Sudan University of Science and Technology

Faculty of Engineering

School of Mechanical Engineering

Power Department

Title:

Design and Fabrication of Small Scale Biomass Units (Wood boiler)

A Project submitted in partial fulfillment for the requirements of the Degree of B.Eng. (Honors) in Mechanical Engineering

(Power Department)

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الآيـــــــة

قال تعالى:

﴿ الَّذِي جَعَلَ لَكُمْ مِنَ الشَّجَرِ الْأَخْضَرِ نَارًا فَإِذَا أَنْتُمْ مِنْهُ تُوقِدُونَ (80)
أَوَلَيْسَ الَّذِي خَلَقَ السَّمَاوَاتِ وَالْأَرْضَ بِقَادِرٍ عَلَى أَنْ يَخْلُقَ مِثْلَهُمْ بَلَى وَهُوَ
الْخَلَّاقُ الْعَلِيمُ (81) إِنَّمَا أَمْرُهُ إِذَا أَرَادَ شَيْئًا أَنْ يَقُولَ لَهُ كُنْ فَيَكُونُ (82)
فَسُبْحَانَ الَّذِي بِيَدِهِ مَلَكُوتُ كُلِّ شَيْءٍ وَإِلَيْهِ تُرْجَعُونَ (83) ﴾

[سورة يس]

Dedication

I dedicate the result of this effort:

To the most precious thing I own ,,,,,,,,,,,

My beloved mother

To those who taught me,,,,,,,,,,,,,,,,,,,,,

My dear father

To Aunt Magbolla, brother Rabee and all friends.

Acknowledgment

In the name of Allah the most gracious and the most the most merciful Alhamdulillah, all praises to Allah for the strength and his blessing in completing this thesis .

I wish to express my thanks to my supervisor Dr.Musab Hassan Zarroug, this thesis would not have been complete without his expert advices and unfailing patience.

I would like to express special word of thanks to Dr.Abualnour Abdeen and Engineer Kamal Abugesesa.

Last but not least my deep thanks to my family and friends for their encouragement.

Abstract

The aims of this thesis is to design and fabricate a boiler that uses Mesquite wood as an alternative fuel to fossil fuels and approve Mesquite wood to produce vapor that can be used to generate electricity , beside that encourage the government to get off Mesquite trees which effect badly in the environment and reduce the environmental pollution.

تجـريدة

تتلخص هذه الدراسة في تصميم وتصنيع غلاية تعمل بخشب المسكيت كوقود بديل للوقود الاحفوري وإثبات كفاءة خشب المسكيت لانتاج بخار ومن ثم استخدامة في عديد التطبيقات خصوصا انتاج الكهرباء ومن ثم تشجيع الجهات الحكومية على التخلص من شجر المسكيت الذي يضر بالبيئة وتقليل استخدام الوقود الاحفور الذي يلوث البيئة بشكل أكبر.

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Chapter One

Introduction

1.1 Introduction

It is now generally accepted that human activities have substantial effects on global warming and that the reduction of greenhouse gas emissions is a vital goal for the coming decades: for instance, the Kyoto protocol is an international agreement based on these assumptions. The use of renewable energy sources for power generation can make a major contribution in this direction. Amongst them, biomass seems to be particularly interesting, because it combines the main advantage of renewable energies (CO2-neutrality) with the ability to be accumulated and exploited through a combustion process, coupling its conversion with more traditional technologies, thus also allowing combined heat and power production. Besides, a considerable potential of this resource is available almost all over the world. In particular woody biomass is the most abundant type and is suitable for power generation.

Biomass power generation is mostly realized in large plants, but its exploitation can be even more interesting on small sizes, due to the difficulty in supplying large quantities of raw material to feed plants, the higher possibility of performing a cogenerated waste heat recovery and the very low environmental impact of the installations. Besides, small plants often enjoy higher economic incentives than larger ones.

Small scale biomass power plants have been widely investigated in recent years:

Literature is proposing several technical solutions. Nevertheless, undoubtedly preferable plant configurations have not been identified yet, which is also due to the recent development in the sector. Moreover, a comparison of their performances is often difficult because investigations are being carried out referring to different operating conditions.

Basing on these considerations, the aim of the present thesis is to perform a full assessment of small-scale biomass fired power generation technologies, focusing on woody resource, in order to allow a complete comparison and identify the most promising solutions from a thermodynamic and an economic point of view.

Wood combustion and gasification are the biomass conversion processes taken into account, while pyrolysis has been neglected since it is not considered a forthcoming technology. On the other hand, internal combustion engines, (micro) gas turbines, both internally and externally fired, and organic Rankine cycles have been considered as power plants.

The most performing solutions then have been subject to an economic analysis, which provides considerable economic incentives for power generation from renewable energy sources [1].

1.2 Problem Statement

Sudan has a steadily increasing requirement for fossil diesel for both transport and electricity generation in regional areas beyond the national electricity grid. There is a growing awareness that biomass produced in Sudan could be blended with the available fossil diesel, resulting in many positive economic, social and environmental benefits. However, using non-food biomass feedstock could help to achieve sustainable, very low emission and cost-effective biomass production through successful development of advanced biomass technologies.

1.3 Project significance

The importance of research is to:

1- The importance of research is to find a way to use biomass as an alternative fuel for the production of electrical power in Sudan

2- To reduce the use of fossil fuels in thermal generation plants and especially in the summer

3-Disposal of environmentally harmful trees and uses them to generate power

1.4 Objective

The objectives of the project is design and fabricate of small scale biomass units using woody fuel to generate power that reaches 5 MW.hr .The tests and analysis processes for Mesquite trees

1.5 Methodology

- **i.** Preparing the samples
- **ii.** Testing the samples to find the calorific value
- **iii.** Choosing the type of the design of the boiler
- **iv.** Designing the boiler
- **v.** Fabricating the boiler
- **vi.** Testing the fabrication
- **vii.** Operating the system by firing the samples

Chapter 2

Literature review and Theoretical Background

2.1 Literature review

2.1.1 Biomass

Biomass is the term used to describe all the organic matter, produced by photosynthesis that exists on the earth's surface. The source of all energy in biomass is the sun, the biomass acting as a kind of chemical energy store. Biomass is constantly undergoing a complex series of physical and chemical transformations and being regenerated while giving off energy in the form of heat to the atmosphere. To make use of biomass for our own energy needs we can simply tap into this energy source, in its simplest form we know, this is a basic open fire used to provide heat for cooking, warming water or warming the air in our home [2].

More sophisticated technologies exist for extracting this energy and converting it into useful heat or power in an efficient way.

2.1.1.1 Advantages of biomass

1-Renewable Energy Source

Biomass energy is generated from organic material, plant or animal waste, which is burned to provide energy, e.g. heat & electricity. Since they come from living sources, these products potentially never run out which makes biomass a renewable energy source.

2-Better for the environment than fossil fuels

The burning of biomass does release carbon dioxide but captures carbon dioxide for its own growth. Carbon dioxide released by fossil fuel is released into the atmosphere and are harmful to the environment.

3-Less Dependency on Fossil Fuels

Using biomass as an alternate source of fuel reduces our dependency on fossil fuels which is better for the planet and more cost effective.

4-Very Easily Available

Biomass is cheap and readily available source of energy. If the trees are replaced, biomass can be a long-term, sustainable energy source.

5-Reduce Landfills

By burning biomass for energy, we can take waste that is harmful to the environment and turn it into something useful. Biomass is cheap and readily available source of energy. If the trees are replaced, biomass can be a long-term, sustainable energy source solution.

6-Renewable Heat Incentive

By installing a biomass boiler, you can get paid under the Renewable Heat Incentive, which is a Government-backed financial incentive to promote the use of renewable heat for both the domestic and commercial markets [3]

2.1.1.2 Disadvantages of biomass

1-High initial cost

The initial costs of a biomass boiler are quite daunting to most, with an automatic biomass boiler costing around £12,000 in a domestic residence, and manual biomass boilers at £7,000.

2-Harmful to the environment

Although there is a large reduction of carbon dioxide emissions compared to other systems, there is an increase in methane gases, which can also be harmful to the Earth's ozone layer. These methane gases can omit unpleasant smells that can possibly attract unwanted pests.

3-Consumes more fuel

In order to acquire enough lumber to power a plant, for example, companies would have to clear large forest area. This makes the use of trees and tree products to power machines inefficient and can create environmental problems. However, providing the fuel is locally sourced the emissions are much lower than that of fossil fuels.

