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EXPERIMENTAL INVESTIGATION ON EFFECT OF CHEMICAL COMPOSITION ON STABILITY OF FLAME

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Abstract: *Flame structure and stability is experimentally analyzed for the LPG-air (Liquid Petroleum Gas) mixture and Methane air mixture. A wide range of Φ is considered to study the effect on flame structure and burning velocity. The result shows that appearance of flame structure and stability is a mainly function of equivalence ratio and the flame overall height increases as equivalence ratio is increased beyond Φ= 1 to Φ=1.8.The effect of Re on the flame structure is studied for the range of 400 to 3200. The flame is laminar up to Re=1500 Beyond Re=1500 the flame becomes turbulent.The flame height increases with increase in the Re but there is no change in the flame structure.*

***Keywords**:* Premixed gas flames, Flame structure, Flame stability, Equivalence ratio and Reynolds number.

1.1 INTRODUCTION

Combustion is a chemical process that release heat. Numerical simulation of practical combustion problem requires study of chemically reacting flow. Study of chemically reacting flow requires detailed understanding of thermodynamics, chemical kinetics, fluid mechanics and transport phenomena.

In a premixed flame, fuel and the oxidizer are mixed at molecular level prior to occurrence of any significant chemical reaction. A flame is caused by self-sustaining propagation of a combustion zone which occupies a small portion of combustible mixture at any time. Combustion is governed by thermo-chemical parameters such as temperature, pressure and reactant concentration. Flame propagates through the reactive mixture at a characteristic velocity.

In a non-premixed flame, initially separated fuel and oxidizer mix at molecular level through convection and diffusion and form a mixing layer. Combustion occurs in the mixing layer. Combustion is governed by the rate of diffusion of reactants and then on chemical reaction rates, as time scale of reaction is shorter than time scale of diffusion.

Impinging jet flames are widely employed to achieve rapid or concentrated heating effects in heating, for example, the domestic gas stove or industrial furnace. Since the impinging jet flame heating is directly affected by the aerodynamic structure of the flame, the types of flame (premixed or diffusion), fuel-oxidizer *Φ* and *Re*.

Flame stability thus has been a significant design parameter of a domestic gas stove or other impinging flame burning facilities. Hence, the objective of the present study is to investigate the LPG-Air flames and Methane-air flames. Wide ranges of *Φ* are considered, and stability criteria are studied. The flame height variations, flame shape transformation and stability as influenced by the effects of inlet velocity of fuel concentration are investigated experimentally.

The experiment on round burner are previously done and we have the readings as well as the results. These readings and image results are taken to compare with the slot burner. In this experiment we are conducting the experiment on round as well as slot burner, the previously conducted readings are used to set the values for pressure readings in the manometer for both gas as well as air side, with these particular readings and values we can easily get the flame structure and could be captured in the camera. This procedure is carried for round as well as slot burner for same values of manometer readings so that comparison can be done easily. This experiment is carried for LPG gas and Methane gas.

1.2 Burners

The burner is the device used to combust the fuel, with an oxidizer to convert the chemical energy of the fuel into thermal energy. A given combustion system may have a single burner or many burners, depending on the size and type of the application. In this experiment we are using two types of burners through which the comparison on their flame structure for different gases is done and the predominant factor is given for both the burners. The first type is the round burner that is commercially used through out the world and the other is the slot burner which is idealized by us for this experiment.

The round burner is having a tip of circular cross section of 14mm diameter of the inlet of nozzle. The slot is created by using stainless steel and moulding it to required shape(14*4mm^2) and area. This slot is placed at the tip of burner so as to obtain the proper flame impingement.

Fig1.1: Top View of Slot burner

1.3Flame

Figure 1.3 shows the laminar premixed flame structure. A flame is a mixture of reacting gases and solids emitting visible, infrared, and sometimes ultraviolet light, the frequency spectrum of which depends on the chemical composition of the burning material and intermediate reaction product. A flame is a thermal wave in which rapid exothermic chemical reactions occur and which travels with subsonic velocities. Subsonic flame propagation is also termed as a deflagration wave. The combustion process in a flame is a combination of chemical reaction, heat transfer by conduction, convection, and radiation, mass transfer by diffusion, and flow pattern. The shape and size of flame is governed by all these factors (Sharma and Chander Mohan (1984)). Analysis of a flame can be quite complex. Coal and solid fuel flames are the most complex, followed in difficulty by liquid fuel flames, and finally gaseous fuel flames. The core of the flame consists of the fuel gas and air pushing steadily outwards in the "flame" shape until they reach the thin combustion zone. The hottest portion of the flame typically is in and immediately outside this zone, which is filled with the immediate products and partial-products of the chemical reaction known as combustion.

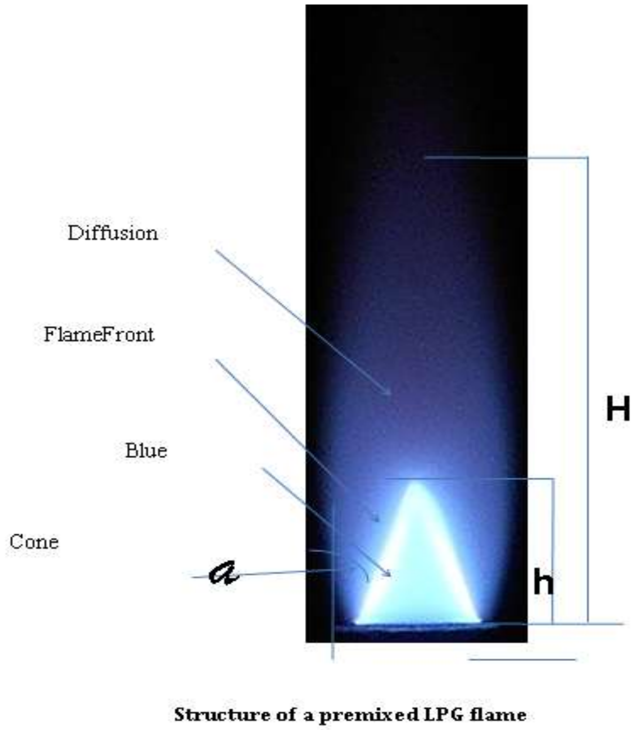


Fig 1.2: Laminar Premixed Flame Structure

H=Height of diffusion flame

h=Height of blue cone

ὰ=Oblique angle to the primary flow direction of the mixture (^{0})

1.4 Stable and Unstable Flames

There are several well-defined areas of operation for a burner that operates on gaseous fuels. The three regimes may be distinguished as follows:

a) Yellow Tipping

When the airflow to burner is prevented, the flame will have a yellow tip and may produce smoke. When the airflow is increased, yellow tip disappears and is replaced by a blue non-luminous flame.

b) Blow Off

When the airflow to burner is gradually increased with a constant gas flow, if sufficient gas flow exists, the yellow tipping will disappear and blue flame will be established. Further increase in airflow will result in the lifting of the flame around the surface of the burner. At this moment, the velocity of mixture leaving the burner approaches the mixture flame speed. If airflow is further increased, the flow velocity will exceed the flame speed and the flame will lift off and be extinguished.

c) Flash Back

With a low burner loading, when the airflow is increased, after observing yellow tipping and blue flame, flame will move down the tube to inlet part which means that flame speed exceeds the flow velocity. At this point when flame moves down the tube is called flash back.

2. LITERATURE REVIEW

2.1 Details of The Work Carried Out By Various Researchers Are Summarized Below

This chapter provides a brief background of various concepts that provide a basis for the ideas presented in this thesis. These papers describe different factors that affect the flame structure, stability and methodologies for stability enhancement.

1. Baukal Jr, C.E. and B. Gebhart,. Studied the heat transfer from oxygen-enhanced/natural gas flames impinging normal to a plane surface. It was the first study to investigate the range of oxidizer compositions between (Ω=0.21) and pure O_2 (Ω=1.00) and the heat flux from the flame to the plane surface increased by 78±280% by increasing the ring rate from 5 to 25 kW

2. Egolfopoulos *et al*. had investigated wall effects on the propagation and extinction of steady, strained, laminar premixed flames. They found that when highly strained, the flame is stabilized close to the wall and the values of the strain rate distribution inside the flame are reduced compared with an opposed jet flame.

3. Dong *et al.* used a premixed butane/air slot jet flame impinging on a horizontal rectangular plate to investigate heat transfer characteristics. They found that a cool central core of low heat flux values in the impinging flame was occurred under two conditions: one was in laminar flames (i.e. Re<1500), and the other was at small burner to plate distances H/d < 4. In addition, the cool central core became more evident when Re or H=d decreased.

