Bachelor Thesis & Colloquium – ME184841

TECHNICAL ANALYSIS OF COPPER MATERIAL EXHAUST GAS PIPE INTERNALLY FINNED PERFORMANCE ON THERMOELECTRIC GENERATOR IN THE MAIN ENGINE WASTE HEAT RECOVERY SYSTEM USING COMPUTATIONAL SIMULATION

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DOUBLE DEGREE PROGRAM
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Tugas Akhir – ME184841

ANALISIS TEKNIS PERFORMA PIPA GAS BUANG BERBAHAN TEMBAGA BERSIRIP INTERNAL PADA GENERATOR THERMOELECTRIC DALAM PEMANFAATAN PANAS YANG TERBUANG PADA MESIN UTAMA DENGAN MENGGUNAKAN SIMULASI KOMPUTASI

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APPROVAL FORM

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BACHELOR THESIS

Submitted to Fulfill One of The Requirement
to Obtain a Bachelor Engineering Degree
On
Marine Fluid Machinery System (MMS) Laboratory
S-1 Program Department of Marine Engineering
Faculty of Marine Technology
Sepuluh Nopember Institute of Technology Surabaya

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SURABAYA
JANUARY 2020

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DECLARATION OF HONOR

I hereby who signed below declare that :

This final project has written and developed independently without any plagiarism act. All contents and ideas drawn directly from intenal and external sources are indicated such as cited sources, literatures, and other profesional sources.

Name	: Dannet Irsyad
NRP	: 04211441000026
Bachelor Thesis Title	: Technical Analysis of Copper Material Exhaust Gas Pipe Internally Finned Performance on Thermoelectric Generator in The Main Engine Waste Heat Recovery System Using Computational Simulation
Department	: Marine Engineering

If there is plagiarism act in the future, i will fully responsible and receive the penalty given by ITS according to the regulation applied

Surabaya, Januari 2020

Dannet Irsyad

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TECHNICAL ANALYSIS OF COPPER MATERIAL EXHAUST GAS PIPE INTERNALLY FINNED PERFORMANCE ON THERMOELECTRIC GENERATOR IN THE MAIN ENGINE WASTE HEAT RECOVERY SYSTEM USING COMPUTATIONAL SIMULATION

Name	**: Dannet Irsyad**
NRP	**: 04211441000026**
Department	**: Marine Engineering**
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ABSTRACT

The waste heat of exhaust gas temperature on ship that collected from ship's main engine can reach up to 300^0 C – 400^0 C. Those abundant amount of waste heat can be utilize for several systems on ship throught Waste Heat Recovery (WHR). WHR is one of the solution to overcome the mentioned issue. WHR is a method to utilize the process heat output to different part of process and the purpose is to increased efficency. The heat transfer process is affected by the value of the surface area (A). The bigger of surface area will absorb more heat that available and produce greater heat transfer. In this research, fin added to pipe to increase the surface area.The finned pipe use copper as the material and it will discusses the effect of the using fins on the exhaust gas pipe heat energy that will be moved through thermal work simulation using CFD, therefore it will get the estimate of heat energy amount that can be used for several waste heat recovery systems on ship. In this research, the waste recovery system is utilized to produce electricity by using thermoelectric generator. Finned pipe absored more heat from exhaust gas than finless pipe, which means the thermoelectric generator will produce more electricity if the TEG sticked on finned pipe rather than finless pipe. At finned pipe at 100% engine power rate, the TEG create 8.92 W, 8.7 W at 90%, 7.97 W at 80%, 8.5 W at 70%, 8.56 W at 60% and 8.76 W at 50%.

Keyword : waste heat recovery system, heat transfer, finned pipe, copper, electricity, thermoelectric generator

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ANALISIS TEKNIS PERFORMA PIPA GAS BUANG BERBAHAN TEMBAGA BERSIRIP INTERNAL PADA GENERATOR THERMOELECTRIC DALAM PEMANFAATAN PANAS YANG TERBUANG PADA MESIN UTAMA DENGAN MENGGUNAKAN SIMULASI KOMPUTASI

ABSTRAK

Panas yang terbuang dari gas buang di kapal yang dikumpulkan dari mesin utama kapal dapat mencapai hingga 3000 C - 4000 C. Jumlah panas terbuang yang melimpah dapat dimanfaatkan untuk beberapa sistem di kapal melalui Waste Heat Recovery (WHR). WHR *adalah salah satu solusi untuk mengatasi masalah tersebut.* WHR *adalah metode untuk memanfaatkan hasil keluaran panas dari suatu proses suatu sistem untuk proses sistem yang berbeda dan tujuannya adalah untuk meningkatkan efisiensi. Proses perpindahan panas dipengaruhi oleh nilai luas permukaan (A). Semakin besar luas permukaan akan menyerap lebih banyak panas yang tersedia dan menghasilkan perpindahan panas yang lebih besar. Dalam penelitian ini, sirip ditambahkan ke pipa untuk menambah luas permukaan. Pipa bersirip menggunakan tembaga sebagai bahan dan akan membahas efek penggunaan sirip pada energi panas pipa gas buang yang akan dipindahkan melalui simulasi kerja termal menggunakan CFD, oleh karena itu akan mendapatkan perkiraan jumlah energi panas yang dapat digunakan untuk beberapa sistem pemulihan panas yang terbuang pada kapal. Dalam penelitian ini, sistem pemanfaatan panas yang terbuang akan dimanfaatkan untuk menghasilkan listrik dengan menggunakan* thermoelectric generator. *Pipa bersirip menyerap lebih banyak panas dari gas buang dari pada pipa tidak bersirip, yang berarti generator termoelektrik akan menghasilkan lebih banyak listrik jika TEG menempel pada pipa bersirip daripada pipa tidak bersirip. Pada pipa bersirip pada tingkat daya engine 100%, TEG menghasilkan 8,92 W, 8,7 W pada 90%, 7,97 W pada 80%, 8,5 W pada 70%, 8,56 W pada 60% dan 8,76 W pada 50%.*

Kata kunci: *sistem pemanfaatan panas yang terbuang, perpindahan panas, pipa bersirip, tembaga, listrik, generator termoelektrik*

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PREFACE

First of all, praise and thank you from the author to Allah SWT, because of his help and permission, the author could complete the bachelor thesis entitled “Technical Analysis Of Copper Material Exhaust Gas Pipe Internally Finned Performance On Thermoelectric Generator In The Main Engine Waste Heat Recovery System Using Computational Simulation” as one of graduation requirements on Marine Engineering department faculty of Marine Technology Sepuluh Nopember institute of technology Surabaya.

The author would also like to thank all those who have helped the author in completing this research, among others :

1. My family, especially my parents and my brother who give countless moral support and endless prayers during author lecture;
2. Mr. Beny Cahyono, ST., MT., Ph.D. as the Head of Marine Engineering department – Faculty of Marine Technology – ITS;
3. Mr. Ir. Agoes Santoso, M.Sc., as the thesis supervisor who has helped and guided the author to complete the research from the start to final stages;
4. Mr. Indra Ranu Kusuma, S.T., M.Sc. as the author’s supervisor during study at Department of Marine Engineering – Faculty of Marine Technology, ITS, who has helped and guided the author as a student during the lecture.
5. To all of my friend from marine engineering batch 2014 who have have supported and helped the author to complete the bachelor thesis
6. The others that the author cannot mentioned one by one who have helped the author finish the bachelor thesis.

In writing this thesis the author realizes that the report is far from perfection. So some suggestions and criticism is needed for the author to helped the author make better writing structure in the future. Finally, the authors hope that this research will benefit for author in particula, the readers.

Surabaya, January 2020

The author

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TABLE OF CONTENT

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CHAPTER I
INTRODUCTION

1. 1 Overview

On ship, the energy requirements are fulfill through marine diesel engines. However, almost half of the energy that ship used is lost to environment in heat form. So a method is needed to utilize those heat losses tho increase ship efficiency. Waste Heat Recovery is one of solution to resolve these problems. This technology is already being used in some vessels to improve the ship fuel efficiency by generate electricity from the themal losses of main engine. The heat sources can be collected from several system on ship with each system have different temperatures.

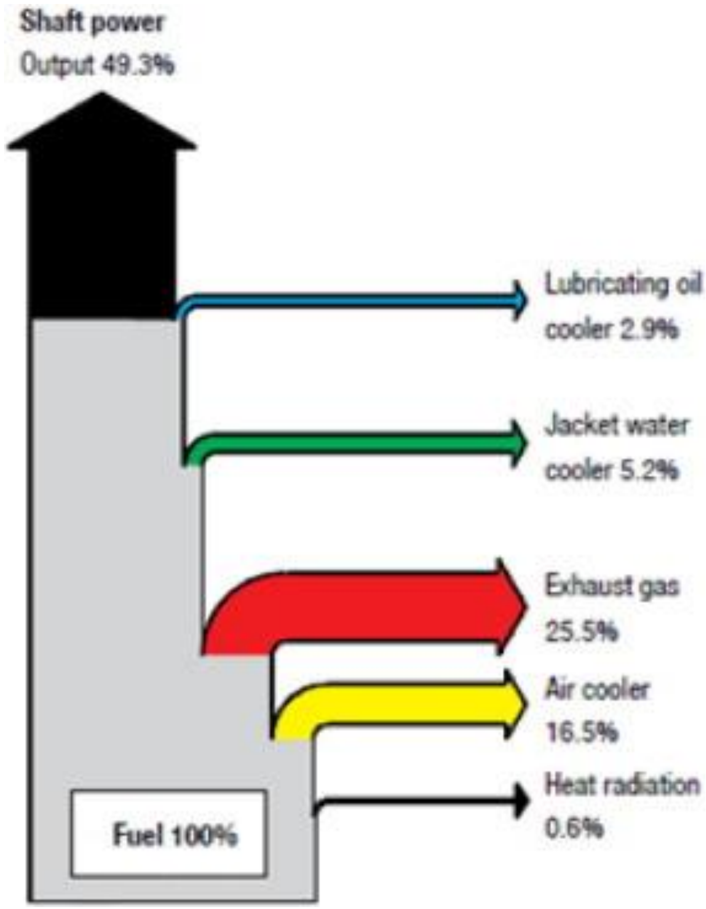


Figure 1.1 Diesel Engine Sankey's Diagram

The heat sources of ship can be get from thermal losses of machinery operation such as, the heat from exhaust gas, lubricating oil system, charge air cooler and jacket water cooling system. The WHRS will have positive impact on ship operational because it will reduce the ship operational cost and also minimize the green house gas emission.

In the combustion process on diesel engines, not all fuels can be completely converted into mechanical energy, only about 30% which can be used as propulsive thrust. About 20% is lost through mechanical and transmission losses and 50% is lost through the exhaust gas and cooling system. Nowadays, fossil energy as the main energy source which is used in several activity is become more limited so it need alternative energy to support it. One of alternative energy is comed from the waste heat of diesel engine. The waste heat of exhaust gas temperature that collected from ship’s main engine can reach up to 300^0 C – 400^0 C. Those abundant amount of waste heat can be utilize to support several systems on ship such as water ballast treatment heater, fresh water generator heater, oil heater and converted to electricity..

The heat transfer process that can happen inside the pipe are conduction and convection process. But,mainly the process of heat transfer inside pipe is through conduction. The pipe surface area (A) will be affected the conduction process, the heat transfer will be better or the pipe will absorb more heat, if the surface area is bigger. The fins installation is an attempt to increase the surface area of the fluid contact with the wall of exhaust gas pipe, to increase conduction heat transfer. So it means internal fins installation on exhaust gas pipe will be effected the thermal performance of exhaust gas pipe main engine.

In the previous research by Wasis Tri Handoko which entitled “Simulasi Komputasional Kinerja Termal Pipa Gas Buang Bersirip Pada Waste Heat Recovery System Main Engine”, it explains the internal fin installation influence against thermal performance and backpressure in exhaust gas pipe using computational simulation. The conclussion from this research is that the internal fins installation in exhaust gas pipe can improve thermal performance for waste heat recovery system and increase the heat that absorbed by the exhaust gas pipe. The material that used as internally finned exhaust pipe in this research is alumunium. The drawback of this internal fin installation is it increase the backpressure in exhaust gas system, but the value of backpressure in this previous research is still allowed to be applied to the system, because it only reach 1% of maximum backpressure limit of main engine.

In this research, it will analyzed the effect of internal copper material fin installation in exhaust pipe on thermal energy that will be transfer to be used as waste heat recovery system. Thermal performance of a heat recovery device, which enables air to air heat transfer, was examine by simulating using CFD.

1.2 Problems Statement

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

1. How is the thermal performance of copper material 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 the copper material fins to the exhaust gas backpressure?
4. How much electrical that can be generated through thermoelectric generator using heat from finned exhaust gas pipe ?

1.3 Research Objectives

The goals to be achieved in this thesis research are:

1. Find out the thermal performance of copper material 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 the copper material fins to the exhaust gas backpressure.
4. Determine the amount of electricity can be generated

1.4 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.

1.5 Research Limitations

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

1. The fin's shape that used is longitudinal fin - rectangular profile.

2. This research data is taken from simulation method using CFD and economic analysis is ignored
3. In this study the application was discussed only in the use of heat to generate electricity using a thermoelectric generator.
4. The engine load which is used as the variable control is started from 500 rpm, 600 rpm, 700 rpm, 800 rpm, 900 rpm, and 1000 rpm.

CHAPTER II
LITERATURE STUDY

2.1 Waste Heat Recovery System

On ship, marine diesel engine is used to supply the requirements of energy. But appreantly, almost half of the energy consumed is lost to surroundings in form of heat. So a method is needed to utilize those losses to increase ship fuel efficiency.

