BTP Stage - I

Report on

Flame Stability And Instabilities In A Backward Step Micro Scale Combustor With Premixed LPG–Air Mixture

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Certificate

Certified that this design project report titled ″**Flame Stability And Instabilities In A Backward Step Micro Scale Combustor With Premixed LPG–Air Mixture**″ by Micky is approved by me for submission. Certified, to the best of my knowledge, further, that the report represents work carried out by the students.

Date   Signature

Abstract

In this report, experimental investigations into the characterization of flame stabilization behavior in a backward step micro combustor with premixed LPG–air mixture are reported. Parametric investigations are carried out to understand the effect of mixture equivalence ratio, flow velocity on flame stability limits, flame position and flame length. The effect of various governing parameters such as equivalence ratio and mixture velocities is investigated in detail. Various stable and unstable flame propagation modes are observed for the range of conditions investigated. The regime diagram is also to understand the regions of instability. The details of these modes are analyzed with the help of a high speed camera and various results are presented.

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Introduction

Micro Scale Combustion

The dimensions of the combustor, which are equivalent or lesser than to that of the quenching distance is called as micro scale combustion. Micro scale combustion has high involvement of phenomena like flame-wall interaction and molecular diffusion on account of the small scale. The foreseen applications of the micro scale combustion are not only for electrical power but for heat and mechanical power sources. Particularly, sensors, actuators, portable electronic devices, robots, rovers, unmanned air vehicles, thrusters, industrial heating devices, heat and mechanical backup power sources for air-conditioning equipment in hybrid vehicles and freight transportation as well are anticipated areas of application. As the energy densities of the hydrocarbon fuels is about two order higher than existing modern batteries, the whole idea of micro scale combustion is based on it. Obtaining and maintaining thermal and chemical stability is the critical part of the micro scale combustion. In micro scale combustion several instabilities like rotating, pulsating or X-flames occur and understanding them is very important.

Organization Of The Report

In this report first the experimental details are covered in depth. Then analysis of the data gathered from the experiments is done. First the stability limits is discussed followed by the flame position characteristics, then flame instabilities observed and at last the conclusions and future work are discussed.

- Experimental Setup
- Regime Diagram And Flame Instabilities
- Flammability Limits
- Flame Position And Length Characteristics
- Conclusions And Future Work

Experimental Setup

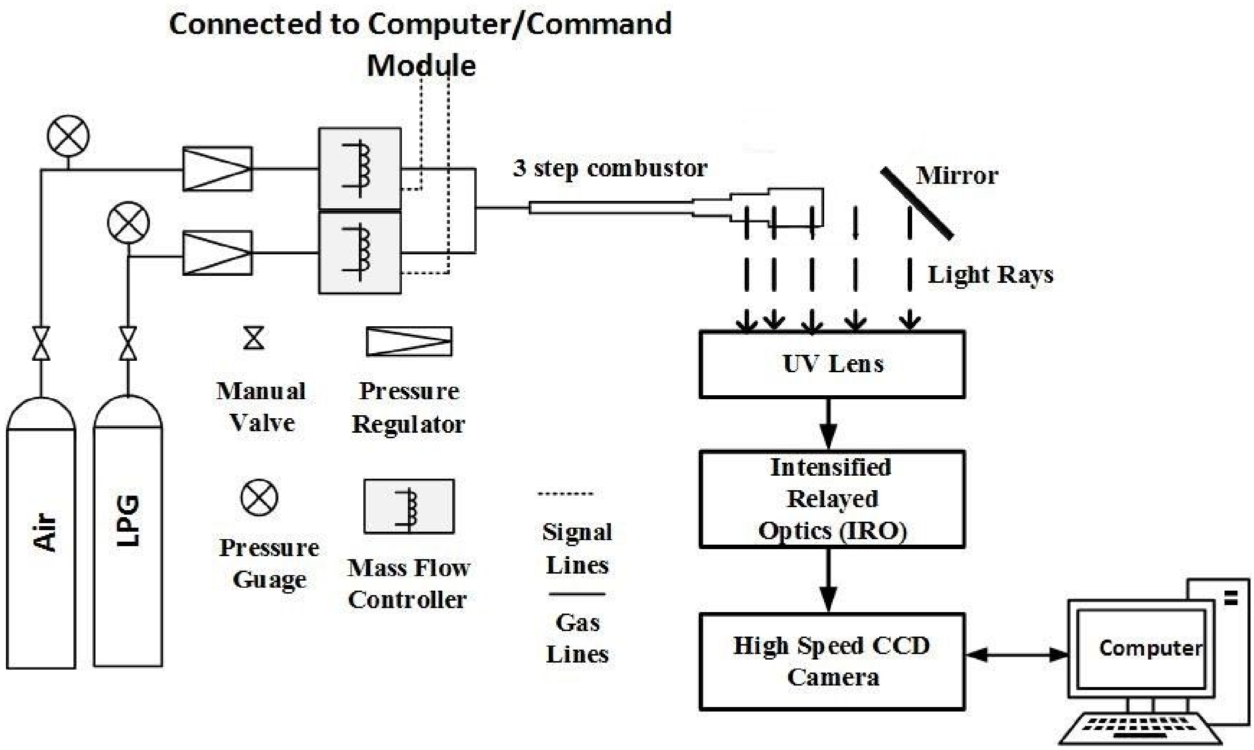
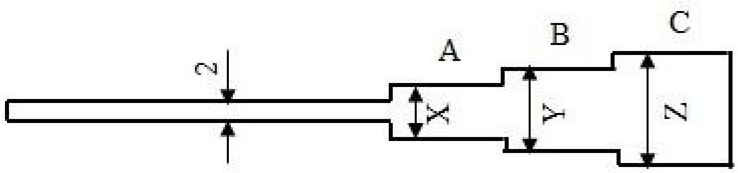