4-Replant of plants

In order for biomass energy to be a renewable resource, crops have to be replanted in order to keep the process continually moving – the process is sustainable as long as new plants continue to grow to replace the fuel used [4].

2.1.1.3 The Basics of Biomass Combustion

The principal chemical reactions that produce heat energy are the same for all common fuels. Carbon and/ or hydrogen are oxidized rapidly, releasing energy. The chemical equations for these reactions are:

$$C + O2 = CO2 + ENERGY$$

2.1.1.3.1 Combustion theory

For solid biomass to be converted into useful heat energy it has to undergo combustion.

There are three main stages to the combustion process:

a. **Drying:** all biomass contains moisture, and this moisture has to be driven off before combustion proper can take place. The heat for drying is supplied by radiation from flames and from the stored heat in the body of the stove or furnace.

b. **Pyrolysis:** the dry biomass is heated and when the temperature reaches between 200ºC and 350ºC the volatile gases are released. These gases mix with oxygen and burn producing a yellow flame. This process is self-sustaining as the heat from the burning gases is used to dry the fresh fuel and release further volatile gases.

c. **Oxidation:** at about 800ºC the charcoal oxidizes or burns. Again oxygen is required, both at the fire bed for the oxidation of the carbon and, secondly, above the fire bed where it mixes with carbon monoxide to form carbon dioxide which is given off to the atmosphere [5].

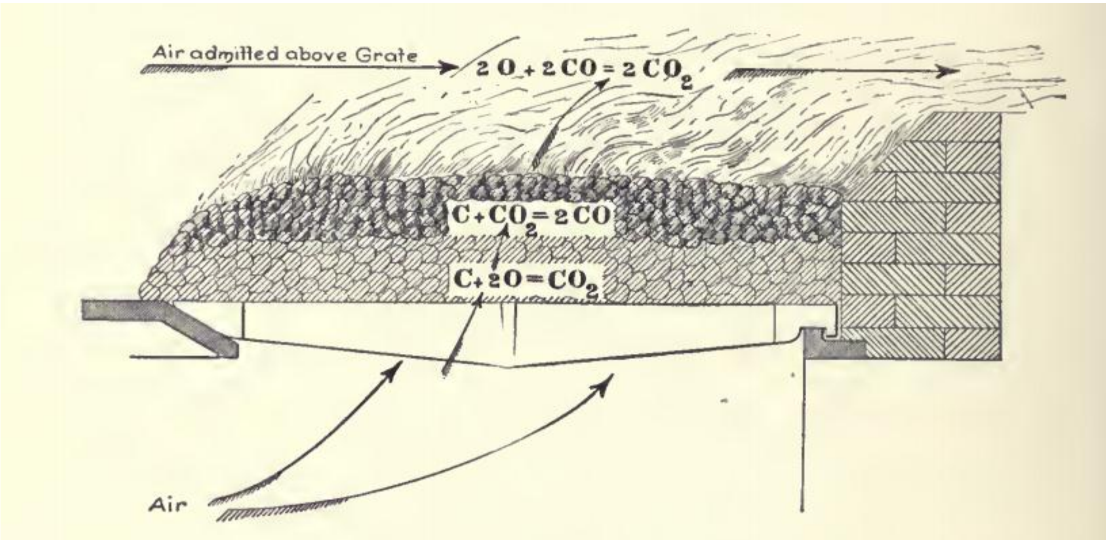

Figure (2-1)

Combustion theory

2.1.1.4 Biomass in Sudan

Sudan has one of the highest levels of fuel's wood consumption per capita in the world, estimated at over two tons per capita per year. Kerosene provides a better lighting service than fuel's wood, but is costlier and generally more difficult to obtain.

Kerosene has negative impacts on indoor air quality and human health, due to high emissions of smoke and particles.

Dry cell batteries are a practical but expensive form of mobile fuel that is used by the rural Sudanese when moving around at night and for powering radios [6].

Table (2.1): Energy carrier and energy services in rural Sudan [6]

Energy carrier	Energy end-use	Typical annual household Consumption
Fuel-wood	Cooking Water heating Building materials Animal fodder preparation	10 tones
Kerosene	Lighting Ignition fires	100 liters
Dry cell batteries	Lighting Small appliance	50 pairs
Animal power	Transport Land preparation for farming Food preparation (threshing)	
Human power	Transport Land preparation for farming Food preparation (threshing)	

2.1.2 Boilers

2.1.2.1 Introduction

Boilers are pressure vessels designed to heat water or produce steam, which can then be used to provide space heating and/or service water heating to a building. In most commercial building heating applications, the heating source in the boiler is a natural gas fired burner. Oil fired burners and electric resistance heaters can be used as well. Steam is preferred over hot water in some applications, including absorption cooling, kitchens, laundries, sterilizers, and steam driven equipment.

Boilers have several strengths that have made them a common feature of buildings. They have a long life, can achieve efficiencies up to 95% or greater, provide an effective method of heating a building, and in the case of steam systems, require little or no pumping energy. However, fuel costs can be considerable, regular maintenance is required, and if maintenance is delayed, repair can be costly.

A boiler is an enclosed vessel that provides a means for combustion heat to be transferred into water until it becomes heated water or a gas (steam). The steam or hot water under pressure is then usable for transferring the heat to a process. Water is a useful and cheap medium for transferring heat to a process. When water is boiled into steam its volume increases about 1,600 times, producing a force that is almost as explosive as gunpowder. This causes the boiler to be an extremely dangerous item that must be treated with utmost respect [7].

Boilers were used in crude fashions for several centuries but development was slow because construction techniques were crude and the operation was extremely dangerous.

2.1.2.2 Boilers Work methodology

Both gas and oil fired boilers use controlled combustion of the fuel to heat water. The key boiler components involved in this process are the burner, combustion chamber, heat exchanger, and controls.

The burner mixes the fuel and oxygen together and, with the assistance of an ignition device, provides a platform for combustion. This combustion takes place in the combustion chamber, and the heat that it generates is transferred to the water through the heat exchanger. Controls regulate the ignition, burner firing rate, fuel supply, air supply, exhaust draft, water temperature, steam pressure, and boiler pressure.

Hot water produced by a boiler is pumped through pipes and delivered to equipment throughout the building, which can include hot water coils in air handling units, service hot water heating equipment, and terminal units. Steam boilers produce steam that flows through pipes from areas of high pressure to areas of low pressure, unaided by an external energy source such as a pump. Steam utilized for heating can be directly utilized by steam using equipment or can provide heat through a heat exchanger that supplies hot water to the equipment.

The discussion of different types of boilers, below, provides more detail on the designs of specific boiler systems.

2.1.2.3 Types of Boilers

Boilers are classified into different types based on their working pressure and temperature, fuel type, draft method, size and capacity, and whether they condense the water vapor in the combustion gases. Boilers are also sometimes described by their key components, such as heat exchanger materials or tube design. These other characteristics are discussed in the following section on Key Components of Boilers.

Two primary types of boilers include Fire tube and Water tube boilers.

A- Fire tube boiler

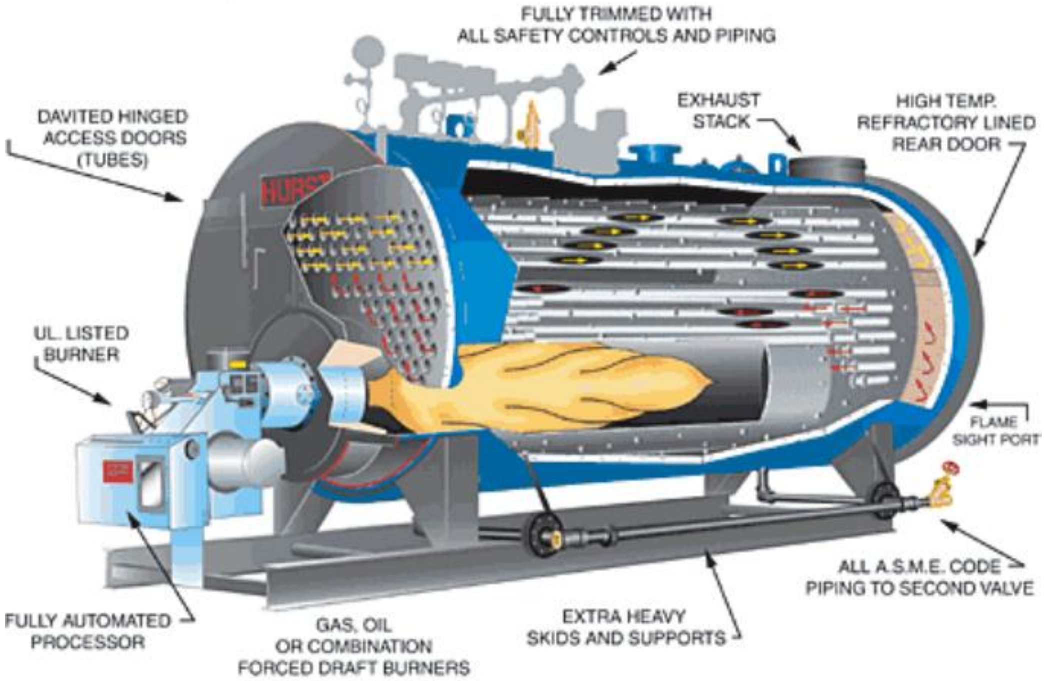

Figure (2-2)