Waste heat recovery system (WHRS) is a system that recover the thermal losses from the operation of machinery or equipment and convert it to generate electricity. Waste heat that get it from ship's engine is a huge source of energy.

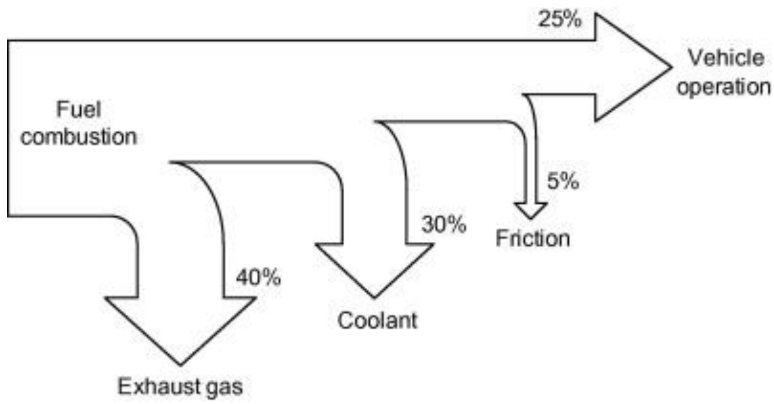


Figure 2. 1 Energy Flow Part in Internal Combustion Engine

The heat sources of ship can be get from thermal losses of machinery operation such as, the heat from exhaust gas, lubricating oil system, charge air cooler and jacket water cooling system. The WHRS will have positive impact on ship operational because it will reduce the ship operational cost and also minimize the green house gas emission

2.2 Exhaust System Backpressure

Backpressure is pressure that opposed the direction of the fluid's stream itself in limited spaces 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.

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. Table 2.1 outlines the VERT recommended back pressure limits for a range of engines sizes.

Table 2.1 VERT Maximum Recommended Exhaust Back Pressure

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.

2.3 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.

2.3.1 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. The rate value of heat transfer by conduction can be formulated by equation below

$$\boldsymbol{q = -kA\frac{dT}{dX}}$$

Equation 2.1 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

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

2.3.2 Convection Heat Transfer

Convection heat transfer occurs due to fluid flow which has a higher temperature. The temperature difference in the wall is influenced by the velocity of fluid flow. In this heat transfer, the surface area also influences the overall heat transfer. The rate value of heat transfer by convection can be formulated by equation below

$$\boldsymbol{q = hA(T_w - T_\infty)}$$

A in the equation above mean the thermal contact surface area and h is the convection heat tranfer coefficient. The heat-transfer rate is related to the overall temperature difference between the surface area (A), fluid and wall. 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

Mode	Film Conductance	
	W/m^2. ^{0}C	**Btu/h. ft^2. ^{0}F**
Across 2.5 cm air gap evacuated to a pressure of 10-6 atm and subjected to		
ΔT = 100 ^{0}C - 30 ^{0}C	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

2.4 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.

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

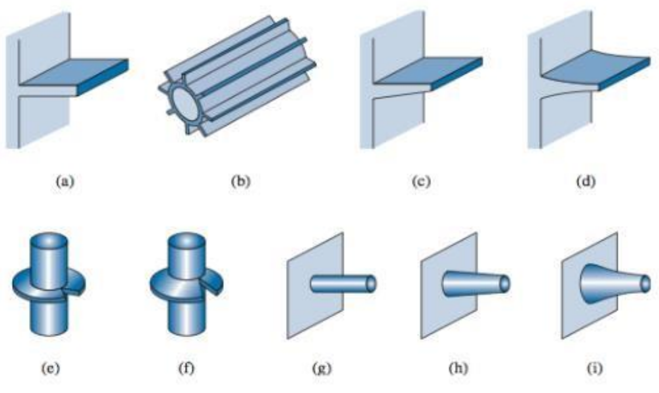


Figure 2.2 Types of Fin Based on Its Shape (Sachdeva, 2009)
(a) Longitudinal – Rectangular (b) Longitudinal – Rectangular (c) Rectangular – Trapezoidal (d) Longitudinal – Concave parabolic (e) Radial – Rectangular (f) Radial – Triangular (g) Pin – Cylindrical (h) Pin – Tapered (i) Pin – Concave parabolic

2.5 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. Although TEG has low efficiency, but it has several good points because it is compact, simple, quiet operation, and has inexpensive price.

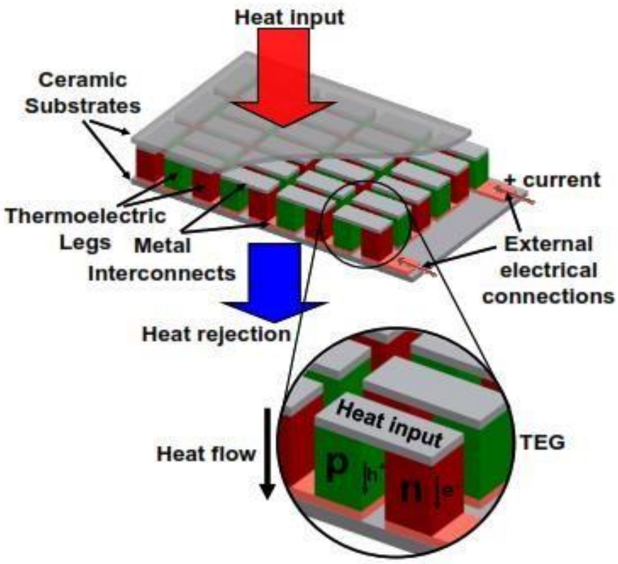


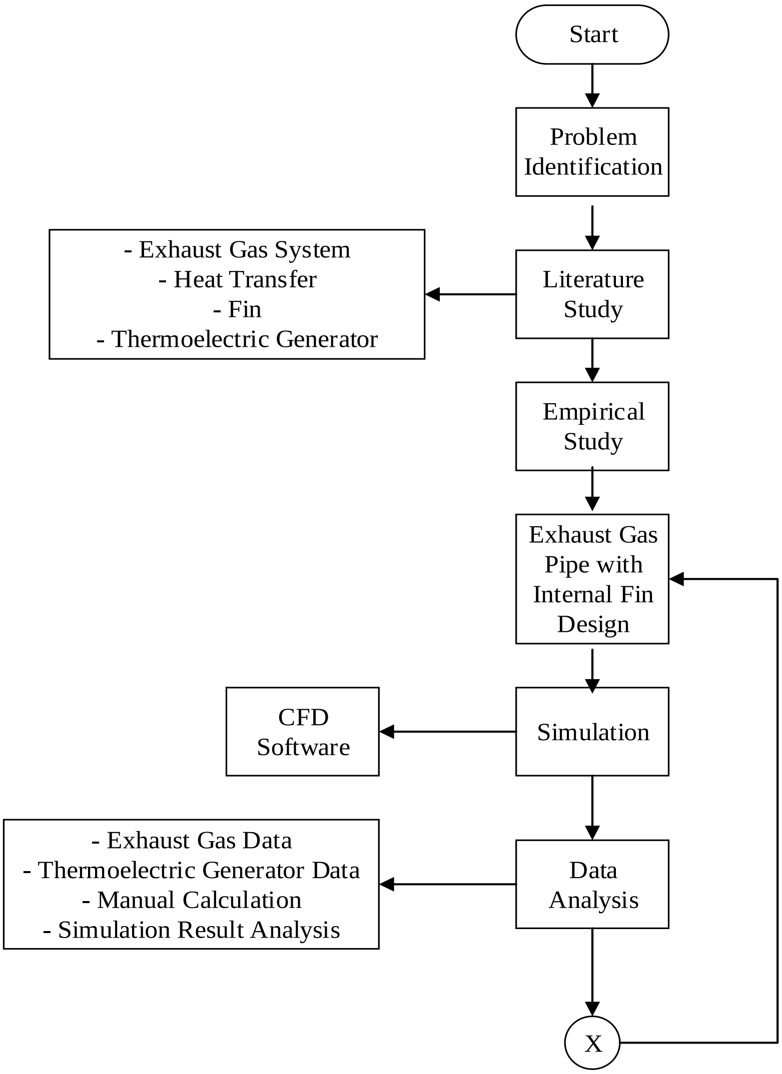
Figure 2.3 Components of a Thermoelectric Module

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.

CHAPTER III
METHODOLOGY

3.1 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



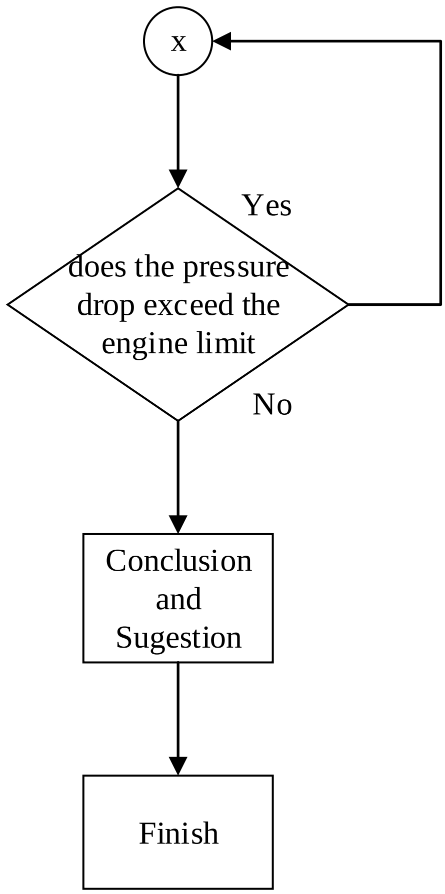


Figure 3. 1 Methodology Flow Chart

3.2 Methodology Definition

3.2.1 Problem Identification

At this stage, the objective is to identified the problem. To identify the problem the writer use the various sources such as books, papers and journals

3.2.2. Literature Study

In this thesis, the literature study is an early stage to plan of basic theory to be studied, data to support this research calculation and analysis of the research so the writer can get the outcome. Basic theories in this literature study is needed as a basic for the writer to find the solution of the problem, such as exhaust gas system, heat transfer, fin and thermoelectric generator

3.2.3 Empirical Study

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.

3.2.4 The Design of Exhaust Gas Pipe

The design of exhaust gas pipe uses initial design as parameters from empirical studies. The design parameters concern about the possibilities that will occur when the fins are added to the exhaust system to the engine, and the characteristics of the exhaust gas so when the system is installed on the exhaust gas line it will not give a negative impact on the engine. In addition, the right design will get the most efficient heat transfer

3.2.5 CFD Simulation

This stage aim is to the simulation of the exhaust gas pipe with internal fin that has been design. The simulation process is using CFD software The simulation results are the amount of heat that transferred by finned exhaust gas pipes, the shape of the exhaust gas flow in finned exhaust gas pipes, the difference in temperature in the inlet and outlet and the right shape of the fin to get huge amount of heat.

3.2.6 Data Analysis

Data analysis is based on data from simulation results , pressure change and heat flow rate are evaluated and if it is not appropriate the process will be repeated from the design. The success parameter of the data is the high heat flow rate so it create a high temperature difference, if this is not achieved then the data is evaluated.. All data are analyzed to get maximum results.

3.2.7 Conclusion and Suggestion

At this stage, the result from this research will be concluded and also some suggestion for more complete research in the future. The coclusions are the summary of the problem and the solution that obtained from this research.

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CHAPTER IV
DATA ANALYSIS

4.1 Heat Transfer Derivation

To determine the value of heat transfer, it is known that the released energy is equal to the received energy . So that the received energy by the tips of the fins through convection is the same as the energy sent to the base of the fin by conduction. The mathematical calculation as follow

$$q_{Konveksi} = q_{konduksi}$$

The received energy of fins through convection with the convection heat transfer equation is q = hA (T_w-T_∞) [5]. Qconduction is heat that is transferred to the base of the fin through conduction with the basic equation q = -kA dT / dx [5]. So the heat transfer equilibrium as it follow

$$hA(T_0 - T_\infty) + hP(T_0 - T_\infty)dx = -kA\frac{(dT)}{dx}$$

The heat exchange area in q2 is the multiplication between the circumference and dx because the area is affected by changes in x along L. Because in this case, the fins received heat at the tip and continued through conduction along L so integration can be carried out on x (0-L) [5], with the thermal energy equation as it follow

$$q_2 = hP(T_0 - T_\infty)dx = \int_0^L hP(T_0 - T_\infty)dx \text{ [5].}$$
$$q_2 = hP(T_0 - T_\infty)x|_0^L = hPL(T_0 - T_\infty)$$

$$q_{Konveksi} = h(PL + A)(T_0 - T_\infty) \text{ (8.a)}$$

As for the integration of heat energy transferred through conduction as follows

$$q_{Konduksi} = -kA\frac{(Tb - T)}{dx}$$

$$-kA(Tb - T) = \int_0^L q_{kond}.dx$$

$$-kA(Tb - T) = q_{Kond}L$$

$$(Tb - T) = -\frac{hL(PL + A)(T_0 - T_\infty)}{kA}$$

Tb - T is the change in temperature between the temperature of the fin tip and the wall at the fin base.

