WASTE HEAT RECOVERY FROM EXHAUST GAS USING STEAM TURBINE MECHANISM

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This report is submitted
in fulfillment of the requirement for the degree of
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DECLARATION

I declared that this project entitled “Waste Heat Recovery from Exhaust Gas Using Steam Turbine Mechanism” is the result of my own work except as cited in the references

Signature :.....

Name :.....

Date :.....

APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Thermal-Fluid)

Signature :.....
Name of Supervisor :.....
Date :.....

DEDICATION

To my beloved

Father and Mother

Pakhrazi Bin Ishak

&

Ume Khalsom Binti Salleh

ABSTRACT

Nowadays, Internal Combustion Engine (ICE) is used in most vehicles around the world as their system. ICE is one of the most inefficient systems for vehicles because most of the energy burned from the fuel is wasted to heat, mechanical and other losses. Either realizes or not, only 15 percent of the energy from the fuel is used to move the vehicles or run useful accessories. To recover the energy losses, Waste Heat Recovery (WHR) mechanism can be used. The mechanism recycles the wasted energy from the vehicle into power as electric current. Exhaust system of the vehicle play the important role in this mechanism, where the power produce for this mechanism is used the wasted heat from the exhaust. The exhaust will cover with good insulator to prevent the heat produced loss to the surrounding. The current produced can be stored in the battery. The electric energy also can be used as the source of energy for the hybrid vehicles. This project is considering the performance of the vehicle when equipped with the WHR system and not the power produced and its storage.

ABSTRAK

Pada masa kini, Enjin Pembakaran Dalaman (EPD) digunakan dalam sistem kebanyakan kenderaan di seluruh dunia. Enjin Pembakaran Dalaman (EPD) adalah salah satu sistem yang paling efisyen untuk kenderaan kerana pembaziran terhadap sebahagian besar tenaga yang dibakar dari bahan api kepada haba, mekanikal dan pembaziran lain. Sama ada sedar atau tidak, hanya 15 peratus daripada tenaga daripada bahan api yang digunakan untuk menggerakkan kenderaan atau aksesori digunakan. Untuk memulihkan pembaziran tenaga tersebut, mekanisme Waste Heat Recovery (WHR) boleh digunakan. Mekanisme ini mengitar semula tenaga yang terbazir dari kenderaan ke dalam kuasa sebagai arus elektrik. Sistem ekzos kenderaan memainkan peranan yang penting dalam mekanisme ini, di mana hasil kuasa untuk mekanisme ini menggunakan haba yang terbazir dari ekzos. Ekzos akan ditutup dengan penebat yang baik untuk mengelakkan haba yang dihasilkan terbazir kepada sekitarnya. Aliran elektrik yang dihasilkan boleh disimpan di dalam bateri. Tenaga elektrik juga boleh digunakan sebagai sumber tenaga untuk kenderaan hibrid. Projek ini sedang mempertimbangkan prestasi kenderaan apabila dilengkapi dengan sistem WHR dan tidak menumpukan kepada kuasa yang dihasilkan dan penyimpanan.

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LIST OF ABBEREVATIONS

CCPP	Combination Cycle Power Plant
ABC	Air Bottoming Cycle
EMF	Electromotive Force
WHRM	Waste Heat Recovery Mechanism
ICE	Internal Combustion Engine
PM	Permanent Magnet

CHAPTER 1

INTRODUCTION

1.1 Background

Every combustion engine has their excessive output called as exhaust gas. Exhaust gas produced after the engine completing one cycle of combustion process. Usually, this gas will be released directly to the environment. This type of gas has high temperature that can be reused as an input to generate electricity. This process called as Waste Heat Recovery which is in this process, the waste heat from the exhaust gas is used to spin a turbine and rotate the generator to produce electric energy output as the result. There are three main components used to create this recovery system. Those are heat exchanger, gas turbine and generator.

Heat exchanger is a device used for transferring thermal energy between two or more working fluids which is transfer heat from one flow of medium without any physical contact or mixing the two media. (Kim et al., 2009). Normally, heat exchanger related to two different temperature of streams which are hot stream and cold stream. There usually no external heat and work interactions in heat exchanger. Basic applications of heat exchanger involve heating or cooling of a fluid stream. For instance, steam generator, feed water heater, reheaters and condensers are all examples of heat exchangers found in our industry. (Reay, D. A., 1999).