4. Julie Buffam & Kevin Cox. studied the Measurement of Laminar Burning Velocity of Methane-Air Mixtures Using a "Slot and Bunsen Burner method". The gas flow rates are measured using a flow meter. In addition, the factors that influence the measurement of laminar burning velocity including equivalence ratio, geometry of the burner, and influence of flame stretch are also analysed. They given the conclusion that flame temperature and burning velocity are directly related, and therefore at ϕ=1 the flame should have its highest possible burning velocity.

5. S. Jerzembeck *et al*. worked on the Experimental and numerical investigation of Spherical flames of *n*-heptanes, iso-octane, PRF87 and gasoline/air mixtures are experimentally investigated to determine laminar burning velocities and Markstein lengths under engine-relevant conditions by using the constant volume bomb method. Data are obtained for an initial temperature of 373 K, equivalence ratios varying from ϕ= 0.7 to ϕ= 1.2, and initial pressures from 10 to 25 bar. To track the flame front in the vessel a dark field He–Ne laser Schlieren measurement technique and digital image processing were used.

6. Kazuhiro Yamamoto *et al* examined the Local flame structure and turbulent burning velocity by joint PLIF imaging by considering the degree of flame wrinkling; they used a cyclone–jet combust or to establish turbulent premixed flames for propane/air mixtures in a wide range of turbulence. The turbulent burning velocity determined by the mean flame shape is increased with turbulence, and the bending effect is observed in thin-reaction-zones regime, the bending is explainedby the reduction of local burning velocity.

7. D. Bradley was studied measurement of turbulent burning velocities in implosions at high pressures. A new technique is described for measuring turbulent burning velocities at higher pressures than is usual in "fan-stirred bomb explosions". Pressure records and schlieren high speed photography define the rate of burning and the smoothed area of the flame front, mixtures of ethanol–air and propane–air were investigated in the pressure range of 0.7–3.0 MPa with a corresponding temperature range of 377–468K.

8. S.P. Marshall, *et al* studied the laminar burning velocity measurements of liquid fuels at elevated pressures and temperatures with combustion residuals. They used the method of a "Constant volume vessel" (rated at 3.4 MPa) in conjunction with a multi-zone model to calculate burning velocity from pressure and schlieren data, allowing the user to select data uncorrupted by heat transfer or cellularity. n-Heptane, iso-octane, toluene, methyl benzene and ethanol were tested over a wide range of initial pressures (50,100,200and400kPa), temperatures (310,380and450K) and equivalence ratios (0.7–1.4), along with tests using combustion residuals at mole fractions of up to 0.3.

9. V. Ratna Kishore, *et al* were worked on Adiabatic laminar burning velocity and flame structures of H_2–CO–CO_2–air mixtures have been investigated experimentally and computationally. "Heat flux method" was used for the determination of adiabatic laminar burning velocity in their work. Chemkin PREMIX has been used for simulating freely propagating planar flames and commercial CFD software. Validation experiments were done for H_2(5%)–CO(95%)–air and H_2 (5%)–CO (45%)–CO_2 (50%)–air mixtures at various equivalence ratios and the results were in good agreement with published data in the literature. And they concluded the dilution with carbon dioxide to H_2-CO mixture reduces the burning velocity remarkably by reducing heat release, flame temperature and thermal diffusivity of the mixture.

10. Emilien Varea and Vincent Modica worked on the measurement of laminar burning velocity and Markstein length relative to fresh gases using a new post processing procedure: Application to laminar spherical flames for methane, ethanol and isooctane/air mixtures the purpose of this study is to present a new tool for extracting the laminar burning velocity in the case of spherically outward expanding flames. This new procedure makes it possible to determine the laminar burning velocity directly based on the flame displacement speed and the global fresh gas velocity near the preheat zone of the flame front.

11. Z.H. Wang, *et al* studied that the investigation of combustion enhancement by ozone additive in CH_4/air flame using direct laminar burning velocity measurements and kinetic simulations. Laminar burning velocities with and without O_3 were directly measured using the Heat Flux method An O_3 kinetic mechanism involving 16 elementary reactions together with the GRI-Mech 3.0 was composed and validated through CHEMKIN calculations, which gives good predictions of the burning velocities with and without O_3 additives. Accurate laminar burning velocities of methane–air mixtures with and without O_3 were determined using the Heat Flux method.

2.2 Objectives

From literature review it is observed that the flame stability, flame depend on the parameters like Φ and *Re*. Many of the previous works related to heat transfer characteristics of the flame. It is observed that not much of the work related to the flame structure and stability is reported.

1. To select the local available various gaseous fuel and study their characteristics.

2. Identifying the types of burners available and modify the geometry of the existing burner to study the flame height variations, flame shape transformation and stability under laminar and turbulent conditions as influenced by the effects of mixture inlet air and gas..

3. Comparing the results of modified burner with the existing data.

3. EXPERIMENTAL SETUP AND METHODOLOGY

This chapter describes the various experimental facilities, instrumentation and the data analysis techniques that were employed in this study. The first section describes the design of the experimental setup and detail arrangement of burner. The next section gives the procedure to conduct the experiment. The last section briefly explains the methods used for analyzing the measurements to obtain flame height at differentΦ and *Re* which can be used to understand the physics behind the flame structure.

3.1Experimental Setup

Figure.3.1 shows the detailed arrangement of experimental setup. It consist of a fuel cylinder, air blower, flow measuring device (orifice meter, venturi meter) manometers, burner and hose pipes.

Air flow rate is measured using aorifice meter which is designed and fabricated to get the required flow rate of air. The venturimeter is having diameter of 6mm, throat diameter of 3mm and the value of Cd is obtained as 0.89 it is made with acrylic material. The outlet of the air blower (STANLEY and 0-13,500 rpm, capable of delivering air at volume 2.5m^3/min and power rating is 600watts) is connected to the venturimeter through hose pipes with reducer. The pressure taps of venturimeter is connected to U-tube water manometer, the outlet of venturi is connected to the air port.

The fuel gas cylinder is connected to plenum chamber through a pressure regulator. The regulated pressure is slightly above the atmospheric pressure, which is measured using a U-tube manometer with one end opened to the atmosphere. Gas flow rate is measured using orifice meter which is designed and fabricated to get the required flow rate of fuel gas. The orifice is made is using a flat plate of thickness 0.4mm and the hole diameter of 2mm known as orifice. The inlet of orifice is made of acrylic material of 4mm diameter with the value of Cd being 0.72. Two pressure taps are used of 1mm diameter at both ends, one at 8mm from orifice at the inlet side and other at 3mm from orifice at outlet side which are further connected to the U tube water manometer.

The flame behaviour are recorded by a high resolution digital camera (Nikon cool-pix L28, 20.1Mp with resolution 5152x3864 and minimum shutter speed of 1sec and max of 2000fps).The images at various operating conditions are captured and analyzed by using Image tool software IMAGEJ. The flame heights are measured with the software IMAGEJ. All measurements taken on the computer are first calibrated by a standard image with reference as burner diameter. The inner flame height is measured vertically at the axis from the burner exit to the brightest point of the flame. The outer flame height is measured vertically at the axis from the burner exit to the convergent of the diffusion flame and cone(flame)angle is measured perpendicular to the flame and slant angle of the inner cone from the periphery of the inner tube to calculate the burning velocity of the mixture flow.

Figure.3.3 shows the schematic diagram of burner and figure 3.4 and figure 3.5 shows the photographic view of slot and round burner respectively. The burner is made to get a premixed flame. The burner is having inlet plenum at the bottom. Plenum is made with 2 inch GI pipe of length 50mm, bottom end of the pipe is sealed with metal disc by welding.Two diametrically opposite ports are provided at the bottom of the plenum through which the regulated fuel gas and air are admitted.The other end of the pipe is connected to 1 inch GI pipe of length 150mm using a reducer. Glass beads are provided at the intersection of the plenum and GI pipe of 150mm length in the reducer up to a height of 30mm.

These glass beads are provided for the purpose of proper mixing of regulated gas and air flow. Two screen mesh are placed at the top and bottom of these glass beads in order to avoid the movement of beads in the burner due to high pressure air and gas inlet.

For round burner a nozzle of inner diameter 14mm is connected at the end of 1inch GI pipe. Care is taken so that the reduction of the area from pipe to nozzle provides a smooth passage. Another screen mesh is provided at the inlet of the nozzle to prevent flash back. For slot burner a slot of size 14*4mm^2 is made using thin stainless steel and is placed at the tip of 1inch GI pipe to have the burner tip as slot. Care is taken so that reduction of area from pipe to slot provides smooth passage and a screen mesh is provided at the inlet of slot in order to avoid flash back. The burnersare then tested for the leakages by using soap waterand observed that there are no leakage.