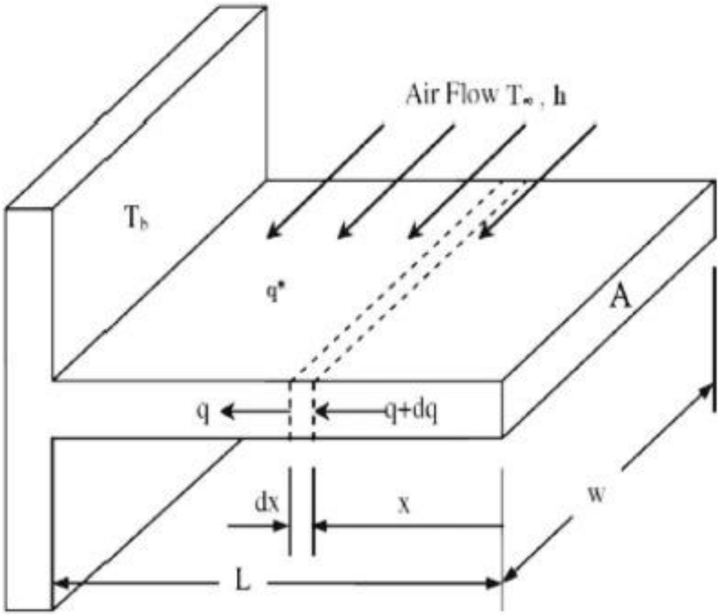

Figure 4.1Finned Pipe Heat Transfer Diagram

4.2 General Data

It is required to know the general data that will be used in this research before doing the simulation and calculation analysis about thermal performance at internally finned exhaust gas pipe with copper as material and also to analyze the electricity that will be generated by using thermoelectric generator.

4.2.1 Engine Spesification

The diesel engine that will be used in this research is Mak 8 M 25 C. The exhaust gas data that will be used is based on this diesel engine exhaust gas system. The following data is obtained based on the main engine project guide :

- Motor model : 4-stroke diesel engine
- Number of cylinder : 8
- Bore : 255 mm
- Stroke : 400 mm
- SFOC : 187 g/kWh
- Max Power : 2400 HP

- Revolutions : 750 RPM
- BMEP : 25.8 bar
- Turbocharging : pulse pressure
- Direction of rotation : clockwise, option: counter-clockwise

Based on the engine project guide, the exhaust gas data is obtained as follows :

- Pressure drop maximum : 0.03 bar
- Pipe diameter : 600 mm
- Length : 450mm
- Max. Flow velocity : 40 m/s
- Atmospheric pressure : 1 bar
- Mass flow and Temperature :

Table 4.1 Main Engine Exhaust Data When Air Intake Temperature Is On 45^{o}c

Rate %	Power	Mass Flow (kg/h)	Temperatur e (^{o}C)
100	2640	18044	335
90	2376	16666	331
80	2112	15210	321
70	1848	13545	322
60	1584	11875	327
50	1320	10171	332

4.2.2 Thermoelectric Generator Data

In this research, the waste heat recovery system that will be analyzed is the performance of thermoelectric generator. The objective of this research is to see the amount of electricity that can be generated by thermoelectric generator based on waste heat of exhaust gas availabe in exhaust gas pipe. The thermoelectric generator that will be used as a reference in this research is a thermoelectric type TEG1-PB-12611-6.0 with specification as follow :

- Hot side temperature : 350^o C
- Cold side temperature : 30^o C
- Open circuit *voltage* : 9.2 v
- Matched Load Resistance : 0.97 ohm
- Matched Load Output Voltage : 4.6 V
- Matched Load Output Current : 4.7 A
- Matched Load Output Power : 21.7 W
- Heat flow in the modul : 310 W

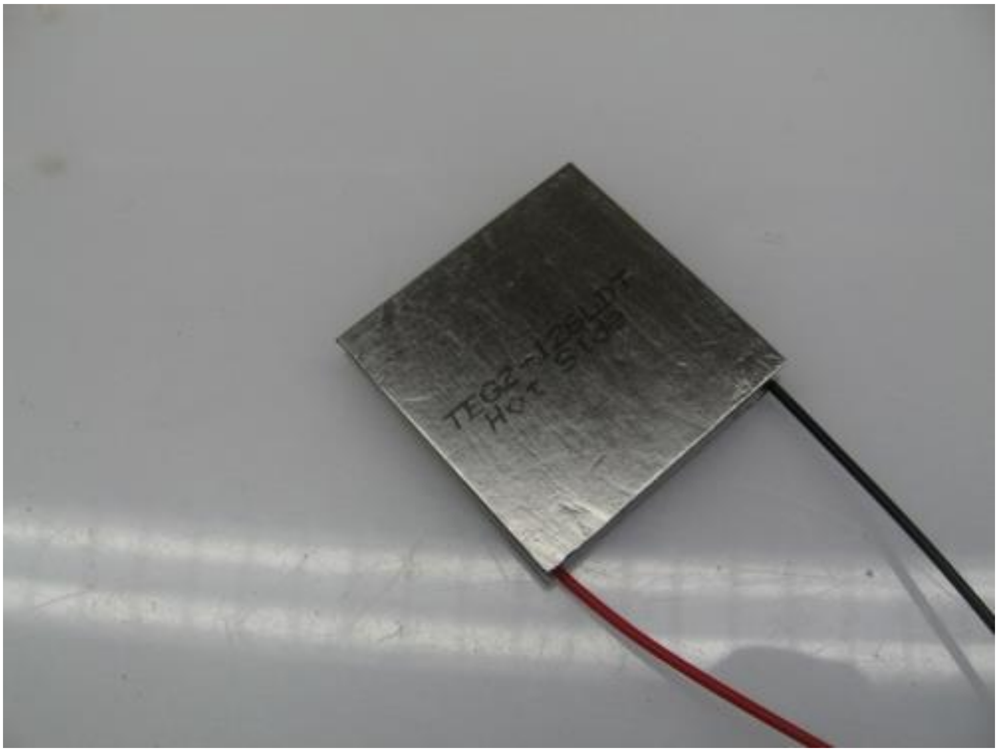

Figure 4.2 TEG1-PB-12611-6.0

The thermoelectric is made of bismuth tellurium and the casing using ceramics as material casing and also has dimensions spesification like in this Figure 4.2 below :

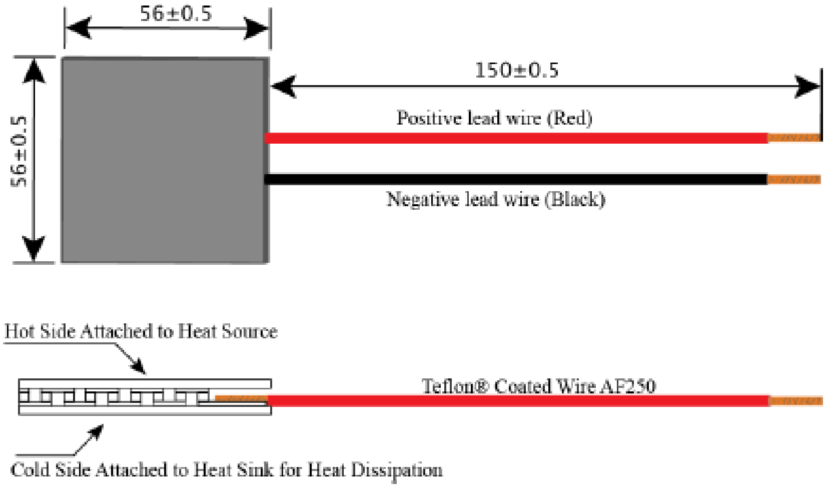

Figure 4.3 TEG1-PB-12611-6.0 Dimensions

The thermoelectric generators will be placed at the outer wall of exhaust gas pipe, then the electricity will be produced by thermoelectric because differential temperature of cool surface and hot surface like on this schematic diagram below :

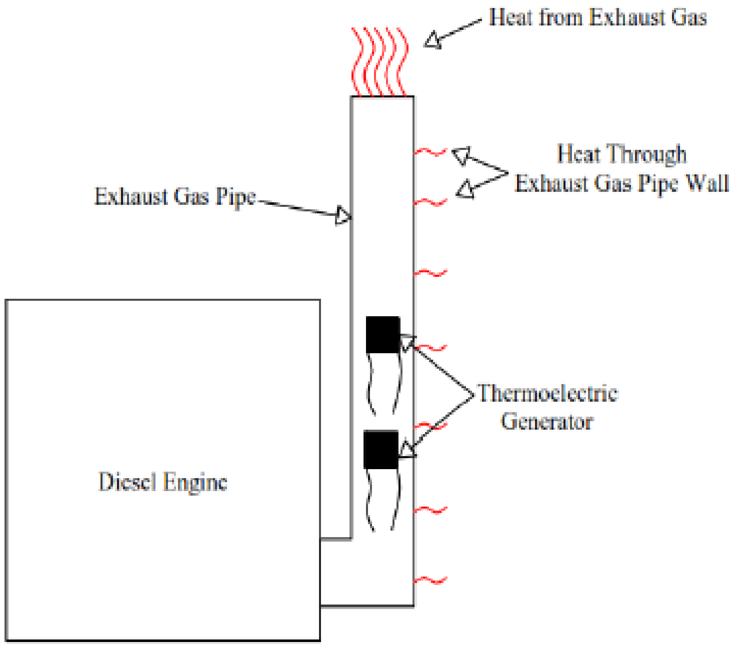

Figure 4.4 Exhaust Gas Heat Utilization Schematic Diagram

4.3 Internally Finned Pipe Design

This module design will be used copper as its material. The designing of the internally finned pipe design in this research is based on the module design from previous research and also has design as follows :

- Pipe diameter : 600 mm
- Pipe thickness : 1 inch
- Fin thickness : 5 mm
- Fin width : 50 mm
- Length : 1 m
- Range between each fin : 50 mm
- Number of fin : 32

Thermoelectric will be placed in all pipe surfaces, to make it this possible, the outer wall of exhaust gas pipe is made in shape of 32 sides with a width of 60 mm on each side. The following figure is the pipe design that will be used as reference.

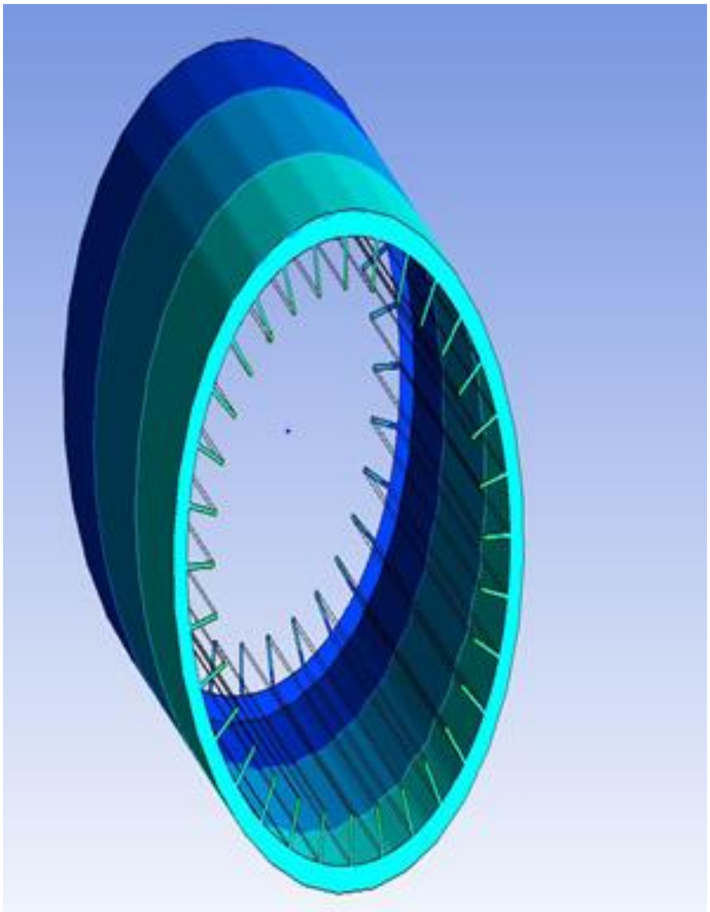

Figure 4.5 Exhaust Gas Pipe Design

4.4 Mathematic Calculation

The objective to do this manual calculation is to determine exhaust gas pipe outer wall temperature by determine value of heat energy that will be tranferred and know the exhaust gas per temperature characteristic through interpolation of exhaust gas data from www.dieselnet.com as shown in the following table

Table 4.2 Exhaust Gas Characteristic

T (K)	T©	ρ (kg/m^3)	Cp(kJ/kg.K)	μ (10^{-4} Pa.s)	k(W/m.k)
500	227	0,5	1030,0	0,2	0,3
600	327	0,4	1051,0	0,2	0,3
800	527	0,3	1099,0	0,3	0,4

Interpolation					
594	321	0,408	1050	0,21	0,32
595	322	0,407	1050	0,21	0,32
600	327	0,403	1051	0,21	0,32
604	331	0,401	1052	0,21	0,33
605	332	0,400	1052	0,21	0,33
607	334	0,399	1053	0,21	0,33
608	335	0,399	1053	0,21	0,33
609	336	0,398	1053	0,21	0,33

Thermal calculation is carried out based on the table above, with formula as follow :

$$(Tb - T) = -\frac{hL(PL + A)(T_0 - T_\infty)}{kA}$$

The boundary condition in this case is that heat is received by the tip of the fin and the temperature of the fins and all areas that are in direct contact with the exhaust gas will be the same as the exhaust gas temperature. The cross-sectional area of the exhaust gas pipe based on the design is 0.2 m^2 and the circumference is 5.08 m, to determine the value of the nusselt number used the equation as follows :

$$Nu = \frac{0.3387 Re^{1/2} Pr^{1/3}}{\left[1 + \left(\frac{0.0468}{Pr}\right)^{2/3}\right]^{1/4}}$$