Gas turbine is one of the basic technologies used to produce electricity. Gas turbine also have a lot of advantages such as fast start up turbine, high efficiency, low pollutants emissions, and have a reasonable size. The gas turbine is combination of cycle power plant (CCPP). There are two means in cycle power plant (CCPP) which area air bottoming cycle (ABC) and recuperator. Recuperator used to utilizes the heat of exhaust gases of topping cycle to heat the compressed air that delivered from compressor of ABC. (O Bolland, M Forde, B. Hande, 1996). This concept of gas turbine has been well established by the 1970s. In such a cycle, the hot exhaust gases from the gas turbine are passed through the HRSG where they produce superheated steam in a bottoming cycle to produce power output. (J. H. Horlock, 1995). Normally,

the exhaust stream temperature of open cycle gas is around 500 ºC. So that, this system is very suitable for heat recovery application to improve cycle efficiency.

Generator is a system that induces a voltage between the loop terminals by spinning a wire loop within a uniform magnetic field in a convenient fashion. The induced voltage influenced by the rotation speed. The higher the rotation, the higher the voltage induced. Generator can produce an electrical load with the desired type of current which are Direct Current (DC) and Alternating Current (AC). For DC generator is called as dynamos while AC generator called as alternator. The basic generator only can produce Alternating Current (AC). To convert into Direct Current (DC), it must have a device working as a mechanical rectifier that used as the collector. (Chapman, Stephen J, 1985). Figure 1 shows the example of a few type of generator.

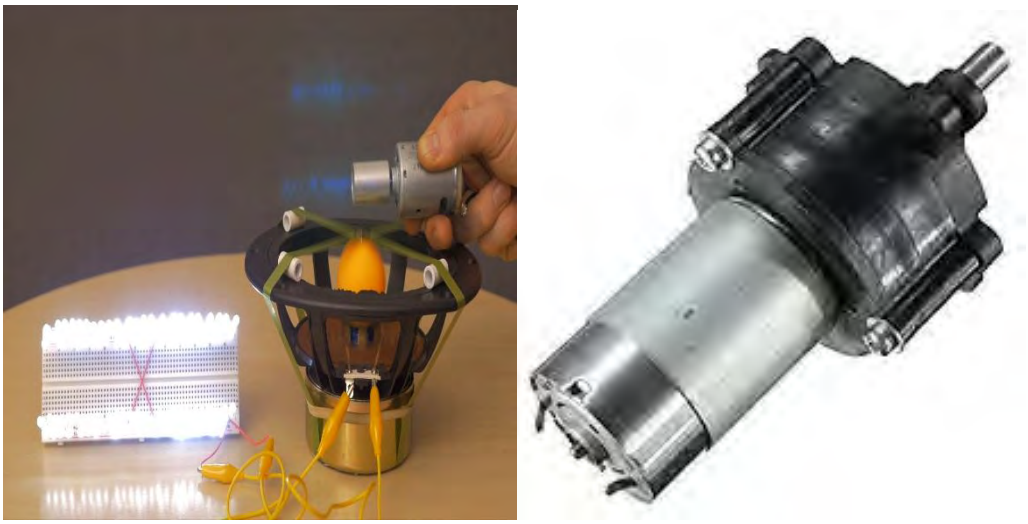


Figure 1 Two type of generator with different power input

1.2 Problem Statement

Free energy concept can be described when the energy can be generated by electromagnetic force of magnet when using any input from free waste source. The definition of free energy is not the same as natural free energy source such as solar, wind, hydro or geothermal energies. This is because these electromagnetic force machine requires some input energy to produce an increased output, which the natural source do not require. Some electromagnetic machine can produce an output only slightly above unity, while others have produced output about three to one. But lately, there are a lot of inventors that created the electromagnetic machine with the output of the machine produced until about five to one.

This project will be conduct to determine the amount of the output power can be generated from the waste heat from exhaust gas by using the steam turbine generator. A steam turbine generator will be installed near the exhaust manifold of a project car to generate electricity energy output. The generator used the excessive waste heat from the exhaust as the input to spin the turbine and rotate the generator. Since, the current generator is not efficient enough to generate the electricity energy, so this project will continue to make the improvement on the generator to increase the output energy to achieve target which is can produce current more than 3.5 A and voltage more than 24 V at normal driving in rural environment.

