THE PERFORMANCE OF STEAM ENGINE SYSTEM WITH RETROFITTED RECIPROCATING ENGINES

by

ZABEER ABHAR BIN ZAINAL ABIDEN

(Matrix no: 127204)

Supervisor:

Prof. Zainal Alimuddin Zainal Alauddin

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

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TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

ABSTRAK

Enjin stim adalah salah satu ciptaan awal manusia dalam teknologi penjanaan kuasa. Ia amat penting semasa revolusi Industri oleh kerana enjin stim yang digunakan dalam kapal, lokomotif dan juga dalam mesin pemanduan di kilang-kilang. Pada masa ini, tidak ada kewujudan enjin stim di pasaran dan ia biasanya direka sendiri dengan menggunakan mana-mana enjin yang tersedia. Projek ini dilakukan untuk mengenalpasti prestasi dua enjin yang tersedia dalam sistem enjin stim. Sistem enjin stim ini terdiri daripada 3 bahagian utama iaitu dandang, injap pengawal tekanan dan enjin stim. Dandang yang dikuasakan oleh cecair gas petroleum (LPG) adalah dandang tiub api menegak dengan kapasiti 7.5 liter dan boleh beroperasi sehingga 10 bar tekanan. Injap mengawal tekanan adalah Yoshitake GD-45P yang mempunyai suhu operasi maksimum 220 ℃ dan tekanan operasi maksimum 2MPa. Enjin stim yang digunakan adalah enjin 2-lejang dan enjin 4-lejang ditukar kepada 2-lejang. Prestasi sistem enjin wap ditentukan pada tiga kelajuan roda dengan variasi beban dan tekanan masuk di mana kelajuan roda dikekalkan. Dandang mempunyai kecekapan sebanyak 44.68% dan boleh membekalkan input kuasa kepada enjin sehingga 5kW. Oleh kerana kecekapan dandang dan kuasa yang dihasilkan oleh dandang agak rendah, enjin 4-lejang tidak sesuai untuk beroperasi dalam sistem ini. Walau bagaimanapun, untuk enjin 2-lejang, kuasa brek tertinggi, kuasa tertunjuk dan kuasa geseran adalah 4.01 W, 5.408 kW dan 5.405 kW. Penggunaan stim tertinggi adalah 4075.09 kg/kWh. Selain itu, kecekapan mekanikal tertinggi ialah 0.127% manakala penggunaan stim tertinggi ialah 4075.09 kg/kWh. Kecekapan keseluruhan yang agak rendah diperolehi untuk enjin 2-lejang dalam sistem ini iaitu 0.0523%.

ABSTRACT

Steam engines were one of the early human inventions in power generation technology. They were essential during the Industrial revolution as steam engines are used in ships, locomotives and also factories in driving machineries. At present, there are no available steam engines in the market and it is usually self-developed by using any engines that are available. This project is done to determine the performance of two engines that are available in a steam engine system. The steam engine system is composed of 3 main parts which are the boiler, pressure regulating valve and the steam engine. The boiler which is fueled by LPG is a vertical fire-tube boiler with a 7.5 liter capacity and can operate up to 10 bar of pressure. The pressure regulating valve is a Yoshitake GD-45P which has maximum operating temperature of 220℃ and maximum operating pressure of 2MPa. The steam engines are a 2-stroke engine and a 4-stroke converted 2-stroke engine. The performance of the steam engine system was determined at three different speeds of flywheel by the variation of load and inlet pressure where the speed of the flywheel is maintained. The boiler has the efficiency of 44.68% and can supply power input to the engine up to 5kW. Due to low efficiency and power generated by the boiler, the 4-stroke engine is not suitable to operate in this system. However, for the 2-stroke engine, the highest brake power, indicated power and friction power is 4.01 W, 5.408 kW and 5.405 kW respectively. The highest specific steam consumption is 4075.09 kg/kWh. Besides, the highest mechanical efficiency is 0.127% while the highest specific steam consumption is 4075.09 kg/kWh. A quite low overall efficiency is obtained for the 2-stroke engine in this system which is 0.0523%.

CHAPTER I
INTRODUCTION

In the early stages of technology, steam engine is very popular and has been used globally for power generation. Steam engines are an external combustion heat engine that uses the heat energy of steam and convert it to mechanical work. Steam engines were used as the prime mover in pumping stations, locomotives, steam ships and other road vehicles. When water is converted into steam, it expands and its volume increases about 1,600 times. The force produced by the conversion is the basis of all steam engines[1].

Savery engine, developed within 1695-1702 was the first steam engine invented. This engine suffered restricted height operation and high fuel consumption rate. In 1712, the Newcomen engine resolved the limited height operation. The Newcomen engines became widespread in mining activities. However, the deficiency was the high fuel consumption due to the need of cooling and heating the cylinder at each stroke and the irregularity of the movements which prevent it for directly rotary motion. In 1769, James Watt solved the problem of the high fuel consumption of the Newcomen engine [2] by ensuring the condensation is not occur in the cylinder thus no re-heating of the cylinder needed at each stroke.

They were essential during the Industrial Revolution and caused widespread commercial use of driving machinery in factories and mills, although most have since been superseded by internal combustion engines and electric motors. Steam turbines, technically a type of steam engine, that are still widely being used for generating electricity. About 86 % of all electric power in the world is generated by steam turbines.

A steam engine requires a boiler to convert water into steam. The expansion of steam exerts force upon a piston, whose motion can be utilized for the work of turning wheels or driving other machinery. The advantages of the steam engine is that any heat source can be used to produce steam in the boiler, but the most common is fueled by wood, coal or oil or the heat energy generated in a furnace. Besides, steam engine also provide fuel flexibility, sensitivity to load, low pressure combustion, modest speeds, pressure and temperature and also fast startup[3].