Figure 1. Schematic representation of the experimental Setup

Figure 1 shows the schematic diagram of the present experimental setup. The detailed dimensions of the combustor and heat recirculating cup are given in Figure 2. Combustor is made of quartz glass material. Both the cup and combustor are fixed in a special holder to ensure that they are concentric to each other. The cup holder and the combustor are fixed on an optical table to ensure a rigid setup for experimental studies. The combustor is held on a 3-axis stage on the optical table to have better freedom of movement for alignment and adjustment of desired gap between the cup and the combustor. High speed imaging system consisting of a *CCD* camera capable of capturing 3600 *fps* with 1 MP resolution, intensified relay optics (*IRO*) to amplify the light intensity of the low luminous small flames and a UV lens. This system is employed for detailed analysis of unstable flame propagation modes. The system is triggered by programmable timing unit, operated through a computer, and Davis imaging software package for image post-processing of the captured results. Longitudinal view of the flame dynamics is recorded directly through the lens, and the end view of the combustor (to observe the simultaneous movement in the transverse plane) is recorded with the help of a mirror setup installed at 45°, as shown in Fig. 1. The air and fuel flow rates are metered from the pressurized tanks through precise electronic mass flow controllers (accuracy *± 1.5 %* of full scale) and controlled with the help of command module connected to a computer. The range of the flow rate meters for air and fuel is 0 – 1 *LPM* and 0 – 0.2 *LPM* respectively. While performing the experiments, the equivalence ratio was kept constant and velocity (mixture flow rates) of the reacting mixture was gradually changed by rate of 0.1m/s. For velocities in steps 0.5m/s, the recording of the images was done only after the steady state was attained. This was confirmed by no change in the temperature on the cup wall.



	A	B	C	X	Y	Z
C1	10	15	7	3	4	6

Figure 2. Details of combustor dimensions. Thickness of the combustor wall is 1 mm. All in 'mm'

