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Flame Speed for Premixed Iraqi LPG/Air Mixture

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بسم الله الرحمن الرحيم

{ يَرفَعِ اللهُ الَذينَ آمنُوا مِنكُم وَالَذينَ
أُوتوا العِلمَ دَرَجاتٍ }

صدق الله العظيم

المجادلة (11)

Certification

I certify that this research entitled " ***Flame Speed for Premixed Iraqi LPG/Air mixture*** *" has been prepared by "***Elaf Abdul-Ameer Ibrahim***" under my supervision at the department of Mechanical Engineering, College of Engineering, University of Babylon as a partial fulfillment of the requirements for the Degree of Higher Diploma of Science in Mechanical Engineering / Fuel and Power.*

I recommend that this research be forwarded for examination in accordance with the regulation of the University of Babylon.

Signature

Assist. Prof. Dr. Samer Mohammed Abdul-haleem

Department of Mechanical Engineering

College of Engineering

University of Babylon/Iraq

/ June / 2022

Dedication

- To whom I was the honor of bearing his name... my dear father, may God have mercy on him

- For who she gave me limitless and gave me strength and determination to continue the path, whose her satisfied is my goal and ambition.. my beloved mother, may God protect her.

- To the supporter and permanent lover, life partner.. my husband

- To God's beautiful gifts and the joy of life.. my daughters .

- To my brothers and sisters, may God preserve them, and I especially remember my dear brother Atheer.

- To all my friends, colleagues and everyone who helped me complete this research

I dedicate to all of you, my dear ones, the fruit of my humble effort

Elaf.

Acknowledgments

(In The Name of Allah, The Gracious, The Merciful)

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I would like also to submit my thanks to all staff members of the Department of Mechanical Engineering at the University of Babylon.

My deepest thanks, love, and gratitude for all of my family. This study would not have been completed without their love and continuous support.

Elaf

/ June / 2022

ABSTRACT

An experimental study of the flame velocity and laminar burning velocity of the Iraqi Liquefied Petroleum Gas/Air mixture was carried out in a centrally ignited fixed volume chamber at different initial pressures (100, 200, 300) kPa and an initial temperature of (298) K, in addition to different equivalence ratios of (0.8 to 1.3). The combustion chamber was designed for the purpose of this experiment in a cylindrical shape closed at both ends. It has an inner diameter of 395 mm, a volume (0.04899 m^3), and a length of 400 mm. Made of stainless steel, a Schillern imaging system using a high-speed camera was used to record flame spread along the combustion chamber. These videos are then analysis by Tracker software to get the laminar flame speed and burning velocity.

Experimental results proved that the velocity of the laminar flame increases at a pressure drop, as its value reaches about (1,49) cm/sec at a pressure of 1 bar and a flame radius (40) mm. The flame velocity decreases with increasing pressure to reach about (0.6) cm/sec at the flame radius (5) mm. As for the combustion velocity, it increases by increasing the equivalence ratio (Ø) of the LPG-air mixture until it reaches Ø = 1.1, where the highest value of the combustion velocity is at a pressure of about 1 bar. (40.5) cm / sec, after which the combustion speed decreases, and the reason is due to reaching the equivalent state, which means that there is enough oxygen to complete the combustion.

Nomenclature

Symbols	Definition	Units
d	diameter	mm
h	enthalpy	kJ/kg
L^b	Markstein length	
A	Flame speed area	
M	Molar mass	Kg
R	Specific gas constant	J/kg.k
R^o	Molar gas constant	J/mol.k
t	time	s
X	Mole of oxygen	Mol

Greek symbols

α	Flame stretch rate	1/s
δ	Flame thickness	mm
Ø	Equivalence Ratio	
$\propto_T$	Temperature exponents	
β_T	Pressure exponents	

Sub scripts

b	burned
f	Fuel
g	gas
i	Component fuel
p	pressure
prod	Product
react	Reactant
U	Un burned
^{o}	Initial condition

Abbreviations

CC	Combustion Chamber
CVC	Constant volume combustion
ILPG	Iraqi liquefied petroleum gas
LPG	Liquefied petroleum gas
PIV	Particle image velocimetry

Contents

CHAPTER ONE

INTRODUCTION

Chapter One: Introduction

1.1 General

The main goal of combustion research is to gain a full understanding of the mechanisms involved in the process of ignition, species distribution, flame propagation, and energy release from combustion mixtures. All practical outcomes of such information are clearly the control of the combustion operation from a safety point of view and its use as a source of energy. The combustion process is defined as the fast oxidation which generates heat or both of heat and light, or slow oxidation related with a relatively little heat without light **[1]**.

Also the burning process might be or might not be related with flame. This is very important to understand the two complementary empirical approaches macroscopic and microscopic. The main purpose to use measuring instruments is to show the details of the flame structure, the profiles of the fluid flow and the composition, transport coefficients, reaction rates and flame speed **[2]**.

To understand the laminar flame speed (SL), which is defined as the propagation velocity of a laminar flame front into an unburned premixed mixture. This parameter is affected by fuel type, air-fuel ratio, temperature, and pressure. It may be estimated with reasonable accuracy for many fuels using kinetic processes. Flame propagation or flame speed is an influencing factor in determining the amount of heat release and pollutant formation and emission. These parameters are the main concern of recent researches since they have a great impact on system efficiency, energy economy and environmental safety **[3].**

There are three modes of combustion depending on the nature of fuel and oxidant mixing, namely premixed, partially premixed and diffusion or non-premixed combustion. The present work is concerned with the study of laminar flame speed for premixed Iraqi LPG/Air mixture**.**

1.2 Modes of combustion

1.2.1 Premixed flames

In premixed mode, the fuel and oxidizer are mixed at the molecular level outside the combustion chamber before combustion takes place as shown on figure (1-1). In this mode there is a flame front moving rapidly into the unburnt mixture with a finite reaction rate and at a characteristic speed. Premixed burning is classified as either deflagration or denotation depending on the flame propagation speed. When the flame front speed is less than local speed of sound, it is called deflagration combustion and when the flame propagates faster than the local speed of sound, it is called detonation combustion **[4]**.

The premixed flame was a combustion mode that takes place when a fuel and oxidizer have been mixed prior to their burning. Premixed flames are present in many practical combustion devices **[5]**.

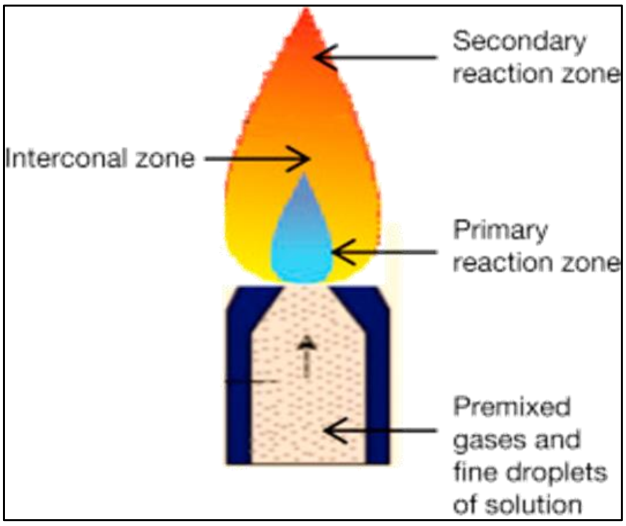


Figure (1.1) premixed flame. [4]

1.2.2 Diffusion flame

Many combustion processes separate the fuel and oxidizer before they enter the zone of reaction, where they blend and burn. The created flame in this combustion process is characterized as a "non-premixed flame" or "diffusion flame" because the fuel and oxidizer are transported into the reaction zone predominantly through diffusion as shown in figure (1-2). Because the fuel and oxidizer are not premixed, many combustions function in the diffusion mode for safety reasons, limiting the possibility of a sudden explosion. **[5]**.

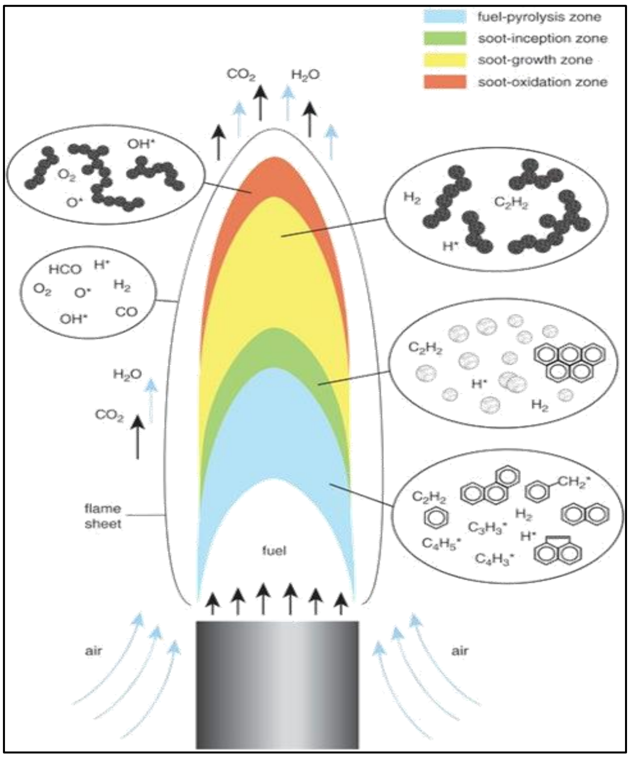


Figure (1.2) diffusion flame. [5]

1.2.3 Partially premixed flame

The partially premixed flames as the flame that occurs when part of the fuel is mixed with oxidant before burning while the other part is introduced to the combustion chamber during combustion process as shown in figure (1-3). These flames are evident in partial engineering appliances such as gas-turbine units and direct injection diesel engines. In these applications the partial premixing occurs in a mixing layer configuration leading to the formation of a complex flame structure **[6]**.