Fig 3.1: Photographic view of Experimental set up

Fig 3.2: Photographic view of Fabrication process

3.2 BURNER

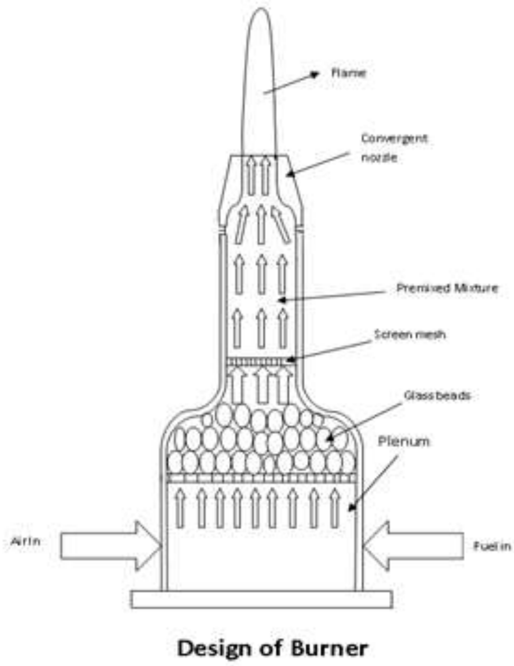


Fig 3.3 Schematic representation of Burner **Fig3.4** Photographic view of Slot Burner

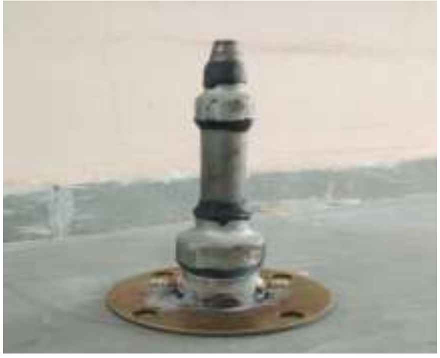


Fig 3.5: Photographic view of Round burner

3.3 METHODOLGY

A leakage test is performed before every experiment to minimize the risk of a gas leak. This is done by first opening the air supply line and applying a leak identifying agent (Soap water) to every point with the potential for leakage. Connections are tightened until bubbles caused by Soap water are no longer present. The same process is completed along the gas line. After this a flame is lit at the top of the apparatus. A camera, approximately half meter away from the apparatus, is positioned for optimal flame photography. A visual scan is performed to ensure that nonflammable objects are within close proximity to the apparatus. Next, a commercial lighter is lit and held over the flame opening as the gas supply is opened. Once the gas ignites the flow is adjusted to a relative desired rate measured by the flow meters. Airsupply is then turned on at a very gradual rate until the flame appears steady with a definedcone within the center. After this the prerecorded values of LPG gas and round burner are used to get particular flame structure. This is done by setting the values of pressure readings in the manometers on both the sides of air as well as gas side. This will give a particular flame structure for a particular Reynolds number and equivalence ratio, this is recorded or captured in the camera for further comparison with slot burner with same Reynolds number and equivalence ratio. The same procedure is carried out for different Reynolds number and equivalence ratio. All the images are captured in the camera. Further the setup is changed to slot burner and again the procedure is carried out. The same Reynolds number and equivalence ratios are used for slot in order to compare both. The control of air and fuel is done with the help of flow control valve present on both the sides.

The experiment conducted is calculated as follows. The flame is controlled by the control valves provided on both sides. Images of flame is captured for every Reynolds number and equivalence ratio. The equivalence ratio is varied from Φ=0.5 to 1.8 and Re=400 to 3200 till the flame stabilizes.All measurements taken on the computer are first calibrated by a standard image with reference as a burner diameter. The flame height is measured using the software IMAGEJ. The inner flame height is measured vertically at the axis from the burner exit to the brightest point of the flame ,The outer flame height is measured vertically at the axis from the burner exit to the convergent of the diffusion flame and cone(flame)angle is measured perpendicular to the flame and slant angle of the inner cone from the periphery of the inner tube.

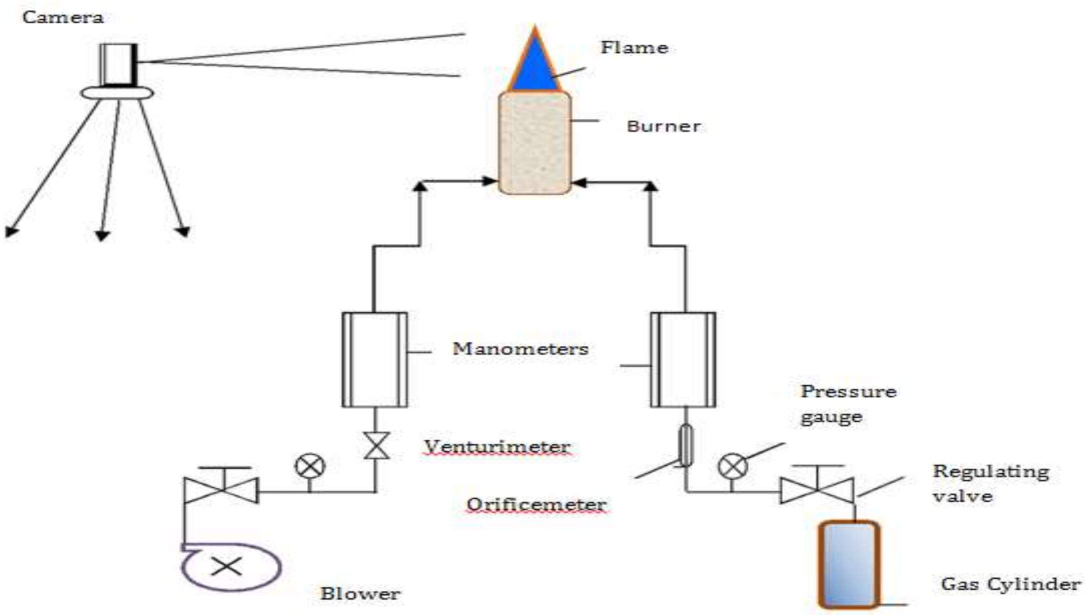


Fig.3.6 Schematic view of Experimental Setup

3.4 DATA REDUCTION:

1. Discharge of orifice meter (Q_{act})

$$Q_{act} = Cd\left[\frac{a_1 \times a_0 \times \sqrt{(2gH)}}{\sqrt{(a_1{}^2 - a_0{}^2)}}\right]$$

Where

Q_{act}= actual discharge of air (m^3/sec)

Cd= coefficient of discharge 0.89

a_1=cross sectional area of inlet pipe (m^2)

a_0= cross sectional area of the orifice (m^2)

g= acceleration due to gravity 9.81 m/sec^2

H= equivalent head $= \left(\frac{\rho_m}{\rho_p} - 1\right) \times x$

ρ_m= density of manometer fluid (kg/m^3)

ρ_p= density of pipe fluid (kg/m^3)

x= manometer deflection (m)

2. Mass flow rate of air ($\dot{m}_{air}$)

$$\dot{m}_{air} = \rho_{air} \times Q_{act}$$

Where

$\dot{m}_{air}$= mass flow rate of air in (kg/sec)

ρ_{air} = density of air in (kg/m^3)

Q_{act} = actual discharge of air (m^3/sec)

3. Reynolds number of air (Re_{air})

$$Re_{air} = \frac{4\dot{m}_{air}}{\pi d\mu}$$

Where

$\dot{m}_{air}$= mass flow rate of air in (kg/sec)

d = hydraulic diameter of pipe in (m)

μ = dynamic viscosity in (kg/m sec)

4. Mass flow rate of fuel ($\dot{m}_{fuel}$)

$$\dot{m}_{fuel} = \frac{p \times \dot{v}}{RT}$$

Where

$\dot{m}_{fuel}$ = mass flow rate of fuel in (kg/sec)

p = pressure in (N/m^2)

$\dot{v}$= volumetric flow rate in (m^3/sec)

R= gas constant in (J/kg K)

T= absolute temperature in (Kelvin)

5. Air fuel ratio (A/F)

$$A/_F = \frac{m_a}{m_f}$$

6. Equivalence ratio (Φ)

$$\Phi = \frac{stoichiometricairfuelratio}{actualairfuelratio}$$

Flow gas mixture (U)

$$U = \left(\frac{\dot{m}_a + \dot{m}_f}{\rho_a + \rho_f}\right) * A_b$$

Where

$\dot{m}_{air}$= mass flow rate of air in (kg/sec)

$\dot{m}_{fuel}$ = mass flow rate of fuel in (kg/sec)

ρ_{air}= density of manometer fluid (kg/m^3)

ρ_{fuel}= density of pipe fluid (kg/m^3)

