REPUBLIC OF IRAQ
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
AL-FURAT AL-AWSAT TECHNICAL UNIVERSITY
ENGINEERING TECHNICAL COLLEGE- NAJAF

STUDY OPERATION OF STEAM GENERATION SYSTEM USING DIFFERENT FUELS

KARRAR SALAH HASAN RAHEEMAH

M.TECH.
IN MECHANICAL ENGINEERING TECHNIQUES OF POWER

2020

STUDY OPERATION OF STEAM GENERATION SYSTEM USING DIFFERENT FUELS

A THESIS
SUBMITTED TO THE DEPARTMENT OF MECHANICAL
ENGINEERING TECHNIQUES OF POWER
AS PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR
MASTER OF THERMAL TECHNOLOGIES DEGREE IN
MECHANICAL ENGINEERING TECHNIQUES OF POWER

(M.TECH.)

BY

KARRAR SALAH HASAN RAHEEMAH

(B.Tch. pumps. Eng.)

Supervised by:

Asst. Prof. Dr.	**Lecturer. Dr.**
Wisam A. Abd Al-Wahid	**Hasan Hadi Salman**

June 2020

بسم الله الرحمن الرحيم

"قالوا سبحانك لا علم لنا إلا ما
علمتنا إنك أنت العليم الحكيم "

صدق الله العظيم (البقرة -32)

عقدتُ بك الأيمان بالنّجح واثقاً
فحلّت يدُ الأقدار ما قد عقدتهُ
وكان اعتقادي أنك الدهر مسعدي
فخانتني الأيام فيما اعتقدتهُ
أردت لك العمر الطويل فلم يكن
سوى ما أراد الله لا ما أردتهُ

صديقي (**محمود عاجل الحساني**) بدءت حلمي الدراسي معك وكل امالي ان ينتهي معك

ولكن قالت الايام كلمتها قبل ان اقف مبتهجا" فرحا" في حفل تخرجك

رحمك الله واثابك بقدر سعيك الجميل لشهادتك العليا

فلا يسعني يا صديقي سوى ان اهديك رسالتي التي تنقصها انت

صديقك

كرار صلاح حسن

Disclaimer

I confirm that the work submitted in this thesis is my own work and has not been submitted to other organization or for any other degree.

Signature:
Name: Karrar Salah Hasan
Date: 21 / 6 / 2020

Acknowledgement

All Praise to ALLAH for his uncountable blessings, assistance during the preparation of this work.

I would like to submit my deep respects and sincere gratitude to my supervisors; ***Asst. Prof. Dr. Wisam A. Abd Al-Wahid*** *and* ***Lecturer. Dr. Hasan H. Salman*** *for their support during the research period and guidance to accomplish this work.*

Special thanks to the head and members of the Mechanical Power Techniques Engineering department for their assistance to me. I would like to thank all lovely, helpful people who support me directly and indirectly to conduct this work. Special thanks to my collagenous for their great assistant and great encouragement.

My deepest thanks and gratitude are due to each member of my family, especially my dearest parents and brothers for their patience, support and encouragement throughout my life.

KARRAR SALAH HASAN

2020

Supervisors Certification

We certify that the thesis entitled "**STUDY OPERATION OF STEAM GENERATION SYSTEM USING DIFFERENT FUELS**" submitted by **Karrar Salah Hasan** has been prepared under our supervision at the Department of Mechanical Engineering Techniques of Power, College of Technical Engineering-Najaf، AL-Furat Al-Awsat Technical University, as a partial fulfillment of the requirements for master of thermal technologies degree.

Signature:
Name: Asst. Prof. Dr. Wisam
A. Abd Al-Wahid
(Supervisor)
Date: / / 2020

Signature:
Name: Lecturer Dr. Hasan
Hadi Salman
(Co-Supervisor)
Date: / / 2020

In view of the available recommendation, we forward this thesis for debate by the examining committee.

Signature: Dhaf
Name: Asst. Prof. Dr. Dhafer Manea Hachim
Head of Mechanical Eng. Tech. of Power

Date: 21 / 6 / 2020

Committee Certification

We certify that we have read this thesis titled "**STUDY OPERATION OF STEAM GENERATION SYSTEM USING DIFFERENT FUELS**" which is being submitted by **Karrar Salah Hasan** and as examining committee, examined the student's thesis in its contents. And that, in our opinion, it is adequate as a thesis for master of thermal technologies degree.

Signature:
Name: Asst. Prof. Dr. Wisam A. Abd Al-Wahid
(Supervisor)
Date: / / 2020

Signature:
Name: Lecturer Dr. Hasan Hadi Salman
(Co-Supervisor)
Date: / / 2020

Signature:
Name: Asst. Prof. Dr. Ahmed Hashim Yousif
(Member)
Date: / / 2020

Signature:
Name: Lecturer Dr. Hayder Azeez Diabil
(Member)
Date: / / 2020

Signature:
Name: Asst. Prof. Dr. Hyder H. Balla
(Chairman)
Date: / / 2020

Approval of the Engineering Technical College- Najaf

Signature:
Name: Asst. Prof. Dr. Hassanain Ghani Hameed
Dean of Engineering Technical College- Najaf
Date: / / 2020

Linguistic Certification

This is to certify that this thesis entitled “**STUDY OPERATION OF STEAM GENERATION SYSTEM USING DIFFERENT FUELS**” was reviewed linguistically. Its language was amended to meet the style of the English language.

Signature:

Name: Asst. Prof. Shubbar A. Mousa

Date: 19th August 2020

Abstract

Study the effect of replacing fuel in midsize laboratory steam generation plant is presented in this work. The plant is 200KW runs by diesel fuel and connected to many thermal equipments in the laboratory. The current work includes two parts; in the first part, the combustion system was replaced to run the plant by LPG. The burner is designed from scratch and implemented to work on the boiler system, after ensuring work the system with the new fuel, the second part of the study involves optimize the design of the burner in term of the burner momentum, where three diameter ratios (1/10, 1/15, 1/20) were tested. The diameter of the burner to the diameter of the boiler where choose to be the function for comparison between each design. The CO, CO_2, O_2, HC and efficiency are calculated for each ratio and the results show that, when making comparison among three burners with three diameter ratio which mentioned above, 1/10 diameter ratio was the best ratio and the boiler best efficiency at this ratio were (90.1, 90.5, 90.8, 93, 92, 91.5)% when equivalent ratios (0.352, 0.527, 0.75, 1.02, 1.25, 2.39). In addition, the emission ratios for CO were (0.85, 0.69, 0.13, 0, 0.25, 1.28)% vol , CO_2 (2, 4.1, 5.9, 10.1, 9.7, 5.1)% vol , O_2 (5, 2.3, 1.2, 0.01, 0.015, 0.01)% vol , and HC (2.2, 1.5, 0.9, 0.1, 120, 513)% vol. The experimental results showed that the general operating conditions of LPG are better than diesel fuel, related to emissions and efficiency. Although safety and control are still an issue, we can conclude that LPG fuel is a promising fuel in a future using especially in Iraq because of its availability.

List of Contents

List of Tables

List of Figures

Nomenclature

Symbol	Definition	Unit
h_s	Enthalpy of Saturated Steam at Operating Pressure	kJ/kg
h_{fw}	Enthalpy of Feed Water	kJ/kg
$m^{\cdot}_{s}$	Mass Flow Rate of Steam	kg/hr
$m^{\cdot}_{f}$	Mass Flow Rate of Fuel	kg/hr
GCV	Gross Calorific Value	kcal/kg
T	Temperature	K
LHV	Lower Heating Value Of Fuel	MJ/kg
P	Pressure	bar
$\dot{m}$	Mass Flow Rate	kg/s
Q	Volume Flow Rate	LPM
Subscripts		
F/A	Fuel-Air Ratio	
FAR_{act}	Actual Fuel Air Ratio	-
FAR_{stoich}	Stoichiometry Fuel Air Ratio	-

Greek Symbols		
P	Fluid Density	kg/m^3
Φ	Equivalence ratio	-
Δ	Difference	-
∅	Diameter	m
H	Boiler efficiency	-

Abbreviations

Symbol	Description
NOx	Nitrogen oxides
SOx	Sulphur oxides
H_2	Hydrogen
C_3H_8	Propane
CH_4	Methane
C_2H_6	Ethane
C_4H_{10}	Butane
C_5H_{12}	Pentane
CFCS	Chlorofluorocarbons
A/F	Air Fuel Ratio
CO	Carbon Monoxide
CO_2	Carbon Dioxide
LPG	Liquefied Petroleum Gas
NO	Nitric oxide
NO_2	Nitric dioxide
C	Carbon
O_2	Oxygen
N2	Nitrogen
S	Sulphur

SO_2	Sulfur dioxide
SO_3	Sulfur trioxide
HC	Hydrocarbon
OH	Hydroxide
CCP	Coal Combustion Products
ppm	Parts Per Million (Volume)
DFB	Dual fuel boiler
Btu	British thermal unit
H2O	Water
PM	Particulate Matter
DHW	Domestic Hot Water
BL	Bio-liquid
dr	Diameter Ratio
HFO	Heavy Fuel Oil
FEGT	Furnace Exit Gas Temperature
CRAHs	Rotary Continuous-Regenerative Air Heaters
B1	Blend
APG	Associated Petroleum Gases
HDO	Heavy Diesel Oil
LDO	Light Diesel Oil
OC	Organic Carbon
TC	Total Organic Matter
EC	Elemental Carbon
MFO	Medium Fuel Oil
ULO	Used Engine Lubrication Oil
FGD	Flue Gas Desulphurization
LHV	Lower Heating Value of Fuel
PF	Pulverized Fuel
ADU	Atmospheric Distillation Unit

Chapter one

Introduction

CHAPTER ONE

Introduction

Energy is the essential supplier for economic development in all countries of the world and it is the fundamental needs for all manufacturing facilities. About 35% of the energy consumed by humans it's used in the manufacturing sector. In the present situation, the use of fossil fuels is rising exponentially and this, in turn, contributes to increasing environmental pollution. By 2025, demand for fuel is expected to triple more than in the past few years. The rate of fossil fuel production is slower compared to the increase in demand. Oil is among the fossil fuels is the main source of commercial energy. Therefore, energy conservation is more important economically and environmentally **[1]**.

Any development on the national level is to invest your resource at a high level of planning and employee any siding product that could reduce expenses of other fields. In Iraq, the petroleum country, where the oil industry represents the main national income, the associated petroleum gases (APG) represent a big problem because the oil industry structure in Iraq does not qualified to collect these gases and used them in a useful way. However, the electricity crisis in the country and it is solutions bring to the market the need for gas to fuel the electricity power plant and the need for the gas represents a new challenge to the gas industry. Expanding use APG depends on upgrading the equipment and the infrastructure of the gas industry, on another hand using liquefied petroleum gases (LPG) is more common and cheaper nowadays.

The ideal use of energy in industrial fields leads to achieving the conservation of energy. Therefore, the equipment is designed to work in the best efficiency. For existing devices, some improvements can be made without major changes to the factory design. Boilers are widely used in industrial fields, including in the manufacturing, textile industries, and Steam power plants. One of the most common energy conservation is heat recovery such as exhaust gas**[1].**

1.1 Boiler

Some types of the boiler is a steam generator. It is a closed container made of metal, which partially contains water. The boiler works to rise of the energy content in the water and turns it into steam by absorbing the thermal energy resulting from the combustion of fuel. So, it can be used in many fields such as power generating equipment, homes heating system and the delivery of steam required for cleaning operations in kitchens **[2]**. Many fuels are used in boilers, but the widely used are fossil fuels (coal, diesel, and natural gas). A large portion of the world's power is being produced, boilers are usually the best choice for turning these forms of energy into electricity **[3]**. Besides, most industrial heating systems use boilers to generate hot water or steam. As a consequence, an effective boiler often has a significant impact on the energy savings associated with heating **[4]**.

The introduction of energy-saving initiatives and the enhancement of total boiler performance will save a significant amount of energy. Briefly, the boiler has the function of providing the necessary steam at a known temperature and pressure **[1]**,**[5].**

Among the common uses of boilers in industrial fields, including in food factories, petrochemical industries, and garment factories, are used in an auxiliary way in power plants, etc. Also, boilers are especially used in homes, hotels, restaurants, and some government offices for heating and providing hot water. Apart from the type of use, the requirements of safe operation are essential in working of the steam boilers to operate at high efficiency **[5].** The heating system consists of many elements, the boiler is one of the main parts in the heating system in addition to others parts such as pipes, pumps, electrical switches, radiators, and control devices **[6]**.

1.2 Boiler Components

Some parts must be added to the steam boiler to increase its performance. They are divided into two categories, (i) boiler mountings and (ii) boiler accessories **[7]**. Figure 1.1 shows a schematic description of the steam boiler **[8].**

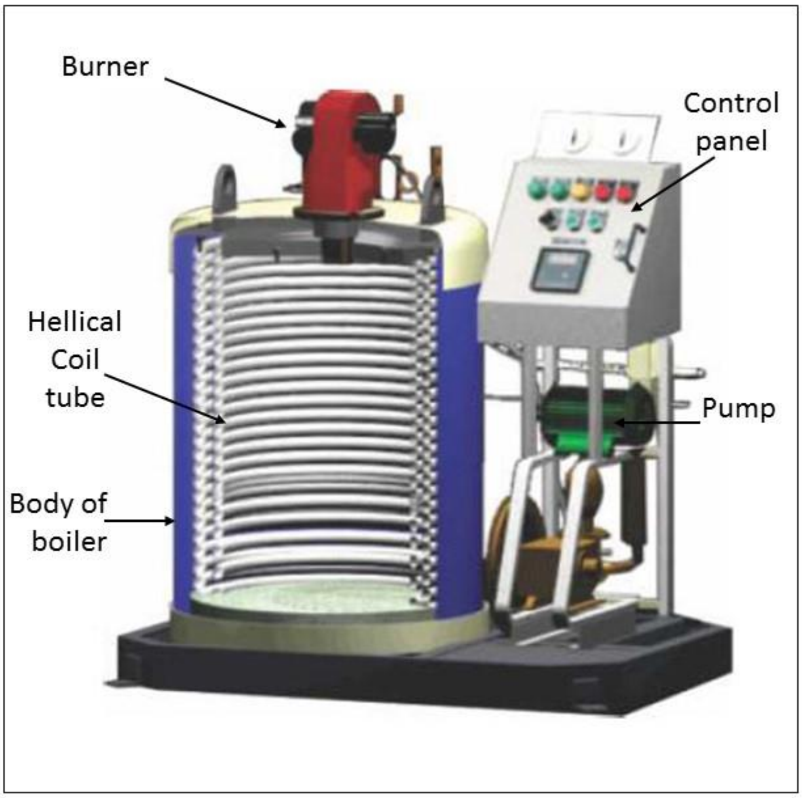


Figure 1.1: General overview of steam boiler **[8]**

1.2.1 Boiler Mountings

Mounting is necessary because without it the boilers will work without safety conditions. Mountings are listed below **[9]**.

- Safety valves
- Indicators of water level
- control of water level
- Water level alarms & cut-out assembly
- Valve blowing down
- Remote water level transmitter
- Main steam outlet valve

- Pressure gauge with cock & Pressure switches
- Oven drain valve
- Feedwater valves
- Burner assembly
- Foam (scum) removal valve
- Air vent
- Water sampling valve
- Manholes
- Soot blower

1.2.2 Boiler Accessories

They are the second group containing components which are designed to improve the performance of steam power plants and allow the boiler to operate. These fixtures are called boiler accessories. It is an integral part of the boiler. Accessories are listed below **[9]**.

- Air pre-heater
- Economizer
- Superheater
- Feed pump
- Injector

1.3 Boilers and their Classification

Boilers used in industries are classified into several categories as shown in fig.1.2 **[10] [11]**.

1.3.1 Fire Tube Boiler

Fire tube boilers are a manner that the hot combustion gasses flow into the pipe, so when the hot gasses flow into the pipe and the water covering the pipe is heated fig.1.3.

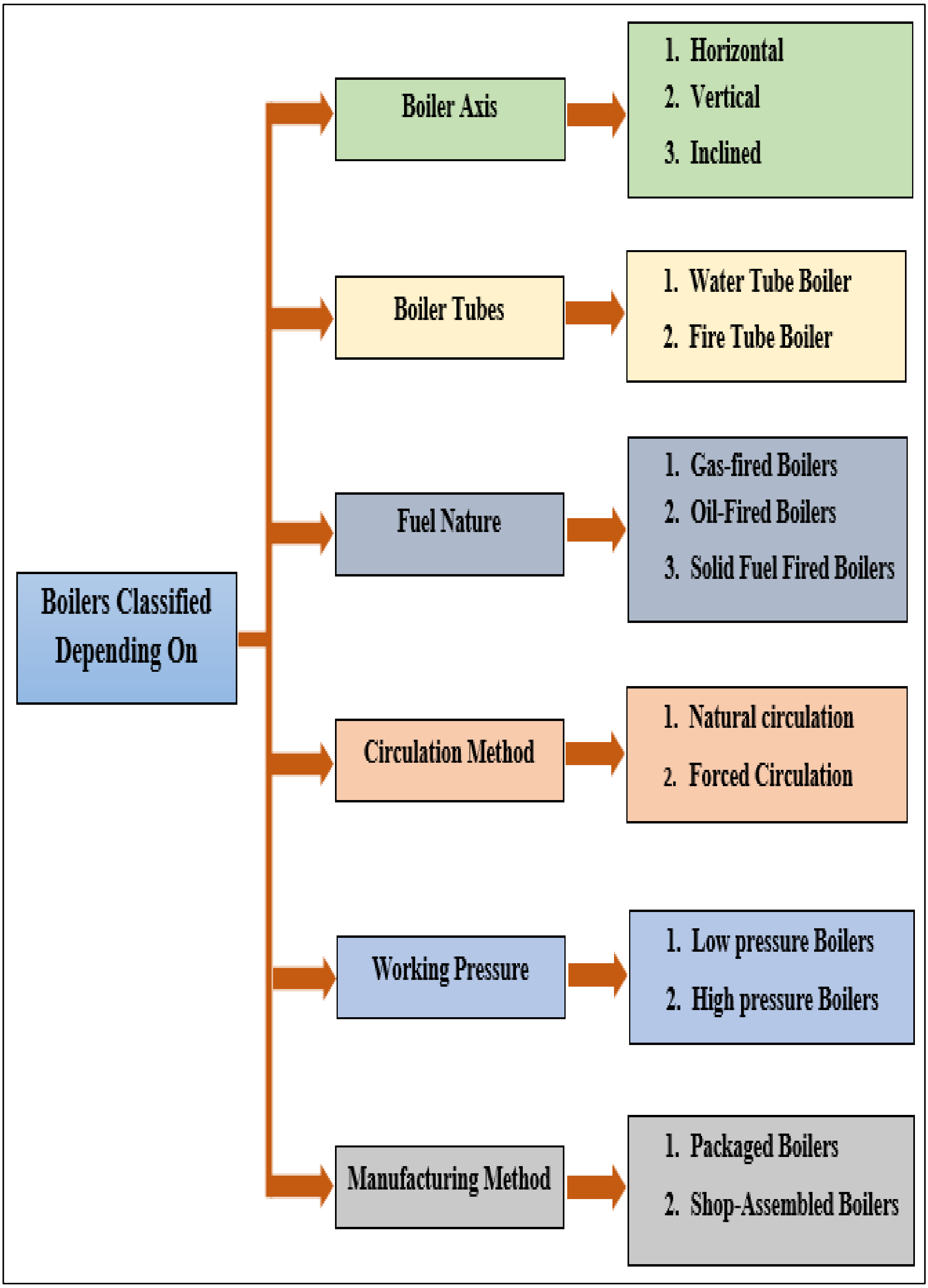


Figure 1.2: Boilers and Their Classification **[11]**

The vapour is constrained by the external casing of the boiler. For low-pressure applications, this sort of boiler is utilized to annul the require for a thick external layer **[1]**,**[10]**.

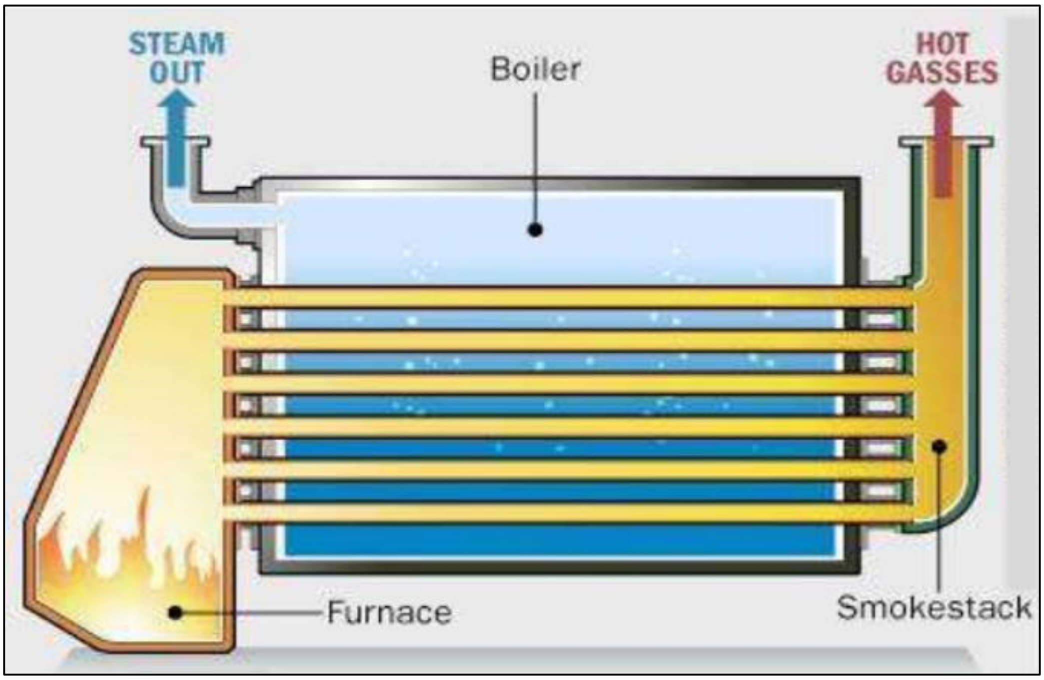


Figure 1.3: Schematic Diagram of a Fire Tube Boiler **[12]**

1.3.2 Water Tube Boiler

This kind of boiler is designed to distribute combustion gases around tubes containing water for heating to evaporate and convert into steam. The tubes were either straight in the older designs or twisted into basic shapes. Boilers of advanced water pipes contain complex multi-bending tubes, and therefore this type of boiler can be produced in large sizes for use in applications that require steam at high pressure **[1]**,**[13]**,**[14]**, as shown in fig.1.4.

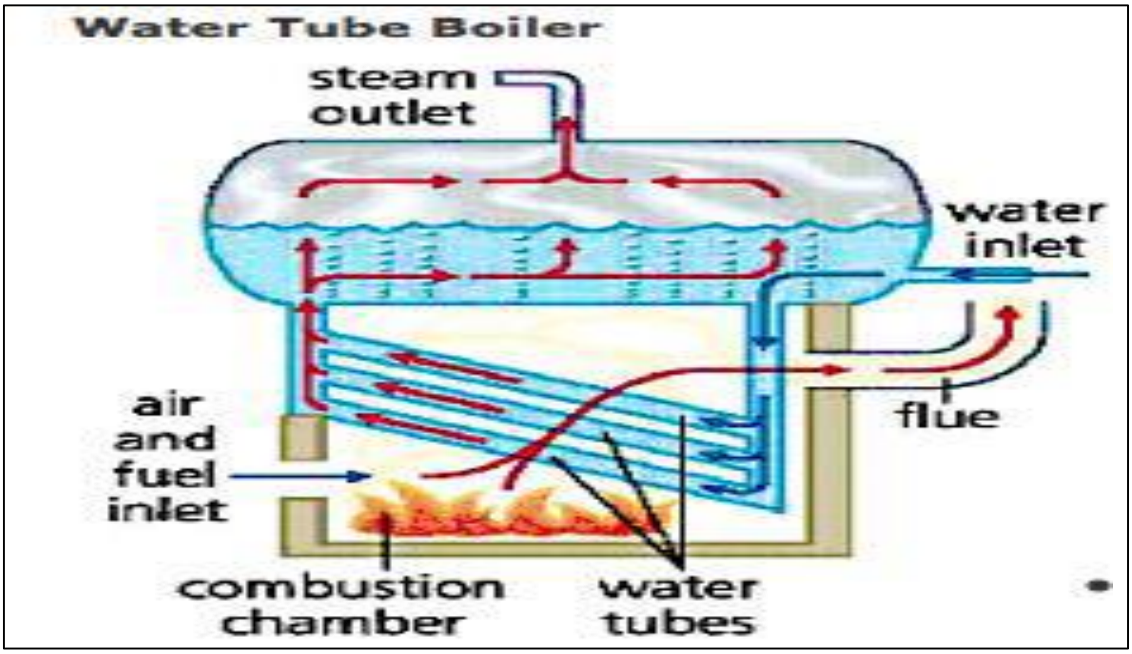


Figure 1.4: Diagram of Water-Tube Boiler **[10]**

1.4 Fundamentals of Steam Generation

1.4.1 Boiling

The steam boiling water cycle is a common practice. The boiling temperature is achieved (the natural boiling point of water reaches 100 ° C at an air pressure of 1 bar).

1.4.2 Circulation

The movement of water and steam in the boiler circuit is called rotation. It is heated near the saturation temperature by the heat energy from combustion. Sufficient circulation must be given to extract heat from the burner system. If the rotation is due to a variation in pressure or density, the boiler is called a natural circulation. While if it is caused by a pump, the boiler is called forced circulation or works **[15].**

1.5 Energy

The burning of any combustibles is the heat source. For energy, fuel which usually used for combustion is wood, natural gas, coal and oil, it has several types of heating elements. Electrical steam boilers typically use heating agents to form resistance. Another source of heat for steam generation is nuclear fission either directly or often in heat exchangers or ‘power generators’. Heat recovery steam generators use the heat which had removed by other systems. the case of heat recovery steam generators shows in the gas turbine **[16]**.

1.6 Fuel Types

Several types of fuel are mostly used in the boilers including solid fuels, natural gas (NG) , nuclear energy, gasoline, among many others. Natural gas is one broadly utilized for its efficiency, and cheaper cost compared to electricity and oil, and it burns cleanly, especially within the European locale. NG contains methane gas and a few of the other gasses. NG can be effortlessly transported into fluid, either by pipeline or by storage tank.