Fire tube Boiler

Hot gases of combustion flow through a series of tubes surrounded by water. Alternatively, in a Water tube boiler, water flows in the inside of the tubes and the hot gases from combustion flow around the outside of the tubes. A drawing of a water tube boiler is shown in Figure

B- Water tube:

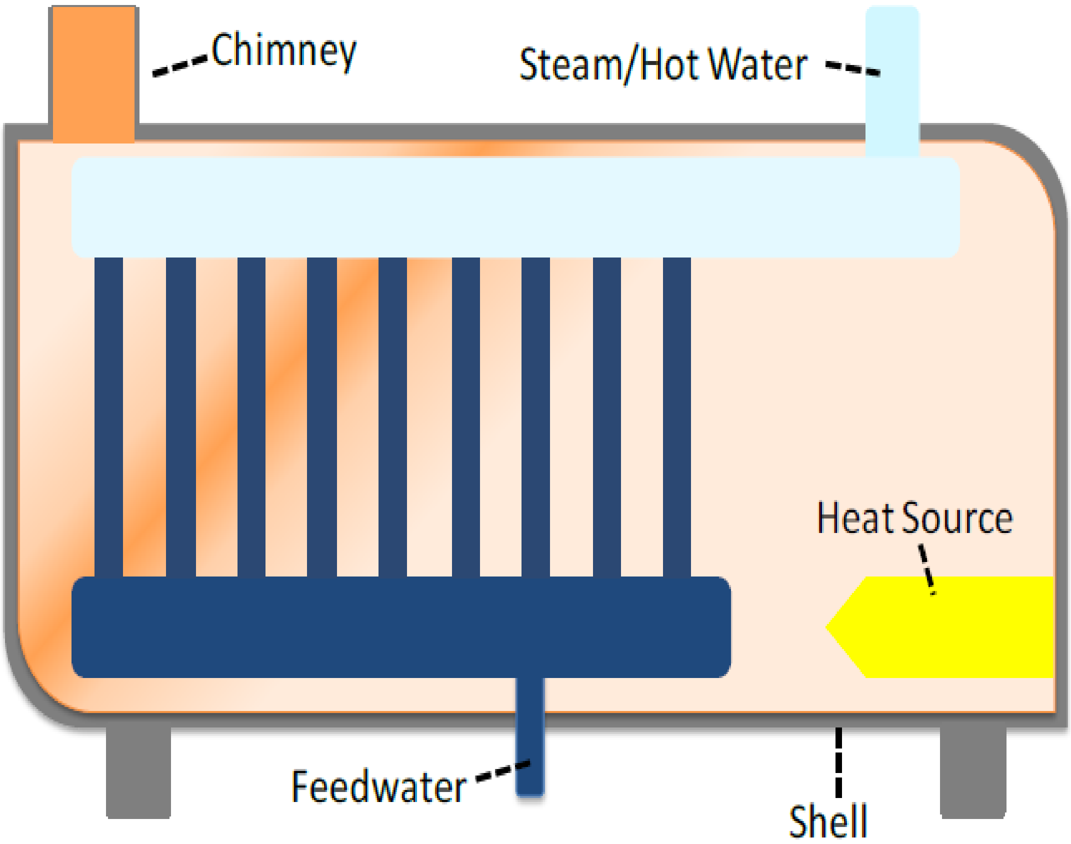

Figure (2-3)

Water tube Boiler

Water tube or "water in tube" boilers in which the conditions are reversed with the water passing through the tubes and the furnace for the hot gasses is made up of the water tubes [7].

2.2Theoretical Background

2.2.1 Vertical cross-tube boiler

As we mentioned in the last chapter that there are two types of boilers, we chose water tube boiler in this research, the design shape that chosen is call vertical cross tube boiler

2.2.1.1 Advantages of vertical cross boiler

- low initial cost because of lesser parts
- Low maintenance cost
- Simple working
- Easy to install and replace
- Occupy small space on ground
- Simple vertical boiler have water level tolerance

2.2.1.2 Disadvantages of vertical cross boiler

- Vertical design limits its working in many places
- Because of the limited grate area steam production is limited
- Impurities settle down at the bottom thus prevent water from heating
- Boiler tubes must be kept short to minimize height. As a result, much of the available heat is lost through the chimney, as it has too little time to heat the tubes [8].

2.2.1.3Parts of the boiler

I. **Cylindrical shell**

The shell is vertical and it attached to the bottom of the furnace. Greater portion of the shell is full of water which surrounds the furnace also. Remaining portion is steam space.

II. **Cross-tubes**

One or more cross tubes are either riveted or flanged to the furnace to increase the heating surface and to improve the water circulation.

III. **Furnace (or fire box)**

Combustion of wood takes place in the furnace (fire box).

IV. **Grate**

It is placed at the bottom of fire box and coal is fed on it for burning.

V. **Fire door**

Coal is fed to the grate through the fire door.

VI. **Chimney (or stack)**

The chimney (stack) passes from the top of the firebox through the top of the shell.

VII. **Manhole**

It is provided on the top of the shell to enable a man to enter into it and inspect and repair the boiler from inside it. It is also, meant for cleaning the interior of the boiler shell and exterior of the combustion chamber and stack (chimney).

VIII. **Hand holes**

These are provided in the shell opposite to the ends of each cross tube for cleaning the cross tube.

IX. Ash pit

It is provide for collecting the ash deposit, which can be removed away at intervals [9].

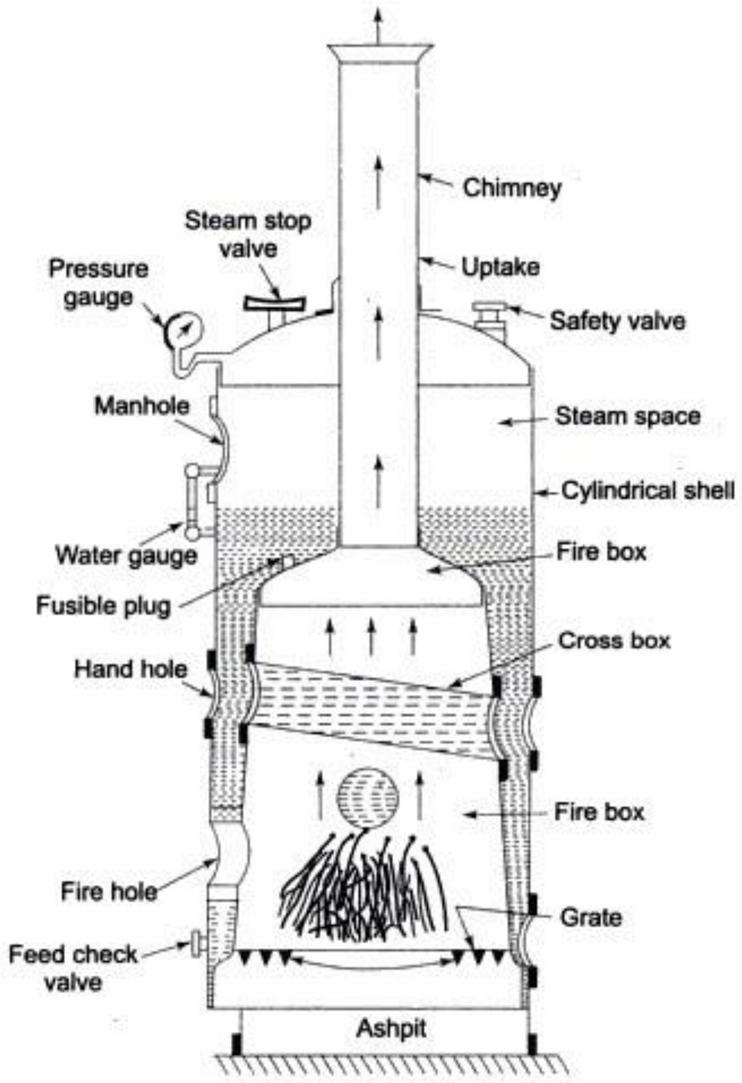

Figure (2-4)

