ISSN (ONLINE): 2454-9762
ISSN (PRINT): 2454-9762
Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 7, Issue 4, April 2021

EXPERIMENTAL INVESTIGATION ON THE CHARACTERISTICS OF AIR AND OXYFUEL LPG FLAMES IN TUBULAR BURNER

S. Arunachalam[1], S.M. Aslam Mohammed[1], N. Boopalan[1], P. ChinnaDurai[1]

[1]Undergraduate Student, Department of Mechanical Engineering, Francis Xavier Engineering College Tirunelveli , Tamilnadu - India.

ABSTRACT*:* The present energy crisis and the growing concern over emission lead to the development of various low emission technologies for efficient utilization of fossil fuels. These technologies offer the benefits of continue using fossil fuels without harming the environment. Oxyfuel combustion technology is one of the promising low emission combustion techniques which have also the advantage of being a better retrofit option. Domestic and industrial burners used nowadays, employ premixed and non-premixed flames for various applications. Both of the modes of combustion are associated with its own advantages and disadvantages. In conventional air combustion, combustion occurs in the presence of O_2/N_2 where oxygen alone is needed for combustion and nitrogen doesn't participate in the combustion process at all. Also, the flue gas leaving the conventional system is primarily N_2 and only a trace amount of CO_2 which is energy expensive to capture and sequestrate. In oxyfuel combustion, combustion occurs in O_2/CO_2. The CO_2 produced out of combustion is recycled back to the burner to make up for N_2. In modern gas turbines and other industrial burners, oxyfuel technology can be adapted with ease.

Keyword: oxy-fuel combustion, lift off, blow off, blow out, stability

I. INTRODUCTION

In recent years, global warming has been a major issue due to continuous growth of greenhouse gas emission from different sources. The contributors to greenhouse effect are carbon dioxide (CO_2), chlorofluorocarbons (CFC'S), methane (CH_4), and nitrous oxide(N_2O). Thecontribution of each gas to the greenhouse effects is CO_2-76%, fluorinated gases- 2%, CH_4-16% and N_2O-6%.Carbon dioxide (CO_2) a major greenhouse gas which is mainly blamed for global warming occupies a large volume of the total emissions. Due to CO_2 emissions into the atmosphere by burning fuel causing global warming, glacier melt, storms and climatic change. It is also responsible for the increase in the earth's surface temperature. The global annual temperature has increased at an average rate of 0.08 degree Celsius per decade since 1880 but it increased at the rate of 0.18 degree Celsius per decade since 1981(after industrial revolution) which is twice than the average rate. So, it is necessary to develop novel technologies to mitigate their impact on the environment from pollutant emissions and to improve efficiency.In CCS-technologies, CO_2 is separated from the flue gas and used in other processes or stored in a safe place, such as underground storage and ocean storage. In this study, only reducing/capturing CO_2 from flue gas will be considered among the three phases (capture, transport, storage) of CCS technology. The idea of separating and storing CO_2 for mitigation of its emissions to the atmosphere was first proposed in 1977. The oxyfuel combustion of coal in a steam turbine process is regarded as a possible way to use the oxyfuel process for CO_2 reduction. Research on this field is very active with the outcome that the first demonstration plants are in operation, and the power generation industry is willing to invest in this technology. Another way of particular interest is the use of oxyfuel combustion in gas turbine.

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II. LITERATURE REVIEW

Combustion is the process of exothermic redox chemical reaction between the fuel and an oxidant. In other words, combustion is a chemical process or a reaction between a fuel (hydrocarbon) and oxygen. When fuel and oxygen react, it releases the heat and light energy. The visible form of energy during combustion is termed as flame. The general formula for combustion reaction takes place is given by,

$$\text{Hydrocarbon} + \text{oxygen} \rightarrow \text{carbon dioxide} + \text{water} + \text{Heat energy}$$

During combustion, the burning of fuel and oxygen yields some other chemical by-products. These by –products are called exhaust. Most of the exhaust comes from the chemical combination of the fuel oxygen.

