IJAAST
ONLINE ISSN 2277- 1565
PRINT ISSN 0976 - 4828

International Archive of Applied Sciences and Technology
IAAST; Vol 4 [2] June 2013: 70-75

[ISO9001: 2008 Certified Organization]
www.soeagra.com/iaast/iaast.htm

CODEN: IAASCA ORIGINAL ARTICLE

Effect of Preheated Air on the Structure of Coaxial Jet Diffusion Flame

S.Sreenatha Reddy
Universal College of Engineering & Technology,Guntur, India
Email: sreenath_sakamm@yahoo.co.in

ABSTRACT

This paper deals with the influence of preheated air on coaxial jet diffusion flame in terms of the flame length, temperature and emission. It has been observed that at ambient co-flowing air, flame gets lifted off with increase in fuel jet velocity. Once the flame lifts off from the burner rim, the base of the flame will transform from yellow to blue color indicating that the occurrence of premixed zone while the upper portion of the flame will remain as yellow. This observation confirms occurrence of triple flame zone for a lifted flame as reported by other researchers. It has also been observed that the increase of coaxial air causes a significant reduction in the flame length. In the present study, an attempt has been made to relate flame height in terms of jet Froude number. The flame length is found to get reduced with increasing preheated air temperature at particular fuel and air jet velocity. Interestingly liftoff height seems to be nonexistent with increase in co-flowing air temperature. The flame is totallyyellow in color, almost without any blue flame base. However, the blue color of lower portion of flame base gets increased slightly by the increasing the fuel flow rate. However, increasing the preheated air temperature increases the NOx concentration in the flue gas as it depends on the flame temperature and residence time in the high temperature region. The CO concentration shows a decreasing trend with higher preheated air temperature as the rate of CO conversion to CO2 is enhanced with the high temperature of preheated co-flow air.

Key Words: *Preheated Air, Diffusion Flame, Emission and Flame Length*

Received 25.05.2013 Accepted 17.06.2013

INTRODUCTION

There is a growing worldwide concern for emissions of green house gases because of global warming. As the combustion of fossil fuels contributes a large amount of green house gases to the atmosphere, there is an urgent need to find out plausible ways of reducing the emission of green house gases from the combustors. The most effective way of reducing emissions is to increase the thermal efficiency of combustion system. Diffusion flame based combustor has huge application in the field of aerospace engineering like gas turbines, liquid thrust chambers,

furnaces, boilers etc. However, the parameters affecting the performances of combustors are flame length, flame stability, temperature distribution emission, etc. Though certain studies related to the flame stability have been undertaken by various researchers, it is still intriguing when it comes to understand the preheated lifted jet diffusion flames. Hence, it is envisaged in the current research proposal to take-up study related to flame stability and emission in a coaxial jet diffusion flame burner with highly preheated air to explore the possibilities of achieving higher efficiency while decreasing the emission levels. The stability of jet diffusion flame can be characterized in terms of liftoff and blow off phenomena which can be described using a schematic of a coaxial jet diffusion flame, shown in Fig 1(a). At sufficiently low fuel exit velocities, U***f***, the flame front is attached to the nozzle rim. By increasing the fuel exit velocity the flame finally detach from the base of the burner rim due to stretching of the flame front. As a consequence, the flame lifts off and stabilizes itself further downstream within the jet. The velocity at which this occurs is known as the lift-off velocity and the distance between the burner rim and the base of the lifted flame is called as the lift-off height, HL, as shown in Fig. 1(b). When jet exit velocity increases further, the lift-off height increases but cannot exceed a critical value at which the flame completely blows out. This velocity is termed the blowout velocity.

The diffusion flames are frequently used in industrial devices such as furnaces, diesel engines and gas turbine engines. Recently, efforts are being made to reduce the emissions from the combustion system and enhancing the thermal efficiencies by oxygen enrichment [1-2]. The research group at Tokyo gas Ltd has developed a flue direct injection concept to enhance the thermal efficiency [3]. In this method, fuel gas is injected discreetly into the hot combustion products. Similar ideas are developed in conjunction with oxy-natural gas combustion. Several developed countries has developed this new combustion processes.

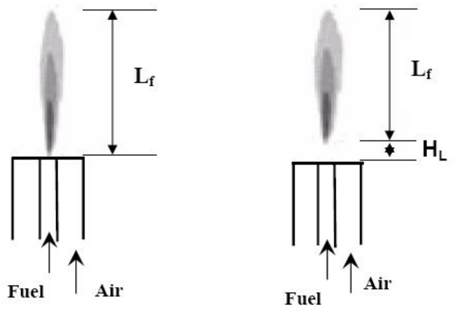

Fig. 1: Schematic diagram of (a) attached diffusion flame (b) lifted diffusion flame on a coaxial burner.