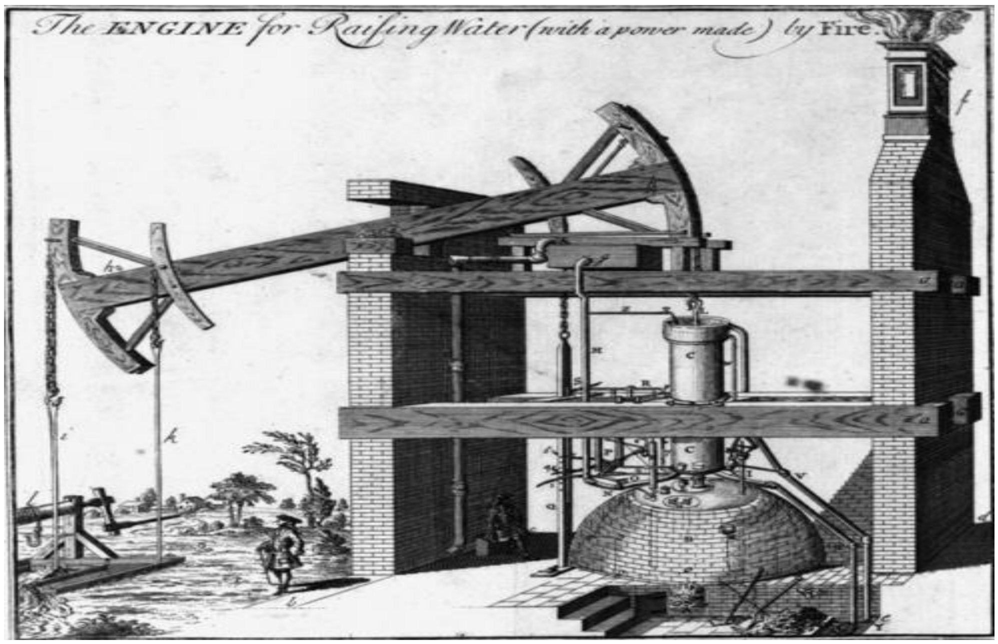

Figure 1.1: Example of early stage steam engine[4]

1.1 OVERALL STRUCTURE OF THE PROJECT

In this project, 2 types of retrofitted engines are going to be tested under the steam engine system. These two engines are basically reciprocating type of internal combustion engines which have been retrofitted to suit into the steam system. The performances of these engines are going to be determined under different pressure with variation of load and constant engine speed powered from the boiler which is fueled by liquefied petroleum gas (LPG).

The performance of the steam engine system depends on the brake power, indicated power, friction power, mechanical efficiency, brake thermal efficiency and indicated thermal efficiency and the specific steam consumption. Besides, the performance of the boiler in this system is also important in determining the performance of the steam engine. From the experiment, the torque, brake power, steam and fuel consumption must be obtained to calculate the components involved in measuring engine performance as stated. The torque and the brake power can be obtained through the dynamometer test. Generally, there are two types of dynamometer test which are transmission type and absorption type. The absorption type of dynamometer test which is rope brake dynamometer was used for this experiment.

1.2 PROBLEM STATEMENT

Steam engines have been attracting a lot of attention in recent years even it is one of the machine that is invented during the industrial revolution. Steam engine introduces a reliable and cost-effective method to generate power and can be more competitive in other power generation system if its performance can be improved. However, there is no available steam engine in the market and it is usually personally developed by the user. For a small scale of steam engine system, variations of designs have been made in determining its performance. Besides, the use of steam engine system for the power generation in rural area is also considered as an issue for this project. Due to the low efficiency of steam engine, steam engine systems with retrofitted IC engines are designed to determine its performance when the boiler is fueled with LPG. Besides, the performance of the boiler which is important in steam power generation is going to be determined. Dynamometer is connected to the flywheel as the output and the performance of the engines with loads exerted on the dynamometer will be measured.

1.3 OBJECTIVES

The following are the objectives of the project:

- To measure the performance of a steam engine system using 2-strokes petrol engine.
- To determine the performance of the boiler when fueled with LPG.

1.4 SCOPE OF WORK

In this experiment, there are some works involved in making the experiment accomplish. First is to make modification on two types of engines so that they can fit into the steam engine system. To determine the power that can be generated from the engines, experiment by using compressed air as the energy source will be done. The dynamometer test will be conducted for measuring the torque and brake power of the engines and thus the performance of the engine can be determined. Besides, the performance of the boiler must be determined first to make sure that it suits the engines requirement to operate. Before running the engines and measure its performance with steam, the power generated by the boiler and its efficiency must be known.

CHAPTER II
LITERATURE REVIEW

2.1 RESEARCH BACKGROUND

Generally, there are many studies that have been made in steam engine system. From time to time, the development of technology causes many designs and alternatives that have been used for the improvement of the steam engine. Many conventional and unconventional designs of steam engine have been done by previous researchers to determine its ability and performance in power generation. Besides design of the system, they also considered the type of fuel such as that will be used to efficiently heat the boiler so that water can be converted into steam. Instead of using steam, many studies have been done in using other type of working fluid for their steam engine system such as organic Rankine cycle fluid and two phase octane.

Steam engine is an engine where the heat from combustion process occurs externally and uses the heat energy in the steam to convert into mechanical work by permitting the steam to expand and cool in a cylinder equipped with movable piston[5]. Basically, steam engine system is mainly composed of a boiler and an engine. The steam, which is used in heating or power generation purpose, is generated in the boiler. The engine plays the role of converting the energy produced from the steam into mechanical work either in a linear or rotary motion. The parameters that are important in this system are the steam pressure, steam flow rate, power generated (indicated and brake power) that influence the performance the system. The importance of indicated power is that it affects directly the thermodynamic performance of the engine and is not affected by that very variable quantity which is friction. The measurement of indicated and brake power allows the friction to be evaluated[6].