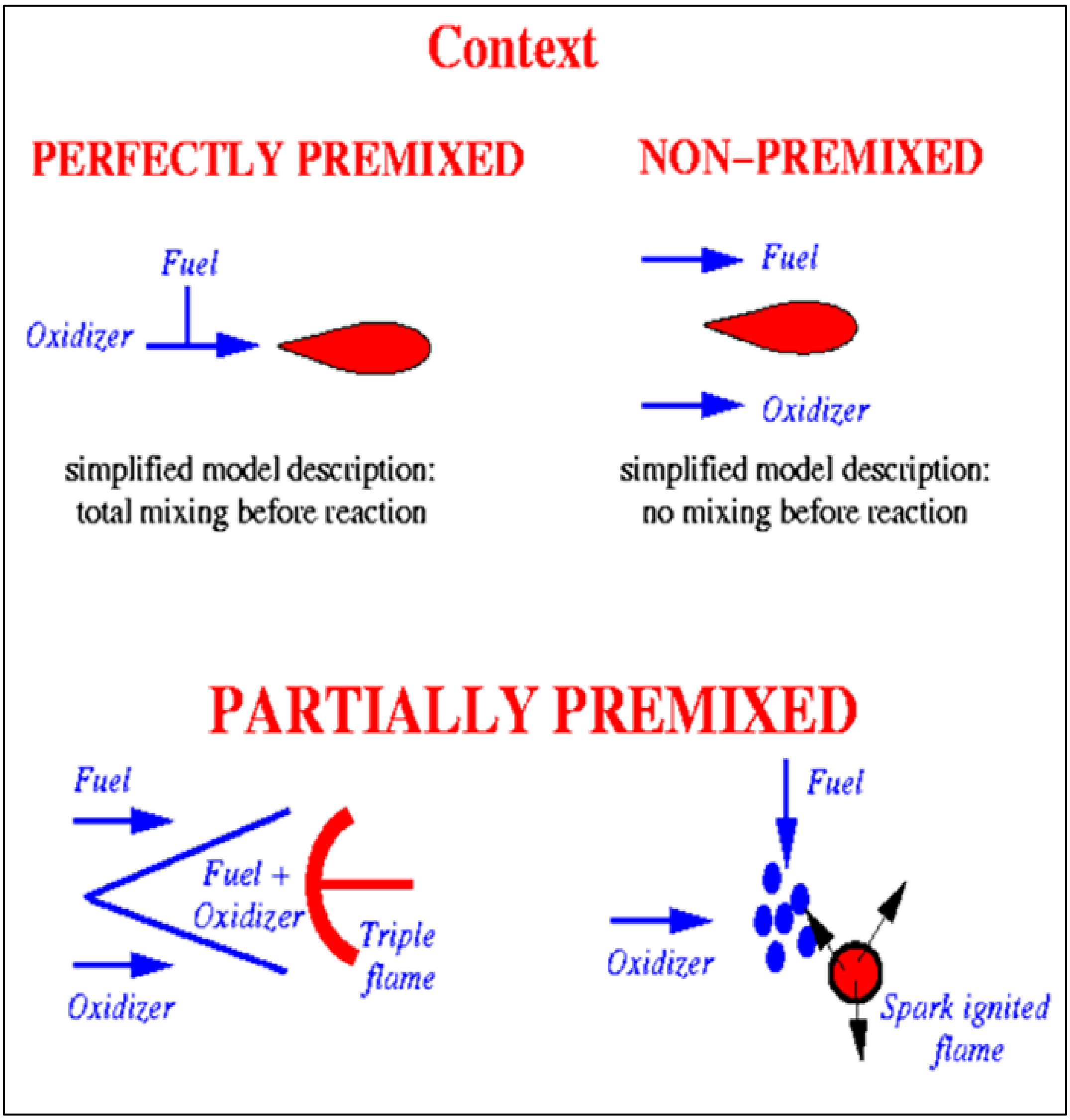


Figure (1.3) partially premixed flame [6].

1.3 Burning velocity and flame speed

1.3.1 Laminar burning velocity

is an important parameter in combustion as it contains fundamental information regarding reactivity, diffusivity and exothermicity. It can be used to validate chemical reaction mechanisms and design internal combustion engines. The burning velocity is defined as the linear velocity that the flame front travels relative to the unburned gas consumed per unit time divided by the area of the flame front in a one – dimensional domain as shown in figure (1-4) **[7].**

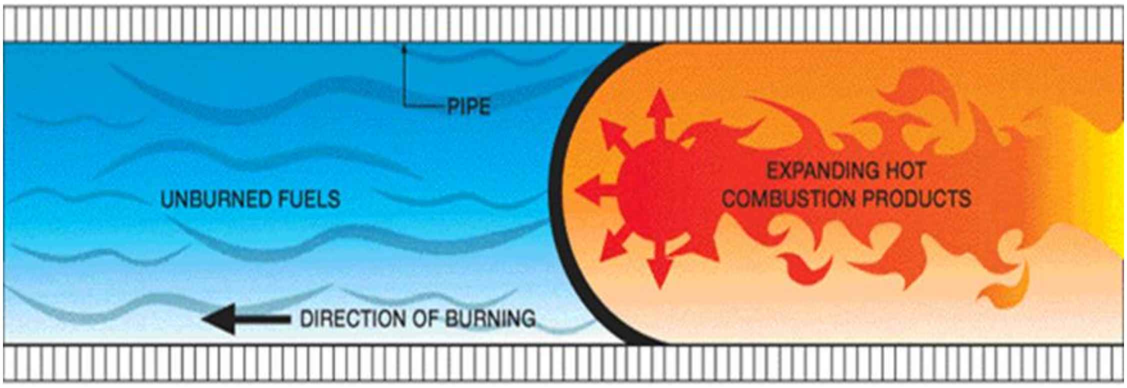


Figure (1.4) laminar burning velocity. [7]

1.3.2 Laminar flame speed

It is an important real property of a combustible mixture. It is defined as the speed at which an adiabatic, un stretched, premixed planner flame propagates relative to the unburned mixture **[8]**.

Many combustion phenomena can be calculated by using this quantity such as blow off, flashback and minimum ignition energy, designing burners and predicting explosions. It is also used to validate kinetic simulations for analyzing of the combustion process like the turbulent combustion in SI engine and power generation system **[9].**

1.4 Liquefied Petroleum Gas (LPG)

LPG fuel consists mainly of propane, butane, propylene, butylene in various properties according to its state or origin.

The composition of LPG fuel varies very widely from one country to another **[10]**.

1.4.1 LPG advantages [11]: -

- High heating value about 46.1 MJ/kg compared with 42.5 MJ/kg for fuel oil and 43.5 MJ/kg for gasoline.
- The near absence of sulpher, leading to cleaner-burning with low ash.
- Less corrosion and engine wear than is seen with gasoline because LPG burns in the engine in the gaseous phase.
- Easy to mix with air, a complete burning process and less carbon generation which could be seen with gasoline due to its high octane rating, with less carbon and spark plugs often last longer.
- Stable flame, low cost and available in Iraq.

1.4.2 LPG disadvantages [11]:-

- Its boiling point is below room temperature, the low vapor pressure of LPG at low temperatures could delay starting in cold conditions.
- Low energy density per volume unit of 26 MJ/l which is lower than of petrol or fuel oil, as its relative density is lower, about 0.5-0.58 kg/l compared to 0.71-0.77 kg/l for gasoline.
- The narrow flammability range of LPG is also a negative factor and significantly limits the application of LPG.
- It still emits a carbon dioxides (CO_2) and unburned hydrocarbon (UHC) during combustion both causing environmental problems.

1.5 Study setup

In order to achieve the purpose of this work, a new experimental rig is manufactured in the laboratories of the Department of Mechanical Engineering at the University of Babylon. The rig consists of a stainless steel cylinder, mixing tank for LPG and air, high speed camera for flame photography, flow control devices and safety devices. The teflon flange carries the ILPG/air mixture. More details about the rig is shown in chapter three.

1.6 Objectives

Due to the pollution and incomplete combustion of part of the fuel this work is mainly oriented to the measurement of laminar flame speed of Iraqi liquefied petroleum gas (ILPG). The improving laminar flame speed may improve combustion efficiency and reduce the concentration of pollutants emission. The main goal of this study is: -

- ❖ To measure the laminar flame speed of premixed ILPG/Air mixture experimentally.
- ❖ To calculate the burning velocity.
- ❖ To compare the results of this work with the other published literature.

CHAPTER TWO

LITERATURE REVIEW

Chapter Two: Literature Reviews

2.1 Introduction

Laminar burning velocities are significant in combustion applications such as burner design, explosion prediction, and spark ignition engine combustion. There are numerous ways for measuring laminar burning velocity, which are divided into two categories:

- The stationary flame
  Several methods that come under this part such as Bunsen burner and flat flame burner methods, slot burner method and the nozzle burning method .
- The non – stationary flame .
  Several methods that come under this part such as tube method, constant volume bomb method, soap – bubble method [**12].**

This chapter provides a brief historical overview of the measurement of burning velocity. The goal is to demonstrate that the concept of burning velocity, as well as the means for measuring it, have developed .

2.2 Flame speed and Burning velocity

Sarli and Benedetto (2007) [13] studied laminar burning velocity of H_2/CH_4 /air premixed flames numerically using the CHEMKIN-PREMIX code with the GRI kinetic mechanism. They showed that the values of the laminar burning velocities are always smaller than those obtained by averaging the laminar burning velocities of the pure fuels according to their molar proportions.

Ibrahim et al (2015) [14] studied the laminar flame speed of methane and LPG fuels. There preliminary results of CH4/LPG –air mixtures showed that SL of a mixture of these two fuels with any percentage is higher than SL of both pure fuels when used separately. Moreover, increasing the percentage of LPG in the mixture from 20% to 60% increase SL considerably, especially around the stoichiometric condition. The reason is not clear at this stage ;however ,it can be related to the expected increase in flame temperature with increase of LPG percentage in the mixture. This may lead to change in the production and consumption rate of the molar fraction of H,O,OH and CH3 radicals in the reaction zone.

Fig et al (2016) [15] studied and performed an experimental and numerical analysis of methane (CH_4) combustion and flame advancing in horizontal cylindrical combustion chamber. This work studied the effect of stoichiometry cylinder diameter and ignition location on the laminar flame propagation velocity. The cylinder has open end to the atmosphere and the other end was closed (solid wall). The range of the types diameters from 5cm to 71cm were used .It was found there was relationship between the maximum laminar flame propagation velocity and tube diameter. A hot wall was used as an ignition source, with burning velocity trends consistent with experimental data.

Bradely (2019) [16] Particle image velocity (PIV) was studied to measure laminar combustion velocities during flame propagation in a spherical explosion by measuring the flame velocity and gas velocity immediately before the flame.

$$Un = Sn - Ug \qquad \dots (2.1)$$

Here Un is the extended laminar coalescence velocity, Sn is the extended flame velocity and Ug is the maximum gas outward velocity, normal to the flame. where Sn, Ug measurements were performed at 0.1 MPa for methane, i-octane and ethanol/air mixtures at 300 k, 358 k and 360 k, respectively, over a range of equivalence ratios, as well as for n-butanol/air mixtures at 383 K between 0.1 and 0.5 MPa. The combustion velocities and Markstein numbers are given for methane, n-octane, ethanol, and n-butanol over a range of equivalence ratios at atmospheric pressure and in the case of n-butanol over a range of pressures taking into account the low rate of expansion where the laminar flame becomes inoperable. It is stable and its combustion rate increases due to the improvement of the flame surface area. The results show that PIV-measured flame measurements may reduce Markstein numbers by about 12%.

2.3 Flame speed measurement techniques

2.3.1 Bunsen Burner method

Fu et al (2014) [17] They used a very simple and common method to study flame structures and measure the speed of flame endurance using a Bunsen burner to conduct the experiment. This method has been used for long periods of time and is still common to this day. This method provides more information than other methods such as the pure flame structure and the flame front. Affected by Flame Extension In contrast to a spherical flame, the Bunsen flame expansion rate is very difficult to measure or is separated from experimental data.

Walter et al (2020) [18] studied the flame of laminar flow in a Bunsen laminar using optical methods such as OH chemiluminescence and streak photography. It was assumed in the first method ,that the burning velocity is uniform all over the flame surface. The laminar flame speed was then be determined using the mass conservation principle :

$$\rho_u \times S_L \times A = \rho_u \times \dot{Q} \qquad \dots(2.2)$$

$$S_L = \frac{\dot{Q}}{A} \qquad \dots(2.3)$$

ρ_u:the density of the unburned mixture.

$\dot{Q}$:unburned mixture volume flowrate.

S_L: laminar flame speed.

