Experimental study of flame propagation and stability of (ILPG)

Mustafa Abdullah Saleh*, Fouad Saleh Alwan

Department of Mechanical Engineering, College of Engineering, Mustansiriyah University, Baghdad, Iraq

*mustafaal_mohandes89@yahoo.com

Abstract. The Study of the premixed and vertical flow makes a special significance in industrial burners design and application of industrial stoves. It included a laboratory study of the flame propagation and stability of liquid petroleum gas (LPG) for a vertical burner of different diameters and a study of the effect of isolating the flame from the external environment by an inert gas which is nitrogen gas. It also included a new experimental and numerical simulation to understand the effect of using inert Nitrogen gas (Nitrogen jacket) on properties of flame propagation in Vertical burner. Accordingly, the test device was modified. The necessary measuring devices were added. It was equipped with an internal nitrogen gas isolation system to determine the properties of the previously mixed vertical flame stability. The experimental combustion tests have been done by using (LPG) under Laboratory conditions (Tu = 298 K, Pu = 1 atm), with high range of air to fuel mixing ratio. The percentage of the maximum value for premixed flame burning velocity between (without N2 and with N2) for burner diameters (9,13,16 mm) were (3.4%,6.02%,2.99%) respectively

1. Introduction

The Combustion process play a vital role for human life since knowing fuel, in the ancient time human used fuel to obtain useful heat. Combustion is defined as fast oxidation accompanied by the generation of thermal energy with the emission of light most of the time or a slow oxidation accompanied by the generation of relatively little heat energy with emission of light Turn 1996 [1]. Worldwide industry growth created combustion for the past 200 years where industries and their processes require immensely the process of combustion. Granting to IEA (International Energy Agency) [2], 88% of energy developed by burning fossil fuels such as petroleum, natural gas. Meantime, combustion considers source of the emissions of NOx, CO2, soot, and so on, which harmful to human and climate [3].

LPG is mainly of 60% propane and 40% butane. It being one of the principle vitality sources utilized for local and business applications, it clean and efficient energy source which is readily available to consumers around the world. points of interest, for example:
1. High heating value about (LHV=46.1 MJ/kg) compared with 42.5 MJ/kg for diesel fuel and 43.5 MJ/kg for gasoline fuel while the high heating value is (HHV=50.1 MJ/kg).
2. The virtual lack of sulfur, which results in cleaner burning with low ash.
3. As LPG burns in the engine in the gaseous process, lower corrosion and engine wear than is seen with gasoline.
4. Stable flame and low processing cost. Flame is a burning glowing mixture. Flame front is the surface or area of the raped chemical reaction and it represent the separate limit between the burning and the non-burning of the fuel –air mixture. Flame either be stationary or non-stationary. In the stationary flame the velocity of the flame propagation is equal to the velocity of the combustion mixture flow, in which the velocity of flame will become equal to zero [4].

The stability of a flame is important while studying stable flame by the burner, this concept can be perceived by guessing the flash back and blow off, which well determine the extent of the burner operation between these limits [5]. Flames can be described as a self-sustaining chemical reaction [6]. It can be divided in to two regions according to the thermal distribution, preheat zone and reaction zone. The increase in temperature is concave upwards, so each factor functions as a heat sink in this area. Increase the effects in the expansion and acceleration of unburned gas. No major chemical reactions are occurring in this field [7].

The effect of Nitrogen jacket on combustion is a technology use pure nitrogen supplied from commercially available 99% pure nitrogen cylinder. The effect of N_2 jacket on the flammability limits investigated by surround the LPG–air mixture with nitrogen gas [8][9]. The importance of studying the stability and flame propagation of (LPG)in the field of energy and industries dependent on them, so in this study briefly review the research related to this field. Vagelopoulos, C. M., &Egolfopoulos, F. N. (1998) [10] introduced an experimental study of measurement of Laminar Burning Velocity of Methane-Air Mixtures Using a Slot and Vertical Burner.