2.1.1 Different designs of the steam engine system

A study from S. Yatsuzuka et al. focused on the steam accumulator volume that affects the liquid-piston steam engine efficiency[7]. They make a numerical analysis to reproduce the characteristics of the liquid-piston steam engine. In the case of large steam accumulator volume, the indicated work and the indicated thermal efficiency decrease as the accumulator acts as a dead volume. In this study, they proposed a nucleate boiling and liquid film evaporation model which has small computational load with high accuracy. The liquid film is left behind on the wall surface after the retracting process of towards the dead center. Thus, the present of liquid film will affect the timing and amount of vaporization so directly affects the steam generation. The indicated thermal efficiency for steam accumulator volume of 0.1cc is 50% smaller than in the 0.3cc case while the indicated work for steam accumulator volume of 0.1cc is 10% smaller than in the 0.3cc case. Thus, by optimizing the steam accumulator volume, the indicated thermal efficiency can be improved. Therefore, this system shows the reversible use of working fluid in making the mechanical power to the engine where the liquid/water is used to generate power to the cylinder by the expansion of the steam. To relate in common type of steam engine, the steam generation in the boiler is really important. Steam accumulator plays a role as a boiler in the steam generation. By consider the size of boiler in a system, the steam generation could be improved thus directly boost the performance of the engine.

Instead of using boiler and fossil fuels to heat the water into steam, studies have been made to find the alternatives for steam engine. Alejandro Forero et al. studied in using solar energy as the energy source for the steam engine. Another study that is quite similar entitled Sunlight powered Steam engine which was done by Mohammad Shahbaz et al. but the difference is in this study they used heat transfer fluid run in the tube to absorb the concentrated sunlight to produce the steam by increasing the thermal efficiency of the pipe. These studies are triggered due to the increasing prices of fossil fuels and its harmful emission that endangered the environment and thus solar energy is the alternative to solve this issues. From these studies, they will investigate the effective method to develop a most efficient solar collector by altering its parabolic angle on the panel surface to receive high sun exposure, surface area of the solar panel, calculate an ideal diameter of the copper wires where the water will be heated on the solar collector and other components such as exit valves and pipe lengths connected on the system[1], [8]. There is a tube, which runs the length of the trough at its focal line. The mirror is oriented so that sunlight which it reflects is concentrated on the tube, which contains a fluid which is heated to a high temperature by the energy of the sunlight. [1]. Heat transfer fluid (usually thermal oil) runs through the tube to absorb the concentrated sunlight. This increases the temperature of the fluid to 400°C. The heat transfer fluid is then used to heat steam in a standard turbine generator. The process is economical and, for heating the pipe, thermal efficiency ranges from 60-80%. Thus for this experiment, the steam is flow to the engine via the pressure regulating valve, thus a good material that can maintain the temperature of the steam should be used to avoid issue in steam transportation into the engine cylinder.

In conventional design of steam engine system, G. Muller studied in developing a steam engine that generates the steam by boiling water at atmospheric pressure. The purpose of this atmospheric steam engine is to show that there is still development potential that can be used in current situation. The simplicity of this engine indicates the cost-effectiveness. The extended steam engine shows that its operation temperature is between 60°C and 100°C. Thus, this will make the efficiency reduced[9]. The theoretical maximum efficiencies are reduced from 0.064% for an initial temperature of 100°C to 0.05% for an initial temperature of 50°C. Then, he introduced an adiabatic forced expansion stroke to the system and the theoretical efficiency increased significantly to 0.25% for initial boiler temperature of 100°C and the efficiencies drop 0.10% for 69°C boiler temperature. In this study, G. Muller developed a cost-effective steam at atmospheric pressure. Even the effectiveness of the system is reduced as it only operates on low range of temperature which is from 60°C-100°C. He came up with an adiabatic forced expansion stroke. It operates by closing off the supply of steam early, before the piston has travelled through its full stroke. Thus the cut off allows the steam to expand within the cylinder.

K. Alanne et al. studied about the thermo-economic analysis of a micro-cogeneration system based on a rotary steam engine(RSE)[10]. In this project, they characterize the boiler-integrated RSE micro-cogeneration system and specify a two-control-volume thermodynamic model to conduct performance analyses in residential applications. From their computational analysis, they concluded that electrical output of 1.925kW with the design temperature of 150°C, electrical efficiency at 9% and thermal efficiency of 77% an overall cogeneration efficiency of 86% can be obtained by using 17kW pellet-fueled boiler. The overall efficiency of the system depends on the condenser temperature, the condenser temperature need to be low to make the efficiency higher. From this study, it can be concluded that the condenser in a steam engine system is really important that could affect the performance of the engine. Thus, to increase the performance of the engine, low temperature of condenser need to be obtained.

2.1.2 Working fluid used in steam system

A study from Y. Wang et al. has done to developed a micro steam engine based on Newcomen steam engine[11]. This prototyped steam engine used a different type of energy source and working fluid in the system. Piston and cylinder are replaced with flexible ripple tube to overcome the serious leakage and friction problem. Electricity as a source of energy, the boiler consists of heating element which will convert fluid to steam. The working fluid used is two-phase octane as it has higher power density than the steam. From their experiment, the micro engine generates a net mechanical work output of 0.406J per cycle and has highest efficiency of 2.58% which exceeds the required level (1%) of micro engine thus proves its feasibility. From this study, it can be seen that the issue of friction and leakage on common steam engine is solved by replacing the piston and cylinder with flexible ripple tube. However, the experiment did not show the performance of the steam as a working fluid in the engine. Thus, to make sure that the prototype functions well with steam, an experiment should be done by using the steam as the working fluid.

2.1.3 Type of fuels used for the boiler

P. Kattan and I. Ruble studied the economic assessment on four boilers with different fuel or energy sources for residential heating. The four boilers are run on olive husk (biomass), liquefied petroleum gas (LPG), diesel and electricity. Boiler A, fueled by olive husk, deliver a heat output ranging from 30kW to 34.9kW. Boiler B, fueled by LPG deliver 32.7kW of output, boiler C which work by diesel oil and deliver 29.1kW to 37.2kW of heat output and lastly the boiler D working by electricity which deliver only 30kW. In this study, they conclude that the electric boiler system is the most polluting and cost ineffective system when considering both the average energy price over the life-time of the system[12]. On the other hand the olive husk (0.13 $/kg), LPG (0.13 $/kg) and the diesel (0.14$/kg) powered systems provided energy at nearly equal average energy prices over the lifetime of the boilers systems.