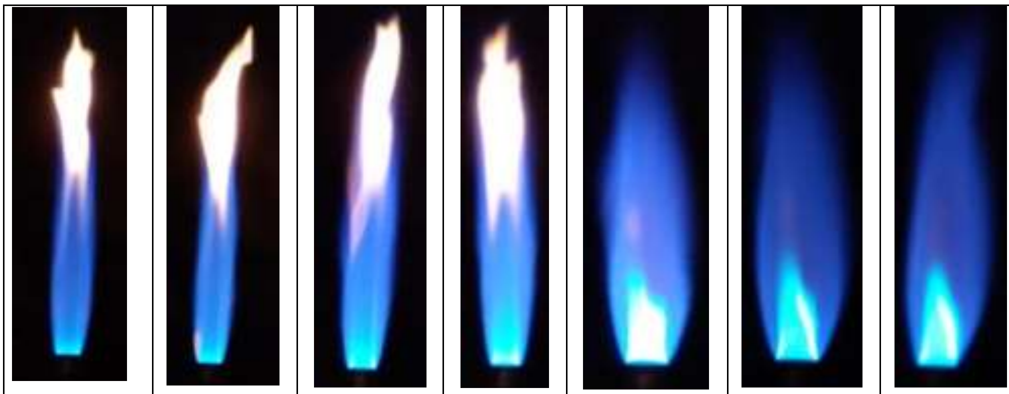
A_b=area of the burner tip (m^2)

4. RESULTS AND DISCUSSION

This chapter describes the results of an investigation to determine the flame structure, flame heights of inner cone and outer cone and cone or flame angle of luminous flame. The Influence of Φ and *Re* on flame structure, flame heights and flame angle are investigated, flame photographs for different condition are provided. The comparison of LPG and Methane flame are also investigated. The experiments are conducted under the steady state condition. The flame structures are studied under the different Φ and Re and the details are presented in the below sections.

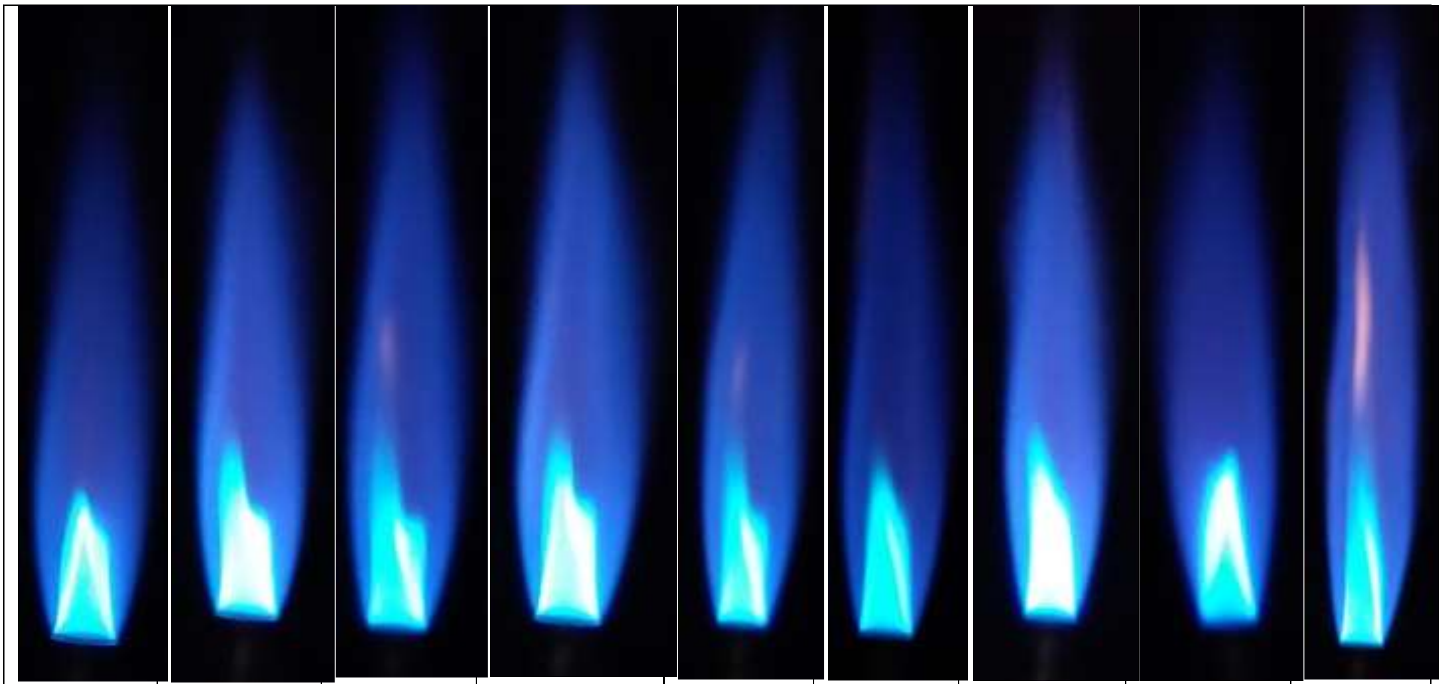
4.1. LPG Flame Structure at Constant Equivalence ratio with Different Re

Figure 4.1(a) shows flame structures for different *Re* from 2800 to 4000 of the mixture at constant Φ=0.5. Figure 4.1(b) shows the structure of the flames at constant *Re* in the range of *Re*=2400 to4000 at Φ= 0.6.Figure 4.1(c) shows the structure of flames at *Re* varies from 2000 to 2800 atΦ= *0.7.*Figure 4.1(d) shows the structure of flames at Re varies from 1800 to 3400 at Φ= 0.8. Similarly figures 4.1(e-i) shows the structure of flames at Re varies from 1800 to 3200 at Φvaries from 0.9 to 1.5.The photographs are taken with a high resolution digital camera, suggest three distinct flame regimes (premixed-like flame, hybrid flame, diffusion flame) according to the flame appearance. It is observed that the flame height increase with increase in Φ for the lower Φ and lower *Re* the flame will be yellow at the outer region and produces the soot particles and there is no formation of inner cone due to incomplete combustion by increasing the Φ with *Re* flame structure varies and produces the inner bright luminous zone and outer diffusion flame for the Φ=2.1 beyond the *Re*=800 the flame get starts blow off.



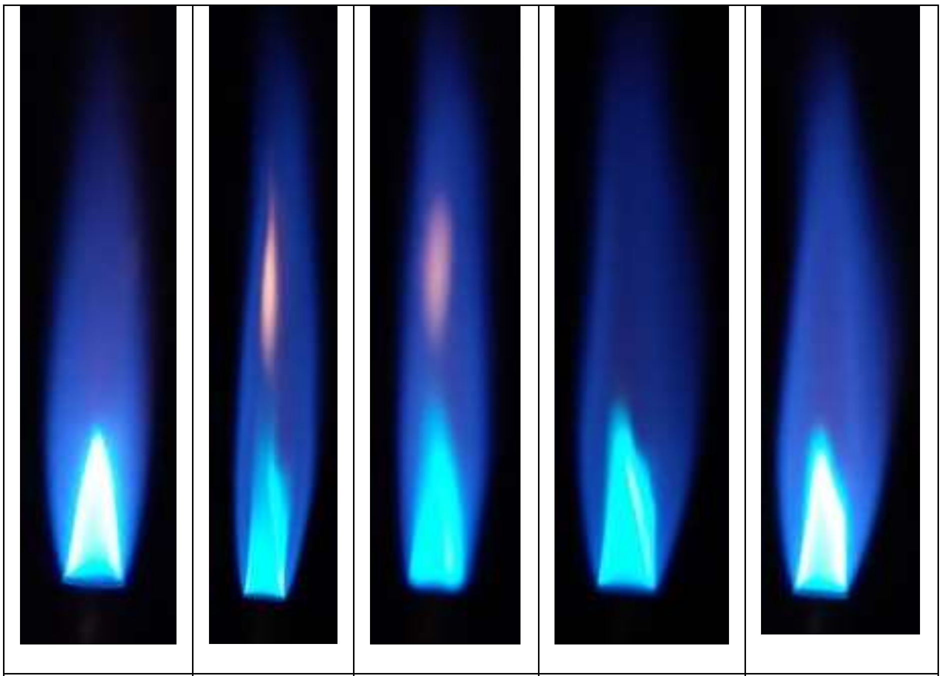
2800	3000	3200	3400	3600	3800	4000
For constant **Φ=** 0.5 and Various Re						

