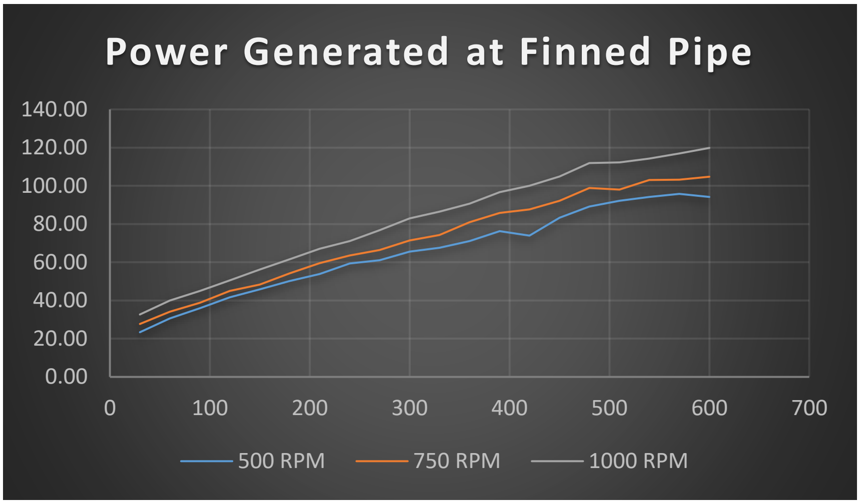

Figure 5.24 Graphic of power generated at finned pipe

V.10 Power Generated Analysis Depend On Fin Installation

On this analysis, the author try to find out the effect of fin installation to the power generated by thermoelectric generators.

Figure 5.25 shows that at the same position at pipe and the same engine RPM where the thermoelectric generators are installed, that internal fins installation can increase the power generated by them. From figure 5.25 also obtained the data of the average power generated from 6 thermoelectric generators which is installed at exhaust gas of an engine which is being operated at 500 RPM:

a. Finless : 55.38 mW
b. Finned : 65.27 mW

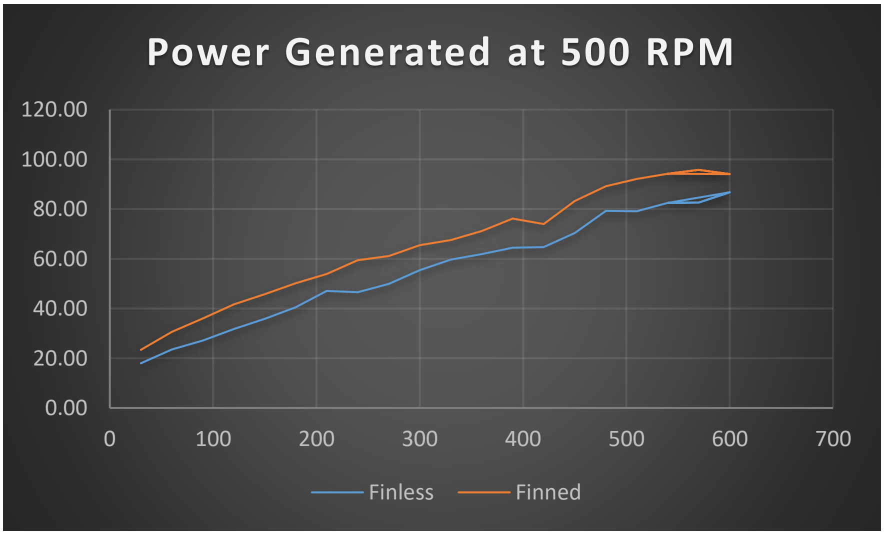

Figure 5.25 Graphic of power generated at 500 RPM engine

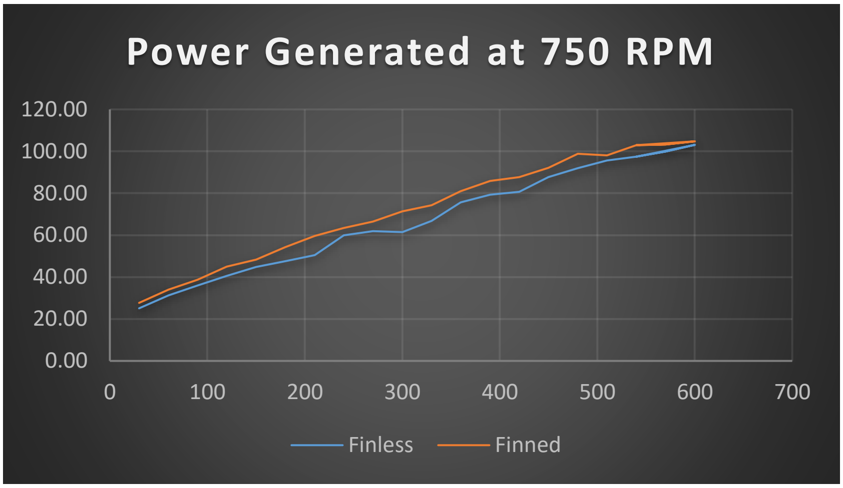

Figure 5.26 Graphic of power generated at 750 RPM engine

Figure 5.26 shows that at the same position at pipe and the same engine RPM where the thermoelectric generators are installed, that internal fins installation can increase the power generated by them. From figure 5.21 also obtained the data of the average power generated from 6 thermoelectric generators which is installed at exhaust gas of an engine which is being operated at 750 RPM:

a. Finless : 66.86 mW
b. Finned : 71.89 mW

Figure 5.27 shows that at the same position at pipe and the same engine RPM where the thermoelectric generators are installed, that internal fins installation can increase the power generated by them. From figure 5.27 also obtained the data of the average power generated from 6 thermoelectric generators which is installed at exhaust gas of an engine which is being operated at 1000 RPM:

a. Finless : 74.39 mW
b. Finned : 81.90 mW

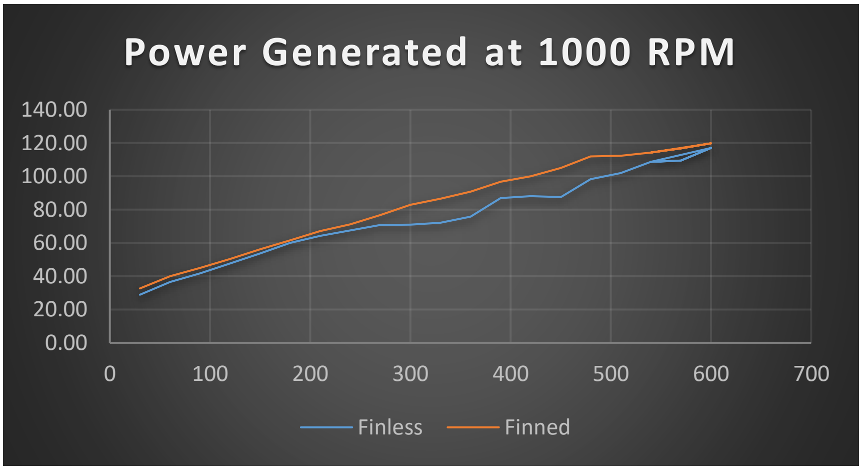

Figure 5.27 Graphic of power generated at 500 RPM engine

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CHAPTER VI
CLOSING

VI.1 Conclusion

The conclusion of this research entitled analysis of internal fin usage on the exhaust gas pipe of main engine to increase the utilization of waste heat recovery for generating electricity using thermoelectric generator are:

1. Internal fin installation at exhaust gas pipe can increase the thermal performance of the exhaust gas pipe itself, where the heat transfer is inversely proportional with thermal resistance. In this experiment, by setting the engine at the same RPM, the finned exhaust gas pipe has lower thermal resistance then finless exhaust gas pipe. At 500 RPM, finned pipe has 44 K/W while the finless pipe is 46 K/W. At 750 RPM, finned pipe has 43 K/W while the finless pipe is 45 K/W. And At 1000 RPM, finned pipe has 42 K/W while the finless pipe is 44 K/W.