Table 4.3 Exhaust Gas Characteristic Per Engine Load

Rate Engine (%)	Coefficient							
	ρ	Cp	μ (10^{-4} Pa.s)	k	Pr	Re	Nu	h
100	0.399	1053	0.21	0.33	0.07	4.E+05	80	44
90	0.401	1052	0.21	0.33	0.07	5.E+05	81	44
80	0.408	1050	0.21	0.32	0.07	5.E+05	82	44
70	0.407	1050	0.21	0.32	0.07	5.E+05	82	44
60	0.403	1051	0.21	0.32	0.07	5.E+05	81	44
50	0.400	1052	0.21	0.33	0.07	4.E+05	81	44

Then to know the temperature on the outside of pipe, it is calculated using thermal resistance with the following equation :

$$Rw = \frac{\Delta x}{kA} \text{ and } Rf = \frac{1}{\eta_f A_f h}$$

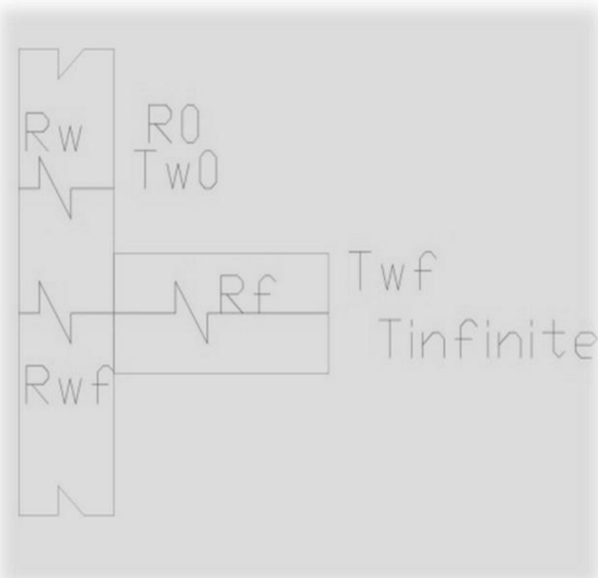

Figure 4.6 Finned Pipe Thermal Resistance

Based on the shape of the fin, the efficiency of the square fin that is designed as 0.98. based on these equations, the calculation of thermal resistance is as shown in the following table :

Tabel 4.6 Thermal Resistance

<table>
<tr><th rowspan="2">Rate</th><th rowspan="2">Lc</th><th rowspan="2">Eff</th><th colspan="4">Thermal Resistance</th></tr>
<tr><th>Rwf</th><th>Rw0</th><th>R pararel 1 fin 1 wall</th><th>rF</th></tr>
<tr><td>100</td><td>0.020</td><td>0.98</td><td rowspan="6">2.E-02</td><td rowspan="6">4.E-03</td><td rowspan="6">4.E-03</td><td>5.E+00</td></tr>
<tr><td>90</td><td>0.020</td><td>0.98</td><td>5.E+00</td></tr>
<tr><td>80</td><td>0.020</td><td>0.98</td><td>5.E+00</td></tr>
<tr><td>70</td><td>0.020</td><td>0.98</td><td>5.E+00</td></tr>
<tr><td>60</td><td>0.020</td><td>0.98</td><td>5.E+00</td></tr>
<tr><td>50</td><td>0.020</td><td>0.98</td><td>5.E+00</td></tr>
</table>

Then the results of mathematical calculations on the outer walls of the exhaust gas pipe are as shown in following table

Table 4.7 Outer Wall Pipe Temperature

Power Rate	T Exh (K)	H	qkonv (W)	hL/k x10^{-4}	hPL2/kA x10^{-3}	dTb	T base	T Outer Wall (K)
100	608	44	64	28	29	9	617	613
90	604	44	63	28	29	9	613	608
80	594	44	61	28	29	9	603	598
70	595	44	61	28	29	9	604	599
60	600	44	62	28	29	9	609	604
50	605	44	63	28	29	9	614	610

4.5 ANSYS Simulation Process

The simulation aims to determine the interaction between the exhaust gas and the internally finned pipe moduwle, as well as the effect of fin on the exhaust gas pressure in the pipe. Meshing the exhaust gas pipe model is carried out with the following size :

- Physical preference : Medium
- Initial sixe seed : Assembly
- Smoothing : Medium
- Transition : Fast
- Span angle center : Coarse
- Inflation option : Smooth transition
- Max face size : 67 mm
- Size Function : Proximity

With the results of meshing as shown in the following Figure 4.7

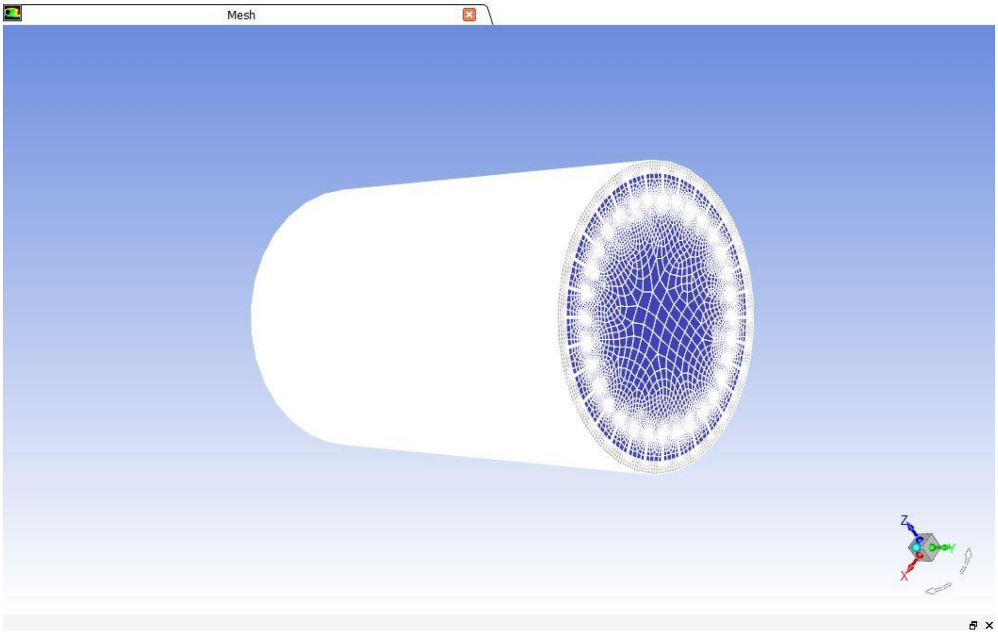

Figure 4.7 Meshing Model Result

The results of the meshing are processed in Ansys Fluent workbench setup menu to determine the boundary condition. The type of fluid used is exhaust gas, with the exhaust gas parameter equal to the exhaust gas data per load percentage. The simulation data as shown in the following table.

a. Simulation results data outer wall temperature per load

Table 4.8 Outer Wall Pipe Temperature Per Load

No	Power Rate	Pipe Temperature (K)
1	100%	525-541
2	90%	522-538
3	80%	510-527
4	70%	516-531
5	60%	519-534
6	50%	522-539

b. Data from the simulation results of exhaust gas pressure on the pipe

Table 4.9 Pressure Wall Pipe Temperature Per Load

Power Rate	Pressure (kPa)	
	Inlet	Outlet
100	100	98.1
90	100	98.1
80	100	98.1
70	100	98.1
60	100	98.1
50	100	98.1

The type of fluid that used in this simulation is exhaust gas, with the exhaust gas parameter equal to the exhaust gas data per load percentage and on the cold side of pipe there is an assumption of air flow with a temperature of 45^0 celsius assumed to be the exhaust of the engine room ventilation system. Based on the simulation results of thermal ansys, there is temperature difference between the inlet and outlet. Where in engine run with 100% power rate condition the inlet temperature is 541K on the pipe outer wall, on the other hand the outlet temperature is 525 K. With the results of thermal analysis as shown in the following Figure 4.8

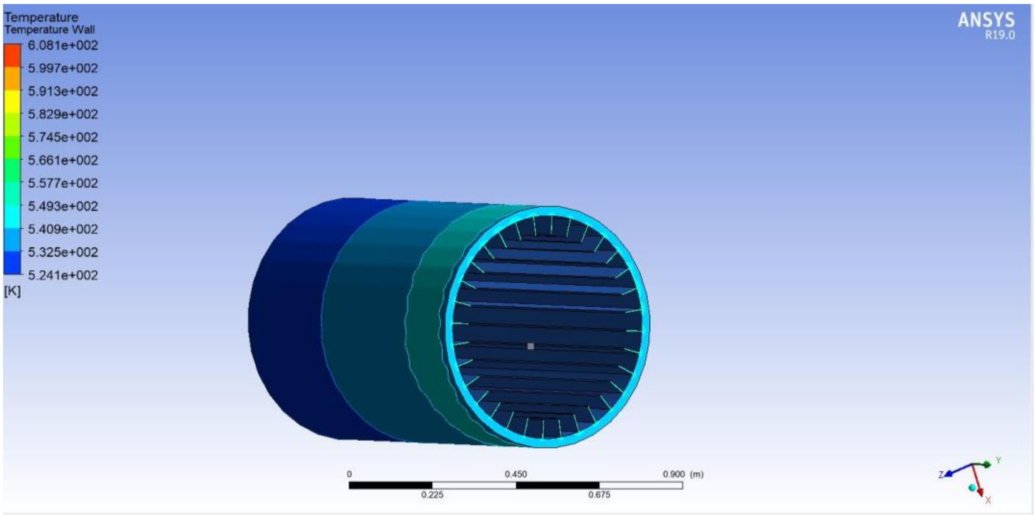

Figure 4.8 Thermal Analysis Result with 100% Engine Power Rate

4.6 Research Results Analysis

a. Internally Finned Pipe Wall Temperature

The temperature in the outer wall of the finned exhaust gas pipe is defined as a form of heat energy absorbed from the exhaust gas by the fins. The heat energy is transferred to the outer wall through the conduction process. The heat transfer is effected by pipe material and environmental temperature. The results of mathematical calculations and simulations as in Figure 4.9 below.

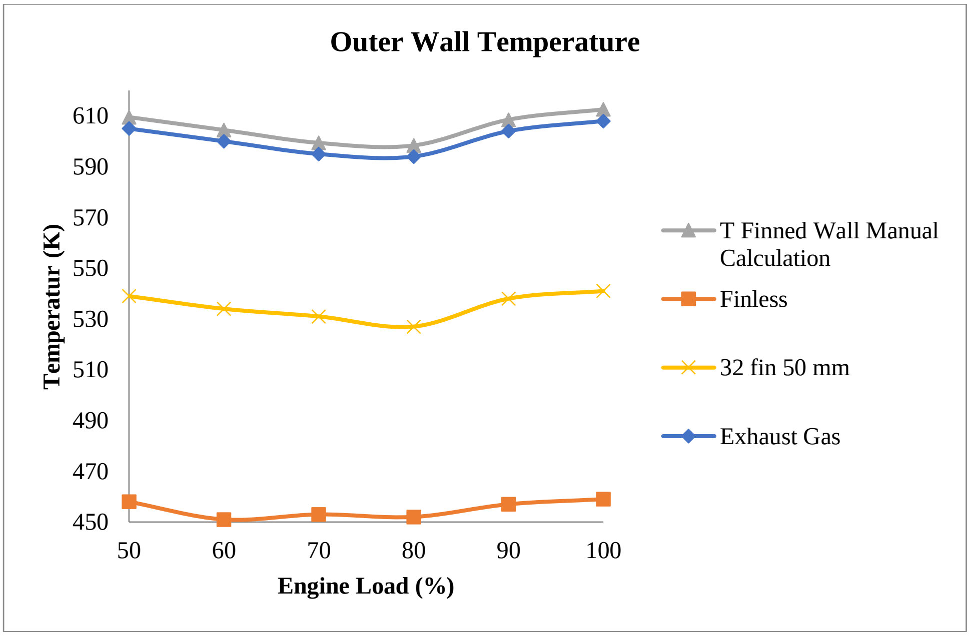

Figure 4.9 Outer Wall Temperature Graph

Based on figure 4.9 the addition of contact surface area can increase the heat absorbed by the pipe wall.The addition of fins can increase the heat temperature that pipe can absorbed. The different of outer wall temperature between finless with finned pipe is quite significant with around 70^0C to 80^0C with finned pipe has higher temperature that finless, which means finned pipe has better heat tranfer rate and absorb more heat from exhaust gas.

b. Changes of Exhaust Gas Pressure

The addition of fins besides to increasing the contact surface area also affects the change in pressure, changes in pressure caused by an increase in the surface of the friction fluid and a reduced cross-sectional area of the exhaust gas pipe. Based on the simulation results, there are some pressure drop in on finned pipe also on finless pipe. The results of the simulation of the pressure at the inlet are shown in Figure 4.10 below.