The maximum burning velocity prevailed when the equivalence ratio is nearly equal to (1) where the fuel and air mixture is equal to the stoichiometric conditions. Thus, there is complete combustion that maximizes the temperature of the flame in turn. Flame temperature and burning velocity are closely related, so the flame should have the highest possible burning velocity at = 1.D.P. Mishra,2006 [11 ] Experimentally used vertical burners with two separate port diameters, (12,15) mm, the flame stability limits of CNG-air premixed flame are used to describe the blow off and flashback limits of CNG-air premixed flames. Stability plots for burners with two separate port diameters have been developed, which can be used for the design and production of CNG air combustion systems. Natarajan J, et al. 2007 [12] studied and measured the Laminar flame speeds for (syngas) compositions.

Two measurement approaches were employed: one using flame area images of a conical Vertical flame and the other based on velocity profile measurements in a one-dimensional stagnation flame. Hugo J. Burbano.et.al.2010[13] Studied the laminar burning velocities of H2/CO/air mixtures and equimolar H2/CO mixtures diluted with N2 and CO2 up to 60% and 20% by volume, respectively, at different equivalence ratios. Flames were generated using contoured vertical burners and Schlieren images were used to determine the laminar burning velocity with the angle method. Bouvet N., et al. 2011 [14] Laminar flame speeds of syngas/air mixtures have been studied using the vertical flame burner and the flame surface area methodology at atmospheric pressure and ambient temperature. The flame surface area and flame cone angle methodologies, respectively based on Schlieren imaging techniques, have been performed to extract flame speeds for a wide range of equivalence ratios (0.3 < Φ < 1.2) and mixture compositions (1% < %H2 < 100%). He, Y., et al.2012 [15] Investigation of laminar flame speeds of typical syngas using laser based vertical burner method and kinetic simulation. laminar flame speeds of typical syngas with different H2 contents were studied using both experimental measurements and kinetic simulations. Measurements were carried out using the Vertical method.

HS Zhen, et.al.2014 [16] Studied and investigated the Characterization of biogas-hydrogen premixed flames using vertical burner. The burner used in this study is of Vertical-type, consisting of a single copper tube, which is sufficiently long for establishing fully developed flow at the tube exit. Souflas K., et al. 2015 [17] Studied of vertical flame technique for measuring flame speeds of methane/air and propane/air mixtures was carried out using experiments and direct numerical simulations. Two common techniques, the angle method and the area method were utilized to extract the flame speed. Hu, S., et al. 2017[18] Studied and investigated of laminar flame speed of premixed
flames as determined using a vertical burner. Laminar methane/air premixed flames at different pressures in a newly developed high-pressure, Vertical flame rig are studied using detailed numerical simulations and laser diagnostics. V.Margos.2019[19] Laminar burning velocity calculations of DNG with hydrogen addition have been studied. With the Vertical burner process, experimental calculations were conducted. To achieve the laminar burning velocity, two experimental methodologies were applied. The first is by using the process of mass conservation, by capturing the OH * chemiluminescence flame front. The second method is to grab the whole PIV velocity region and then apply the semi-cone angle method.

Naive Bayes (NB) is a Bayes-oriented learning method that is very useful for learning involving high-dimensional data[1]–[3], such as text classification[1], [4]–[6], Searching[7]–[10] and web mining[11]. In general, the Bayesian classification method has a conditional dependency between random variables. This problem is often called the independent assumption of attribute which assumes all independent attributes so that the effect is time consuming because it examines the relationship between all random variables in which this task is a combinatorial optimization task[1]. Alternatively, the NB relaxes the restriction of the dependency structure between attributes by simply assuming that attributes are independent by class labeling. Consequently, examining relationships between attributes is no longer necessary and derivation of NB methods can be linearly measured by training data.

Many data sets are used to solve the problem of NB attribute independence attributes, different methods and frameworks[12]–[14], so a thorough overview of the assumptions of independent attribute solutions is necessary. This literature review aims to identify and analyze the research trends, data sets, methods and frameworks used in the study of attribute independent assumptions on NB between 2010 and 2017.

