Study of Combustion Characteristic of LPG with Steam in a Burner

By

Afiq Azreen Bin Zainuddin

10307

A Project Dissertation Submitted in Partial Fulfillment of

The requirement for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

MAY 2011

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Study of Combustion Characteristics of LPG with Steam in a Burner

by

Afiq Azreen Bin Zainuddin

A report submitted to the
Mechanical Engineering Department
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
Bachelor of engineering (Hons)
(Mechanical Engineering)

Approved by,

(Dr.Ir Shaharin Anwar Bin Sulaiman)
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
MAY 2011

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

(Afiq Azreen Bin Zainuddin)

ABSTRACT

Nowadays, improving fuel efficiency and environment protection have become an important issues in industrial since the era of cheap fuel are over and the pollution caused due to the combustion process from the rapidly growing industrial. This report basically discusses the preliminary research done and basic understanding of the chosen topic, which is to study the combustion characteristic of LPG (Liquefied Petroleum Gas) and steam in a burner. The objective of the project is to find the potential of saving fuel by increasing the combustion efficiency and reducing emission of pollutants by using steam in a burner. The challenge in this project is to find the most favorable way to introduce the steam to the combustion process that was in the burner (C491 Combustion unit) and analyzing the effect of steam in increasing the combustion efficiency. There are 2 method prepared for this project. First method is by using the C491 combustion unit. Some modification has been done to this unit where the flange that were used as a observation windows were modified to allow the steam injection directly to the flame in the C491 combustion chamber. The modified flange also been used in the second method where a new combustion chamber have been fabricated and using a Bunsen burner as a heat producer. The modified flange will also be used as a steam input to the new fabricated combustion chamber. Varies amount of steam flow rate have been injected in order to studying its effect on the combustion process. The effect of steam in both environment protection and increasing the combustion efficiency has been identified by the heat and flame produced during the combustion process. Based on the result, the combustion efficiency start to increase at the first 30 seconds of the heating process. Type of flame produced is the same without the steam injection means there is no decrease on pollutant emission.

ACKNOWLEDGEMENT

First and foremost I would like to express my heart filled gratitude to God for His guidance and blessing thorough my study years in UniversitiTeknologiPetronas. Not forgetting the family especially my parents, sincere gratitude for their love and support.

I also would like to take this opportunity and give my sincere thanks to my supervisor, Dr.IrShaharin Anwar Bin Sulaiman for his relentless guidance and willingness to share his knowledge throughout my Final Year Project (FYP). This project would not be a success without his supervision and advices.

My grateful thanks also go for University for providing their lab facilities for me run the experiment. Special thanks also go for the technician in charge of the lab in making sure the facilities runs well all the time.

Finally, thanks to all the people directly or indirectly contribute to the successful of the Final Year Project, their cooperation, encouragement, constructive suggestion and helping during the final year project until it is fully completed.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Nowadays, the era of cheap fuel is over. Both fuel saving and environment protection is an increasingly important topic. The price of energy is inevitably on a long-term upward path while the global recession means everyone has less money to spare. Fuel bills, whether for the home, industrial or for the car take up an ever increasing proportion of people's or company budgets. Improved fuel efficiency is the best way to mitigate rising prices, but it can be difficult to know where to start. Fuel efficiency meaning the efficiency of a process that converts chemical potential energy contained in a carrier fuel into kinetic energy or work. Overall fuel efficiency may vary per device, which in turn may vary per application, and this spectrum of variance is often illustrated as a continuous energy profile. Non-transportation applications, such as industry, can benefit from increased fuel efficiency, especially fossil fuel power plants or industries dealing with combustion, such as ammonia production during the Haber process. Optimizing burner's efficiency is important to minimize fuel consumption and unwanted excess to the environment. To ensure complete combustion of the fuel used, combustion chambers are supplied with excess air. Excess air increases the amount of oxygen and the probability of combustion of all fuel. The combustion efficiency will increase with increased excess air, until the heat loss in the excess air is larger than the heat provided by more efficient combustion. My project is about one of the many possible ways to save fuels by increasing the combustion efficiencies and reducing pollution emission by introducing steam to the combustion process. In this project, liquefied petroleum gas (LPG) which is a flammable mixture of hydrocarbon gases will be used as a fuel in the heating. The steam used in this experiment was saturated steam temperature range from 110°C to 115°C. There are 3 test that has been conducted each with different amount of steam flow rate that been injected to the combustion chamber.

1.2 Problem Statement

In this project, two methods will be use in to analyze the effect of steam to the combustion process. Method 1 is by using C491 combustion unit. It is floor mounted designed for students to study many aspects of combustion using a small scale unit which will be easily understood and controlled. The unit comes with burner, combustion chamber, control panel and instrument all at convenient working height. But the challenge to this project is this unit does not have a proper input system to inject steam into the combustion chamber. Some modification should be done to the combustion unit to allow the injection of steam and the best way of introducing it has to be studied. Method 2 is by designing and fabricating a new combustion chamber. The specification of the chamber should be analyzed to fulfill this project requirement in order to get the desired result. At first, the steam source/output was suppose to be from the boiler itself but after some testing the result shows that the boiler output operation is not working smoothly so the steam source was change to kettle. By introducing the steam, the result on how the steam help increase the fuel efficiency and reducing emission of pollutants during the combustion process will be determine by analyzing the heat and flame produced.

1.3 Objective and Scope of Study

The main objectives of this research are:

- To determine the characteristic of combustion process of LPG with steam in a burner
- To study the best way to introduce steam to the combustion process.
- To analyze the safety requirement for the piping installation

The scope of this study is to look into the potential of saving fuel and reduction of pollution generation by using steam and to investigate the characteristic of combustion process of LPG with steam in a burner. Once the steam has been added, the effect on heat produced, flame temperature, burning velocity and carbon limit of adding steam to a premixed flame will be investigated using a burner operated at atmospheric pressure and LPG as fuels. These tests shall simulate the potential of steam in increasing the fuel efficiency and reducing the emission of air pollutant by the heat combustion produced. Heat combustion is the heat energy obtained when a certain quantity of fuel is burned. Since the steam source have been changed from using the boiler that produced a 9 bar and 220°C steams to a kettle that only producing a 110°C to 115°C steam, a silicone rubber braided rubber hose will be used in this experiment. The hose installation procedures have to be prepared and the safety issues in running this project have to be considered.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Combustion researches are always concerned with meeting various industrial, societal, and national needs. An example of this can be seen from the excess enthalpy concept that was used for the combustion of low heating value fuels without using any auxiliary fuel. Global environmental problems, including acid rain, particulate, ozone layer destruction, and global warming from greenhouse gases, such as CO_2 and methane, are now recognized to cycle between atmosphere and the earth. Besides, the era of cheap fuel is over. Increase the fuel efficiency in the combustion process is the best solution in order to save fuel. Fuel efficiency meaning the efficiency of a process that converts chemical potential energy contained in a carrier fuel into kinetic energy or work. Overall fuel efficiency may vary per device, which in turn may vary per application, and this spectrum of variance is often illustrated as a continuous energy profile Simultaneous requirements of both environment protection and energy conservation require rapid development of combustion science and technology for various applications. The science and technology of combustion has made significant progress during the past century, in particular after World War II.

2.2 LPG (Liquefied Petroleum Gas)

Ed (1996) says that LPG is synthesized by refining petroleum or "wet" natural gas, and is usually derived from fossil fuel sources, being manufactured during the refining of crude oil, or extracted from oil or gas streams as they emerge from the ground. It was first produced in 1910 by Dr. Walter Snelling, and the first commercial products appeared in 1912. It currently provides about 3% of the energy consumed, and burns cleanly with no soot and very few sulfur emissions, posing no ground or water pollution hazards. LPG has a typical specific calorific value of 46.1 MJ/kg compared with

42.5 MJ/kg for fuel-oil and 43.5 MJ/kg for premium grade petrol (gasoline). In a study done by Zhang (2005) and Qi (2007), LPG-fuel-oil fuel mixes reduce smoke emissions and fuel consumption but hydrocarbon emissions are increased. The studies were split on CO emissions, with one finding significant increase and the other finding slight increases at low engine load but a considerable decrease at high engine load.

2.3 Saturated Steam

The kettle used in this project producing saturated steam. The temperature and the pressure of the saturated steam are mutually dependent. When one of them is given, the other can be determined. According to Singh (2001), saturated steam is steam at equilibrium with liquid water. It defines the boundary between wet steam and superheated steam on the temperature-enthalpy diagram. The kettle used in this project produce a steam at 110°C to 130°C. The steam table list the properties of saturated steam at varying pressures and temperatures refer to appendix A:

2.4 Steam Injection

Combustion reaction can be defined as the chemical reaction between oxygen and combustion compounds in fuel. The three components in fuel are carbon, hydrogen, and sulphur. It is a good combustion between combustion reaction and energy if all parts of the components are combusting to combustion reaction and all of the heat energy can be received by the fluid, with no heat loss discarded to the environment. LPG contains mixes that are primarily propane, C_3H_8. Propane undergoes combustion reactions in a similar fashion to other alkanes. In the presence of excess oxygen, propane burns to form water and carbon dioxide. When not enough oxygen is present for complete combustion, incomplete combustion occurs when propane burns and forms water, carbon monoxide, carbon dioxide, and carbon. Propane combustion is much cleaner than gasoline combustion, though not as clean as natural gas combustion. The presence of C–C bonds, plus the multiple bonds of propylene and butylene, creates organic exhausts besides carbon dioxide and water vapor during typical combustion. These bonds also cause propane to burn with a visible flame.