Fig4.1(a) shows LPG flame photographs at constant **Φ=0.5**



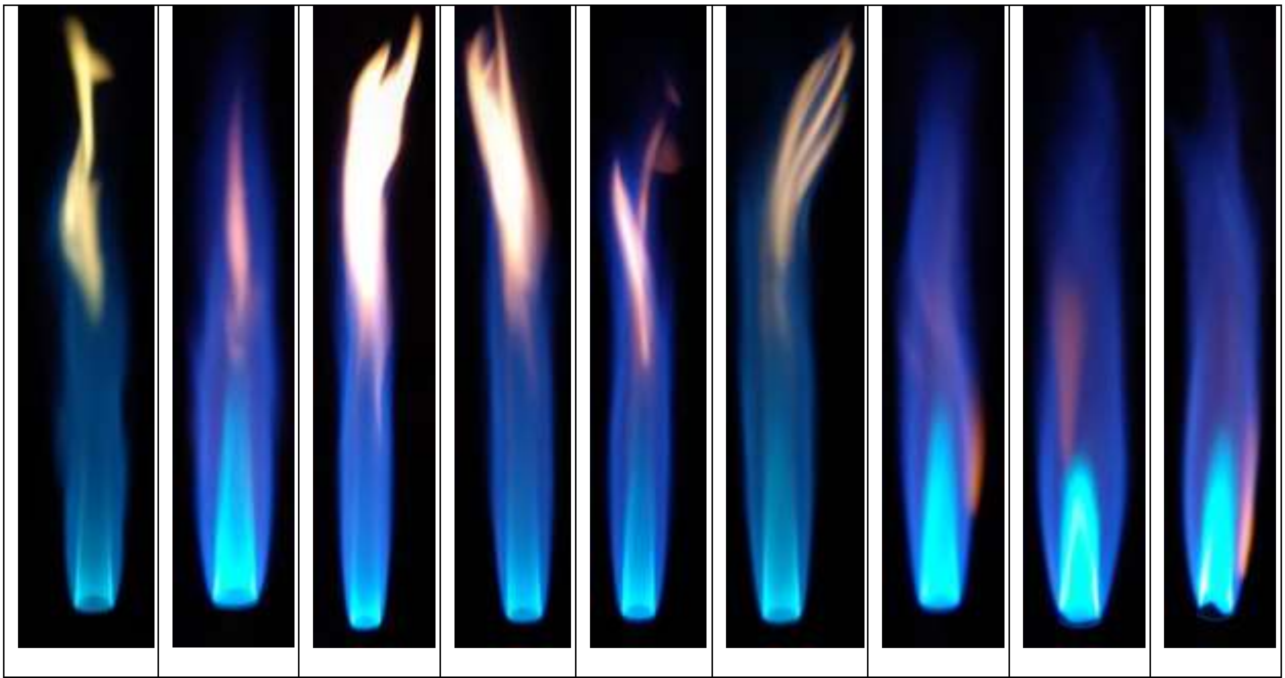
2400	2600	2800	3000	3200	3400	3600	3800	4000
For constant **Φ=** 0.6 and Various Re								

Fig4.1(b) shows LPG flame photographs at constant **Φ=0.6**



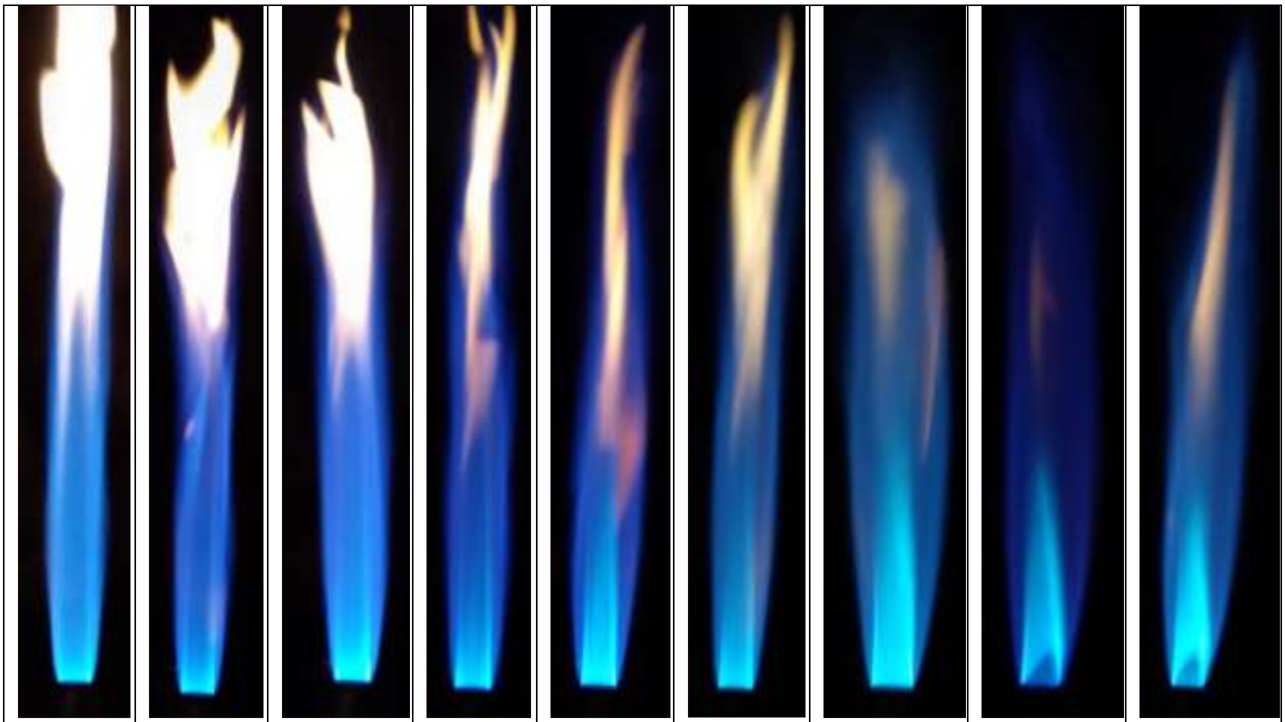
2000	2200	2400	2600	2800
For constant **Φ =** 0.7 and Various Re				

Fig4.1(c) shows LPG flame photographs at constant **Φ=0.7**



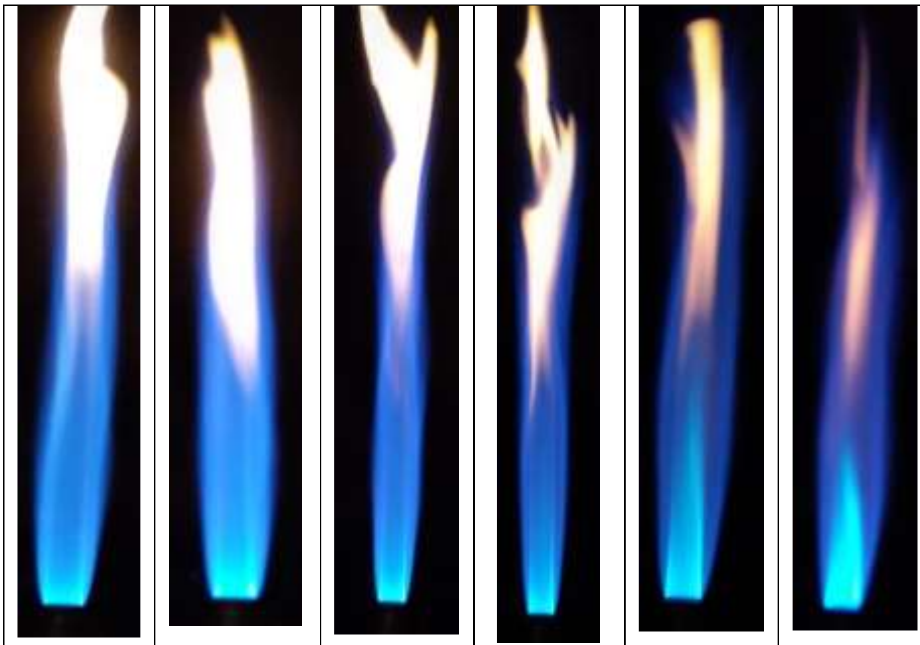
1800	2000	2200	2400	2600	2800	3000	3200	3400
For constant **Φ =** 0.8 and Various Re								