Vertical cross tube boiler [8]

2.2.2 Rankine cycle

Rankine cycle is ideal cycle for vapor power cycles. Many of the impracticalities associated Carnot cycle can be eliminated by superheating the steam in the boiler and condensing it completely in the condenser, as shown schematically on T-S diagram the cycle that results is the Rankine cycle, which is the ideal cycle for vapor power plants. The ideal Rankine cycle does not involve any internal irreversibility's and consist of the following four processes [10]:

1-2Isentropic compression in a pump

2-3 Constant pressure heat addition in a boiler

4-1 Constant pressure heat rejection in a condenser

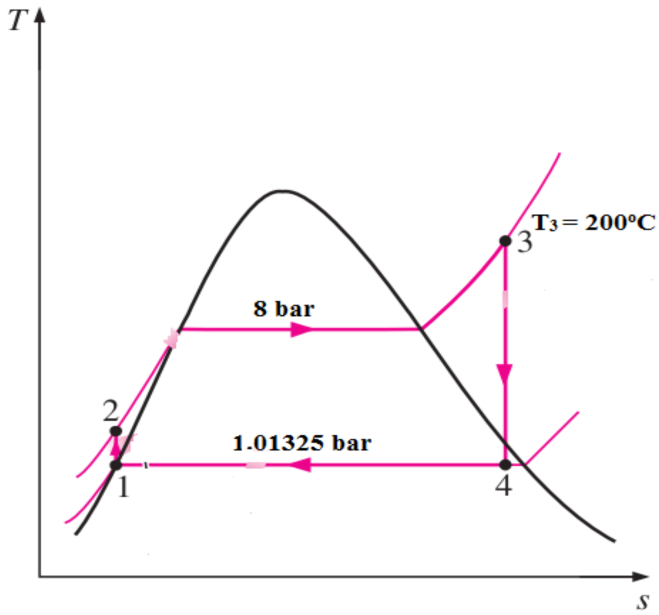

Figure (2-5)

T-S diagram of Rankine cycle [1]

2.3 Previous Studies

1- Manually fed boilers for log wood

Capacity range: Usually 15 to 70 kW

Fuels used: Wood logs with 33 or 50 cm length Use of wood briquettes possible (not usual)

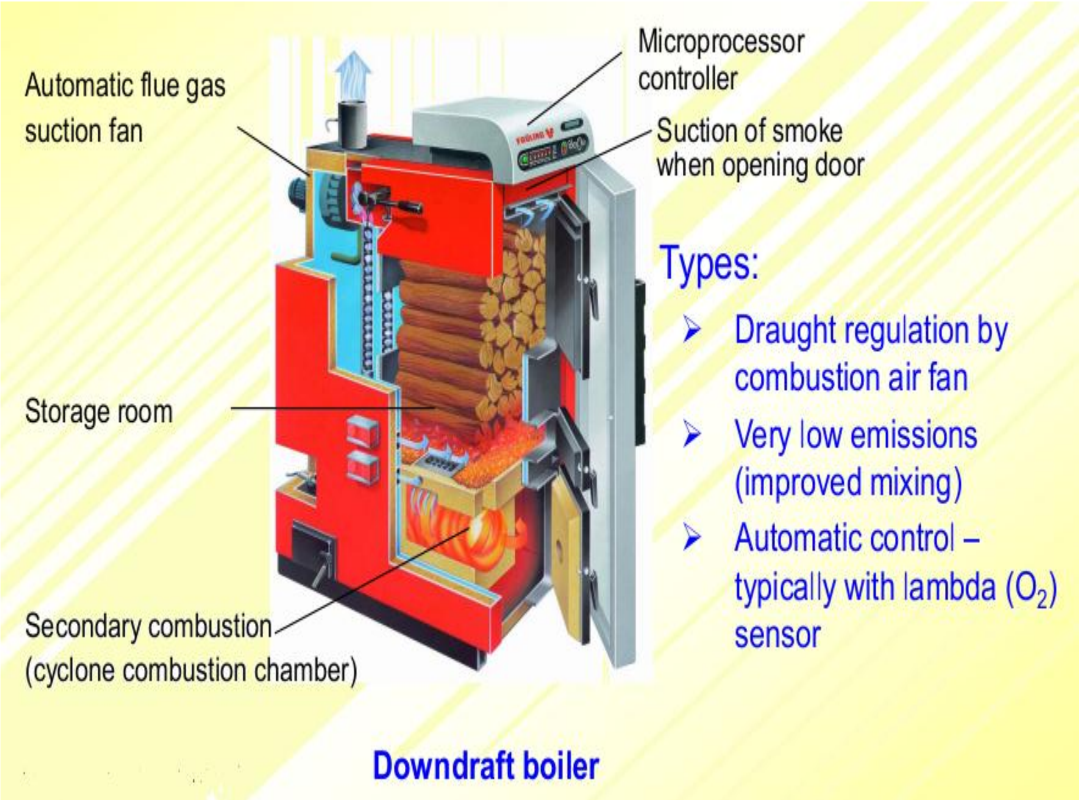

Figure (2-6)

Downdraft boiler

2- Automatically fed boilers for wood chips

Capacity range: 15 up to several 100 kW

Fuels used: wood chips

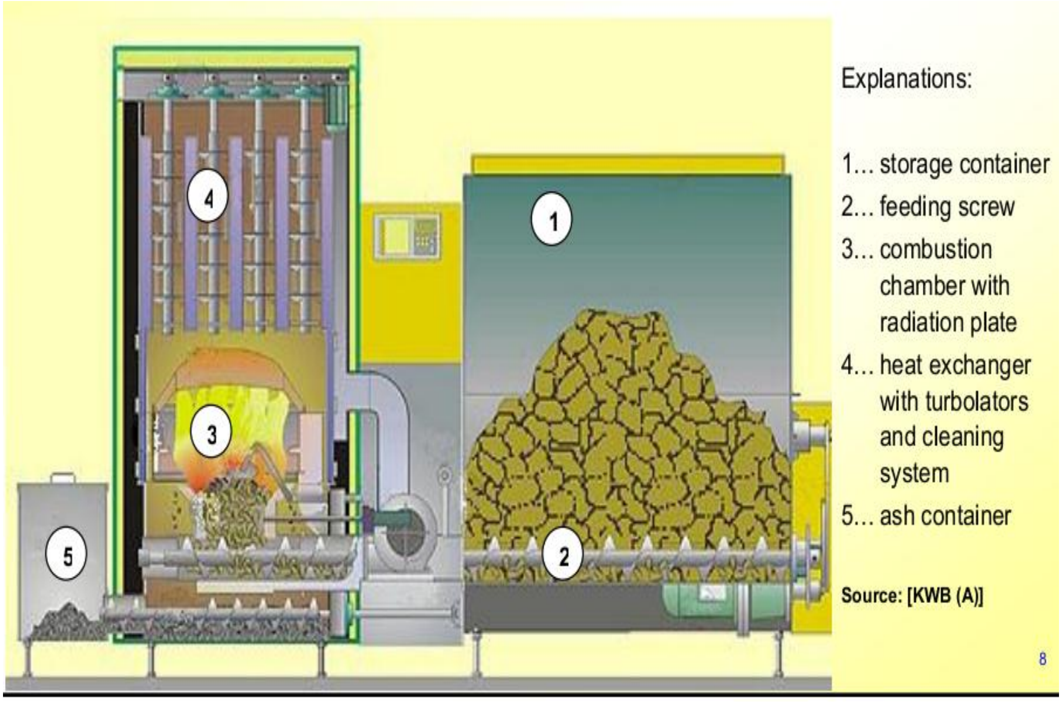

Figure (2-7)

Automatically fed boilers for wood chips

3- Automatically fed boilers for wood pellets

Capacity range: 6 to 300 kW (usual capacities in Austria)

Fuels: wood pellets

4- Dual-fuel boilers (wood pellets / wood chips and wood pellets / firewood)

*** Wood pellets / wood chips**

Nominal thermal capacity: 15 - 300 kW

Fuels: wood chips (up to w50) and wood pellets

*** Wood pellets / firewood**

Nominal thermal capacity: 15 – 40 kW

Fuels: wood pellets and firewood [11].