N. Coovattanachai et al. studied the feasibility of using a small-scale steam engine for the production of mechanical power by using wood and rice husk as the fuel or energy source. They developed special wood furnace and rice husk furnace as a place where the boiler will be installed. This is to make sure the engine could be operated on both fuel. Besides, they also involved the addition of condenser in the steam engine system and compare the performance of the steam engine with and without the condenser[13]. From the project, maximum mechanical output produced is high when steam engine is operated without condenser (4.85kW) compared to the engine that operated with condenser (3.35kW). This is due to the condenser that consumes 1.5kW of the mechanical power produced. Besides the furnace efficiency, fraction of combustion energy that is converted to energy in the steam decreases with the furnace capacity. The furnace efficiencies for wood furnace and rice husk furnace are about 50% and 37% respectively. Fuel consumption on wood is less than the rice husk where 11.6kg/kWhr on wood and 14.0kg/kWhr respectively while the specific fuel consumption 27-30kg/kWhr for wood furnace and 26-29 kg/kWhr for rice husk furnace. For the overall efficiency, the fraction energy in the fuel that is converted to shaft power is 2.5% and 1.9% for wood and rice husk respectively.

From all these studies, there are many things that have been done to the steam engine to study its performance. There was some gap in research that drives me to focus on what research to make. A study of the performance of steam engine with retrofitted internal combustion engines are one of the study that need to be explore more. Besides generating electricity and pumping water, this steam engine system operates with dynamometer with loads as its output.

Reciprocating engines also known as piston engine where the steam causes the piston movement in a sealed chamber or cylinder. The piston reciprocating action can be translated by a mechanical linkage into either linear motion, usually for working water or air pumps, or else into rotary motion to drive the flywheel of a stationary engine, or else the wheels of a vehicle[5]. The main types are of reciprocating engine are the internal combustion (IC) engine, commonly founded in motor vehicles.

Generally, there are many type of fuels used for the steam generation in the boiler. As the steam engine is reliable and flexible, various energy sources have been designed into a steam engine system. Based on previous studies, there are electrical powered steam engines, solar powered steam engine and most commonly used is fossil fuel such as coal, petroleum and natural gas. However, there are also continuous studies on using renewable energy such as biomass as the power generator to the boiler. Biomass is generated from decaying plant or animal waste. Biomass sources can be transformed to solid, liquid, and gas, and biomass energy (bioenergy) obtained from these sources can be utilized in transportation, heating and electricity generation[14]. Biomass feedstock can include crops such as corn or soy, as well as wood [15]. In this experiment, LPG is used as a fuel to heat up the boiler. LPG known as liquefied petroleum engine is primarily composed of propane, butane or propane-butane blends. It can be in liquid or gas (vapor) depends on the pressure and temperature exert on it. LPG has many properties including density (specific gravity), flame temperature, boiling point, flash point, vapor pressure, odor, appearance, energy content, gaseous expansion, combustion formula, limits of flammability, nomenclature and molecular formula[16]. Due to the low energy and power that can be generated from biomass by this boiler system, the use of biomass which is mangrove tree wood in this steam engine system is not suitable and inappropriate.

Biomass such as tree wood has lower low heating value which is around 18MJ/kg compared to LPG which has 46MJ/kg. Figure 2.1 shows the properties of fuel which includes petrol, ethanol and LPG.

Property	Petrol	Ethanol	LPG
Chemical formula	C4 to C12	C2H5OH	C3H8+C4H10
Density @20oC, kg/m3	719.7	789	260
Calorific value, MJ/kg	47.3	26.8	46.1
Octane number	90	111	1.85/505
Cetane number	20	8	-

Figure 2.1: Fuels properties chart

For this steam engine system, vertical fire-tube boiler is used. Basically, there are two types of boiler exist which are fire-tube boiler and water tube boiler. The fire-tube boiler is basically the boiler which allows the hot gases to pass through the tubes that is surrounded by water. For water-tube boiler, it works oppositely to that fire-tube boiler whereas the water pass through to a large number of tubes which the hot gases flow. Fire-tube boilers are commonly used for facility heating application while the water-tube boilers are used in large steam users such as industrial process applications. Usually, the fire-tube boilers are long and wide while the water-tube boilers are narrow, long and tall. For the fire-tube boiler, the width is the function of the design whereas the more conservative design, the more the water can be stored by the boiler[17]. The efficiency on the fire-tube boiler is higher compared to the water-tube boiler which is 80-82% and 77-79% respectively where its efficiency varies on different firing rates.

CHAPTER III
RESEARCH METHODOLOGY

3.1 APPARATUS

Figure 3.1 shows the complete setup of the steam engine system. This system consists of 3 main parts which are the boiler with stove, the pressure regulating valve and the reciprocating engine.