In a study done by Bustan (2006), with the steam injection to the combustion process, the reaction between fuel and steam at the burner caused the decrease of carbon deposits forming in the combustion chamber. The minimizing of carbon in the combustion chamber gave good effect to the tube surface and enhanced the heat transfer. The Increase in temperature is because of the heat resulting from the spontaneous reaction between carbon and steam at the furnace. In a study on effect of steam on flame temperature, burning velocity and carbon formation in hydrocarbon flames done by Müller-Dethlefs and Schlader (2003), the effect on flame temperature ,burning velocity and carbon limit of adding water vapor to a premixed flame has been investigated using a Bunsen-type burner operated at atmospheric pressure and employing propane and ethylene as fuels. The results indicate that water vapor does not act as an inert diluent but instead inhibits carbon formation and gives rise to a greater heat release than in its absence. The additional heat release, in turn, partly counteracts the cooling effect of the added steam, so that the flame temperature and burning velocity do not decrease with steam addition to the extent they would if water vapor were an inert heat sink, provided the equilibrium state is attained. The shift of the carbon limit towards higher ratios with steam addition gives evidence of the major role of OH radicals in inhibiting carbon formation.

CHAPTER 3

METHODOLOGY

3.1 Execution Flow Chart

This project was divided into a few stages. In each stage, different type and plan of project approach were impellent in order to execute the whole experiment from the beginning until the result analysis.

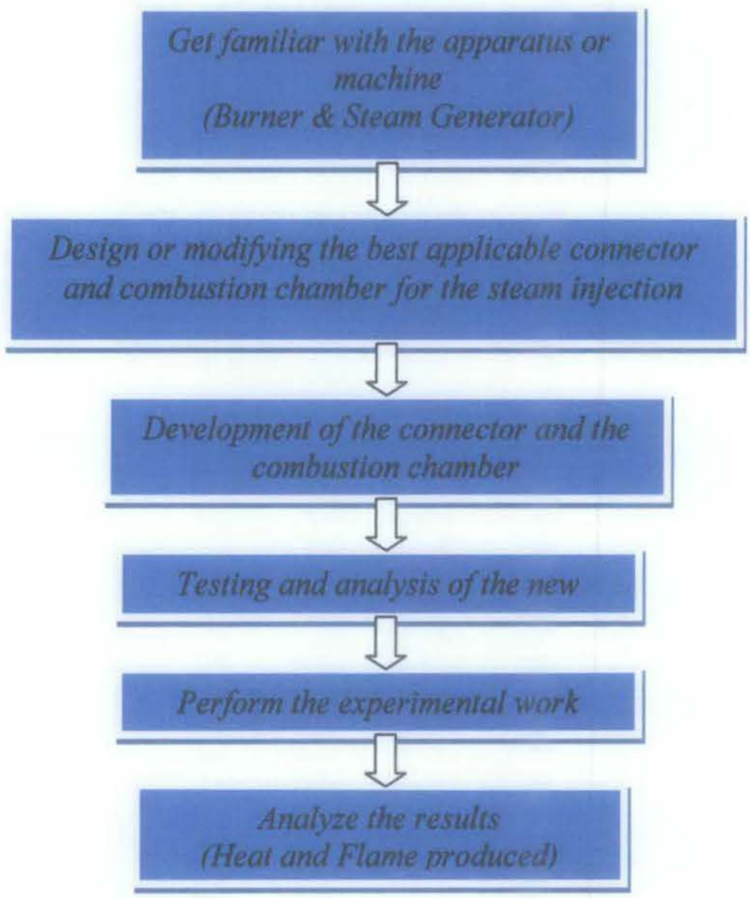


Figure 3.1 : Execution flow chart

Procedure identification for the project approach in each stages and the Gantt chart are provided in Appendix B and Appendix C:

3.2 Combustion Process

In this project, there are two method that already been planned to study and analyze the effect of steam to the combustion process. First method is by using the C491 (combustion laboratory unit) and the other one is by designing and fabricating a new combustion chamber.

3.2.1 C491 (Combustion Laboratory Unit)

Figure 3.2 : C491 (Combustion Laboratory Unit)

C491 combustion laboratory unit is a fully instrumented water-cooled combustion chamber with oil and/or gas burner for studying burner operation and the combustion process. The C491 unit mounted on a frame allows easy access to the burner control and the combustion chamber. The package burner starts with an air purge ignites its appropriate fuel oil or gas and automatically sets to a safe firing condition. Combustion air is provided by the integral fan and a sensor monitors the flame, shutting the fuel valve in the event of flame failure. Air/fuel ratio and fuel firing rate can then be varied by the user. Gas from either an LPG cylinder stored outside the building, or local mains supply, is fed through pipes to the connection on the frame. Oil is supplied from portable tanks provisioned with the oil burner. The flame burns within a stainless steel combustion chamber which is water cooled and of sufficient size to prevent flame impingement under normal conditions. Observation windows on the side of the chamber allow the flame to be observed. The combustion product leaves the combustion chamber through a duct in the end remote from the burner, and is turned to discharge vertically upward. Due to high temperature, an air break transition piece is supplied between the chamber duct and the main flue, to entrain the cool air and so reduce flue temperature. A flue system is available as an optional extra. The unit must be installed in a well ventilated area, with access to the burner end at least one of the two sides. The standard instrumentation provides measurement of flue temperature, O_2 content, excess air, combustion efficiency, cooling water inlet and outlet temperature, water and fuel flow, thereby allowing energy balances to be determined.

Requirement for c491 (combustion laboratory unit) operation and the ignition procedure using gaseous fuel (LPG) can be refer to Appendix D and Appendix E:

3.2.2 C491 Unit Design Modification

Since there is no proper input to introduce steam to C491 burner, the most favorable way to introduce the steam that produced by the boiler to the combustion process that was in the burner have to be studied. The main idea was to replace and modify the flange used as an observation window with the new fabricated one that will act as a connection from the kettle to the burner for introducing steam. Once the steam has been added, it shall simulate the potential of steam in increasing the fuel efficiency and reducing the emission of air pollutant by the heat combustion and flame produced.

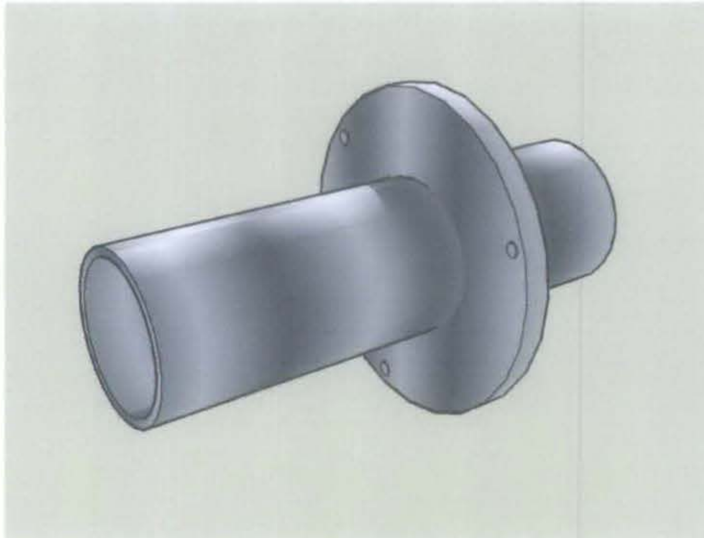


Figure 3.3 : Front view of the modified flange.

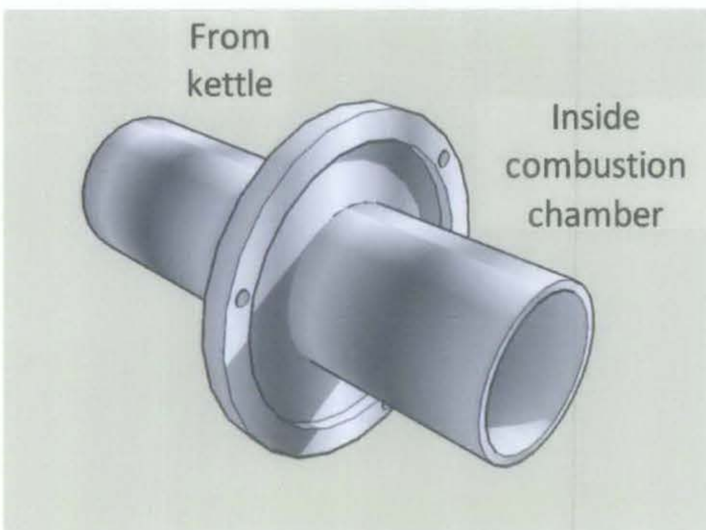


Figure 3.4 : Back view of the modified flange

This new design of flange will also be used in the new fabricated combustion chamber as an input for steam injection process.

3.2.3 Design and Fabrication of Combustion Chamber

Due to the problem with the C491 Combustion Unit air valve, new combustion chambers have been designed. The design includes two holes for the thermocouple connection on the upper side of the new design chamber.

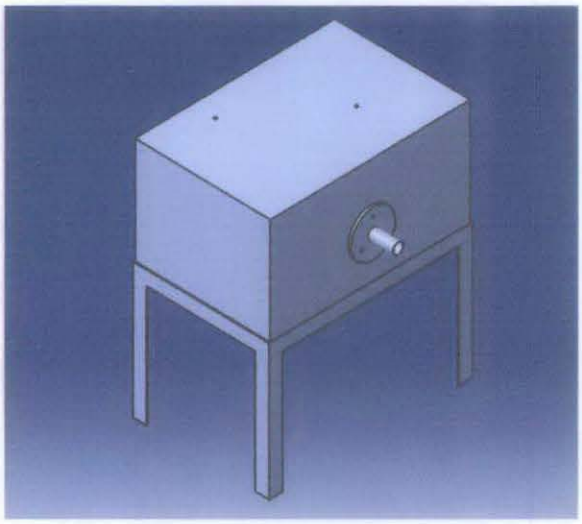


Figure 3.5 : Isometric view of the combustion chamber design

Modified flange will act as a connection from the kettle to the burner for introducing steam. The new flange were bolted at the front side of the combustion chamber.