2. The engine load is influencing the thermal performance of exhaust gas pipe. Bigger engine load will increase the thermal performance. For finned exhaust gas pipe, the thermal resistance is 44 K/W at 500 RPM, 43 K/W at 750 RPM, and 42 K/W at 1000 PRM. While for finless exhaust gas pipe, the thermal resistance is 46 K/W at 500 RPM, 45 K/W at 750 RPM, and 44 K/W at 1000 RPM.
3. Internal fin installation at exhaust gas pipe can increase the thermal performance of the exhaust gas pipe itself. Because of that, it results bigger temperature at the outside wall of the exhaust pipe and it makes the thermoelectric generator can produce more electricity. In this experiment, by setting the engine at the same RPM, the TEG which are installed at finned exhaust gas pipe has higher electricity generated then the TEG which are installed at finless exhaust gas pipe. At 500 RPM, TEG at finned pipe have produce 1374 mV while TEG at the finless pipe is 1211 mV. At 750 RPM, TEG at finned pipe has produce 1507 mV while the TEG at finless pipe is 1473. And At 1000 RPM, TEG at finned pipe has produce 1723 mV while the TEG at finless pipe is 1639 mV.
4. Internal fin installation at exhaust gas pipe can increase the thermal performance of the exhaust gas pipe itself. Because of that, it results bigger temperature at the outside wall of the exhaust pipe and it makes the thermoelectric generator can produce more electricity. At finned exhaust gas pipe, the TEG are produce 1375 mV at 500 RPM, 1507 mV at 750 RPM, and 1723 mV at 1000 PRM. While for finless exhaust gas pipe, the thermal resistance is 1211 mV at 500 RPM, 1473 mV at 750 RPM, and 1638 at 1000 RPM.