An important feature that distinguishes the use of a specific type of fuel is its availability and energy content, as well as the ease to burn and spread it inside the boiler's combustion chamber. In some boilers, the combustion system is modified to enable it to burn more than one fuel, and this is called a Double Fuel Boiler (DFB). Where it is possible to burn liquid fuel such as oil or gaseous fuel such as natural gas, which provides the possibility to switch between the two types when the price of one of them increases in the market without the need to change to a new boiler. Thus, the DFB is economically justified. Figure 1.5 shows global energy consumption in various fields according to the type of fuel used (energy sources). Coal combustion products (CCP) are the materials produced when we burn coal to generate electricity. They include ash, bottom, slag, flue, and other power plant byproducts [17] .The commonly used fuels are shown in the following sections **[16].**

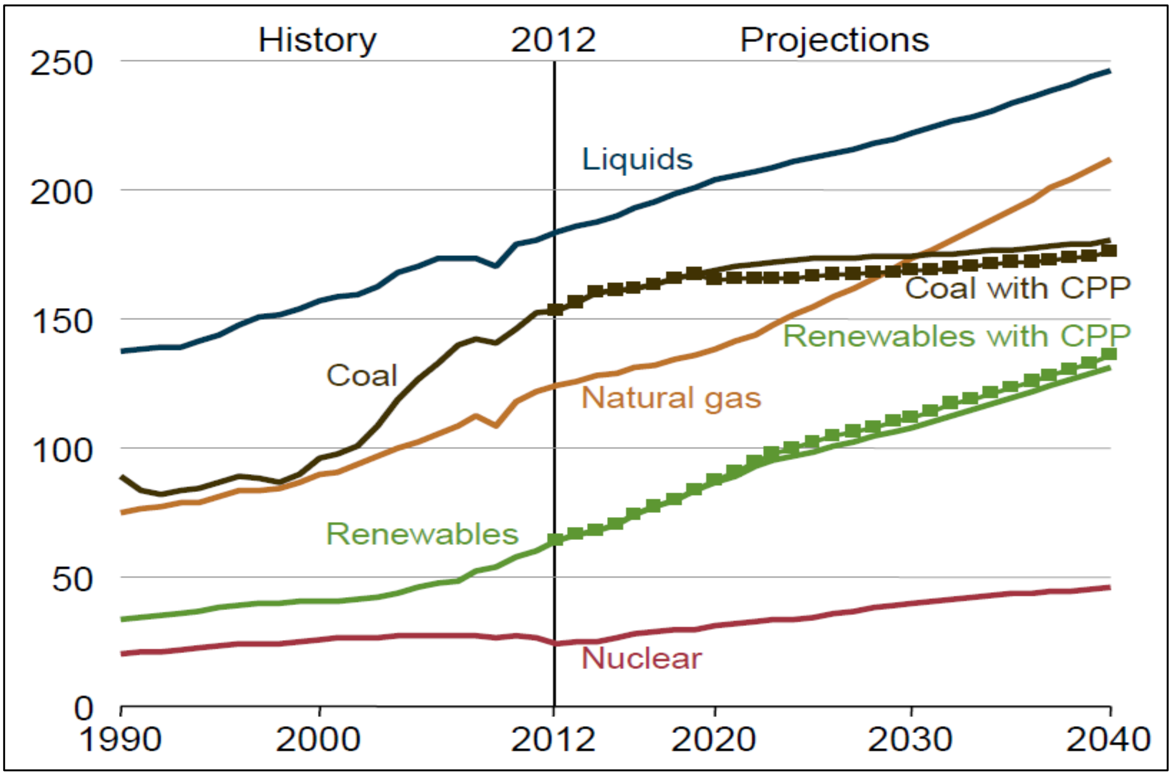


Figure 1.5: World Energy Consumption by Type of Fuel Used, 1990-2040 (Quadrillion Btu) **[17]**

1.6.1 Solid Fuel

Various types of solids can be used as fuel in boilers combustion processes. Among the types of solid fuels are all combustible waste, such as coal and biofuels, as well as household garbage which is a heterogeneous fuel due to its multiple components of plastic, paper, food, minerals, etc. It causes a high demand for combustion equipment suitable for this type of fuel to filter the flue gas and reduce emissions. Therefore waste is used as a fuel in the production of central heating.

Coal is considered one of the main non-renewable energy source. Where it is formed due to the exposure of the organic materials to pressure and heat for long periods. Bituminous coal is considered one of the most common types in some European countries, as it is used in industries and used by more than 41% in power plants. Emission problems (SOx, NOx), combustion deposits, acid rain

and the economic cost of coal mining is the main factor in determining the future of coal use **[18]**,**[19]**.

Biofuels are a common species, such as woody crop residue, straw, and reed remains. To facilitate the transportation and storage of biofuels, their composition may be substituted in moulds of certain engineering shapes or powder form. The burning efficiency of the wood grain is very high compared to wood, as it is very dense and low moisture **[18]**. Biofuels are less expensive compared to many other fuels, and liquid or gaseous biofuels are characterized by low emissions and this increases making them the appropriate fuel in many fields **[20]**. Of the common biofuels (Biogas, Biodiesel, Vegetable Oil, Solid Biofuels, Ethanol, and other Vital Alcohols) **[21]**.

1.6.2 Liquid Fuel

Most liquid fuels are derived from crude oil through refining operations. It is known that crude oil is caused by the decomposition of living organisms after their death under the ground as a result of pressure and heat in the underground. The main components of crude oil are hydrocarbons, in addition to other components such as sulfur, nitrogen, and others **[21]**. The fuel oil classes 1-2 are characterized by their low density, they are less viscous and are called distillation oils. Diesel fuel belongs to this category. The most common fuel for burners is the first type of oil. Where distillation oils are lightweight oils, and they are used in domestic heating due to lack of ash resulting from them and low sulfur content **[18]**,**[22]**. Other classes of fuel oil are of high density and tend to solidify at low temperatures, so one of the most important causes of the weak stove of this type of oil is insufficient heating temperature before combustion. Sometimes mixing of high viscosity fuel oil with some biofuels (palm oil, canola oil) is used to facilitate the process of its use **[18]**.

1.6.3 Gaseous Fuels

Gaseous fuel is one of the easiest types of fuel to use as it can be sprayed regularly and it achieves complete combustion compared to other types of solid and liquid fuels. Gaseous fuels contain less carbon in terms of energy compared to other fuels, resulting in relatively low emissions. Among the types of gaseous fuels used in energy production, such as natural gas, biogas, and city gas **[18]**. The conditions of natural gas formation are similar to the conditions of the formation of crude oil, where it is present directly with it or with separate wells. The natural gas varies in its composition from one region to another. The main component of natural gas is methane (CH_4), which is the lightest hydrocarbon molecule. Natural gas also contains heavy gas hydrocarbons such as ethane (C_2H_6), butane (C_4H_{10}), and propane(C_3H_8) in addition to other gases containing sulfur in different quantities. Hydrogen sulfide is usually removed from the gas distributed by the system because of its high toxicity **[23]**.

Biogas represents gas that is produced from the decomposition of organic matter in the absence of oxygen and certain conditions, it is formed in sewage networks as well as in landfills. The gas produced is mainly CH_4 and CO_2. Biogas is a renewable energy source that does not contribute to the production of any pollutants in nature, it is used in some combustion processes as heat production and the work of some vehicles **[18]**.

1.6.4 Energy Content

The calorific value or the amount of energy released from the fuel is a basic parameter when comparing fuels, and it represents the amount of heat produced from the total combustion of a specific fuel unit **[17]**. When using gaseous fuel, the flow rate of these gases differs from the burner nozzle due to the difference in density, which in turn gives different heat values. The Wobbe index was used to compare gases, where the higher heating value in MJ/m^3 is divided by the specific density relative to air. The calorific value is the same for gases containing the same values from the Wobbe index **[24]**.

1.7 Combustion Chamber

It is the place which the mixture of air and fuel is burned inside it, thus the heat transfer from the combustion to the water conduces it to turn into steam. Usually, the combustion chambers are made of steel and cast iron and well insulated from the environment, as the heat inside the combustion chamber reaches several hundred degrees of heat gradually **[25]**.

1.8 Boiler Efficiency

Boiler efficiency is directly related to the heat transfer rate and fuel combustion efficiency. In the case of complete combustion, the combustion efficiency is great, as the burning of fuel only produces water, carbon dioxide, and heat. When the amount of oxygen decreases, this will result in incomplete combustion, which reduces the combustion efficiency, and hence a decrease in the boiler efficiency. Boiler operation must be kept in complete combustion for safety purposes as well as the amount of non-combustible fuel may cause the boiler to explode. In low-pressure steam boilers used in buildings, the combustion efficiency is usually 80% **[16]**.

The efficiency of the combustion system affects several factors such as the parameters used for the boiler, fuel, and working fluid temperature. In the case of using oxygen instead of air in the fuel combustion process, the products contain water and carbon dioxide, which can be separated by the condensation process, and thus the recycling of a portion of carbon dioxide to the combustion chamber, which effects on the heat transfer to the water pipes**[16]**,**[26]**. The general equation for boiler efficiency **[1]**:

$$\eta = \frac{m^{\cdot}{}_{s}(h_s - h_{fw})}{m^{\cdot}{}_{f} * GCV} * 100\% \quad \text{...(1-4)}$$

Where,

η: Boiler efficiency

h_s: Enthalpy of saturated steam at operating pressure (kJ/kg)

h_{fw}: Enthalpy of feed water (kJ/kg)

$m^{\cdot}{}_{s}$: Mass of steam formed per hour (kg/hr)

$m^{\cdot}{}_{f}$: Mass of fuel supplied into the combustion chamber (kg/hr)

GCV: Gross Calorific Value

1.9 Emissions

The secondary result of industrial progress in some countries was an increase in air pollution, by the emission of some toxic substances from lead and arsenic particles as well as CO, CO_2, SO_2, and NOx. Therefore, strict instructions were applied to reduce and control these emissions, these regulations have been applied to emissions that can be seen or felt, and with continuous development, it has become possible to discover and measure very small quantities of chemicals. The new form of pollution has appeared in the form of climate change or so-called global warming, which is largely caused by human activities. Among the main pollutants that are related to combustion processes can be illustrated in the table1.1 **[18]**,**[24]**.

Table 1.1: Sources of emission and its effects **[18]**

Emission	**Source**	**Effect**
Carbon Dioxide (CO2)	Complete combustion of carbon in the fuel	Global warming
Carbon Monoxide (CO)	Incomplete combustion of carbon in the fuel	Smog
Sulfur Dioxide (SO2)	Combustion of sulfur in fuel	Smog, acid rain
Nitrogen Oxides (NOx)	A byproduct of most combustion processes	Acid rain
Nitrogen Dioxide (NOx)	A byproduct of most combustion processes	Global warming
Water Vapour (H2O)	Combustion of hydrogen in fuel	Localized fog
Particulate Matter (PM)	Unburned or partially burned carbon and hydrocarbons, also dirt and ash in fuel	Smog

Chapter Two

Literature Review

CHAPTER TWO

LITERATURE REVIEW

Introduction

This chapter presents a review of previous studies that have been conducted on the use of different types of fuels in boilers operation, to verify which type gives the best efficiency as well as knowledge of emissions from its work that have an impact on increasing global warming. However, a connection between fuel type and efficiency of the boiler directly is not scientifically accurate, because the boiler could be represented as a heat exchanger which is used as a transporter of heat from the combustion chamber to water. So the literature review will try to introduce the previous works in such a way go firstly through the fuel type in a boiler system, pollutant and then geometry of boiler on its efficiency.

2.1 Methods for reducing emissions:

2.1.1 The effect of equivalence ratio (Φ):

Valerie J. Lyons et.al [27] study the effect of the non-uniformity of the fuel to inlet air ratio affecting the emission focus of NOx was studied. Theoretical levels of nitrogen oxide were verified in the flame tube apparatus with inlet air temperatures (600, 700, and 800) K. The apparatus pressure was 0.3 MPa, the reference velocity 25 m / s, with the valence ratio (0.6), and the residence time about 0.002 s. The results appeared a boost in NOx concentrations when increasing the F/A ratio, and for the rate equivalence ratios least than 0.6, nitrogen oxides levels decreased when the average Φ approached 1 (stoichiometric state).

Rohschild, W . G et.al [28] Study the effect of equivalence ratio on emissions in a persistent combustion burner working on ethylene and ethane fuels. The calculation was performed over the axial distance of the combustion chamber for the valence ratio 1.43 to 1.51 for the rich mixture and at 0.75 for the lean mixture. The results showed an increase in unburned HC and CO for both kinds of lean and rich mixture.

R. Pavri et.al [29] study the influence of the equivalence ratio and flame temperature of the continuous external combustion system, and it was spotted that in the stoichiometric state $\Phi = 1$, the flame temperature arrived the utmost point, and the nitrogen oxides concentration increased. But when the $\Phi > 1$, the instantaneous nitrogen oxides decreased rapidly, then the NOx ratios could be controlled by lowering the flame temperature in the unmixed (diffuse) mixture.

A. Ergut et.al [30], study the effect of equivalence ratio on the chemistry of soot initiation in a one-dimensional, pre-mixed, ethyl-benzene flame. The research examined three flames with Φ equal to (1.68, 1.74, and 1.83). According to the experimental work, the maximum temperature of this flame should be recorded similar by changing the relative amounts of fuel vapour, oxygen, and nitrogen. The results present that the flame temperature function is not only the limit of the start of soot, and due to conservation the maximum temperature constant, soot not depend on the equivalence ratio and may be generated with the flame. A chemical kinetic model was previously tested against pre-mixed soot with benzene and ethyl-benzene, and the results appear that CO was directly proportional to increasing the Φ when it exceeded the unit.

2.1.2 The effect of fuel droplet size:

M. K. Razdan et.al [31] studied the importance of the precise fuel drops of the mixture and this will lead to good dispersal. Both of them participate in a homogeneous F/A mixture and decrease the duration of stay. If the spray is coarse, it means that the vaporization will be slow. So that, the bulk of the fuel will be burned in rich pockets or droplets combustion, and the temperature increase is much higher if compared with the combustion of the lean mixture and will lead to a higher formation of NOx. The droplet distribution directly affects the homogeneity of the mixture and also influenced the formation of nitrogen oxides, which means that rising the dissolution pressure results in a more homogeneous mixture and leads to elimination of UHC and CO emissions.

Chenn Zhou et.al. [32] Studied the dissolution pressure of liquid fuels and found that this parameter is directly affected by the focus of emissions and vaporization if the fuel droplets affect the mixing degree of air and fuel. The results showed that the spray structure depends on the density of fuel, nozzle injector size, differential Pressure, viscosity and the vaporization rate depends on the droplet size, boiling point, gas temperature and the implicit heat of the liquid fuel.

Two fuels are studied and compared, namely, diesel and hydrated ethyl alcohol for different proportions of F/A by **Edgar Paz et.al [33]**. The investigation was concerned about UHC emissions and CO_2.they were found that the emissions concentrations were inversely proportional to the atomization of the A/F ratio, and the results showed that emissions (UHC and CO) from diesel combustion were greater than those from the combustion of aqueous ethyl alcohol for the same limited conditions.

Amir Mahdi Ghasemi et.al [34] investigated the size of the fuel droplets and the temperature of the air entering the complex soot process in a turbulent liquid fuel burner. The results expound a decrease in the incoming air temperature, and an increase in the size of the fuel droplets will increase the formation of soot from the spray flame.

N. Chigier et.al [35] investigated the effect of injection pressure and found that it directly affects the uniformity of the A/F mixture. For the air blast, the researchers found an increase in a liquid break-up, resulting in less air-fuel generation, and as a result, fewer emissions of soot, CO_2 and NOx were obtained.

2.1.3 Effect of adding percentage of thermal load by LPG:

S.A.B. Al Omari et.al [36] worked experimental research was carried out to test the thermal efficiency of dual-fuel furnaces fueled with diesel blends and using lubricating oil (ULO), co-with LPG. ULO is known as a source of renewable resources. The term "renewable" is used in the present sense as the excess lubricant oil generator must be available and should continue as long as the engines are in operation. they discuss the reduction in pollution from gaseous fuel combustion, such as LPG, by co-fired with certain limited volumes in lower-grade liquid fuel with higher pollution susceptibility. The liquid fuel used is a combination of ULO and diesel fuel. The mineral analyses carried out found a large concentration of metals in the ULO used relative to the metal content of discarded fresh crude. It is expected to be the explanation behind the enhanced flame radiation capabilities found while using ULO. Results indicate that substituting 30% of the LPG mass with a liquid fuel mixture consisting (in this study) of 20% ULO and 80% diesel raises radiation to furnace walls by around 1% above the amount achieved When only LPG of the same overall equal sum as the liquid mix or LPG component is included. In the liquid fuel blend, 20 percent ULO correlates to nearly 6 percent of the overall fuel mass supplied to the furnace. To illustrate the role that may have been performed by the disproportionate concentrations of metals in ULO to radiation, it has been replicated under the same circumstances, albeit with fresh oil replacing ULO in a liquid mixture. The findings have yet again verified the supremacy of ULO when it comes to radiation enhancement. The study also describes certain findings from previous studies performed by the first author and co-authors of the present review testing used engine lube oil against waste liquid oil of biological origin, called a "used cooking oil". This distinction also encourages the usage of ULO as a fuel replacement that allows in the furnaces to pass heat through radiation. Additionally, the analysis provides certain ULO characterizing measures such as viscosity at various temperatures and the calorific benefit. This research is thought to have valuable lessons for design, operation, and control in applications such as radiative boiler applications.

Lee et.al [37] experimental investigating in a pre-mixed cylindrical stove test perforated at multiple sizes for use in condensation boilers, and the effect of change in hole sizes was examined as well as showing the extent of stability of flame spread from holes at the equivalent share of 0.7 for different loads (13.96,23.26,30.24) kW as shown in fig.2.1. In this burner, the concentrations of NO_2 and CO were less than 40 ppm and 30 ppm, respectively at 0% oxygen. When using LPG and LNG with this type of burners, there is no gap between them in terms of flame stability.

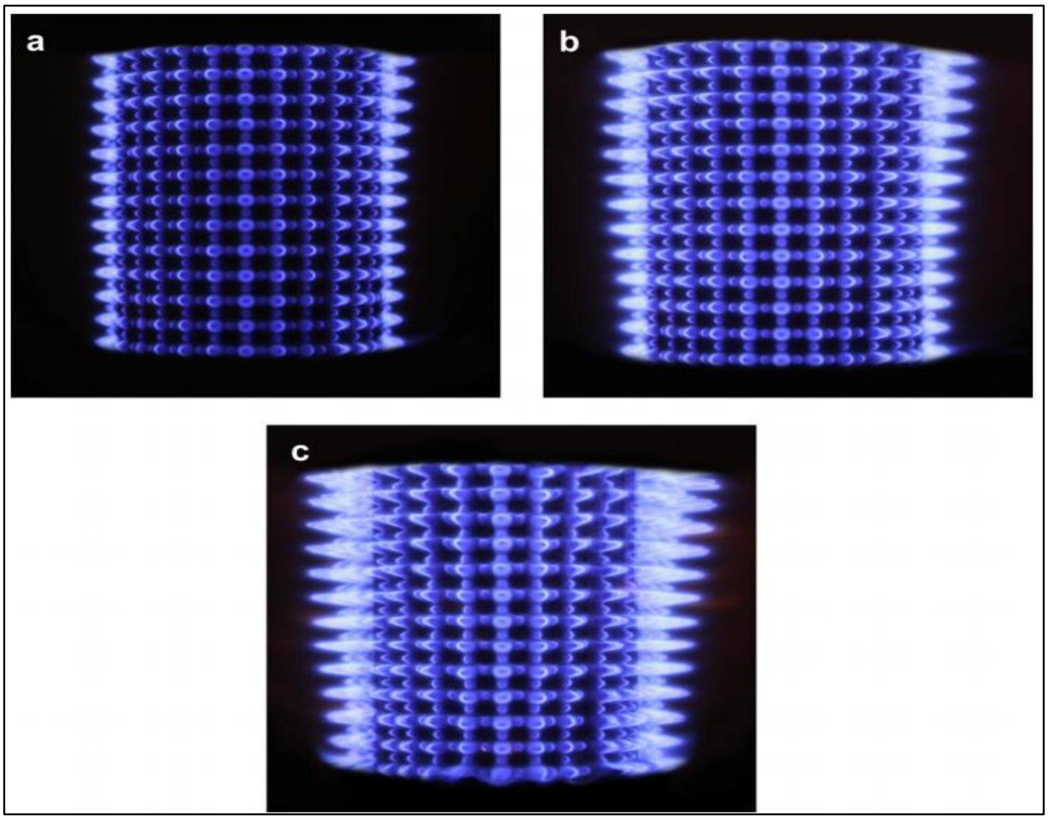


Figure 2.1: Spread Of Flames From Holes At Equivalence Ration Of 0.7 For Different Loads (a) 13.96 kW, (b) 23.26kW, and(c) 30.24 kW

The current research was conducted by **Johnson et.al [38]** to cover the carbon emissions resulting from the use of heating oil and liquefied petroleum gas, which is often used to heat homes in many European cities. The study evaluated these in seven European countries. Systems were identified using the

Eco-Boiler model. When using bio-oil (100% methyl ester) the result was identical to LPG, And by mixing 20/80 with standard heating oil, the bio-heating oil system produces a footprint of about 15% more than the LPG system.

2.2- Boiler fuels:

2.2.1 Liquid fuel boilers

Park et.al [39] experimentally studied a 0.7 MW oven and a 75 MW generating boiler were used to burn two different types of fuel (BL and HFO) and compare their combustion characteristics. The tests revealed the basic and important differences between BL and HFO namely, the extent of viscosity, the strength of the initial heating degree, and their sulfate and nitrogen content. Which in turn greatly affects the improvement of operating conditions. The results of a flame inspection of BL fuel in the combustion chamber of the furnace showed a less lit and brighter flame compared to the HFO fuel combustion as shown in fig.2.2 because, in HFO burning, pollutants and soot are produced at higher concentrations than BL. In the case of burning BL fuel, a decrease in the heat flow at the burner nozzle and a rise in the gas temperature is observed. The nitrogen oxides and sulfur resulting from the combustion of BL are less than the burning of HFO fuel due to the low sulfur and nitrogen content in BL, and this gives a safe indication of the boiler's work to generate energy at the lowest concentration of pollutants. However, upon burning the BL, it was found that there was a decrease in heat transfer and its propagation towards the oven walls, so a type of FEGT enhancer was added to improve the combustion relative to the burning of HFO fuel. From the above, there was a need for more studies to know the stability of operation for different types of BL to use them in energy production plants.

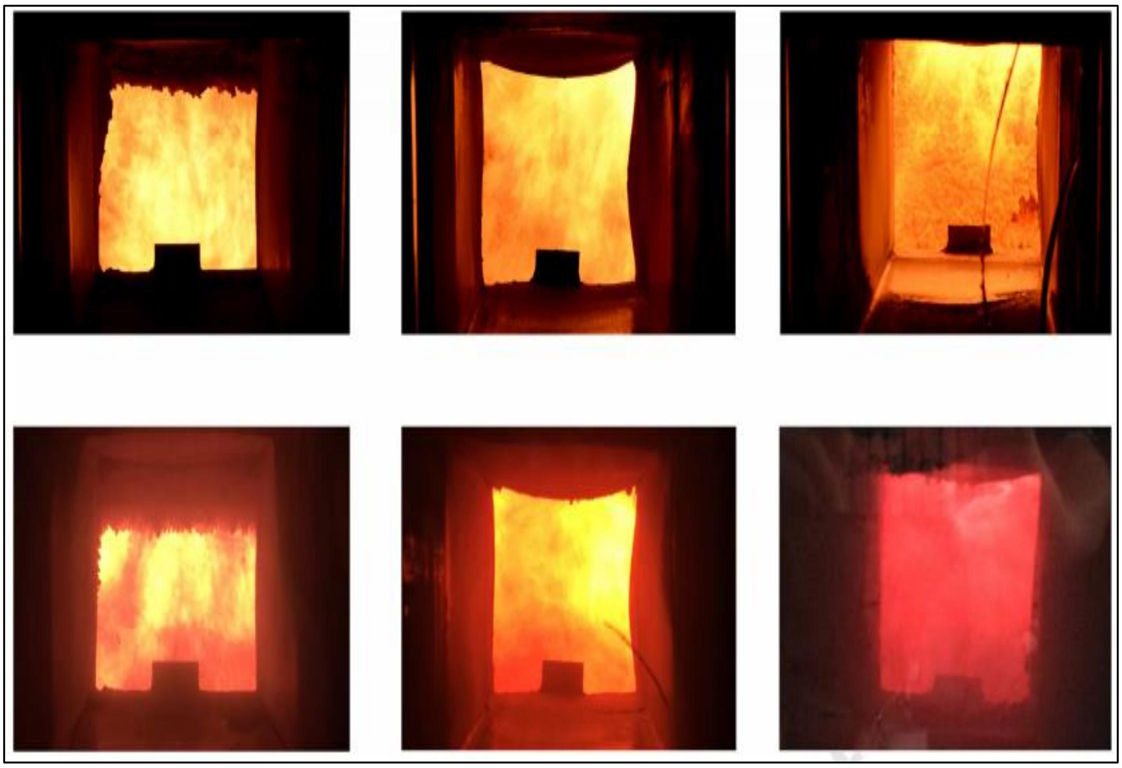


Figure 2.2: Illustration of Bl (Upper) and HFO (Lower) Flames

At the power plant, an experimental study of corrosion treatment in some parts of the boiler resulting from the use of heavy fuel oil has been studied by **Barroso et.al [40]**, the study was done in three experimental states for burning fuel. The first state uses heavy fuel oil without any additives, the second state burns heavy fuel oil with the presence of a slurry additive, and the third state burns heavy fuel oil after adding an organometallic substance. In the first type of experiment, it was found that there are very high risks to rotary continuous regenerative air heaters CRAHs, which reduces the shelf life of use to 1.5 years. When using the second case by mixing heavy fuel oil with magnesium additives, it reduces the risk of corrosion and works to slightly increase the efficiency of the boiler and thus reduces the excess air and SO_3 concentrations in the exhaust gases. The acid dew point and its relationship to SO_3 concentrations were recognized. In the last stage of the experiments with the addition of an organic substance to the heavy fuel oil, some improvement in the boiler efficiency and an increase in the shelf life against erosion for 7 years was observed, and a decrease in the

Concentration of emissions on CRAHs. The use of biofuel additives for heavy fuel oil, if only partially, gives economic benefit.

In this experimental study، **Huang et.al [41]** used a 300kw furnace that uses fuel mixtures that is an alternative to pure diesel, like castor oil, which is characterized by its viscosity and high oxygen content. Experiments were carried out in the furnace by burning different proportions of the Castor/diesel oil mixture. The rates of castor oil used were 5%, 10%, 20% and 30% in diesel at the lowest possible level of excess oxygen, as the air supply was 245, 241, 240, 237 and 236 Nm/h and the apparent decrease in airflow compared to with an increase in the percentage of castor oil due to the presence of oxygen in the composition of castor oil. Through experiments, a slight decrease in the oven wall temperature and the exhaust gases is very similar to that of the pure diesel burning. Due to the operating conditions with minimal excess oxygen, O_2 and CO_2 concentrations in the exhaust gas are similar in both the case of pure diesel combustion and the case of diesel mixed with castor oil. The addition of castor oil showed no effect on NOx emissions relative to pure diesel.