1.3 Objective

The objectives of this project are as follows:

1. To study and determine the best design for the steam turbine generator to increase the efficiency of the generator.
2. To study the relationship between the number of coil turn, the diameter of the turn, and the diameter of the coil with the efficiency of the generator.
3. To fabricate the generator with high efficiency.
4. To improve the amount of the output voltage that can generated from generator.

1.4 Scope of Project

The scopes of this project are:

1. Study on the application of electromagnetic force and how to produce a high power output.
2. There are few type of design will be used to create the generator in order to increase the power output of the generator.
3. Power input and type of turbine will be fix during this project to measure the efficiency of the generator.

1.5 General Methodology

The actions that need to be carried out to achieve the objectives in this project are listed below:

1. Literature review

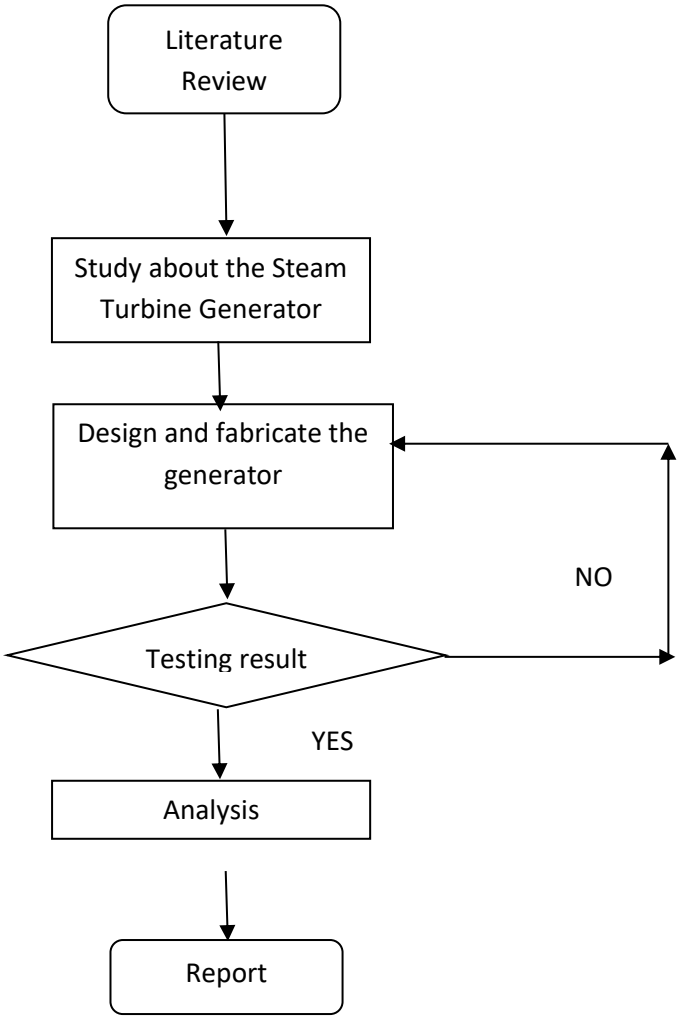
   Journal, articles, web or any material regarding this project will be reviewed.
2. Experimental

   Experiment will be conducted to collect the data regarding the output power generated from the steam turbine generator.
3. Analysis

   Analysis will be carry on to improve the output power of the steam turbine generator.
4. Report writing

   A report writing for this project will be written at the end of this project.

The methodology of this study is summarized in the flow chart as shown below.



CHAPTER 2

LITERATURE REVIEW

2.1 Review of Thermodynamics

Steam control era has reliably been founded on the Rankine cycle or its adjustment. Be that as it may, with a specific end goal to completely comprehend its working standards, it is helpful to present the Carnot cycle to begin with, since it represents the beginning stage for all the accompanying investigations (Capano, 2014).

2.1.1 Carnot Cycle

Nicolas Sadi Carnot (1769-1832), a French military designer, the individual that capable to present the idea of thermodynamics. The fundamental reason for the idea is to decide the framework which could work at greatest efficiency by utilizing heat at constant temperature that have four change stage, two isothermal and two adiabatic.

Figure 2.1 that shows the cycle on a T-s diagram, the transformations that take place are:

1→2: Reversible adiabatic compression (isentropic). Work is done on the fluid.

2→3: Constant temperature evaporation. The working fluid receives heat from an external source.

3→4: Reversible adiabatic expansion (isentropic). The working fluid generates useful work.

4→1: Constant pressure and temperature condensation. The fluid is giving off heat to the environment and returns to the initial conditions.