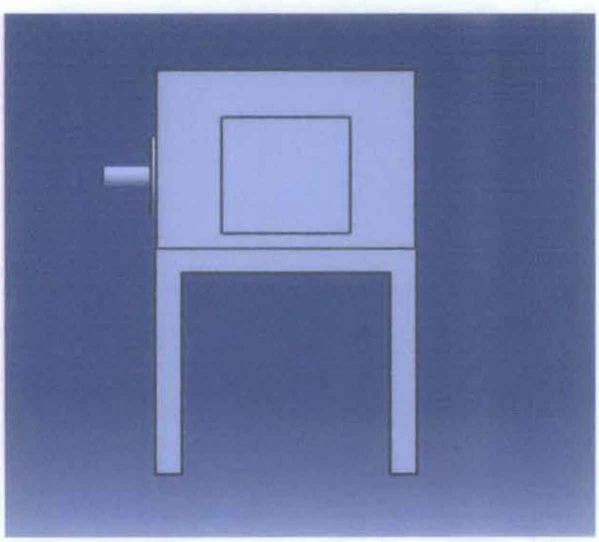


Figure 3.6 : Side view of the combustion chamber design

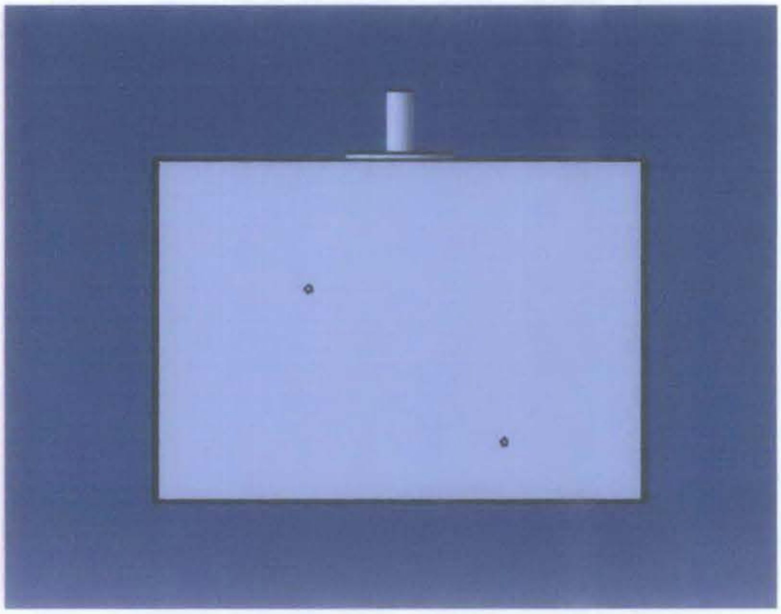


Figure 3.7 : Top view of the combustion chamber design

A 4cm in diameter hole were drillied at the back side of the combustion chamber to act as an exhaust port function to discharges the products of combustion. The open exhaust hole allows the exhaust gases to escape the chamber.

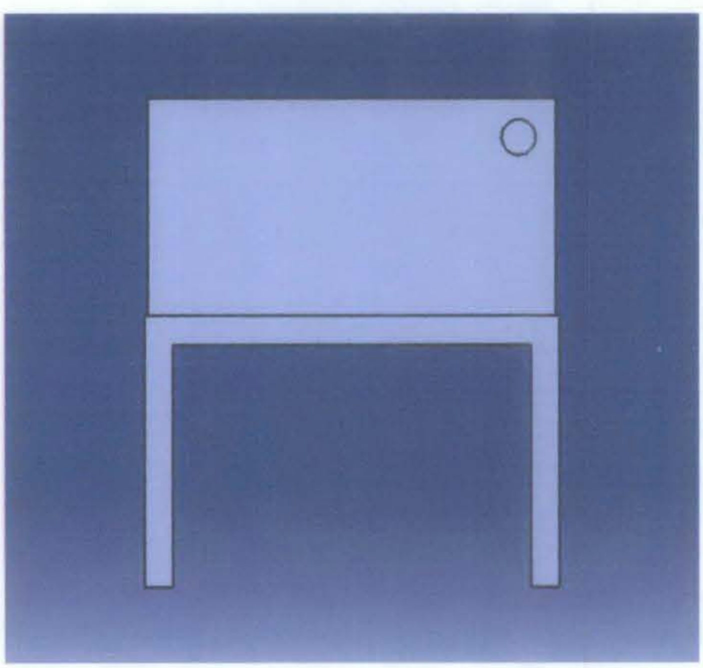


Figure 3.8 : Back view of the combustion chamber design

Observation windows were used for study and analyzing the effect of steam to the combustion process especially the flame produced. Perspex were used as a windows used as alternative to glass its moderate properties, easy handling and processing, and low cost, but behaves in a brittle manner when loaded, especially under an impact force, and is more prone to scratching compared to conventional inorganic glass.

Figure 3.9 : Side view of the combustion chamber

Steam was injected directly to the combustion process through the front side of the chamber and a thermocouple was bolted to the metal flange to measure the steam temperature before it involve with the combustion process. Once the steam has been added, it shall simulate the potential of steam in increasing the fuel efficiency and reducing the emission of air pollutant by the heat combustion and flame produced.

Figure 3.10 : Front view of the combustion chamber

Figure 3.11 : Isometric view of the combustion chamber

Two thermocouple K type wire were plug from the upper side of the chamber to measure the combustion process inside. The two wires then connected to the OMEGA data logger thermometer for analyzing the result

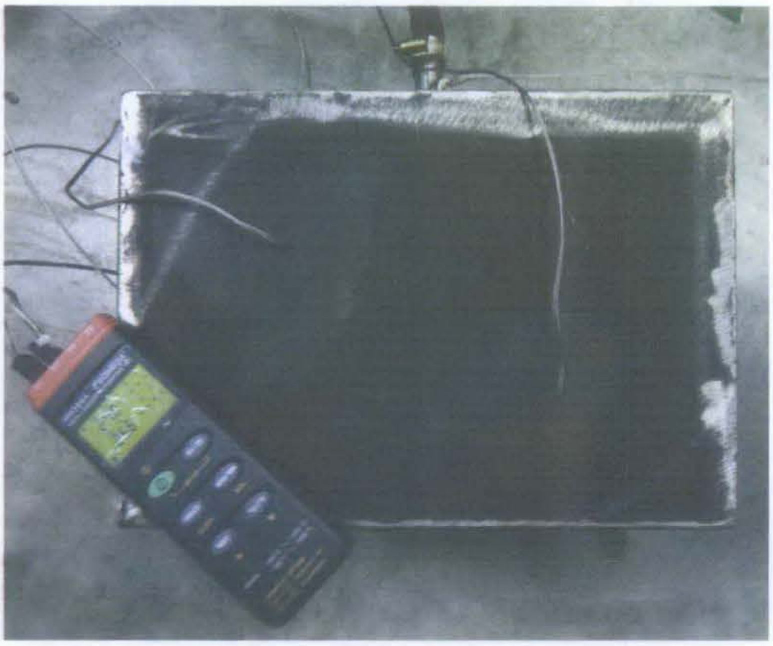


Figure 3.12 : Top view of the combustion chamber

3.2.4 Bunsen Burner

In method 2, the Bunsen burner is used to heat the fabricated combustion chamber. The Bunsen burner consists of a metal tube on a base with a gas inlet at the lower end of the tube, which has an adjusting valve; opening in the sides of the tube can be regulated by a collar to admit as much air as desired. The mixture of air and gas is forced by gas pressure to the top of the tube, where it is ignited with a match. It burns with a pale blue flame, the primary flame, seen as a small inner cone, and a secondary, almost colorless flame, seen as a larger, outer cone, which results when the remaining gas is completely oxidized by the surrounding air. The amount of air mixed with the gas stream affects the completeness of the combustion reaction. Less air yields an incomplete and thus cooler reaction, while a gas stream well mixed with air provides oxygen in an equimolar amount and thus a complete and hotter reaction. The air flow can be controlled by opening or closing the slot openings at the base of the barrel, Burner used in this experiment is designed to be used in the laboratories and schools. Operates n a 190g pierce able gas cartridge using approximately 38g/hour on continuous usage. The advantages is its saves gas, requires no unnecessary and costly gas fittings, safe and economical

3.3 Measuring Steam Temperature

The steam temperature has to be measured before it enters the combustion to study the effect of different in steam temperature to combustion efficiency. Thus a modification has to be made to the already modified flange to allow the steam temperature measurement.

Figure 3.13 : Front view of the thermocouple bolted to the modified flange

Figure 3.14 : Back view of the thermocouple bolted to the modified flange

Thermocouple K Type will be used in this project to measure the steam temperature produced by the kettle. It is bolted to the modified flange pipe before entering the combustion chamber so the length of the thermocouple sensor inside the modified flange pipe can be control not to block or disturb the steam flow.