Fig4.1(d) shows LPG flame photographs at constant **Φ=0.8**



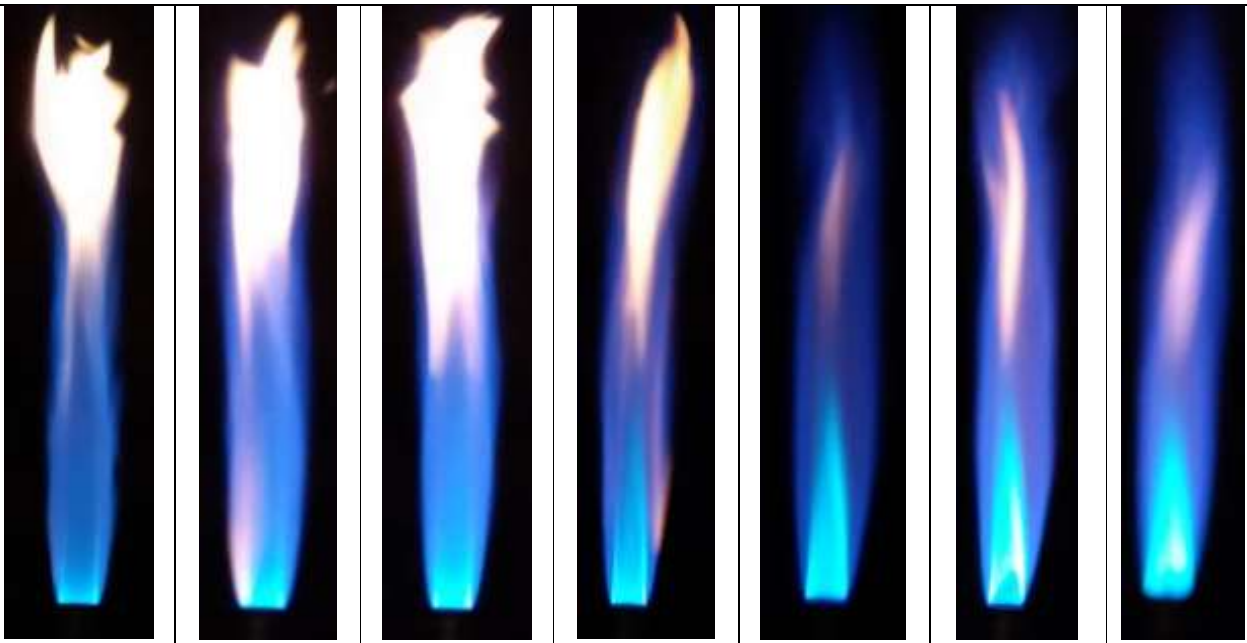
1600	1800	2000	2200	2400	2600	2800	3000	3200
For constant **Φ =** 0.9 and Various Re								

Fig4.1(e) shows LPG flame photographs at constant Φ=0.9



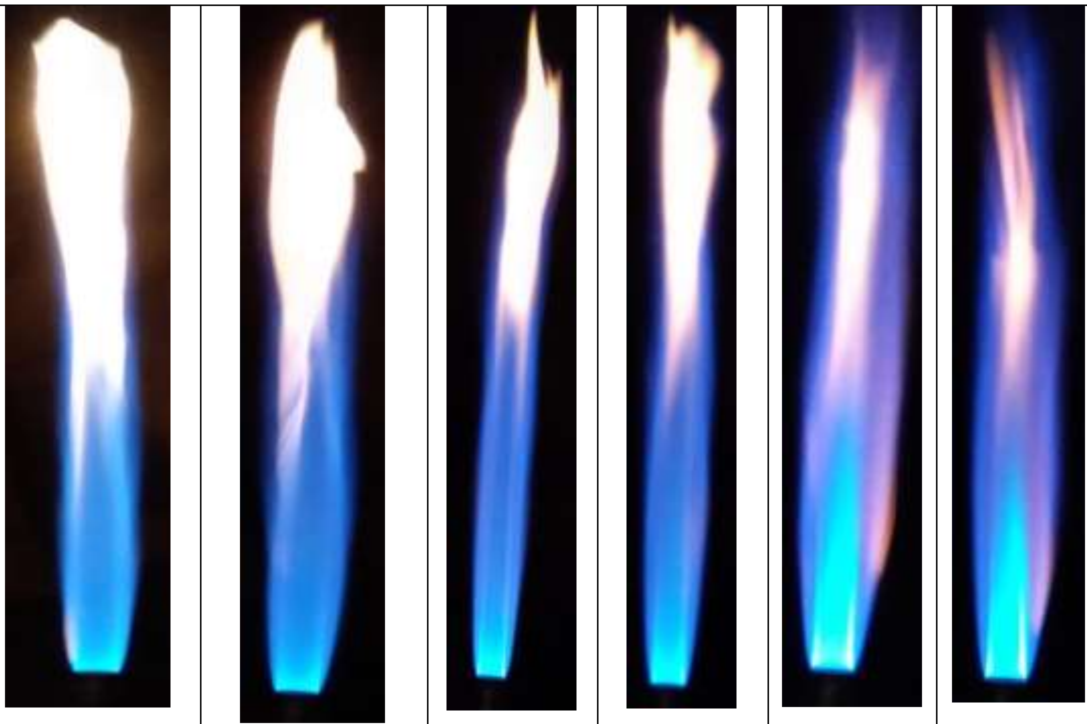
1800	2000	2200	2400	2600	2800
For constant Φ = 1 and Various Re					

Fig4.1(f) shows LPG flame photographs at constant Φ=1



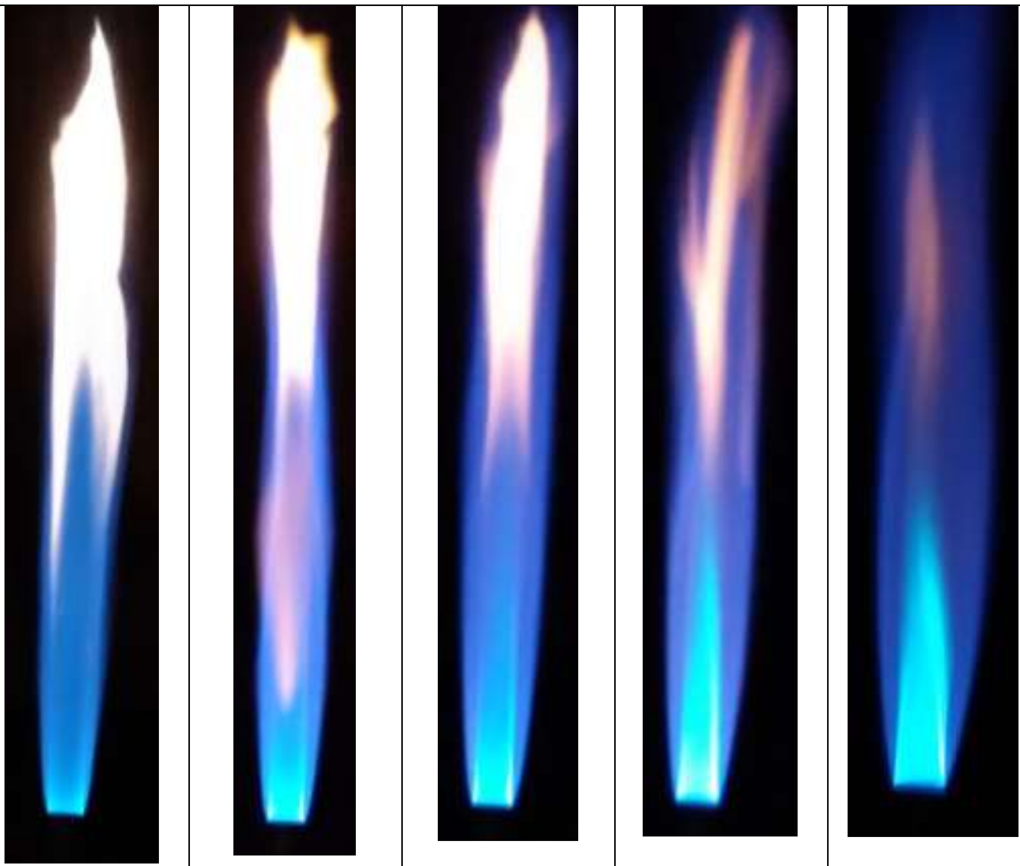
1200	1400	1600	1800	2000	2200	2400
For constant Φ = 1.2 and Various Re						

Fig4.1(g) shows LPG flame photographs at constant **Φ=1.2**



1200	1400	1600	1800	2000	2200
For constant Φ = 1.3 and Various Re					

Fig4.1(h) shows LPG flame photographs at constant **Φ=1.3**



1200	1400	1600	1800	2000
For constant Φ =1.5 and Various Re				

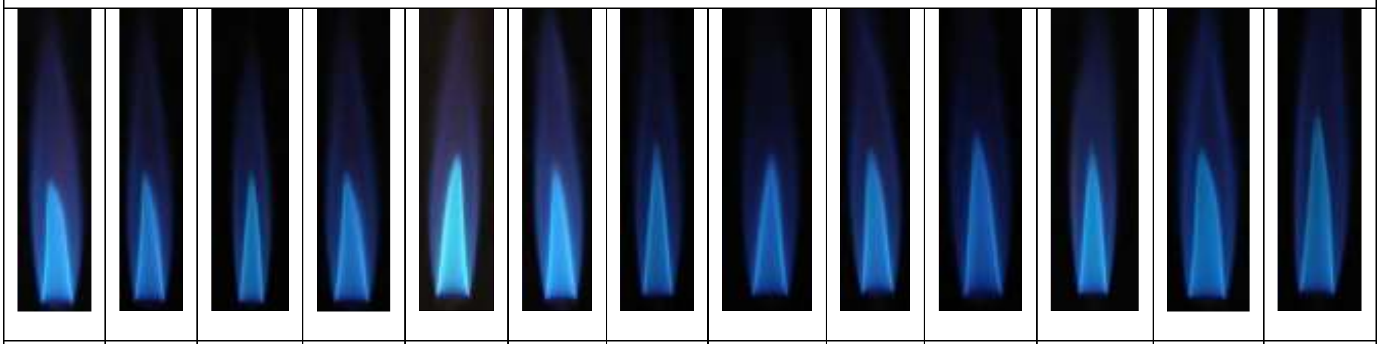
Fig4.1(i) shows LPG flame photographs at constant **Φ=1.5**

The flame structure is giving a yellow layer at the top from Reynolds number varying from 1200 to 2200 which shows that there is insufficient supply of fuel to air ratio and fuel burns incompletely. This flame gives complete combustion after Reynolds number 2400 where blue flame is available the structure height increases from lower Reynolds number to higher Reynolds number.The flames fromΦ=1, the flame structures are similar to those of non-premixed flames, in which a portion of the flame tip becomes a luminous soothing region. And the flame height increases slightly as the Φ increases. The double flame structure (two distinctly visible envelops) exists at shorter flame heights and these flames adjust to locations where the reactant (LPG–air) layers are relatively wide. The reaction zones are synergistically coupled and they either provide or receive heat and/or radical species for the other. The premixed flames require H-atoms for the initiation of reactions and for O_2 consumption, and produce partial oxidation products, e.g., CO and H_2, which provide the fuel for the non-premixed flame, and hydroxyl radicals.