The sulfur dioxide emissions are similar to the case of combustion of pure diesel or mixed with castor oil because they contain small amounts of sulfur in their composition. The importance of the study highlights the possibility of maintaining the same burning system as shown in fig.2.3 and not having to make changes to it when using this type of fuel mixture, with the possibility of further studies on it through knowing the effect of fuel pressure and the speed of spread of fuel spray on the combustion efficiency and emissions.

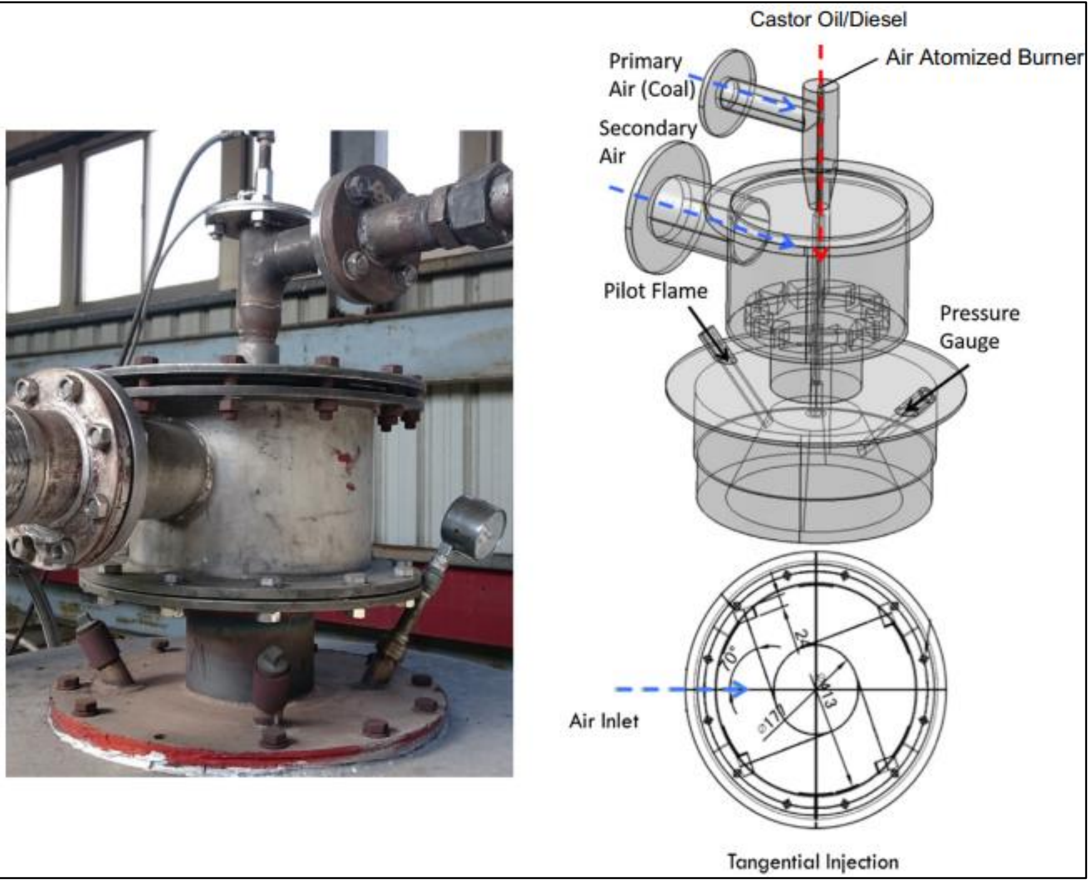


Figure 2.3: Real View and Schematic of the Air Atomized Burner

Biodiesel has recently become more appealing because it is produced from renewable energy, and also because fossil fuel supplies are diminishing day by day. **Ghorbani et.al [42]** researcher compares B5, B10, B20, B50, B80 and B100 combustion with petroleum diesel over large input air flows in an experimental boiler, at two energy stages. The distinction is rendered in terms of combustion efficiency and pollution of flue gas (CO, CO_2, NOx, and SO_2) and the effect of airflow at two energy ranges of 219 kJ / h and 249 kJ / h.

The results indicate that the energy efficiency of diesel was a little higher than that of biodiesel at a higher level, but that biodiesel is efficient at the lower level than diesel. Biodiesel and other blends, except for B10, released less polluting CO, SO_2 and CO_2 than diesel. B10 produced less CO_2 and NOx but more SO_2 than diesel. Notwithstanding studies showing a rise in the amount of NOx resulting from burning biodiesel in engines over traditional petroleum diesel fuels, our results showed a decrease in the amount of NOx in the flue gases resulting from burning biodiesel at second energy stage.

Many commercial boilers in Malaysia use low-fuel oils as the energy source, such as the Medium Fuel Oil (MFO). The need to shift MFO to a cheaper and safer fuel is beneficial due to related pollution problems, operational costs and repair costs. **Najmi et.al [43]** researcher provides part of a report on the possibility of combining MFO with natural gas power. Tests were carried out on a large boiler with a steam capacity of 16,000 kg/hour, using various configurations of low, medium and high fire settings. The topic covers fuel properties, pollution, energy consumption as well as combustion efficiency. In the case of natural gases, the maximum combustion efficiency is 83.9 percent, equivalent to 43.9 MJ/kg of heat produced. Optimal output was 84.3 percent recorded at medium fire and 30.6 percent recorded at excess air. With MFO the efficiency of combustion decreases from low to high fire, with minor improvements as the process switches from medium to high fire level. The output of combustion efficiency was 85.1 percent, which correlates to the heat energy of 77.8 MJ/kg. Nonetheless, due to the significant difference in energy densities of both fuels, a more thorough study is needed particularly in terms of fuel consumption cost.

Mahfouz et.al [44] studied the flame analysis spectrometer when using cooking oil waste and mixing it with conventional fuel. Where cooking oil waste was mixed with light diesel and heavy diesel fuel by a mass of 20%, without any other additions, B1 and B2 respectively. The combustion process was carried out using a vortex burner in a water boiler at different thermal loads, Φ = (0.63, 0.75, 0.96, and 1.1) respectively. When measuring the temperature of the flame it turns out that the highest energy can be measured when burning HDO. The B2 mixture produced about 7.5% less heat energy than HDO, and thus the amount of heat transferred to the boiler is about 12.2%, 2.1%, 8.2%, and 7.6% lower than the

HDO, while the energy produced from the B1 mixture was about 17%, 13.6%, 29.4%, and 6.1% lower compared to LDO. Because of high energy released, HDO and LDO produced very high CH and C_2 radicals relative to the other fuels.

Varia et.al [45] when it becomes incredibly difficult and expensive to upgrade the current combustion equipment in the boiler with the correct modern technologies. The vast capacity and comparative efficiency of the diesel engine makes biodiesel derived from inedible oil a successful substitute fuel in India. Mixing biodiesel with diesel offers an intermediate solution to solving big problems. The key issue, such as lack of availability and pollution of diesel fuel, has shown the good capacity and comparable efficiency for alternative fuels with the same efficiency and better pollution characteristics made from inedible oil. Biodiesel in the pressure ignition engines is widely accepted as similar to diesel fuel. It provides other advantages including a higher certain number, nitrogen oxides, carbon dioxide, hydrocarbons, lower toxicity, lower particulate emissions, better protection, lower CO_2 emissions in the life cycle.

2.2.2 Solid fuel boilers

Niklitschek et.al [46] they focused in this study on the usage of wood chips, which are biomass commonly accessible in the Valdivia woods, a medium-sized town in the middle of southern Chile. For a standard residential building, the expense of heating and domestic hot water (DHW) with wood chips has been measured with specific thermal insulation conditions. The effects of the wood chips technologies (traditional firewood, diesel technologies and liquefied petroleum gas (LPG) were contrasted. The feasibility of replacing firewood boilers used in wood boilers and liquefied petroleum gas was also evaluated. The higher costs of dissolving wood chips were balanced by lower fuel prices, resulting in lower heating and DHW prices than LPG and diesel. The strong reliability and combustion performance of the wood chips device often contributes to lower heating and DHW expense than the firewood method, even if this machine is already working. Thermal insulation greatly lowered maintenance expenses and fueling, offering a budgetary rationale for replacing the heating network and DHW with wood chips as part of the initiative. Just for low heating rates and DHW demand, the alternative with LPG seems more appealing. Connecting four similar buildings (7,680 square meters) in the energy grid allows exposure to the lowest heating costs and DHW per home, combining economies of scale in boiler production with the expense of extending the distribution network. The resultant expense is projected to be 16% smaller than the LPG method, which is the second-lowest-cost option. The response to the research question posed in this report is therefore optimistic under climatic conditions and the abundance of forest biomass in Valdivia, even if the minimum thermal requirement is met. That inference can also extend to many southern Chilean towns.

Pronobis et.al [47] they are attempted to determine the effect of biomass on the fouling of boiler thermal surfaces. Measurements were conducted on the pulverized fuel (PF) OP 140 steam generator to illustrate the effect of combined biomass with bituminous coal on boiler production. Typical upper silesian coal was chosen as the primary fuel, which has a slight inclination for fouling. There are three types of biomass: straw, wood, and dried waste sludge. Results indicate that all forms of biomass studied are distinguished by a higher fouling propensity than gas, leading to a decrease in boiler performance degradation as well as improvements in boiler operating parameters (ash stream, amount of water pumped into attempters, and hot air temperature). The biomass during co-firing replaces the coal, but the extra fuel consumption is still greater than that of the replacement coal. Therefore, the real decline in coal consumption is less than the thermal fraction of biomass.

Tanetsakunvatana et.al [48] worked on a 300 MW boiler powered by Thai lignite with three experimental groups to test the effects of excess air ratio, unit load, and thermal fuel efficiency on the thermal unit and emission characteristics, which are affected by the type of fuel used. As a result of the experiments, the following results were obtained:

(A) At different excess air levels:

- Nitrogen oxide emissions from the unit increase with increasing air levels, indicating a fuel cycle for nitrogen oxides treatment in the Thai lignite ignition boiler.
- The concentration of sulfur dioxide emissions (corrected to 6 percent of O_2 flue gas) is independent of the excess air level, despite only differences in fuel.

(B) In different unit loads:

- When reducing the unit load from 96% to 83%, nitrogen oxide emissions will increase from the unit from 361 ppm to 418 ppm. However, when the load becomes (67%), nitrogen oxide emissions decrease to 265 ppm.
- Sulfur dioxide emissions decrease as the unit load decreases due to the increased efficiency of FGD

(C) With different fuel characteristics:

- The thermal efficiency of boilers and environmental properties (except for nitrogen oxides) improves when firing higher LHV fuel
- With lower fuel consumption, both the nitrogen oxide emission rate and the actual nitrogen oxide emissions increase with a higher fuel content due to the effect of the fire temperature on the burner area.

The thermal efficiency of the boiler was marginally determined by the lower heating factor of the excess air ratio, unit load, and power, varying from 90.3% to 92.3% for a wide variety of variables above. The levels of NOx, SO_2, and PM for these contaminants were below the national pollution standards in all the samples.

Drosatos et.al [49] This work includes a quantitative mathematical parametric study of the indirect fire regime for a lignite boiler at 35% of the nominal thermal load during its service, below the normal theoretical minimum. Parametric analysis is required to determine the various configurations of the firing theory and the impact of two different types of fuel supports: pre-dried lignite and spent olive cake. When the biomass is added as a fuel enhancer, the boiler efficiency will increase, as it raises temperatures intensively inside the boiler. The injection system used for injection of dried lignite material greatly affects nitrogen oxide emissions, and it has a great role in using different types of fuel mixtures.

Kattan et.al [50] investigated an economic analysis for comparison between boilers operating with different types of energy sources (olive peels, LPG, diesel, and electricity) and used to warm homes and heat water in the mountainous areas of Lebanon. It turns out that the electric boiler system is the most polluting and least effective in terms of economics because electricity is supplied to homes from two sources, one of which is the national grid with 50% and a private generator with 50%. Boilers that operate with olive shells or LPG provide energy at 0.13 $/ KWh and that operate with diesel, whose energy price is 0.14 $/ KWh, compared to the price of energy for electric boilers, which is approximately 0.31 $/ KWh throughout the year. To get clean low-emission energy, olive peel must be used to operate boilers in Lebanon, but diesel fuel subsidies and the difficulty of importing olive peels, and taxes, on the other hand, make it difficult to rely on at present.

2.2.2 Gases fuel boilers

Karademir et.al [51] have analyzed potential air pollution from industrial boiler exhaust, the study was conducted on more than 100 factories in one of the Turkish industrial cities, of which (44 and 34, respectively) depend mainly on their work on the use of natural gas fuel and light fuel oil compared to those that use other types of fuel. The emission levels of combustion pollutants in these boilers (CO, SO_2, NO_2, PM, and formaldehyde) is lower than in other countries. The preference for the use of gaseous fuel is that it is safe, low pollutants, and compliant with Turkish regulations, and also for its ease of availability. Although SO_2 and CO_2 pollutants decrease over time, the NOx problem is the biggest concern in Turkey. It is possible to say that the amount of SO_2 resulting from the combustion of light fuel oil emissions has a sulfur content of 2%, however, it is reduced to 1% to match the environmental specifications of the European Union.

Balanescu et.al [52] studied the boiler condensation, the process that takes place in developed boilers. This type of boiler often uses natural gas in which the methane ratio is more than 0.95%, and if not available it uses cooking gas (LPG). The energy capabilities of seven other types of fuel (butane, coal gasification gas, biogas, diesel, heavy fuel oil, propane, and biofuels) are measured using the latent heat of the flue gas water vapours and the reference fuel is methane. The analysis reveals that the difference between the different volumetric flow levels of combustion air is close to any of the seven combustion types. From the above, it is not required to change the air blower when using condensation boilers and this means when changing between fuels only requires a change in the combustion system and its supplies, and this means reducing the economic cost. Among the fuels used, biofuels have the highest potential to save energy by heating the latent heat of water vapours in the flue gas, while heavy fuel oil has the lowest potential to save energy. In economic terms, the fuel that gives the minimum price of heat is the most appropriate.

2.3 Summary

The previous researchers have studied the efficiency and emissions of steam generating systems (boilers) and different types of fuel such (solid, liquid, and gas) were used in their studies. Therefore, the present study, investigate experimentally a new design with different specification compared to the studies in the literature survey, therefore the present work can be summarized by manufacturing a tangential swirl burner to generate steam water.

2.4 Objectives of the Work

1. Steam generation system (Boiler GMT/V-20) rehabilitation.
2. manufacturing a new burner design for LPG (tangential swirl burner) and study the effects of diameter ratio on the thermal performance of the steam generator.
3. Replacing the fuel used in the college's steam station from diesel to (LPG), which represents a promising fuel in the Iraq country, especially with a tendency to invest in this gas and not burn because the country has a very large stock of it.
4. Comparison of thermal efficiency and emissions of the present study with the original case.

Chapter Three

Experimental Work

CHAPTER THREE

EXPERIMENTAL WORK

Introduction

The previous studies, as mentioned in the literature review, give a clear indication of the possibility of improving the efficiency of a steam boiler in several ways, including the ability to change the type of fuel used in line with its cost and availability in the labour market. In this study, a vertical steam boiler was used with changing the type of fuel used from its original state using diesel fuel to liquefied petroleum gas, where the gas burner was designed and built for use in the generation of steam and then compared to the original case by using the standard stickers for Iraqi fuel. However, this chapter will describe in detail the experimental apparatus, procedure, and experimental conditions used in the current work.

3.1 Working Fluid

3.1.1 Water

Pure water has many characteristics as the phase can change with increasing temperature, moving from the liquid state to the gas (steam) state. It has a high specific heat capacity which makes it an effective heating fluid. Also, it is fairly common, which means it is readily available. Moreover, the cost of water is somewhat low. Water also has a low viscosity, which represents the fluid's resistance to flow and fits comfortably at pH scale 7, which means it is neither alkaline nor acidic.

3.1.2 Fuel Types

3.1.2.1 Diesel

Diesel fuel was used in the steam boiler, and its specifications were in accordance with the Iraqi standards**[46]**. Table3.1 list of fuel specifications.

Table 3.1: Iraq Standard Specification for Diesel Fuel**[53]**

Parameters	**Value**
Density (g/cm^3) at 15 ℃	0.870
Flash Point ℃ (min)	54
Viscosity (cst) at 40 ℃ (max)	12-18
Pour Point c (max)	+9
Sulfur Content % wt (max)	2.5
Diesel Index (min)	50
Carbon Residue % wt (max)	1.5
Water % v (max)	0.5
Ash Content % wt (max)	0.1
Gross Calorific Value (kcal/kg)	10500

3.1.2.2 Liquefied Petroleum Gas (LPG)

LPG is one of the important fossil fuel which consists of gases such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), pentane (C_5H_{12}) **[54]**. The mentioned gases depending mainly on the type of filed.

LPG usually used in the chemical materials industries. It is also used as a fuel in heating and cooking elements for homes purposes. In Iraq (LPG), fuel is promising, especially because of its tendency to invest in gas and not burn it because the country has a large stock of it. The specifications of the fuel production sources were checked. Table3.2 lists the fuel specifications used**[55] [56]**.

Table 3.2: Iraq Standard Specification for LPG Fuel

Properties	**Unit**	**LPG**
Density	Kg/m3	1.85
Flammability Limits	-	4.1-74.5
Auto Ignition Temperature For Air	°C	588
Low Calorific Value	KJ/Kg	42790
Gross Calorific Value	KJ/Kg	49707
Octane Number	-	+105
Flame Velocity	m/s	0.48
The Adiabatic Temperature Of The Flame	K	2263
Quenching Distance	(mm)	-
Fuel/Air Mass Ratio	-	0.064
Heat Of Combustion	MJ/kg air	1.9-8.5
Flammability Limits	Ø	3

3.2 Experimental Apparatus

The experiments of the present work are carried out with GMT / 20 – V steam boiler (140 KW potential capacity). Schematic view and operational characteristics are illustrated in fig.3.1 and table 3.3 respectively **[57]**. The inner diameter of the boiler combustion chamber is 50 cm.

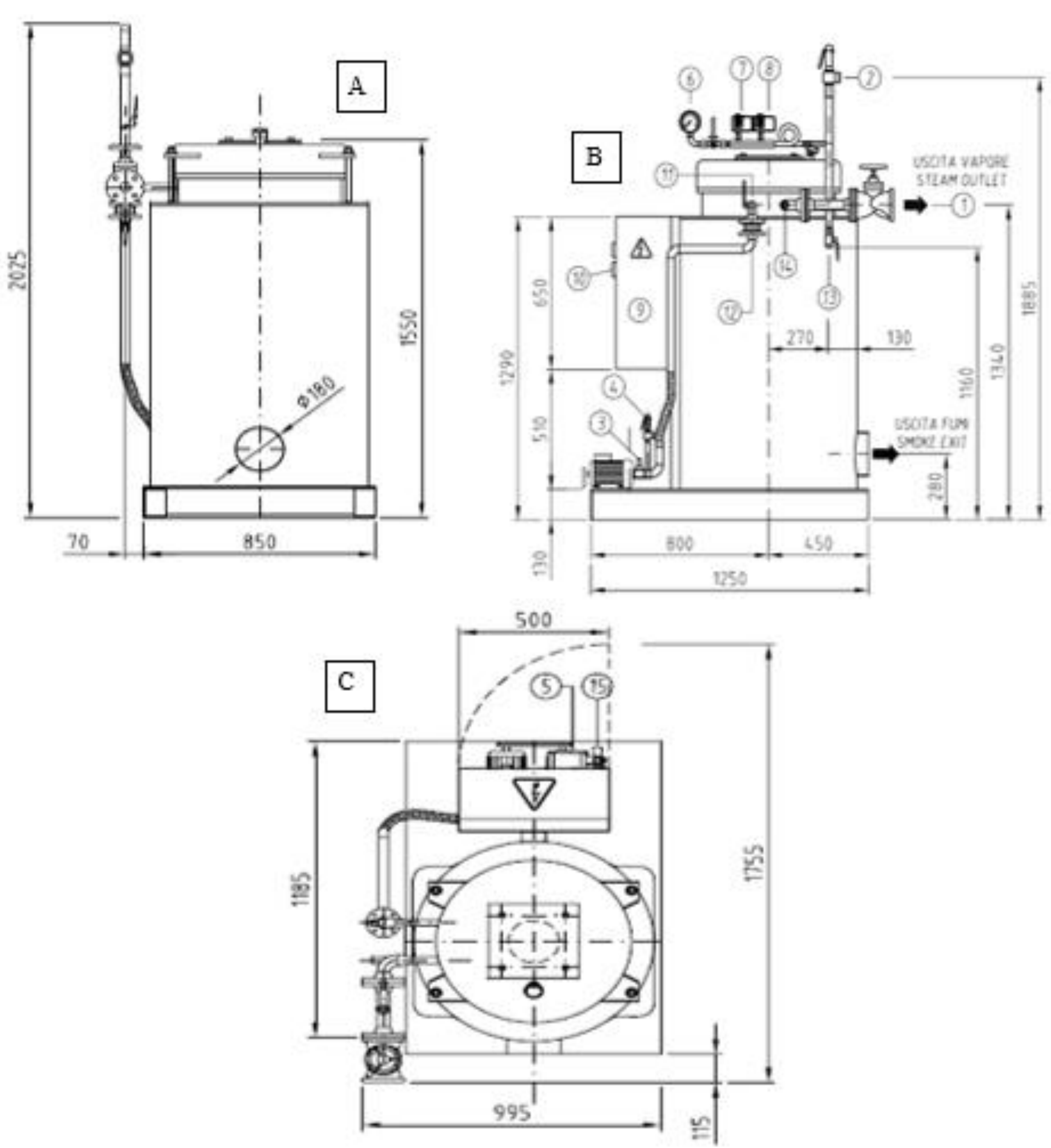


Figure 3.1: Schematic View of GMT/20-V Boiler: A- Front View B- Side View C- Top View and 1- Steam Outlet Valve, 2- Safety Valve, 3- Flow Switch, 4- Over Pressure Valve Outlet, 5- Feed Water Pump, 6- Pressure Gauge, 7- High To Low-Pressure Switch, 8- Safety Pressure Switch, 9- Electric Panel, 10- Steam Thermostat, 11- Back Washing Blow-Down, 12- Check Valve, 13- Start-Up Blow –Down, 14- Thermostat Prop, 15- Water Inlet **[50]**

Table 3.3: The Operational Characteristics of the Boiler

property	Quantity	unit
Steam production	200	Kg/h
Capacity	140	kW
Pressure	11.76	bar
Empty weight	750	Kg
Minimum length burner head	220	mm

3.2.1 Boiler Rehabilitation

System of the steam generation before rehabilitation depicted below in fig.3.2. The system of the steam generation was out of work and ignored for a long time as seen in the mentioned figure. Firstly, the system was disassembled totally and cleaned up all the parts especially the combustion chamber which was has a lot of soot as seen in the fig.3.3. Secondly, the main parts of old burner have been damaged such as control system, vanes and the spark ignition as clarify in the fig.3.4. Moreover, the flame sensor of the old burner was affected by the high temperature as shown in the fig.3.5. General view of the steam generation after rehabilitation is illustrate in fig.3.6.

Figure 3.2: Steam Boiler before Rehabilitation

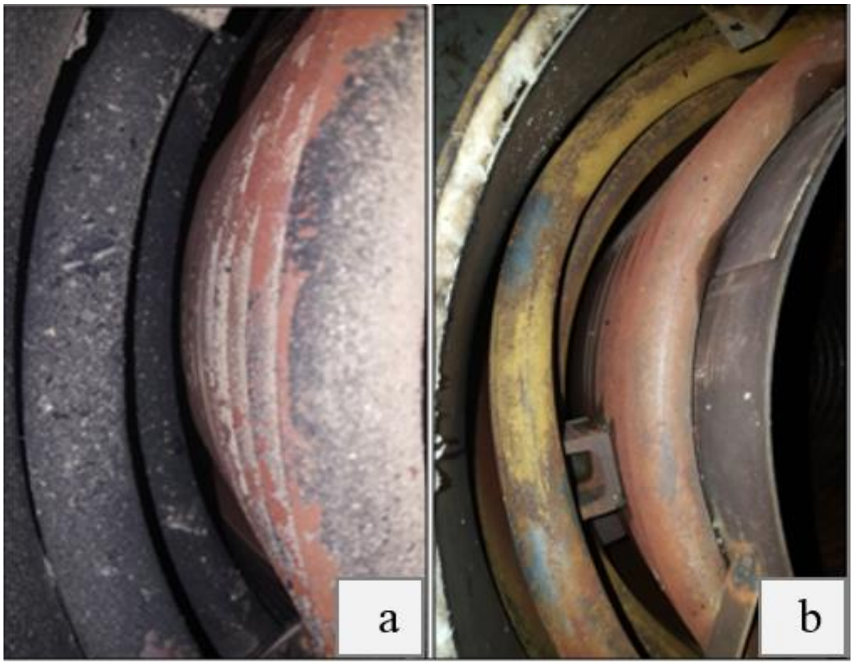


Figure 3.3: Helical Coil Tubes.

a: Before Cleaning, b: After Cleaning

Figure 3.4: Damage Parts

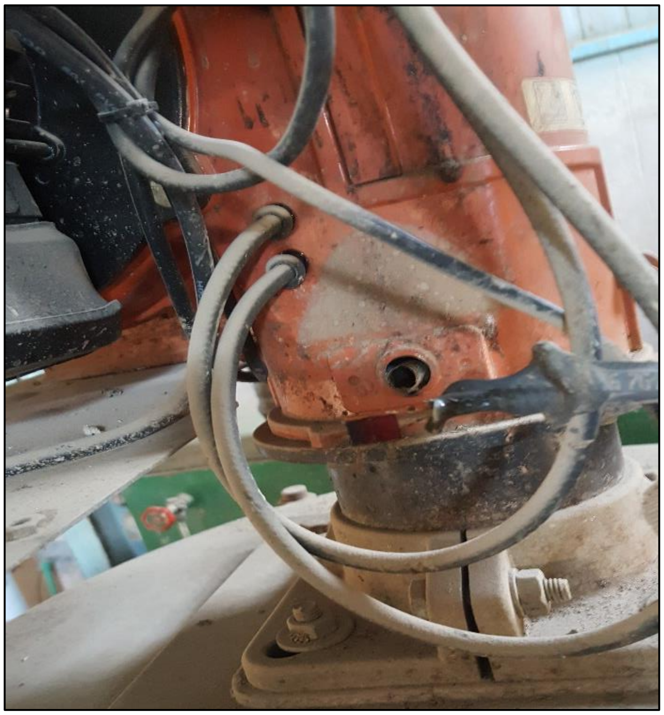


Figure 3.5: Flame Sensor

Figure 3.6: Steam Boiler after Rehabilitation

3.2.2 Burner of diesel fuel

As mentioned in the previous paragraph (3.2.1), there are some parts with Italian burner were damaged as seen in fig.3.7. Therefore, to avoid any defects in experiments of the presents study, proposed to use a new burner with technical specification (see table 3.4) almost closed to the old one. Figure 3.8 illustrates a new burner (Iranian burner). Figure 3.9 express unit of a steam generation with a new burner integrally.