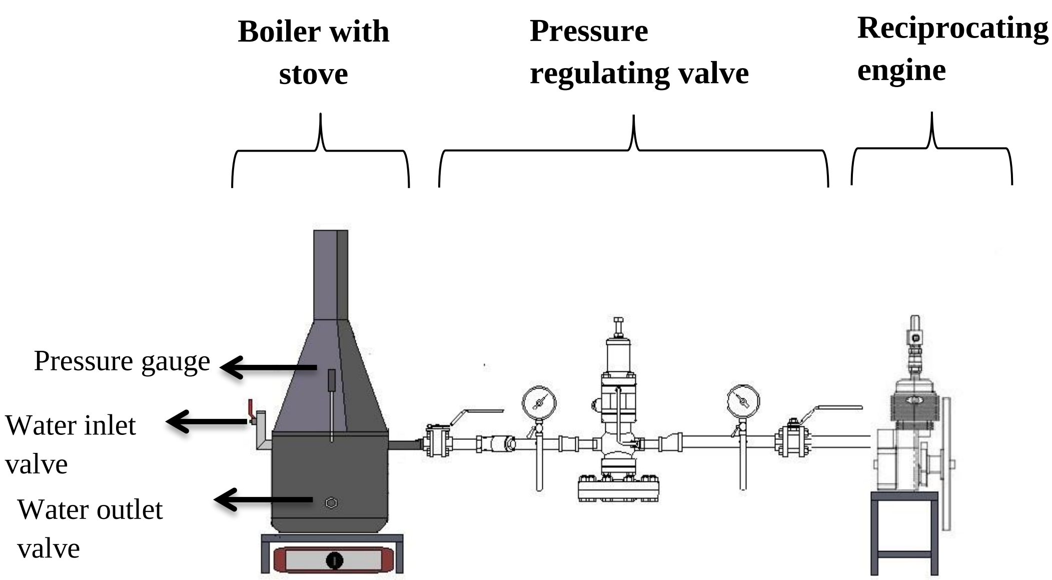

Figure 3.1: The setup of the experiment

3.1.1 The boiler with stove

The boiler used is the vertical fire-tube type which is made from stainless steel as shown in Figure 3.2. It can contain maximum up to 7.5 liters of water and can operate up to 10 bar pressure. This fire-tube boiler consists of 9 heating tubes with 3 x 3 array arrangement as shown in Figure 3.3. Components of the boiler are the water inlet and outlet valve, water tube level indicator, pressure gauge and safety valve. The pressure regulator used for the LPG tank is Chestar high pressure regulator with 0.5-10 bar and 0-2 bar inlet and outlet operating pressure. It has the capacity of 0-6kg/h of gas flow rate that will be supplied to the stove.

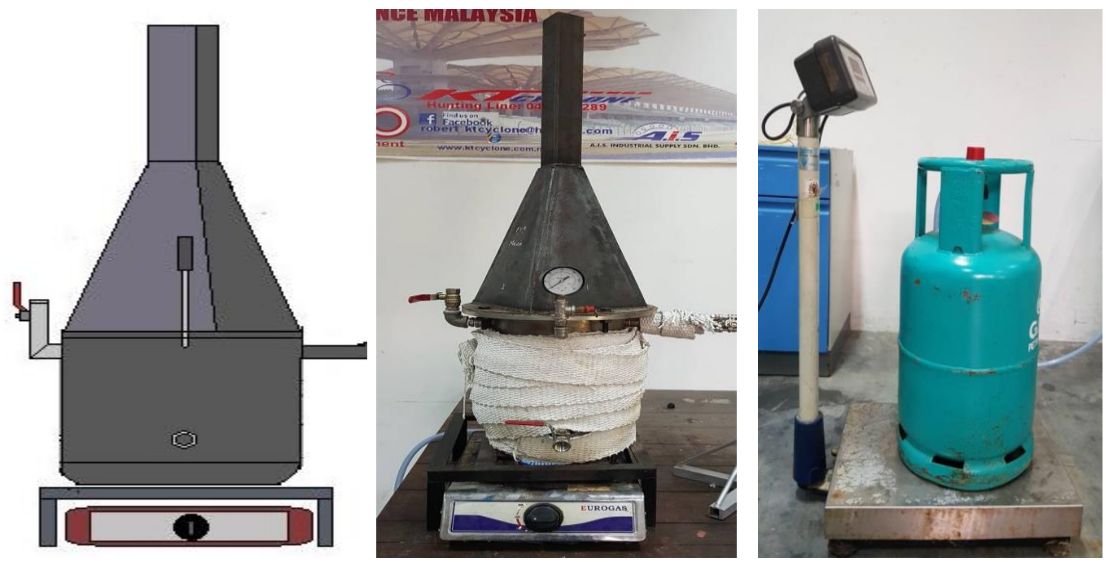

Figure 3.2: The boiler with stove and the LPG tank with weighing balance

Figure 3.3: The arrangement of boiler tube

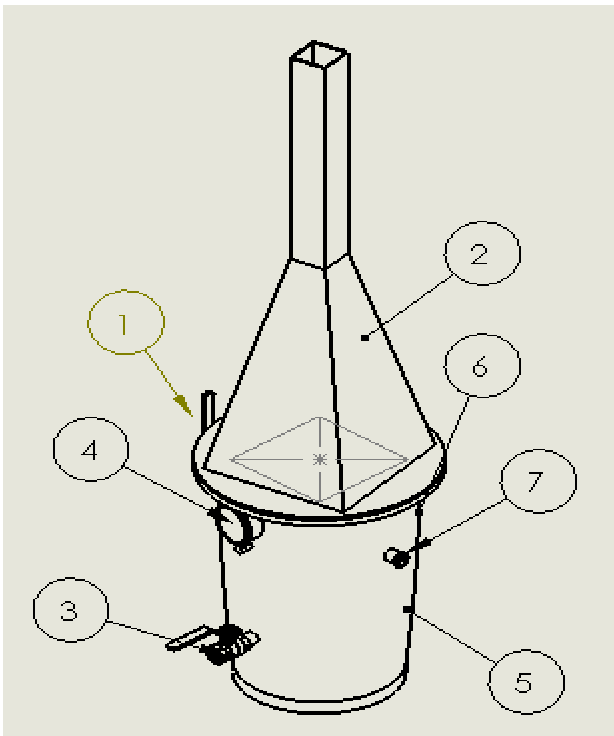

Figure 3.4: The drawing of vertical fire-tube boiler

Table 3.1: The components of the boiler

ITEM NO	PART NUMBER	QUANTITY
1	Water inlet	1
2	Chimney	1
3	Water outlet	1
4	Pressure gauge	1
5	Boiler container	1
6	Water level indicator	1
7	Pipe outflow	1
8	Regulator ball valve	2