A: flame surface area (the area of the flame was obtained by inspecting the photographs of the flame using different programs ,use the equation (2.4)

$$cos\left[\frac{\pi}{2-\alpha}\right] = \frac{\rho_L}{\rho_u} \qquad \ldots(2.4)$$

$$S_L = S_u \sin(\alpha) \qquad \ldots(2.5)$$

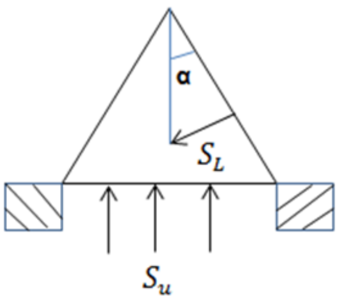


Figure (2.1)

2.3.2 Cylinder tube method

Huzayyin et al. (2008)[19] They made an extensive study to show the differences in laminar combustion velocity and the explosive index of mixtures of liquefied petroleum gas and air, propane and air across different values of temperature (Ti=295-400), pressure (pi=50-400 kpa) and equivalence ratio (Φ=0.7-2.2). For this purpose a cylinder combustion bomb was used. The results showed propane exhibits higher pressure dependency than that of LPG. The maximum laminar burning velocity found for propane is nearly 455 mm/s at Ø=1.1 while that for LPG is nearly 432 mm/s at 4.5% fuel percent (Ø=1.5). The maximum explosion be 93 bar m/s for propane, and nearly 88 bar m/s for LPG.

Wang et al. (2013) [20] used k-ε turbulence models Zimont premixed combustion model, and SIMPLE algorithm to analysis the premixed methane–air flame propagation velocity and its pressure in a half-open square tube with three forms of solid obstacles. Simulation results showed that the same blockage ratio of 40%,the triangular prism obstacle was beneficial to the flame and airflow accelerating processes, and its propagating velocity and deflagration pressure induced by obstacle were large than cuboid and cylinder obstacles.

Brune (2013) [21] used several reaction vessels of various sizes to measure the average burning velocities of methane flames without obstacles. This experimentation was carried out to validate a CFD model and establish a baseline for later comparison .When an explosion happens in a mine, the resulting pressure and temperature increases are enough to endanger both personel and equipment.

Ahmed and Thaer (2020) [22] performed a mathematical simulation of a cylindrical combustion chamber with an internal diameter of (510 mm). The heat distribution was improved and implemented for five flame models where LPG fuel was injected through the nozzle with a diameter different from (5-26) mm and the results showed the effect of heat distribution inside the combustion chamber on the exhaust. The temperature of the gases when injecting the fuel up and down the vertical combustion chamber. Also, the temperature of the exhaust gases will increase until the nozzle diameter is 15mm, after which the temperature will be almost constant, and the LPG injection speed also changes from 34 m/s to 12.6 m/s depending on the nozzle diameter.

Zeenathul et al (2021) [23] studied the stability and flame characteristics of LPG flame in a tubular burner investigated oxidizing gas and N_2 or CO_2 as the balance gas. The preliminary experiments show that the flame height decreases with the increase in the primary aeration for both air and oxygen cases and premixed blue zone increases with primary aeration. The flames observed for oxygen cases are dull and weak at all equivalence ratio. The measured axial flame temperature indicated that the temperature of oxygen flames is lower than that of the air flames for the same primary aeration. The data obtain from the stability tests show that the oxygen flames can with stand at lower port velocity than its air counterpart. The stable operating range of the given burner design lower when CO_2 is used as a balance gas. These difference in the stability and flame characteristics is attributed to the difference in the thermo physical properties such as heat capacity, mass diffusivity and thermal conductivity.

Zhenminl et al (2021)[24] investigated the influences of an obstacle on the deflagration behavior of premixed liquefied petroleum gas-air mixture. Experiments were conduct in a closed tube with length /diameter ratio (L/D) equal to 0.59 at a atmospheric temperature and pressure. The effect of blockage ratios from 0-0.9 of the flame propagation, the combustion time ,the explosion pressure, the pressure siding rate and the deflagration index of LPG-air mixture were observed and analyzed. The results showed that the flow field structure of the unburned gas induced by obstacle increased the degree of flame front and sharply increased the flame propagation speed. During the subsequent propagation, various extremely irregular flame shapes emerged on the flame front. The sudden acceleration of the flame in the duct generated the pressure wave. These pressure waves interacted with flame front and produced flame disturbances.

2.3.3 Spherical flame method

Liao et al (2004)[25] investigated experimentally the premixed laminar combustion of liquefied petroleum gas –air mixture. It is conducted in a constant volume combustion chamber. Spherically expanding flame have been employed to measure laminar flame speeds over wide equivalence ratios, at the initial pressure of 0.05, 0.1 and 0.15 Mpa, and preheat temperatures, from 300 to 400K .To study the effects of initial temperature and pressure on these parameters discussed .Over the ranges studied, laminar burning velocity are corresponding with equation (2.6):

$$u_l = u_{L\circ}\left(\frac{T_u}{T_{u\circ}}\right)^{\propto T}\left(\frac{p}{p_{u\circ}}\right)^{\beta T} \quad \dots (2.6)$$

Where $\propto_T$ & β_T are the temperature and pressure exponents .

$\propto_T$: 1.86,1.68 and 1.74

$\beta_p = -0.5, -0.45 \text{ and } -0.46$

Huang et al. (2006 [26] measured the laminar burning velocity of H_2-natural gas/ air mixture in a constant volume bomb at normal temperature, pressure and equivalence ratios (Ø from 0.6 to 1.4). The results showed that for lean and rich mixture combustion, there exists a linear correlation between flame radius and time. Combustion at stoichiometric mixture demonstrated the linear relationship between flame radius and time for natural gas/air, hydrogen/air, and natural gas/hydrogen/air flames. Flame instability increased with the increase of hydrogen fractions in the mixture. Based on the experimental data, a formula for calculating the laminar burning velocity of natural gas/hydrogen/air flames was proposed.

Ilbas et al. (2006) [27] investigated experimentally the H_2/CH_4/air mixture in constant volume chamber at ambient temperature and pressure for variable equivalence ratios (Ø = 0.8-3.2). They demonstrated that increasing the hydrogen percentage in the hydrogen–methane mixture brought about an increase in the resultant burning velocity and caused a widening of the flammability limits and also suggested that a hydrogen–methane mixture (i.e.

30% hydrogen/70% methane) could be a competitive alternative fuel for existing combustion plants.

Jayachandran et al. (2015) [28] An experimental and modeling study was conducted in both ethylene and n- heptane flame formations, and the flow velocity was measured using particle image measurement in both spherically expanding flames and counter flows. The accuracy and consistency of the results were evaluated by comparing the directly measured and directly computed physical properties. The results showed that the directly measured data in both configurations are consistent against the direct numerical simulation results. It was also shown that the observed uncertainty is introduced when the extrapolation and intensity corrections are carried out in the spherically expanding flame.

2.4 Factors effecting on burning velocity and flame speed

2.4.1 Chemical effect

Cardona et al.(2013)[29] studied the velocity of laminar combustion in the flame generated using a nozzle burner of the type with specific slots and the schileren technique and changing the ratio of air to fuel at standard temperature and pressure. In this study, an equimolar mixture of Natural Gas (100% CH_4) and Synthesis Gas (40% H_2 + 40% CO + 20% CO_2) was used as an alternative to reduce the consumption of hydrocarbons and emission of pollutants. This study found that the flame speed of an equimolar mixture increases with respect to pure methane and this is explained by the presence of hydrogen in the fuel mixture, which affects the combustion movement and the generation of H and OH radicals, which increases the reaction rate of the mixture and thus increases the combustion speed .

Miao et al. (2014) [30] used 30% of propane and 70% butane to simulate commercial standard LPG available in Hong Kong, to investigate laminar burning velocity with hydrogen enrichment of (10%-90%) in volume. They found that the accelerating effectiveness is substantial when the percentage of hydrogen is larger than 60%. Hydrogen addition decreased the flame thickness. Equivalence ratio had a more dominating effect on flame thickness than hydrogen did. For the fuel with 10% LPG and 90% hydrogen, the flame thickness values were close for all equivalence ratios.

Abdul and Sardar (2017) [31] used different concentration of Iraqi liquefied petroleum gas (ILPG) from 10% to 26% with different of dozens of Iraqi Gas-oil fuel from 90% to 75% with constant load to reduce the emission. Also, a dual fuel burner was used with different equivalence ratio, the range of ϕ from 0.8 to 1.4 which was used to study the emission concentration based on these equivalence ratio. Also, the range of mass flow rate of cool water from 12kg/s to 40kg/s which used to reduce the emission and heat recovery from the exhaust gases. The results showed that when increasing percentage participant of LPG fuel as a secondary fuel ,UHC ,CO, and soat decreased by 8% and NO_X and CO_2 increased slightly .

2.4.2 Physical effect

Hamid and Said (2001) [32] studied experimentally the effect of initial temperature on measuring the combustion speed of fuel – air mixtures , where the combustion velocity of mixtures (methane, propane, liquefied petroleum gas, iso - butane) / air was measured inside a copper tube of 1920 mm length, 10 mm inner diameter and 6 mm thickness to heat the mixture to a certain temperature. Partial pressures of components according to Gibbs- Dalton's law. The preparation process was carried out in a closed vessel designed for this purpose to increase the partial pressure of the gaseous fuel. A heating tape was placed around the tube to heat the mixture to a certain initial temperature. The temperature was measured by a thermocouple. After that, a flame nucleus was produced by a unit ignition and then experimentally measuring the flame velocity of the gas mixture using the photovoltaic cell technology. This study has proven that the combustion speed of the fuel-air mixtures varies according to the equivalence ratio, temperature and the number of carbon atoms.

Hu et al. (2009) [33] studied the laminar burning velocity of hydrogen–air flames at different initial pressures and temperatures. It was found that the laminar burning velocity increases exponentially with the increase of initial temperatures. They suggested the following curve fitted equation:

$$u_l(T_u) = -2.37 + 2.038\exp\left(\frac{T_u}{3621}\right), (P_u = 0.1MPa, 303K \le T_u \le 950K) \qquad \ldots(2.7)$$

The effects of temperature and pressure on laminar burning velocity can be correlated through the following empirical expression similar in equation (2.6) :

$$u_l = u_{lo}(T_u/T_{uo})^{\alpha_T}(P_u/P_{uo})^{\beta p}$$

Guet et al (2011) [34] studied the laminar flame speed and Markstein lengths of tert-butanol-air premixed mixture over a wide range of equivalence ratios at different initial temperature and pressure in a constant volume combustion chamber using schileren photography. Results showed that the un stretched flame propagation speed and laminar flame speed of the tert–butanol-air mixtures increased with the increasing of initial temperature and decrease with increase of initial pressure. Peak values of laminar flame speed occurred at an equivalence ratio is 1.1 regardless of initial pressure and temperature. Markstein length decreased with the increase of initial pressure.

Salih and Chaichan (2014) [35] experimentally studied the effect of the initial temperature and pressure on measuring the laminar combustion velocity of mixtures of propane and air using thermocouples. High temperature and the importance of this data for applications in engines and turbines, it is necessary to obtain data for these conditions. Experiments were carried out for a wide range of equivalence ratios Ø=0.5 to Ø=1.5 initial mixture temperatures T=300 to T=350 k^o and the initial pressure of the mixture from P=0.5 to P=1.5 bar and the results of the higher initial pressures and temperatures were obtained for a wide range of equivalence ratios. It was noted that the combustion velocity decreases with the increase in the initial pressure and the markstein number increases with the increase in the equivalence ratio of the flat – free mixtures to the rich mixture, but it decreases with the increase in the initial temperature.