2. Methodology

Device in this work generally consists of a group of systems. It consists of the following units: - 1. Combustion System unit: - Combustion system through which initialize the Vertical flame front which consists of a) Valves and Regulators to Control the flow (b) Flowmeters for Air and Fuel c) Flame Temperature Measuring Unit (d) Nitrogen Supply Unit 2. Schlieren Optical unit (a) The Light Source (b) Expanding Set of the Beam (c) Focusing Set of the beam 3. Recording and filming unit for combustion phenomenon which the Schlieren photos are recorded. Figure (1) shows the photographic picture of Experimental Test Rig with all Unit.

This paper will use the SLR approach to review research on the Naïve Bayes algorithm with the problem of attribute independence assumptions. Systematic Literature Review (SLR) is a process for identifying, assessing, and interpreting all available research with a view to providing answers to specific RQs[15]. In the guide that Kitchenham has made in 2007[15], the literature review will be compiled based on the Systematic Literature Review.

![Figure 1. Experimental Test Rig with all Units and Test section](image-url)
Figure 2. Photograph of the Experimental Test-Rig

The burner Tube (Test section) is a model of three copper burner tube have been designed. Burners diameters are (9, 13,16) mm. A normal burner length was chosen based on the conventional (50*d) in order to ensure that a fully-developed laminar flow is achieved at the burner rim for each case. The choice of such a pipes plays an essential role in determining flame stability. At the same time Reynold’s number is a value less than the critical value of the limner flow which is within (Re<2300) limits, while the length of the pipe secondary role in operation of the burner where the length used to achieve a complete laminar flow which in turn is necessary to guess the limits of stability flame accurately[20].

The mechanism for surrounding the vertical burner with Nitrogen gas(Nitrogen jacket) , required technician to design a new part to be installed on the tube burner at its upper end at of burner .This design consists of an open cylinder from the top and inter the burner tube from the bottom so that the burner orifice is same level as the cylinder orifice for Nitrogen the outer diameter of this cylinder (96mm) the height of this cylinder is(62mm) made of stainless steel the base on which a tube burned from the bottom gives homogeneous flow the diameters of the hole at the Nitrogen exit area are (2,3,4,5,6) mm respectively.

3. Experimental Procedure And Calculation

The mixture preparation process plays an important role in accurately measuring the flame propagation velocity by maximizing operating conditions (0.6<Ø<1.6) approximately, determination of mixing ratios that include the best performance of the burner when operation with diameters (9,13,16 mm), for mixture (ILPG) with air this method was performed by following steps:

1. System operation (Air-Fuel): - this includes operating the fuel (LPG)system and it is controlled by a valve that opens and closes manually, then the air blower is also operated and controlled by a valve on the (Air-Fuel) flowmeter board.

2. A volume of air and fuel flow is taken, which it measured by (L/S) with an assurance that the indicator of flowmeter is stable and not fluctuated while taking the reading and the indicator is fixed for period of time to ensure the correct reading is taken

3. Ignition of (Air-fuel) mixture: this is done by an external source of ignite (lighter) then leave the mixture to ignite for period of time until the flame stabilize.

4. Instil the camera at fixed location for all cases and at fixed distance from imagine board.
5. Tacking a picture of flame trace on a white board fixed in front of the flame, this procedure done with help of Schlieren optical system to obtain high-resolution image of flame shape.
6. Repeat the same previous steps and take different values of air and fuel volumetric a mount (Vf) volumetric of fuel and (Va) volumetric of air.
7. Repeat the previous step above using different diameters of the burner.
8. Repeat the previous steps that were previously done with the addition and use of the Nitrogen system as insulator gas. To find the experimental data and to obtain results showing properties of flame in Vertical burner. Below showing equations used to find experimental results.