3.3.1 K Type Thermocouple

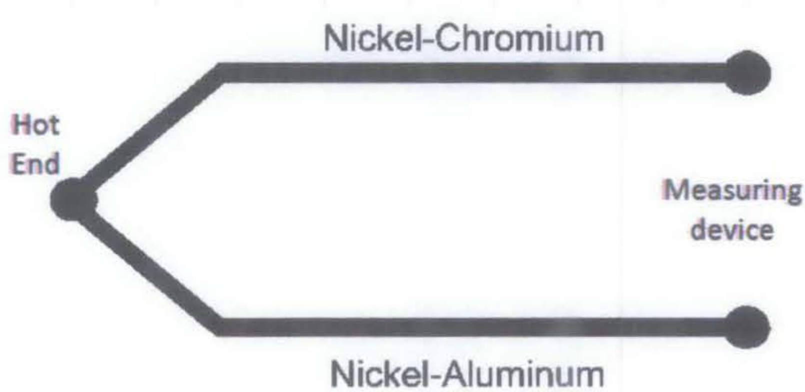


Figure 3.15: K type thermocouple diagram

Type K (chromel{90 percent nickel and 10 percent chromium}–alumel) (Alumel consisting of 95% nickel, 2% manganese, 2% aluminium and 1% silicon) is the most common general purpose thermocouple with a sensitivity of approximately 41 µV/°C, chromel positive relative to alumel. It is inexpensive, and a wide variety of probes are available in its −200 °C to +1350°C range. Type K was specified at a time when metallurgy was less advanced than it is today, and consequently characteristics may vary considerably between samples. One of the constituent metals, nickel, is magnetic. A characteristic of thermocouples made with magnetic material is that they may undergo a step change in output when the magnetic material reaches its Curie point (around 354 °C for type K thermocouples).

3.4 Silicone Rubber Braided Hose

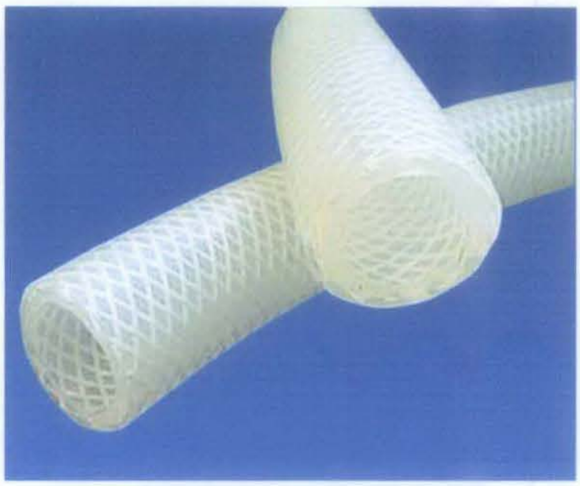


Figure 3.16: Silicone rubber braided hose

In this project, silicone braided hose will be used to connect the steam from the kettle to the combustion chamber. Silicone braided hoses is appreciated for its high strength. These braided hoses are made of premium quality silicone and suit highly demanding industrial applications. It also has multi-layer reinforcement. Silicone rubber hose is actually a quality hose that are made of natural translucent silicone rubber, a braided polyester multi-filament yarn or fiberglass reinforced. Used in diverse industry, these hose are designed to work under a wide range of temperature variation from-600 C to 1500C and for intermittent exposure up to 1800 C. It is highly resistant to chemical and does not leave behind any toxic or physiological effect. Resistance to UV and Corona discharge, this range of hose are well also suited for use with many acid and alkali.

3.5 Steam Flow Rate

Kettle is a non-flow or batch heating type applications process, the fluid is kept as a single batch within a tank or vessel. A coil heats the fluid from a low to a high temperature.

If q is the mean rate of heat transfer for such applications where, m = mass of the product (kg), c_p = specific heat capacity of the product (kJ/kg.°C), dT = Change in temperature of the fluid (°C) and t = total time over which the heating process occurs (seconds) then;

$$q = m\, c_p\, dT / t \qquad (3.5)$$

The amount of heat transfer rate calculated in equation 3.5 can be used in the equation 3.6 to calculate the amount of steam(kg) produced per second, where m_s = mass of steam (kg/s), q=calculated heat transfer (kW) and h_e = evaporation energy of the steam (kJ/kg);

$$m_s = q / he \qquad (3.6)$$

The evaporation energy at different steam pressures can be found in the Steam Table with SI Units or in the Steam Table with Imperial Units. By varying the amount of water in the kettle which is the amount of water (kg), the value of steam flow rate (kg/s) that going to be injected into the combustion chamber can be verify thus its effect on the flame and the heat produced by the combustion can be studied.

CHAPTER 4

RESULTS AND DISCUSSIONS

In this experiment, kettle which is a non-flow or batch heating type applications process is used to heat the water to produce steam. A coil heats the fluid from a low to a high temperature. The amount of steam produced by this kettle need to be verifies to study the effect of its different value to the combustion process. There are two methods being used in measuring the amount of steam produced.

4.1 Amount of Steam Calculation

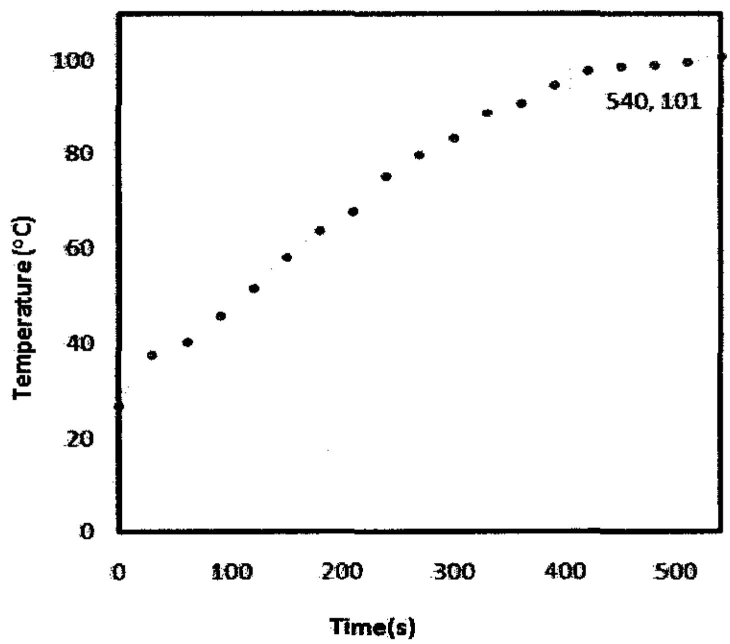


Figure 4.1 : Kettle water heating

Amount of steam injected to the combustion process in this experiment was 0.562 (gram/s), 0.471 (gram/s), and 0.351 (gram/s). Methods used for calculating the value of steam injected can be referred to Appendix F and Appendix G. The water kettle heating water is provided in Appendix H.

4.2 Combustion Characteristic (C491 Unit)

Experiment using C491 (combustion laboratory unit) cannot be continued for the time being since the gas valve of this unit was not working during the first trial of this experiment. This test should be continued once the supplier has replaced or repaired the gas valve with the new one.

4.3 Combustion Characteristic (Fabricated Combustion Chamber)

Using the two thermocouple K type wire that were plug at two different point from the upper side of the chamber, the heat produced by the combustion process were analyzed. The two wires connected to the OMEGA data logger thermometer to verify the combustion heat reading.

4.3.1 Without steam injection

For the first setup of this experiment, the normal combustion process was run. The burner used a 190g pierce able gas cartridge using approximately 38g/hour on continuous usage. The valve opening in the sides of the tube was fully open to ensure the same amount of air was used in the combustion process for the whole experiment setup. The heat produced by normal combustion process without any steam injection were analyzed using the two thermocouple wire plug at two different point that connected to the OMEGA data logger thermometer. The data collected by both point than were plotted in the graph.

Table 4.1 : Normal combustion chamber temperature

	Temperature	
time	**point 1**	**point 2**
0	27.6	27.7
30	139	127.3
60	142	146.9
90	148.7	148.9
120	152.9	151.9
150	165	163.7
180	164.7	166.9
210	167.2	167.4
240	179.5	180.6
270	180.1	181.3
300	189.2	185.7

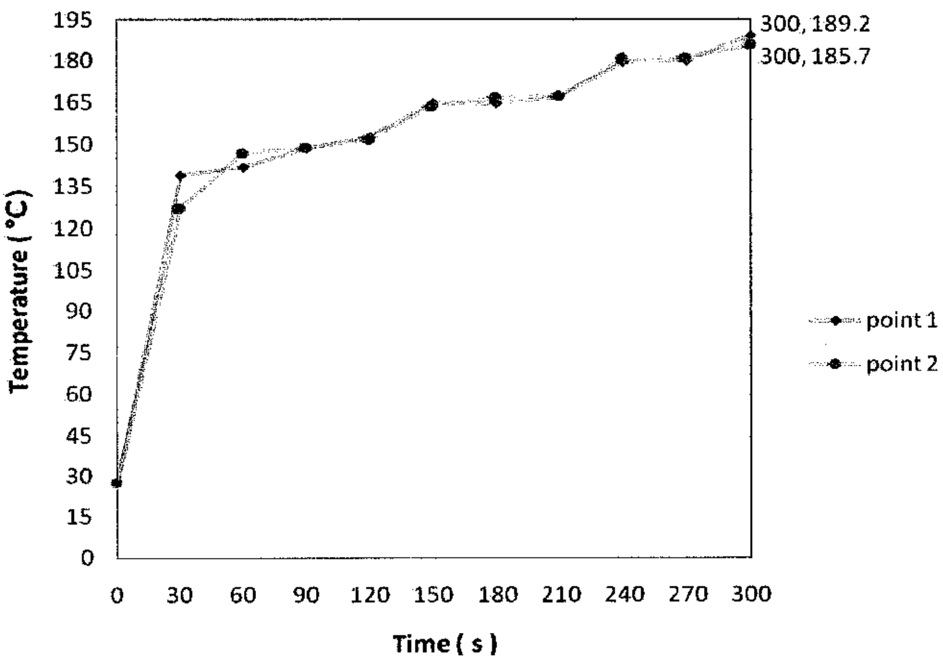


Figure 4.2 : Combustion chamber without steam injection temperature

Time it takes for the combustion process to reach the maximum temperature is 5 minutes (300s) and the maximum temperature produced is 189.2 °C. Based on the data plotted, the heat produced by the normal combustion process was rapidly increased during the 30 seconds of the combustion process. Point 1 producing higher heat detected compare to point 2 due to the location of point 1 that is nearer to the center of burner tip. Point 1 reach its maximum temperature which is 189.2°C in 5 minutes while point 2 reach its maximum temperature, 185.7°C in 5 minutes of combustion process.