2.4 Bomb calorimeter experiment

2.4.1 The purpose of the experiment

Find calorific value of the fuel

2.4.2 Fuel user

Mesquite (Prosopis chilensis) wood

2.4.3 Introduction

Calorimeter is an important field of analytical chemistry which deals accurately measuring heats of reaction and finds application in fields ranging from nutritional analysis to explosive yield tests.

2.4.4 Device

It consists of a cylinder made of iron non-stainless steel which is a special kind of resists heat, pressure and corrosion

At the top of the sector is priced There valves with the first one-way for the entry of oxygen and the second valve to drain resulting from the combustion gases and the discharge of the air valve, It contains also the crucible made of silica or porcelain to carry the fuel sample and ignition wire diameter made of platinum and one of the ten thousand millimeters reached limbs with ignition calorimeter is placed inside large cylinder columns by a slot to install the thermometer cover

(Figure 2-8)
Bomb calorimeter

2.4.5 Experiment procedures

Ten centimeter pieces of wire platinum then weighed sample of the solid fuel powder amount of one gram was then compress the powder in the piston was then wrapped platinum wire in the sample and then placed the crucible in the allotted place was arrived Parties wire columns conduction then been linked to the top cover and then device is connected to the oxygen cylinder and oxygen valve was opened to flow for a period of time to expel the air and then been closed discharge valve was left then was separated oxygen device for oxygen cylinder lock their ends

Using hand calorimeter device has been put in the right place then it has been put water engine and thermometer in their places and then cover the calorimeter, Was developed two hundred cubic centimeters of water inside the calorimeter was to make sure that the device is completely submerged in water and after five minutes was recorded and then read thermometer been reached power to burn and then the sample was taken the highest temperature read and recorded readings thermometer has been re-experience again [IKA laboratory equipment].

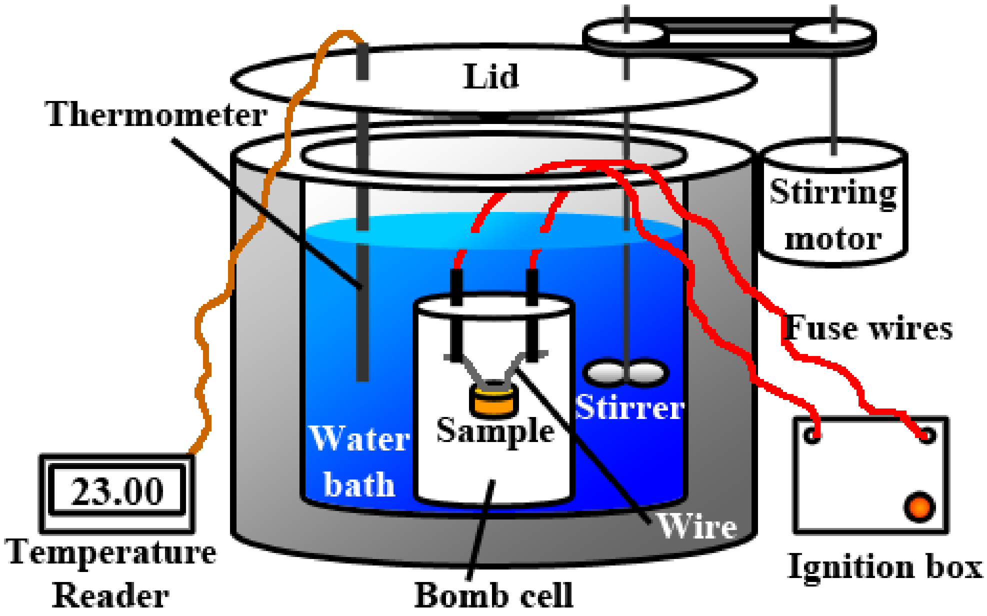

Figure (2-9)

Bomb calorimeter experiment operation

Chapter 3

Methodology

3.1 Introduction

This chapter contains the Calculation of fuel laboratory tests used to determine important characteristics in design, it also contains the equations of the boiler design and information relied upon by Design.

It is known that we have the boiler operates according to the Rankin cycle, which will be addressed in Chapter.

3.2 Calculations of Bomb calorimeter experiment

The amount of heat transmitted to the water in the calorimeter can be calculated from the equation [12]:

$$Q_t = (m_w + m_{cw}) \times Cp_w \times \Delta T - m_{wire} \times C.V_{wire} \quad (3.1)$$

But the value of ($m_{wire} \times C.V_{wire}$) is too small and can be neglected

The amount of heat generated from the combustion can be calculated from the equation:

$$Q_c = \dot{m}_f \times C.V_f \quad (3.2)$$

Considering that the amount of heat transmitted to water equal to the amount of heat generated from the combustion

$Q_c = Q_t$

$$\dot{m}_f \times C.V_f = (m_w + m_{cw}) \times Cp_w \times \Delta T$$

$$C.V_f = \frac{(m_w + m_{cw}) \times Cp_w \times \Delta T}{\dot{m}_f} \quad (3.3)$$

Where:

Q_t: The amount of heat transfer to water.

Q_c: The amount of heat generated from the combustion.

m_f: mass of fuel in combustion

$C.V_f$: calorific value of fuel

m_w : mass of water in calorimeter.

m_{cw}: water equivalent

Cp_w : specific heat at constant pressure.

ΔT: different between water temperature after and before combustion.

3.3 Boiler Design

3.3.1 Energy analysis of the ideal Rankine cycle

All four components associated with the Rankine cycle (the pump, boiler, turbine, and condenser) are steady-flow devices , and thus all four processes that make up the Rankine cycle can be analyzed as steady-flow processes . The kinetic and potential energy changes of the steam are usually small relative to the work and heat transfer terms and are therefore usually neglected. Then the steady flow energy equation per unit mass of steam reduces to:

$$(q_{in} - q_{out}) + (W_{in} - W_{out}) = h_e - h_i \quad \text{(KJ/kg)} \qquad (3.4)$$

The boiler and the condenser do not involve any work, and the pump and the turbine are assumed to be isentropic. Then the conservation of energy relation for each device can be expressed as follows [10]:

Pump (Q=0)

$$W_p = V(P_2 - P_1) = h_2 - h_1 \qquad (3.5)$$

$$W_t = h_3 - h_4 \qquad (3.6)$$

$$W_{net} = W_t - W_p \qquad (3.7)$$

Boiler (W=0)

$$Q_{add} = h_3 - h_2 \qquad (3.8)$$

3.3.2 Boiler Design Equations

Equations used to design are equations of the ideal Rankine cycle.

The design is based from the power plant which existing in the thermal lap in Sudan University of Science and Technology [10]].

Data given:

No	Definition	Symbol	Value
1	Power output	P_{out} (MW.hr)	5
2	Boiler pressure (outlet pressure)	P_2 (bar)	8
3	Suction pressure (inlet pressure)	P_1 (bar)	1.01325
4	Temperature exist boiler	T_3 (°C)	200

Power generated equation

$$P = \dot{m}_s \times W_{net} \quad (3.8)$$

Heat generated from combustion

$$Q_{comb} = \dot{m}_f \times C.V$$

Thermal Efficiency of plant

$$\eta_{th} = \frac{Work\ net}{\text{heat added}} = \frac{W_{net}}{Q_{add}} \quad (3.9)$$

Boiler efficiency

$$\eta_b = \frac{Q_{add}}{Q_{comb}} \quad (3.10)$$

Where:

W_p: Workpiece at the pump

W_t : Workpiece output of the turbine

W_{net} : Net work done

Q_{add} : The amount of heat added in the boiler

Q_{comb} : The amount of heat generated from the combustion

h_i : enthalpy

Enthalpy of any point can be found from the steam table

3.4 Schematic for parts of the boiler

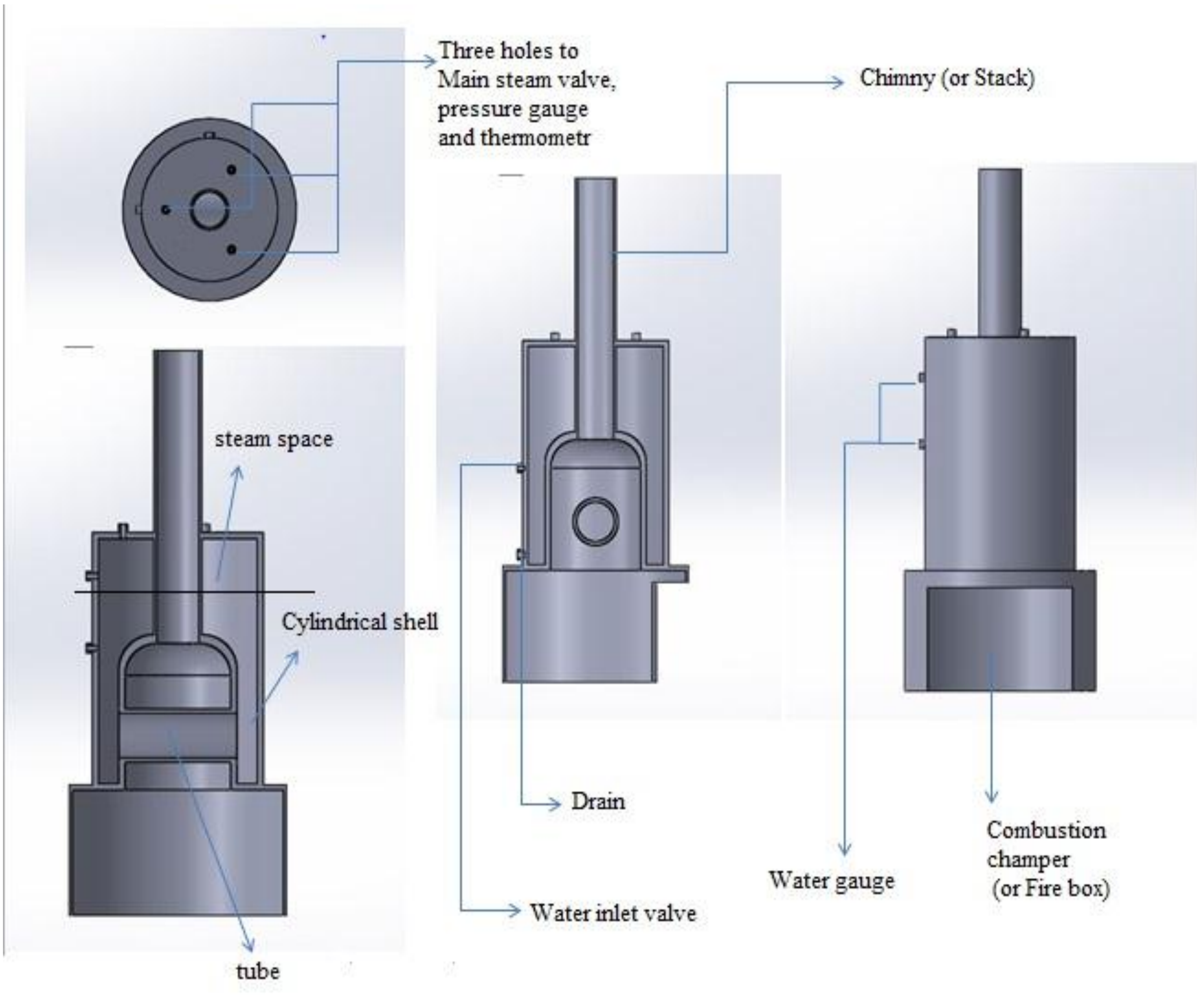

Figure (3-1)

Plans and sections of the boiler drawing [by solid work]

Chapter 4

Results and Discussion

4.1 Introduction

In this chapter we are going to show the result of fuel experiments and the results of design and fabrication (theoretical and actual).

4.2 Bomb calorimeter experiment

4.2.1 Results Bomb calorimeter experiment

No	**Definition**	Symbol	Value
1	Temperature of water before combustion	T_{w1} (K)	306.92
2	Temperature of water after combustion	T_{w2} (K)	309.28
3	different between water temperature after and before combustion	ΔT (K)	2.36
4	mass of fuel in combustion	m_f (kg)	0.001

4.2.2 Calculation Bomb calorimeter experiment

$$C.V_f = \frac{(m_w + m_{cw})\times Cp_w \times \Delta T}{\dot{m}_f}$$

$$C.V_f = \frac{(2 + .455)\times 4.187 \times 2.36}{.001}$$

$C.V_f$ = 24258.6406 kJ/kg

4.3 Design calculation

Enthalpy from the table:

$h_1 = h_{f\ @\ 1.0135bar}$ =418.59 kJ/kg

$h_2 = h_1 + v\,(P_2 - P_1)$ = 418.59+0.001(8-1.01325) $\times 10^2$

h_2=419.2887kJ/kg

$h_3 = h_{g\ @\ P=8\ bar\ \&\ T=200\ ^oC}$ =2840 kJ/kg

$S_3 = S_{g\ @\ P=8\ bar\ \&\ T=200\ ^oC} = 6.817$ kJ/kg. K

$S_4 = S_3 = 6.817$ kJ/kg. K

$X_4 = \frac{S_4 - S_f}{S_{fg}} = \frac{6.817 - 1.306975}{6.047785} = 0.911 = 91.1\ \%$

$h_4 = h_f + (X_4 \times h_{fg}) = 418.59 + (.911 \times 2257.0725)$

$h_4 = 2474.783$ kJ/kg

$W_{net} = W_{gross} - W_{pump}$

$W_{net} = (h_3 - h_4) - (h_2 - h_1)$

$W_{net} = (2840 - 2474.783) - (419.2887 - 418.59)$

$W_{net} = 364.5193$ kJ/kg

Power $= \dot{m}_s \times W_{net}$

$\dot{m}_s = \frac{Power}{W_{net}} = \frac{5 \times 1000}{364.5193 \times 3600}$

$\dot{m}_s = 3.81 \times 10^{-3}$ kg/s

$Q_{add} = \dot{m}_s (h_3 - h_2) = 3.81 \times 10^{-3} \times (2840 - 419.2887)$

$Q_{add} = 9.2229$ kJ/s

$Q_{comb} = \dot{m}_f \times C.V$

Assume that:

$Q_{comb} = Q_{add}$

$\dot{m}_f \times C.V = Q_{add}$

$\dot{m}_f = \frac{Q_{add}}{C.v} = \frac{9.2229}{24258.6406} = 3.8019 \times 10^{-4}$ kg/s

$\eta_{th} = \frac{W_{net}}{Q_{add}} = \frac{364.5193}{2420.711} = 15.06\ \%$

Assume that:

$Q_{trans.} = Q_{add}$

$T_{water} = 28^oC$

$T_{comb} = 815.5\ ^oC$

$h_{air} = 55\ W/m^2.K\ K$

$h_{water} = 1525\ W/m^2 .\ K$

$k_{c.steel} = 45\ W/m\ .K$

$Q_{trans.} = U\ A\ \Delta T$

$$U=\frac{1}{\frac{1}{h_{air}}+\frac{\Delta x}{k_{c.steel}}+\frac{1}{h_{water}}}$$

$$U=\frac{1}{\frac{1}{55}+\frac{15\times10^{-3}}{45}+\frac{1}{1525}}$$

$U = 52.162\ W/m^2\ .K$

$$A=\frac{Q_{trans.}}{U\times\Delta T}=\frac{9.2229\times1000}{52.162\ \times(815.5-28)}$$

$A = 0.2245\ m^2$

4.4 Fabrication calculation

4.4.1 Test result

No	Definition	Symbol	Value
1	Pressure of boiler	P_2 (bar)	7
2	Steam temperature	T_3 (ºC)	190
3	Mass flow rate of steam	$\dot{m}_s$ (kg/s)	2.206×10^{-3}
4	Mass flow rate of fuel	$\dot{m}_f$ (kg/s)	2.577×10^{-3}

4.4.2 Calculation

$h_1 = h_{f\ @\ 1.0135bar} = 418.59$ kJ/kg

$h_2 = h_1 + \nu\,(P_2 - P_1)$ but W_p= zero

$h_2 = h_1 = 418.59$kJ/kg

$h_3 = h_{g\ @\ P=7\ bar\ \&\ T=190\ ^oC} = 2822.57$ kJ/kg

$S_3 = S_{g\ @\ P=7\ bar\ \&\ T=190\ ^oC} = 6.8368$ kJ/kg. K

$S_4 = S_3 = 6.8368$ kJ/kg. K

$$X_4 = \frac{S_4 - S_f}{S_{fg}} = \frac{6.8368 - 1.306975}{6.047785} = 0.9144 = 91.44\ \%$$