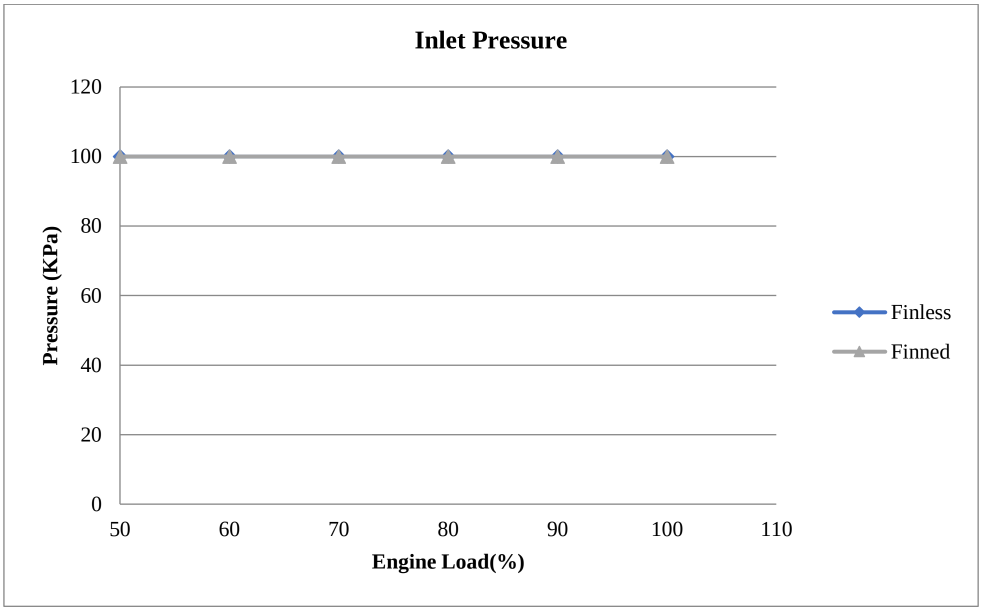

Figure 4.10 Inlet Pressure Graph

The inlet pressure for finned and finless pipe have sam value of pressure, which is 100kPa. Besides paying attention to the inlet pressure, the pressure at the outlet side is also used to calculate the pressure drop. The outlet pressure of the simulation results is as shown in Figure 4.11 below.

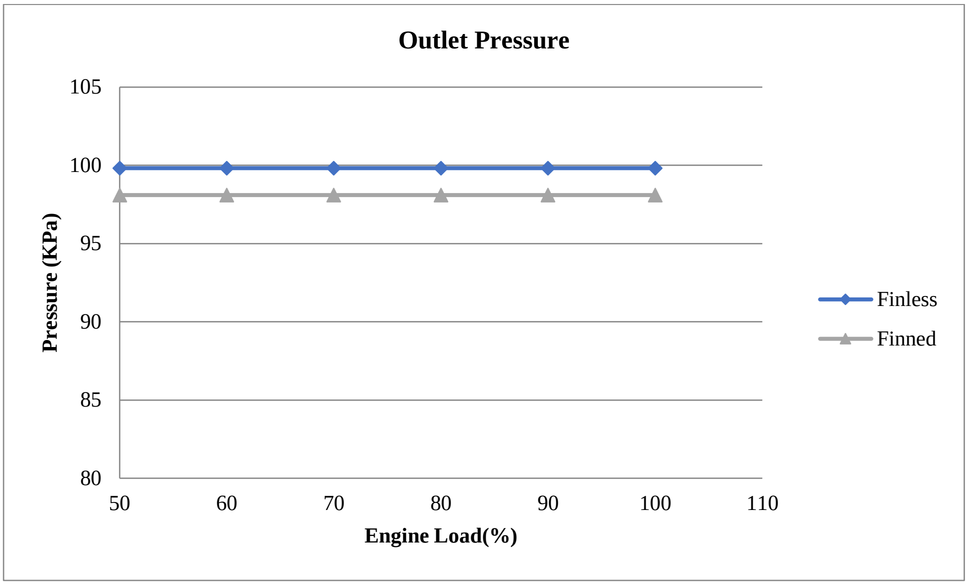

Figure 4.11 Outlet Pressure Graph

The results of pressure simulations at the inlet and outlet can be used to calculate the pressure drop at each area and the average pressure drop of the entire system. Pressure drop calculations are important because the pressure drop and average pressure drop values must be below the maximum pressure drop engine used. The results of pressure drop calculations are as in table below:

Table 4.10 Pipe Pressure Drop

Power Rate	Pressure (kPa)					
	Finless			Finned		
	Input	Output	Drop	Input	Output	Drop
100	100	99.82	0.18	100	98.1	1.9
90	100	99.82	0.18	100	98.1	1.9
80	100	99.82	0.18	100	98.1	1.9
70	100	99.82	0.18	100	98.1	1.9
60	100	99.82	0.18	100	98.1	1.9
50	100	99.82	0.18	100	98.1	1.9

Based on data from the MaK M 25 C project guide, the maximum pressure drop from the exhaust gas system is 0.03 bar or 3 kPa, so that it can be displayed using the graph as shown in the following figure

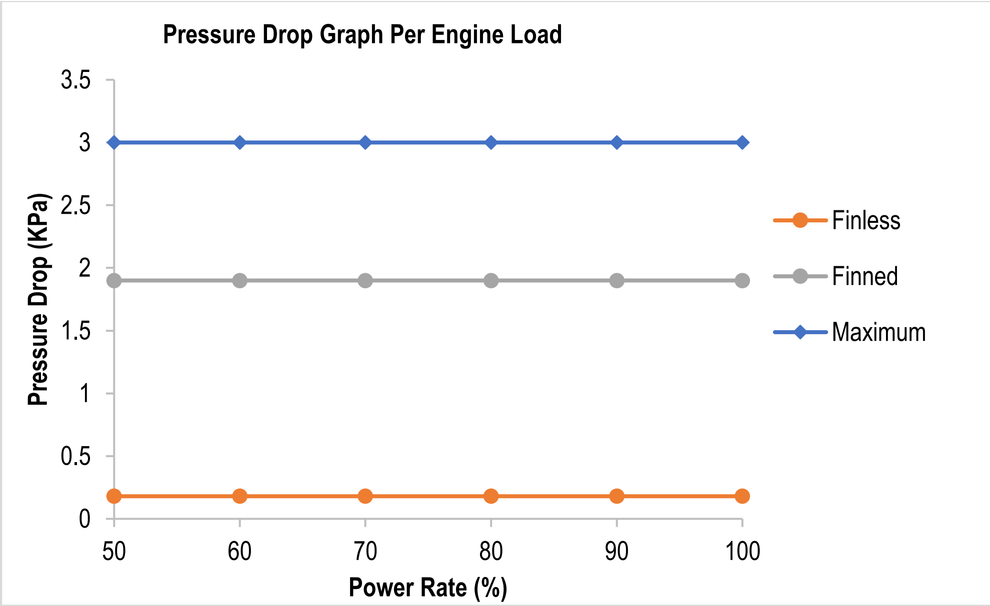

Figure 4.12 Pressure Drop Graph

C. Temperature on the thermoelectric heat side

The thermoelectric heat side temperature based on the simulation results is the same as the temperature of the outer wall of the exhaust pipe. The temperature of the thermoelectric heat side as in table 4.11 below

Table 4.11 Thermoelectric Generator Temperature

Power Rate	Temperature HS (K)		Temperature CS (K)	
	Finless	Finned	Finless	Finned
100	461	531	323	325
90	452	528	323	325
80	447	521	323	325
70	448	525	323	325
60	451	526	323	325
50	452	529	323	325

With the temperature of the thermoelectric cold side the simulation results vary and read the matched load graph in the thermoelectric catalog to determine the magnitude of the current and voltage generated per thermoelectric on the hot side temperature variation.

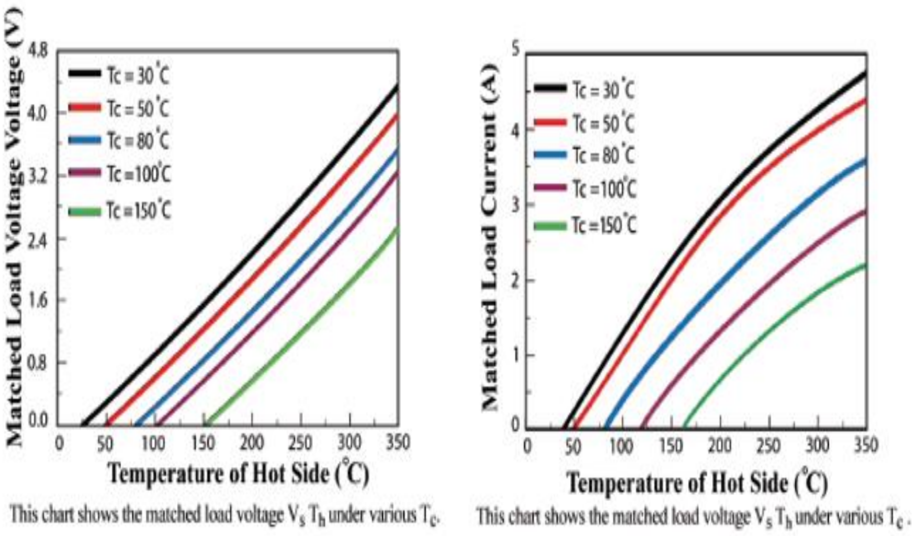

Figure 4.13 TEG Matched Load Voltage and Current

Based on the graph in Figure 4.8, the voltage and current generated at the cold side temperature are 50 and 80 Celsius, so that to get the performance at the cold side temperature in accordance with the simulation results and if not found on the graph then interpolation is done, and to find out the amount of power the resulting multiplication is carried out between the currents flowing with the potential difference generated.

Table 4.12 Thermoelectric Generator Voltage and Current

Hot Side	Cool Side (C)			
	Volatge (V)		Current (A)	
	50	80	50	80
100	0.6	0.25	1	0.4
125	0.9	0.55	1.5	0.81
150	1.2	0.85	2	1.2
175	1.5	1.15	2.5	1.6
200	1.8	1.45	2.8	1.9
225	2.1	1.8	3.2	2.3
250	2.45	2.15	3.5	2.6
275	2.8	2.45	3.7	2.9
300	3.2	2.81	3.95	3.1
325	3.53	3.15	4.15	3.4

350	3.9	3.5	4.35	3.55

d. Estimated electrical power output per engine load

To determine the amount of electric power generated, the thermoelectric performance graph is combined with the data temperature of hot and cold side of the thermoelectric results of the thermal work simulation module. From interpolating data from the thermoelectric catalog, it is obtained thermoelectric performance per hot side temperature as shown in the following table 4.13

Table 4.13 Thermoelectric Generator Voltage and Current Per Load

Power Rate	Temperature HS (K)		Temperature CS (K)		Voltage (V)		Current (A)	
	Finless	Finned	Finless	Finned	Finless	Finned	Finless	Finned
100	461	531	323	325	1.66	2.54	2.66	3.51
90	452	528	323	325	1.55	2.50	2.55	3.48
80	447	521	323	325	1.49	2.40	2.48	3.32
70	448	525	323	325	1.50	2.46	2.50	3.46
60	451	526	323	325	1.54	2.47	2.54	3.46
50	452	529	323	325	1.55	2.51	2.55	3.49

Table 4.14 TEG Voltage and Current Interpolation

Hot Side	Cool Side (C)							
	Voltage (V)				Current (A)			
	50	52	54	80	50	52	54	80
174	1.49	1.46	1.44	1.14	2.48	2.42	2.36	1.58
175	1.50	1.48	1.45	1.15	2.50	2.44	2.38	1.60
178	1.54	1.51	1.49	1.19	2.54	2.48	2.42	1.64
179	1.55	1.52	1.50	1.20	2.55	2.49	2.43	1.65
179	1.55	1.52	1.50	1.20	2.55	2.49	2.43	1.65
188	1.66	1.63	1.61	1.31	2.66	2.60	2.54	1.76
248	2.42	2.40	2.38	2.12	3.38	3.32	3.26	2.48
252	2.48	2.46	2.44	2.17	3.52	3.46	3.40	2.62
253	2.49	2.47	2.45	2.19	3.52	3.46	3.41	2.64
255	2.52	2.50	2.48	2.21	3.54	3.48	3.42	2.66
256	2.53	2.51	2.49	2.22	3.55	3.49	3.43	2.67

258	2.56	2.54	2.52	2.25	3.56	3.51	3.45	2.70
281	2.90	2.87	2.85	2.54	3.76	3.71	3.65	2.95
282	2.91	2.89	2.86	2.55	3.77	3.72	3.66	2.96
287	2.99	2.97	2.94	2.62	3.82	3.77	3.71	3.00
290	3.04	3.02	2.99	2.67	3.85	3.79	3.74	3.02
291	3.06	3.03	3.01	2.68	3.86	3.80	3.75	3.03
294	3.10	3.08	3.05	2.72	3.89	3.83	3.78	3.05

The thermoelectric performance in table 4.14 is the thermoelectric performance of each thermoelectric heat side temperature corresponding to the exhaust gas temperature. Thermoelectric cold side temperature is not uniform, then interpolation is done from table 4.14 to get the voltage and current that will be generated by the thermolelctric generator. The interpolation results from table 4.14 as in table 4.15 below.