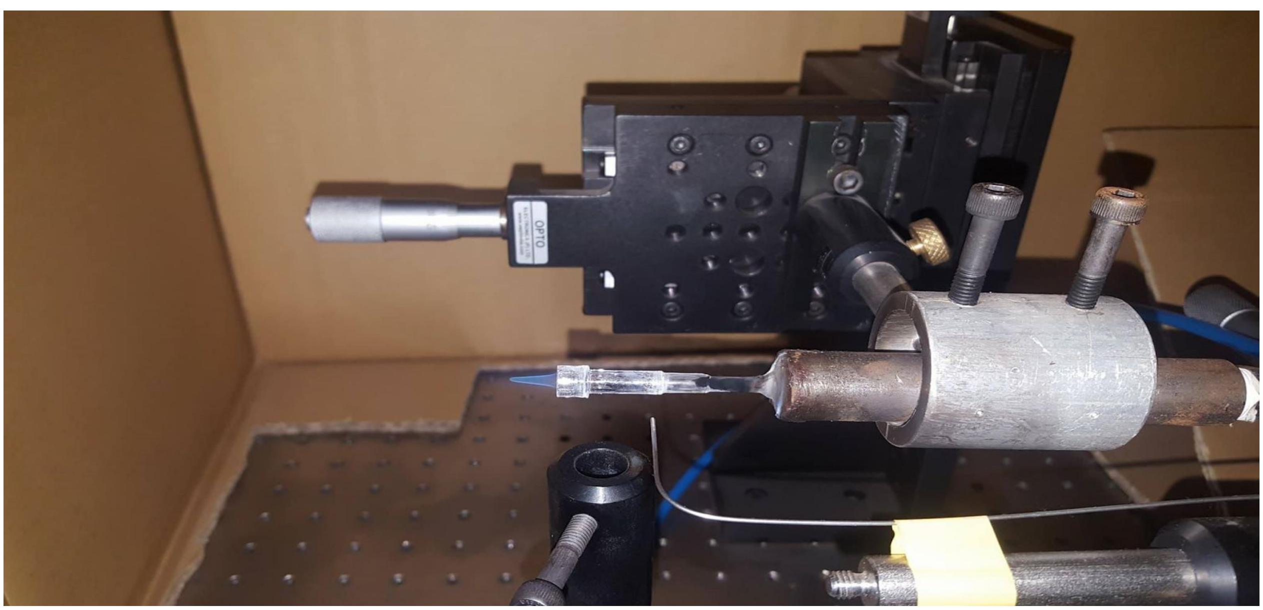


Figure 3. Experimental Setup

Flame Regime Diagram And Flame Instabilities

In this work, experimental studies are carried out on a three stepped micro combustor for a range of mixture flow velocities, V varying from 0.5 – 5.5 m/s and mixture equivalence ratio, varying from 0.8 - 1.4. Flame regime diagrams, different types of unstable flames occurring and their respective behavior is reported. This study will help provide a wide database to understand the intricate flame dynamics in backward step combustors for a range of operating conditions.