Figure 3.7: Italian Burner Used in the Steam Generation System (Diesel Fuel)

Figure 3.8: Iranian Burner Used in the Steam Generation System (Diesel Fuel)

Table 3.4: Technical Specifications of the Diesel Fuel Burner

Property		**Quantity**
Heating capacity, kcal/h	Minimum	42000
	Maximum	155000
Combustion function		One- stage
Fan motor specification		$1\phi\sim 240\ W$
Control unit		G 790
Minimum gas pressure, mbar		17.5
Dimensions, cm	Burner length	55.2
	Flame cover length	14
	Burner width	46
	Flame cover width	11

Figure 3.9: Boiler by using Diesel Fuel Burner

3.2.2.1 Composition of Simple Centrifugal Injector

The simple centrifugal injector mainly consists of pressure nut, core, junior plate, filter, and body of the fuel injector. The main component of fuel atomization is the atomizing sheet, which consists of a transverse passage, a whirlpool, a faucet **[58] [59]**. A simple centrifugal injector is shown in fig.3.10.

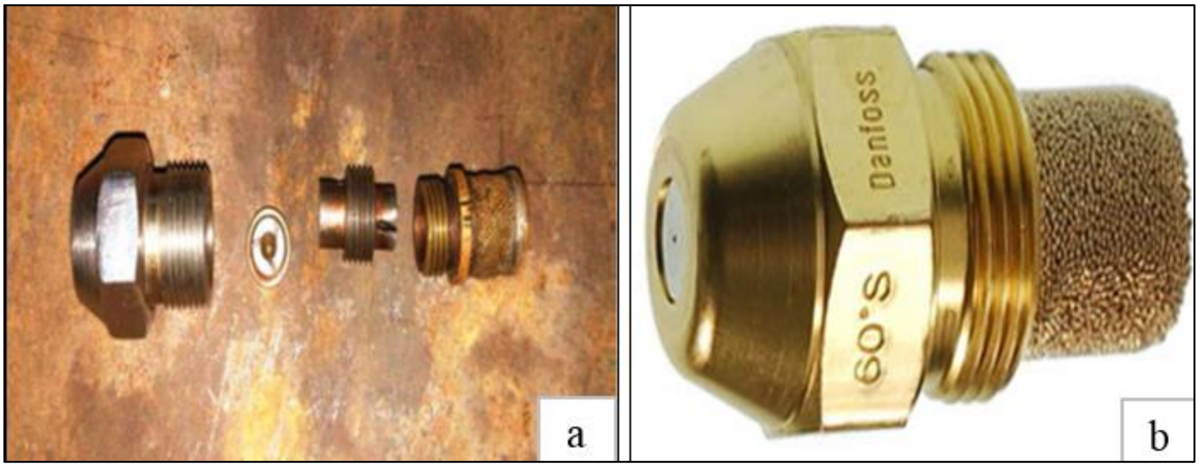


Figure 3.10: a) Composition of Simple Centrifugal Injector **[58]** ,and b) Burner Nozzle **[59]**.

3.2.3 LPG Burner

In the past decades, technologies used in industrial fields have evolved where the swirl burner technology has been used. As it is the case for combustion of gas turbines, internal combustion engines, pulverized coal plants, boilers, refineries, and combustion processes **[60],[61]**. These swirls improve the mixing rate of the materials used in the combustion process, which increases the energy produced and reduces emissions. The combustion process includes a more stable range, such as flashback and blowoff levels, high levels of turbulent flame speed and low combustion volumes using these flows **[60],[62],[63],[64].**

To obtain a combustion system appropriate to the nature of work and more efficient and with low fuel and maintenance costs and fewer pollutants, there was a significant development in the design and manufacture of swirlier burners, and therefore there are different types of swirling burners, and they differ according to the nature of its use as in the aviation sector or fixed gas turbines or propulsion systems Marine or boilers. Multi-input combustion systems and rotary burner furnace systems can burn low-quality fuels and low calorific value (1.3-1.4 MJ / m^3) without any improved fuel **[65]**.

Two different types of swirls mixing are used. The first type is swirl guided that used in the work that presented in **[66]**, where in this work, the swirl guided has 16 slots and 30° as shown in fig.3.11. The other type of swirl mixing is a tangential swirl as shown in fig.3.12 **[67]**. In terms of performance, the transverse entry system has a better performance in forming a spiral at the heart of the internal wall of the burner.

Figure 3.11: Swirl Vane Guide **[66]**

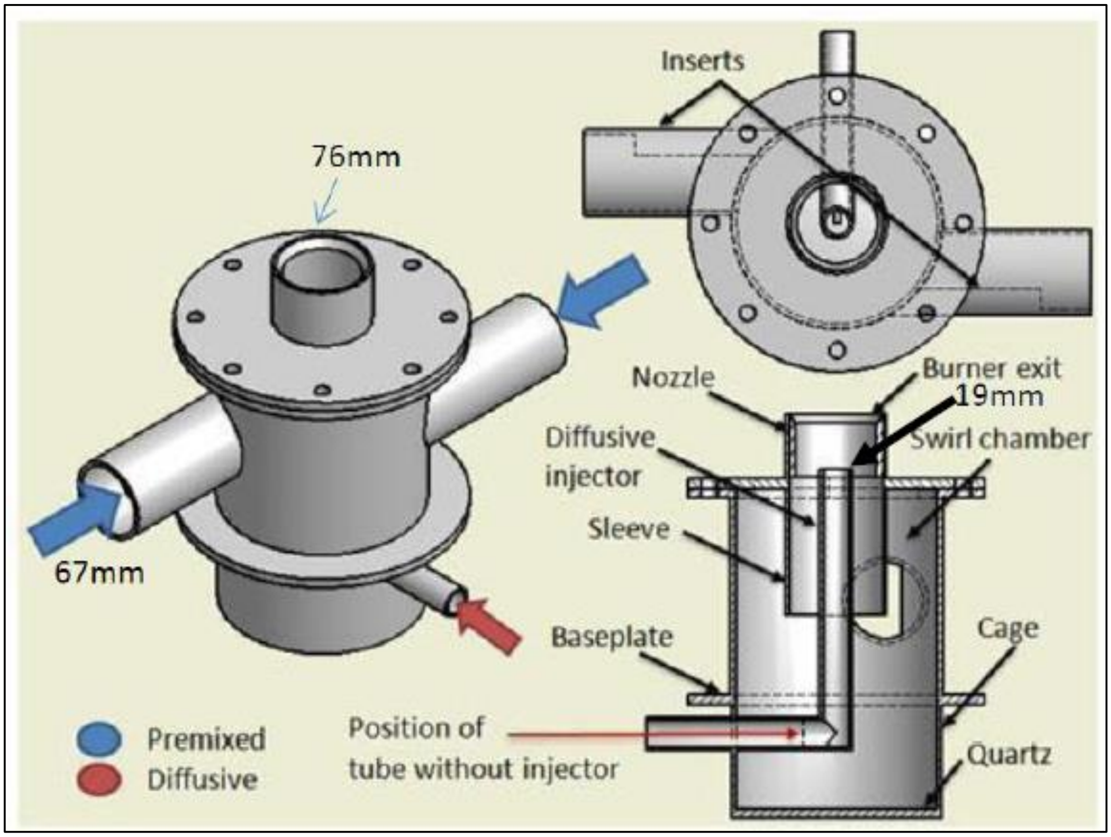


Figure 3.12: Tangential Swirl Burner **[67]**

3.2.3.1 Steps of Manufacturing

The process of manufacturing a tangential swirl burner required to manufacturing several models which also required to perform some testes before using in the final experimental rig such as flashback and blowoff phenomena. The workplace is laboratories of engineering technical college/Al-Furat Al-Awsat Technical University- Najaf.

All burners manufactured were consists of two side air intakes with 1.4 cm in diameter for each side, to create vortices inside the combustion chamber. Where the air is mixed with the liquefied petroleum gas (LPG), which is supplied from the bottom of the swirl chamber with a diameter of 0.6 cm. Thus creating a homogeneous mixture of fuel and air which is ready for combustion at the burner exit. Some changes in the diameters of the burner nozzle and additional air supplying design steps are detailed as the following:

1- The first model was manufactured with a nozzle has a two different diameter, the first diameter has an inner diameter 1 cm and second diameter 1.5 cm as shown in fig.3.13. some experiments were done on it at different fuel/air ratios, but it was found that the burner was affected by the two phenomena of flashback and blowoff.

Figure 3.13: First Design of Tangential Swirl Burner

2- The second model of the tangential swirl burner is similar to the first one, with the addition of an external container that is equipped with additional air, which in turn spreads alongside the flame through the four holes at the front of the burner as shown in fig.3.14. However, it was found that the available quantities of fuel into the air are not suitable, and therefore this model is not stable if it's used in a confined space (boiler).

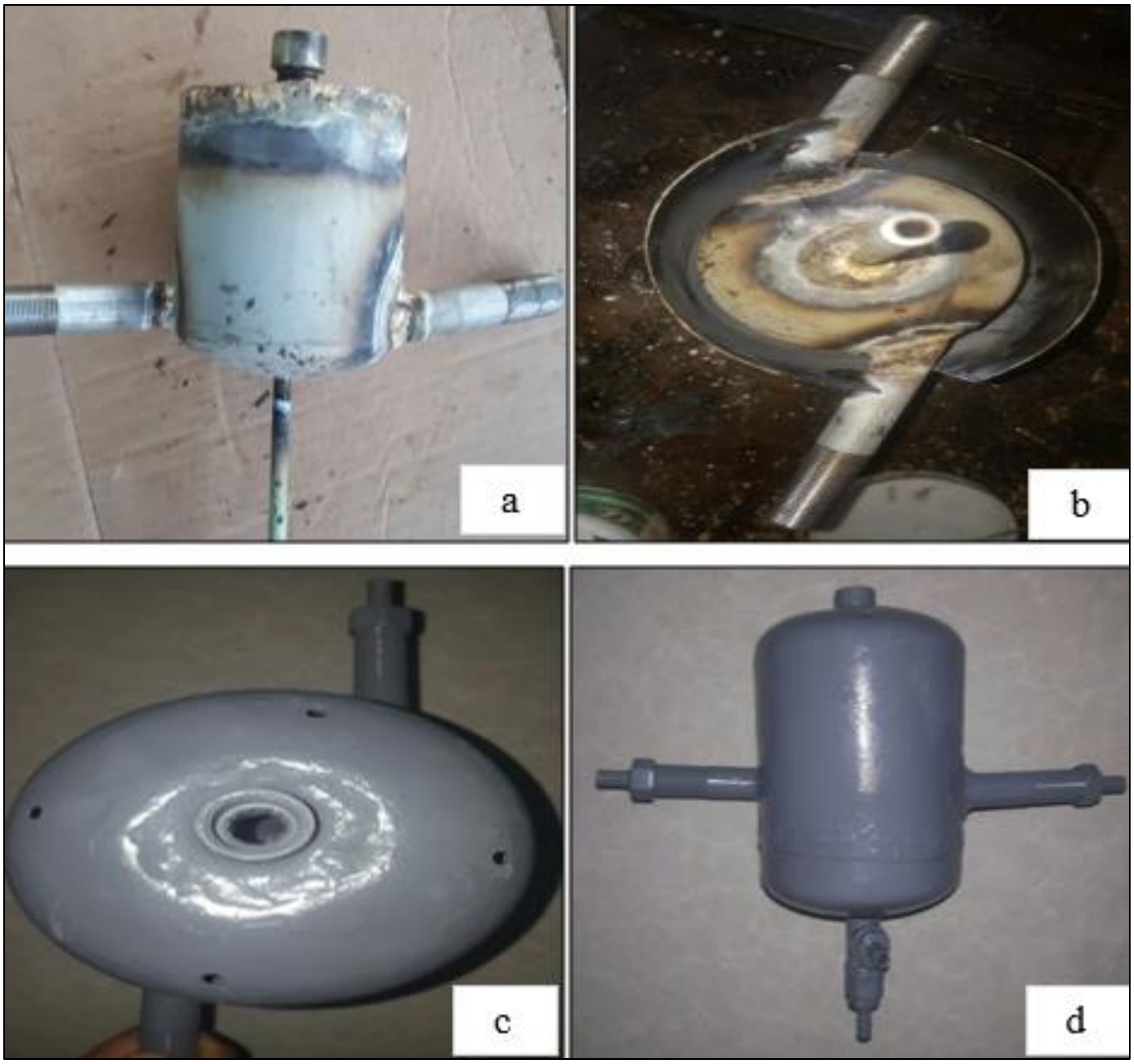


Figure 3.14: Steps of Manufacturing of Tangential Swirl Burner with Additional Air

3- Finally, the same design was used as the first with changing the diameter of the burner nozzle, the diameters were (2.5, 3.3, 5) cm, while the diameter ratio of the burner to the boiler was (1/10, 1/15, 1/20). Figure 3.15 shows the tangential swirl burner with a nozzle diameter of 5 cm and fig.3.16 shows the geometry specifications for a tangential swirl burner with a nozzle diameter of 5 cm.

The practical photo is shown in fig.3.17a low swirl combustion for the burner of the diameter nozzle 5cm. Which features a separate flame that is raised above the burner where it is more stable. Since the flame does not touch the burner, the low swirl combustion is also highly energy-efficient due to the non-loss of the burner energy. Figure 3.17b shows the flame approaches the sides of the burner nozzle, which creates a Boundary Layer Flashback (BLF), while the Combustion Induced Vortex Breakdown (CIVB) can be observed as the flame starts attacking the core of the burner as shown in fig.3.17c. The blue colour indicates that the fuel mixture is completely burned in this region due to the presence of a sufficient quantity of oxygen, which means clean combustion.

Figure 3.15: Steps of Manufacturing a Tangential Swirl Burner at Nozzle Diameter 5cm

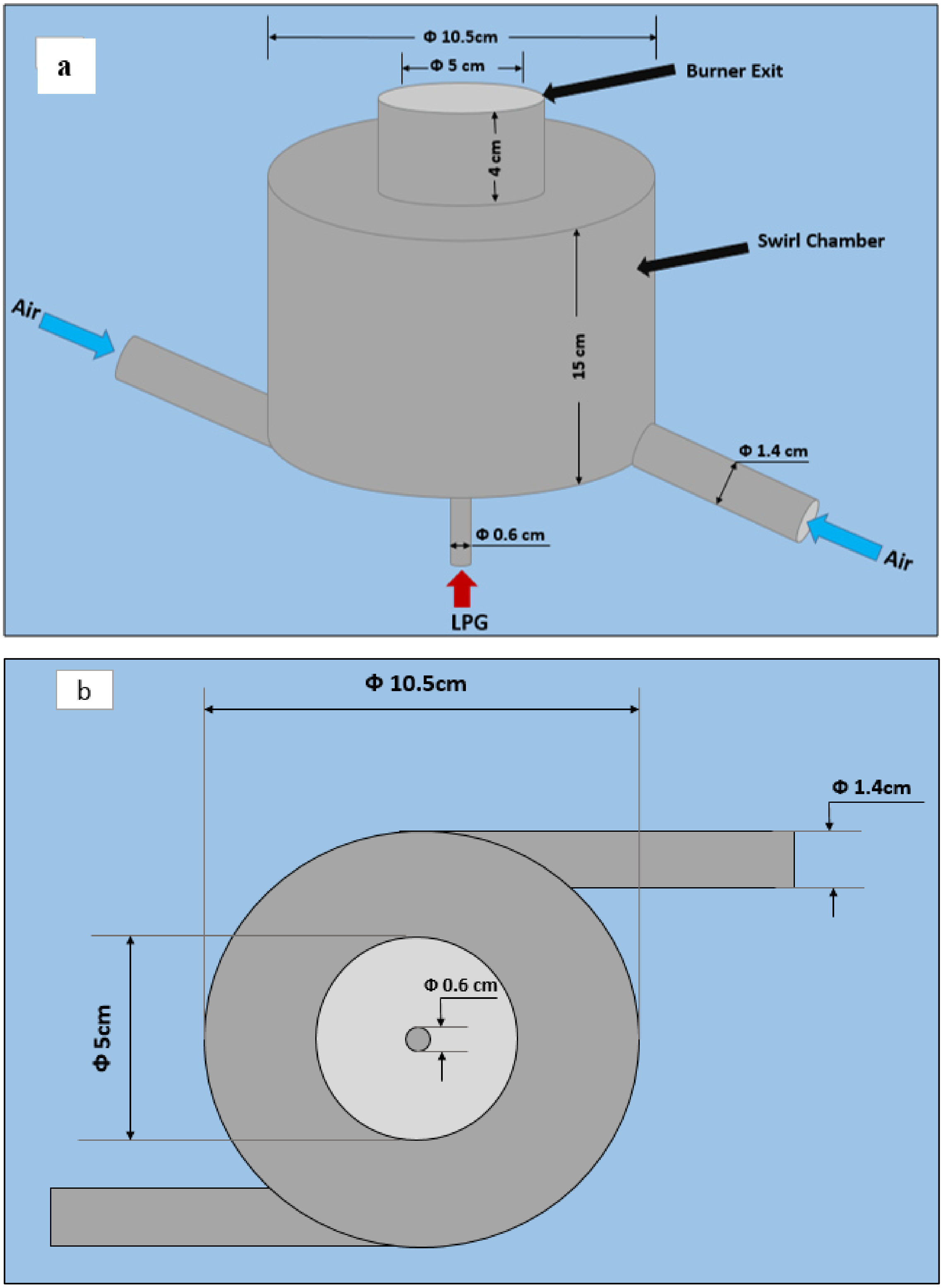


Figure 3.16: Geometry Specifications of the Tangential Swirl Burne: (a) Front View ،(b) Top View

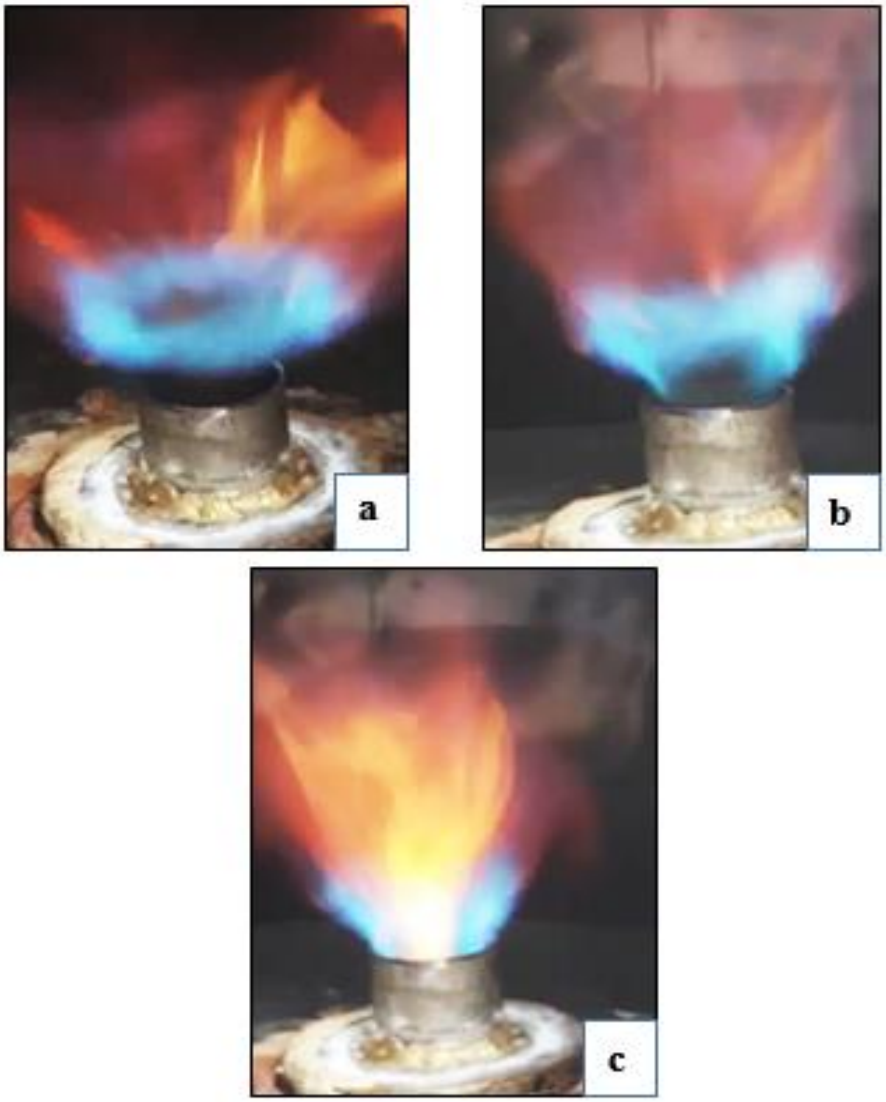


Figure 3.17: (a) Flame Separations in Low Swirl Combustion, (b) Boundary Layer Flashback (BLF), (c) Combustion Induced Vortex Breakdown (CIVB)

The LPG burner has been used in the steam generation system (boiler) as shown in fig.3.18.

Figure 3.18: General View of LPG Steam Boiler

3.3 Flow Meters

It is a measuring instrument used to measure fluid flow rates. By flowing the liquid to a tapered tube, the higher the flow rates, the greater the tube space, and the higher the pendulum to give a reading of the available quantity. For the burner, it is important to note the position of the buoyancy because it depends on the principle of gravity, therefore it is necessary to operate the device vertically (oriented vertically) as shown in fig.3.19. Two types of flowmeter were used, ones for measuring air flow rate and the other for measuring the LPG flow rate.

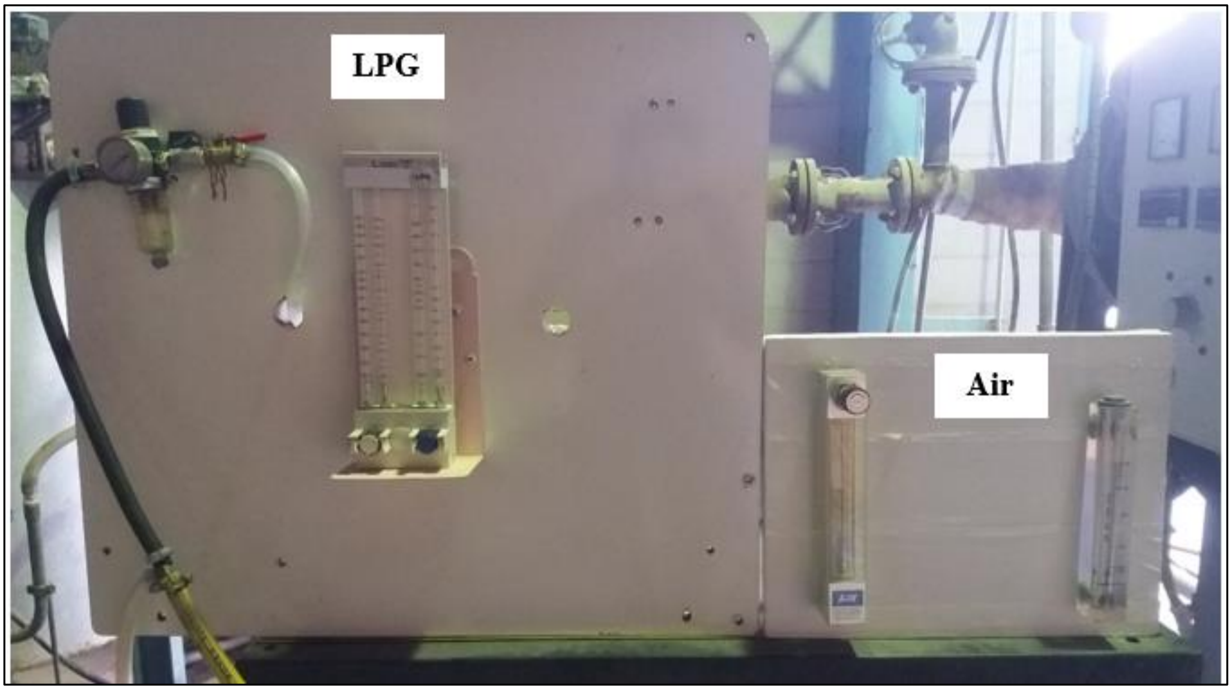


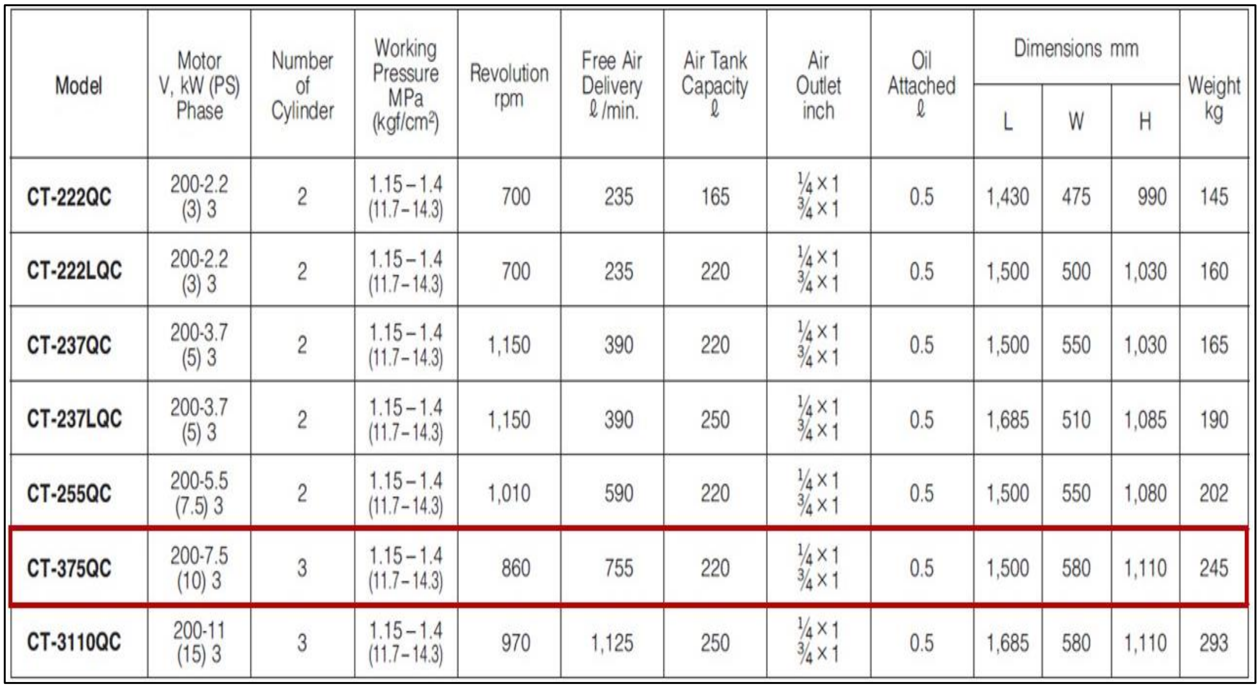
Figure 3.19: Flow Meters

3.4 Air supply unit

Banzai CT-375 QC air compressor made in japan, (see fig.3.20) has been used to supply LPG stove with compressed fresh air. This compressor consists of a three-phase electric motor, three-stage, air compressed tank, pressure gauge, pressure switch control. Technical data of air compressor are tabulated in Table3.5 **[68]**

Figure 3.20: Air Compressor **[68]**

Table 3.5: Air Compressor Specifications**[68]**



Model	Motor V, kW (PS) Phase	Number of Cylinder	Working Pressure MPa (kgf/cm²)	Revolution rpm	Free Air Delivery ℓ/min.	Air Tank Capacity ℓ	Air Outlet inch	Oil Attached ℓ	Dimensions mm			Weight kg
									L	W	H	
CT-222QC	200-2.2 (3) 3	2	1.15 – 1.4 (11.7 – 14.3)	700	235	165	¼ × 1 ¾ × 1	0.5	1,430	475	990	145
CT-222LQC	200-2.2 (3) 3	2	1.15 – 1.4 (11.7 – 14.3)	700	235	220	¼ × 1 ¾ × 1	0.5	1,500	500	1,030	160
CT-237QC	200-3.7 (5) 3	2	1.15 – 1.4 (11.7 – 14.3)	1,150	390	220	¼ × 1 ¾ × 1	0.5	1,500	550	1,030	165
CT-237LQC	200-3.7 (5) 3	2	1.15 – 1.4 (11.7 – 14.3)	1,150	390	250	¼ × 1 ¾ × 1	0.5	1,685	510	1,085	190
CT-255QC	200-5.5 (7.5) 3	2	1.15 – 1.4 (11.7 – 14.3)	1,010	590	220	¼ × 1 ¾ × 1	0.5	1,500	550	1,080	202
CT-375QC	200-7.5 (10) 3	3	1.15 – 1.4 (11.7 – 14.3)	860	755	220	¼ × 1 ¾ × 1	0.5	1,500	580	1,110	245
CT-3110QC	200-11 (15) 3	3	1.15 – 1.4 (11.7 – 14.3)	970	1,125	250	¼ × 1 ¾ × 1	0.5	1,685	580	1,110	293

3.5 Water Tank

Dimensions of the water tank are (81 * 81 * 50) cm. It contains a thermometer and a graduated tube to measure the water level in the tank as depicted in fig.3.21.