Ahmed et al. (2015) [36] studied to use alternative fuel mixtures ,mainly LPG (60% butane, 20% ISO –butane and 20% propane) and methane in addition to other gases and fuels such as hydrogen, oxygen, carbone dioxide and nitrogen, will be studied to know how the change in the fuel mixture composition affects the combustion characteristics of this fuel ,specially the laminar flame speed (S_L). A simple test rig developed to measure the speed. It consists of a 4.5m long optical –quartz tube. The flame is ignited at inlet of the tube and S_L is measured by two methods simultaneously; two type –k thermocouples fixed at the inlet and exit the tube–and high speed camera. The results showed that the CH_4/LPG –air mixtures show that S_L of mixture is higher than S_L for single fuel. When the concentration of LPG increases the S_L will increased too.

Ichikawa (2015) [37] investigated experimentally and numerically the laminar burning velocity of ammonia/H_2/air premixed flames at elevated pressures (1-5 bar) in a constant volume chamber. The results showed that the laminar burning velocity increases non-linearly with an increase in the hydrogen blends and decreases with an increase in the initial mixture pressure.

Aravind et al. (2015) [38] studied the effect of adding hydrogen on the combustion properties of air and liquefied petroleum gas mixtures using a USC mesh II reaction mechanism, which contains 111 species and 784 reaction zones. The results showed a variation in the flame speeds and the variation was small for the different compositions of the mixtures of liquefied petroleum gas and air used. The volumetric effect of H2was also studied. Take 50% propane – 50% butane. The investigation was carried out for mixture temperature up to 450 k and pressure ranging from 1 to 10 bar. It was observed that there is a linear relationship to the flame speed as a function of hydrogen addition.

shakir (2016)[39] experimentally investigated the laminar flame speed in a premixed (ILPG/H2/air) mixture in a centrally ignited constant volume combustion chamber at initial temperature of 308K and changing pressures from 1 to 3 bar. The equivalence ratios changing from 0.8 to1.3 and the range of amount of H_2 from 0-80% according to the mass. The parameter, which were studied such as laminar flame speed, combustion chamber pressure, and laminar burning velocity. Also used high speed camera to show and calculate the speed of the laminar of ILPG. It was noticed that increasing the initial pressure reduced the stretched laminar flame speed and laminar burning velocity of ILPG air mixture .

Li et al.(2017) [40] studied the experimental measurement and numerical simulation to perform sensitivity analysis and component concentration analysis to reveal. The mechanism of the effect of hydrogen addition on the flame speed of methane, ethane and propane and to compare the difference between these three types of gaseous fuels a flat flame method was used to measure the laminar flame velocity in order to create a backflow associated with the particle image velocimetry (PIV) system. The results showed that with the increase in the amount of hydrogen, the laminar flame speeds of methane, ethane and propane increased almost linearly, in addition to the fact that the flame speed of methane has an increasing amplitude between them as the hydrogen increases. Which indicates that methane gas is more sensitive to adding hydrogen in the flame speed than the two fuels others

Zhou et al. (2018) [6] [41] studied experimentally and numerically the effect of the ignition energy on the externally spreading spherical flame paths of the premixed (O_2,H_e,CH_4,N_2) mixture. The experiment was carried out in a fixed – size combustion bomb at high initial pressures and temperatures (0.07-0.7) Mpa (298-398) K, and equal ratios from (0.9-1.3) with different Lewis numbers. The results showed that raising the ignition energy increases the speed of the initial flame spread and widens the range of the flame path that is affected by the ignition energy, and that with the increase in the ignition energy, the flame spread speed of N_2 during the initial spreading period and the radius of the flame path affected by the ignition energy mixes. .

2.5 Scope of Study

As focused on the literature review, several researchers have studied the effect of LPG premixing on flame propagation and of some hydrocarbons. But there were few researcher who studied the flame speed of LPG using only a horizontal combustion chamber. The detailed scope of the present work is to study experimentally the flame speed for premixed LPG / air mixture in the constant volume combustion chamber. The laminar flame speed and the laminar burning velocity are then calculated using the Schlierens technique.

CHAPTER THREE

Experimental Work

Chapter Three Experimental work

3.1 Introduction

In this chapter, the rig and the measured tools used for the practical study of the flame velocity of a mixture of liquefied petroleum gas and premixed air are described, as well as the safety, and security systems used with the device, and each part is explained in detail. The device is located in the laboratories of the university of Babylon, Department of mechanical Engineering. The complete installation of the combustion chamber as shown in Figure (3.1).

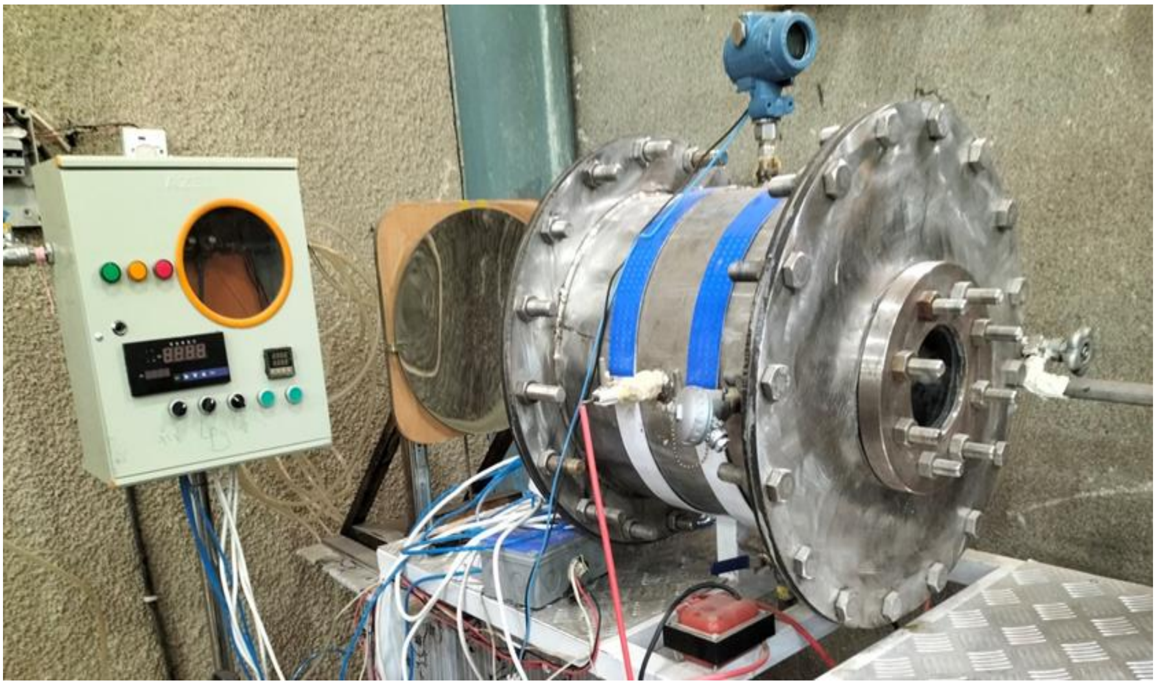


Figure (3- 1) The experimental apparatus

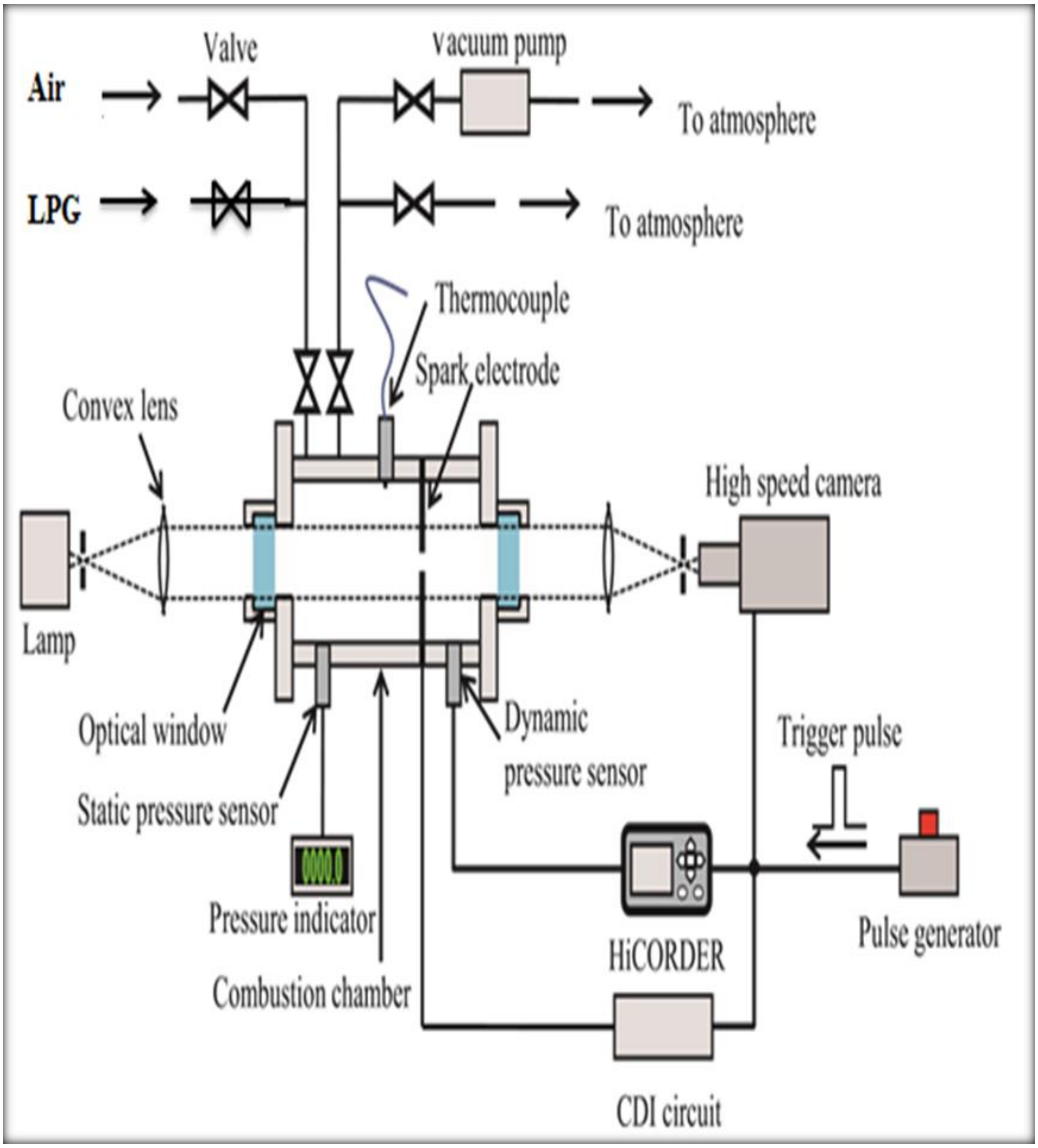


Figure (3- 2) Schematic Layout of Experimental System

3.2 Combustion chamber unit

It is a fixed-volume cylindrical chamber (0.04899 m3) with an inner diameter of 395 mm and a length of 400 mm as shown in figure (3.3). The chamber has flanges of 1 mm thickness and top and bottom flanges of 407 mm and 570 mm in diameter, respectively. Made of stainless steel to resist outdoor conditions. These flanges are attached to the combustion chamber by 16 hex bolts of type 12.1 per flange. Pressure-resistant quartzite windows (100 mm, 140 mm) are installed on both sides of the combustion chamber by flanges to allow visual access to the combustion process. The cylinder is supplied with central electrodes connected to the ignition system.