4.3.2 Combustion characteristic with 0.562 (gram/s) of steam injection

The experiment then continued with a 0.562 (gram/s) of steam injection to the combustion process by using 2.2 liter of water. The Bunsen was setup the same as the previous set up where sides of the tube was fully open to ensure the same amount of air was used.

Table 4.2 : Combustion chamber temperature with 0.562 (gram/s) of steam added

	Temperature	
time	**point 1**	**point 2**
0	30.1	28.6
30	136.4	134.7
60	146.7	149
90	153.4	156.7
120	158	157.7
150	170.3	166.4
180	175.7	167.6
210	183.4	177.9
240	190.2	184.7
270	189.6	186.5
300	190	188.4

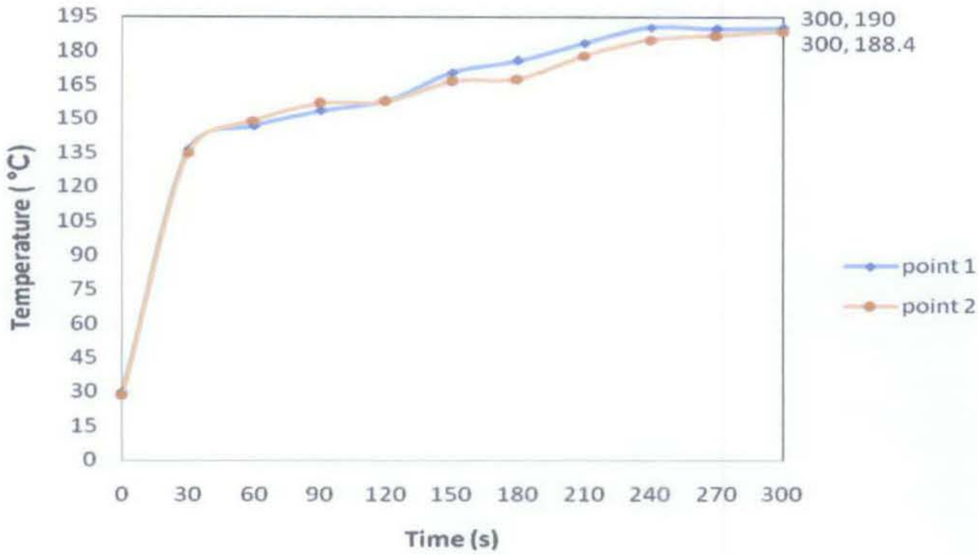


Figure 4.3 : Combustion chamber temperature with 0.562 (gram/s) of steam added

Time it takes for the combustion process with 0.562(gram/s) of steam injection to reach the maximum temperature (190.2°C) is 4 minutes, 1 minutes quicker compare to the normal combustion process. As expected, point 1 show a higher heat produced due to its location that is neared to the center of the burner tip.

4.3.3 Combustion characteristic with 0.475 (gram/s) of steam injection

The experiment then continued with a 0.475 (gram/s) of steam injection to the combustion process by using 1.8 liter of water. The Bunsen tube was fully open to ensure the same amount of air was used for this combustion process with the other combustion set up. The data collected using the OMEGA data logger thermometer then plotted to the graph.

Table 4.3 : Combustion chamber temperature with 0.475(gram/s) of steam added

	Temperature	
time	**point 1**	**point 2**
0	29.5	30.1
30	136.7	136.4
60	145.5	144.2
90	150.4	148.1
120	158	159.8
150	170.3	166.3
180	175.3	167.6
210	180.4	180.1
240	187.4	182.4
270	187.3	184.6
300	188.7	185.4

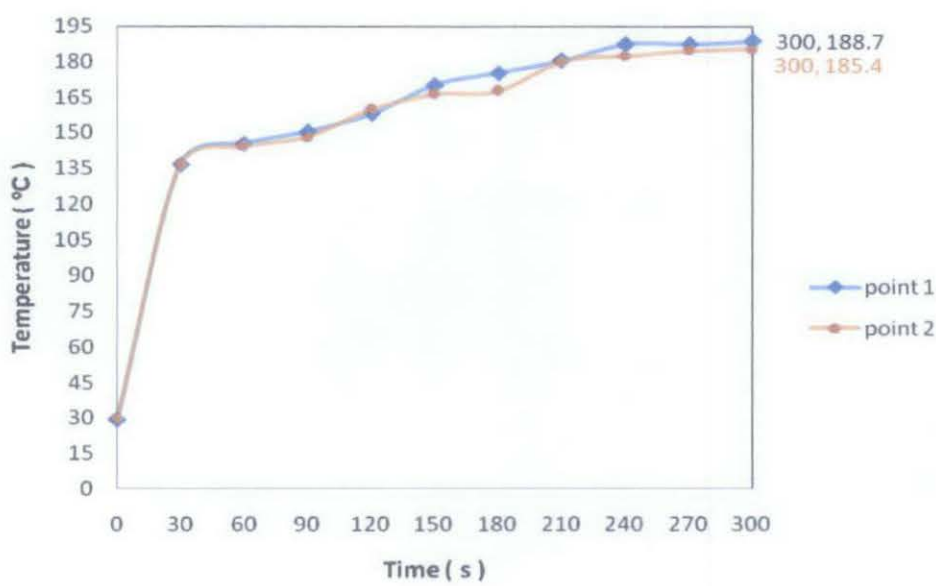


Figure 4.4 : Combustion chamber temperature with 0.475(gram/s) of steam added

Time it takes for the combustion process with 0.475(gram/s) of steam injection to reach the maximum temperature (188.7°C) is 5 minutes, same as the normal combustion process.

4.3.4 Combustion characteristic with 0.351 (gram/s) of steam injection

1.3 liter of water was used to produced 0.351 (gram/s) of steam that were injected to the combustion process. The Bunsen setup was the same as the previous set up where sides of the tube was fully open to ensure the same amount of air was used.

Table 4.4 : Combustion chamber temperature with 0.351 (gram/s) of steam added

	Temperature	
Time	**point 1**	**point 2**
0	30.5	31.7
30	127.9	135.4
60	139.47	143.8
90	147.6	149.9
120	158.6	158
150	171.3	169.4
180	176.6	173.2
210	180	176.8
240	184.7	183
270	188.9	186.6
300	188.6	186.9

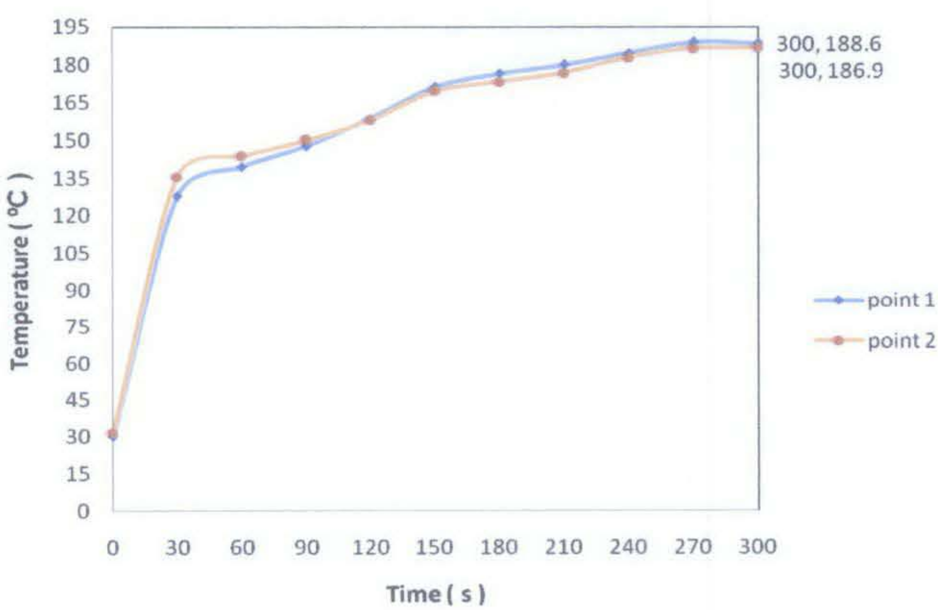


Figure 4.5 : Combustion chamber temperature with 0.351 (gram/s) of steam added

Time it takes for the combustion process with 0.351 (gram/s) of steam injection to reach the maximum temperature (188.9°C) is 4.5 minutes (270s), 30 seconds quicker compare to the combustion process with 0.471 (gram/s) of steam injection.

4.4 Result Comparison

Since point 1 shows higher reading at each test, it was choose to compare the heat produced by the combustion with all the other experiment set up. There are a total a total of 4 set up for this experiment, normal combustion process, combustion with 0.562(gram/s), 0.471(gram/s) and 0.351(gram/s) of steam injected. Data collected for all the experiment using point 1 was shown in table 6.