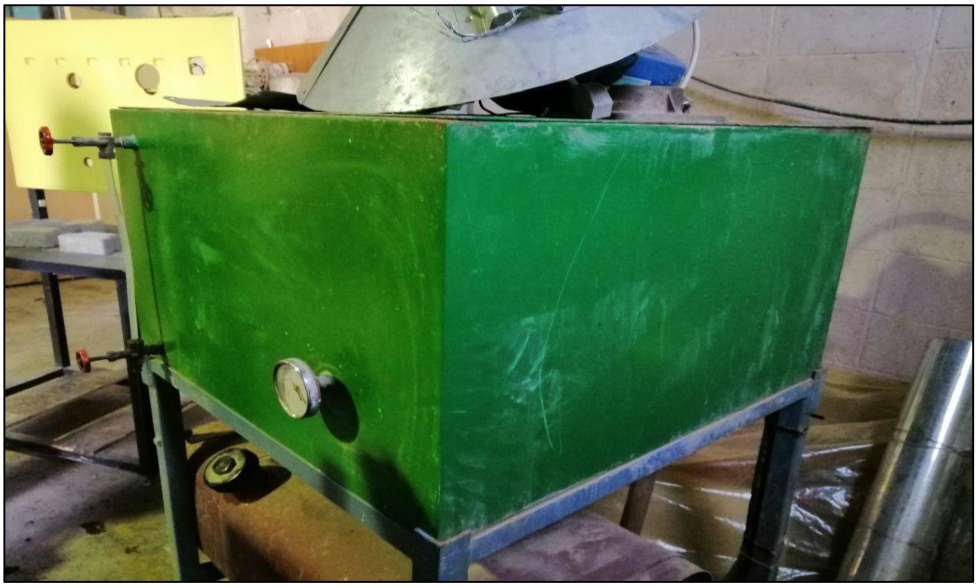


Figure 3.21: Water Tank

3.6 Digital Manometer

The Dwyer Arrangement 475-FM Check III Handheld Advanced Manometer (see fig.3.22) **[69]** is perfect for field calibration, monitoring or troubleshooting HVAC systems This handy instrument measures positive, negative or differential pressures of air and natural gases in ranges from 1 in w.c. (0.249kPa) to 150 psid (10.34 bar). When used with a Pitot tube, else be used as an air velocity gage. Table3.6 technical specifications of the digital manometer.

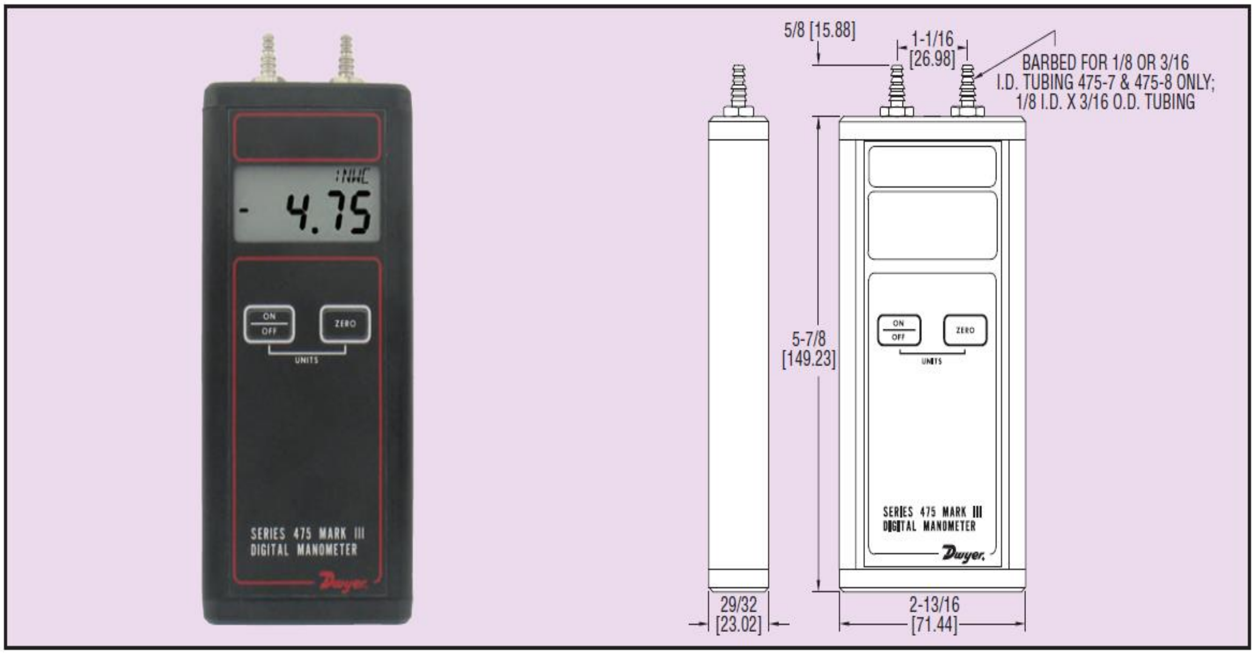


Figure 3.22: Digital Manometer **[69]**

Table 3.6: Technical Specifications of Digital Manometer **[69]**

Parameters	Description
Service	Air and compatible combustible gases
Wetted Materials	Consult factory
Accuracy	±0.5% FS, 60 to 78°F (15.6 to 25.6°C); ±1.5% FS from 32 to 60°F and78 to 104°F (0 to 15.6°C and 25.6 to 40°C)
Pressure Hysteresis	±0.1% of full-scale
Temperature Limt	0 to 140°F (-17.8 to 60°C)
Compensated Temperature Limits	32 to 104°F (0 to 40°C)
Display	0.42˝ (10.6 mm) 4 digit LCD
Power Requiremints	9 V alkaline battery, installed non-functional, user replaceable
Wieght	10.8 oz (306 g)
Connections	Two barbed connections for use with 1/8˝ (3.18 mm) or 3/16˝ (4.76 mm) ID tubing. Two compression fittings for use with 1/8˝ (3.18 mm) ID x 1/4˝ (6.35 mm) OD tubing for 475-7-FM & 475-8-FM only

3.7 Exhaust Analysis Device

Exhaust gas analyzer was used in the technical test (T156 / D3) as shown in fig.3.23 for analyzing exhausts resulting from the use of diesel and liquefied petroleum gas and to display, measure and print gas concentrations such as (CO, CO_2, HC, O_2, NOx).

Figure 3.23: Gas Analysis Unit T156D

3.8 Experimental Procedure

In this work, many experiments were carried out to generate steam, the experiments are divided into two types depending on the type of fuel used

3.8.1 Diesel Fuel

The steam generation was experimented by diesel fuel as shown in fig.3.24 and the following steps were followed:

1. Checked the water tank level
2. Checked the fuel tank level

3. The water is pumped to the boiler tubes and the amount of water supplied is recorded by gradual measurement found beside the tank
4. The burner is turned on
    a. It is supplied with fuel through a pump connected to it, and the consumption rate is calculated through the gradients located beside the tank
    b. It is equipped with air through an internal fan and the air supply rate changed manually controlled by the gate (airflow is calculated through the use of a digital manometer)
5. The temperature of the water rises rapidly, within 2 minutes the temperature becomes about 100 ° C, as well as the pressure, becomes about 3 bar
6. The ventilation valve open to purge some air trapped in the tubes until the pressure becomes (1 ~ 2) bar and close again
7. The process of converting water to steam inside the shell tubes continues until the steam temperature reaches 160 ° C and the pressure reaches 4.5 bar (superheated).
8. The steam supply valve opens
9. The water feeding process is repeated every (1.5 minutes)
10. Use the exhaust analyzer to find out the proportions of the exhaust gases during the experiment. In fig.3.25 the experiment steps chart using diesel fuel is shown.

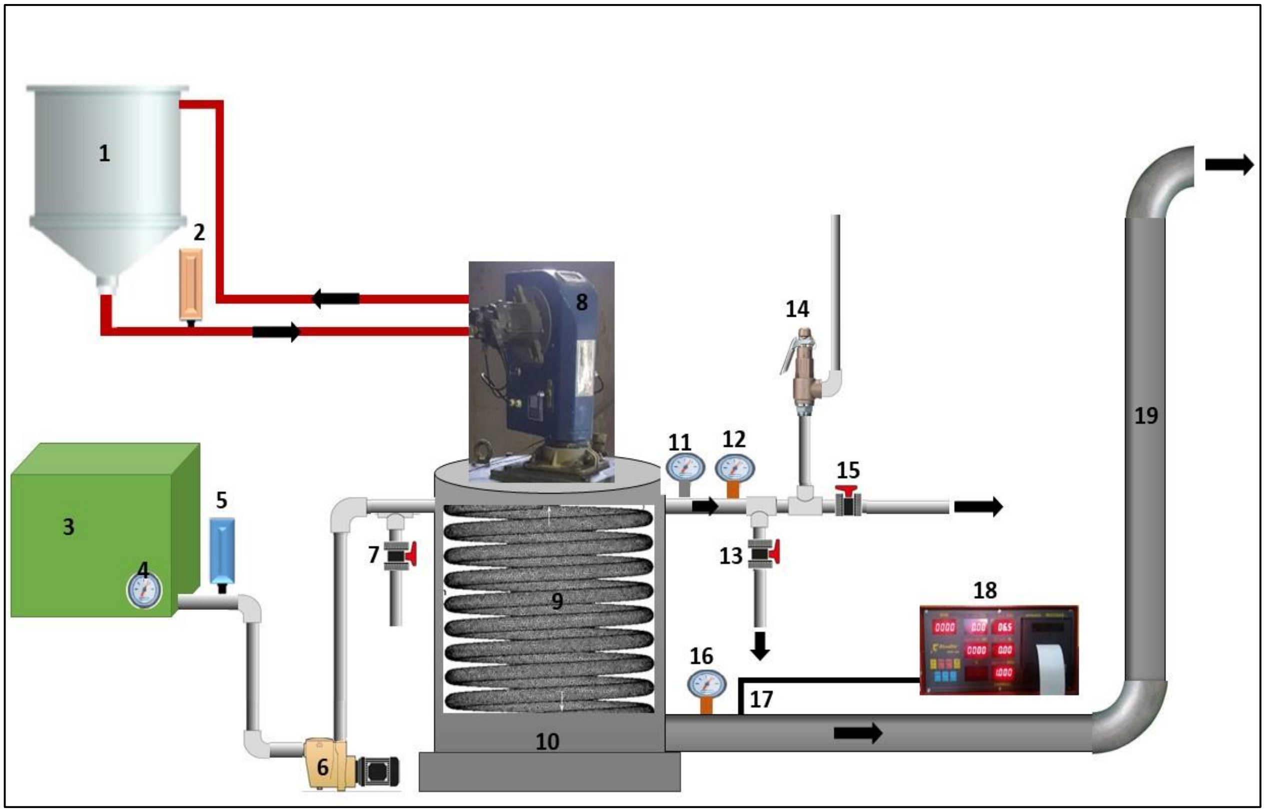


Figure 3.24: A Schematic View of the Experimental Set-Up (Diesel Fuel): 1.Diesel Tank, 2. Diesel Flow Meter, 3. Water tank, 4.Water Thermometer, 5.Water Flow Meter, 6.Feedwater Pump, 7.Drain Valve, 8.Diesel Burner, 9.Helical Coiled Tube, 10.Body Of Boiler, 11.Steam Pressure Gage, 12.Steam Thermometer, 13.Steam Supply Valve, 14.Safety Valve, 15.Steam Vent Valve, 16.Exhaust Gas Thermometer, 17.Exhaust Gas Analyzer Prop, 18.Exhaust Gas Analyzer, 19.Chimney

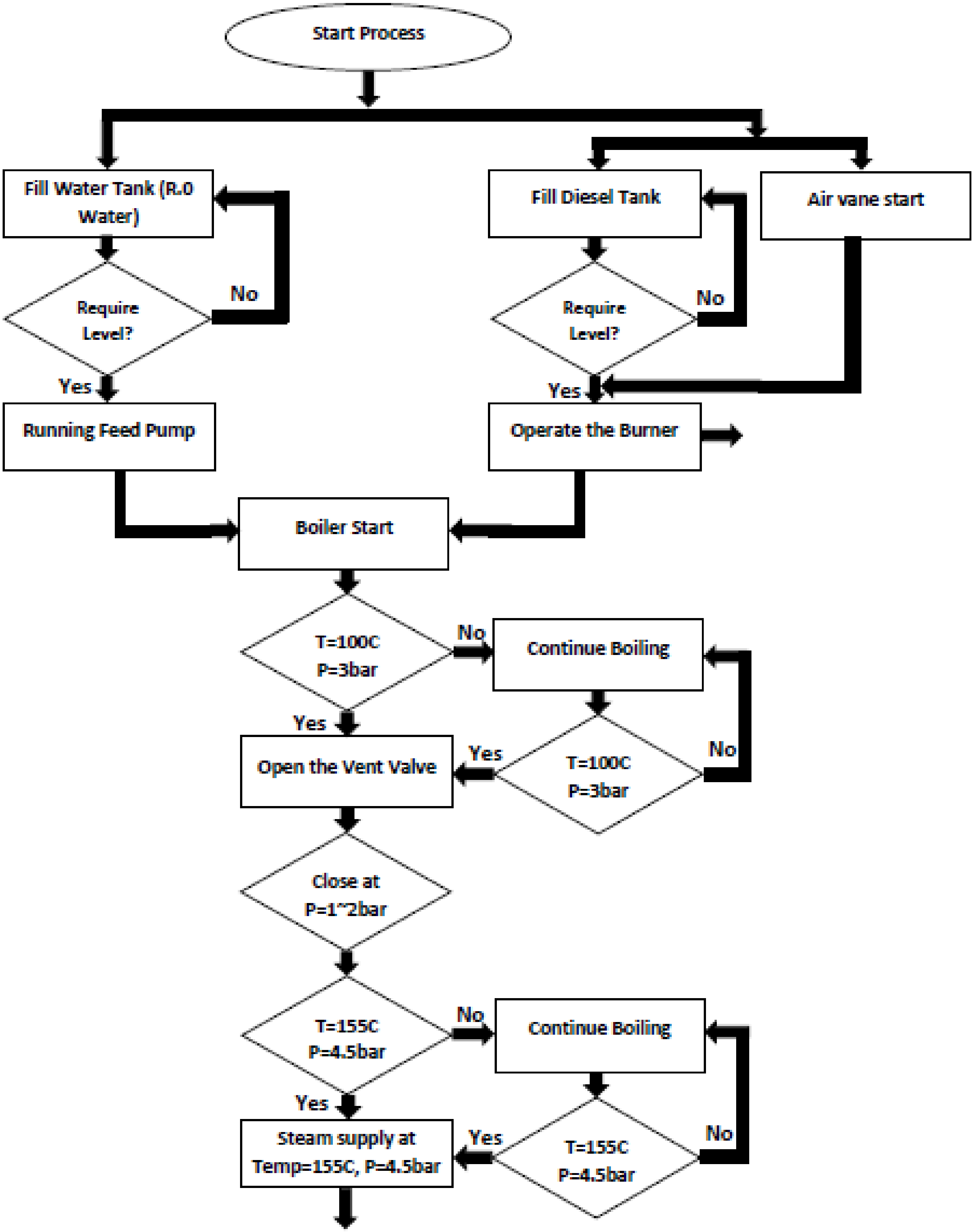


Figure 3.25: Experiment Steps Chart by Diesel Fuel

3.8.2 LPG fuel

The steam generation was experimented by LPG fuel as shown in fig.3.26 and the following steps were followed:

1. Checked the water tank level
2. Checked the fuel tank level
3. The air compressor was started
4. The water is pumped to the boiler tubes and the amount of water supplied is recorded by Gradual measurement placed beside the tank
5. The air and fuel mixture is equipped with an initial flow rate to ignite the burner by an external igniter
6. The temperature of the water rises gradually, within (15 minutes) the temperature and pressure becomes 100 ° C and 3 bar, respectively
7. The ventilation valve was opened to expel some of the air trapped in the tubes until the pressure becomes (1 ~ 2)bar and close again
8. The process of converting water into steam inside the shell tubes continues until the steam temperature reaches 145C and the pressure is 2.5bar
9. The water feeding process is repeated every (3 minutes)
10. Use the exhaust analyzer to find out the proportions of the exhaust gases during the experiment. .In fig.3.27 the experiment steps chart using LPG fuel is shown.

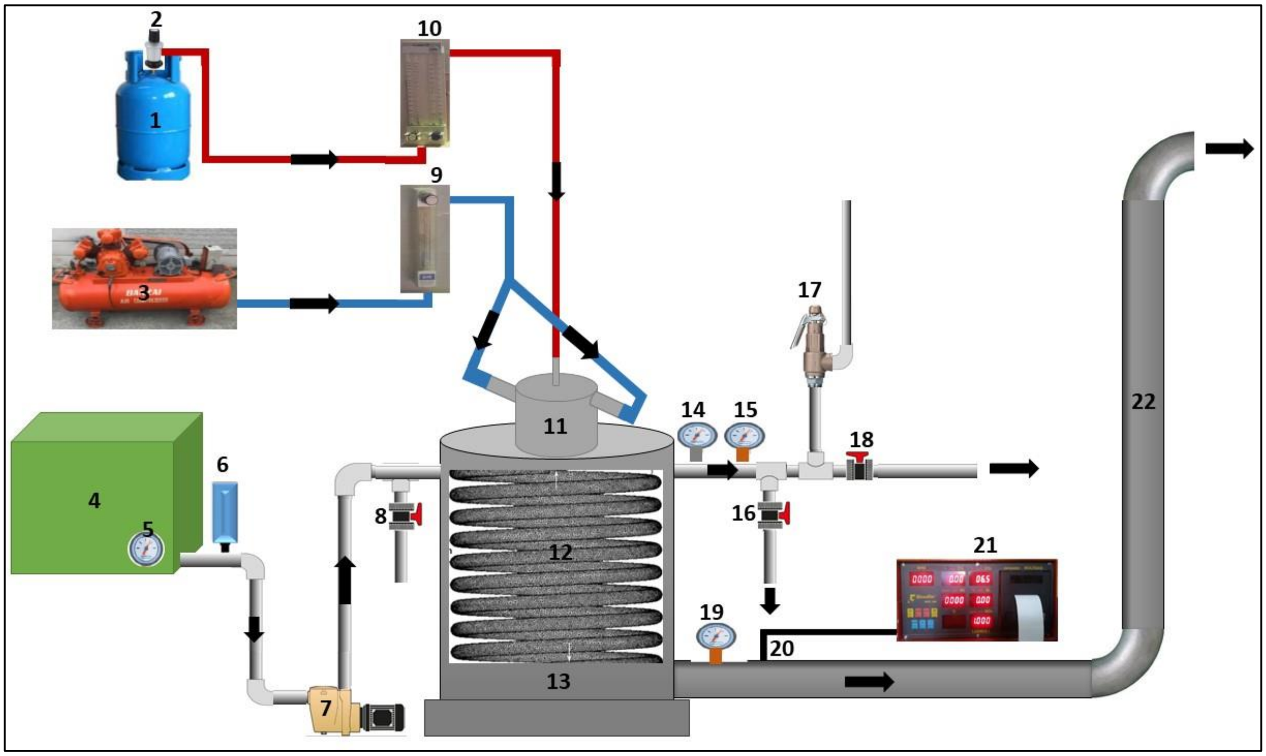


Figure 3.26: A Schematic View of the Experimental Set-Up (LPG Fuel): 1.LPG Gas Tank, 2.Regulator, 3.Air Compressor, 4.Water Tank, 5.Water Thermometer, 6.Water Flow Meter, 7.Feedwater Pump, 8.Drain Valve, 9.Air Rotameter, 10.LPG Rotameter, 11.Tangential Swirl Burner, 12.Helical Coiled Tube, 13.Body Of Boiler, 14.Steam Pressure Gage, 15.Steam Thermometer, 16.Steam Supply Valve, 17.Brsafety Valve, 18.Steam Vent Valve, 19.Exhaust Gas Thermometer, 20.Exhaust Gas Analyzer Prop, 21.Exhaust Gas Analyzer, 22.Chimney

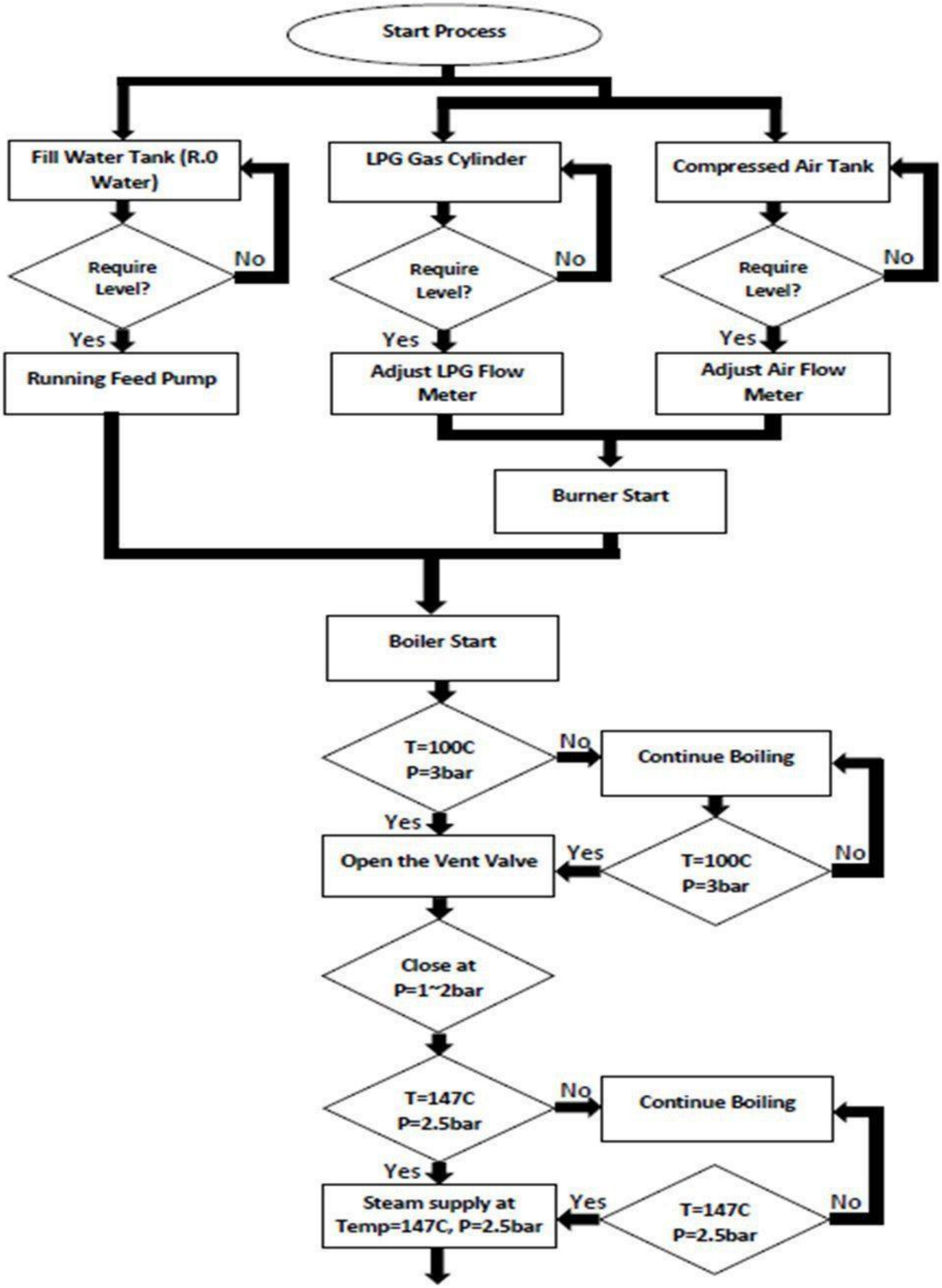


Figure 3.27: Experiment Steps Chart by LPG Fuel

Chapter Four

Experimental Results

and

Discussion

CHAPTER FOUR

EXPERIMENTAL RESULTS

Introduction

In this chapter, the experimental results of different burner designs with different fuel types are performed. As explained in previous chapters the system is a steam generation unit that uses diesel as fuel and the present work works to change the burner design to operate the system with LPG, as a consequence the dimensions of the gaseous burner were altitude to obtain the maximum power depending on the supplying fuel system. The obtained result from LPG combustion as compared to those of diesel and finally, a comparison between two systems have been obtained.