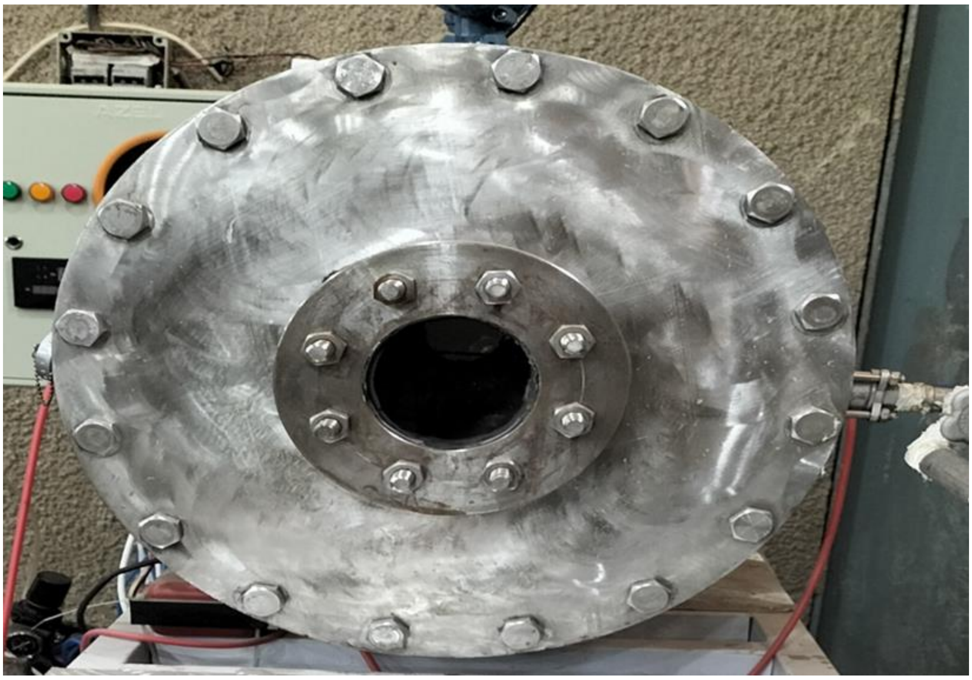


Figure (3. 3) cylinder of combustion chamber

One pressure gauges from type PS6000 series pressure and digital penal meter – series as shown in figure (3.4).

Figure (3-4) pressure gauges, type PS6000 series pressure and digital penal meter.

3.3 Pressure gauges

This series of products suitable for petroleum, chemical, metallurgy, electric power, water conservancy, scientific research, environmental protection and other various enterprises and institutions, to realize the measurement of fluid pressure and is suitable for various occasions all-weather environment and all kinds of corrosive fluid as shown in Figure (3.5). Table (3.1) shows a details and the properties of the pressure gauges which are used in this work.

Features

1- Multi measure range selection. 2.Digital LCD display.

2- Digital LCD display.

3-Convenient debugging for zero range.

4- Intrinsically safe explosion-proof.

5- High performance price ratio.

6-High precision & stability.

Specifications

Table (3-1) the details and properties of the pressure gauge

Measure range	-0.1 – 100 Mpa	Precision	0.2 % - 0.5%
Over load	150%	Out put	4 ˜20 ma with Hart
Stability	<0.1% /year	Power supply	18̃˜ 36 VDC
Display	5 – digit LCD	Display range	-19999˜ 99999
Operating temperature	- 20℃ ˜ 70℃	Relative humidity	<80%
Thread	M20 * 1.5	Interface material	Stainless steed

Figure (3-5) Pressure gauges QYB02

3.4 Thermal gasket: -

Thermal Gasket was used to prevent leakage between the flanges. Two thermal gaskets are used for each flange of (1.5). The gasket is made from a material that is partially yielding such that it can deform and tightly fills the spaces designed for.

3.5 Safety valve: -

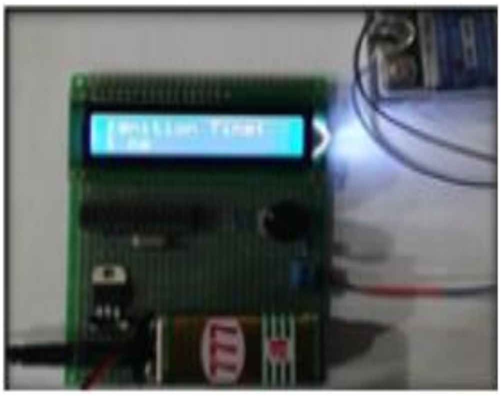
A safety Valve is installed in the lower edge of the combustion chamber to prevent any excessive pressure increase resulting from the burning process with in the chamber and is seized for opening at high pressure (60 bar) to avoid the explosion or damage of the cylinder.

3.6 Vacuum pump

The combustion chamber shall be emptied from combustion products and cleaned by air after each combustion process using an ¼ HP ,220V-50HZ.

3.7 Ignition circuit: -

To produce a strong spark, an electronic circuit is used to provide power to poles as shown in the figure (3.6 A and B) A continuous current energy source is produced from a current – line converter (220 VF). The transformer (2*5000 V) HOSEL) is 10 KV at the peak. An electronic circuit is used to control the duration of the operation (e-payment area) it is placed in front of the transformer to produce an on- off to initiate the spark in the combustion chamber. the duration of ignition can be controlled manually from (1-1000) MS the duration of ignition used in the experiment is (5 MS) and the ignition energy supplied about 2 Joules.



A: Electronic Circuit Controlling the Duration of Ignition **(CDI)**

B: Transformation Type.

Figure (3.6) Ignition circuit

Ignite the mixture at appoint along the central axis of the cylindrical the using intensive discharge flaring (CDI). The diameter of the spark electrodes was 2 mmand the spark gap was set to 1.5 mm. The electrostatic energy which was charged in the capacitor in the CDI circuit as shown in fig (3.7).

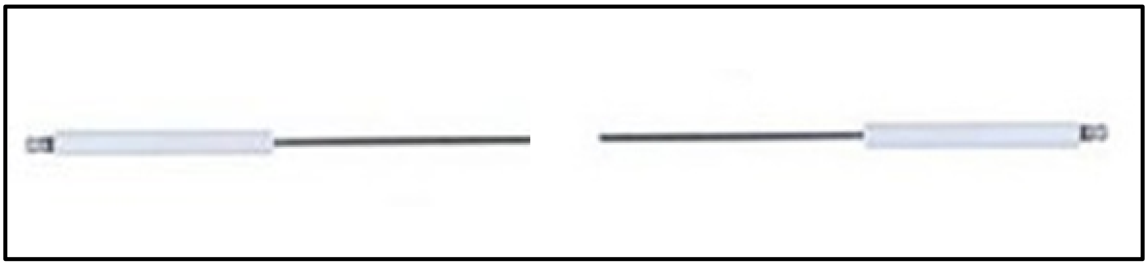


Figure (3-7) Modified Electrode Used in the combustion chamber

3.8 Mixture preparing unit: -

To prepare the mixture of the LPG - air, mixing done inside the combustion chamber before the ignition process. So that the pressure is measured separately. The shape of the combustion chamber is cylindrical which gives the shape of a vortex to the mixture after injection process allows the mixture to be homogenous.

3.8.1 Compressor

A compressor (type DARI, type DEC 720/520 HP4 40068, ITALY, 2002) is used to provide the air at high pressure to mixture-preparing unit. The capacity of compressor is (270 Liter), works at (1160 RPM), and the maximum working pressure is (10.5 bar) as shown in Figure (3.8).

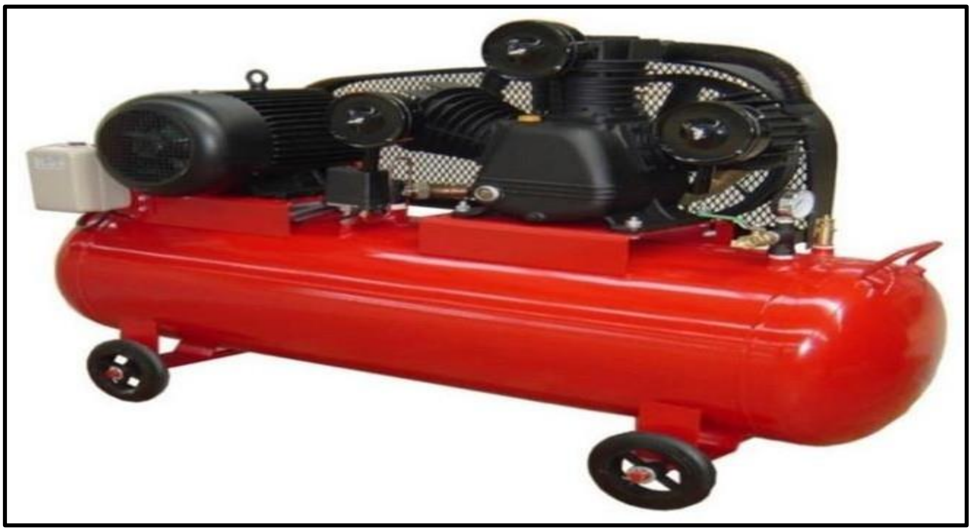


Figure (3-8) Air compressor

3.8.2 Fuel storage tank

Fuel storage tank are used to control the supply of LPG fuel. Fuel is admitted directly to the storage with a prescribed pressure and temperature. The output from the storage tank is controlled by a pressure regulator at (-1, -12 bar) and (0, -4 bar) for LPG fuel storage. The main use of the storages is to control the admitting process from the storage to the combustion chamber rather than from high pressure main storage and reduce the temperature raising during the injection from main source.

3.8.3 Pressure gauges

A pressure gauge was used to control the amount of LPG [0-4 bar] and prevent the occurrence of ignition or Gas leakage because the regulating meter has the property of non-leakage and non-return of gas in the opposite direction. As showed in figure (3.9).

Figure (3.9) Regulator and Gauge pressure for LPG.

3.9 Control unit

The main purpose of the control unit to regulate and control the amount of gasses entering the combustion chamber by means of (3) celluloid with (2) valve and contain (2) screen , one of which displays the temperature reading and the second for purpose of reading the amount of pressure added to a transformer from 220 V to 24 V to control; in addition to the presence of switches for opening and closing the valves for gasses (LPG-air) the main purpose of this unit is to accurately regulate entry and exit and control one location . Figure (3.10) shows control unit.

Figure (3.10) control unit

3.10 Capturing Unit

An optical system is used to visualize and record the flame and flame flashback process with a high-speed camera. Figure (3.11) shows schematic diagram for capturing unit. A light source and concave mirror are used depending on Schlieren photography.