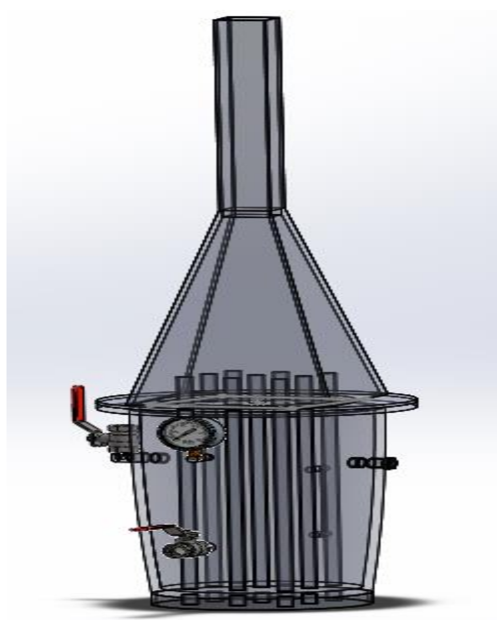

Figure 3.5: The vertical fire tube boiler with its internal details

3.1.2 The pressure regulating valve

The steam pressure regulating valve as shown in Figure 3.6 is connected between the boiler and the engine which is the medium of steam flows from the boiler through the engine. The 2-way pressure regulating valve used is Yoshitake GD-45P which controls the amount of steam flows from the boiler to the engine. It has maximum operating temperature of 220℃ and maximum operating pressure of 2MPa. Attached on both sides of the pressure regulating valve are the upstream and the downstream valve with pressure gauges. The asbestos mesh is wrapped on the boiler body and the pressure regulating valve and act as heat insulator and dirt resistor.

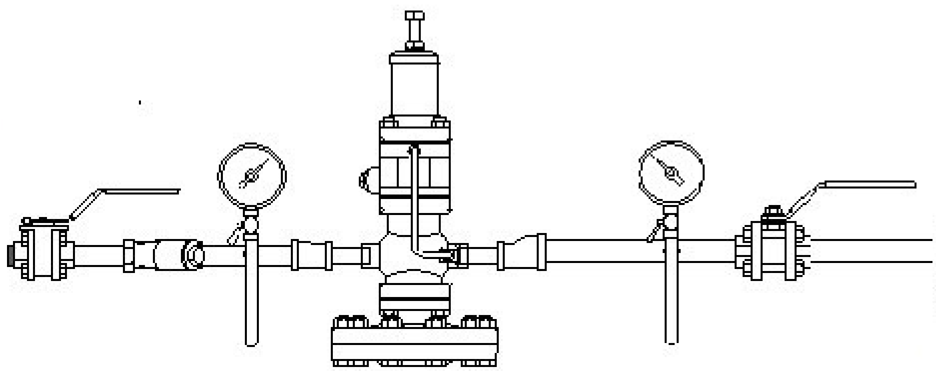

Figure 3.6: The pressure regulating valve

3.1.3 Steam engines

At the early progress of this project, the modifications of the engines to make them fit into the steam powered system also have been determined. The disassembly of the engines has been done to measure the dimension of the engines components and the drawings of the engines are made through Solidworks software. Figure 3.7 shows the setup of the 2-stroke engine with the rope brake dynamometer.

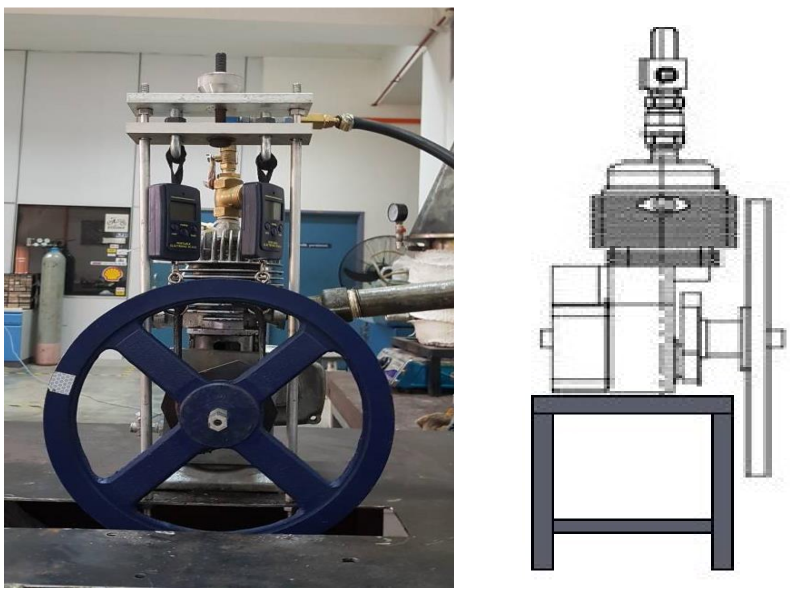

Figure 3.7: The 2-stroke engine with rope brake dynamometer

3.1.3 a) 2-stroke engine

To summarize the modification made in this 2-stroke engine, the spark plug is removed from the engine and been replaced by the regulator ball valve. This is to make sure that steam or air can flow directly through the engine cylinder. Then, an 8.5cm length with 0.6cm diameter stainless steel rod is placed between the air valve and the engine cylinder to make sure that the power from the steam or air can be transferred to the cylinder directly. This engine has 84.86cm^3 of cylinder displacement volume, V_d. The schematic drawing of the 2-stroke engine is shown in Figure 3.8.