$h_4 = h_f + (X_4 \times h_{fg}) = 418.59 + (0.9144 \times 2257.0725)$

$h_4 = 2482.457$ kJ/kg

$W_{net} = W_{gross} - W_{pump}$

$W_{net} = (h_3 - h_4) - (h_2 - h_1)$

$W_{net} = (2822.57 – 2482.457) – zero$

$W_{net} = 340.113$ kJ/kg

$Q_{add} = \dot{m}_s (h_3 – h_2) = 2.206\times10^{-3} \times (2822.57 – 418.59)$

$Q_{add} = 5.303$ kJ/s

$Q_{comb} = \dot{m}_f \times C.V = 2.577\times10^{-3} \times 24258.6406 = 62.515$ kJ/s

$Q_{loss} = Q_{comb} – Q_{add} = 62.515 – 5.303 = 57.212$ kW

Power $= \dot{m}_s \times W_{net} = 2.206\times10^{-3} \times 340.113 = 0.75$ kW

Power generation in hour:

P= 0.75×3600 =2700 kW.hr = 2.7 MW.hr

4.4.3 Fabrication pictures

Figure (4-1)

Thermometer

Figure (4-2)

The Boiler

Figure (4-3)

Pressure gauge

4.5 Comparative

No	Definition	Theoretical	Actual
1	Power output (MW.hr)	5	2.7
2	Mass flow rate of steam (kg/s)	3.81×10^{-3}	2.206×10^{-3}
3	Mass flow rate of fuel (kg/s)	3.8019×10^{-4}	2.577×10^{-3}
4	Heat added in boiler (kW)	9.2229	5.303
5	Heat generate from combustion (kW)	9.2229	62.515
6	Pressure of boiler (bar)	8	7
7	Steam temperature (^{o}C)	200	190

4.6 Discussion

- There is no insulation around the boiler and that led to heat transfer outside the boiler which made heat losses
- Opened combustion chamber led to heat losses through the hole
- There is no control of the air inside the combustion chamber thus no control for air fuel ratio
- The chimney is attached directly with the combustion chamber and that led to a fast heat escaping through chimney without staying for a longer time to give more heat to the water

Chapter Five

Conclusion and Recommendations

Conclusion and Recommendations

5.1 Conclusion

- It has been designing and manufacturing a boiler vertical cross tube type.
- Long wood from mesquite trees used as a fuel, and the calorific value equal to 24258.6406 kJ/kg (approximately half of the calorific value of the diesel)
- The superheated steam generated at 7bar and, 190 ^{o}C and mass flow rate 2.206×10^{-3}kg/s.
- Power generation 2.7MW.hr

5.2 Recommendation:

- We recommend to continue in this project to develop the design and Make more experiments on the project to reach to scientific values and urged the government to adopt the project as a national project
- To improve the design and results, it is recommended to :
  - Use insulation around the boiler
  - Use grate to the combustion chamber (close combustion chamber)
  - Use air source to combustion chamber for the wood ignition and to distribute heat regularly inside the combustion chamber
  - Use wood chips and make feeding operation automatically
  - Use treated water to get off impurities and salts
  - Use super heater above the chimney

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Appendix

Saturated Water and Steam

p	t_s	v_g	u_f	u_g	h_f	h_{fg}	h_g	s_f	s_{fg}	s_g
1·0	99·6	1·694	417	2506	417	2258	2675	1·303	6·056	7·359
1·1	102·3	1·549	429	2510	429	2251	2680	1·333	5·994	7·327
1·2	104·8	1·428	439	2512	439	2244	2683	1·361	5·937	7·298
1·3	107·1	1·325	449	2515	449	2238	2687	1·387	5·884	7·271
1·4	109·3	1·236	458	2517	458	2232	2690	1·411	5·835	7·246
1·5	111·4	1·159	467	2519	467	2226	2693	1·434	5·789	7·223
1·6	113·3	1·091	475	2521	475	2221	2696	1·455	5·747	7·202
1·7	115·2	1·031	483	2524	483	2216	2699	1·475	5·707	7·182
1·8	116·9	0·9774	491	2526	491	2211	2702	1·494	5·669	7·163
1·9	118·6	0·9292	498	2528	498	2206	2704	1·513	5·632	7·145
2·0	120·2	0·8856	505	2530	505	2202	2707	1·530	5·597	7·127
2·1	121·8	0·8461	511	2531	511	2198	2709	1·547	5·564	7·111
2·2	123·3	0·8100	518	2533	518	2193	2711	1·563	5·533	7·096
2·3	124·7	0·7770	524	2534	524	2189	2713	1·578	5·503	7·081
2·4	126·1	0·7466	530	2536	530	2185	2715	1·593	5·474	7·067
2·5	127·4	0·7186	535	2537	535	2182	2717	1·607	5·446	7·053
2·6	128·7	0·6927	541	2539	541	2178	2719	1·621	5·419	7·040
2·7	130·0	0·6686	546	2540	546	2174	2720	1·634	5·393	7·027
2·8	131·2	0·6462	551	2541	551	2171	2722	1·647	5·368	7·015
2·9	132·4	0·6253	556	2543	556	2168	2724	1·660	5·344	7·004
3·0	133·5	0·6057	561	2544	561	2164	2725	1·672	5·321	6·993
3·5	138·9	0·5241	584	2549	584	2148	2732	1·727	5·214	6·941
4·0	143·6	0·4623	605	2554	605	2134	2739	1·776	5·121	6·897
4·5	147·9	0·4139	623	2558	623	2121	2744	1·820	5·037	6·857
5·0	151·8	0·3748	639	2562	640	2109	2749	1·860	4·962	6·822
5·5	155·5	0·3427	655	2565	656	2097	2753	1·897	4·893	6·790
6	158·8	0·3156	669	2568	670	2087	2757	1·931	4·830	6·761
7	165·0	0·2728	696	2573	697	2067	2764	1·992	4·717	6·709
8	170·4	0·2403	720	2577	721	2048	2769	2·046	4·617	6·663
9	175·4	0·2149	742	2581	743	2031	2774	2·094	4·529	6·623
10	179·9	0·1944	762	2584	763	2015	2778	2·138	4·448	6·586
11	184·1	0·1774	780	2586	781	2000	2781	2·179	4·375	6·554
12	188·0	0·1632	797	2588	798	1986	2784	2·216	4·307	6·523
13	191·6	0·1512	813	2590	815	1972	2787	2·251	4·244	6·495
14	195·0	0·1408	828	2593	830	1960	2790	2·284	4·185	6·469
15	198·3	0·1317	843	2595	845	1947	2792	2·315	4·130	6·445
16	201·4	0·1237	857	2596	859	1935	2794	2·344	4·078	6·422
17	204·3	0·1167	870	2597	872	1923	2795	2·372	4·028	6·400
18	207·1	0·1104	883	2598	885	1912	2797	2·398	3·981	6·379
19	209·8	0·1047	895	2599	897	1901	2798	2·423	3·936	6·359
20	212·4	0·09957	907	2600	909	1890	2799	2·447	3·893	6·340
22	217·2	0·09069	928	2601	931	1870	2801	2·492	3·813	6·305
24	221·8	0·08323	949	2602	952	1850	2802	2·534	3·738	6·272
26	226·0	0·07689	969	2603	972	1831	2803	2·574	3·668	6·242
28	230·0	0·07142	988	2603	991	1812	2803	2·611	3·602	6·213
30	233·8	0·06665	1004	2603	1008	1795	2803	2·645	3·541	6·186
32	237·4	0·06246	1021	2603	1025	1778	2803	2·679	3·482	6·161
34	240·9	0·05875	1038	2603	1042	1761	2803	2·710	3·426	6·136
36	244·2	0·05544	1054	2602	1058	1744	2802	2·740	3·373	6·113
38	247·3	0·05246	1068	2602	1073	1729	2802	2·769	3·322	6·091
40	250·3	0·04977	1082	2602	1087	1714	2801	2·797	3·273	6·070

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Figure (1)