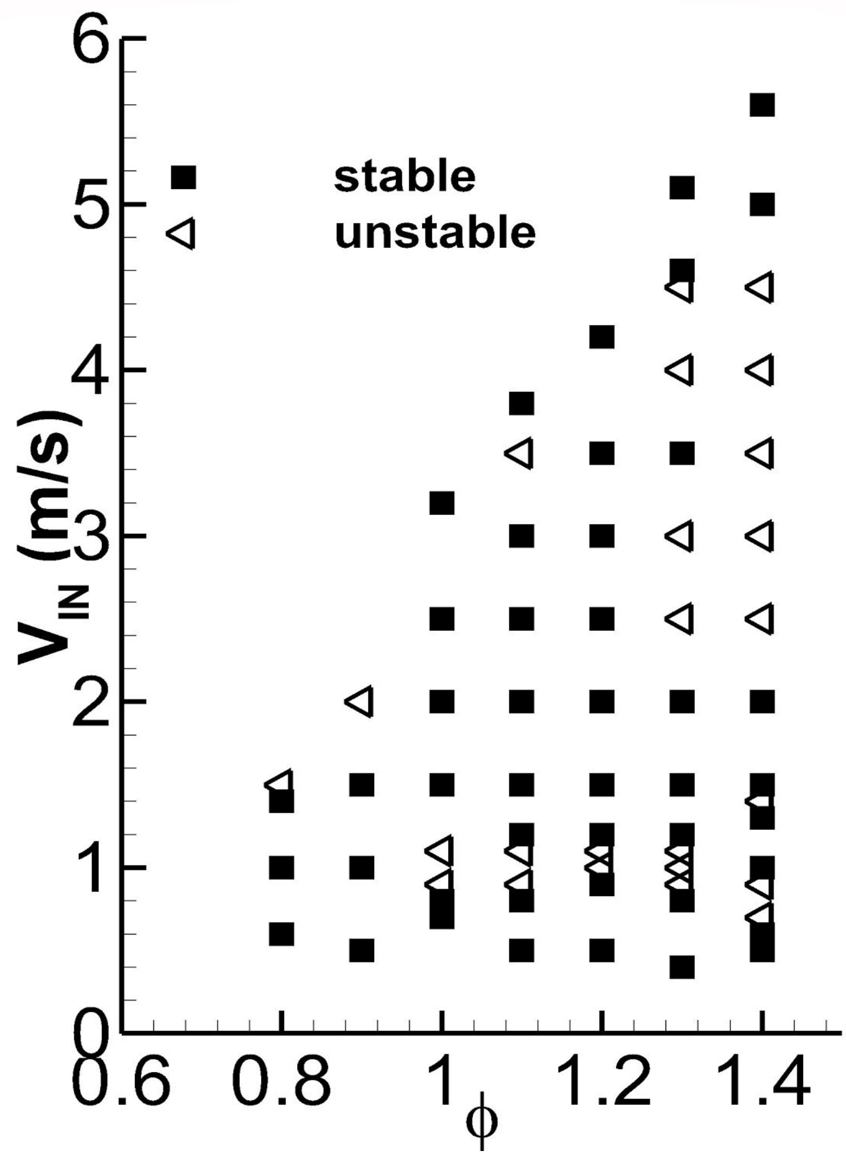


Figure 4. Regime Diagram

In the unstable region X-Flames were observed. In most of the experiments stable flames were observed. X-Flames are observed either at low velocities or at high velocities. As the equivalence ratio is increased the number of X-Flames observed also increases. In the experiments no pulsating flames were observed.

The following figure shows the X-Flame for equivalence ratio of 1.4 and velocity = 3.5 m/s

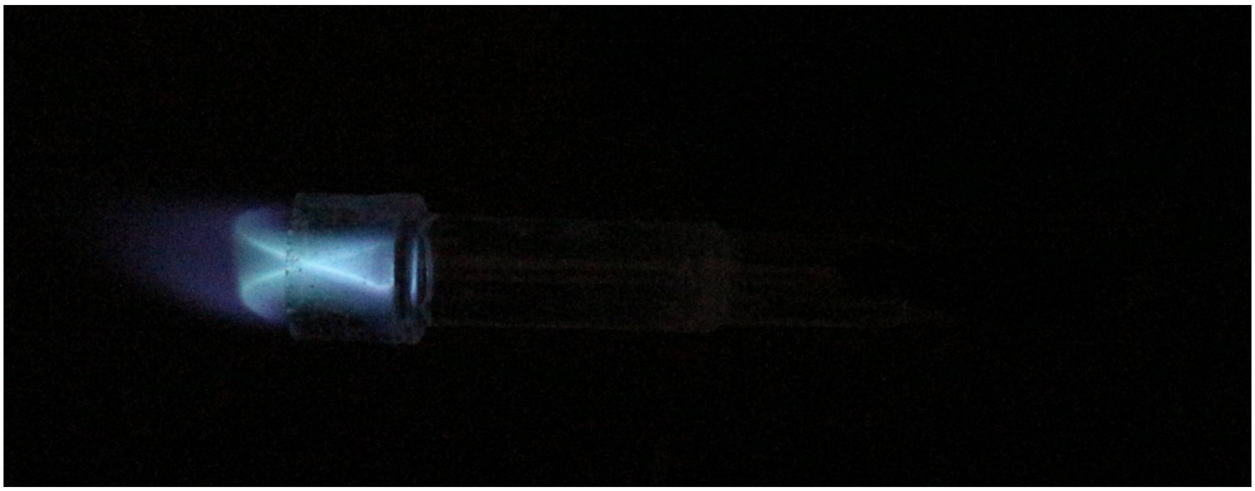
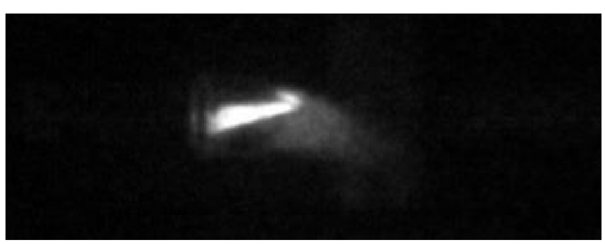
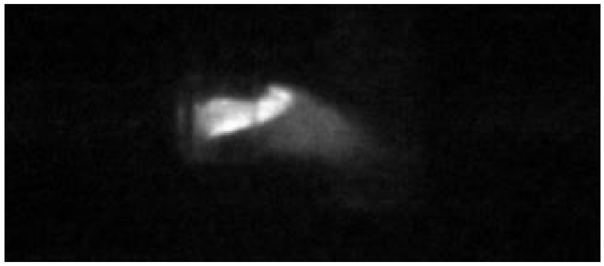