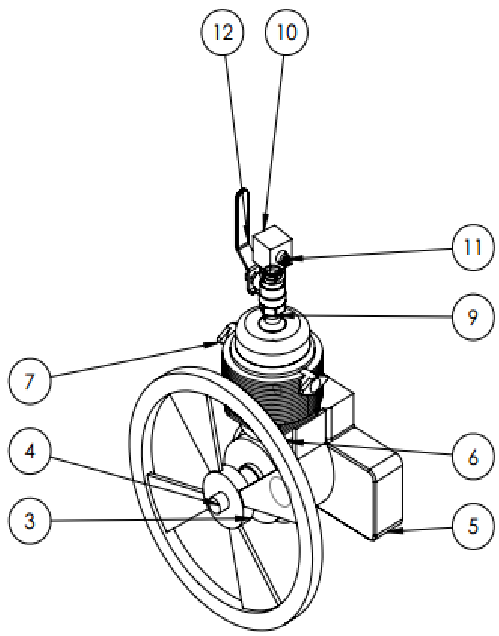

Figure 3.8: Drawing of 2-stroke engine

Table 3.2: The parts of 2-stroke engine

ITEM NO	PART NUMBER	QUANTITY
1	Pin	1
2	Rod	1
3	Flywheel	1
4	Crankshaft	1
5	Lower case	1
6	Crank rod	1
7	Upper case	1
8	Piston	1
9	Air valve connector	2
10	Cuboid valve outflow	1
11	Outflow tube	1
12	Regulator ball valve	1
13	Check valve	1

3.1.3 a) i) Mechanism of the rod-check valve

For this 2-stroke engine, the most important modification that has been made is the intake valve which replaces the spark plug on the upper case of the engine. The vertical orientation of the spark plug placement leads to no further modifications need to be made in ensuring the rod-check valve mechanism works out in controlling the flow of fluid (steam) into the engine cylinder. The function of the check valve is to allow the fluid to flow only in one direction.

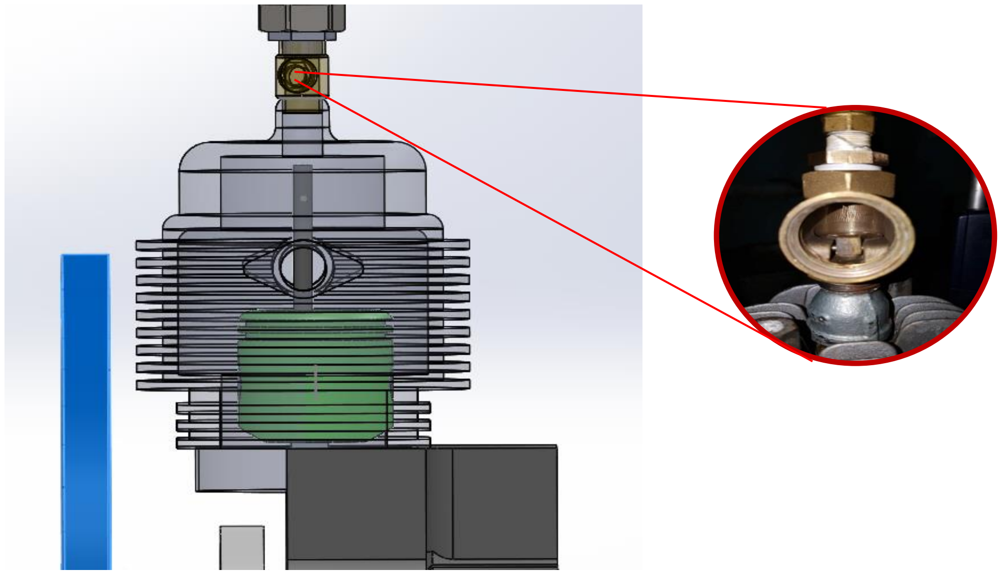

Figure 3.9: The closing of the check valve disk at bottom dead center (BDC)

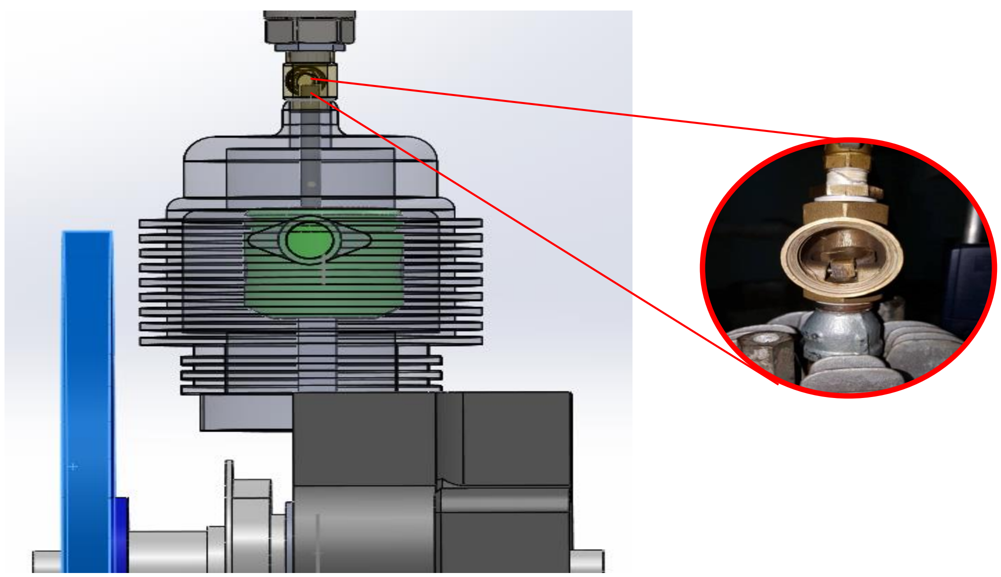

Figure 3.10: The opening of the check valve at top dead center (TDC)

From the figures above, it can be seen the position of stainless steel rod and the check valve when the engine piston is at bottom dead center (BDC) and top dead center (TDC). From Figure 3.9, at BDC, the rod moves downward along with the engine piston and causes the check valve at closing position thus not allows the fluid (steam) flows backward.

From Figure 3.10, the engine piston moves upward and reaches TDC. Therefore, the rod moves along with the piston upward and lift up the check valve slightly to allow the entering of fluid (steam) into the engine cylinder.