Table 4.5 : Combustion chamber temperature comparison

	Point 1			
Time	No steam	0.56 (gram/s)	0.47 (gram/s)	0.351 (gram/s)
0	27.6	30.1	29.5	30.5
30	139	136.4	136.7	127.9
60	142	146.7	145.5	139.47
90	148.7	153.4	150.4	147.6
120	152.9	158	158	158.6
150	165	170.3	170.3	171.3
180	164.7	175.7	175.3	176.6
210	167.2	183.4	180.4	180
240	179.5	190.2	187.4	184.7
270	180.1	189.6	187.3	188.9
300	189.2	190	188.7	188.6

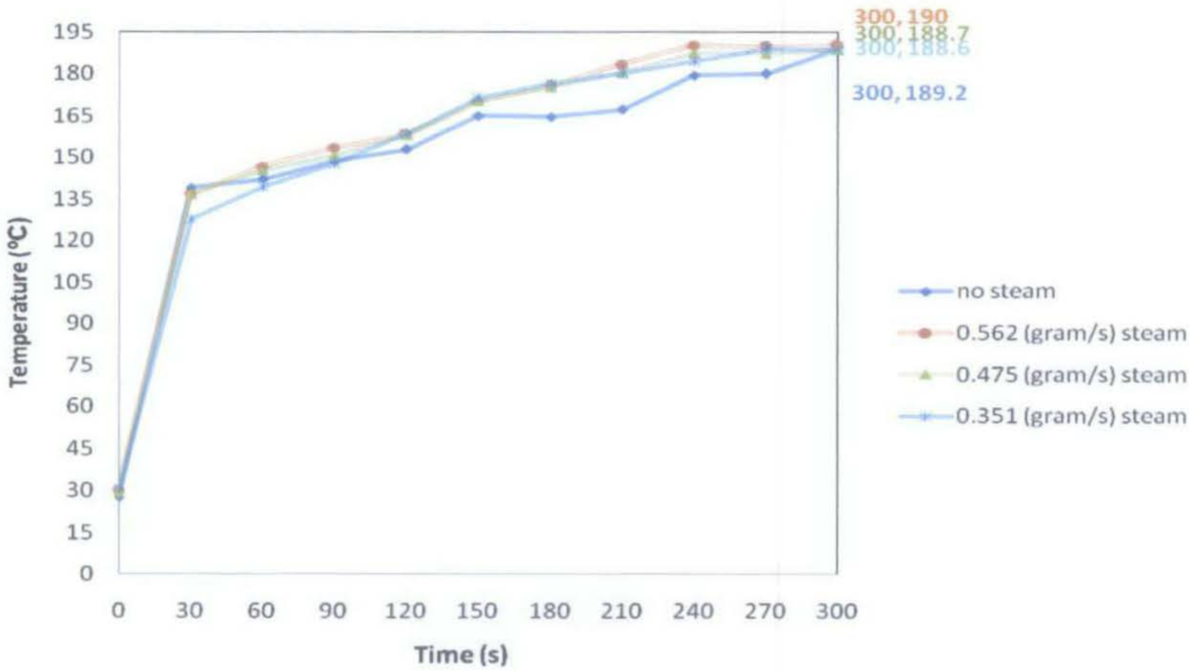


Figure 4.6 : Comparison of combustion chamber temperature

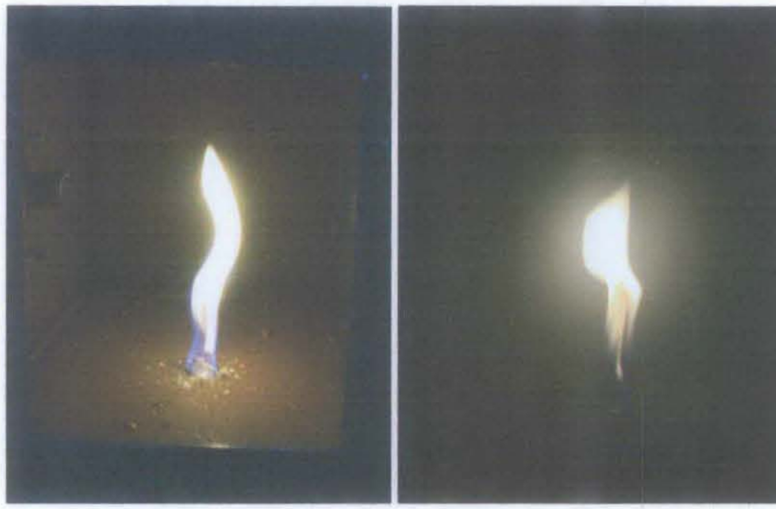
Based on the graph in Figure 4.6 is shown that with the steam injection, the heat produce by the combustion increase starts from the first 30 seconds of the process. It then continuously increases faster than the normal combustion process. As for example, for 0.562(gram/s) of steam injected, at 150 seconds, the combustion chamber reached 170.3°C while the normal combustion only reached 165°C. 1 and a half minutes later, at 240 seconds, the combustion heat with 0.532(gram/s) reached 190.2°C while the normal combustion is 179.5 °C. Based on this reading, with the steam injection, the heat produced increase around 20°C in 1 and a half minutes while without the steam injection, it increase only around 14 °C. From my testing result it shows that after the steam injection to the flame, combustion performance increase from the starting of combustion but in the last stage (max temperature) it was slightly the same. It means after inject the steam in the combustion chamber, lead time to reach maximum temperature was shorter than before.

4.5 Flame Characteristic

The Bunsen burner gas valve was fully open and the air hole is closed for all the test to ensure the burner provide the same amount of heat and type of flame in every different amount of steam injected and also before the steam injection.

Figure 4.7: LPG flame photographs with no steam injection

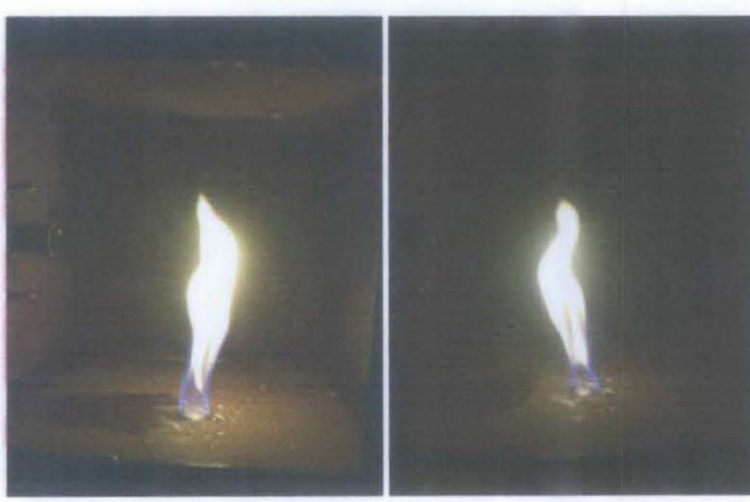
Using the same amount of air and gas provided by the burner, the experiment was proceed with a 0.562(gram/s) amount of steam injected to the flame. The steam was generally injected directly to the flame to ensure it mixing well with the flame thus enhancing the combustion. The results show that with 0.562(gram/s) of steam injection, the flame was yellow, noise level of the flame/combustion was lower and the flame fluttering a little. This is the same type of flame produced with the normal combustion process.



(a) (b)

Figure 4.8 : (a) LPG flame photographs with 0.562 (gram/s) of steam injection after reach maximum temperature. (b) Initial photo of LPG flame after 0.562 (gram/s) was injected.

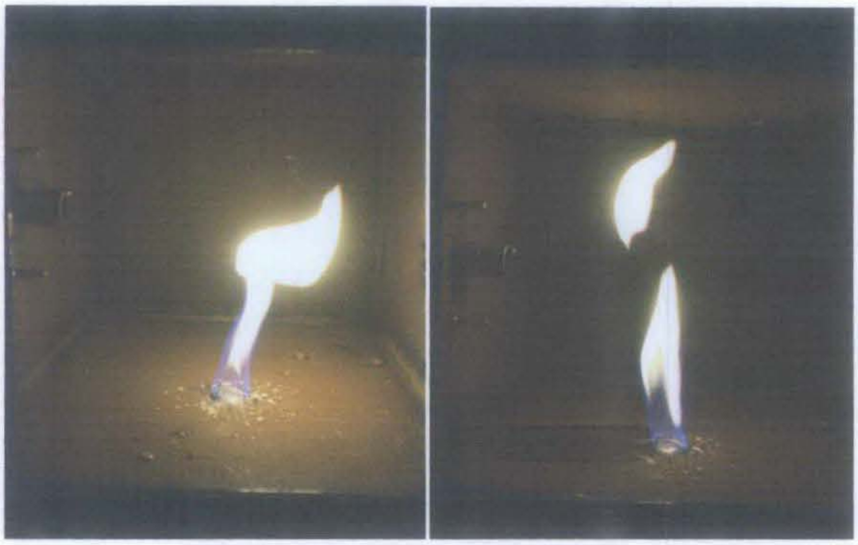
The amount of steam injected then lowered to 0.475 and the type of flame produced was photographed. It shows that the combustion still produced the same type of flame with the previous amount of steam injected.



(a) (b)

Figure 4.9 : (a) LPG flame photographs with 0.475(gram/s) of steam injection after reach maximum temperature. (b) Initial photo of LPG flame after 0.471 (gram/s) was injected.

The last setup for the experiment was using a 0.351(gram/s) amount of steam. The combustion process still produced the same type of flame with the others which is yellow, fluttering a little and the noise level of combustion was lower.



(a) (b)

Figure 4.10 : (a) LPG flame photographs with 0.351 (gram/s) of steam injection after reach maximum temperature. (b) Initial photo of LPG flame after 0.351 (gram/s) was injected.

In this experiment under normal gravity conditions and with a closed oxygen valve, a Bunsen burner burns with yellow flame (also called a safety flame) at around 1,000 °C (1,800 °F). After the steam injection for both 3 amount, the effect to the flame characteristic cannot be differentiate. All both experiment including the normal combustion without the steam injection produce the same type of flame which is yellow, noise level lower and fluttering a little.