Figure 5. Image Taken By A DSLR

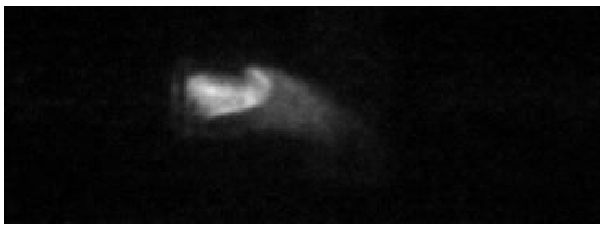
The following set of images are taken using High Speed IRO. The flame is rotating very fast and it looks like that an X has formed if seen through the naked eye. But in slow motion we can see the rotation of the flame.



(a)



(b)



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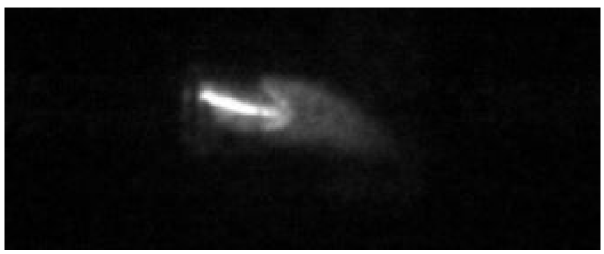

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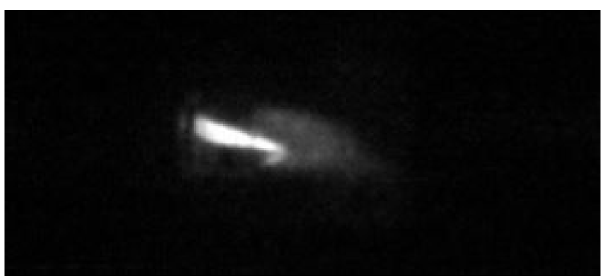

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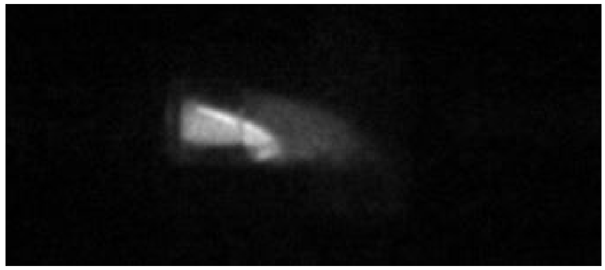

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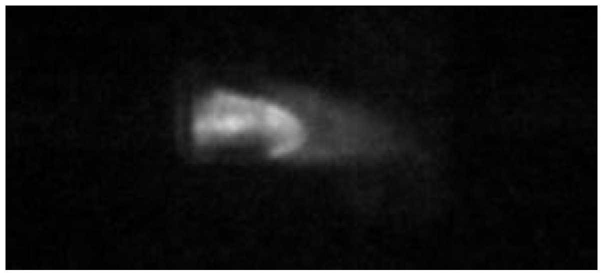

(g)

Figure 6. X-Flame

Flammability Limits

It was observed that the flame would either stay in the combustor or would stand at the exit plane of the combustors. The following 2 figures (4 and 5) show the positions of the flames.