Hasegawa and Tanaka [4] were first in Japan to propose high temperature air combustion as revolutionary combustion technology. They had demonstrated that by using preheated air at 1010 oC and 3.0 % O2, the flame stability and flame volume can be enhanced considerably. They could achieve very low values of NO and CO emission level with a uniform temperature distribution across the whole furnace. Takagi et al [5] could manage to establish stable combustion in the furnace by using preheated air containing a very low level of oxygen concentration. They have also observed that thermal field in the furnace is much more uniform as compared to conventional furnace. However, the flow characteristics in the furnaces are complicated where recirculation zone is likely to be formed which influences strongly the mixing processes of fuel with oxidizer. Hence, it is important to look at the coaxial turbulent flame with preheated air to understand the basic processes with relatively simple and well-defined flow fields. Ishiguro et al [6] have investigated the effects of oxygen concentration in the preheated air on combustion using an inverse concentric burner. The volume fraction of oxygen in the air was varied from 10 to 20 %. They have also used ultra violet high-speed video camera to determine the spatial distribution of OH, CH and C2 emission. They have observed that the flame to be more stable
as compared to ambient air combustion. They have argued that the homogenization and stabilization of flames at higher air temperature can lead to higher thermal efficiency by adopting effective use of exhaust gas recirculation. However, they have not characterized the net pollutant emissions of this kind of burner from its exit. Subsequently, the effects of liftoff on the NOx emission of the turbulent jet flame in a high temperature co-flowing air have been investigated by Fujimori et al [7] who observed two types of lifted flame, namely near-lifted and far-lifted flame. They have observed that the NOx emission decreases rapidly with increase in preheated air temperature as the liftoff height increases in the case of far-lifted flame. In contrast, such kind of distinct decrease in NOx has not been found to be occurred near-lifted flame case. Lille et al [8] have studied combustion in a single fuel jet of gasol, under steady state conditions. They have found very stable and complete combustion with reduced oxygen concentration in flue gases and increased flame size, increased lift off distance and decrease luminosity and visibility with very low emissions of pollutants such as NO and CO. In the experimental investigation of Costa et al [9] measurements of flame length and lift off height are reported for lifted diffusion flame under ambient temperature condition in terms of plot between the variations of the flame length, normalized by the nozzle exit diameter, with the jet Froude number for propane. From this it has been observed that the buoyancy-dominated regime, Lf/Df scales with Fr 1/5, in agreement with the findings of Rokke et al [10] who had proposed a theoretical correlation to predict the flame length for buoyancy-dominated hydrocarbon turbulent jet diffusion flames. Flame size, visibility, color and liftoff height was examined by Lille et al [11] in highly preheated air combustion while varying the oxygen concentration. It was concluded by them that an enhancement in oxidizer temperature reduces the size and liftoff distance of the flame. Furthermore, when oxygen content is slightly increased it proportionately improves the liftoff. But when it comes to the flame visibility, it goes down with reducing oxygen concentration and goes up with temperature. The flame color changes from luminous yellow to blue with the decrease in oxygen concentration. Maruta et al [12] investigated the combustion limit and reaction zone structure of non-premixed counter flow flames by highly preheated air and methane diluted with nitrogen. They have found that air temperature higher than 1300 K has resulted in disappearance of the extinction limit because of the high energy inflow, carried by the high-temperature air into the reaction zone. The reaction without any temperature peak was observed under fuel-lean conditions with very low NO

emissions. Gupta [13] has used a specially designed regenerative combustion test furnace facility to preheat the combustion air to high temperatures. He has found that the flame with highly preheated air is much more stable and homogeneous with low levels of NOx along with negligible amounts of CO and HC. He has concluded that the thermal and chemical behavior of high air temperature combustion flame depends on fuel property, preheat temperature and oxygen concentration in air. The flame volume is also found to go up with the air temperature and lesser oxygen concentration in combustion air. At constant temperature, the total flame size has reduced with varying the oxygen concentration from 2% to 21%. Under certain conditions flameless oxidation has also been observed.