VI.2 Suggestion

For making perfect this research, so there are several suggestions which can be done at the next research, there are:

1. Because in this research doesn't keep the temperature of the cool side surface of TEG, so the temperature difference is still small and make the electricity generated also small. So it's needed to care and keep the temperature of the TEG in cool or environment temperature for gaining more electricity from it.
2. It is necessary to make technical analysis for determining the optimum place at the exhaust gas pipe for gaining the highest heat from the exhaust gas pipe. So the TEG also will produce bigger electricity.

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ATTACHMANT 1

Engine Spesification

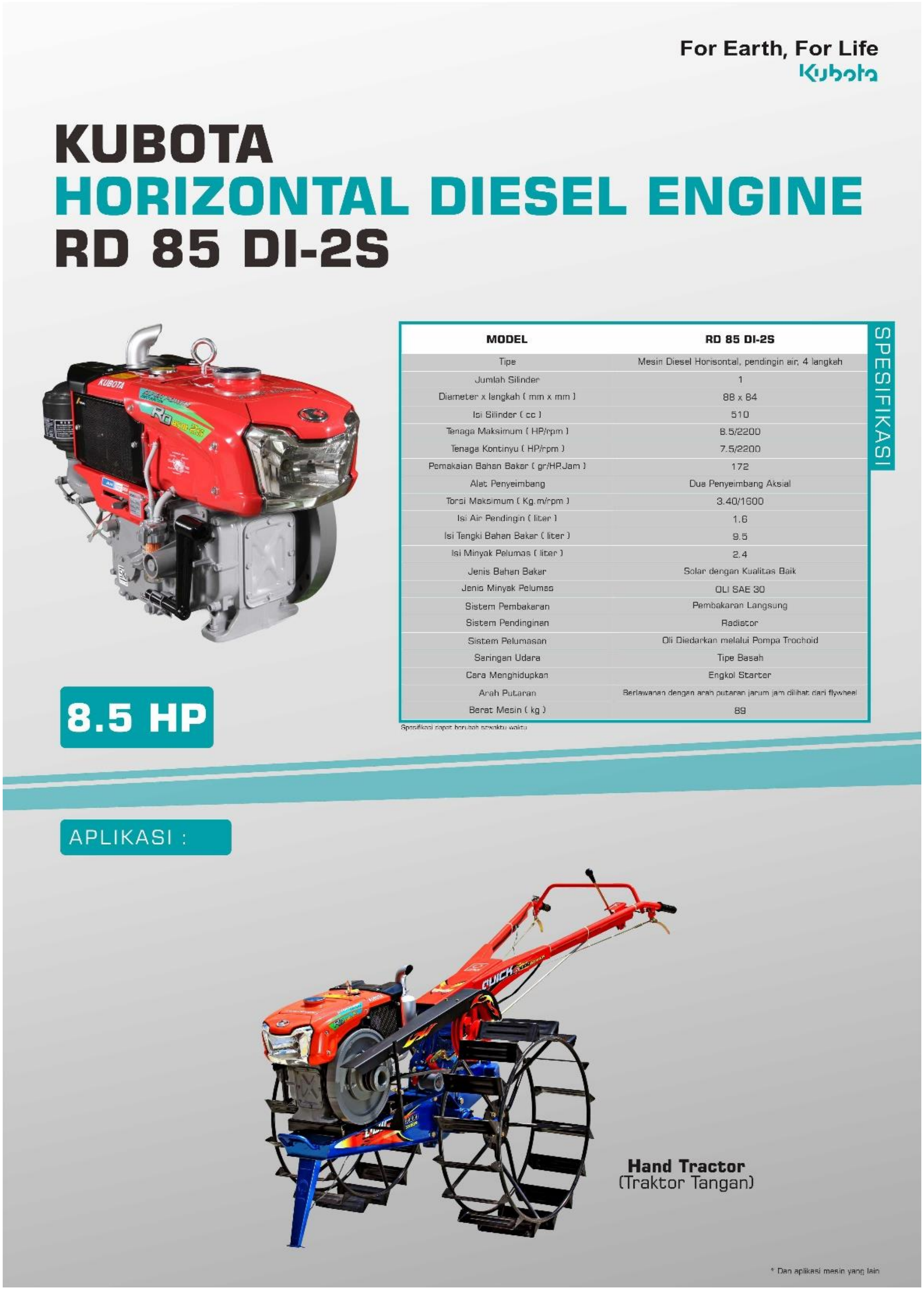

Figure 1. Brochure of Kubota RD 85 DI-2S

Table 1. Diesen Engine RD 85 DI-2S Spesification

Name	: RD 85 DI-2S
Type	: Horyzontal, Water Cooling, 4 Step
Category	: Diesel Engine
Diameter x Step	: 88 mm x 84 mm
Number of Cylinder	: 1
Continues Power	: 7.5/2200 HP/rpm
Cylinder Volume	: 510 CC
Maximum Torque	: 3.40/1600 Kg.m/rpm
Maximum Power	: 8.5/2200 HP/rpm
Ballancer	: 2 Axial Ballancer
Combustion System	: Direct Combustion
Fuel Type	: Diesel Fuel With Good Quality
Starter	: Crank Starter
Rotation Direction	: Contrary to the clockwise rotation seen from Flywheel
Lubrication System	: Lube Oil Is Circulated With a Trochoid Pump
Cooler Volume	: 1.6 Lt
SFOC	: 170 gr/HP. Hour
Lubrication Volume	: 2.4 Lt
Cooling System	: Radiator
Type of Lube Oil	: SAE 30. SAE 40, 20W50, D10W30
Weight	: 89 Kg
Tank Fuel Volume	: 9.5 Lt
Lamp	: 12:32/32 (With IC Regulator) V:W/W V:W/W

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ATTACHMANT 2

Thermoelectric Generator Spesification

Table 2. Electricity Generated Based on Temperature Difference

ΔT (^{0}C)	Voltage (V)	Current (mA)	Power (Watt)
20	0.97	225	0.22
40	1.8	368	0.66
60	2.4	469	1.13
80	3.6	558	2.01
100	4.8	669	3.21