3.1 Equivalent ratio

\[ \Phi = \frac{(A/F)_{stoic}}{(A/F)_{act}} \]  

Where (A/F) stoic is air to fuel ratio at stoichiometric by volume and (A/F) act : is air to fuel ratio at actual by volume it can be evaluate (A/F) stoic by stoichiometric equation of fuel liquid petroleum (LPG)as follow:

\[ C_{x}H_{y} + a(O_{2} + 3.76N_{2}) \rightarrow xCO_{2} + \frac{y}{2} H_{2}O + 3.76N_{2} \]  

\[ (A/F)_{a} = \frac{m_{a}}{m_{f}} \]  

\[ \alpha = \frac{x}{y} \]  

For Stoichiometry

\[ (A/F)_{s} = 4.76 * a * \frac{M_{a}}{M_{f}} \]  

\[ \rho_{a} = \frac{p}{RT} \]  

\[ m_{f} = \rho_{f} * Q_{f} \]  

\[ m_{a} = \rho_{a} * \sigma_{a} * A_{a} \]  

\[ Q_{a} = U_{a} * \sigma_{a} \]  

\[ a_{mix} = s_{a} + s_{f} \]  

\[ \rho_{mix} = \rho_{mix} \cdot Q \]  

3.2 Renolds number of mixture

\[ R_{emix} = \frac{\rho_{mix} \cdot U \cdot D}{\mu \cdot mix} \]  

Where : D = diameter of tube

D = 9, 13, 16 mm

3.3 Density of mixture

\[ \rho_{mix} = \rho_{air} \% \ air + \rho_{fuel} \% \ fuel \]  

\[ Q_{mix} = \rho_{mix} \cdot A_{flame} \]  

\[ \mu_{mix} = \mu_{air} \% \ air + \mu_{f} \% \ fuel \]  

\[ Q_{mix} = \frac{m_{mix}}{\rho_{mix}} \]  

The purity of the gas fuel used has a key role in the accuracy of determining the equivalent ratio , the purity of (ILPG) was(98,42)% according to refinder laboratories (AL-Doura) Baghdad. The components (ILPG) (Ethane (C2H6) 3.3%, Propane (C3H8) 57.08%, Isobutene (C4H10) 16.45%, n-Butane 21.93% ,Iso.pentane (C5H12) 1,24%). It was found that the gas behaves between propane and butane (C3.375H8.75) ,as a result of the largest proportion of this fuel consist of propane and butane.
4. Result and Discussion

Through figures (2,3,4,5,6,7), it can be noted that the schematic charts of the premixed flame stability with different diameters (9,13,16) mm, and using Nitrogen gas to isolate the flame front from the outside. Where the dark blue line represents the stoichiometric line at ratio ($\phi = 1.07$), and the area of red represents the lean flame area, but if the amount of air increases, the flame will be extinguished. The black zone represents the rich flame area, but if increasing amount of fuel leads to the instability of the flame (separation and distortion of flame). It is observed through the figures using the diameter of burner (9) mm that give the largest stability limits area to work vertical burners, the reason is due to the diffuse and mixing of the reactors.

The stability of the flame depends on the efficiency of the pre-mixing. Also noticed that the use of Nitrogen increase the area of stability of flame between (rich line and lean line). So the stability range of the flame with nitrogen increased. The increasing in stability range of flame is due to the Nitrogen shell which will prevent the participation of the external air in the interaction with the front flame.

![Figure 3. Stability Limits of premixed vertical Flame at (D=9 mm), (without N2)](image)

![Figure 4. Stability Limits of premixed vertical Flame at (D=9 mm), (with N2)](image)

![Figure 5. Stability Limits of premixed vertical Flame at (D=13 mm), (with N2)](image)
Figures (8, 9, 10) illustrate the effect of burner diameters (9, 13, 16) mm (with and without Nitrogen) on the flame burning velocity for premixed Vertical burners. It was found that burner diameter of (9) mm is giving a highest value of the burning velocity, while burner diameter of (16) mm is giving a lowest value of the burning velocity. Also there is effect of equivalent ratio on the laminar burning velocity, the burning velocity is increased with increasing the equivalent ratio on the lean limit of the mixture unit it reaches at (ϕ = 1.07). Then it starts to decrease with increase in the rich limits. From the observation of the images of schlieren cone, it is clear that the maximum burning velocity is at the smallest surface area of the flame decreasing by the equivalent ratio in the lean limits and then increases in the rich limits.
Figure 9. Burning velocity of premixed Vertical Flame at (D=13 mm), (with and without N2)