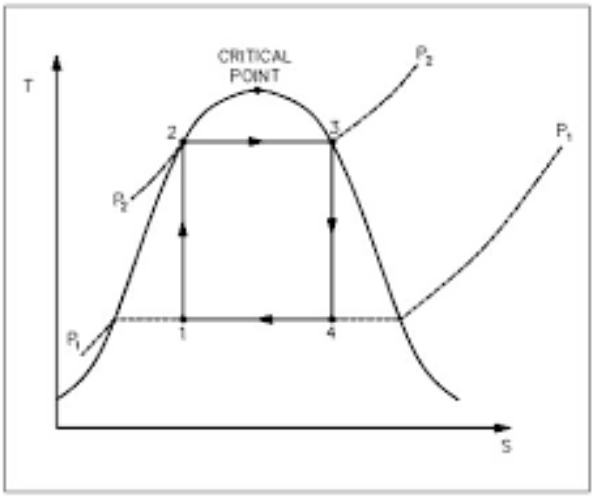


Figure 2 Carnot cycle on T-s diagram

(Gianmarco Capano, 2014)

Carnot cycle efficiency can be acquired from the highest cycle that can be accomplished by whatever other cycle that working inside the same range of temperature, additionally characterized as:

$$\eta_{carnot} = \frac{Q\,23 - Q\,41}{Q23} = 1 - \frac{Q\,41}{Q23} = 1 + \frac{T-}{T+} \qquad (2.1)$$

Where;

- $T+ = T_2 = T_3$ is maximum temperature approached by the fluid to the vaporization temperature
- $T- = T_4 = T_1$ is minimum temperature (condensation temperature)

It has been doable to form the last simplification as a result of heat is changed at constant temperature. This expression provides rise to a crucial consideration: even there is no irreversibility within the cycle, the efficiency cannot be equal to 100% unless the low temperature source was at 0K, but, the condition never possible.

Nevertheless, the practicality of Carnot cycle is very difficult because of the problem of elimination of irreversibility in actual process and also difficulties in expanding and compressing partially wet vapor in purely mechanical view. Despite of

its thermodynamics advantages, Carnot cycle is not used in any application (Capano, 2014)

2.1.2 Rankine Cycle

Rankine cycle is named from the name of William John Macquorn Rankine (1820-1872), the person who founding contributors to the science of thermodynamics. Rankine cycle represents a practical modification of the Carnot cycle that also known as standard vapor cycle. This cycle used to overcome the limitations in Carnot cycles such as the reversibility. Figure 2.1.2 and Figure 2.1.3 shows the visual representation of Rankine cycle diagram which are T-s and P-h Diagram (Capano, 2014; Condle, 2012).

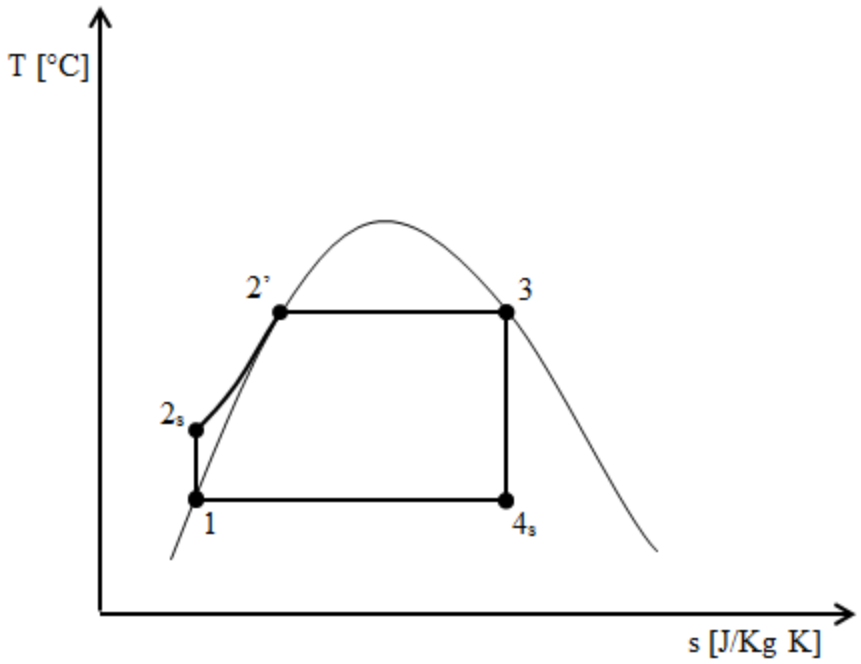


Figure 3 T-s Diagram for Rankine Cycle

(Capano, 2014; Condle, 2012)