Saturated Water and Steam table

Superheated Steam

p (t_s)			t	200	250	300	350	400	450	500	600
5 (151·8)	v_g	0·3748	v	0·4252	0·4745	0·5226	0·5701	0·6172	0·6641	0·7108	0·8040
	u_g	2562	u	2644	2725	2804	2883	2963	3045	3129	3300
	h_g	2749	h	2857	2962	3065	3168	3272	3377	3484	3702
	s_g	6·822	s	7·060	7·271	7·460	7·633	7·793	7·944	8·087	8·351
6 (158·8)	v_g	0·3156	v	0·3522	0·3940	0·4344	0·4743	0·5136	0·5528	0·5919	0·6697
	u_g	2568	u	2640	2722	2801	2881	2962	3044	3128	3299
	h_g	2757	h	2851	2958	3062	3166	3270	3376	3483	3701
	s_g	6·761	s	6·968	7·182	7·373	7·546	7·707	7·858	8·001	8·267
7 (165·0)	v_g	0·2728	v	0·3001	0·3364	0·3714	0·4058	0·4397	0·4734	0·5069	0·5737
	u_g	2573	u	2636	2720	2800	2880	2961	3043	3127	3298
	h_g	2764	h	2846	2955	3060	3164	3269	3374	3482	3700
	s_g	6·709	s	6·888	7·106	7·298	7·473	7·634	7·786	7·929	8·195
8 (170·4)	v_g	0·2403	v	0·2610	0·2933	0·3242	0·3544	0·3842	0·4138	0·4432	0·5018
	u_g	2577	u	2631	2716	2798	2878	2960	3042	3126	3298
	h_g	2769	h	2840	2951	3057	3162	3267	3373	3481	3699
	s_g	6·663	s	6·817	7·040	7·233	7·409	7·571	7·723	7·866	8·132
9 (175·4)	v_g	0·2149	v	0·2305	0·2597	0·2874	0·3144	0·3410	0·3674	0·3937	0·4458
	u_g	2581	u	2628	2714	2796	2877	2959	3041	3126	3298
	h_g	2774	h	2835	2948	3055	3160	3266	3372	3480	3699
	s_g	6·623	s	6·753	6·980	7·176	7·352	7·515	7·667	7·811	8·077
10 (179·9)	v_g	0·1944	v	0·2061	0·2328	0·2580	0·2825	0·3065	0·3303	0·3540	0·4010
	u_g	2584	u	2623	2711	2794	2875	2957	3040	3124	3297
	h_g	2778	h	2829	2944	3052	3158	3264	3370	3478	3698
	s_g	6·586	s	6·695	6·926	7·124	7·301	7·464	7·617	7·761	8·028
15 (198·3)	v_g	0·1317	v	0·1324	0·1520	0·1697	0·1865	0·2029	0·2191	0·2351	0·2667
	u_g	2595	u	2597	2697	2784	2868	2952	3035	3120	3294
	h_g	2792	h	2796	2925	3039	3148	3256	3364	3473	3694
	s_g	6·445	s	6·452	6·711	6·919	7·102	7·268	7·423	7·569	7·838
20 (212·4)	v_g	0·0996	v		0·1115	0·1255	0·1386	0·1511	0·1634	0·1756	0·1995
	u_g	2600	u		2681	2774	2861	2946	3030	3116	3291
	h_g	2799	h		2904	3025	3138	3248	3357	3467	3690
	s_g	6·340	s		6·547	6·768	6·957	7·126	7·283	7·431	7·701
30 (233·8)	v_g	0·0666	v		0·0706	0·0812	0·0905	0·0993	0·1078	0·1161	0·1324
	u_g	2603	u		2646	2751	2845	2933	3020	3108	3285
	h_g	2803	h		2858	2995	3117	3231	3343	3456	3682
	s_g	6·186	s		6·289	6·541	6·744	6·921	7·082	7·233	7·507
40 (250·3)	v_g	0·0498	v			0·0588	0·0664	0·0733	0·0800	0·0864	0·0988
	u_g	2602	u			2728	2828	2921	3010	3099	3279
	h_g	2801	h			2963	3094	3214	3330	3445	3674
	s_g	6·070	s			6·364	6·584	6·769	6·935	7·089	7·368
50 (263·9)	v_g	0·0394	v			0·0453	0·0519	0·0578	0·0632	0·0685	0·0786
	u_g	2597	u			2700	2810	2907	3000	3090	3273
	h_g	2794	h			2927	3070	3196	3316	3433	3666
	s_g	5·973	s			6·212	6·451	6·646	6·818	6·975	7·258
60 (275·6)	v_g	0·0324	v			0·0362	0·0422	0·0473	0·0521	0·0566	0·0652
	u_g	2590	u			2670	2792	2893	2988	3081	3266
	h_g	2784	h			2887	3045	3177	3301	3421	3657
	s_g	5·890	s			6·071	6·336	6·541	6·719	6·879	7·166
70 (285·8)	v_g	0·0274	v			0·0295	0·0352	0·0399	0·0441	0·0481	0·0556
	u_g	2581	u			2634	2772	2879	2978	3073	3260
	h_g	2772	h			2841	3018	3158	3287	3410	3649
	s_g	5·814	s			5·934	6·231	6·448	6·632	6·796	7·088

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Figure (2)

Superheated Steam tabl

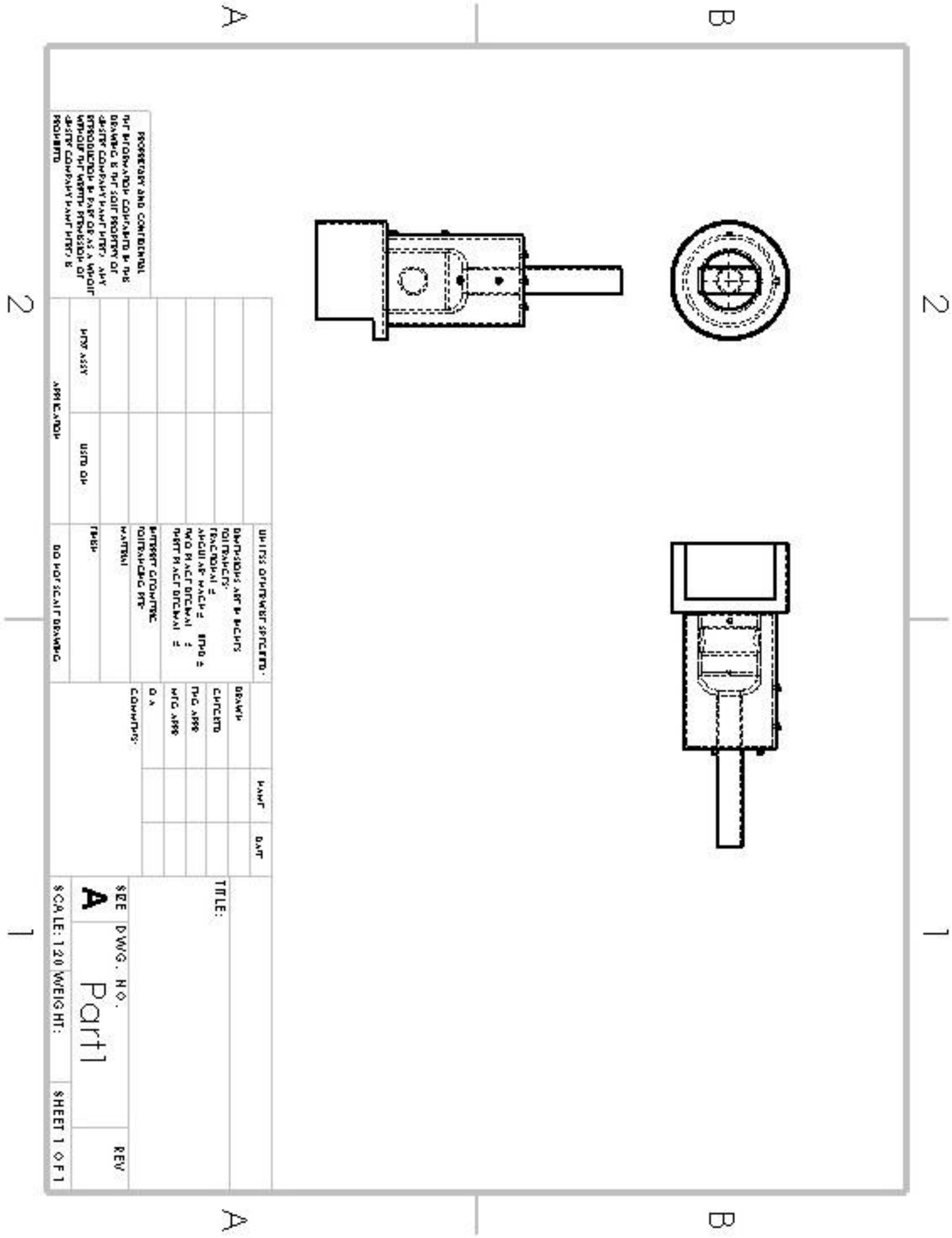

Figure (3)

Plans of simulation