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Effects of Reynolds Number and Equivalence Ratio on Flame Shapes

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Abstract – Experiments were conducted on premixed LPG/air circular flame jet to study the flame shapes. The parameters like equivalence ratio and Reynolds number have been varied to study the flame shapes and characteristics. Increased in both equivalence ratio and Reynolds numbers there was increase in height of the flame and soot formation in the flame was observed.

Keywords: Premixed LPG /Air Combustion, Analysis of Flame Shapes

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I. INTRODUCTION

Impinging jets have wide range of applications in melting the scrap, heating local areas, shaping the glass, drying of industrial material and domestic purposes. Flame jets are also used in breaking under sea rocks, cutting steel plates, concretes and ceramics to dismantle underwater structures.

H.B.Li et al. [1] conducted experiments to investigate the heat transfer and CO emission and also studied the flame shapes for different fuel/air mixture, equivalence ratio. S.G.Tuttle et al. [2] studied axial and radial profiles of time-averaged local heat flux of Methane-air jet flames impinging to a cooled plate by changing the equivalence ratio, Reynolds number and nozzle-plate placing. L.L.Dong et al. [3] conducted experiment to study the heat transfer characteristics of a premixed butane/air slot flame jet impinging on a rectangular plate by varying the Reynolds number and nozzle to plate distance. X.Q.Huang et al. [4] investigated the heat transfer characteristics by a premixed impinging laminar flame jet with induced swirl by varying Reynolds number and nozzle to plate distance. Z.Zhao et al. [5] used an array of three premixed butane-air fired impinging circular flames with induced swirl to identify heat transfer characteristics. C.E.Baukal and B.Gebhart[6] investigated heat transfer from oxygen-enhanced/natural gas flames impinging on a plate.

Subhash Chander and Anjan Ray [7] conducted experiment to study heat flux distribution of the target plate by three interacting Methane-air flame jest(arranged in a triangular configuration).H.S.Zhen et al.[8] investigated heat transfer behaviour of an annular jet flame impinging to a flat plate for different Reynolds number, equivalence ratio and nozzle to plate distance. It has been observed that peak heat flux occurs at a radial position at small nozzle to plate distance and increase in the nozzle to plate distance, heat flux coincides with jet axis. Naeem Khan et al.[9] studied jet diffusion flames fuelled by a LPG and Hydrogen. The flame height, lift-off velocity and lift-off heights were studied.Wei-Dong Hsieh and Ta-Hui Lin[10] conducted experiments and studied flame jet stability impinging onto a wall for different equivalence ratio, burner to plate distance, inlet velocity and inlet fuel concentration. From literature it has been observed that, there are few studies focused on flame shapes, therefore, the objective of present work is to study the flame shapes. The equivalence ratio and Reynolds number are varied to study the flame shapes

Nomenclature

Re	Reynolds number
m	Mass flow rate(kg/s)
d	Diameter of nozzle(m)
μ	Dynamic viscosity(Cp)
y	Mole fraction
M	Molecular weight
A/F	Air-to-fuel ratio
Ø	Equivalence ratio
Subscriptions	
mix	Air/fuel mixer
i	Mixture component of fuel and gas
stoic	Stoichiometric

II. EXPERIMENTAL SET-UP

The schematic diagram of experimental set-up is shown in Fig.1. The 10mm nozzle diameter burner has been employed to produce circular flame. The nozzle was fixed to a mixing chamber where various sized steel balls have been introduced for proper mixing of fuel (LPG) and air. The screen mesh has been attached above the steel balls in the nozzle to avoid the flashback of the flame. The designed, fabricated and calibrated orifice meters have been used to adjust the flow rate of LPG fuel and air according to the Reynolds number and equivalence ratio selected. The compressor was used to supply the compressed air to the burner. The digital camera was used to capture the flame shapes.