In the past, combustion processes are the main source of energy. Combustion is a chemical reaction process in which rapid oxidation of fuel occurs, and the cause of oxidation is usually oxygen. To preserve the environment, combustion processes must be controlled and known for the resulting products in the exhaust. As the common fossil fuel contains various types of hydrocarbons and results in the combustion of many of these hydrocarbonates to produce CO_2 and H_2O **[18]**.

For the combustion process to take place, the ratio of the fuel mixture to the air must be appropriate and the required ignition temperature of the fuel should be achieved. Boiler combustion takes place in the combustion chamber **[17]**. Combustion process equation **[70]:**

$$C_m H_n + \left(m + \frac{n}{4}\right) O_2 + \left(m + \frac{n}{4}\right)\left(\frac{79}{21}\right) N_2 \rightarrow \mathrm{m}CO_2 + \frac{n}{2} H_2O + \left(m + \frac{n}{4}\right)\left(\frac{79}{21}\right) N_2 \text{.........(4.1)}$$

4.1 Combustion

4.1.1 Stoichiometric Combustion

In the case of ideal combustion, it occurs when the fuel is completely burned and is called Stoichiometric combustion. Where the C, S, and H atoms are oxidized to form H_2O, CO_2. The F/A ratio (fuel/air) is an important parameter utilized to depict combustion, it is expressed either in size or mass. The ratio is indicated to be equivalent when the amount of air is sufficiently accurate to theoretically consume all fuel. Practically it is difficult to achieve Stoichiometric combustion because there is not enough time to mix fuel and air, so combustion processes occur in the presence of excess air **[18]**.

The stoichiometric (F/A) ratio is**[70]:**

$$FAR_{stoicio} = \frac{\text{Weight of the Fuel}}{\text{Weight of the Air}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.2)$$

And the equivalence ratio is **[70]:**

$$\Phi = \frac{\mathrm{FAR_{act}}}{\mathrm{FAR_{stoic}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4.3)$$

Equivalence ratio refers to the state of combustion whereas,
When $\Phi = 1$ Ideal state will be satisfied
$\Phi < 1$ Lean mixture conditions
$\Phi > 1$ Rich mixture conditions

4.1.2 Complete Combustion

Total combustion occurs when the amount of oxygen is sufficient, as energy is released through the combustion of fuel and its elements are converted into exhaust products where the atoms of (C, H, N, and S) combine with oxygen to form (CO_2, H_2O, NO_2, and SO_2) respectively. The combustion process is carried out in the presence of air that contains different proportions of gases, where the amount of air is higher than the theoretical amount **[24]**,**[71]**.

4.1.3 Incomplete Combustion

Deficient combustion happens when the O_2 content is low or inadequately blending in the combustion chamber during the limited time when the fuel and oxygen are in contact or when the combustion products contain non-combustible fuel components such as OH, CO, or HC. As hydrocarbons that are not fully oxidized form partially oxidizing compounds, such as CO, instead of $H_2O$and CO_2. Since oxygen binds faster to the hydrogen molecules to form of water, some of the carbon molecules combine with small amounts of oxygen forming CO, or remains as carbon particles in the exhaust. Incomplete combustion is extremely dangerous due to waste in the use of fuel as well as to the production of highly toxic gases **[18]**,**[24]**.

4.1.4 Excess Air

The process of complete combustion occurs when the amount of oxygen is closed to the theoretical level of the process, and the amount that exceeds the theoretical amount is called excess air. It is difficult to determine the amount of excess air without knowing and measuring combustion products. Although the excess air is important incomplete combustion processes and no squandering in fuel, it is very important in reducing toxic gas emissions such as CO **[18]**.

4.1.5 Combustion Gases

Many gases result from combustion processes whether complete or incomplete combustion, for example, the chemical equilibrium analysis of methane/air products of combustion which shown in fig.4.1 **[72]**. In some condensing boilers, the condensation process of the exhaust gases is carried out at a certain temperature and the beginning of the condensation is called the dew point, and it is necessary to know the temperature of the dew point because the water droplets may mix with the sulfur dioxide present in the exhaust gases creating a very harmful substance to the boiler structure, which is a sulfuric acid **[72]**.

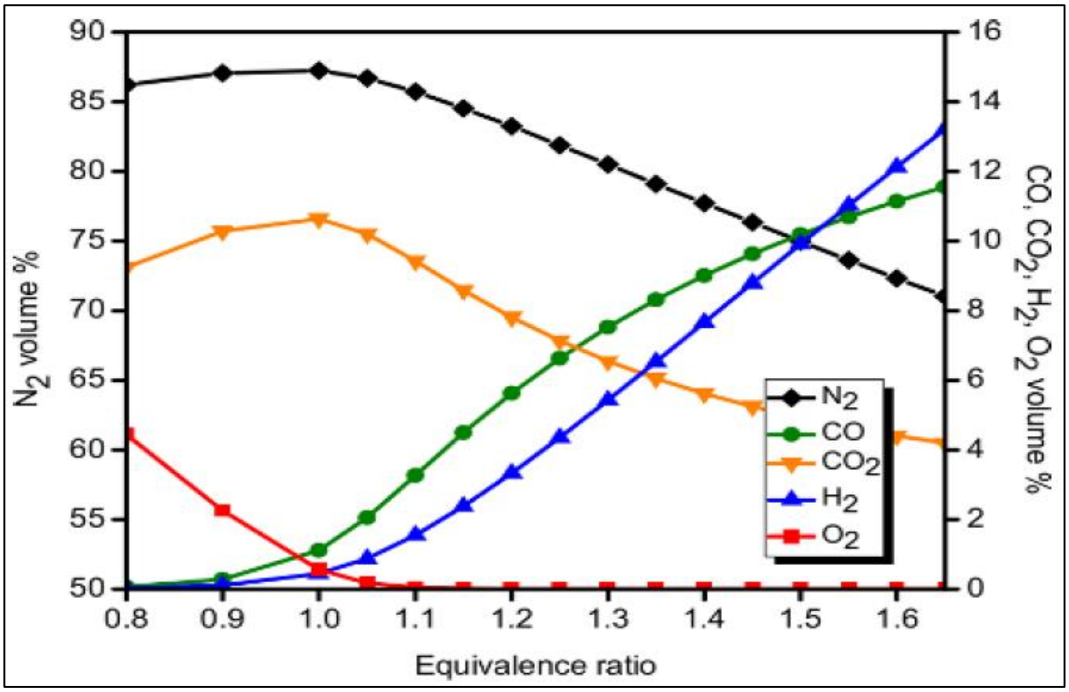


Figure 4.1: Chemical Equilibrium Analysis of Methane/Air Products of Combustion**[72]**

4.2 LPG Burner Performance

Three configurations of burner diameter (2.5, 3.3, and 5) cm were tested at different equivalence ratio (0.352, 0.527, 0.75, 1.02, 1.25, and 2.39). The results show different behaviour with a change of diameter ratio (variable diameter of the burner to invariant boiler diameter), below the combustion gas analysis, were performed and will be presented:

4.2.1 Gas Exhaust Analyzing

Figure 4.2 shows the variation of the volumetric ratio of CO_2 emission during LPG combustion with equivalence ratio (Φ) at three different diameter ratios (dr). It is obvious that the CO_2 emission increases with increasing Φ until reaching its maximum value at Φ =1, and then sharply decreased. This behavior is completely agreed with the fact that when Φ <1 (lean combustion) a completed fuel combustion in a swirl burner is evidently occurred. However, the lower the Φ, the better the reaction is. This could be attributed by the large amount of excess air available for achieving the reaction.

However, the maximum CO_2 volume percentage value is obtained at Φ =1 when ideal combustion state is more stratified. With increasing of the equivalence ratio (Φ >1) to the rich combustion zone, which means that the amount of excess air in the burner has retreated, the amount of CO_2 emitting is significantly reduced. This gives an indication that the reaction in the burner still efficient although with insufficient amount of the excess air. This finding discloses that the combustion of LPG in the tangential swirl burner can mutually be achieved even with a low air content in the burner. Along with that, the figure (Fig.4.2) illustrates the effect of the diameter ratio (variable diameter of the burner to invariant boiler diameter) on CO_2 emission. It is clear that at the same Φ, the amount of CO_2 released from the combustion increases with increasing the diameter ratio. The larger the diameter ratio, the higher the CO_2 emission is. As seen in the fig.4.2, CO_2 curve of Milcarek et.al **[72]** study has the same behaviour of CO_2 curves of the current study

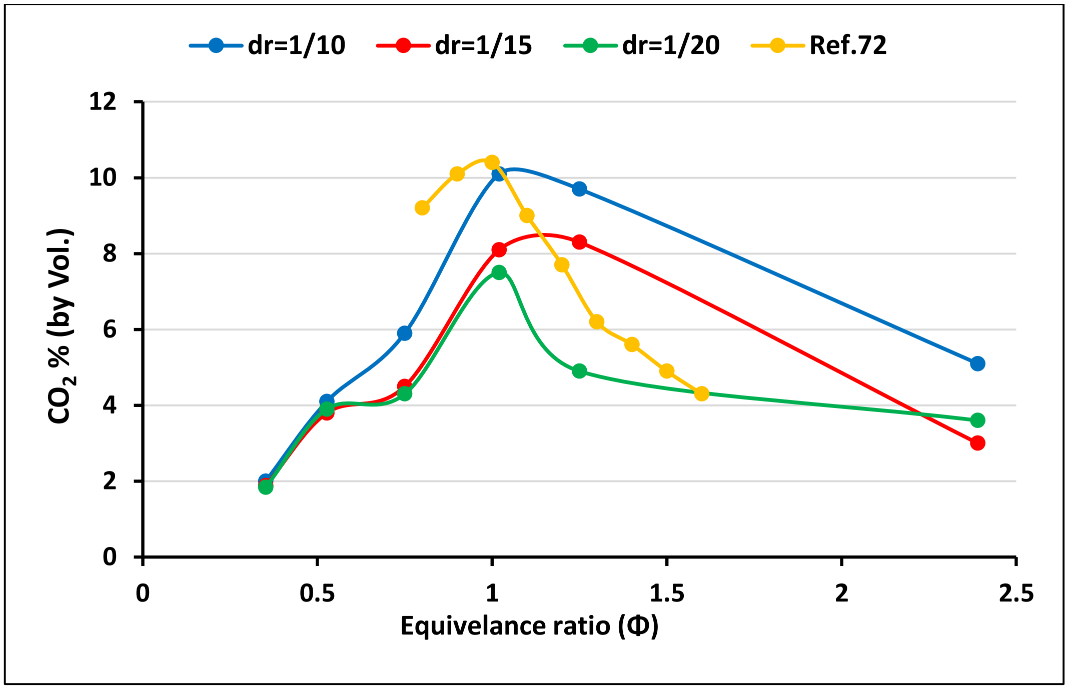


Figure 4.2: CO_2 Release with Different Equivalence Ratio at Different Diameter Ratio

Figure 4.3 demonstrates the variation of the volumetric ratio of CO in exhaust gases with Φ at three different diameter ratios. From the figure, it is vivid that the CO emission-reducing in the exhaust gases at a lean combustion area with increasing Φ and becomes at its lowest concentration at Φ =1. However, the CO returns to build up in the exhaust gases when Φ accedes 1. This is completely agreed with our knowledge in fuel combustion since when Φ is closed to 1 the reaction is moving to be perfect. On the other hand, when (Φ <1) and backwards the rate of chemical reaction in the burner turns into slower or the reaction needs more time to complete the oxidization reaction in the burner which leads to a high level of CO emission. However, when the mixture in the burner exceeds 1 (Φ >1) to rich combustion area, CO is significantly increased in the exhaust gases which refer to a bad reaction because of the lack of O_2 and excess fuel amount in the burner which acts as a coolant.

The figure also shows the effect of the diameter ratio on the volumetric ratio of CO in the exhaust gases. No noticeable effect of the diameter ratio on the volumetric ratio of CO emission in during lean combustion area (Φ <1) is quite evident; however, under rich combustion condition it is clear that the reaction releases a large amount of CO and this amount becomes worsen with the smaller diameter ratio and larger Φ. This could be justified by that at this conditions, the high-velocity mixture at the exit of the burner results in reducing of the time required to perform mature combustion consequently offers an opportunity to form a large amount of CO. Whilst at the lean condition (Φ <1) this could be returned to the abundance amount of excess air or O_2 in the tangential swirl burner where LPG combustion can occur at a similar rate for all diameter ratios under study. As seen in the fig.4.3. CO curves of the current study for three diameter ratio have a similar behavior when compared with the Milcarek et.al [72] studies in the lean region. While with the Milcarek et.al [72] study can be observed clearly that value of the CO increases continuously in the rich region compared to the values of the current study for three diameter ratio in the same region.

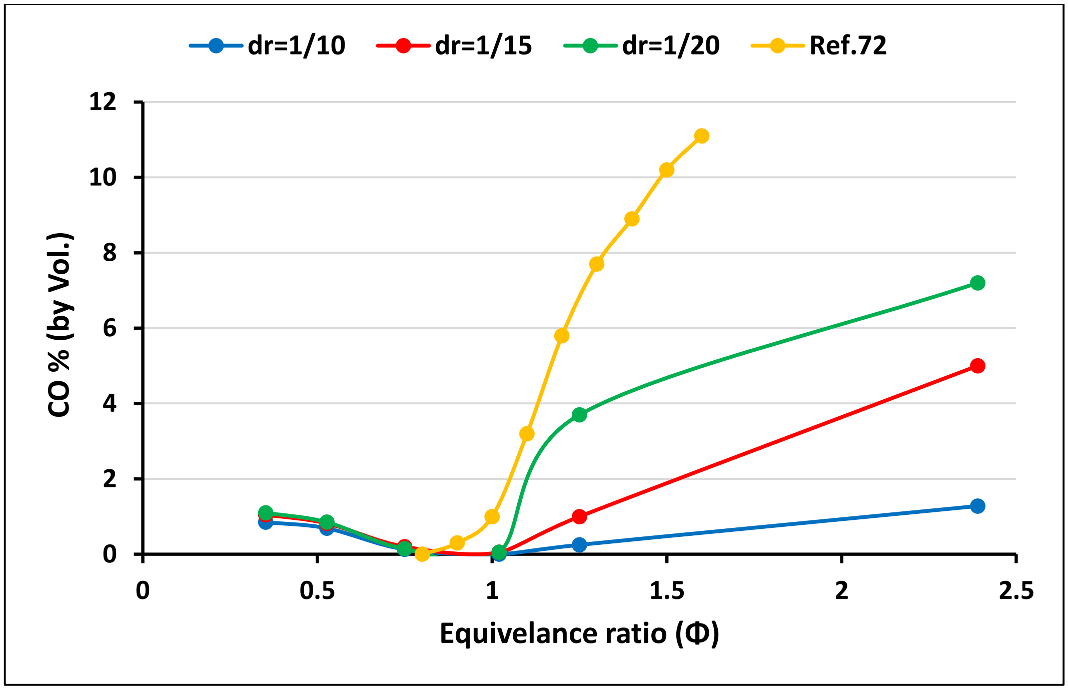


Figure 4.3: CO Release with Different Equivalence Ratio at Different Diameter Ratio

The analysis of normal combustion process shows a trace of unburned hydrocarbon (HC) in the flue gases which attributes to the lack of the time required to accomplish the reaction in the burner or the shortage of O_2 in the burner. In fig.4.4 shows the variation of HC with the equivalence ratio (Φ) at three different diameter ratios. It is obvious that HC being more generated in the exhaust gases with increasing Φ. However, the content of HC was zero along the lean combustion area and for Φ =1 with no impact of the diameter ratio which could be justified similar to above by the availability of an abundance of O_2 in the burner. Conversely, at Φ >1 or rich combustion zone, the content of HC in the exhaust gases is sharply raised with increasing Φ due to the shortage of O_2 or excess air at the rich zone which effects the LPG combustion in the burner. On the other hand, the diameter ratio affects significantly and inversely the HC content, where the lower the diameter ratio, the lower the HC content is. Obviously, the low diameter ratio refers to the large burner chamber exist consequently a large flame diameter within the boiler and hence a good heat transfer between the flame and the coil surface.

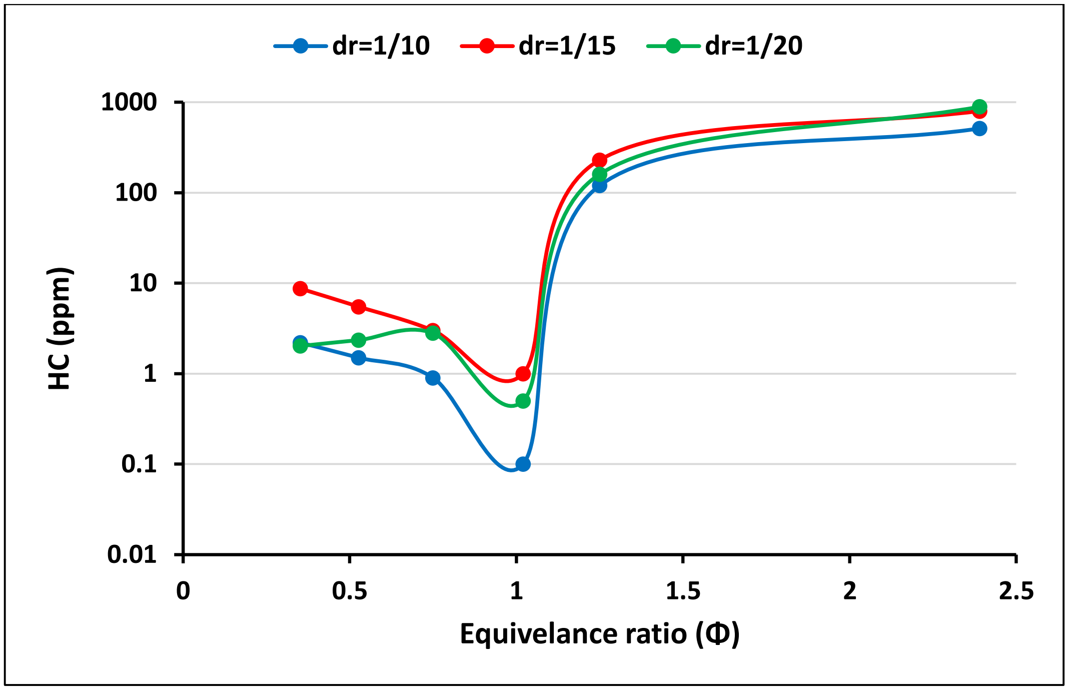


Figure 4.4: HC Release with Different Equivalence Ratio at Different Diameter Ratio

As pointed out above, the much excess air than the ideally required results in a negative impact on the combustion efficiency in the burner as some heat is removed with the leaving air and reducing the flame temperature. However, fig.4.5 presents the variation of the unbeneficial volumetric ratio of O_2 that leaving the reaction in the burner with Φ at three various diameter ratios. It is clear that the ideal combustion process can be achieved when Φ =1 and greater than 1 (rich combustion zone), otherwise at lean combustion zone (Φ <1), the reduction in Φ makes the combustion process mature with an excess O2 released with the exhaust gases. As expected, at rich combustion zone (Φ >1) where the reaction occurs with lack of O_2 or excess air, there is no O_2 can release with the exhaust gases. However, no, the considerable influence of the diameter ratio on the released O_2 at this zone is clearly shown by the figure which confirms our finding above regarding. As shown in fig.4.5, the equivalence ratio through three diameter ratio of the present work has lower value compared to the Milcarek et.al **[72]** study.

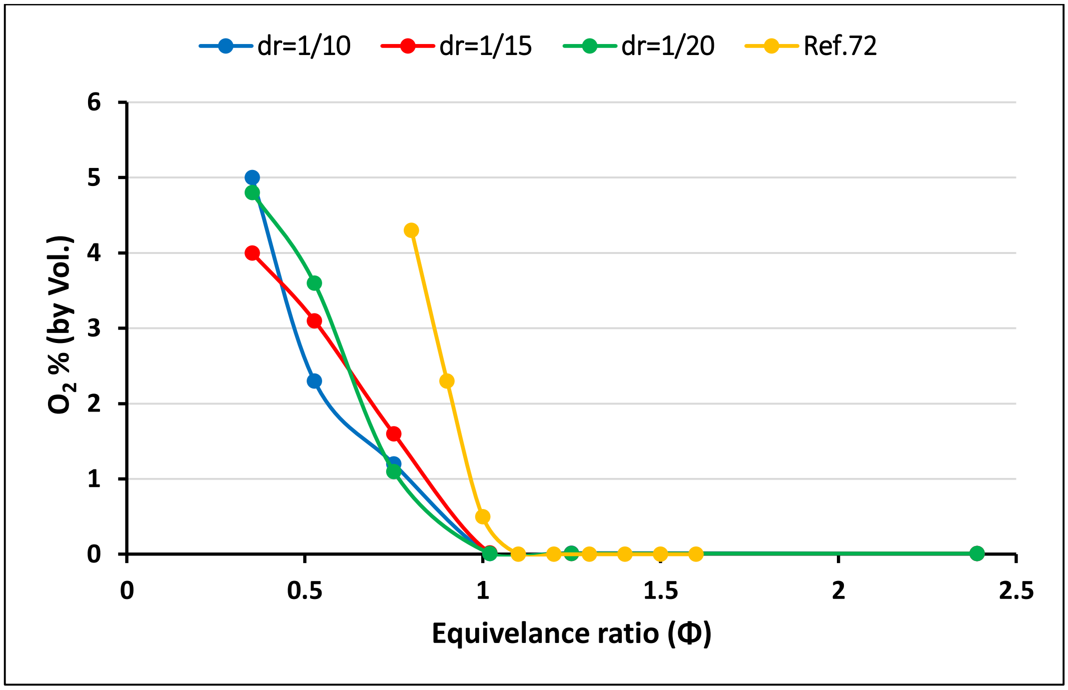


Figure 4.5: O_2 Release with Different Equivalence Ratio at Different Diameter Ratio

Boiler works as a heat exchanger where it can transfer heat indirectly from the combustion side to the waterside. Therefore, the efficiency of the boiler is a measure of how good the heat transfer process is. However, various parameters can affect the boiler efficiency such as the boiler physical condition and the health of the combustion process. Figure 4.6 illustrates the variation of boiler efficiency with Φ at three different diameter ratios. Unsurprisingly, the efficiency value increases from the lowest Φ value at lean combustion zone ($\Phi < 1$) to become at its maximum value at $\Phi = 1$, and then slightly reduces and stays steady at a constant value along $\Phi > 1$ region. This could be attributed by that when the amount of excess air or O_2 is being decreased when Φ goes toward 1, the negative effect of the excess air is diminished since the amount of heat loss with the excess air leaving the burner is reduced. As indicated elsewhere above, the lack in the excess air at the rich combustion zone ($\Phi > 1$) in the burner entails to affect the reaction and hence reducing the combustion efficiency or boiler efficiency. Simultaneously, the figure shows the effect of the diameter ratio on the efficiency of the boiler. It is clear that the larger diameter ratio performs better through the entire equivalence ratio than that of the other two smaller diameter ratios. In comparison with the small diameter ratio, the large diameter ratio characterize with a large flame diameter which covers almost all the internal boiler diameter and becomes closer to the boiler wall. Consequently, the heat transfer process between the flame and the waterside located near to the boiler wall will be efficient. Nevertheless, the boiler efficiency shows less sensitivity to the burner diameter in the rich combustion zone in comparison with the lean combustion zone which could be due to that the high flame temperature is eliminated the effect of the flame size on the heat transfer rate.

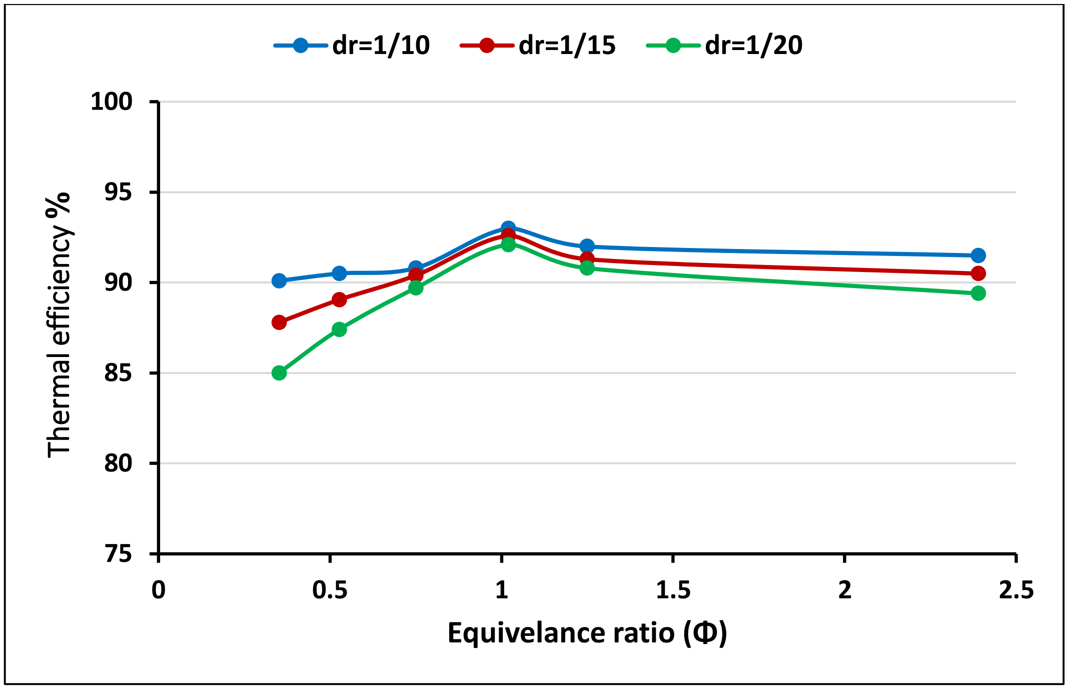


Figure 4.6: Boiler Efficiency with Different Equivalence Ratio at Different Diameter Ratio

From the results presented above the best diameter ratio to be adapted and compared to the original design of the boiler system is 1/10.

4.3 Diesel Burner Performance

The fuel injection in diesel burner depends on the injector nozzle and back airflow from the adjusting gate. The specification of the system was listed in the previous chapter, so the results of the exhausted gases will be performing. in fig.4.7 the CO and CO_2 volumetric ratio are presented and it is noticed that with the increase of fuel ratio (equivalence ratio) the amount of CO will be decreased sharply till the equivalence ratio close the 1 where the combustion reaches the best performance with the increase of fuel concentrate in a mixture the amount of CO will rocket high and the performance of the combustion becomes worse.