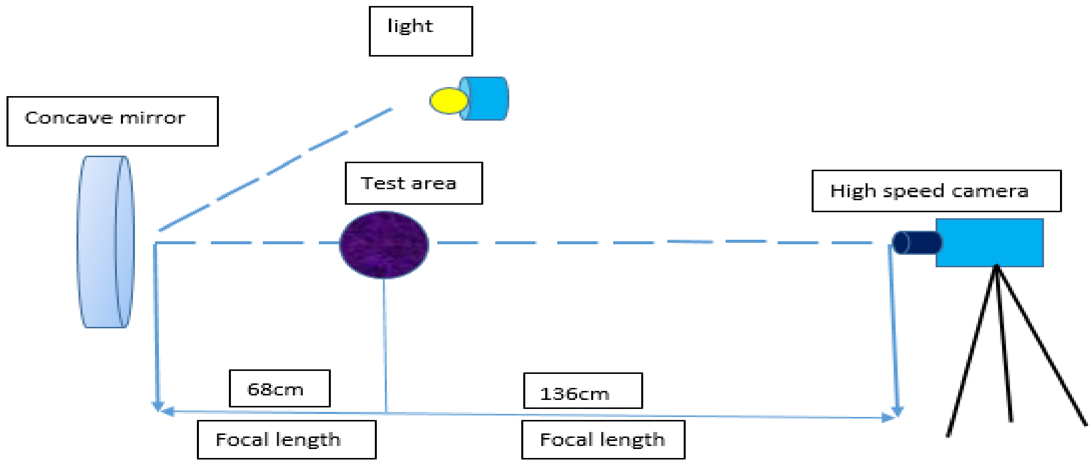


Figure (3-11) Schematic diagram for capturing unit

3.10.1 Concave mirror

A concave mirror is used to generate both real and virtual images from real objects. The parabolic shape focuses parallel rays to a single point. The focal length of the mirror is 68 cm and its diameter is 40.5 cm. This mirror is concave mirror as shown in Plate in Figure (3.12).

Figure (3-12) Concave mirror.

3.10.2 Camera and Lightening source

In this study the high- speed portable camera AOS-Q-PRI and the high accuracy of the picture (3 Mega Pixel) and an inner memory of 1.3 gaga Pete and 16,000 tyros per second were used to measure the spread of flame as shown in figure (3.13). The preparation used in the experiment is 576 *500 lams for 4,000 tyros per second, the total time for registration is 1.2 seconds, and 10% of the time is designated as pre-operating to ensure that all operations are recorded when operating the operators, the ignition unit and the camera. A 5 mm bulb NE-2 type neon lamp (12V DC) is housed in a closed box with a single output and is placed before the lamp a focal length of the lens (5 mm) to collect and scatter the light.

Figure (3-13) AOS -Q PRI High Speed Camera.

Calculations

3.11 Test procedure

The mixing process relies on the Gibbs - Dalton Act for the partial pressure of each component of the mixture to obtain a precise parity ratio. The mixture is prepared within the mixing combustion chamber. the total absolute pressure (5bar) per test by: -

A-Combustion Chamber Preparation Processes: -

1**. Cleaning process**: - This process is done through the introduction of air into CC for three minutes. This process is repeated three times to ensure that the CC is completely surveyed.

2. **Scavenging process**: **-** The unloading process is carried out by closing all fuses except for the discharge pump and discharge scale valves so that the CC pump can be sufficiently cleaned from any previous mixture, until its pressure is almost reached (-1 bar).

3. **Filling process**: **-** The mixture enters into the combustion chamber at the required initial pressure, then closes all the fuses and waits for 10 minutes before ignition to stabilize the mixture, obtain a laminar flame and sustain a mixture free of turbulence and eddies.

B- Combustion and Recoding Processes:-

A homogeneous mixture was prepared in previous steps thereafter.

1. Initial pressure and temperature shall be adjusted on the initial status of the test.
2. The electronic pressure transformer starts to record the combustion pressure.
3. Determine the duration of ignition (5 milliseconds).
4. High-speed camera was seized at the time of formation (1.2 seconds with 10% pre-operability) and the lighting system begins to open.
5. Both the ignition logging operators and the camera are moved at the same time.

6. The data is re-coded and photographs are taken. Step (A) is repeated with different initial conditions.

3.12 Mixing Ratio and combustion processes

LPG is mixture of many types of hydrocarbons (Ethan, propane, butane, and pentane) The volume percentage of a component of LPG is shown in the table (3.2). Analysis of LPG components provided from Hilla Gas plant.

Table (3.2) chemical compositions of LPG

Composition	C_2H_6	C_3H_8	C_4H_{10}	C_5H_{12}
Volumetric fractions %by volume	0.95	66.01	32.42	0.62

The general from of combustion equation

$\sum\ XIC_{ni}H_{mi} + \left[\frac{x}{\emptyset}\right](O_2 + 3.76\ N_2) \rightarrow e_2H_2O + e_1CO_2 + e_3CO + BO_2 + e_4\ N_2$ (3.1)

While: -

$\sum X_I C_{ni}H_{mi} = X_1C_2H_6 + X_2C_3H_8 + X_3C_4H_{10} + X_4C_5H_{12}$

Where: -

$\emptyset$: equivalence ratio

e_2 : NO .of moles of H_2O in prod

e_1: NO. of moles of CO_2 in prod

e_3: NO. of moles of CO in prod

e_4: NO. of moles of N_2 in prod

B: NO. of moles of O_2 in prod

$\left[\frac{x}{\emptyset}\right]$: NO. of moles of O_2 in react

AND

n_i : Equivalent NO. of Carbon atoms $= 3.327$

m_i : Equivalent NO. of Hydrogen atoms $= 8.6542$

Over all equivalence ratio for duel fuel calculated using the equation [5]

$$Ø = F/A/(F/A)_{st} \tag{3.2}$$

Daltons Law of partial pressure indicates that the ratio of the partial pressure of the fuel and the air is equal to their molar ratio: -

$$P_f = \frac{n_f}{n_f + n_{air}} P_{mix} \tag{3.3a}$$

For per unit mole of fuel

$$P_f = \frac{1}{1 + (4.76 * x)} P_{mix} \tag{3.3b}$$

For a non-stoichiometric mixture, this is modified to

$$P_f = \frac{1}{1 + \left(\frac{4.76 \times x}{\phi}\right)} P_{mix} \tag{3.3c}$$

3.13 Stoichiometric Mixture Ø = 1

Ideal combustion, where fuel is ideally burned as equal combustion, full combustion is the burning of the air and fuel mass ratio leading to full fuel combustion. Stoichiometric Combustion for LPG gives: -

$$e_1 = \sum Xi\boldsymbol{n}_i \tag{3.4a}$$

$$e_2 = \frac{\sum Ami}{2} \tag{3.4b}$$

$$e_3 = 0 \tag{3.4c}$$

$$e_4 = 3.76 \frac{x}{Ø} \tag{3.4d}$$

$$B = 0 \quad (3.4e)$$

$$\mathrm{X} = \mathrm{e}_1 + 0.5\mathrm{e}_2 \quad (3.4f)$$

3.14 Rich mixture Ø >1

The rich mixture occurs when the amount of air available is lower than the amount of equal measurement, which means that there is not enough air to burn all available fuel the oxygen, hydrogen, carbon, nitrogen,

$$e_1 = 3\frac{\mathrm{B}}{\emptyset} - \sum \mathrm{a}\left(n\mathrm{i} + \frac{m1}{2}\right) \quad (3.5a)$$

$$\mathbf{e}_2 = \frac{\sum aim\mathrm{i}}{2} \quad (3.5b)$$

$$e_3 = 2\frac{x}{\emptyset} - e_2 - 2e_1 \quad (3.5c)$$

$$e_4 = 3.76\frac{x}{\emptyset} \quad (3.5d)$$

$$B = 0 \quad (3.5e)$$

$$\mathrm{X} = \mathrm{e}_1 + 0.5\mathrm{e}_2 \quad (3.5f)$$

3.15 Lean Mixture Ø <1

The fat-free mixture is an excess air available in this survey, where the dynamics of interaction and separation are neglected. The excess air passes the process without combustion. However, although it does not interact chemically, it mainlyaffects the combustion process because it falls temperature to its ability to absorbenergy.

$$\mathrm{e}_1 = \sum ain_{\mathrm{i}} \quad (3.6a)$$

$$\mathrm{e}_2 = \frac{\sum aim\mathrm{i}}{2} \quad (3.6b)$$

$$\mathrm{e}_3 = 0 \quad (3.6c)$$

$$\mathrm{e}_4 = 3.76\frac{x}{\emptyset} \quad (3.6d)$$

$$X = e_1 + 0.5e_2 \qquad (3.6e)$$

$$B = X * (1/\emptyset - 1) \qquad (3.6f)$$

3.16 Density ratio calculations

The intensity of the burning mixture to the non-burn mixture density was recognized at the density calculated assuming the temperature constant equilibrium of burning gases**.**

$$\rho = \rho_b / \rho_u \qquad (3.7)$$

ρ: density ratio

$\rho_{b:}$ density burned gasses

ρ_u: density un burned gasses

the equation (4.8) get from applying ideal gas law for initial and final state to get.

$$P_i = \rho_u R T_i \qquad (3.8)$$

$$R = R_\circ / M_w \qquad ..(3.9)$$

R: specific gas constant from equations (4.9) , 4.10) then

$$(\rho_u)_I = P^* M_w / R_\circ T \qquad .. (3.10)$$

The unburned gasses density is computed by using the following equation that is derived from Dalton Law

$$\rho_u = X_{air} . \rho_{air} + X_{fuel} . \rho_{fuel} \qquad ..(3.11)$$

X: the mole fraction of each component

3.17 Flame Speed Analysis

The values of the flame radius (r) as a time function of each run are obtained from the data obtained from the images using a software (Tracker version 4.87)

$$S_n = \left.\frac{dr}{dt}\right|_{(j+1/2)} = \frac{r_{j+1} - r_j}{t_{j+1} - t_j} \qquad \ldots(3.12)$$

The radius corresponding to this speed is taken to be the mean radius,

$$r_{(j+1/2)} = \frac{r_{j+1} + r_j}{2} \qquad \ldots(3.13)$$

$$S_n = \frac{dr}{dt} = \frac{\left((r_{i,j+n+1} - r_{i,j+n+2}) + (r_{i,j-n-1} - r_{i,j-n-2}) + (r_{i+n+1,j} - r_{i+n+2,j}) + (r_{i-n-1,j} - r_{i-n-2,j})\right)/4}{t_{j+1} - t_j} \qquad ..(3.14)$$

3.18 laminar burning velocity

The un- stretched laminar burning velocity, U_b is related to S_l through the mass conservation across the flame front.

$$A\,\rho_b\,S_l = A\,\rho_u\,U_b \qquad (3.15)$$

Where A is the flame front area

ρ_u & ρ_b are the unburned and burned gas densities, respectively.

The un-stretched laminar burning velocity can be obtained from equation (3.16)**[30]**:-

$$U_b = S_l\,\frac{\rho_b}{\rho_u} \qquad (3.16)$$

CHAPTER FOUR

Results And Discussion

Chapter Four: Results and Discussion

4.1 Introduction

In this results present the experimental readings data of the flame speed and burning velocity when concentration is (100% LPG) for combustion in chamber of constant volume which used in experimental test with various equivalence ratio and at different pressure. The results included all effect of variable pressure and variable equivalence ratio on burning velocity. Also, presentation and analysis the radius time of flame combustion. The experimental results will be validated and discussed with others researchers.

4.2 The Effect of Pressure on the Burning Velocity

Figure (4-1) shows the effect of the pressure on the burning velocity with variable equivalence ratio, when the equivalence ratio (Ø) increase the burning velocity increased till (Ø) equal 1.1 after that the burning velocity decreased gradually. The reasons of that the value of (Ø) is stoichiometric or near stoichiometric, that is mean it has enough oxygen to lead a complete combustion.