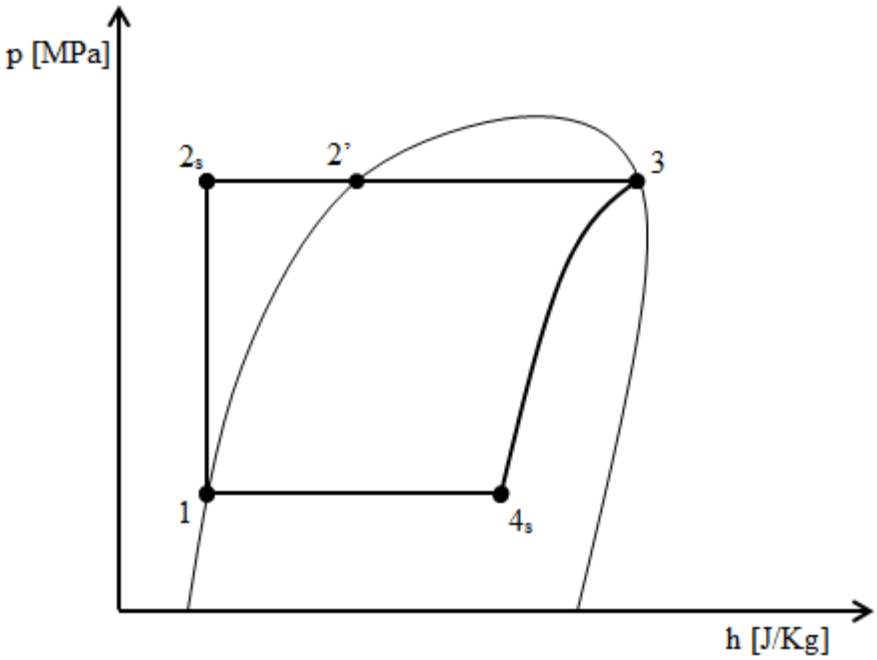


Figure 4 : P-h Diagram for Rankine Cycle

(Capano, 2014; Condle, 2012)

Based on those two figure above, there are a few transformations of the fluid occurred. The processes of the transformations are described below:

1-2 : Isentropic transformations where the low pressure and temperature saturated liquid is compressed up to become high pressure. The work per unit mass required by the pump is equal to the enthalpy difference between point 1 and point 2s;

$$w_{pump} = w_{12s} = \frac{P1-P2s}{P1} = (h_1 - h_2)$$

2s-2 : The high pressure sub-cooled liquid is heated up until it reaches the saturation curve, point 2" at constant pressure,

2'-3 : The constants temperature and pressure liquid is vaporized where the heat per unit mass is absorbed by the flowing fluid between state 3 and state 2s.

3-4s : Isentropic expansion. The high pressure saturated vapor become low pressure.

4s-1 : Condensation process occurred, thus the low pressure vapor turns to its initial condition where the pressure and temperature become constant.

2.2 Waste Heat Recovery in Automotive Industry

For decade, the usage of fossil fuel has been increase continuously by the human activity especially in the production industry. This activity has caused a lot of negative effects to the environment such as global warming, ozone depletion, atmospheric pollution and many more. In order to reduce this side effect and keep our environment health, energy saving activity should be implemented and the best way is introducing new energy conversion technologies. With this kind of technologies, power can be generated without any negative side effect to the nature that already polluted (Capano, 2014).

It One of the larger fossil fuel consumer come from the vehicle that use internal combustion engine (ICE) (Jadhao & Thombare, 2008). ICE also one of the main cause of the increasing of carbon dioxide (CO_2) which can lead to the greenhouse effect and the global climate change associated to this phenomenon. Figure 2.2 shows the average number of CO_2 produced by the vehicle from a few automakers (Capano, 2014; Jadhao & Thombare, 2008).