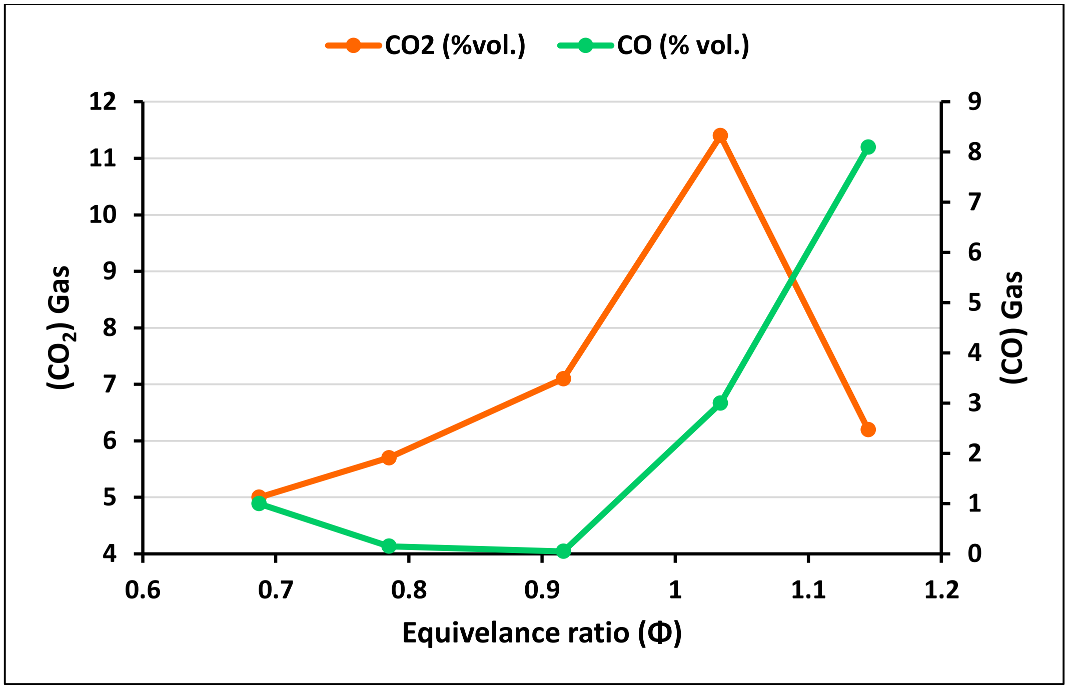


Figure 4.7: Exhaust Gases (CO and CO_2) At Different Equivalence Ratio

The increase in fuel concentration in the mixture will consume the air (O_2) in the mixture to perform or reach to best combustion. However, in rich mixture combustion, the amount of fuel is much high than the ideal amount which leads to poor combustion. In poor combustion all O_2 consumed and there are more fuel is left which could be treated as HC in exhaust gases. In fig 4.8 the HC concentration is presented with increase the equivalence ratio and it is easily shown that the amount of HC is high in the rich side of the mixture.

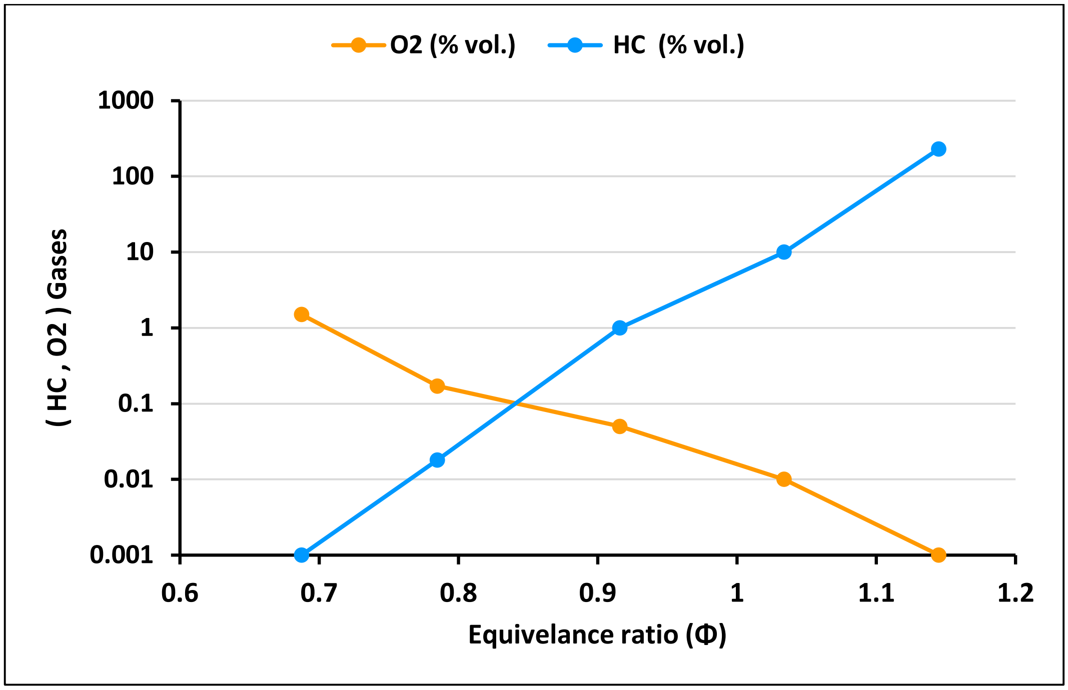


Figure 4.8: Exhaust Gases (O_2 and HC) At Different Equivalence Ratio

4.4 Comparative of Diesel and LPG

Figure 4.9 shows the relation between CO_2 and the equivalence ratio for both diesel and LPG, as seen in fig. 4.9 CO_2 increases with any increment on equivalence ratio during both types of fuel especially in the diesel type the increase in CO_2 is more than LPG until the equivalence ratio becomes 1. While the CO_2 after the equivalence ration over 1 decreases sharply with diesel fuel and gradually decreases with LPG.

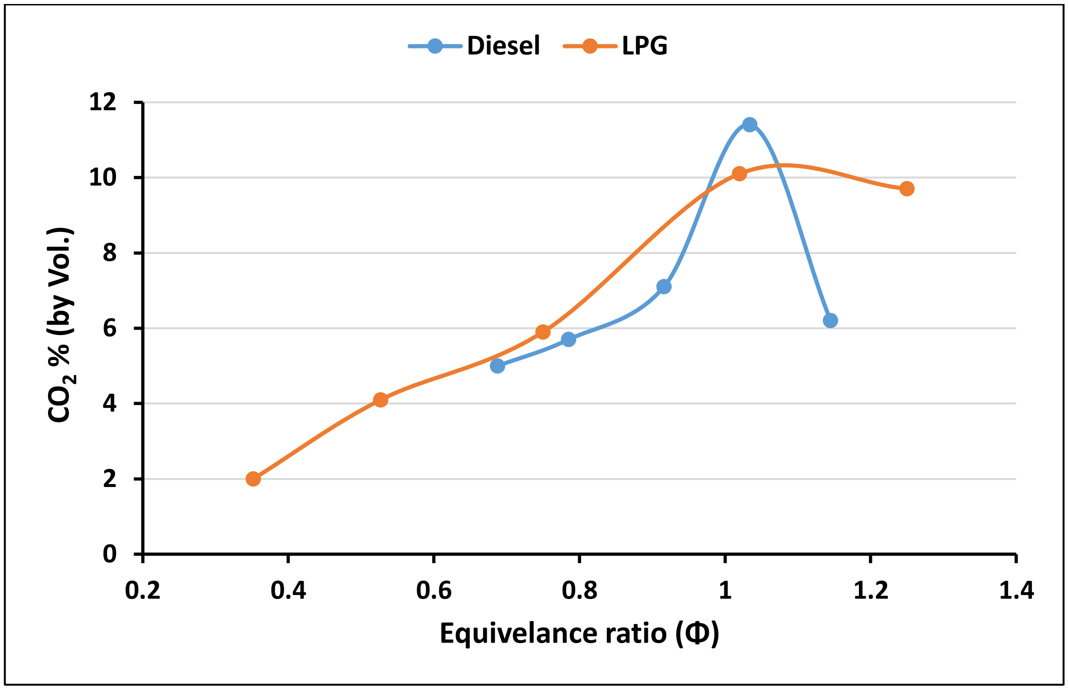


Figure 4.9: Comparison Exhaust Gas (CO_2) At Different Equivalence Ratio for diesel and LPG0

Figure 4.10 illustrates the relation of CO gas with equivalence ratio in both types of fuel (diesel and LPG). As seen in the figure below the CO gas decreases scientifically with increased equivalence ratio until 1. CO gas becomes zero when the equivalence ratio is 1. While the CO value starts to increase gradually in the LPG but sharply increases with diesel fuel.

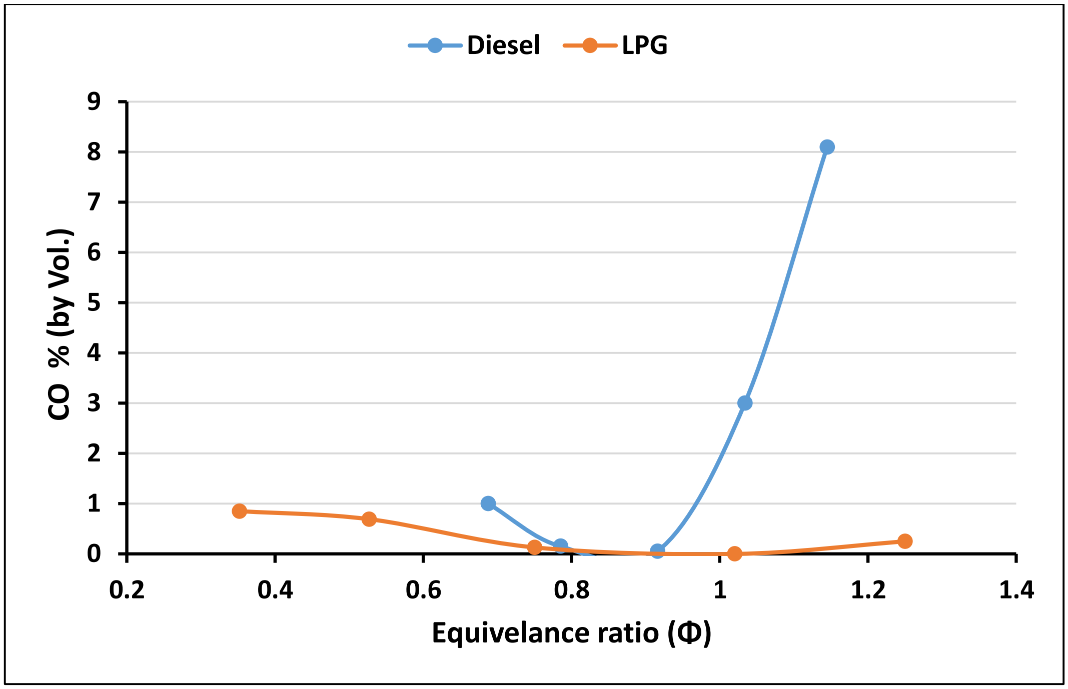


Figure 4.10: Comparison Exhaust Gas (CO) At Different Equivalence Ratio for diesel and LPG

As seen in fig 4.11 the O_2 is available scientifically in the lowest equivalence ratio, and O_2 value starts to descend to zero with the increased value of equivalence ratio.

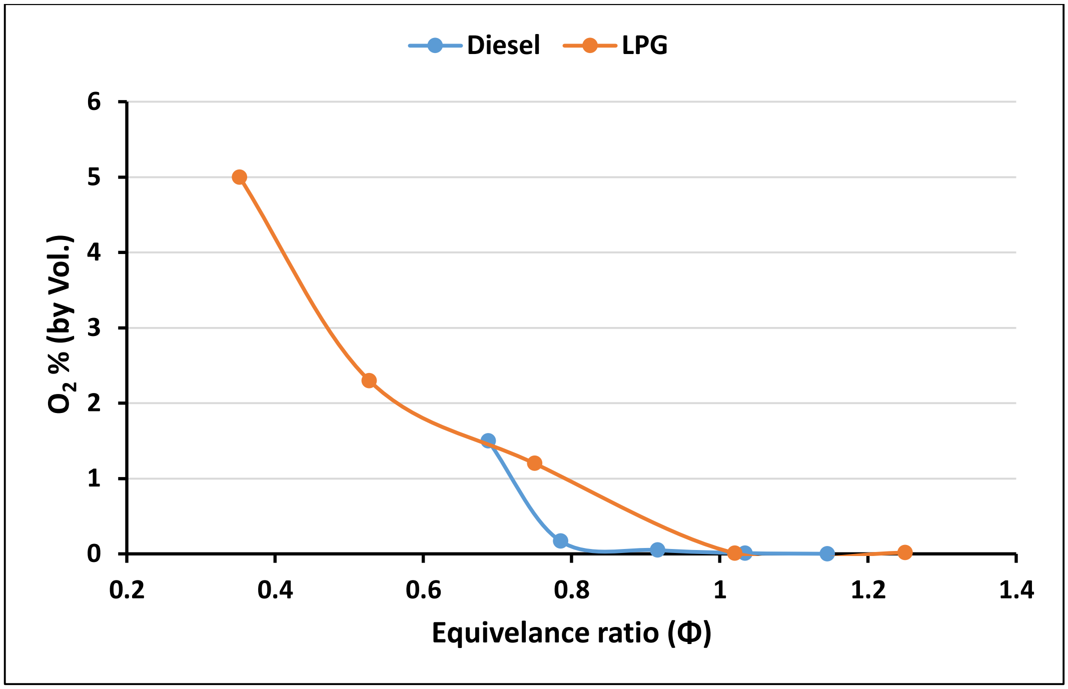


Figure 4.11: Comparison Exhaust Gas (O_2) At Different Equivalence Ratio for diesel and LPG

Figure 4.12 explains the variety of HC with equivalence ratio so from the figure below observed that HC almost is zero with equivalence ratio less than 1, while the HC is increased scientifically when the equivalent ratio rises over than 1

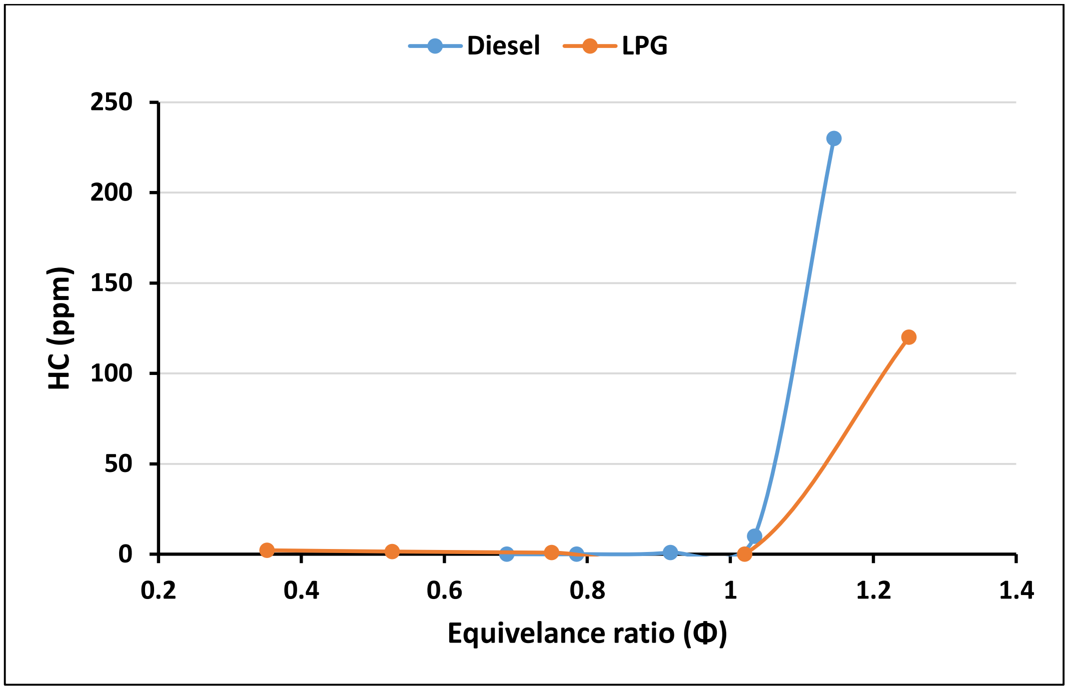


Figure 4.12: Comparison Exhaust Gas (HC) At Different Equivalence Ratio for diesel and LPG

Boiler efficiency and equivalence ratio relations are expressed in fig.4.13. as shown in the figure, the efficiency of boiler increases with increasing value of equivalence ratio until 1, after that the behaviour of boiler efficiency is different according to fuel type, where in the LPG, the efficiency almost keeps a high value while in the diesel oil decreases with increase equivalence ratio over than 1. That means boiler efficiency in diesel oil is decreased when the equivalence ratio becomes less or over 1.

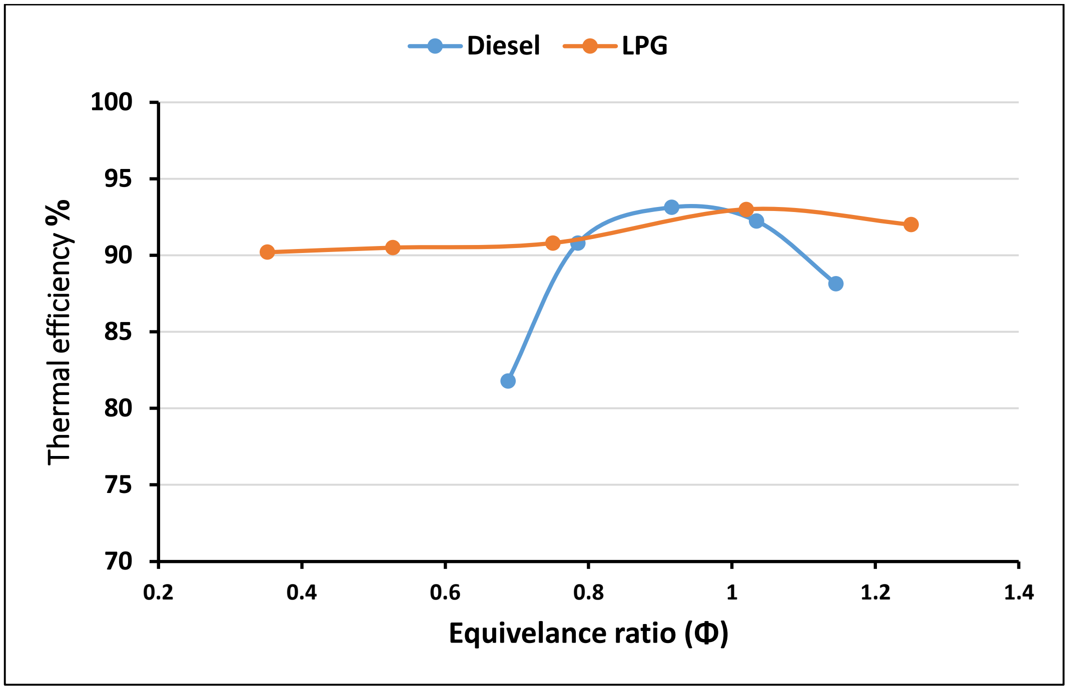


Figure 4.13: Boiler Efficiency with Different Equivalence Ratio for Diesel and LPG

Chapter Five

Conclusions
and
Recommendations

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The current work investigates the chances to use LPG as a fuel in a small lab boiler using diesel as a fuel. The study involves an analysis of the exhaust gases to understand the combustion process health when different geometries of burner have been tested. The main conclusions are listed below followed by the recommendations for future works

5.1 Conclusions

In the present study, the feasibility of using LPG as a fuel instead of diesel oil fuel in a steam boiler is presented experimentally. To do so, a new tangential swirl burner was designed, manufactured and installed in the boiler to be consistent with the LPG fuel. However, the CO_2, CO, HC gas emission in the exhaust gases of LPG fuel are tested for different equivalence ratios and diameter ratios. The obtained results of LPG fuel are compared with diesel oil fuel to assess its capability to be used as a fuel in the steam boiler. However, according to the experimental results, the following conclusions can be drawn:

1. The possibility of changing the combustion system used in the steam-generating boiler from a liquid fuel (Diesel) combustion system to another that is powered by gaseous fuel (LPG), whose manufacturing process is simple and inexpensive and without affecting the other parts of the boiler.

2. Through practical experiments, among the three diameters of the gas burner 2.5, 3.3, and 5 cm, the burner with a diameter of 5 cm gives the best steam generation efficiency. This is because the large diameter of the nozzle leads to a better spread of the flame and its arrival near the inner tubes of the

boiler, which speeds up the process of heat transfer to the water inside the tubes and thus the speed of steam generation.

3. The ratio of CO gas resulting from combustion at equivalence ratio approaching or moving away from 1, is high for a diesel burner in comparison with the LPG tangential swirl burner which confirms that the LPG burn is cleaner than the diesel burn.

4. When operating in the weak mixture area, the excess oxygen content of combustion and outside in the exhaust is high for the LPG tangential swirl burner as it is compared to the diesel burner. This means that the possibility of complete combustion can occur with the least amount of oxygen in the weak mixture area in the case of an LPG tangential swirl burner.

5. Although the equivalence ratios have changed, the efficiency of steam generation from the boiler in the case of using LPG tangential swirl burner is high, while in the case of using a diesel burner the efficiency is better when the equivalence ratio approaches to 1 and dramatically falls when the mixture is rich. Hence, the LPG tangential swirl burner is better at generating steam from the boiler.

5.2 Recommendations

Conducting the current work opens the door for more questions to be answered and for the current circumstances the list of the recommendations are below:

1. Study the possibility of a change in the geometrical or dimensional shape of the LPG tangential swirl burner and its effect on the boiler

efficiency in generating steam and the percentage of exhaust gases emitted from it.

2. Study the use of a mixture of LPG with other gases with a high hydrogen level at different ratios.
3. Study the use of other types of liquid fuel as a pure fuel or mixed with known proportions, to generate steam from the boiler.

Reference:

1. Narendran, V., Sivamani, S., Hariram, V., Gnanaprakash, M., Raffiq, A. M., & Kumar, D. S. (2016). Theoretical and numerical analysis of convective recuperator for an oil fired water tube boiler to improve the boiler performance. Indian Journal of Science and Technology, 9(42), 9.

2. Jayamaha, L. (2006). Energy-Efficient Building Systems: Green Strategies for Operation and Maintenance: Green Strategies for Operation and Maintenance. McGraw Hill Professional.

3. Outlook, A. E. (2011). with Projections to 2030. US Energy Information Administration, US Department of Energy, DOE/EIA, Washington, DC, 20585, 2011.

4. Ganapathy, V. (2002). Industrial boilers and heat recovery steam generators: design, applications, and calculations. CRC Press.

5. Elie Tawil, P.J.C.E. and D. NY (2013), Boiler Classification and Application. 10980.

6. from, B.T.a.S.R. “Boiler Type and Specifications.” Retrieved from https://www.myodesie.com/wiki/index/returnEntry/id/3061#Boiler%20Room%20Definition/Terminology.

7. from,https://www.indiamart.com/proddetail/instant-steam-generator-4042094997.html

8- Alazemi, A. S. K. R., Ali, M. Y., & Daud, M. R. C. (2019). Preventive Maintenance of Boiler: A Case of Kuwait Industry. International Journal of Engineering Materials and Manufacture, 4(2), 48-58.

9. Boiler Mountings and Accessories - Mechanical Booster.pdf https://www.mechanicalbooster.com/2016/05/boiler-mountings-and-accessories.html. 2016.

10. Badr, A. A. Z. (2018). THE EFFECTS AND CAUSES OF BOILER TUBES FAILURES ON EFFICIENCY OF POWER PLANT (Doctoral dissertation, Sudan University of Science and Technology).

11. Paul, A. R., & Alam, F. (2018). Compliance of Boiler Standards and Industrial Safety in Indian Subcontinent. International Journal of Engineering Materials and Manufacture, 3(4), 182-189.

12. Faizal, M., Hamzah, M. H., & Navaretsnasinggam, A. Study on the thermodynamics performance of industrial boiler.

13. Balogun, M. B., Kulla, D. M., & Anafi, F. O. (2016). Design and construction of an agricultural solid waste fluidised bed boiler for steam generation. In Proceedings of the 29th International Conference and Annual General Meeting of Nigerian Institution of Mechanical Engineers (pp. 1-19).

14. Nag, P.K. (2008) , Power Plant Engineering (3rd Edition). Tata McGraw-Hill Publishing Company Limited, 7 West Patel Nagar, New Delhi.

15. Teir, S., & Kulla, A. (2002). Steam/water circulation design. Steam Boiler Technology eBook, Helsinki University of Technology, Espoo.

16. Shuib, S. S. (2016). Simulation Study on Combustion Characteristics of Water Tube Boiler with Different Type of Fuel. IRC.

17. Outlook, A. E. (2014). with Projections to 2040//US Energy Information Administration. April 2014. URL: http://www. eia. gov/forecasts/aeo/pdf/0383 (2014). pdf.

18. Kristinsson, H., & Lang, S. (2011). Boiler Control Improving Efficiency of Boiler Systems. CODEN: LUTEDX/TEIE.

19. Lee, S., Speight, J. G., & Loyalka, S. K. (Eds.). (2014). Handbook of alternative fuel technologies. crc Press.

20. Gupta, K. K., Rehman, A., & Sarviya, R. M. (2010). Bio-fuels for the gas turbine: A review. Renewable and Sustainable Energy Reviews, 14(9), 2946-2955..

21. IEA, Energy Technology Essentials. Available: https://www.iea.org/publications/freepublications/publication/iea-energy-technology-essentials-biofuel-production.html. (2007)

22. Oland, C. B. (2002). Guide to low-emission boiler and combustion equipment selection. The Laboratory.

23. Tunå, P. (2008). Substitute natural gas from biomass gasification. Malmö, Sweden: Svenskt Gastekniskt Center.

24. Jenkins, B., & Mullinger, P. (2011). Industrial and process furnaces: principles, design and operation. Elsevier.

25. Cengel, B., Thermodynamics An Engineering Approach. USA: McGraw-Hill.(2006). 2006.

26. Habib, M. A., Ben-Mansour, R., Badr, H. M., Ahmed, S. F., & Ghoniem, A. F. (2012). Computational fluid dynamic simulation of oxyfuel combustion in gas-fired water tube boilers. Computers & fluids, 56, 152-165.

27- Lyons, V. J. (1981). Effect of fuel-air-ratio nonuniformity on emissions of nitrogen oxides.

28- Rohschild, W. G., Kaiser, E. W., Rohschild, G. A., & Lavo, L. (1986). Effects of fuel-air equivalence ratio, temperature, and inhibitor on the structure of laminar methane-air flames. Combustion science and technology, 47(3-4), 209-227.

29- Roointon Pavri and Gerald D. Moore. 2003,"Gas turbine emission and control", GE Power Systems, 03/01.

30- Ergut, A., Levendis, Y. A., Richter, H., Howard, J. B., & Carlson, J. (2007). The effect of equivalence ratio on the soot onset chemistry in one-dimensional, atmospheric-pressure, premixed ethylbenzene flames. Combustion and flame, 151(1-2), 173-195.