EXPERIMENTAL APPARATUS

The schematic of the present experimental setup shown in Fig. 2(a) has been designed and developed in the laboratory indigenously to study the coaxial jet diffusion flames with preheated air. The various components of the set-up include combustion chamber, heater, air and fuel supply system, burner, flow regulating valves, flow meters, CCD camera and NDIR and Chemiluminescence analyzer etc as shown in Fig. 2(a). The combustion chamber is rectangular stainless steel assembly of height 1500 mm, and width of 150 mm. One side of the chamber has two quartz windows of height 300 mm and width of 80 mm. One end of the chamber is attached to a base which contains gas and air injection units at its centre. Fuel, supplied from the Liquefied Pertroleum Gas (LPG) cylinder is metered through a calibrated rotameter to the burner. Air is supplied to burner through a heater from high pressure air chamber. It passes through a series of pressure regulating valves, needle valves and calibrated rotameters before entering into the combustion chamber through heater. A CCD video camera is used for flame photography (Sony, Model No-DCR-PC350E). The time-averaged photographs are processed to determine the lift-off and flame length using edge detection method with the help of Image-J software. The co-axial burner used in present study is shown

schematically in Fig. 2(b). It consists of an inner tube with an orifice of 1 mm diameter for carrying the fuel to the combustion zone. The inner diameter of 43 mm tube is used for supplying coaxial air to the burner. The experiments are conducted by the use of preheated air using an electric heater. The heater is made up of spherical Galvanized Iron (GI) pipe cylinder of inner diameter 105 mm and 300 mm height, internally coated with high temperature cement containing three probe holes of diameter 20 mm, each furnished with heating coil. The K-type

(Nickel-Chromium vs. Nickel-Aluminum) thermocouple is used to measure the temperature of preheated air. A schematic of the exhaust gas sampling system employed is also shown in the Fig. 2(a). Combustion gases from the post flame region are sampled using a water-cooled stainless steel probe for the measurement of NOx, O2, CO, and CO2 concentration. For measurement of CO2 and CO emission levels, a non-dispersive infrared gas analyzer is employed while electrochemical gas analyzer is used for O2 measurements. For the measurement of NOx a chemiluminescence analyzer is used.