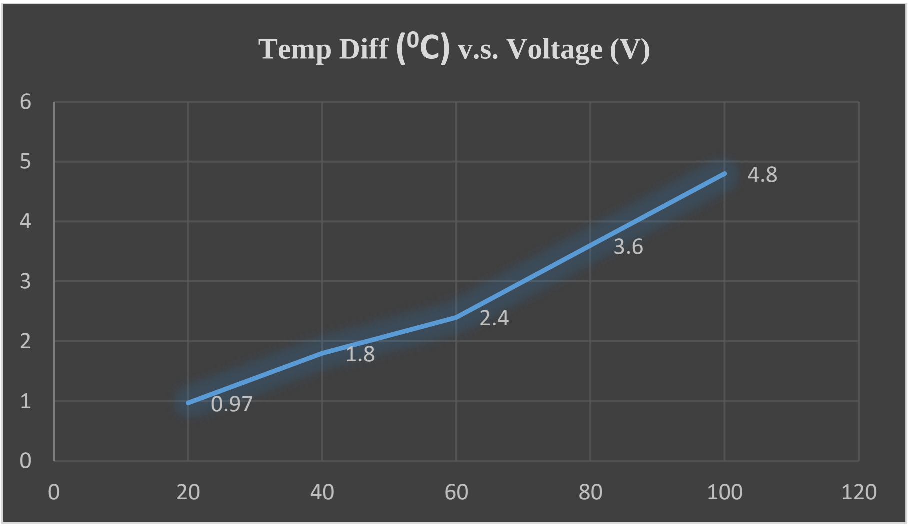

Figure 2. Graphic of Temperature Difference v.s. Voltage

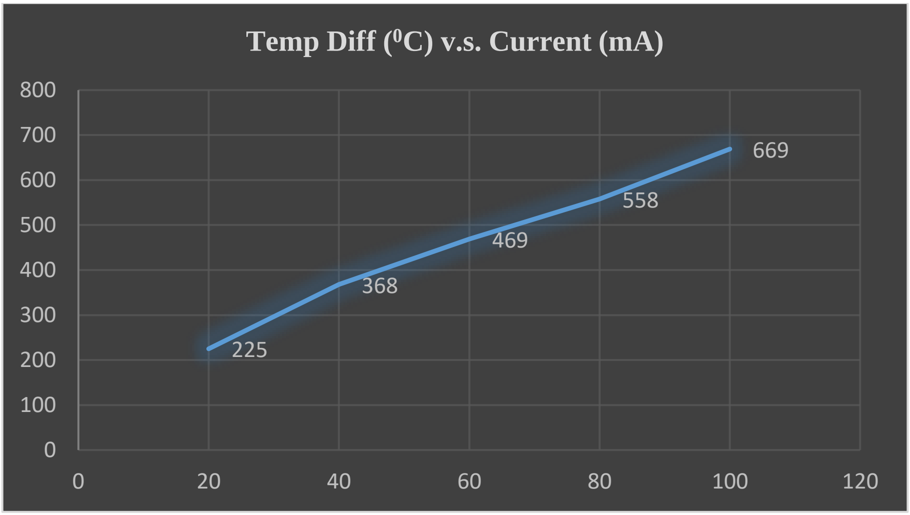

Figure 3. Graphic of Temperature Difference v.s. Current

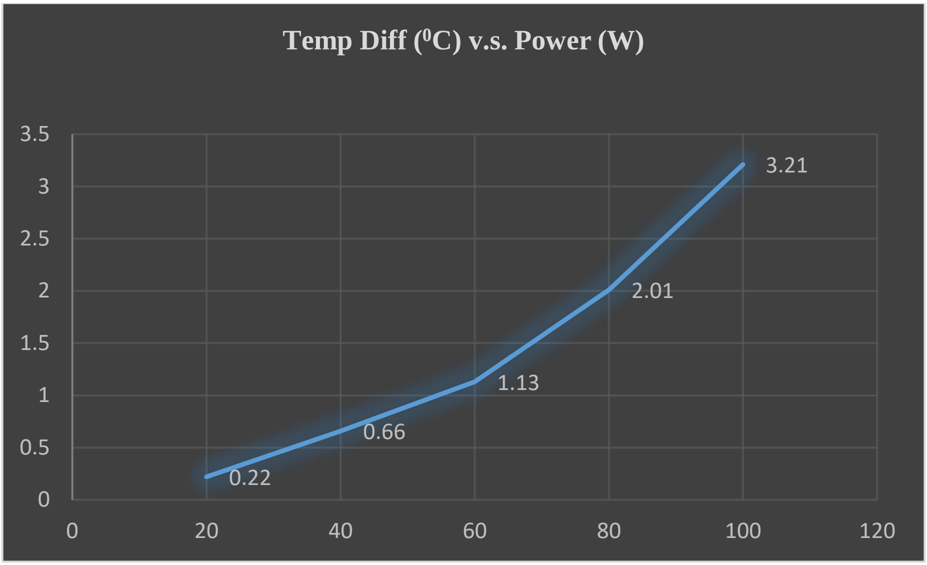

Figure 4. Graphic of Temperature Difference v.s. Power

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ATTACHMANT 3

Finless Exhaust Gas Pipe Design

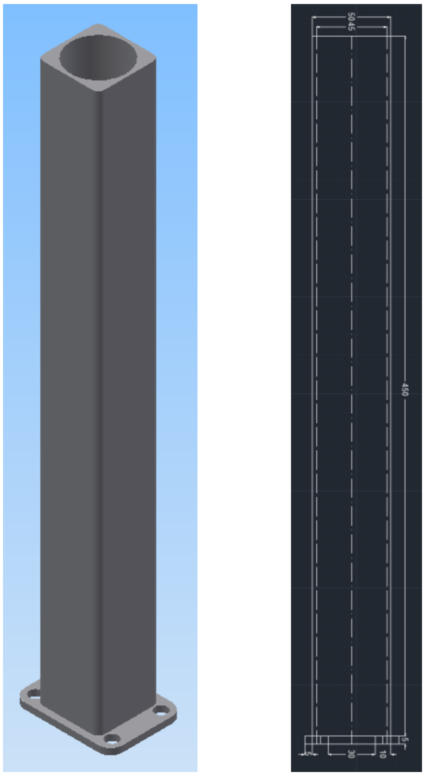

Figure 5. Finless Exhaust Gas Pipe Design 3D View and Side View

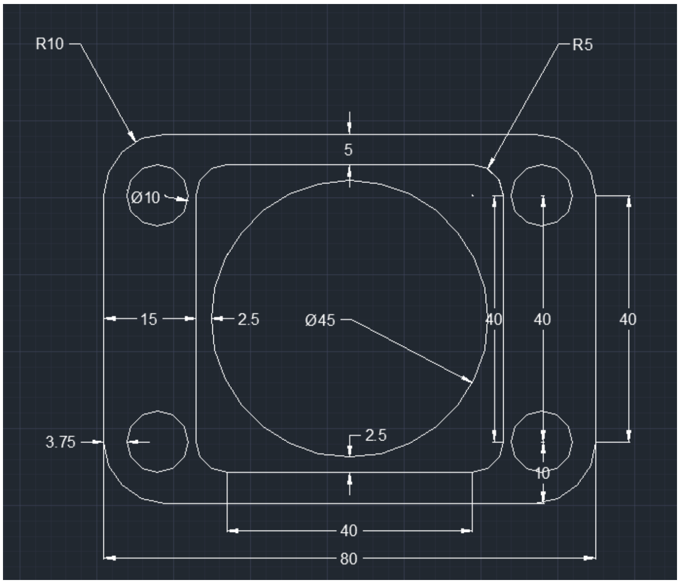