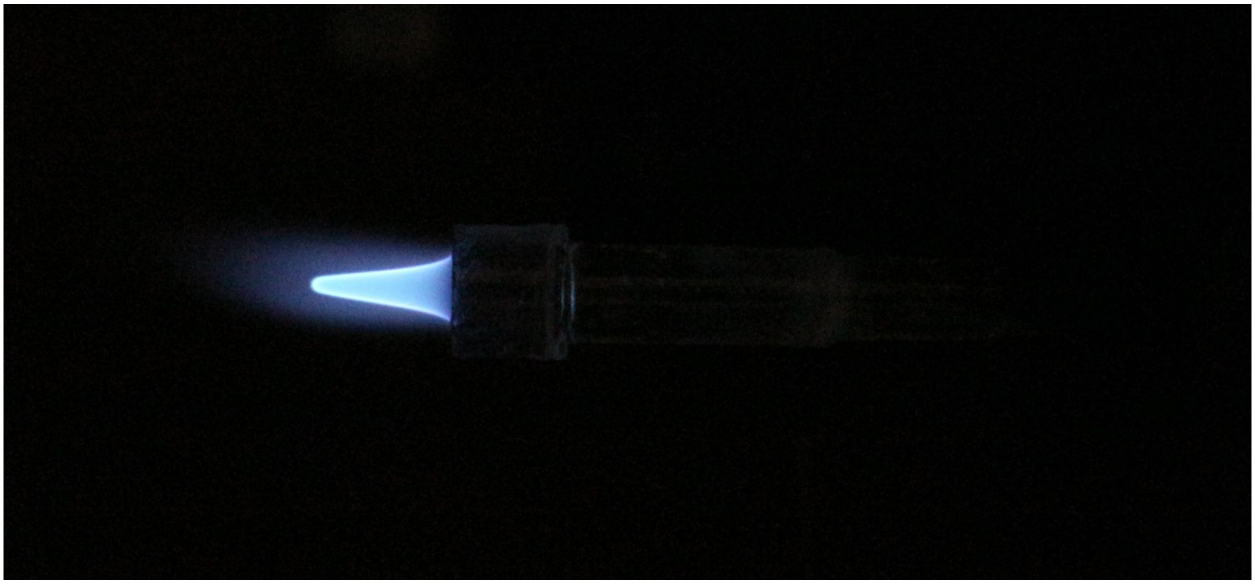

Figure 7. Flame At The Exit Plane

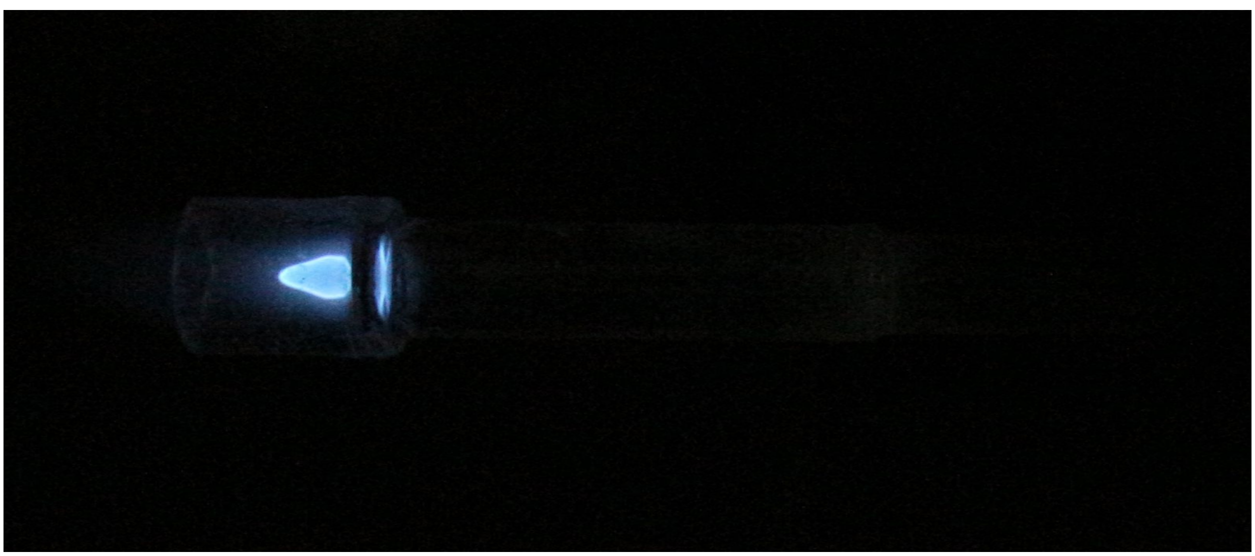

Figure 8. Flame Inside The Combustor

Figure 6 shows the flammability limits. The flame stands at the exit of the combustor for high velocities for a particular equivalence ratio. For lower velocities at a particular equivalence ratio the flame resides in the combustor.