CHAPTER 5

CONCLUSIONS AND RECOMENDATIONS

From the research that have been made until now, combustion process involving a steam has a possibilities in reducing energy consumption. Reducing energy consumption translate directly into fuel saving. This is because, steam does not act as an inert diluent but instead inhibits carbon formation and gives rise to a greater heat release than in its absence. The additional heat release, in turn, partly counteracts the cooling effect of the added steam, so that the flame temperature and burning velocity do not decrease with steam addition to the extent they would if steam were an inert heat sink, provided the equilibrium state is attained.

After the steam injection to the flame, combustion performance increase from the starting of combustion but in the last stage (max temperature) it was slightly the same. It means after inject the steam in the combustion chamber, lead time to reach maximum temperature was shorter than before. In the most common type of flame, hydrocarbon flames, the most important factor determining color is oxygen supply and the extent of fuel-oxygen pre-mixing, which determines the rate of combustion and thus the temperature and reaction paths, thereby producing different color hues but all the experiment including the normal combustion without the steam injection produce the same type of flame which is yellow, noise level lower and fluttering a little. This is possibly because the steam was not well mix and not in the smooth flow condition when injected to the combustion process.

Fire flame will supposedly changed change color if the steam well mixes with air and LPG. The combustion process that is well mix with the flame will supposedly produce bluish color of flame which states a good combustion condition that produced less amount of pollution emission. This setup for this experiment will actually needs the steam to be injected at two areas, at the mixer, where air and gas are mix together and at the flame area. The steam flows have to be constant for an easier control with a high pressure of air supply around 5(kgf/cm^2). For the flame area, the steams have to be fully vaporized and mix well with the flame. Since I am using a Bunsen burner, a modification to inject the steam at the mixer area was not possible, only at the flame had been done.

My recommendation is a modification can be done to the C491 combustion unit to allow the process of injection steam to the mixer area (air + gas) once the machine have been repaired. The effect of steam injection to the combustion later can be study to analyze its effect in enhancing the combustion efficiency and reducing pollution emissions.

REFERENCES

Ed, H.B. 1996. Automotive Handbook (4th ed.). Stuttgart: Robert Bosch GmbH. pp. 238–239.

Bustan, M.D. 2006, *Effect of Steam Injection Flow in Burner and Outside Water Tube to the Increasing of Boiler Temperature*, Department of Chemical Engineering, University of Sriwijaya, Indonesia.

Dethlefs, M. and Schlader A.F., 2003, “Combustion and flame”, Max-Planck Institut für Strömungsforschung, 34 Göttingen, West-Germany.

Qi, D., Bian, Y., Ma, Z., Zhang, C., Liu, S., 2007. "Combustion and exhaust emission characteristics of a compression ignition engine using liquefied petroleum gas–fuel-oil blended fuel". *Energy Conversion and Management* **48** (2): 500.

Singh, R.P., 2001, “Introduction to Food Engineering. Academic Press”, New York. 301 pp.

Zhang, C., Bian, Y., Si, L., Liao, J., Odbileg, N., 2005. "A study on an electronically controlled liquefied petroleum gas-diesel dual-fuel automobile", Proceedings of the Institution of Mechanical Engineers, Part D: *Journal of Automobile Engineering* **219 (2)**: 207.

The steam tables list the properties of saturated steam at varying pressures and temperatures

Absolute pressure (kPa, kN/m^2)	Temperature (°C)	Specific Volume (m^3/kg)	Density - ρ - (kg/m^3)	Specific Enthalpy of Liquid - h_l - (kJ/kg)	Specific Enthalpy of Evaporation - h_e - (kJ/kg)	Specific Enthalpy of Steam - h_s - (kJ/kg)	Specific Entropy of Steam - s - (kJ/kgK)
0.8	3.8	160	0.00626	15.8	2493	2509	9.058
2.0	17.5	67.0	0.0149	73.5	2460	2534	8.725
5.0	32.9	28.2	0.0354	137.8	2424	2562	8.396
10.0	45.8	14.7	0.0682	191.8	2393	2585	8.151
20.0	60.1	7.65	0.131	251.5	2358	2610	7.909
28	67.5	5.58	0.179	282.7	2340	2623	7.793
35	72.7	4.53	0.221	304.3	2327	2632	7.717
45	78.7	3.58	0.279	329.6	2312	2642	7.631
55	83.7	2.96	0.338	350.6	2299	2650	7.562
65	88.0	2.53	0.395	368.6	2288	2657	7.506
75	91.8	2.22	0.450	384.5	2279	2663	7.457
85	95.2	1.97	0.507	398.6	2270	2668	7.415
95	98.2	1.78	0.563	411.5	2262	2673	7.377
100	99.6	1.69	0.590	417.5	2258	2675	7.360
101.33	**100**	**1.67**	**0.598**	**419.1**	**2257**	**2676**	**7.355**
110	102.3	1.55	0.646	428.8	2251	2680	7.328
130	107.1	1.33	0.755	449.2	2238	2687	7.271
150	111.4	1.16	0.863	467.1	2226	2698	7.223
170	115.2	1.03	0.970	483.2	2216	2699	7.181
190	118.6	0.929	1.08	497.8	2206	2704	7.144
220	123.3	0.810	1.23	517.6	2193	2711	7.095
260	128.7	0.693	1.44	540.9	2177	2718	7.039
280	131.2	0.646	1.55	551.4	2170	2722	7.014
320	135.8	0.570	1.75	570.9	2157	2728	6.969
360	139.9	0.510	1.96	588.5	2144	2733	6.930
400	143.1	0.462	2.16	604.7	2133	2738	6.894
440	147.1	0.423	2.36	619.6	2122	2742	6.862
480	150.3	0.389	2.57	633.5	2112	2746	6.833
500	151.8	0.375	2.67	640.1	2107	2748	6.819
550	155.5	0.342	2.92	655.8	2096	2752	6.787
600	158.8	0.315	3.175	670.4	2085	2756	6.758

Procedure identification for the project execution in eachstage.

Get familiar with the apparatus or machine.

For the first step of this project, it will more focus more on understanding the proper step in operating both the burner and the boiler. Study the manual for both machines help to find out the concept of both machine and how it actually operates to produce the output. Other than that is to study the characteristic of the element involve which is LPG and steam.

Design or modifying the best applicable connector and combustion chamber for the steam injection.

After familiar with the machine also the flow of the experiment, the conducting stage will take over. For method 1 which using C491 combustion unit, there are two main job to be done in this stage that are designing and new flange and a hose connection for steam introduction and the experimental work. Experimental work is more on analyzing the effect of steam in energy saving (save fuel) and reduction in emission of air pollutant producing but firstly, the new design of hose/piping for the steam introduction need to be done since there is no available hose/piping input to the combustion chamber that were can be use for steam injection. Therefore, a new hose/piping system and some modification to combustion units have to be proposed to allow steam from the boiler to be added to the combustion process. For method 2, a new combustion chamber will be design based on this project requirement and the best way for the steam to be injected to the combustion process should be analysed.

Development of the connector and combustion chamber

After completed the steam injection system design with considering all the safety requirement and the applicability of the steam flow to the combustion chamber, the next stage is to fabricate the piping for the C491 unit and the new combustion chamber that have been fully analyzed.

Testing and analysis of the new design

Next stage is to test and analyse the new hose/piping design and the fabricated burner chamber to ensure its function well in providing steam to the combustion chamber before proceed to the experimental work. The entire safety requirement must be applied during the first time run of the new fabricated piping.

Perform the experimental work

Run the combustion with the steam injection to it after the first time run of the new piping satisfy all the safety issues and requirement. The quantity of air, fuel (LPG), steam can be modify to study the variation in the result. For method 2, using a newly fabricated combustion chamber, 3 different amount of steam flow rate will be injected to analyse its effect to the combustion process.

Analyze the results

The last process flow is analyzing the result data from the experimental work. In this project, we will investigate the possibilities of steam in saving fuel and reducing emission of air pollutant by the built in thermometer at the back of the burner which can measure the combustion heat from various angle and also by studying the combustion flame through the burner glass. For method 2, a thermocouple that been plug inside the combustion chamber will be used for analysing the heat produced and an observation hole that covered with perspex use to observe the flame characteristic.

APPENDIX C

No	Details	Week 1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Selection of Project Topic	■														
2	First meeting with my supervisor		■													
3	Preliminary work															
	a) Get familiar with the boiler and burner operation			■	■	■	■		■							
	b) Research about the suitable design for the experiment					■	■		■							
4	Preliminary Report preparation			■												
5	Submission of Preliminary Report (15 February2008)				●											
6	Seminar 1 (optional)					■	■									
7	Progress report preparation								■							
8	Submission of Progress Report (17 March 2008)									●						
9	Study the effect of steam to the combustion process									■	■	■				
10	Research for the best method for the experiment									■	■	■				
11	Proposed the piping design for steam injection											■	■	■		
12	Seminar 2 (compulsory)										■	■	■	■		
13	Submission of Interim Report Final Draft														●	
14	Oral Presentation preparation													■	■	
15	Oral Presentation (Week 14)															●

Mid semester break ▭ Process ■ Suggestion milestone ●

Gantt chart for the first semester

No	Details	Week 1	2	3	4	5	6		7	8	9	10	11	12	13	14
1	Piping Fabrication	■	■	■												
2	Submission of Progress Report 1				●											
3	Project works continues				■	■	■									
4	Submission of Progress Report 2									●						
5	Seminar(compulsary)									●						
6	Project works continues								■	■	■	■	■	■	■	■
7	Poster exhibition												●			
8	Submission of Dissertation Final Draft															●
9	Oral Presentation															●
10	Submission of Dissertation (Hard Bound)															●

● Suggestion milestone ■ Process

Gantt chart for the second semester

Requirement for c491 (combustion laboratory unit) operation

a) Air

A medium pressure air blower is supplied to produce a maximum of 160 kg/h which is regulated to a constant pressure of 250 mm water gauge.

b) Water

Cooling water from mains is required with a minimum flow rate of 1800 kg/h (4000lb/h). The connection at the lower end of the flow meter on the left hand control panel is of the compression type suitable for an inlet pipe of 25mm outside diameter. A 3 m length of suitable 25 mm inside diameter flexible hose is supplied.

c) Electric Power

A blower fan is supplied to operate on 240/1/50Hz or 110/1/60Hz with direct on line starters. The electrical ignition and flame failure systems are operated from the same power source.

d) Fuel (liquid)

Any suitable container can be used as a reservoir but should be placed at least 1.5 meters (5ft) above the burner.

e) Gaseous Fuels (*LPG* , propane , butane)

If installed specifically for the C491 Unit the pressure from the bottled supply should be reduced less than 0.75 Bar by a first stage regulator of 25 kg/h capacity.