4.2 Comparison of LPG flames with Methane flames at Re=800 and varying Equivalence ratio

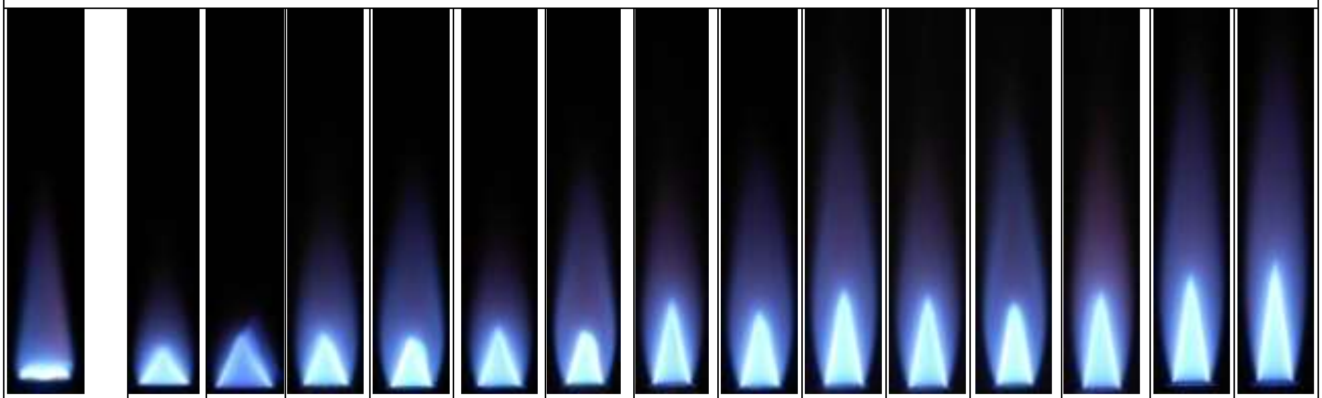
- For methane gas we get blue flame with inner cone Φ= 0.5 but for LPG we do not get flame at that equivalence ratio.
- At Φ= 0.7 we get correct image of flame in methane gas and in case of LPG the flame just starts to occur and the height of inner cone is very small.
- Methane flames are available up to equivalence ratio of 1.8, where as for LPG the flame structure is complete up to equivalence ratio of 2.1.
- The shape of outer cone in case of methane flames is very light and is almost equal to the inner cone, where as the shape of outer cone in LPG is completely visible and is bright.

Fig 4.2(a) Methane flame images for Reynolds number Re=800



Φ=0.5	**Φ=0.6**	**Φ=0.7**	**Φ=0.8**	**Φ=0.9**	**Φ=1.1**	**Φ=1.2**	**Φ=1.3**	**Φ=1.4**	**Φ=1.5**	**Φ=1.6**	**Φ=1.7**	**Φ=1.8**

LPG flame images for Reynolds number Re=800



Φ=0.7	Φ=0.8	Φ=0.9	Φ=1	Φ=1.1	Φ= 1.2	Φ=1.3	Φ=1.4	Φ=1.5	Φ=1.6	Φ=1.7	Φ= 1.8	Φ=1.9	Φ=2	Φ=2.1

Fig.4.2(b) Photo graphs of LPG at constant Re=800

5.1 Conclusions

The flame structure, height of LPG and Methane is experimentally studied. The influence of *Φ* and *Re* on flame structure is studied. The general conclusions drawn from the results of present study are summarized as follows:

5.1.1 For LPG

1. The appearance of flame structure is a mainly a function of *Φ*and *Re*. The flame overall height is increases from lean mixture to rich mixture. As the mixture becomes richer the mixture requires large residence time for complete combustion, hence the flame is stretched in axial direction resulting in increased flame height. At higher *Φ* the flame becomes yellow as temperature of flame decreases due to slow chemical reaction resulting in formation of soot.
2. The inner cone height increases from *Φ*=1.1 to 2.1 then the inner cone height is decreases and finally it disappeared beyond the *Φ*=2.1.
3. Increase in either the *Φ* or the *Re* will increase the length of the inner cone.
4. The LPG flame has more unburnt gases within inner cone and they burn in the outer cone hence the outer cone height is increases.
5. The LPG flame is stable up to the *Re*=2800, beyond which, the flame becomes unstable and blow off occurs at around *Re*= 3000.
6. The flames for slot burner did not ignite at those Reynolds number and Equivalence ratio that are used for calculation of round burner as there was complete blow off due to high pressure on the air side.

5.1.2 For Methane

1. The appearance of flame structure is mainly a function of $\Phi$and Re. The flame overall height is increases from lean mixture to rich mixture. As the mixture becomes richer the mixture requires large residence time for complete combustion, hence the flame is stretched in axial direction resulting in increased flame height.

2. The flame is having continuous blue flame and does not give any yellow tipping as there is complete combustion of fuel at any Reynolds number and Equivalence ratio.

3. Increase in either the Φ or the Re will increase the length of the inner cone.

5.2 Scope for future work

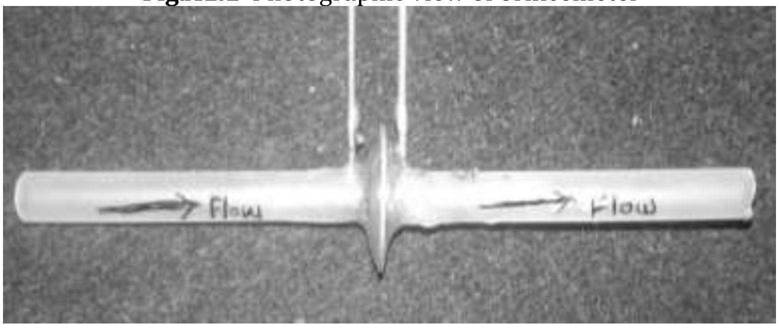
- The structure of the slot can be varied to any other shape and the procedure can be carried out.
- Other than Methane and LPG gas can be used to investigate the flame structure for varying Reynolds number and Equivalence ratio.
- Heat transfer characteristics for each and every Reynolds number and Equivalence ratio can be calculated.
- Proper calculations should be done for the calibration and preparation of slot.
- The procedure should be done for varying Reynolds number and Equivalence ratio and not by taking some constant values.
- While the comparison of the structure of slot burner with round burner, care is to be taken to take the images at varying the Reynolds number and by taking any constant and the same readings is to be taken for both round as well as slot burner.

APPENDIX A1

A1.Design and Calibration of Orifice meter

Orifice is a circular plate made up of GI plate of thickness 0.4mm which has a circular sharp edged hole called orifice with diameter 2mm.The orifice meter having inlet diameter of 4.5mm is made with acrylic material,the fabricated orifice meter is calibrated with water. In which the inlet of the water from the pipe is connected to the inlet of the orifice pipe of diameter 4.5mm with reducer and nozzle, one pressure tap of 8mm distance from the orifice plate is connected to inlet pipe, another pressure tap of 3mm distance from orifice plate is connected to the outlet side. The pressure taps of both inlet and outlet are connected to the simple U-tube water manometer. In the inlet side, flow is controlled using a gate valve. With no flow condition it is ensured that there is no deflection in the manometer by removing air bubbles. Then the gate value is opened gradually till the required deflection in the manometer. The stop watch is used to measure the time required to collect the 1000cc of water. This procedure is repeated for different deflection. For every deflection, the collecting time is recorded. By using the data of deflection and time required to collect the 1000cc of water. The actual and theoretical discharges are calculated and C_d is evaluated. The calibration curve for the orificemeter is drawn for coefficient of discharge vs.Re which is shown in figA1.3 The C_d value for the orificemeter is increasing with Re.Repeat the experiment 2-3 times to find out the errors in the reading and take the average values for the calculation.