Table 4.15 Thermoelectric Generator Voltage and Current Per Load for Finned and Finless Pipe

Power Rate	Temperature HS (K)		Temperature CS (K)		Volatge (V)		Current (A)	
	Finless	Finned	Finless	Finned	Finless	Finned	Finless	Finned
100	461	531	323	325	1.66	2.54	2.66	3.51
90	452	528	323	325	1.55	2.50	2.55	3.48
80	447	521	323	325	1.49	2.40	2.48	3.32
70	448	525	323	325	1.50	2.46	2.50	3.46
60	451	526	323	325	1.54	2.47	2.54	3.46
50	452	529	323	325	1.55	2.51	2.55	3.49

From table 4.15 we can know the current and voltage can be done to calculate the output power from thermoelectric. The output power per thermoelectric per keeping is as the following figure 4.15 below

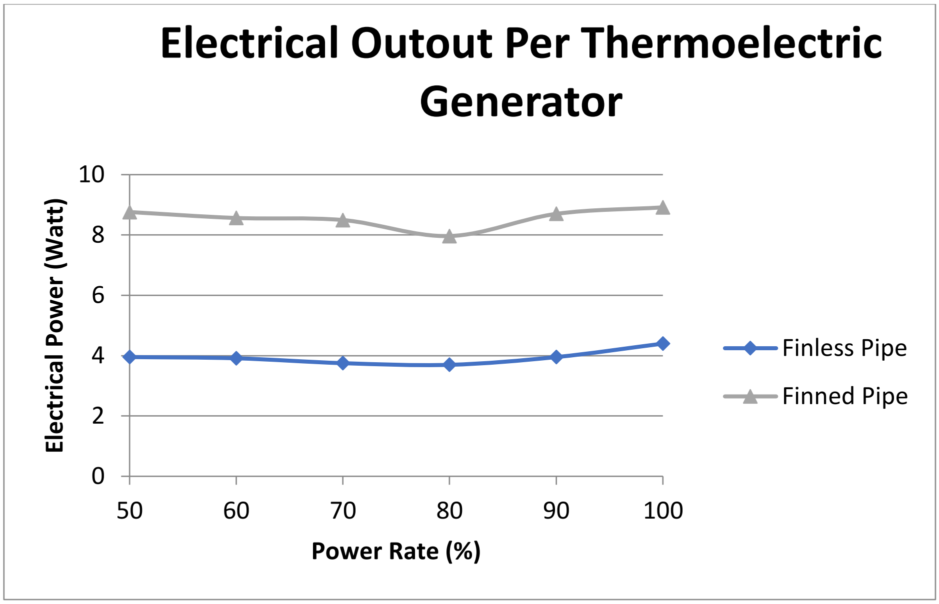

Figure 4.14 TEG output power per 1 chip Graph

From the table above, thermoelectric generator which stick on outer wall of finned pipe produced more electricity than finless pipe, where the most optimal condition is when engine run in 100% power rate because it produce more electricity than any other power rate and the least optimal state is when engine run in 80%.

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CHAPTER V
CONCLUSIONS AND SUGGESTIONS

5.1 Conclusions

From the results of data analysis of simulation results and mathematical calculations, the conclusions that can be drawn from this final project research are as follows:

1. The addition of fins to the exhaust gas pipe can improve thermal performance for the main engine waste heat recovery system because when it absorbed more heat than finless pipe, when engine operate on 100% power rate, the outer wall temperature is 541 K, 538 K at 90%, 527 K at 80%, 531 K at 70%, 534 K at 60% and 539 K at 50%. On the other hand, the outer wall pipe temperauter of finless pipe at 100% engine power rate is 459 K, 457 K at 90%, 452 K at 80%, 453 K at 70%, 451 K at 60% and 458 K at 50%.

2. The addition of fins also affects changes in exhaust gas pressure that can create backpressure. This is the drawback of finned pipe design because if the value of backpressure is exceeding the limit of backpressure of the main engine, it can damage the engine. In this research, the engine that is used is Mak 8 M 25 C which has 0,03 bar for backpressure limitation.The backpressure of both finned pipe and finless pipe has been lower than the limitation, with finned pipe has backpressure of 1.9 bar, meanwhile finless pipe has backpressure of 0.18 bar.

3. Finned pipe absored more heat from exhaust gas than finless pipe, which means the thermoelectric generator will produce more electricity if the TEG sticked on finned pipe rather than finless pipe. At 100% engine power rate in finless pipe, the TEG create 4.40 W, 3.95 W at 90%, 3.70% at 80%, 3.75 W at 79%, 3,91 W at 60% and 3,95 W at 50%. At finned pipe at 100% engine power rate, the TEG create 8.92 W, 8.7 W at 90%, 7.97 W at 80%, 8.5 W at 70%, 8.56 W at 60% and 8.76 W at 50%.

4. The most optimal condition is when engine run in 100% power rate because it produce more electricity than any other power rate which is 8.92 W for finned pipe at 100% meanwhile the least optimal state is when engine run in 80%, because it just create 7,97 W

5.2 Suggestions

To perfect this research, the author have several suggestions, imcluding :

1. It is necessary to do experimental about this research to know the real results and concrete evidence from the simulation
2. It is necessary to do economical analysis to see the price of making finned pipes, to be used as one of the considerations in making finned pipes

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ATTACHMENT

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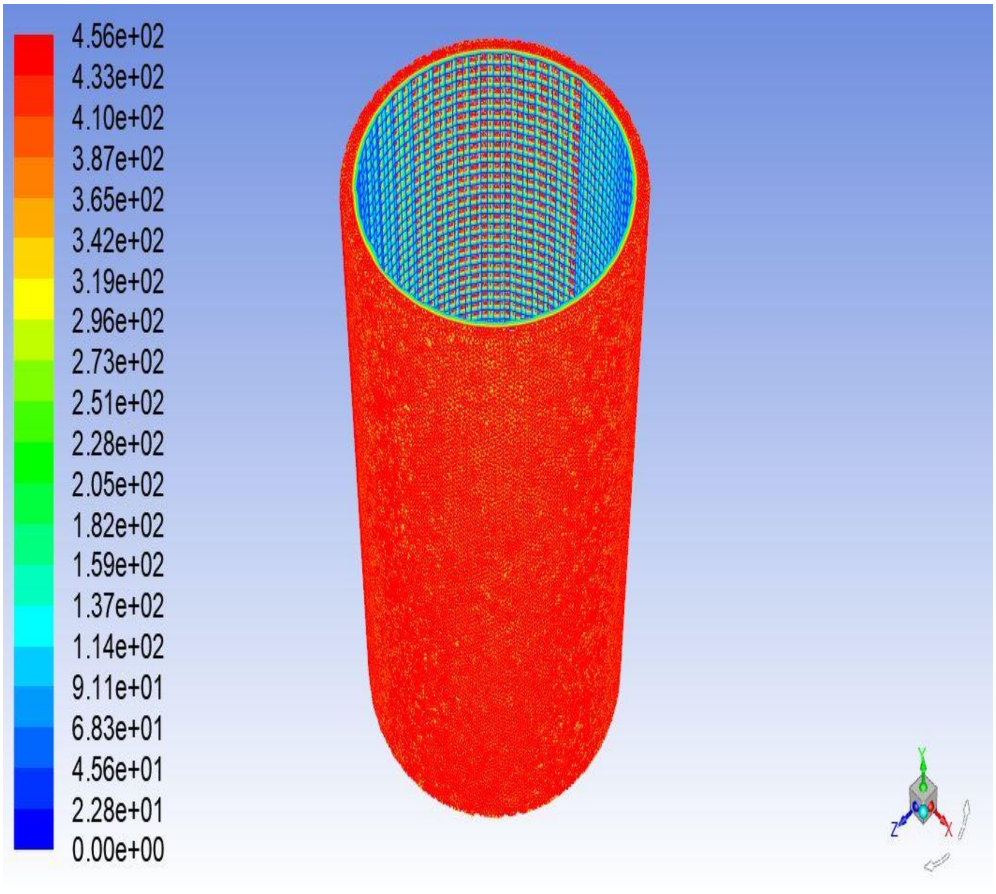
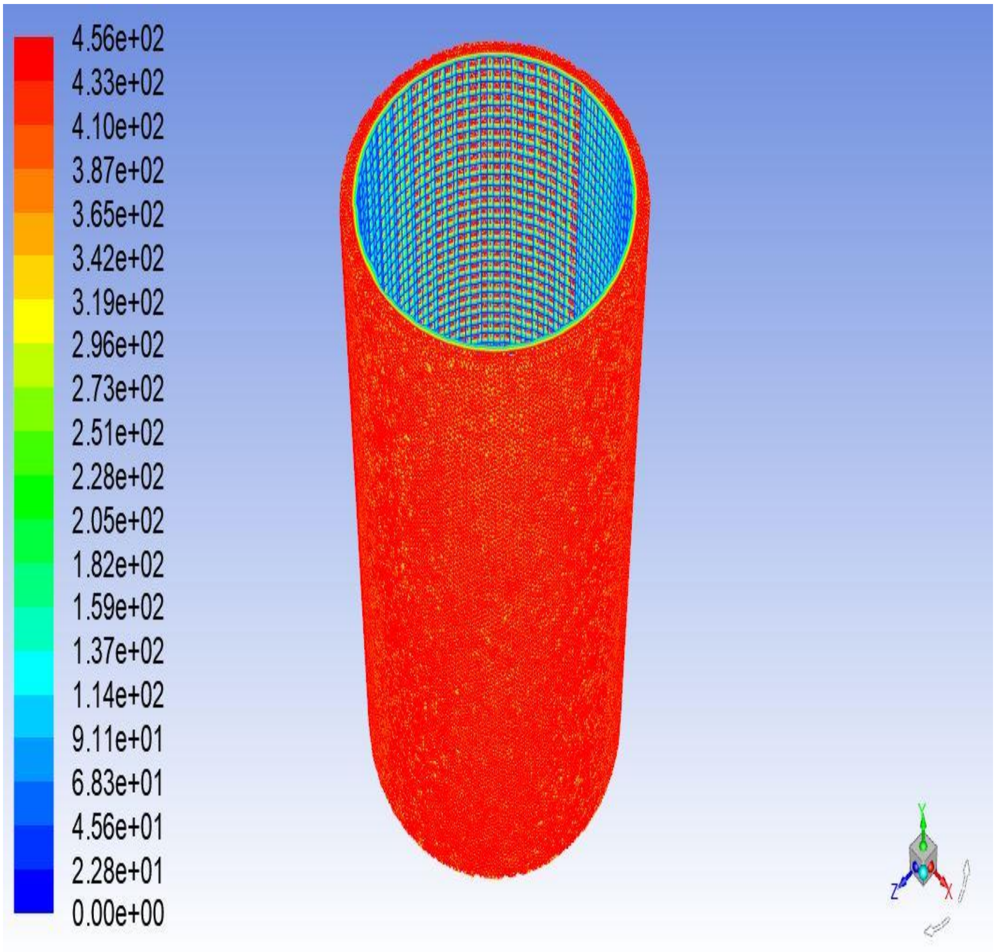
ATTACHMENT 1 : Finless Pipes Ansys Simulation

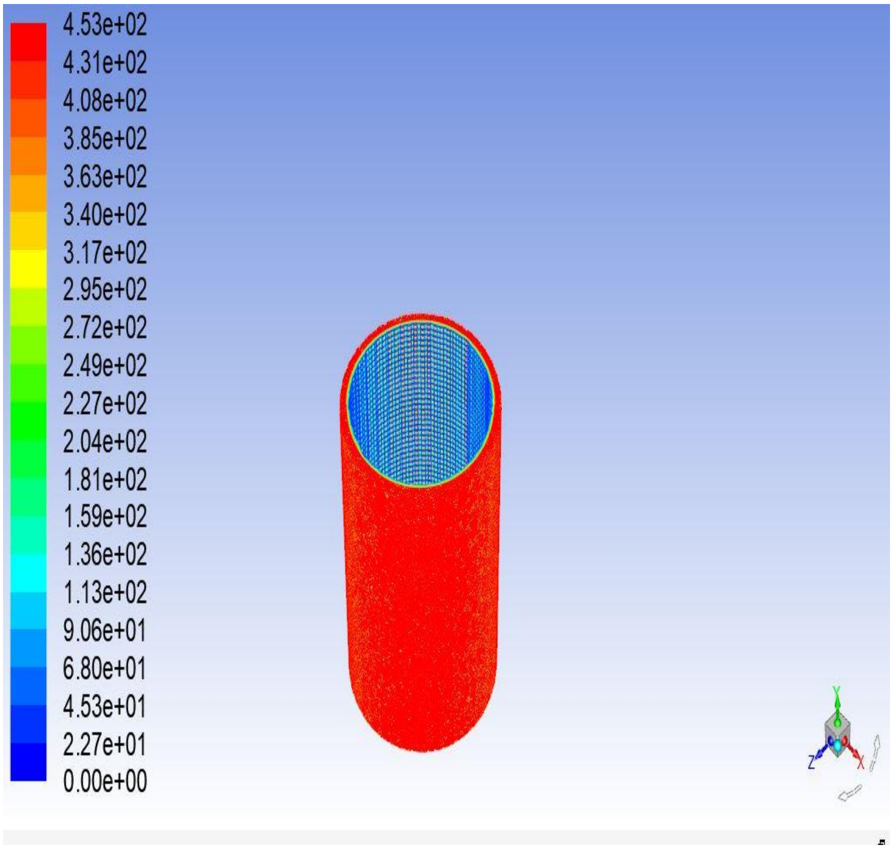
1. Finless 50 % engine rate ansys simulation