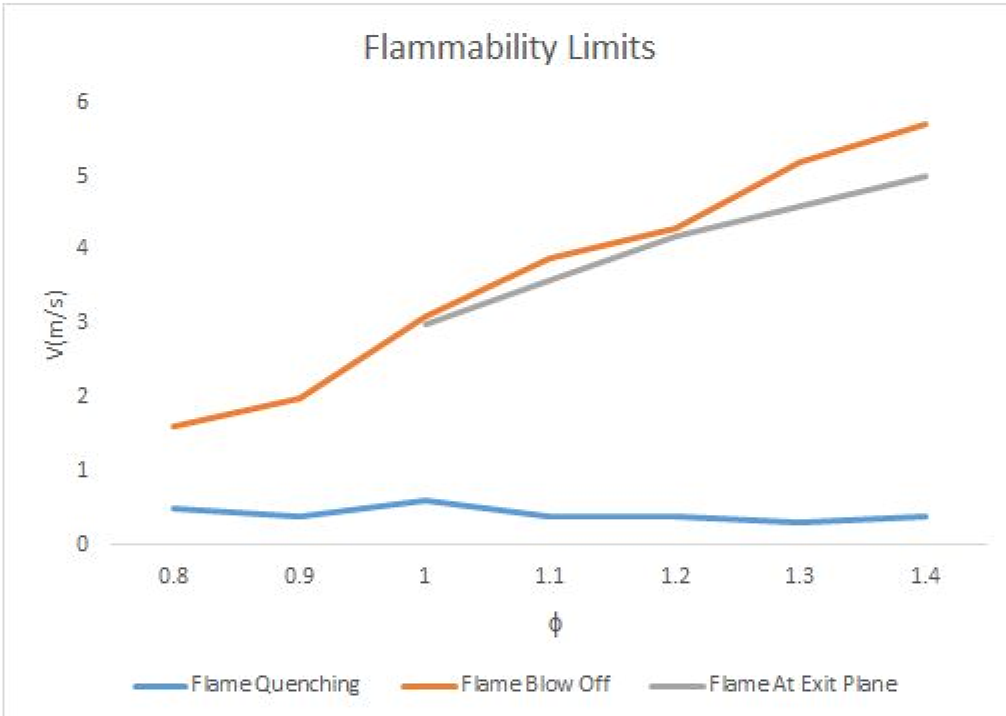

Figure 9. Flammability Limits

Flame Position And Length Characteristics

For different flow velocities and equivalence ratios the flame positions are also different. As the velocity is decreased for a particular equivalence ratio, the flame goes towards the inlet of the combustor till quenching. Figure 7 show the plots of flame velocity v/s flame position for equivalence ratio of 1.3. The flame position is measured from the combustor exit.