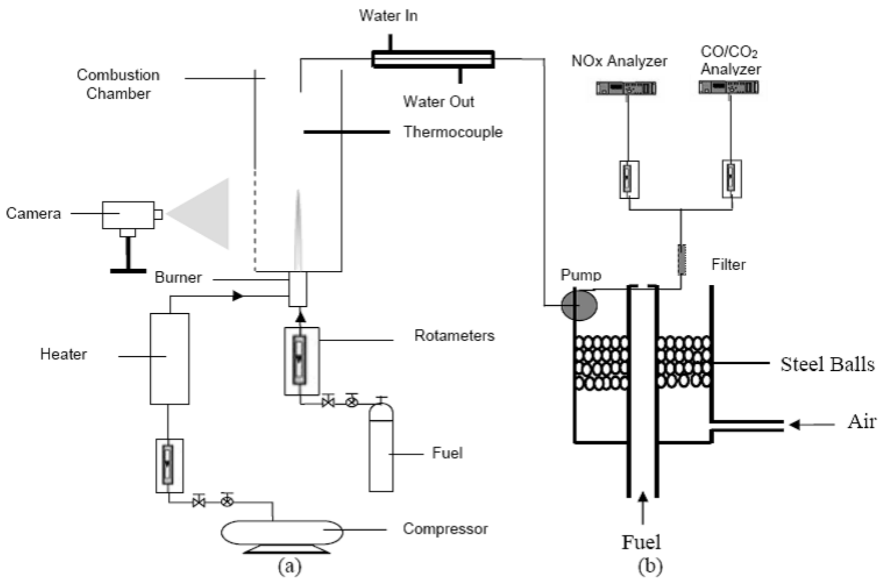

Fig. 2: Schematic of (a) Experimental Set-up (b) Co-axial burner

RESULTS AND DISCUSSION

The effect of preheated combustion air on the structure and shape of the diffusion flame for different fuel flow rates is investigated in the present study. The flame length normalized by the nozzle exit diameter with jet Froude number for different co-flow air temperatures are shown in Fig. 3. It can be observed that there is a change in slope of this curve, indicating the occurrence of two different flame regimes, such as buoyancy and momentum dominated regime. In the buoyancy dominated regime, the flame length is the function of Jet Froude number, whereas, it is independent of the jet Froude number in momentum dominated regime. It can also be seen that when preheated air is fed, the flame length gets reduced as compared to the normal temperature air. Interestingly liftoff height seems to be very small or negligible with the enhancement of co-flowing air temperature. Lille et al [12] while studying highly preheated air combustion with varying the oxygen concentration observed the similar results. It is concluded by them that an enhancement in oxidizer temperature reduces the size and liftoff distance of the flame. At low fuel flow rate, the flame is observed to be totally yellow in color, almost without any blue flame base. But the blue color of flame base increases slightly by the increasing the fuel flow rate. Variation of flame length with co-flow air temperature (Ta) for different fuel flow rate is shown in Fig. 4. The flame length is inversely affected with preheated air temperature at particular fuel and air jet velocity. The overall reduction in flame length for 0.1 and 0.2 lpm of fuel is about 27% and 25% respectively with increasing preheated air temperature. According to the Roper's correlation, for circular burner ports and co-flowing air, the flame length is inversely proportional to diffusion coefficient which is directly proportional to the temperature (T3/2).

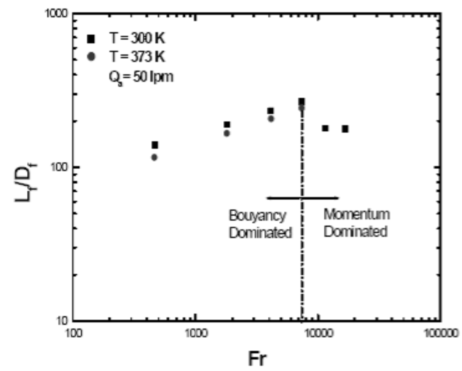

Fig. 3: Variation of the Flame length (L_f), normalized by the nozzle exit diameter (D_f), with jet Froude number, Fr for different co-flow air temperatures.

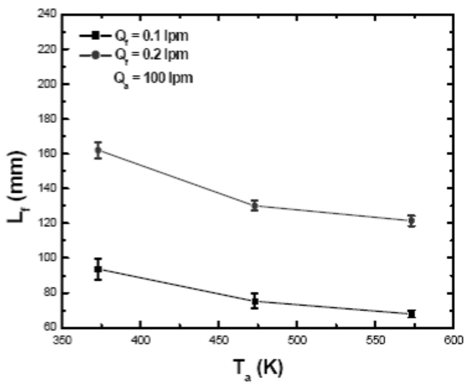

Fig. 4: Variation of flame length with co-flow air temperature for different fuel flow rate.

The change in the NOx emission level with co-flow air temperature for different fuel flow rate is shown in Fig. 5. It can be seen that with higher preheated air temperature, the thermal NOx concentration attains a maximum value which may be attributed to the higher flame temperature as observed in Zeldovich mechanism. Further, it can be noted that NOx concentration is affected in the same way as that of preheated air with fuel flow rate at fixed air flow rate. This is because of the change in the preheated air temperature which increases the flame temperature and hence bringing the strong dependency of NOx production as mentioned Zeldovich mechanism. Figure 6 shows variation in the concentration of CO with co-flow air temperature for different fuel flow rate. The concentration of CO is showing further increase with the fuel flow rate at fixed air flow rate. This may be due to the reason, that at higher fuel flow rate, it does not get completely oxidized resulting in more CO concentration in the flue gas. Further, the CO level shows a decreasing trend with higher preheated air temperature. This is perhaps due to the enhancement of CO conversion to CO2 at higher preheated co-flowing air temperature. Figure 7 shows the CO2 concentration variation with the co-flow air temperature for different fuel flow rate. It can be observed from the figure that CO2 concentration becomes higher with respect to flow rate. However, it can be observed that the temperature is not having much effect in enhancement of the carbon dioxide concentration. The O2 emission level

variation with co-flow air temperature is shown in Fig. 8 for different fuel flow rates that the O2 concentration in the flue gas remains almost constant throughout the combustion process with the higher preheated air temperature at constant air flow rate. But it decreases with increase in fuel flow rate as expected because more oxygen is to be consumed for burning excess of fuel.

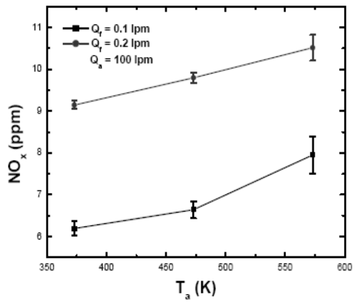

Fig. 5: Variation of flame length with co-flow air temperature for different fuel flow rates.