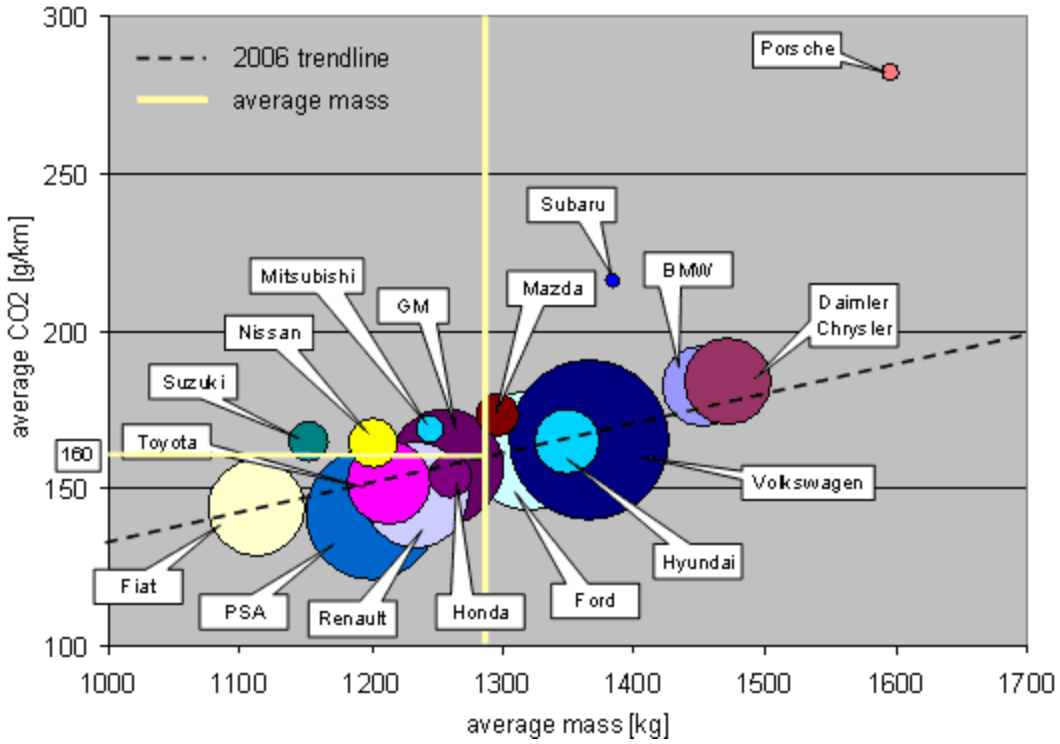


Figure 5 Average CO2 emissions of main car manufacturer in Europe (2006) (Capano, 2014).

In ICE, it is only about 30 to 40% from the fuel usage is converted to the mechanical energy, while others are expelled to the environment through the exhaust gases and engine cooling system (Jadhao & Thombare, 2008). The estimation of the fuel energy wasted through the exhaust is about 21% at the average speed range and the rest is lost in the cooling system (Herawan, Rohhaizan, Ismail, & Shamsudin, 2015). As the energy conversion technologies has been introduced in order to reduce the consumption of fossil fuel and conserved the earth from the pollution and other negative effects, this idea can be implemented in ICE system by utilize the wasted heat energy from the exhaust through the heat recovery system. By developing the heat recovery system, the fuel consumption can be decreased, improve the efficiency and also reduce the greenhouse effect to the environment.

The recent technologies on waste heat recovery of ICE vehicle is consist of low grade heat from cooling system and high grade heat from the exhaust system (Herawan et al., 2015). The low grade heat from the cooling system is not a good choice for the waste heat recovery because of the output temperature is very low, thus it is difficult to harvest. Since the high grade heat from the exhaust system has a very high temperature, it has a larger potential for waste heat recovery and will be the right choice (Ahmad & Amin, 2017). This waste heat recovery has been proved that not only improve the fuel consumption, but also increase the power output of the engine (power density) which was predicted that there is about 10% fuel consumption can reduced, if 6% of the waste heat from the exhaust successfully converted into electrical energy (Capano, 2014).

2.3 Steam Turbine Generator

Many researchers have been studied about the energy saving technologies through Waste Heat Recovery Mechanism (WHRM) from ICE exhaust. There are a lot of applications that can be applied to recover the waste heat energy such as thermoelectric generator, turbocharger, turbo-compound, steam turbine generator and many more (Capano, 2014; Herawan et al., 2015). The previous analysis state that evaporator pressure give better efficiencies compare to others. From those applications about the waste heat recovery, steam turbine generator would be the best application to be explored since the cost is less with the simple construction, while the fuel consumption improvement is also promising (Capano, 2014; Herawan et al., 2015).