Figure 10. Burning velocity of premixed Vertical Flame at (D=16 mm), (with and without N2)

This change in the burning velocity is the result of a change in the flame temperature, and this confirms that increasing the flame temperature with equivalent ratio in the lean side of the mixture leads to an increase in the rate of the chemical reaction, thus an increase in the burning velocity. The percentage of increase the maximum value for premixed flame burning velocity between (without N2 and with N2) for burner diameters (9,13,16 mm) were (3.4%, 6.02%, 2.99%) respectively.

5. Conclusion
1. A wider field of (stability of flame) was obtained that gives the largest area to use premixed Vertical burners (with N2) at different burner diameters (D= 9, 13, and 16 mm), The increasing of burner operation area gets stability of flame front, due to use of nitrogen, which prevents the participation of the external air in the interaction with the front flame.
2. The burner diameter represents great role in the mechanism of flame stability, because it is the main cause behind increasing the efficiency of per-mixing process between air and fuel.
3. The values of highest premixed flame burning velocity for burner diameters (9,13,16mm) at equivalence ratio Φ=1.07 were (29.1, 26.6, 25.9) (cm/s) (with outN2) respectively. While the highest premixed flame burning velocity for burner diameters (9,13,16mm) at equivalence ratio Φ=1.07 were (30.1, 28.2, 26.7)(cm/s) at burner diameters (9,13,16) mm (with N2) respectively. The percentage of the maximum value for premixed flame burning velocity between (with and without N2) for burner diameters (9,13,16 mm) were (3.4%, 6.02%, 2.99%) respectively. that due
use Nitrogen gas as (Nitrogen jacket) leads to increase in burning velocity of premixed flame, because the Nitrogen gas work as insulator flame from surround and maintain the efficiency of the mixture (air and fuel) and prevents the air in outside environment from effecting on the reaction and combustion process.

### Table 1. Nomenclature

| Symbol | Description                                      | Unit(s)   |
|--------|--------------------------------------------------|-----------|
| A      | Cross section area                               | mm²       |
| Aa     | Cross section area of air tube                   | mm²       |
| Af     | Cross section area of fuel tube                  | mm²       |
| Amix   | Cross section area of mixture tube               | mm²       |
| (A/F)a | Actual air to fuel ratio                         | -         |
| (A/F)s | Stoichiometric air to fuel ratio                 | -         |
| D      | Diameter of tube                                 | mm        |
| m      | Mass flow rate                                   | Kg/s      |
| ma     | Mass flow rate of air tube                       | Kg/s      |
| mf     | Mass flow rate of fuel tube                      | Kg/s      |
| mₜₙₘ  | Mass flow rate of mixture (air and fuel)         | Kg/s      |
| ms     | Constant of fuel concentration                   | -         |
| N²     | Nitrogen gas                                     | -         |
| O²     | Oxygen                                           | -         |
| p      | Pressure                                         | atm.,(N/m²)|
| Qa     | Volumetric flow rate of air                      | L/S       |
| Qf     | Volumetric flow rate of fuel                     | L/S       |
| Qₘᵢₓ  | Volumetric flow rate of mixture gases            | L/S       |
| R      | Gas constant                                     | kJ/kg K   |
| Remix  | Reynolds number of mixture                       | -         |
| Su     | Burning velocity                                 | cm/sec    |
| T      | Flame temperature                                | K         |
| Ua     | Air velocity                                     | cm/sec    |
| Uf     | Fuel velocity                                    | cm/sec    |
| Umix   | Mixture gases velocity                           | cm/sec    |
| x      | Number of Carbon atoms                           | -         |

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