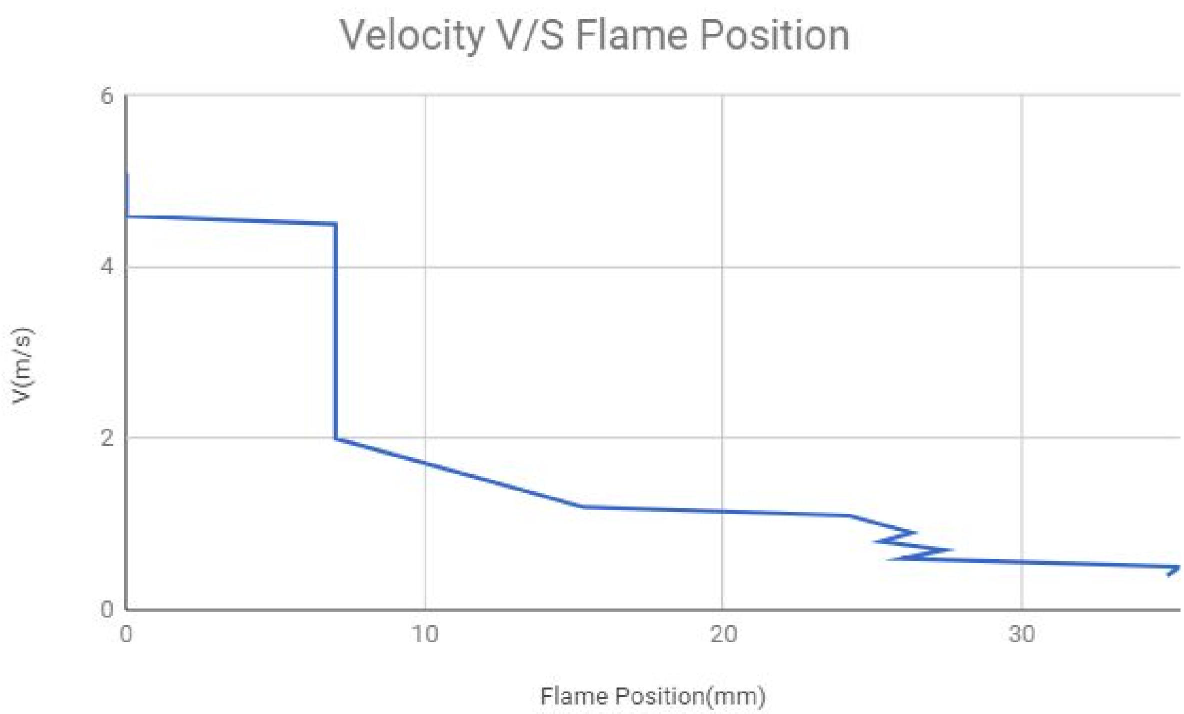

Figure 10. Velocity v/s Flame Position

As the velocity is decreased the flame starts going towards the combustor inlet till it gets quenched

Figure 8 shows the plot of velocity v/s flame length for equivalence ratio of 1.3. As the velocity is decreased the flame length also decreases.

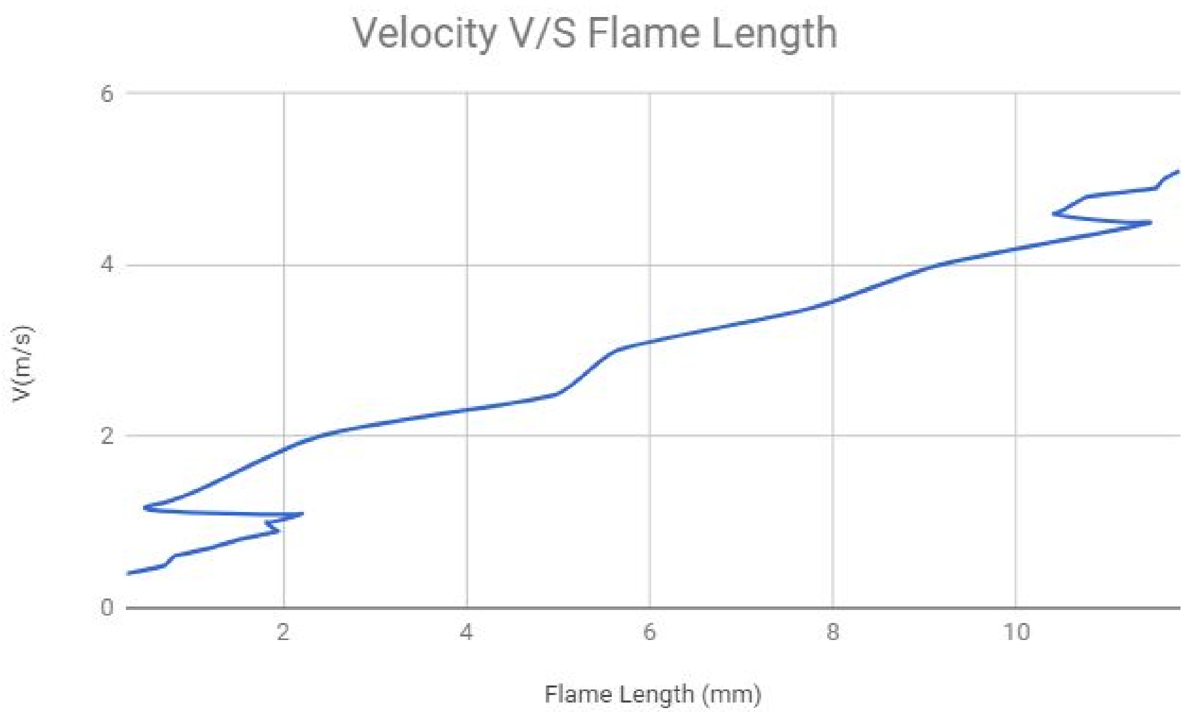

Figure 11. Velocity v/s Flame Length

Conclusions And Future Work

The flame for LPG-air premixed mixture has been studied in detail. The effect of mixture velocity and equivalence on the flame quenching, flame blow off, flame length and flame position in the backward step micro-combustor has been observed. The flame instabilities like X-flame observed are also described in detail. From the Regime diagram it is seen that the instabilities occur more for high velocity and fuel rich mixtures.

More analysis of flame instabilities needs to be done. CFD could also be done for flames in micro-combustors and the results can be validated against the experimental results presented in this report.

References

1. Bhupendra Khandelwal, Gur Partap Singh Sahota and Sudarshan Kumar1, *"Investigationsintotheflamestabilitylimits in a backward step micro scale combustor with premixed methane–air mixtures"*