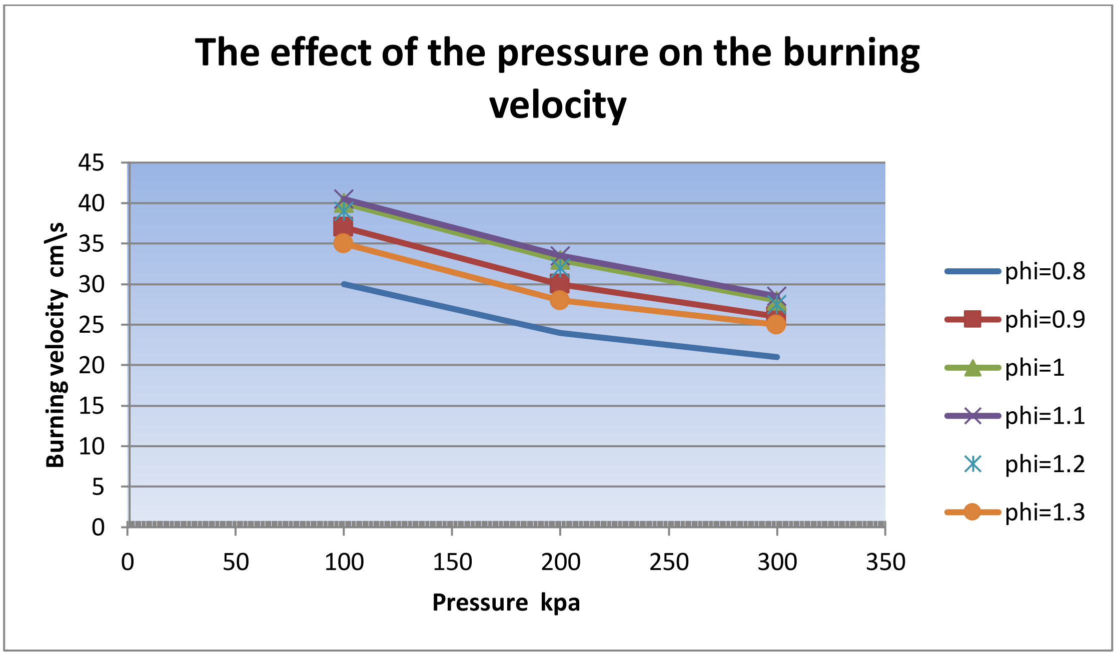


Figure (4-1) the effect of the pressure on the burning velocity with variable equivalence ratio.

4.3 The effect of equivalence ratio(Ø) on the burning velocity with variable pressure

Figure (4-2) shows the effect of equivalence ratio on the burning velocity with variable pressure. When the pressure decreases the burning velocity increases, it is found the maximum burning velocity at 100 KPa because the increasing of pressure prevents some of oxygen to participate in the combustion. Also the increasing of pressure prevents the mixture to move fast that make the burning velocity a bit slow.

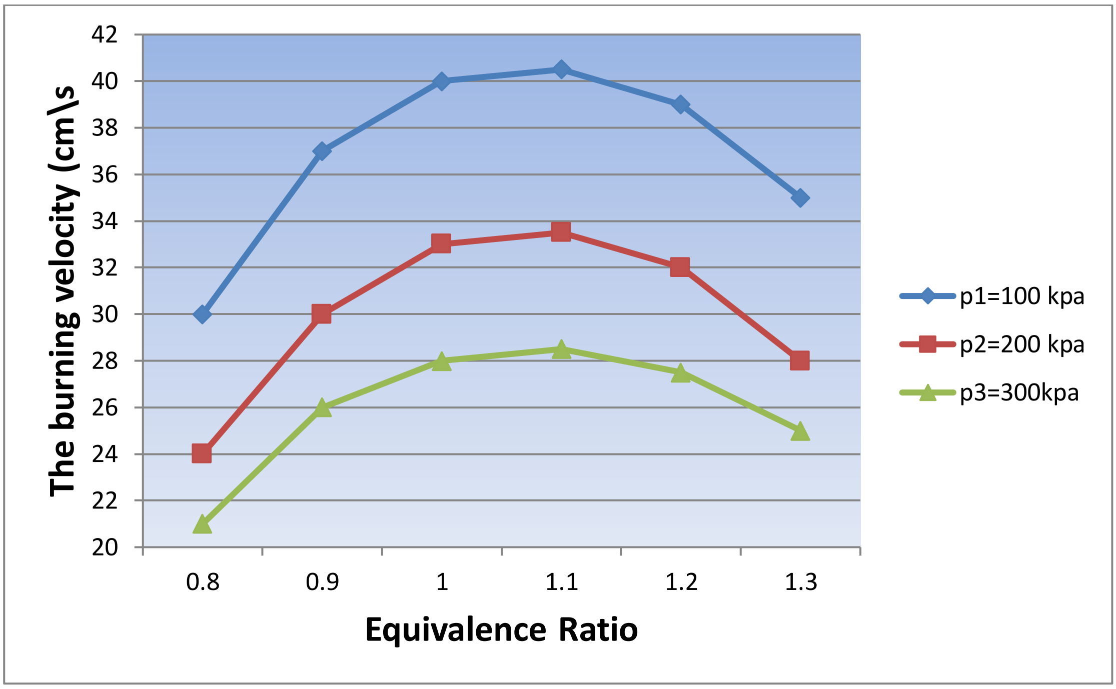


Figure (4-2) the effect of the equivalence ratio on the burning velocity with variable pressure

4.4 The effect of radius of flame (r) on time with variable pressure.

Fig (4-3) shows the effect of the radius of the flame on the time with variable pressure, when the radius of the flame increases that is mean it will take more time to find the oxygen as well as when the radius decrease that is mean there is enough oxygen and take short time.

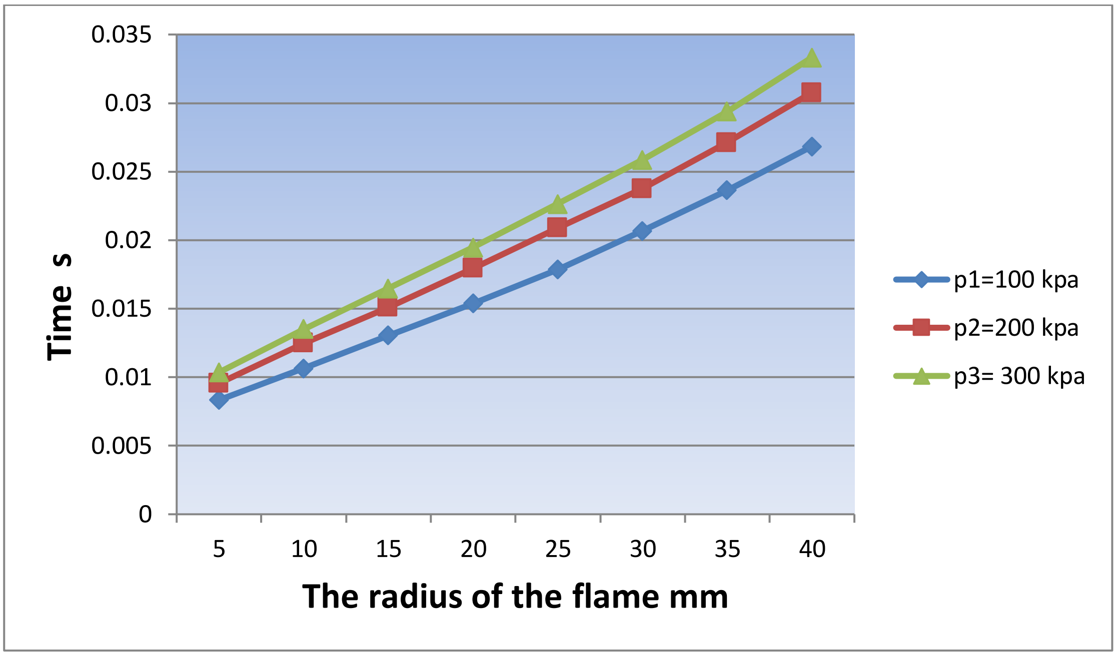


Figure (4-3) the effect of the equivalence ratio on the burning velocity with variable pressure

4.5 The effect of flame radius (r) on flame speed (Sn) with variable pressure.

Figure (4-4) represents the effect radius of flame on Speed of flame with a variable values of pressure. When the pressure decreases the flame speed increases, it is found the maximum flame speed at 100 KPa because the increasing of pressure prevents some of oxygen to participate in the combustion. Also the increasing of pressure prevents the mixture to move fast that make the flame speed slow and restricted.

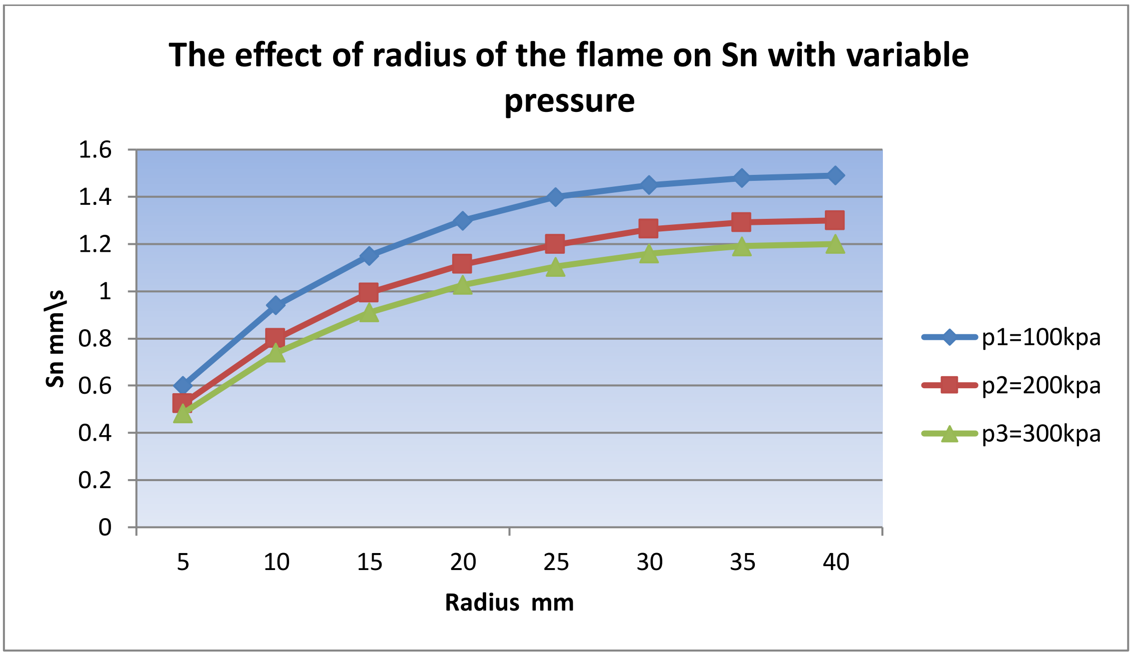


Figure (4-4) the effect of the equivalence ratio on the burning velocity with variable pressure

4.6 Comparison between Present work and Previous works

In this present work, we use Iraqi Liquefied Petroleum Gas (ILPG) and we have got this results at variable pressure (100 to 300) KPa of the effect of equivalence ratio on the burning velocity. When the pressure decreases the burning velocity increases, it is found the maximum burning velocity at 100 KPa because the increasing of pressure prevents some of oxygen to participate in the combustion. Also the increasing of pressure prevents the mixture to move fast that make the burning velocity a bit slow. In this **[39]** used LPG at first and then mixed with percentage of Hydrogen (H_2) for increasing the Burning velocity because H_2 is very fast and also the density is very low and has a lot of energy ,when mixing a 20% H_2 the burning velocity increased from ILPG case and more in 40% H_2 and 60%, reach to maximum burning velocity at 80% H_2. It clear when using ILPG get a combustion desirable and burning velocity acceptable, but when using H_2 percentage increased led to increase the burning velocity of flame. Also, this is an undesirable case because the burning velocity is very high lead to combustion is very fast not within the required ranges.

