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Effect of Primary Aeration on the Stability of Partially Premixed Tubular Flames

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Abstract — **The scope of this paper is to investigate the stability and characteristics of premixed flames with varying primary aeration. The effect of port velocity on flame stability at incipient lift and lift off conditions has been thoroughly investigated for a range of fuel flow rate and equivalence ratios. The results showed that, the lift off velocity decreases with increasing equivalence ratio. Flame characteristics such as flame shape, height and colour has been observed and compared for various premixing (equivalence ratio) and port velocity. The results of the experiments indicated that the flame height decreases with increasing premixing i.e., with increasing equivalence ratio. Tthe flame colour changed from sooting yellow to blue when the stoichiometry changed from sub stoichiometry to stoichiometry. The measured flame temperature shows that the temperature increases with increasing premixing. The experimental results were qualitatively analyzed to study the flame height and colour. The flame length results were quantified by processing the flame images using Matlab.**

Index Terms— **Equivalence ratio, premixing, primary aeration, diffusion, flash back, lift off**

I. INTRODUCTION

Combustion is a phenomenon in which the chemical energy in the fuel is converted into heat energy and light energy. The visible form of energy during combustion is termed as flame. There are two major types of flames depending on where and how the fuel and oxidizer meet.

A. Premixed flame

In a premixed flame the fuel and the oxidant are mixed in the molecular level before the combustion process takes place. This type of flame is shorter but hotter and its colour ranges from yellow to bluish green. Premixed mode of combustion takes place in petrol engine, household burners, etc.

B. Diffusion flame

Diffusion or a non premixed flame is a type of flame where oxidizer and fuel gradually diffuse into one another only at the flame front. (i.e) the fuel and oxidizer do not meet until it reaches the flame front.

Diffusion flames are highly luminous which is red or orange in colour. Luminosity is high due to high emission from soot particles which are the remains due to incomplete combustion.

C. Partially premixed flame

A Partially Premixed Flame is described as a flame possessing the features and characteristics of both premixed and non-premixed flames. Partially premixed flames occur in many applications including Bunsen burners, industrial furnaces; gas fired domestic burners and gas turbine. The flash back problem is eradicated as the fuel and air are not completely premixed. The issue of soot does not occur as some amount of premixing is always done.

D. Flame Stability

The stability of flame is characterized by the attachment of the flame base at the port of the burner. The instability in a flame is caused when there is a mismatch between the local burning velocity (flame speed) and the port velocity. When the port velocity is higher, the flame is pushed downstream and the flame positions itself stable at a location above the rim. Increasing the velocity beyond the limit will make the flame to blow off and eventually the flame blows out. In another case, decreasing the port velocity will make the flame to travel upstream and causes instability.

II. LITERATURE REVIEW

In a study, for a given air flow rate, a marginal increment in the length of blue region in the flame is observed with the increase in the co-flow air. At higher values of primary aeration, addition of co-flow air tends to decrease the flame speed. They concluded that in a dual air stream configuration, the partial premixing is optimum around around 45% primary aeration as it gives lower emissions and higher flame stability for LPG-air flames [1].

The flame patterns at different equivalence ratios of premixed flames have been analysed and it has been concluded that the stability of the premixed flame increased with decrease in the equivalence ratio. The flame patterns are changed into four different types with decrease in the equivalence ratio values. The temperature measurement was done and they concluded that the multi hole matrix plate burner is found to be more efficient with less species emissions in comparison with an ordinary large size single hole burner [2].

The detrimental effects on the stability of micro-premixed flames do not depend only on equivalence ratio but also with flow rate. The flame stability limit is affected by condition of diffusion mixing between fuel and the oxidizer. When the diameter is varied, then the shape of the flame will deform. The main reason is

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due to velocity gradient near the burner wall which increases as the diameter decreases under the same flow velocity [3].

III. MOTIVATION AND OBJECTIVES

The important parameters that affect the performance of any combustor or burner are fuel efficiency, burner size, flame stability and emission level. These factors are predominantly affected by the degree of premixing or the quality of the combustible mixture. Design of an efficient burner for appliances depends on the flame characteristics including stability. The scope of this work is to investigate the effect of the mixture quality on the flame stability and characteristics.

The primary objectives of this study are

1. To understand the fundamentals of combustion and different types of flames and flame stability
2. To perform an experimental investigation on the stability of premixed flames in a co-flow burner to study the effect port velocity and combustible mixture quality on flame stability and flame characteristics.