Fig.A1.1 Photographic view of orificemeter



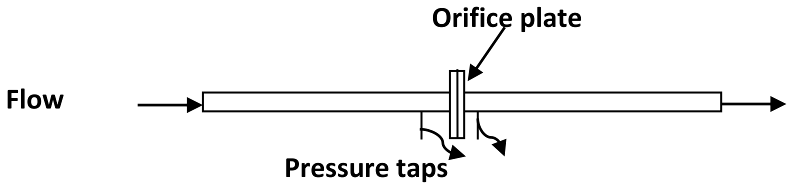


Fig.A1.2 Schematic view of orifice meter

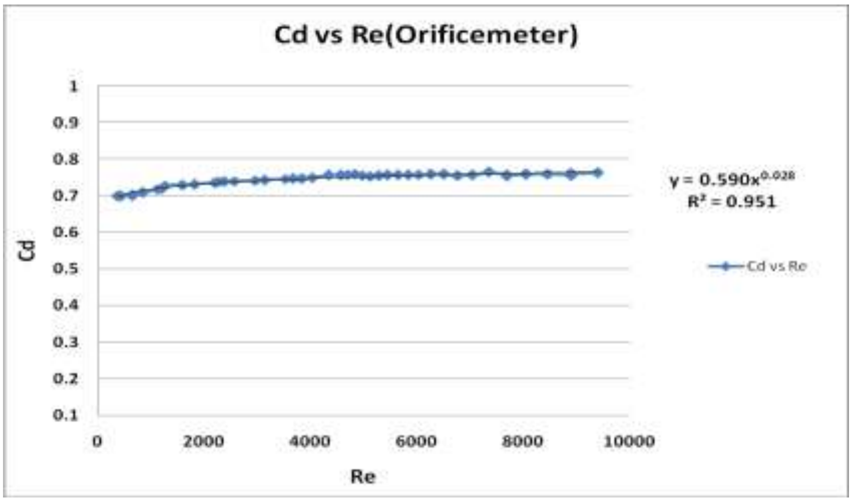


Fig.A1.3 Calibration curve(Orifice meter)

Specifications

- Inlet diameter =4.5mm
- Orifice diameter =2mm
- Cd=0.72

APPENDIXA2

A2.Design and Calibration of Venturi meter

A Venturi is a system for speeding the flow of the fluid, by constricting it in a cone shaped tube. In the restriction the fluid must increase the velocity reducing its pressure and producing a partial vaccum. As the fluid leave the constriction, its pressure increases back to the ambient or pipe level.

A venturi can also be used to inject a liquid or a gas into another liquid. A pump forces the liquid flow through a tube connected to:

- A venturi to increase the speed of the fluid (restriction of the pipe diameter).
- A short piece of tube connected to the gas source.
- A second venturi that decreases speed of the fluid (the pipe diameter increase again).

The venturi is the Throttling effect caused in the flow of fluid through a pipe. Here the venturimeter is made of

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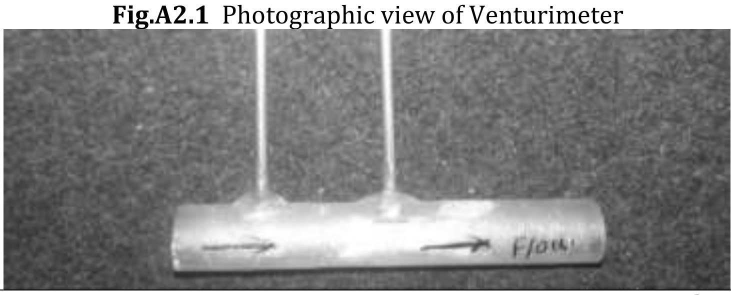
acrylic material of inlet diameter 6mm and has a throat of 3mm diameter. The fabricated venturimeter is calibrated with water, in which the inlet of the water from the pipe is connected to the inlet of the venturi pipe of diameter6mm with reducer and nozzle, one pressure tap before the throat and other at the throat are placed to check the pressure difference.

The pressure taps of both inlet and outlet are connected to the simple U-tube water manometer. In the inlet side, flow is controlled using a gate valve. With no flow condition it is ensured that there is no deflection in the manometer by removing air bubbles.

Then the gate value is opened gradually till the required deflection in the manometer. The stop watch is used to measure the time required to collect the 1000cc of water. This procedure is repeated for different deflection. For every deflection, the collecting time is recorded. By using the data of deflection and time required to collect the 1000cc of water. The actual and theoretical discharges are calculated and C_d is evaluated.The calibration curve for the venturimeter is drawn for coefficient of discharge vs.*Re* which is shown in figA2.3. The C_d value for the venturimeter is increasing with *Re*.Repeat the experiment 2-3 times to find out the errors in the reading and take the average values for the calculation.

Fig.A2.1 Photographic view of Venturimeter



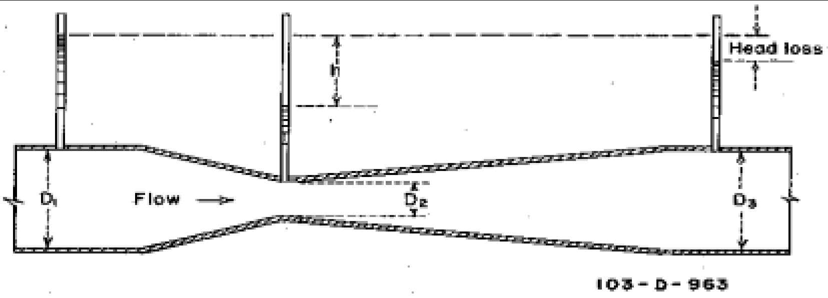


Fig.A2.2 Schematic view of venturimeter

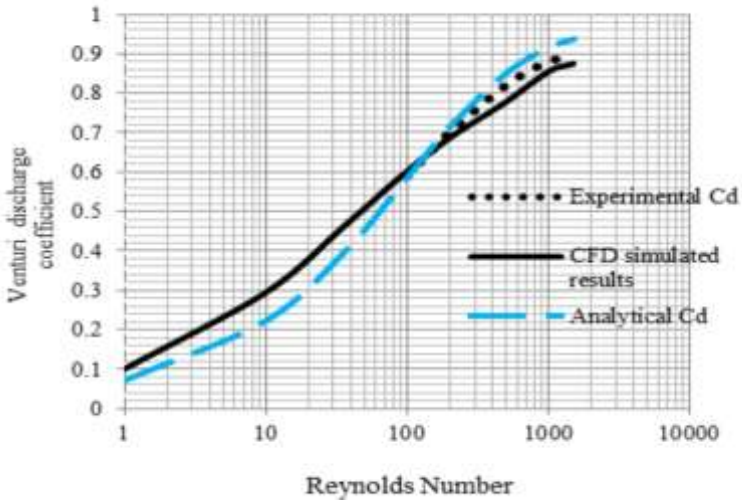


Fig.A2.3 Calibration curve(Venturimeter)

Specifications

- Inlet diameter =6mm
- Throat diameter =3mm
- Cd=0.89

APPENDIXA3

IMAGEJ IMAGE TOOL (IT) SOFTWARE FOR WINOWS VER 3.0

The image tool software which is used for study the flame structure and burning velocity of the flame at different equivalence ratio (Φ) and burner Reynolds number (Re) as per the experiment different data of the flames of gas to estimate their heights and flame angle it is not easy by measuring it physically so for the error free analyses we need a software i.e., image tool software gives the accurate results for the particular input data.

Steps involved for measuring the flame heights and burning velocity by using Image Tool Software (IT)

1).Make a separate folder of particular images those are taken during the experiment asinput data. Crop the images to the size of the flame including tip of the burner in MS-Office picture manager.

2).By installing the IT software create a short cut icon on the desk top which it is easy to identify the path .For analyses double click on the software blank work sheet will openwhich issimilar to MS excel sheet

4).Click on the icon' open image' which located in the tool bar it asks the path for thefolder and specify the correct path where the images are stored.

5).Double click on the image whose structure has to study; it comes on the work sheet of the IT

6).First we have to calibrate the image for adjusting the pixels of the images to the tool, insettings click on the calibrate spatial measurement draw a line for the known length it gives the dialogue box with default as how long is the line? In this by default that take . The values in pixels, select the millimeters and give the standard length then say OK and save itas a spatial calibration for the further references.

7).While measuring the height and angle of the flame go to settings select the load spatialcalibration it automatically gives the calibrated value for the measurements, after click on the distance tool from the tool bar menu and it asks draw a line, for measuring the height of the inner and outer cone of the flame draw a vertical line from the reference and for cone angle draw the tangent to the inner cone take the values for the further calculations.

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