31- Razdan, M. K. (1999). Fuel/Air preparation in the design of low emissions gas turbine combustion systems. In RTO Meeting proceedings.

32- Zhou, C., Fleeter, S., Houstis, E. N., & Rice, J. R. (1999). Gas Turbine Spray Dynamics and Combustion Simulation Design.

33- Paz, E. P., Carvalho Jr, J. A., Carrocci, L. R., Cortez, E. V., & Ferreira, M. A. (2009). Comparative study between diesel fuel and hydrated ethanol in direct burning. In Proceedings of the european combustion meeting.

34- Ghasemi, A., Moghiman, M., Javadi, S. M., & Hosseini, N. (2010, January). Effects of Droplet Size and Air Preheating on Soot Formation in Turbulent Combustion of Liquid Fuel. In Engineering Systems Design and Analysis (Vol. 49156, pp. 211-217).

35- Chigier, N., Bachalo, W., Reitz, R. D., Bellan, J., & Herrmann, M. (2011). Spray control for maximizing energy efficiency and reducing emission in combustion engines. Atomization and Sprays, 21(7).

36- Al Omari, S. A., & Abu-Jdayil, B. (2013). Some considerations of the performance of small dual fuel furnaces fueled with a gaseous fuel and a liquid fuel mix containing used engine lube oil. Renewable energy, 56, 117-122.

37- Pronobis, M. (2006). The influence of biomass co-combustion on boiler fouling and efficiency. Fuel, 85(4), 474-480.

38- Johnson, E. P. (2012). Carbon footprints of heating oil and LPG heating systems. Environmental Impact Assessment Review, 35, 11-22.

39- Park, H. Y., Han, K., Kim, H. H., Park, S., Jang, J., Yu, G. S., & Ko, J. H. (2020). Comparisons of combustion characteristics between bioliquid and heavy fuel oil combustion in a 0.7 MWth pilot furnace and a 75 MWe utility boiler. Energy, 192, 116557.

40- Barroso, J., Barreras, F., & Ballester, J. (2004). Behavior of a high-capacity steam boiler using heavy fuel oil: Part I. High-temperature corrosion. Fuel processing technology, 86(2), 89-105.

41- Huang, W. C., Hou, S. S., & Lin, T. H. (2017). Combustion characteristics of a 300 kWth oil-fired furnace using castor oil/diesel blended fuels. Fuel, 208, 71-81.

42- Ghorbani, A., Bazooyar, B., Shariati, A., Jokar, S. M., Ajami, H., & Naderi, A. (2011). A comparative study of combustion performance and emission of biodiesel blends and diesel in an experimental boiler. Applied Energy, 88(12), 4725-4732.

43- Najmi, W. M. W. A., & Arhosazani, A. M. (2006). Comparison Of Combustion Performance Between Natural Gas And Medium Fuel Oil At Different Firing Settings For Industrial Boilers. In Int. Conf. Energy Environ (pp. 1-10).

44- Mahfouz, A., Emara, A., Gad, M. S., El-fatih, A., El-Sherif, A. F., & Ayoub, H. S. (2019). Thermal flame spectroscopy of various diesel fuels and their blends with waste cooking oil through using coaxial burner. Egyptian Journal of Petroleum, 28(3), 307-313.

45- Niraj, V., Darshan, R., Raxit, S., Vijay, S. U., & Dabhi, D (2017). A Review in Performance Measurement of Diesel Fired Boiler Using Coconut Oil.

46- Niklitschek, M. E., Labbé, R., & Guerrero, J. (2020). Heating and hot water with wood chips. Is it convenient to replace firewood boilers in southern Chile?. Energy for Sustainable Development, 55, 24-31.

47- Pronobis, M. (2006). The influence of biomass co-combustion on boiler fouling and efficiency. Fuel, 85(4), 474-480.

48- Tanetsakunvatana, V. I. K. V., & Kuprianov, V. I. (2007). Experimental study on effects of operating conditions and fuel quality on thermal efficiency and emission performance of a 300-MW boiler unit firing Thai lignite. Fuel processing technology, 88(2), 199-206.

49- Drosatos, P., Nikolopoulos, N., Karampinis, E., Strotos, G., Grammelis, P., & Kakaras, E. (2020). Numerical comparative investigation of a flexible lignite-fired boiler using pre-dried lignite or biomass as supporting fuel. Renewable Energy, 145, 1831-1848.

50- Kattan, P., & Ruble, I. (2012). An economic assessment of four different boilers for residential heating in Lebanon. Energy and buildings, 50, 282-289.

51- Karademir, A. (2006). Evaluation of the potential air pollution from fuel combustion in industrial boilers in Kocaeli, Turkey. Fuel, 85(12-13), 1894-1903.

52- Bălănescu, D. T., & Homutescu, V. M. (2019). Study on condensing boiler technology potential accounting various fuels. Procedia Manufacturing, 32, 504-512.

53. Iraq standard specification for diesel fuel.

54. Fahim, M. A., Al-Sahhaf, T. A., & Elkilani, A. (2009). Fundamentals of petroleum refining. Elsevier.

55. Iraqi standard specification for LPG fuel.

56. Chaichan, M. T., Kadhum, J. A., & Riza, K. S. (2016). Spark Ignition Engine Performance When Fueled with NG, LPG and Gasolin. environment, 12, 59.

57. GMT_V.pdf>,O.T.S.G.T.G.A., https://www.scribd.com/document/77754387/D52-0704-GMT-reszletes.

58. Liu, S., Sun, H., Zhang, J., Liu, B., & Wang, Z. (2019, December). Study on Virtual Assembly and Disassembly Technology in Practical Teaching of Fuel Injector of Marine Auxiliary Boiler. In 2019 2nd International Conference on Mathematics, Modeling and Simulation Technologies and Applications (MMSTA 2019). Atlantis Press.

59. danfoss, Oil Nozzles Type LE https://store.danfoss.com/en/Heating-and-District-Energy/Burner-Components/Oil-Nozzles/Oil-Nozzles%2C-LE%2C-1-50-gal-h%2C-5-84-kg-h%2C-60-%C2%B0%2C-Solid/p/030F6728. 2019.

60. Syred, N. (2006). A review of oscillation mechanisms and the role of the precessing vortex core (PVC) in swirl combustion systems. Progress in Energy and Combustion Science, 32(2), 93-161.

61. Valera-Medina, A., Syred, N., Kay, P., & Griffiths, A. (2011). Central recirculation zone analysis in an unconfined tangential swirl burner with varying degrees of premixing. Experiments in Fluids, 50(6), 1611-1623.

62. Lucca-Negro, O., & O'doherty, T. (2001). Vortex breakdown: a review. Progress in energy and combustion science, 27(4), 431-481.

63. Durox, D., Moeck, J. P., Bourgouin, J. F., Morenton, P., Viallon, M., Schuller, T., & Candel, S. (2013). Flame dynamics of a variable swirl number system and instability control. Combustion and Flame, 160(9), 1729-1742.

64. Coghe, A., Solero, G., & Scribano, G. (2004). Recirculation phenomena in a natural gas swirl combustor. Experimental thermal and fluid science, 28(7), 709-714.

65. Griffiths, A. J., Syred, N., & Fick, W. (2000). A review of biomass and associated work at Cardiff relating to small scale heat and power systems.

66. Jameel Al-Naffakh (2019) .experimental investgation of the effect of burner geometrey on flame stability. al-furat al-awsat technical university.

67. Hatem, F. A., Alsaegh, A. S., Al-Faham, M., & Valera-Medina, A. (2017). Enhancement flame flashback resistance against CIVB and BLF in swirl burners. Energy Procedia, 142, 1071-1076.

68. BANZAI, H AIR COMPRESSOR AND AIR LINE EQUIPMENT http://www.banzai.co.jp/en/en_products.html.

69. dwyer, 475-FM Mark III Handheld Digital Manometer http://www.dwyer-inst.com/Product/TestEquipment/Manometer/AirVelocity/Model475-1-FM-AV

70. Hatem, F. (2017). Flashback analysis and avoidance in swirl burners (Doctoral dissertation, Cardiff University).

71. Handbook-Fundamentals, A. S. H. R. A. E. (2009). American society of Heating. Refrigerating and Air-Conditioning Engineers.

72. Milcarek, R. J., Garrett, M. J., Baskaran, A., & Ahn, J. (2016). Combustion characterization and model fuel development for micro-tubular flame-assisted fuel cells. JoVE (Journal of Visualized Experiments), (116), e54638.

Appendixes

Appendix (A): Calculations

1- For Iraqi liquefied petroleum gas (LPG):

The chemical formula of LPG:

$0.5(C_4H10) + 0.45\ (C_3H_8) + 0.05\ (C_2H_6)$

Stoichiometric chemical reaction:

$\mathbf{C_nH_m} + (n + m/4)*(\mathbf{O_2} + 3.76*\mathbf{N_2}) \rightarrow n\mathbf{CO_2} + (m/2)\mathbf{H_2}O + (3.76)*(n + m/4)\mathbf{N_2}$

$\therefore n = 3.45$ and $m = 8.9$

$0.5(C_4H_{10}) + 0.45\ (C_3H_8) + 0.05\ (C_2H_6) + (3.45 + 8.9/4)*(O2 + 3.76N_2) \rightarrow$

$3.45*CO_2 + 4.45*H_2O + 21.338*N_2$

$$(F/A)\text{stoich.} = \frac{0.5*(4*12+10*1)+0.45*(3*12+8*1)+0.05*(2*12+6*1)}{5.675*(32+3.76*28)} = \frac{50.3}{779.064} = \frac{1}{15.5}$$

LPG Case.1

Equivalence ratio:

$$\phi = \frac{(F/A)\text{actu}}{(F/A)\text{stoich.}} = \frac{(0.31/13.65)}{(1/15.5)} = 0.354$$

Boiler efficiency:

$$\eta = \frac{m^{\cdot}{}_s(h_s - h_{fw})}{m^{\cdot}{}_f *\ GCV} * 100\% = \frac{5.18 * (2678.955)}{0.31 * 4717} * 100\% = 90.2\%$$

2- For Iraqi Diesel:

The chemical formula: $C_{9.12}H_{16.85}$

Stoichiometric chemical ratio:

$C_{9.12}H_{16.85} + 13.3325*(O_2 + 3.76*N_2) \rightarrow 9.12*CO_2 + 8.425*H_2O + 50.1302*N_2$

$$(\mathrm{F/A})\mathrm{stoich.} = \frac{9.12 * 12 + 16.85 * 1}{13.3325 * (32 + 3.76 * 28)} = \frac{126.20}{1830.3} = \frac{1}{14.5}$$

Diesel Case.1

Equivalence ratio:

$$\phi = \frac{(\mathrm{F/A})\mathrm{actu}}{(\mathrm{F/A})\mathrm{stoich.}} = \frac{(10.456/134.608)}{(1/14.5)} = 1.1423$$

Boiler efficiency:

$$\eta = \frac{\dot{m}_s(h_s - h_{fw})}{\dot{m}_f * \mathrm{GCV}} * 100\% = \frac{150.193 * 2695.7}{10.456 * 43933.054} * 100\% = 88.13\%$$

Appendix (B): Calibration

1- LPG Flowmeter

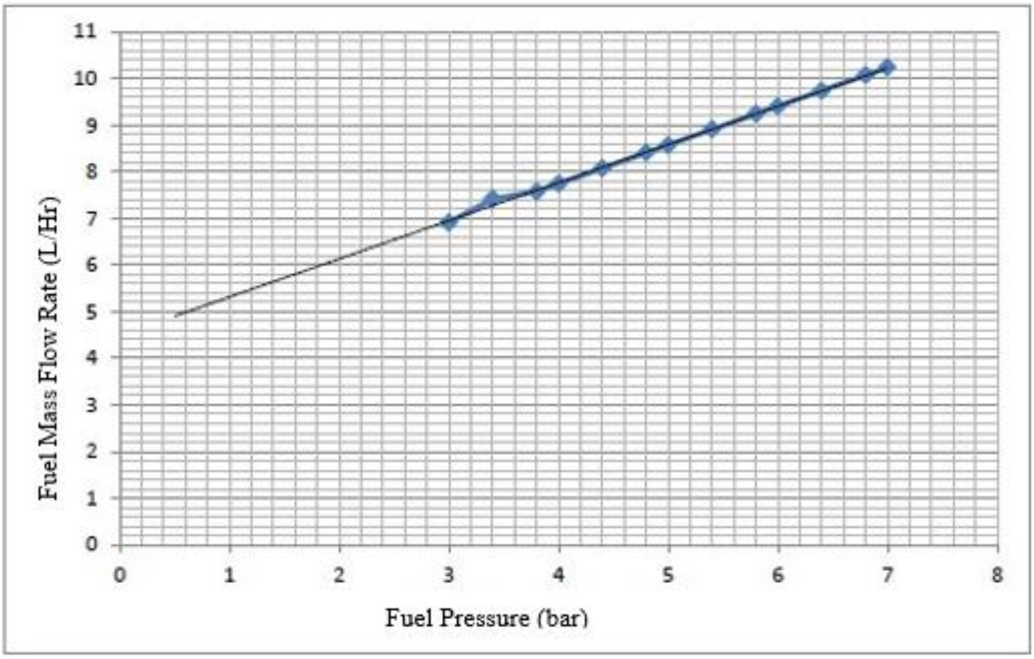


Figure A-1 Calibration Curve of LPG Flowmeter

Appendix (C): Experimental Data

Table (C-1) All Data about Equivalence Ratio and Boiler Efficiency When Used Diesel Fuel

Case No.	$\dot{m}_{air}$	$\dot{m}_{water}$	$\dot{m}_{diesel}$	Equivelance ratio	GCV_{diesel}	Feed Water			Steam			Boiler Efficiency
						Temperature	Pressure	Enthalpy	Temperature	Pressure	Enthalpy	
	(kg/hr)	(kg/hr)	(kg/hr)		(KJ/Kg)	°C	(bar)	(KJ/Kg)	°C	(bar)	(KJ/Kg)	(%)
1	134.6	150.19	10.456	1.1423	43933.05	18	1	75.64	160	4.5	2771.34	88.13
2	156.59	165.36	11	1.033	43933.05	18	1	75.64	160	4.5	2771.34	92.24
3	188.97	178.76	11.778	0.9166	43933.05	18	1	75.64	160	4.5	2771.34	93.13
4	227.8	180.08	12.171	0.7857	43933.05	18	1	75.64	160	4.5	2771.34	90.79
5	276.81	172.37	12.941	0.6875	43933.05	18	1	75.64	160	4.5	2771.34	81.79

Table (C-2) All Data about Equivalence Ratio and Boiler Efficiency When Used LPG Fuel

Case No.	$\dot{m}_{water}$	$\dot{m}_{air}$	$\dot{m}_{LPG}$	Equivelance ratio	GCV_{LPG}	Feed Water			Steam			Boiler Efficiency
						Temperature	Pressure	Enthalpy	Temperature	Pressure	Enthalpy	
	(kg/hr)	(kg/hr)	(kg/hr)		(KJ/Kg)	C	(bar)	(KJ/Kg)	C	(bar)	(KJ/Kg)	(%)
1	5.18	13.65	0.31	0.354	49717	18	1	75.64	145	2.5	2754.595	90.2
2	11.185	19.746	0.666	0.527	49717	18	1	75.64	145	2.5	2754.595	90.5
3	11.222	13.875	0.666	0.75	49717	18	1	75.64	145	2.5	2754.595	90.8
4	14.739	12.082	0.854	1.02	49717	18	1	75.64	145	2.5	2754.595	93
5	18.951	13.875	1.11	1.25	49717	18	1	75.64	145	2.5	2754.595	92
6	11.309	4.35	0.666	2.39	49717	18	1	75.64	145	2.5	2754.595	91.5

Table (C-3) Emission Analysis at Different Equivalence Ratio When Used Diesel Fuel

No.	Equivelance Ratio	CO (% vol.)	CO_2 (% vol.)	HC (% vol.)	O_2 (% vol.)	Thermal Efficiency (%)
1	1.145	1.1	6.2	230	0.001	88.13
2	1.034	0	11.4	10	0.01	92.24
3	0.916	0.05	7.1	1	0.05	93.13
4	0.785	0.15	5.7	0.018	0.17	90.79
5	0.6875	1	5	0.001	1.5	81.79

Table (C-4) Emission Analysis at Different Equivalence Ratio for three diameter ratio and compart with Ref.**[72]**, When Used LPG Fuel

Diameter Ratio	**Equivalence Ratio**	**CO (%Vol.)**	**CO_2 (%Vol.)**	**HC (%Vol.)**	**O_2 (%Vol.)**	**Thermal Efficiency (%)**
1/10	0.352	0.85	2	2.2	5	90.2
	0.527	0.69	4.1	1.5	2.3	90.5
	0.75	0.13	5.9	0.9	1.2	90.8
	1.02	0	10.1	0.1	0.01	93
	1.25	0.25	9.7	120	0.015	92
	2.39	1.28	5.1	513	0.01	91.5
1/15	0.352	1.05	1.88	8.7	4	87.8
	0.527	0.82	3.8	5.5	3.1	89.05
	0.75	0.2	4.5	3	1.6	90.4
	1.02	0.05	8.1	1	0.02	92.6
	1.25	1	8.3	230	0.01	91.3
	2.39	5	3	800	0.01	90.5
1/20	0.352	1.1	1.84	2.02	4.8	85
	0.527	0.85	3.9	2.35	3.6	87.4
	0.75	0.145	4.3	2.8	1.1	89.7
	1.02	0.05	7.5	0.5	0.01	92.1
	1.25	3.7	4.9	160	0.01	90.8
	2.39	7.2	3.6	890	0.01	89.4
Ref.[72]	0.8	0	9.2	-	4.3	-
	0.9	0.3	10.1	-	2.3	-
	1	1	10.4	-	0.5	-
	1.1	3.2	9	-	0	-
	1.2	5.8	7.7	-	0	-
	1.3	7.7	6.2	-	0	-
	1.4	8.9	5.6	-	0	-
	1.5	10.2	4.9	-	0	-
	1.6	11.1	4.3	-	0	-

Appendix (D):

1. **List of publications**

D-1.1 “Experimental investigation of the flame stability map (operating window) by using a tangential swirl burner for the confinement and unconfinement space”

IOP Publishing

ISCAU – 2020
15-16 July 2020
Al-Ayen University

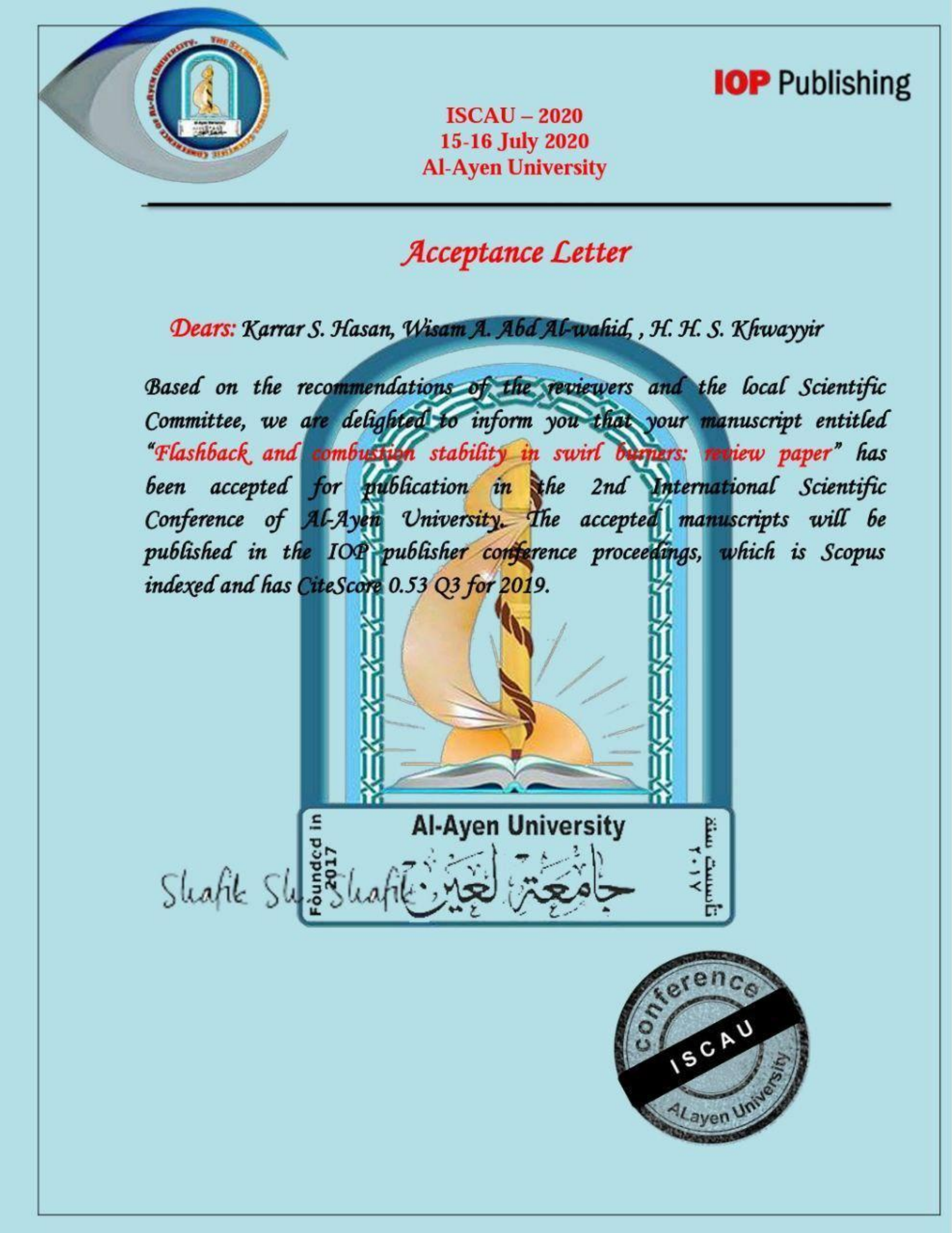
Acceptance Letter

Dears: Karrar S. Hasan, H. H. S. Khwayyir, Wisam A. Abd Al-wahid

Based on the recommendations of the reviewers and the local Scientific Committee, we are delighted to inform you that your manuscript entitled “EXPERIMENTAL INVESTIGATION OF THE FLAME STABILITY MAP (OPERATING WINDOW) BY USING A TANGENTIAL SWIRL BURNER FOR THE CONFINEMENT AND UNCONFINEMENT SPACE” has been accepted for publication in the 2nd International Scientific Conference of Al-Ayen University. The accepted manuscripts will be published in the IOP publisher conference proceedings, which is Scopus indexed and has CiteScore 0.53 Q3 for 2019.

Shafik Sh Shafik

D-1.2 “Flashback and combustion stability in swirl burners: review paper”



IOP Publishing

ISCAU – 2020
15-16 July 2020
Al-Ayen University

Acceptance Letter

Dears: *Karrar S. Hasan, Wisam A. Abd Al-wahid, , H. H. S. Khwayyir*

Based on the recommendations of the reviewers and the local Scientific Committee, we are delighted to inform you that your manuscript entitled “Flashback and combustion stability in swirl burners: review paper” has been accepted for publication in the 2nd International Scientific Conference of Al-Ayen University. The accepted manuscripts will be published in the IOP publisher conference proceedings, which is Scopus indexed and has CiteScore 0.53 Q3 for 2019.

Shafik

conference ISCAU ALayen University

الخلاصة

البحث الحالي يدرس مختبريا" تأثير استبدال الوقود في مرجل بخاري متوسط الحجم . تم العمل على منظومة بسعة ٢٠٠ كيلوواط تعمل بوقود الديزل ومتصلة بالعديد من المعدات الحرارية في المختبر. يتضمن العمل جزئين رئيسيين ؛ في الجزء الأول ، تم استبدال نظام الاحتراق (المحرق) لتشغيل المنظومة بواسطة LPG. تم تصميم المحرق من الصفر وتم استخدامة لعمل المرجل البخاري ، بعد التأكد من عمل التصميم الجديد بالوقود الجديد ، تضمن الجزء الثاني من الدراسة ايجاد افضل تصميم للمحرق ، حيث تم اختبار ثلاثة اقطار للمحرق نسبة الى قطر المرجل وهي كالاتي (١٠/١، ١٥/١، و ٢٠/١). تم استخدام قطر المحرق إلى قطر المرجل اساس للمقارنة بين التصاميم المذكورة انفا".تم دراسة غازات العام المتمثلة ب CO ، CO2، O2 ، HC بالاضافة الى كفاءة المرجل لكل نسبة ،حيث بينت النتائج أنه عند إجراء مقارنة بين ثلاث تصاميم لنفس المحرق وبالنسب المذكورة أعلاه ، كانت نسبة قطر المحرق الى قطر المرجل ١٠/١ هي أفضل نسبة حققت افضل كفاءة تشغيل للمرجل (٩٠,١ ، ٩٠,٥ ، ٩٠,٨ ، ٩٣ ، ٩٢ ، ٩١,٥)% عندما كان Ø(٠,٣٥٢ ، ٠,٥٢٧ ، ٠,٧٥ ، ١,٠٢ ، ١,٢٥ ، ٢,٣٩). بالإضافة إلى ذلك ، كانت نسب الانبعاثات الحجمية لCO هي() (٠,٨٥، ٠,٦٩، ٠,١٣، ٠، ٠,٢٥، ١,٢٨)% و CO_2 هي(٢ ، ٤,١ ، ٥,٩ ، ١٠,١ ، ٩,٧ ، ٥,١)% و O_2 هي (٥، ٢,٣، ١,٢،٠,٠١ ،٠,٠١٥،٠,٠١) % وكذلك HC هي (٢,٢، ١,٥، ٠,٩.، ٠,١، ١٢٠، ٥١٣) %.

أوضحت النتائج التجريبية أن ظروف التشغيل العامة لل LPG أفضل من وقود الديزل من ناحية الانبعاثات والكفاءة الحرارية. على الرغم من أن السلامة والسيطرة لا تزال مشكلة ، يمكننا أن نستنتج أن وقود LPG هو وقود واعد في الاستخدامات المستقبلية خصوصا" في العراق وذلك لكونة متوفر بنسب عالية.

جمهورية العراق
وزارة التعليم العالي والبحث العلمي
جامعة الفرات الاوسط التقنية
الكلية التقنية الهندسية- نجف

دراسة تشغيل نظام توليد البخار باستخدام أنواع مختلفة من الوقود

رسالة مقدمة الى
قسم هندسة تقنيات ميكانيك القوى
كجزء من متطلبات نيل درجة الماجستير في تكنلوجيا الحراريات
في هندسة تقنيات ميكانيك القوى

تقدم بها
كرار صلاح حسن رحيمة
بكلوريوس في هندسة تقنيات المضخات

إشراف

الأستاذ المساعد الدكتور
وسام احمد عبدالواحد

المدرس الدكتور
حسن هادي سلمان

شوّال / ١٤٤١