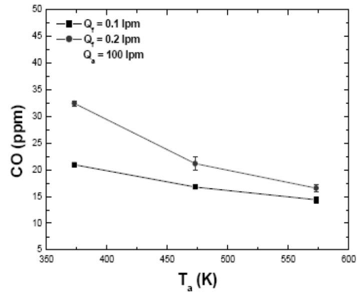

Fig. 6: Variation of CO emission level with co-flow air temperature for different fuel flow rates.

CONCLUSION

The present investigation indicates that the preheating has a substantial effect on the structure of the flame. The flame length with preheated co-flow air decreases substanitally in comparison to the normal co-flow air. However negligible difference could be observed with the lift off height, when combustion is carried out with preheated air. The flame becomes highly yellow color almost without any blue flame base at low fuel flow rate. But as the fuel flow rate is increased, a thin blue portion is appeared at the base of the flame and further increases with further

increase in fuel flow rate. As per expectation, increasing the preheated air temperature increases the NOx concentration in the flue gas as NOx formation is directly dependent on the flame temperature as per Zeldovich mechanism. The CO concentration shows a decreasing trend with higher preheated air temperature as the rate of CO conversion to CO2 is enhanced with the high temperature of preheated co-flow air. However, CO2 concentrationbecomes higher with respect to fuel flow rate and found to be having less effect on the carbon dioxide concentration. It has also been found that with higher air preheat the oxygen

concentration remains unchanged, but a slight decrease is observed with higher fuel flow rate. This study will help in great deal to have a better understanding of preheated air diffusion flame which will be helpful in the design and development of better combustion system.

ACKNOWLEDGEMENTS

The authors greatly appreciate the financial support of this work by the "Management of Universal College of Engineering & Technology,Guntur, India

REFERENCES

1. Poukashanian M, Yap T, L and William A,(1990). "The use of oxygen enrichment in combustion technology", Proceedings of the Institute of Energy, ISBN 0/85274/2800, pp 301-314.
2. Hedly J. T, Pourkashanian M, Willam A and Yap T. L,(1995). "NOx formation in large scale oxy-fuel Flames," Combustion Science Technology, 108, pp. 311-322.
3. Nakamachi, I, Yasuzawa K, Miyahara T and Nagata T, (1990)."Apparatus or method for carrying out combustion in a furnace", US patent 4945841.
4. Toshiaki Hasegawa and Ryoichi Tanaka, (1998). "High temperature Air combustion-Revolution in combustion Technology", JSME International Journal Series B, Vol4, No.4, pp.1079-1084.
5. Takagi, T, Xu Z, and Komiyama, M,(1996). Combustion & Flame, 106, 252-260.
6. Ishiguro T, Tsuge S, Furuhata K, Kitagawa N, Arai T, Hasegawa R, Tanaka and A K Gupta, (1998). "Homogenization and stabilization during combustion of hydrocarbons withpreheated air", 27th symposium (International) combustion, p p3205-3213.
7. Fujimori T, Riechelmann and Sato J,(1998). "Effect of liftoff on NOx emission of turbulent jet flame in high temperature coflowing air", 27th symposium (International) combustion, pp1149-1155.
8. Lille S, Blasiak W, Jewartowski M,(2005). "Experimental study of the fuel jet combustion in high temperature and low oxygen content exhaust gases", Royal Institute of Technology (KTH), Energy 30, 373-384.
9. Santos, A and Costa, M,(2005). "Reexamination of the scaling laws for NOx emissions from hydrocarbon turbulent jet diffusion flames", *Combustion and Flame* 142, pages: 160-169.
10. Rokke, N. A., Hustad, J. E, Sonju, O. K., and Williams, F. A, "Scaling of nitrogen oxide emissions from buoyancy-dominated hydrocarbon turbulent jet diffusion flames", Twenty-Fourth Symposium (International) on

combustion, The Combustion Institute, pages 385-393, Pittsburgh, 1992.
11. Lille S., Dobski T., and Blasiak W.,(2000). "Visualization of fuel jet in conditions of highlypreheated air combustion", Journal of propulsion and power, Vol. 16 No. 4.
12. Maruta K., Muso K., Takeda K., Niioka T.,(2000). "Reaction zone structure in flameless combustion", The Combustion Institute, Vol. 28, pages 2117-2123.
13. Gupta A. K.(2000). "Flame characteristics and challenges with high temperature air combustion", International Joint Power Generation Conference, Miami Beach Florida, IJPGC 2000-15087, July 23-26..

Citation of Article: S.Sreenatha Reddy. Effect of Preheated Air on the Structure of Coaxial Jet Diffusion Flame. Int. Arch. App. Sci. Technol., Vol 4 [2] June 2013: 70- 75