This reduced pressure may then be introduced to the fixed second stage regulator situated at the base of C491 unit steel frame.

The fixed second stage regulator situated at the base will further reduce the gas pressure to between 125 and 500mm water gauge pressure suitable for supply to the burner.

f) Mains Gas

If the locally available mains gas supply pressure is between 125 and 500mm water gauge then this may connected directly to the base of the gas fuel flowmeter bypassing the fixed second stage regulator.

In the event that local mains gas supply pressure is above 500mm water gauge and below 0.75 Bar the supply should be connected to the inlet of the fixed second stage regulator at the base of the C491 frame.

g) Drainage

Provided for cooling water from the combustion chamber and from the water cooled sampling probe.

Ignition procedure – Gaseous Fuel (LPG)

1) Turn on the gas at the supply only. Check that gas pressure at the manometer is between 125 and 500 water gauge by depressing the green pressure check button to control panel. Using a suitable screwdriver, rotating the internal adjuster to increase the pressure.
2) Turn on the main water supply. Slowly open the water control valve to the chamber and adjust the flow to 1800 kg/h. Maintain this flow until the outlet is seem to be running fuel.
3) Reduce the water flow to 1600 kg/h
4) Switch on the mains electricity supply and the master switch at the unit.
5) Open the air control to position 1 and switch on the air fan. Wait for the motor to reach normal operating speed.
6) Open the air control to a flow at least 170 kg/h and run for at least 1 minutes at this setting to purge the chamber
7) Reduce the air flow to 120 kg/h
8) Set the cut out on the final water temperature meter to 80°C
9) Press the "press to reset" button. Switch on the set switch and check that the red light on the water outlet temperature gauge is illuminated.
10) After 5 second delays the reset switch red indicating light on the control panel illuminates to indicate that the flame failure system is operational.
11) Press and hold the ignition switch
12) At the same time quickly open the gas fuel control valve to give an indicated flow rate of 8 kg/h.
13) When the flame is established release the ignition switch and allow the system to stabilize.
14) Stable running conditions are indicated by a steady cooling water and exhaust gas temperatures and also a steady exhaust note

Methods used for calculating the value of steam injected

Method 1

Water used in the kettle was at room temperature (23 °C) has a density of 0.997 g/cm3 and 1cm^3 is 1 ml.

So, 1 liter = 0.997kg = 997 gram

Total volume of water used in the kettle in ; 1st test : 2.2 L

2nd test : 1.8 L

3rd test : 1.3 L

The mean rate of heat transfer for such applications can be expressed as:

$$q = m\ c_p Dt / t$$

q = mean heat transfer rate (kw(kJ/s))

m = mass of the product (kg)

c_p *= specific heat capacity of the product (kJ/kg.K)*

Dt = Change in temperature of the fluid (K)

t = total time over which the heating process occurs (seconds

If we know the heat transfer rate – the amount of steam can be calculated:

$$m_s = q / h_e$$

m_s *= mass of steam (kg/s)*

q = calculated heat transfer (kw)

h_e *= evaporation energy of the steam (kJ/kg)*

The evaporation energy at different steam pressures can be found in the Steam Table with SI Units refer appendix.

1st test, volume of water = 2.2 L

2.2 L of water equal to 2193.4 gram = 2.193 kg

m = mass of the product =2.193 kg

c_p = specific heat of water = 4.187 kJ / kg K

Dt = change in temperature of the water= 101 °C – 27 °C = 74 °C = 74 K

t = time = 540 s

Kettle heat transfer rate = q = (2.193 kg) (4.187 kJ/kg K) (74 K) / 540 s

= 1.25 kJ/s (kw)

Maximum temperature of steam produced by the kettle with 2.2 L water is 113.2 °C

Based on the table, the evaporation energy of the steam (kJ/kg) at 113.2 °C = 2221.6 kJ/kg

The amount of steam produced (kg/s) ; $m_s = q / h_e$

q = (1.25 (kJ/s))/(2221.6 (kJ/kg))

= 5.626 x 10^{-4}kg/s = 0.562 gram/s

2nd test, volume of water = 1.8 L

1.8 L of water equal to 1794.6 gram = 1.794 kg

m = mass of the product = 1.794 kg

c_p = specific heat of water = 4.187 kJ / kg K

Dt = change in temperature of the water = 100.1 °C – 27.6 °C = 72.5 °C

t = time = 515 s

Kettle heat transfer rate = q = (1.794 kg)(4.187 kJ/kg K)(72.5 K)/515 s
= 1.06 kJ/s(kw)

Maximum temperature of steam produced by the kettle with 1.8 L water is 110.1 °C

Based on the table, the evaporation energy of the steam (kJ/kg) at 110.1 °C = 2229 kJ/kg

the amount of steam produced (kg/s) ; $m_s = q / h_e$

q = (1.06(kJ/s))/(2229(kJ/kg))

= 4.755 x 10^{-4}kg/s= 0.475gram/s

3^{rd} test, volume of water = 1.3 L

1.2 L of water equal to 1296.1 gram = 1.296 kg

m = mass of the product = 1.296 kg

c_p = specific heat of water = 4.187 kJ/ kg K

Dt = change in temperature of the water = 100 °C – 26.9 °C = 73.1 °C

t = time = 508 s

Kettle heat transfer rate = q = (1.296kg) (4.187 kJ/kg K) (73.1 K) / 508 s
= 0.78 kJ/s(kw)

Maximum temperature of steam produced by the kettle with 1.3 L water is 114.7 °C

Based on the table, the evaporation energy of the steam (kJ/kg) at 114.7 °C = 2217 kJ/kg

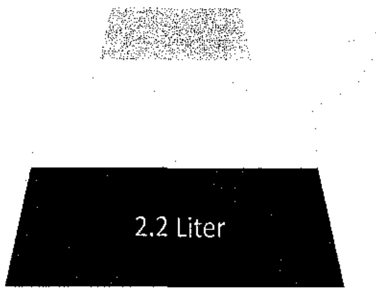
The amount of steam produced (kg/s) ; $m_s = q / h_e$

q = (0.78(kJ/s))/(2217(kJ/kg))

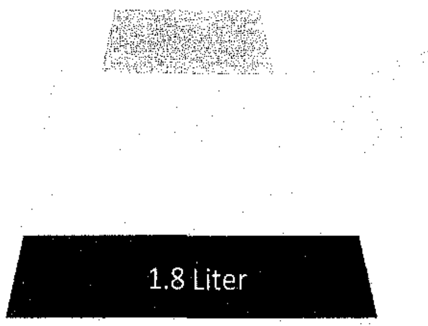
= 3.518 x 10^{-4}kg/s = 0.351 gram/s

Method 2

Before heating;



After heating for 12 minutes = 720 s;



Total volume of water lost; 2.2 Liter – 1.8 Liter = 0.4 Liter

I liter = 997gram

0.41 Liter x (997 gram/ 1 Liter) x 1 / 720 s = 0.567 (gram/s)

For 2.2 Liter of water used, the amount of steam produced is 0.567 (gram/s). The amount of steam calculated by both methods more or less the same.

Kettle water heating

Time	Temperature (°C)
0	27
30	37.7
60	40.3
90	46
120	51.7
150	58.2
180	63.9
210	67.7
240	75.4
270	80
300	83.6
330	88.9
360	91
390	94.7
420	98
450	98.9
480	99.1
510	99.7
540	101

Job Safety Analysis (JSA)

Title of Job Operation	Handling of C491Combustion Unit	Date		Ref. No.	Mech/JSA/ 001
Title of Person Who Does The Job	Technician	Employee Observed		GhaniMihat (Assistant of UTP Lab Department)	
Location	Block 15				
Department/Program:	Mechanical Eng.	Prepared By:		M Sani (Head of UTP Lab Department)	
Section/ Lab:		Approved By:		Dollahsalleh (Assistant of UTP Lab Department)	

Sequence of Basic Job Steps	Potential Accidents or Hazards	Recommended Safe Job Procedure
1. Steam flow in the hose	1.1 Hose wall rupture due to internal pressure 1.3 Steam gas leak from the flange welding area	1.1.1 Use silicone rubber braider hose usually used for high pressure pipeline 1.3.1 Manpower must wear face mask and protective clothing during the process 1.3.2 Standby fire extinguisher

2. Steam introduction to the combustion chamber	2.1 Fire and explosion	2.1.1 Wear protective clothing including glove and goggle 2.1.2 Monitor from far during the first time run 2.1.3 Barricade the combustion area 2.1.4 Standby fire extinguisher