2. Finless 60 % engine rate ansys simulation



3. Finless 70 % engine rate ansys simulation



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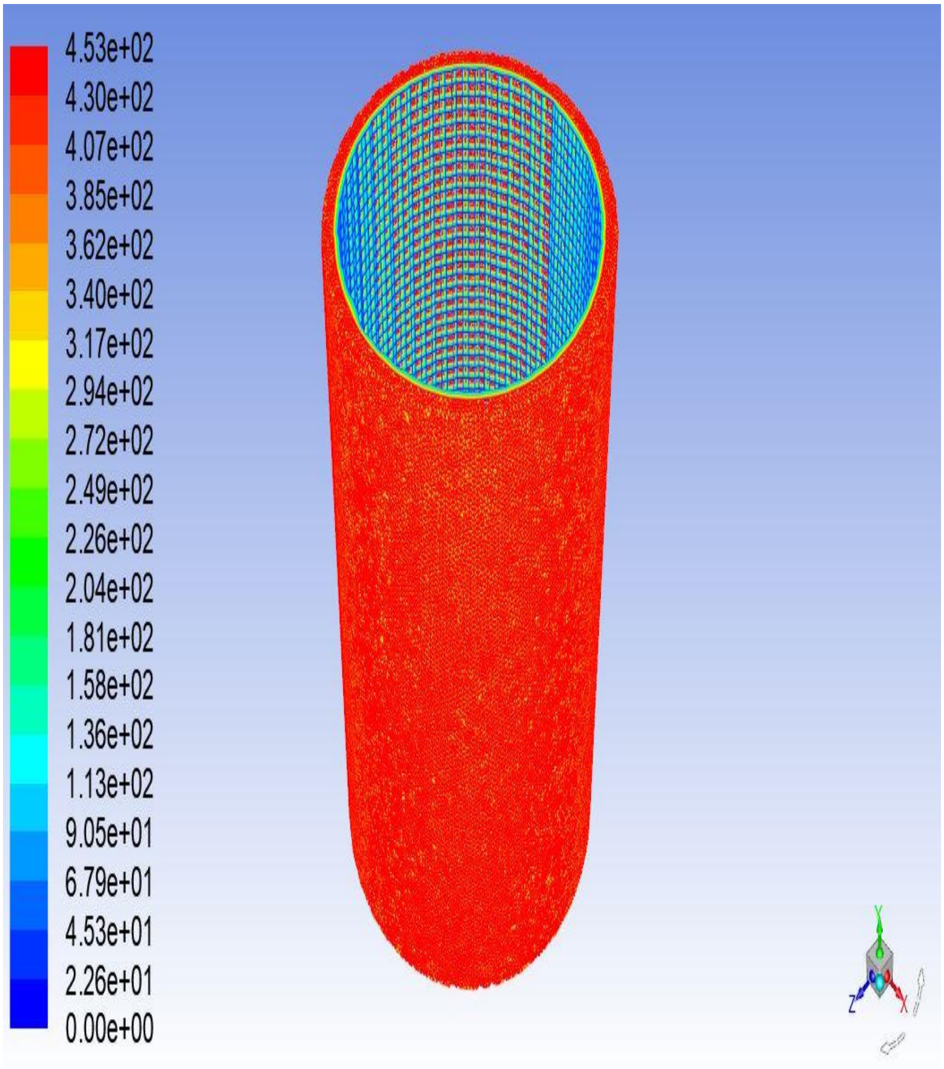
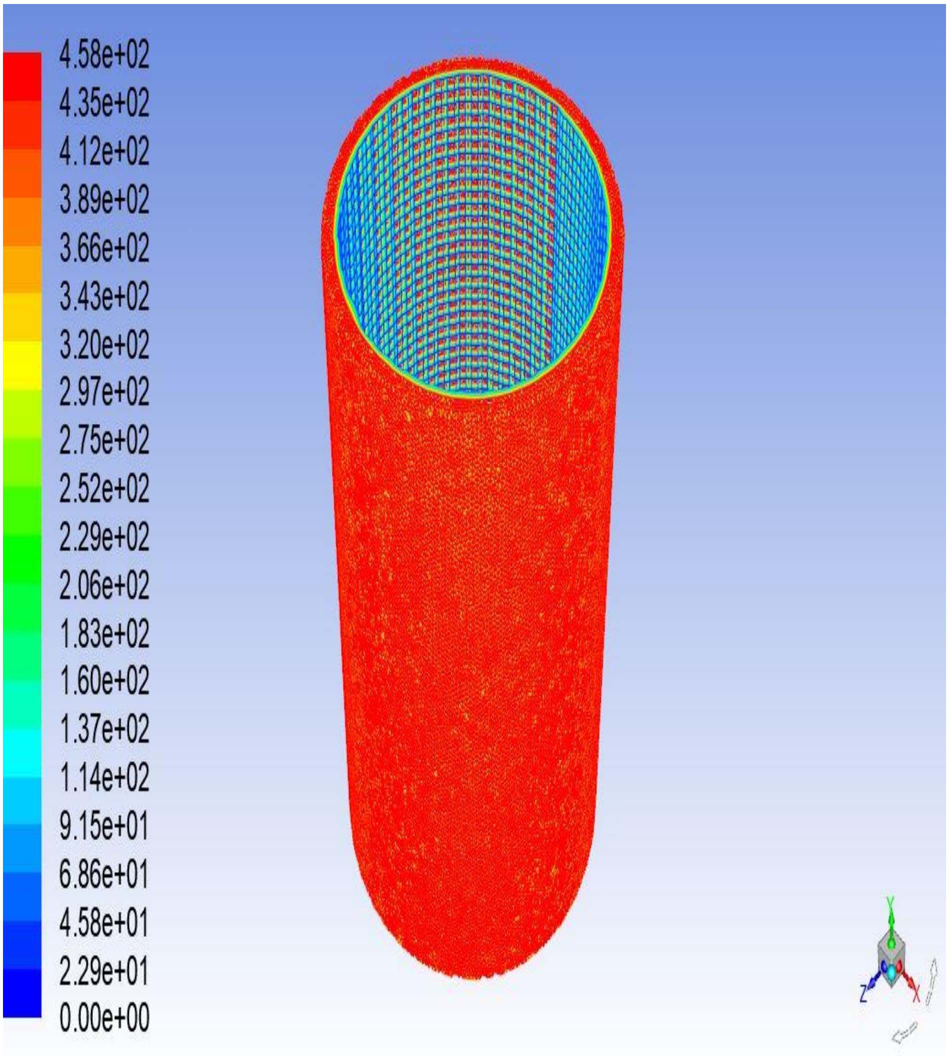
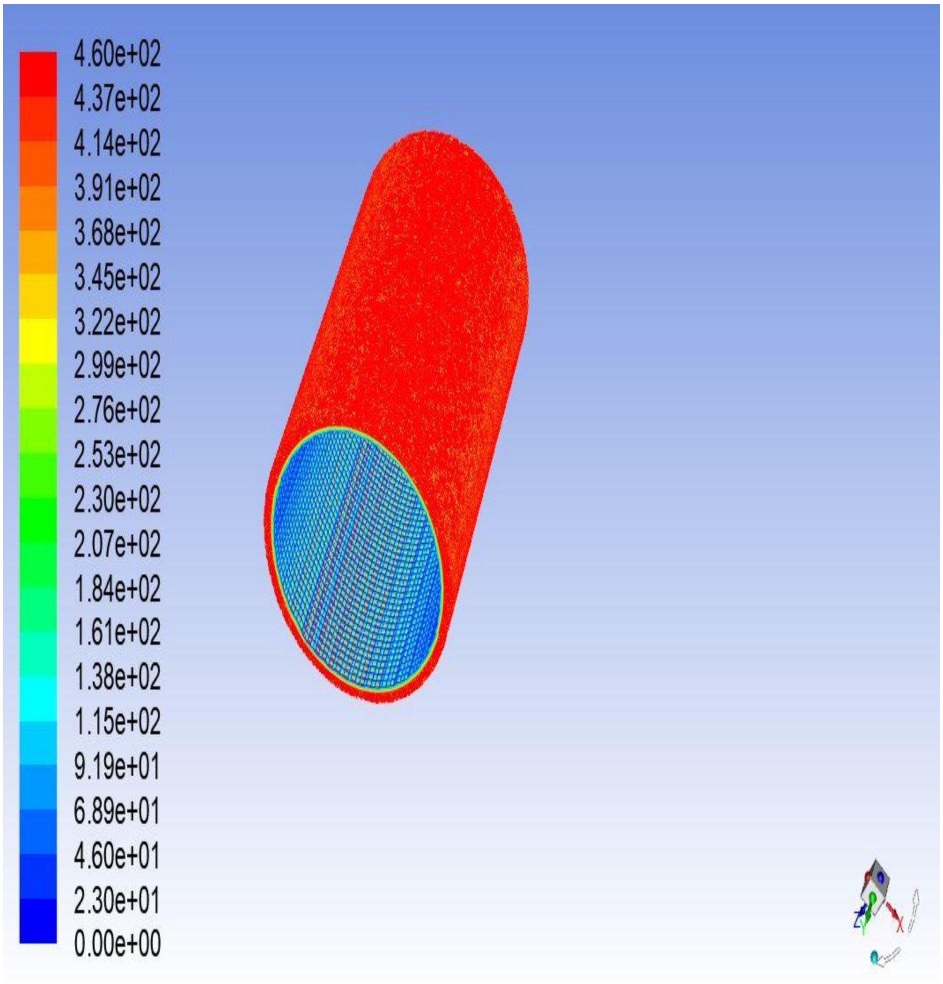


5. Finless 90 % engine rate ansys simulation



6. Finless 100 % engine rate ansys simulation



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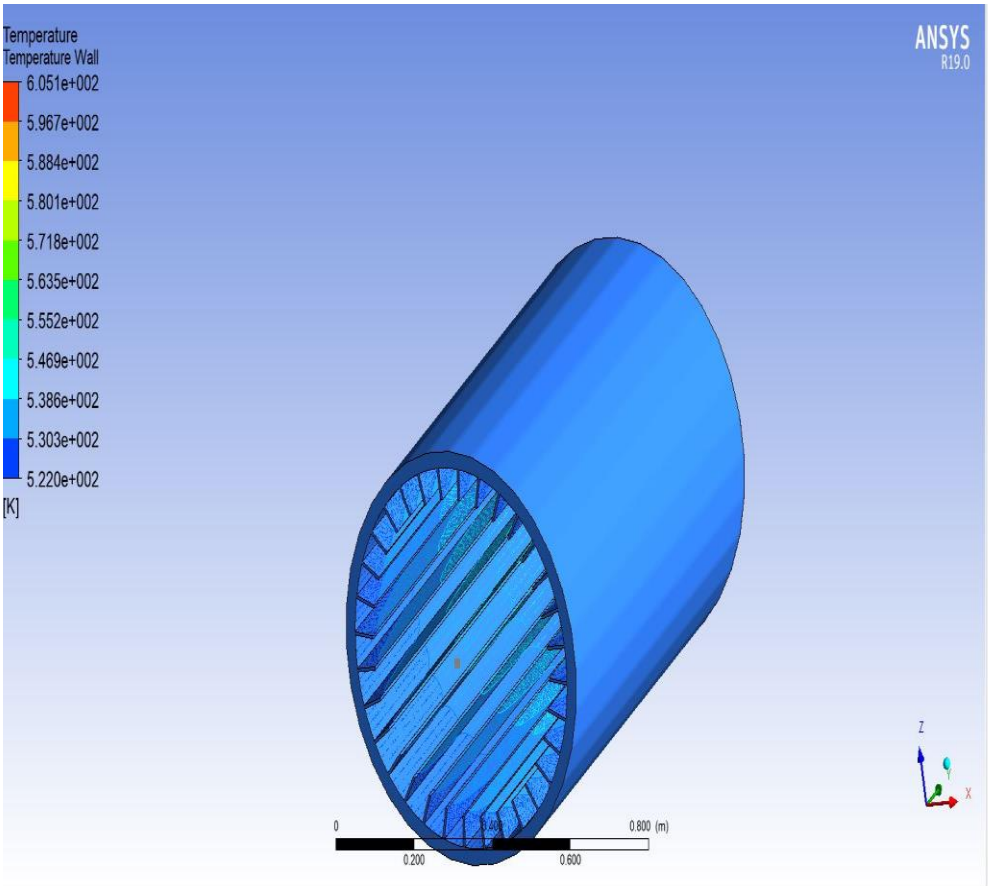
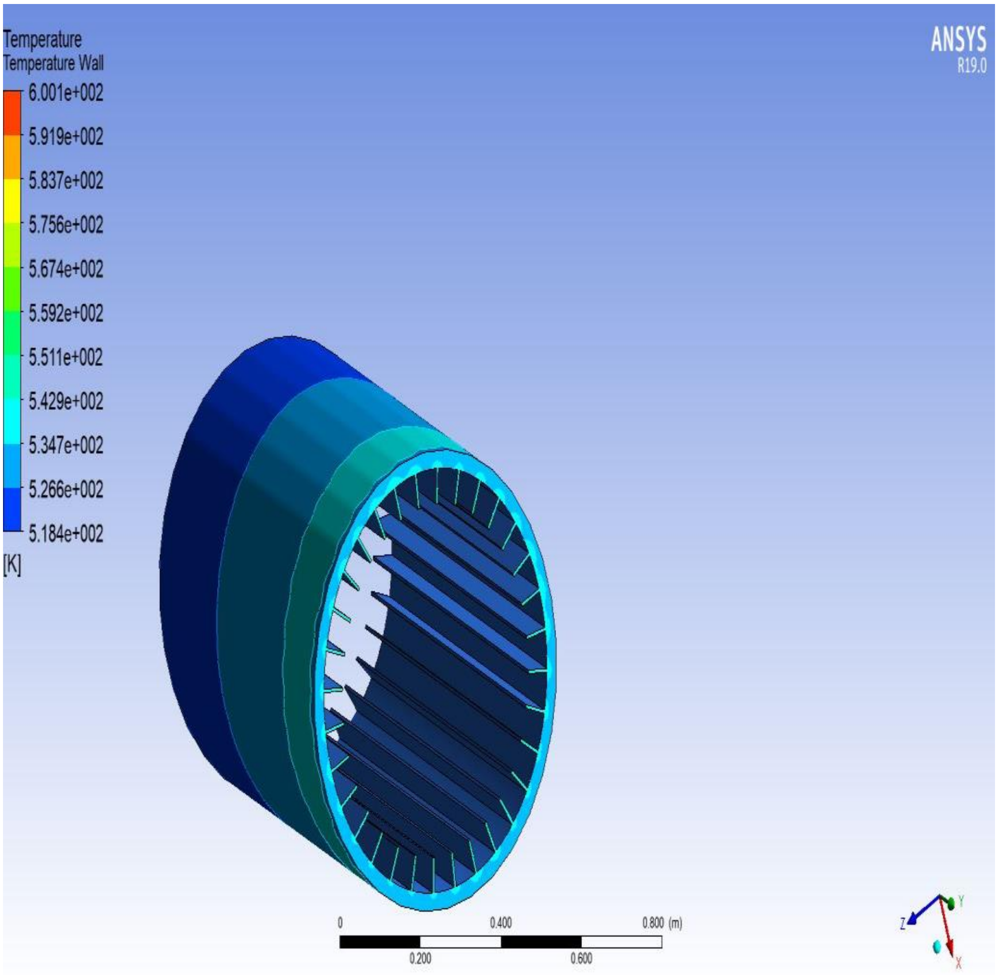
ATTACHMANT 2 : Finned Pipes Ansys Simulation