III. Data Reduction

The flame jet, exit Reynolds number was calculated based on air/fuel mixer as

$$Re = \frac{4m_{mix}}{\pi d \mu_{mix}} \quad \text{.....(1)}$$

Dynamic viscosity of mixture was calculated according to Ikoku [11] as

$$\mu_{mix} = \frac{\Sigma(\mu_i y_i \sqrt{M_i})}{\Sigma(y_i \sqrt{M_i})} \quad \text{.....(2)}$$

Equivalence ratio was calculated by

$$\emptyset = \frac{(A/F)_{stoic}}{(A/F)_{actual}} \quad \text{..... (3)}$$

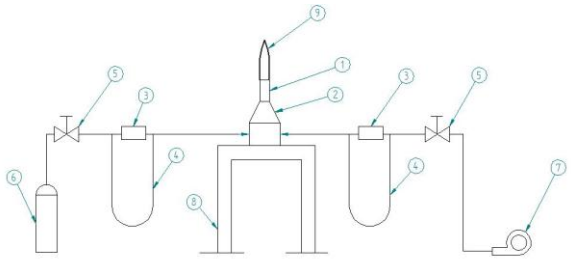

Fig.1. Schematic of Experimental setup.

1. Nozzle 2.Burner 3. Orifice meter 4. U -Tube manometer 5. Control valve 6. LPG Cylinder 7. Compressed air line 8. Steel frame 9. Flame jet

IV. EXPERIMENTAL PROCEDURE

For the selected Reynolds number and equivalence ratio, the metered quantity of air and fuel was supplied to the mixing chamber of the burner. The calibrated orifice meters were used to ensure the supply of fuel/air mixture to the burner (Fig.1). The fuel was ignited at the tip of the nozzle. The camera was placed at the fixed position to capture the flame shapes for different operating conditions. In the experiments both equivalence ratio (Ø =1, 1.2, 1.4, 1.6, 1.8 and 2) and Reynolds number (Re=1000, 1200, 1400, 1600, 1800 and 2000) have been varied and flame shapes were captured.

V. RESULTS AND DISCUSSIONS

Circular flame shapes of LPG/air flame jet have been studied in the experiments. The effects of parameters like equivalence ratio and Reynolds number on flames were studied. Fig.2 to Fig.7 shows the photographs of flame shapes for different operating conditions. For each of the equivalence ratio the Reynolds number have been varied. The equivalence ratio selected to conduct the experiments were Ø= 1, 1.2, 1.4, 1.6, 1.8 and 2. And the Reynolds number selected were Re= 1000, 1200, 1400, 1600, 1800 and 2000. From the figures it is observed that, all the flames are in conical in shapes with bright blue colour inner reaction zone and light blue colour outer diffusion zone. With the increase in the Reynolds number, the flame height increased gradually and this is because of large amount of charge (Fuel and air) coming out of nozzle of the burner. At the equivalence ratio of Ø =1.8 and 2, the flame exhibits in bright yellow colour at the outer envelope.

The reason for this is the indication of formation of soot in the combustion. Higher the equivalence ratio, rich mixture is created and incomplete combustion of this fuel results in the soot formation.

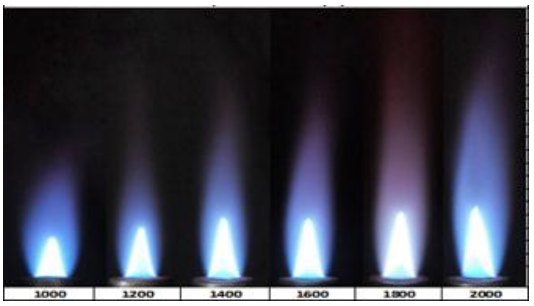

Fig.2. Flame shapes at Ø=1 and at Re=1000, 1200, 1400, 1600, 1800 and 2000.

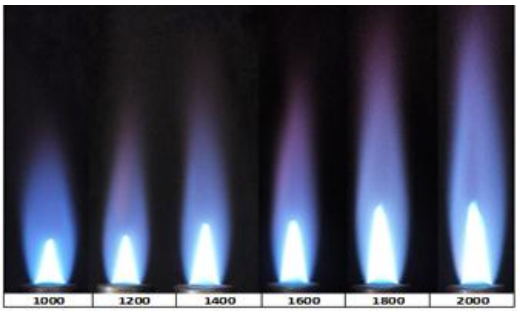

Fig.3. Flame shapes at Ø=1.2 and at Re=1000, 1200, 1400, 1600, 1800 and 2000.