3.1.3 b) 4-stroke engine

For this 4-stroke engine, the modification that has been made is the change of the cam lobe type used. The type of cam lobe used is dual cam lobe. Instead of using the egg-shaped type of cam lobe, the ellipse shape of the cam lobe is used as shown in figure 3.12. The ellipse shape of the cam lobe is obtained by the addition brass-made lift to the other side of the lobe base circle. This is to control the timing of opening and closing of intake and exhaust valve and to make it operates similar to the 2-stroke engine which completes the power cycle in one crankshaft revolution instead of two crankshaft revolution. Besides, this 4-stroke engine has a swept volume of $197cm^3$. The drawing of the 4-stroke engine is shown in Figure 3.11.

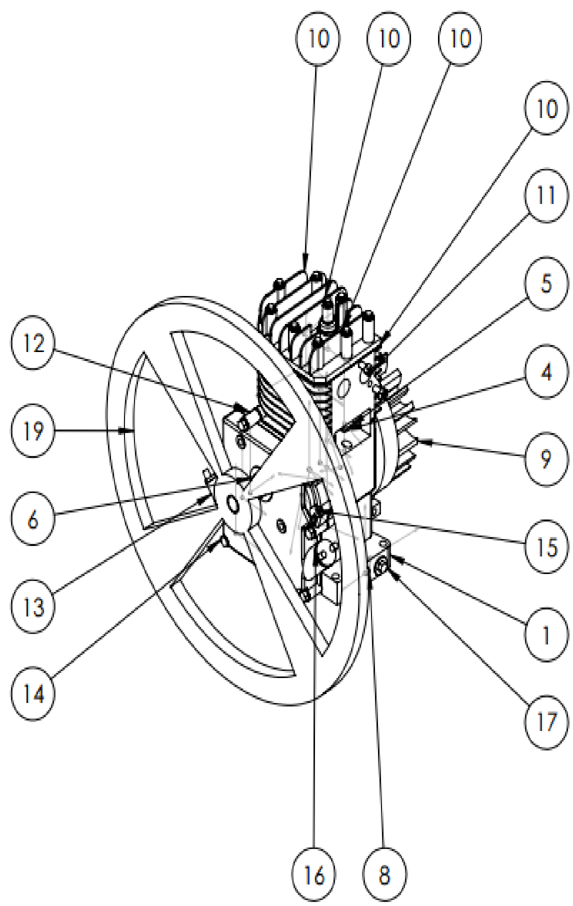

Figure 3.11: Drawing of 4-stroke engine

Table 3.3: The parts of 4-stroke engine

ITEM NO.	PART NUMBER	QUANTITY
1	Block	1
2	Exhaust valve	1
3	Intake valve	1
4	Valve lifter	2
5	Valve spring clip	2
6	Crankshaft	1
7	Piston	1
8	Oil plug	2
9	Flywheel	1
10	Head case	1
11	Carburetor bolt	2
12	Crank gasket	1
13	Crank cover	1
14	Crank bolt	6
15	Crank cover pin	2
16	Oil cap	2
17	Fuel tank bolt	1
18	Cam lobe	1
19	Pulley flywheel	1

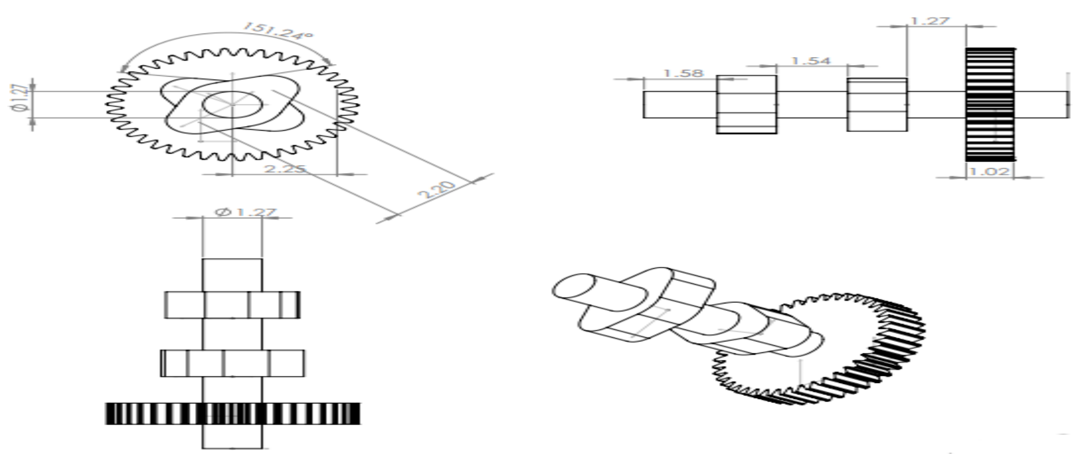

Figure 3.12: The ellipse shaped cam lobe used

3.2 DETERMINIG BOILER EFFICIENCY

Initially, the boiler is filled with 4 liters of water. The stove was switched on to the maximum setting with the high pressure regulator on the LPG tank set to highest and safest firing rate on the stove. The boiler was heated until it reached 7 to 8 bar which higher than the pressure being tested. The pressure regulating valve adjusted to 3.0 bar. The LPG tank was placed on the weighing scale and the initial weight of the tank before the steam flows were recorded. The downstream valve was opened and being altered until the pressure of the boiler remain constant which shows the equilibrium between the steam produced by the boiler and steam being supplied to the engine. For safety purposes, the steam was allowed to flow up to 20 minutes to make sure the water in the boiler was remained at safety level (not less than 1 liter). After 20 minutes, the water level of the boiler and the mass of the LPG tank was recorded. The experiment was repeated for the pressure 3.5 bar, 4.0 bar, 4.5 bar and 5.0 bar. The formula to calculate the boiler efficiency is given in Eq. 1.

$$Boiler\ efficiency, \eta_b = \frac{steam\ flow\ rate \times latent\ heat\ of\ vaporization\ , hg}{fuel\ mass\ flow\ rate \times LHV} \qquad \text{(Eq. 1)}$$