IV. EXPERIMENTAL WORK

Burner and Setup

The experiments on the partially premixed flames were carried out in a tubular co-flow burner. The burner of port diameter 10 mm inner diameter and 12 mm outer diameter is used. To study the effect of co-flow on flame length and stability, a co-flow chamber of inner diameter 42 mm has been concentrically placed around the main tube.

Through the main port of the burner, LPG and air mixture flows after getting mixed in the mixing chamber. The primary airflow rate and the fuel flow rate are regulated and metered using rotameters. The fuel and compressed air entered into the mixing chamber of the central tube. When the air-fuel mixture from main flame mixing chamber reaches the burner mouth, it gets ignited and combustion starts. Only compressed air flows through the coflow chamber. This co-flow air is used to improve the flame stability. The schematic of the setup is shown in Figure 1

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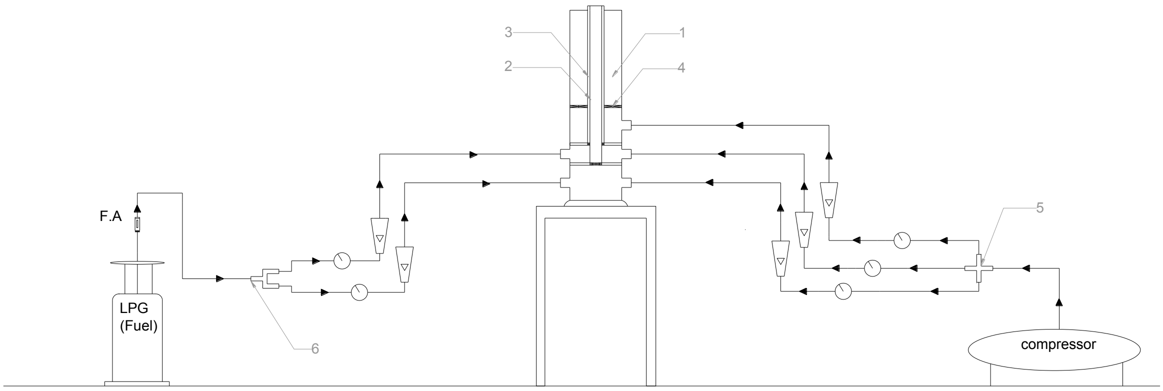

Fig. 1 Schematic Diagram of the Experimental Setup

1 – Co-flow chamber	4 – Mesh	7. Rotameter
2 – Main burner	5 – Air Manifold	
3 – Pilot Flame burner	6 – LPG Gas Manifold	8. Pressure Gauge

Experimental procedure and operating conditions

The experimental procedure adopted in this study is as follows

1. The connections are checked for leak using soap solution and the gas connection from the cylinder to the burner is fitted with the flashback arrestor to avoid flashback.
2. Air and gas flows were regulated using gas rotometers fitted with a pressure gauge. Experiments were carried out at atmospheric pressure.
3. Two sets of experiments were carried out. In the first set of experiment, the fuel flow rate is kept constant and the equivalence ratio and port velocity were varied by increasing the air flow rate for incipient lift and lift off and blow out conditions.
4. In the second set of experiment, the fuel flow and air flow are varied to maintain a constant equivalence ratio.
5. In this set of experiment, co-flow air was used to investigate the effect of co-flow air on flame color and length.
6. For both the set of experiments, the images of the flame were taken using a DSLR camera. For capturing lift off, sequence of images were taken as a video.
7. A fire extinguisher is always kept in place as a safety precaution.

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V. RESULTS AND DISCUSSION

A. Stability Experiment

In this experiment, the quality of the air fuel mixture (equivalence ratio) and port velocity at lift off has been determined. The fuel flow rate has been fixed from 0.2 lpm to 0.8 lpm with an increment of 0.2 lpm. For a fixed gas flow rate, the air flow rate is gradually increased until incipient (just about to) lift is observed. From the flow rate of the fuel and air (at incipient lift), the port velocity and equivalence ratio at incipient lift off is calculated and plotted. In the same experiment, if the flow rate of air is increased further, the flame gets completely lifted off from the burner rim and eventually extinguished.