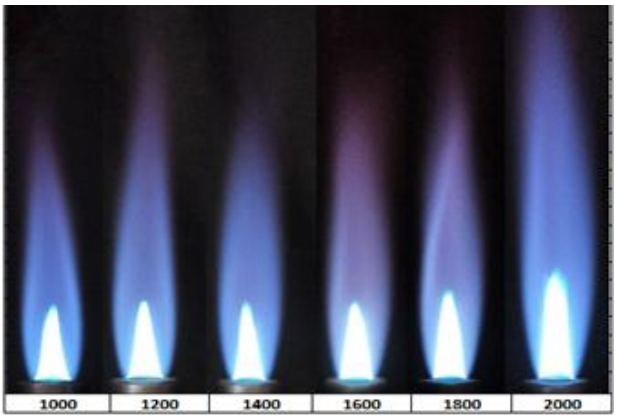

Fig.4. Flame shapes at Ø=1.4 and at Re=1000, 1200, 1400, 1600, 1800 and 2000

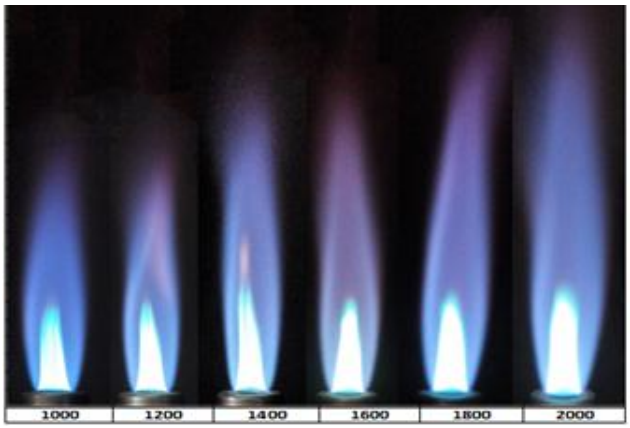

Fig.5.Flame shapes at Ø=1.6 and at Re=1000, 1200, 1400, 1600, 1800 and 2000

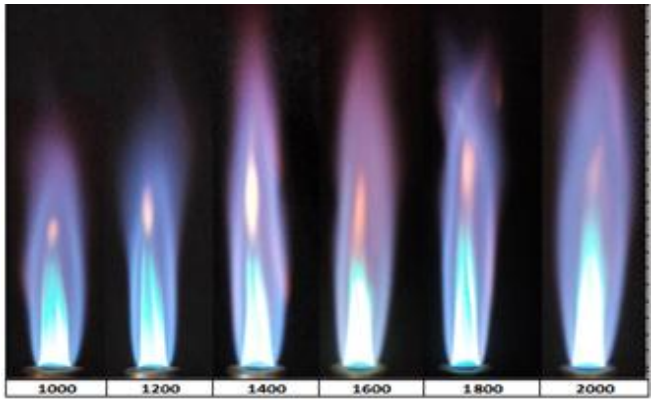

Fig.6. Flame shapes at Ø=1.8 and at Re=1000, 1200, 1400, 1600, 1800 and 2000

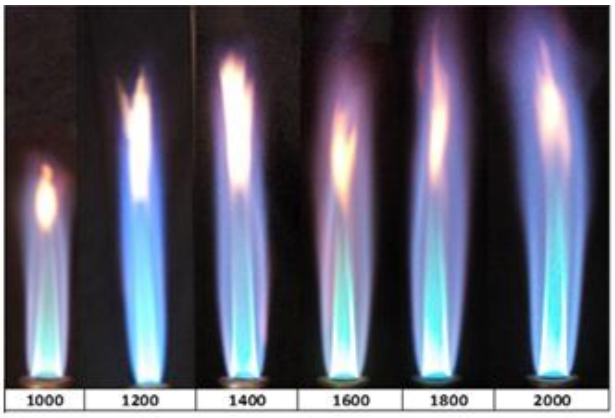

Fig.7. Flame shapes at Ø=2 and at Re=1000, 1200, 1400, 1600, 1800 and 2000

CONCLUSION

Experiments were conducted to study the flame shapes of circular premixed LPG/air flame jet. Both the Reynolds number and equivalence ratio were varied to study the effects on flame shapes. Based on the experimental results, the following conclusions were made.

- Inner reaction cone (bright blue colour) and outer envelope (light blue colour) has been observed for all the Reynolds number and equivalence ratio.
- Increase in the Reynolds number increased the height of the flame.
- For the Equivalence ratio of Ø =1.8 and 2, the flame exhibits in bright yellow colour at the outer envelope which indicates the soot formation.

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