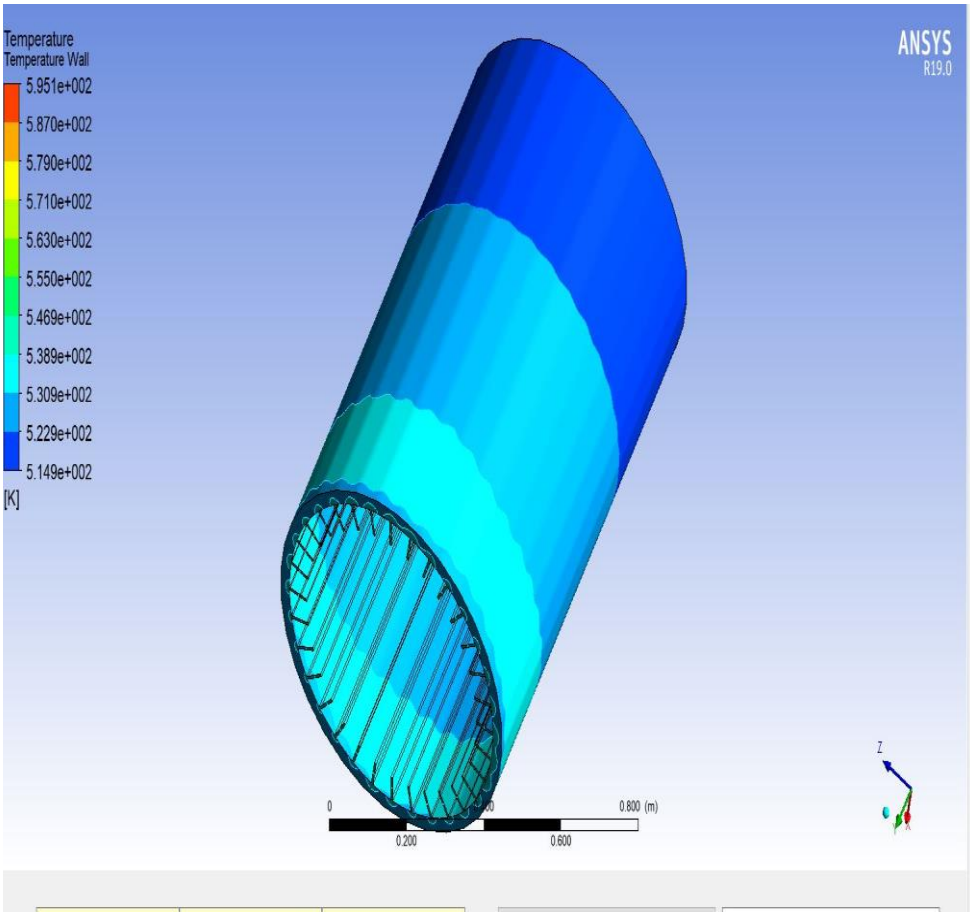
1. Finned 50 % engine rate ansys simulation



2. Finned 60 % engine rate ansys simulation



3. Finned 70 % engine rate ansys simulation



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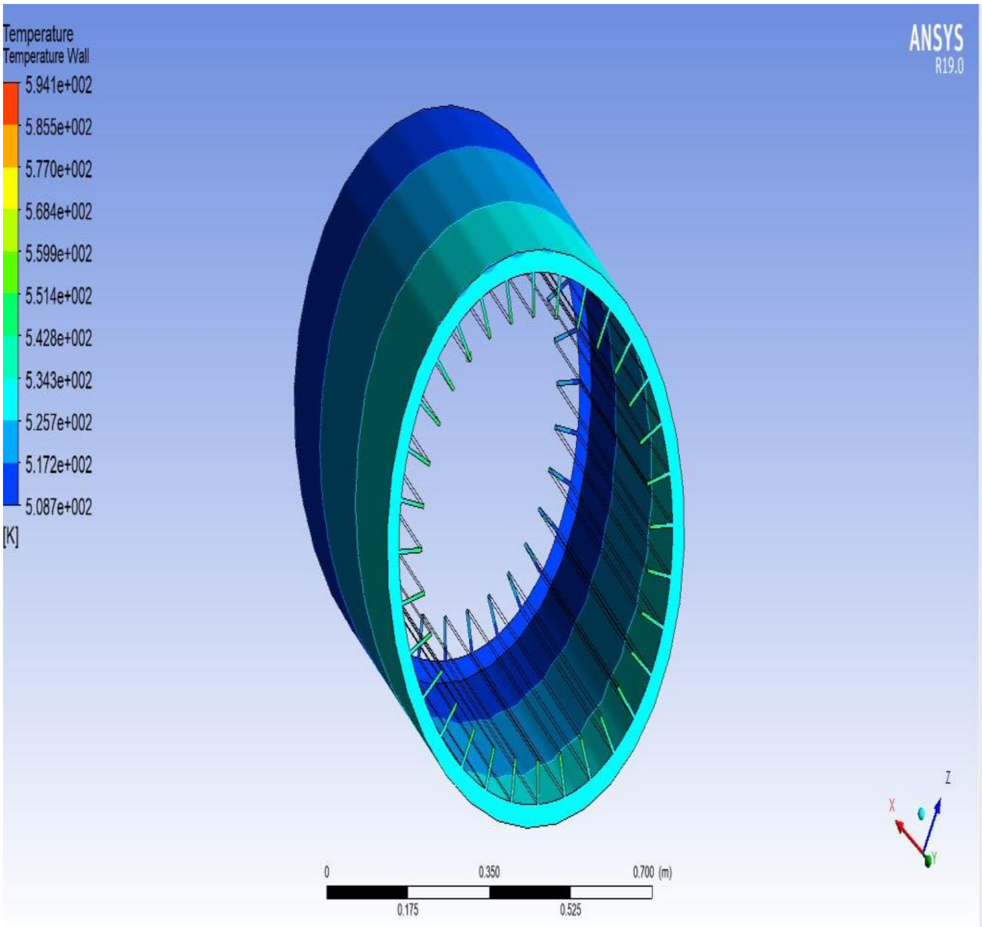

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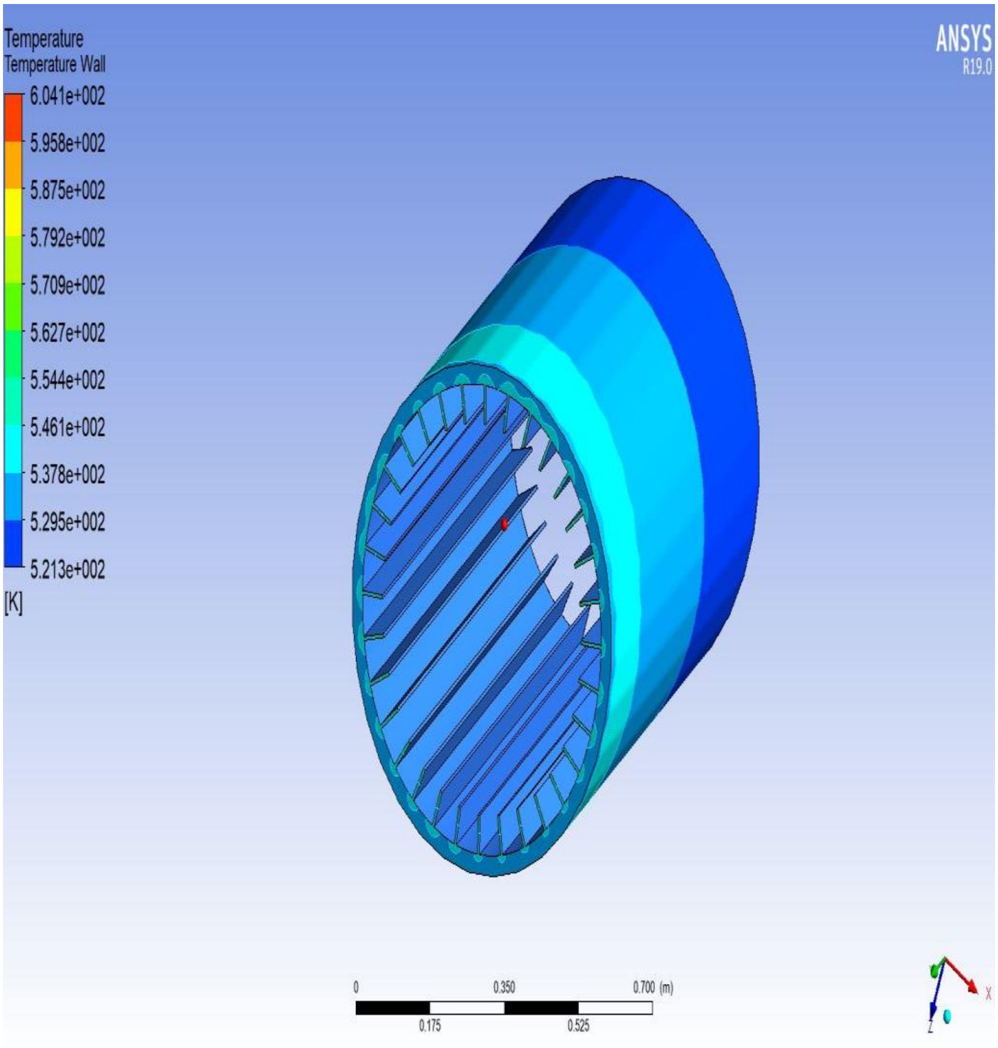

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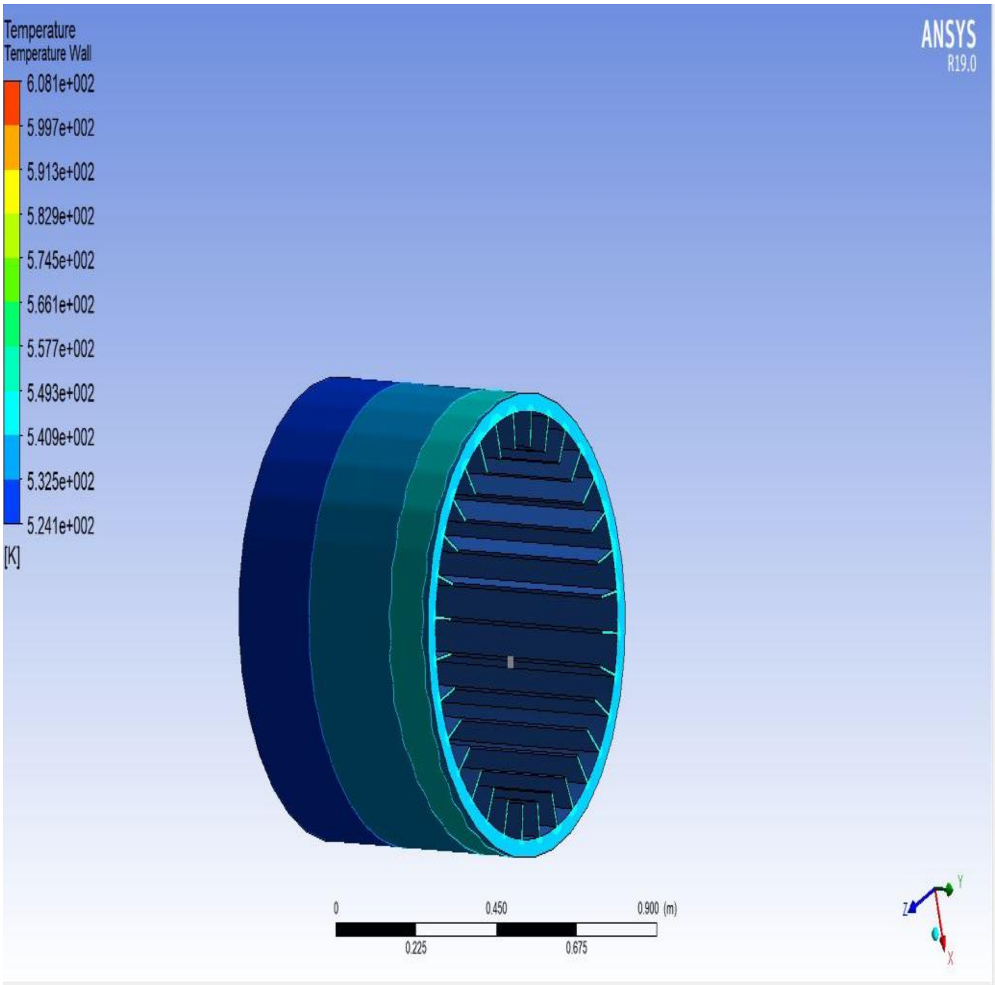

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