Figure 6. Finless Exhaust Gas Pipe Design Top View

ATTACHMANT 4

Finned Exhaust Gas Pipe Design

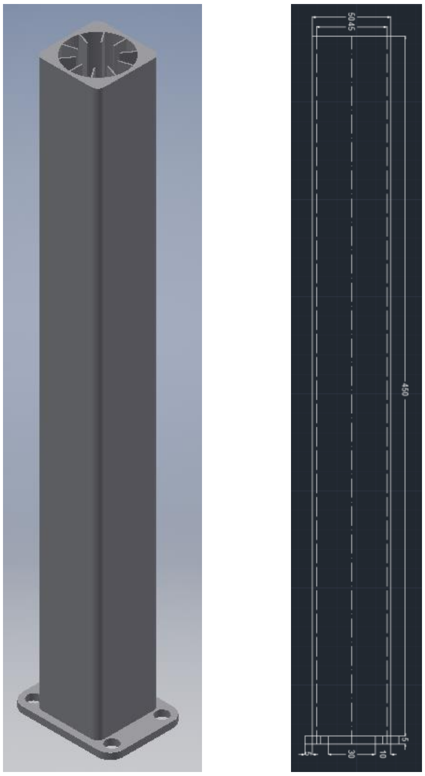

Figure 7. Finless Exhaust Gas Pipe Design 3D View and Side View

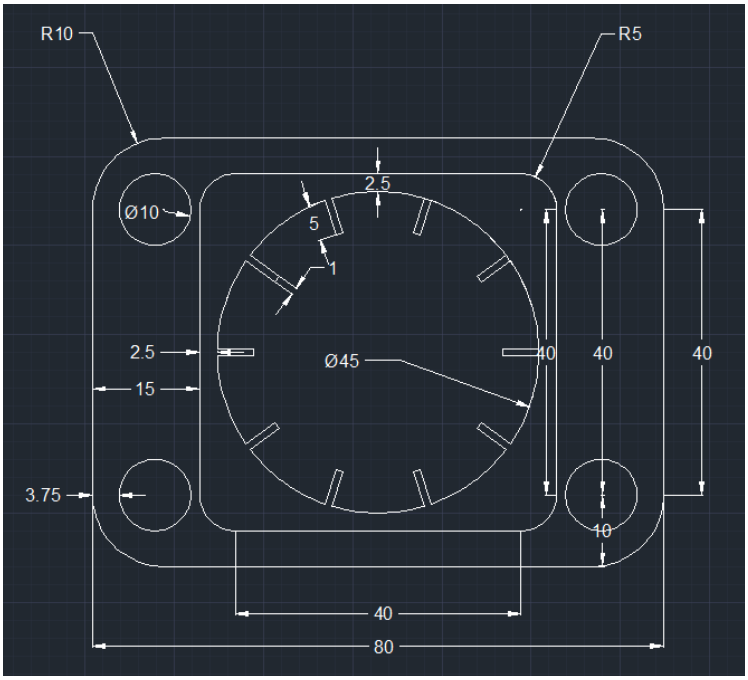

Figure 8. Finless Exhaust Gas Pipe Design Top View

ATTACHMANT 5

Air Properties

Table 3. Air Properties

Temperature (^{0}C)	**ρ (kg/m^3)**	**Max Water Content (kg/m^3)**
0	1.292	0.005
5	1.269	0.007
10	1.247	0.009
15	1.225	0.013
20	1.204	0.017
25	1.184	0.023
30	1.165	0.03
35	1.146	0.039
40	1.127	0.051
STP Condition		