Figure (4-5) observed that the behavior of variable pressure with burning velocity of using ILPG is same of behavior of present work when pressure increased the burning velocity decreased with variable equivalence ratio (0.8, 0.9,1,1.1,1.2,1.3) for the ILPG, when the equivalence ratio (Ø) increase the burning velocity increased till (Ø) equal 1.1 after that the burning velocity decreased gradually. The reasons of that the value of (Ø) is stoichiometric or near stoichiometric, that is mean it has enough oxygen to lead a complete combustion. In the **[39]** observed whenever increasing in pressure for pressure range (1 to 3) bar, the drop in burning velocity is more sharply. Because high pressure do not allow quantities of Oxygen with contributing in the combustion process. The deviation between these curves, it return to initial pressure values ranges of these studies of (1 to 3) bar and (100 to 300) KPa for **[39]** and present work respectively .Finally, we have a good agreement with results of **[39]** .

In order to present an example of the flame propagation video recording, Fig. (4.5) shows a sequence of frames of an expanding spherical flame with a different stoichiometry lean mixture at different time.

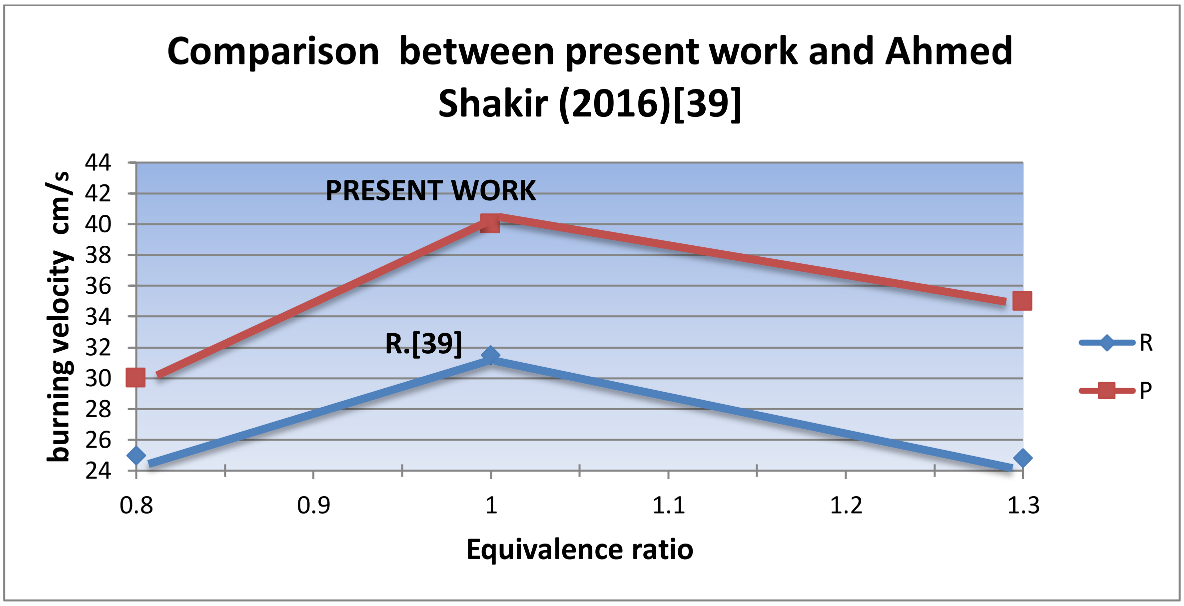


Figure (4.5) the comparison of present work and Ahmed Shakir (2016) [39]

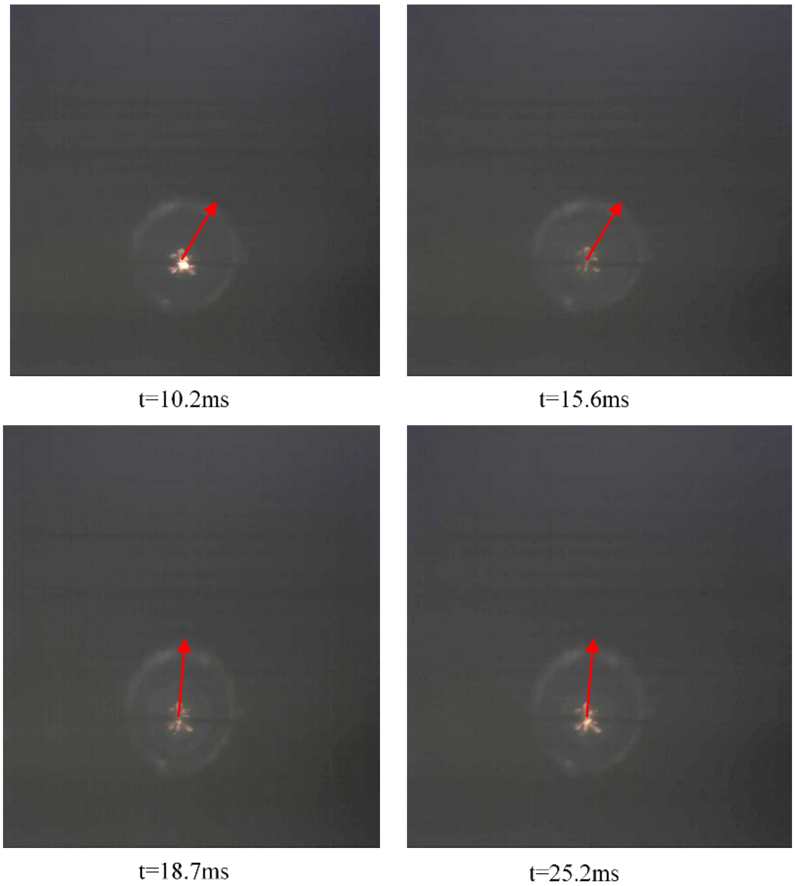


Figure (4.6) Photographs of Flame Propagation at: lean mixture

Chapter Five

Conclusions and Suggestions for Future Work

Chapter Five: Conclusions and recommendations

5.1 Conclusions

The following conclusions have been obtained from the experimental results of the present work:

1- Increasing of equivalence ratio on the burning velocity with variable pressure. When the pressure decreases the burning velocity increases, it is found the maximum burning velocity at 100 KPa because the increasing of pressure prevents some of oxygen to participate in the combustion. Also the increasing of pressure prevents the mixture to move fast that make the burning velocity a bit slow.

2- The increasing in pressure on the burning velocity with variable equivalence ratio, when the equivalence ratio (Ø) increase the burning velocity increased till (Ø) equal 1.1 after that the burning velocity decreased gradually. The reasons of that the value of (Ø) is stoichiometric or near stoichiometric, that is mean it has enough oxygen to lead a complete combustion. Maximum adiabatic flame temperature for pure gasoline, duel fuel mixtures and triple fuel mixtures occurs at stoichiometric combustion.

3- The effect of the radius of the flame on the time with variable pressure, when the radius of the flame increases that is mean it will take more time to find the oxygen as well as when the radius decrease that is mean there is enough oxygen and take short time.

4- The radius of flame on Speed of flame with a variable values of pressure. When the pressure decreases the flame speed increases, it is found the maximum flame speed at 100 KPa because the increasing of pressure prevents some of oxygen to participate in the combustion. Also the increasing of pressure prevents the mixture to move fast that make the flame speed slow and restricted.

5.2 Suggestions

The following suggestions are put forward for future works:

1- The experimental rig can be used for further work to study the laminar flame speed and burning velocity for other types of liquid fuels with another different equivalence ratios and pressure.

2- Studying the effect of initial temperature on the laminar flame speed and burning velocity for temperatures higher than the atmospheric conditions.

3- Extending the theoretical part to study the laminar flame speed of theoretically.

4- Modifying ignition unit to study the effect of ignition energy and spark gap.

5- Replacing the Schlieren photography system with Z-type Schlieren photography.

6- Two high-speed cameras can be taken to perform the capturing measurements.

7- Flame temperature can be experimentally measured by using special temperature sensor for this purpose.

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الخلاصة

تم اجراء دراسة عملية لسرعة اللهب وسرعة الاحتراق الطباقية لخليط غاز البترول المسال العراقي والهواء المسبق الخلط باستخدام حجرة احتراق ثابتة الحجم مع اشعال مركزي عند ضغوط ابتدائية (١٠٠،٢٠٠،٣٠٠) كيلو باسكال ودرجة حرارة ابتدائية (٢٩٨) كلفن بالاضافة الى نسب تكافؤ مختلفة من (٠,٨- ١,٣) .

تم تصميم وانشاء حجرة احتراق ذات شكل اسطواني مغلقة من الطرفين لغرض اداء هذه التجربة مصنوعة من الفولاذ المقاوم للصدأ لمقاومة الظروف الخارجية , القطر الداخلي لها (٣٩٥) ملم وطولها (٤٠٠) ملم وحجم حجرة الاحتراق (٠,٠٤٨٩٩) م٣ . واستخدمت منظومة اشعال ومنظومة شيليرن للتصوير باستخدام كاميرا عالية السرعة لقياس سرعة اللهب الطباقي للهب المسبق الخلط لوقود غاز البترول المسال العراقي .

اثبتت النتائج التجريبية ان سرعة اللهب الطباقية تزداد عند انخفاض الضغط حيث تصل قيمتها حوالي (١,٤٩) سم/ثا عند ضغط 1 بار ونصف قطر لهب (٤٠) ملم وذلك لانه بزيادة الضغط تزداد الكثافة وتزداد مقاومة الخليط غير المحترق لنشر اللهب فتنخفض السرعة بينما تنخفض سرعة اللهب كلما ازداد الضغط حيث تصل حوال (٠,٦) سم /ثا عند نصف قطر اللهب (٥) ملم. بالنسبة لسرعة الاحتراق فانها تزداد بزيادة نسبة التكافؤ (Ø) لخليط غاز البترول المسال والهواء حتى تصل الى ١,١ =Ø حيث تصل اعلى قيمة لسرعة الاحتراق عند ضغط 1 بار حوالي (٤٠,٥) سم/ ثا بعدها تنخفض سرعة الاحتراق والسبب يعود الى وصول للحالة المكافئة هذا يعني ان هناك اوكسجين كافي يقود الى اكتمال الاحتراق.

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سرعة اللهب لخليط غاز البترول المسال العراقي / الهواء المخلوط مسبقًا

بحث
مقدمة إلى كلية الهندسة – جامعة بابل وهي جزء من متطلبات نيل درجة الدبلوم العالي في الهندسة / الهندسة الميكانيكية/ وقود وطاقة

أعدت من قبل
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