Fig. 2 Flame images at equivalence ratio $\phi = 1.86$ and lift off velocity = 2.48 m/s

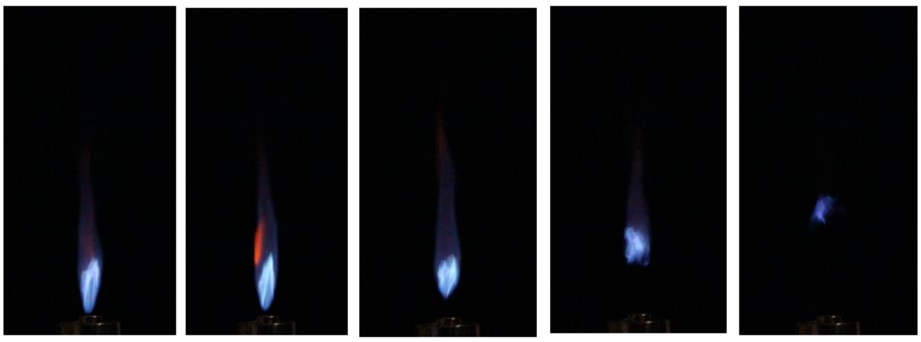

Fig. 3 Flame images at Equivalence ratio $\phi = 1.2$ and lift off velocity = 3.2 m/s

Fig. 4 Flame images at Equivalence ratio $\phi = 1.04$ and lift off velocity = 3.4 m/s

The following set of images (Figure 2 – Figure 4) show the flame dynamics at different equivalence ratio and thus different lift off velocity. The images were captured as a video and fragmented so that the actual lift off dynamics will not be missed when captured as a still image. The flame just after the incipient lift was taken as video image so that the lift off frame will not be missed. The video file was then fragmentized to get the series of images. As can be seen, the lifted off flame still get stabilized for sometime before it completely goes off.

The equivalence ratio varied within a range from 1 to 1.86. The velocity at which lift off occurs within this range of equivalence ratio is found to vary from 2.48 to 4.14 m/s. With the change in equivalence ratio, the flame shape varies, with increasing velocity, the flame length increases as the upward velocity stretches the flame causing an increase in velocity.

B. Flame Characterization Experiments: Flame Height and Flame Color

Flame characteristics experiments were carried out by varying the amount of premixing. Premixed air which is also known as primary air is varied from below stoichiometric (sub stoichiometric) to above stoichiometric air (excess air). The effect of premixing on flame characteristics like flame colour and flame height is shown in Figure 5. The equivalence ratio was kept constant, however, the port velocity was increased by increasing both fuel and air flow rate.

Figure 5 (a) to (c) hows sub stoichiometric flames where the equivalence ratio is 0.25, 0.5 and 0.75. The flame length is longer for $\phi = 0.25$ where the flames look more like diffusion flames. The flame colour is orange with very small blue part. Longer flames resulted because the flame gets elongated seeking for oxygen available in the ambience. There is a blue region near the flame base as a result of partial premixing. The flame becomes yellow at the top as the effect of premixed air wears off. As can be seen, (d) to (f) the flame length shortens with increasing stoichiometric ratio. Also, it is significant that the blue part of the flame also increases with increasing stoichiometric ratio. The flame is blue except for some intermittent yellow streaks.

Figure 7 (e) and (f) show flames above stoichiometric air. i.e., excess air is supplied in this case. The flames are comparitively shorter than stoichiometric flame, however, the excess air dilutes the intensity of combustion and hence reduces the temperature.

A double flame structure with a light blue premixed inner cone and elongated plume are clearly visible from the photographs and the stretch of flame with increase in port velocity can also be seen. The height of the flame is decreasing with increasing premixing, as the amount of secondary air entrainment needed for complete combustion decreases with increased premixing.