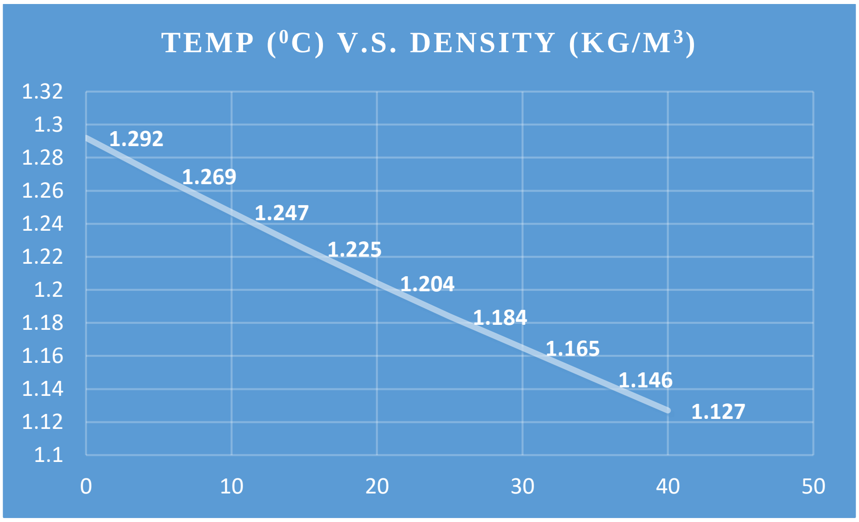

Figure 9. Graphic of Temperature v.s. Density in Air properties

ATTACHMANT 6

Exhaust Gas Properties

Table 4. Exhaust Gas Properties

Temperature (^0C)	ρ (kg/m^3)	Cp (kJ/kg.K)	u x 10^6 (Pa.s)	v x 10^6 (m^2/s)
0	1.295	1.042	15.8	12.2
100	0.95	1.068	20.4	21.54
200	0.748	1.097	24.5	32.8
300	0.617	1.122	28.2	45.81
400	0.525	1.151	31.7	60.38
500	0.457	1.185	34.8	76.3
600	0.405	1.214	37.9	93.61
700	0.363	1.239	40.7	112.1
800	0.33	1.264	43.4	131.8
900	0.301	1.29	45.9	152.5
1000	0.275	1.306	48.4	174.3
1100	0.257	1.323	50.7	197.1
1200	0.24	1.34	53	221

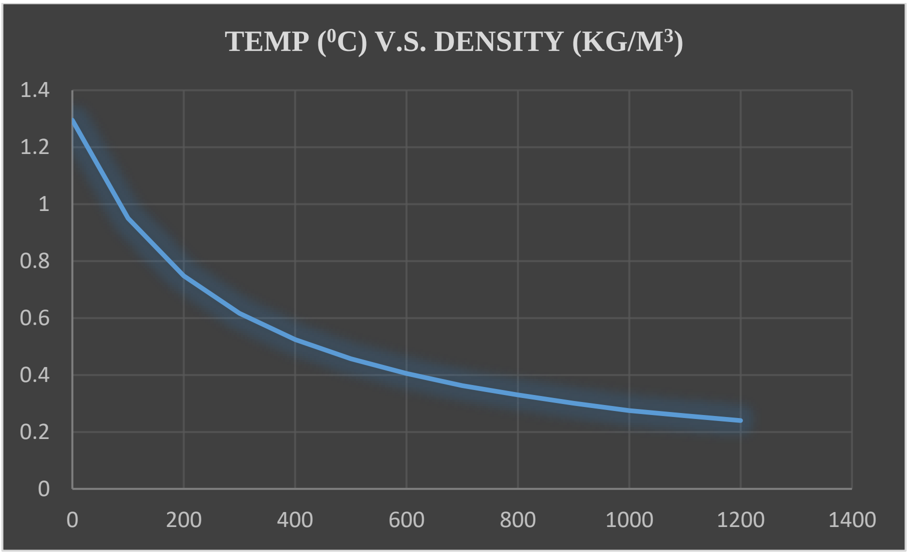

Figure 10. Graphic of Temperature v.s. Density in Exhaust Gas Properties

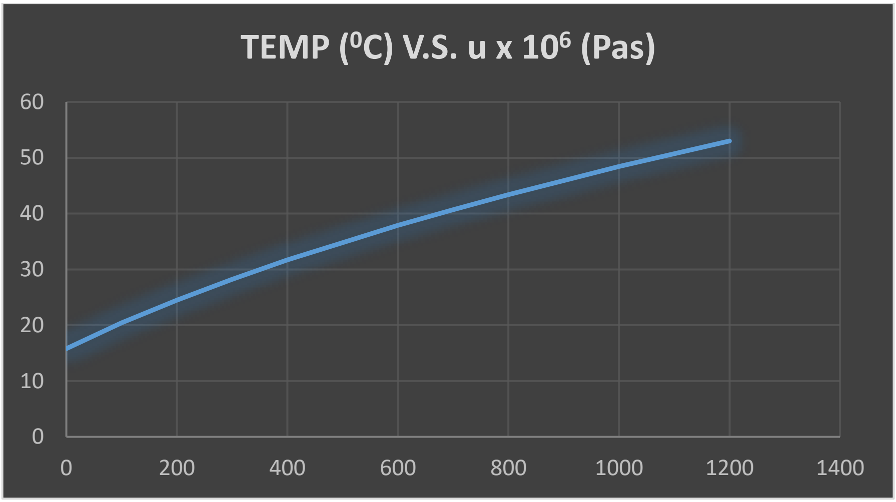

Figure 11. Graphic of Temperature v.s. Static Viscosity in Exhaust Gas Properties

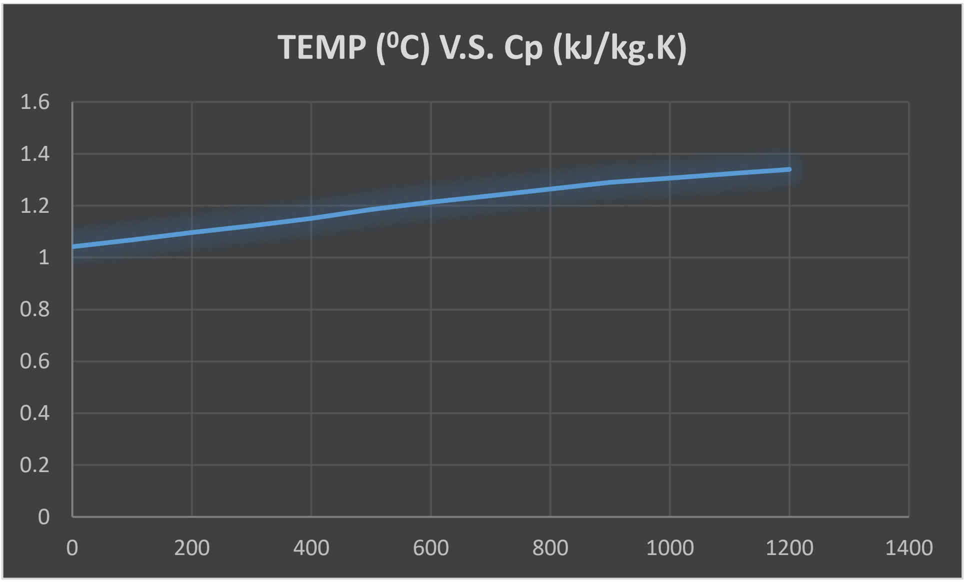

Figure 12. Graphic of Temperature v.s. Heat Specific in Exhaust Gas Properties

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THE AUTHOR'S BIODATA

Mohammad Syahirul Mubarok is in his fourth year of marine engineering at Sepuluh Nopember institute of technology. In September 2018 he will graduates with an integrated Bachelor/Double degree with a focus on Heat Transfer in Marine Fluid Machinery and System. Born on, 22nd of Nopember 1995, in Gresik, East Java. The author has completed the elementary school at MI Miftahul Ulum III Melirang, Junior high school in SMP Negeri 1 Bungah, senior high school in SMA Negeri 1 Sidayu, and continued higher education in the Department of Marine Engineering Double degree Program, Faculty of Marine Technology, Institute Technology Ten November (ITS) Surabaya. The author has run on the job training in several companies namely PT. Yasa Wahana Tirta Samudera in Semarang and PT. Star Energy as geothermal power plant in Garut. Throughout his time at Sepuluh Nopember institute of technology, Mohammad Syahirul Mubarok has remained involved in a variety of organizations. As a dedicated member of HIMASISKAL ITS, Caroline held various officer positions, including vice president during her third and fourth years. In addition to academic activities, experienced and active author joined in some organizational activities and student activity units. The author has joined the Marine Icon 2015, 2016, and 2017 HIMASISKAL ITS. In addition, the authors are active in participating in soft skills development activities. Beyond school involvement, Mohammad Syahirul Mubarok's hobbies are traveling, hiking, and playing badminton.