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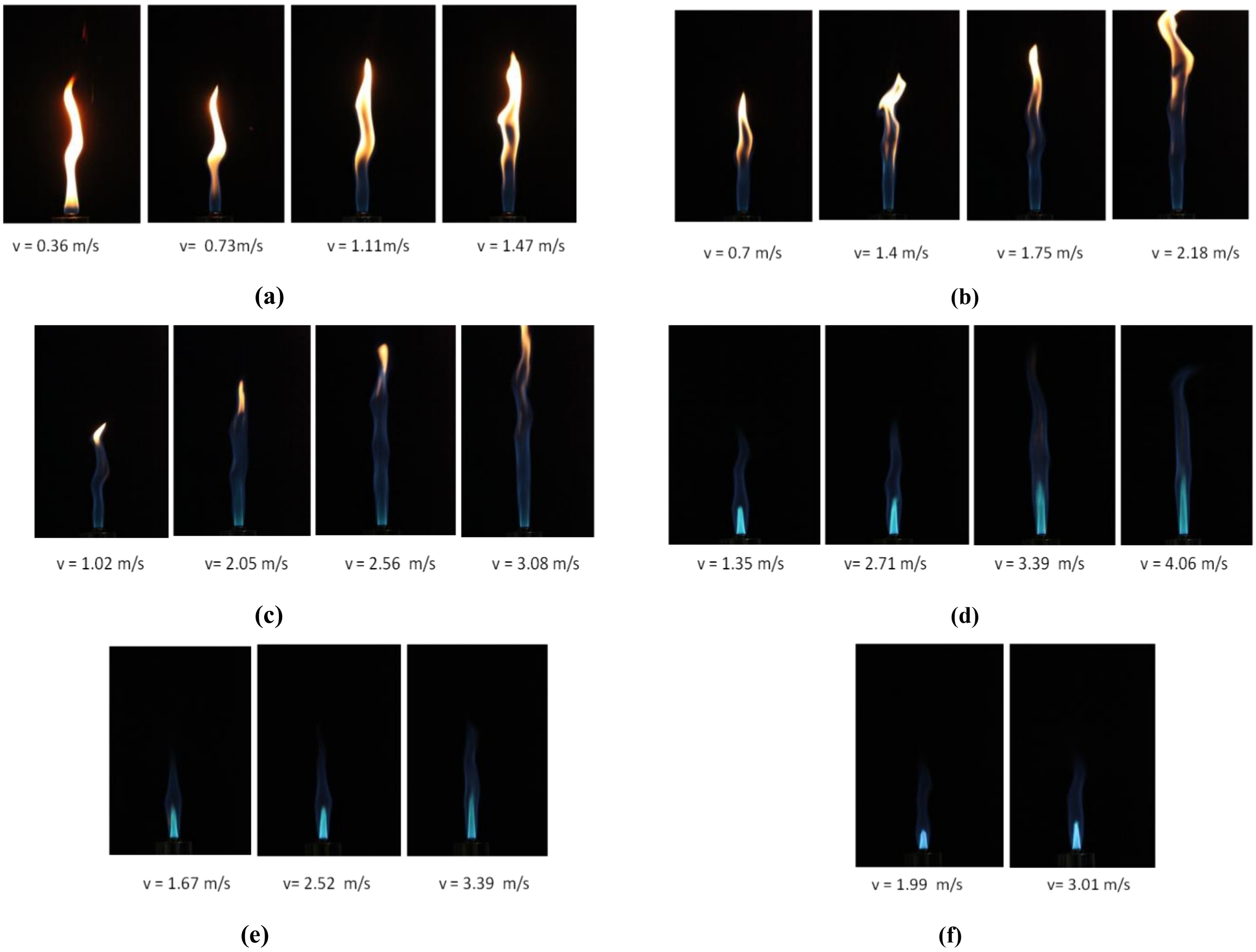

Fig. 5 Effect of port velocity on flame length at various equivalence ratio

(a) ϕ =0.25 (b) ϕ= 0.5 (c) ϕ = 0.75 (d) ϕ =1.0 (e) ϕ = 1.25 (f) ϕ= 1.5

The flame lengths are quantified by image processing using Matlab codes. A known reference length was captured with the same camera setting to calculate the number of pixels in 1cm. With this reference all the images were read using Matlab and the conversion of pixel count to linear dimension was carried out.

VI. Conclusion

The scope of this paper is to investigate the stability and characteristics of premixed flames with varying primary aeration. The effect of port velocity on flame stability at incipient lift and lift off conditions has been thoroughly investigated for a range of fuel flow rate and equivalence ratios. The results showed that, the lift off velocity decreases with increasing equivalence ratio. Flame characteristics such as flame shape, height and colour has been observed and compared for various premixing (equivalence ratio) and port velocity. The results of the experiments indicated that the flame height decreases with increasing premixing i.e., with increasing equivalence ratio. Tthe flame colour changed from sooting yellow to blue when the

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Authors Biography

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