Based on the level of premixing the combustion can be classified in to three types

1. Premixed Combustion
2. Non-Premixed Combustion or Diffusion
3. Partially Premixed Combustion

In N_2 diluted combustion the minimum oxygen content to sustain the steady combustion is 0.13, while that diluted by CO_2 is 0.18. to achieve the same adiabatic flame temperature, the oxygen content should be much increased for CO_2 dilution, however the measured temperature is highest in the CO_2 diluted combustion owning to increased fuel consumption [1]

It is deducted that fuel dilution by CO_2 increases the flue density, volume flow rate and heat capacity but decrease the kinematic viscosity, thermal conductivity and mass diffusivity. It is deducted that, for a fixed value of CO_2 content and increasing the equivalence ratio leads to a transition from a standard flame to mild flame [4]

In CO_2/O_2 atmosphere, however, an increase of O_2 concentration from 18% to 21% leads to a reduction of almost two times of the measured CO levels in the reaction zone. It can be estimated that the chemical effect of CO_2 presence has a significant impact on the production and consumption rates of carbon monoxide in oxyfuel combustion. An increase in O_2 may reduce this impact [5].

The stability of the oxy combustion flame is affected when the operating percentage of oxygen in the oxidiser mixture is reduced below 25%. In addition, the ignition was not possible for the burner with less than 21% oxygen in the oxidiser mixture [3].

The laminar burning velocity of $CH_4/CO_2/O_2$ decrease with increase of the CO_2 fraction in the oxidiser. It proves that increase in the CO_2 fraction decreases burning velocity and affect the flame stabilisation. We know that burning velocity and flow velocity are the important factor that the flame stability depends on. So, increase in CO_2 concentration leads to lift off and further increase in CO_2 concentration leads to blow off.

The heat capacity of CO_2 is greater than the heat capacity of N_2 is the main physical factor that enables the CO_2 dilution to be more efficient in lowering the adiabatic temperature rise, thus promoting the occurrence of the MILD state.[8] It shows that in nitrogen dilution, strong flame is obtained but in CO_2 dilution the flame is mild and weaker.

The stability limits of the $C_3H_8/O_2/N_2$ flames are shifted towards leaner condition compared to those of the $C_3H_8/O_2/CO_2$ flames. In other words, for the same equivalence ratio, N flames reached their blowout and flashback extinction limits at a smaller oxygen fraction, as compared to CO_2 flames [7-10].

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III. EXPERIMENTAL WORK

In the oxy-fuel combustion of gaseous fuel that held in the tubular burner shows in the figure below. LPG contained in a steel cylinder which is used as a fuel for the process, which consists of 60% of butane and 40% propane by volume and diluted over a range of equivalence ratios. The burner is of coaxial tubular concentric burner. which is used to carry out the experiment. It consists of several feed pipe each has its own diameter respectively. The inner pipe consists of two ports for fuel inlet. The coaxial pipe consists of two ports for co-flow air and two tangential ports to supply swirl air. The outer concentric tube consists of diametrically opposite tangential inlets for the entry of swirl air at the last case. The first case is held is the primary air case detailed that when air which comes out from the compressor directly into the burner on the opposite port there should be fuel just into the burner. At that case the flame should be low intensive pre-mixed flame and that would occur. The second case is the oxy case carried out by the help of the oxygen and carbon dioxide cylinders. At each fuel and air passage, there exists a pressure gauge to regulate the pressure of flow. Compressed air is supplied continuously by means of the air compressor. When the fuel and air get reached the burner mouth, it gets ignited and starts combustion. The fuel from LPG cylinder and the air from compressor is allowed to flow into the burner system through the pressure gauges and rotameters individually. The pressure inside an LPG cylinder is dependent upon the temperature of the cylinder. The higher the temperature, the higher the pressure of the LPG contained in the cylinders LPG, propane and butane exist in both liquid and vapour phase.

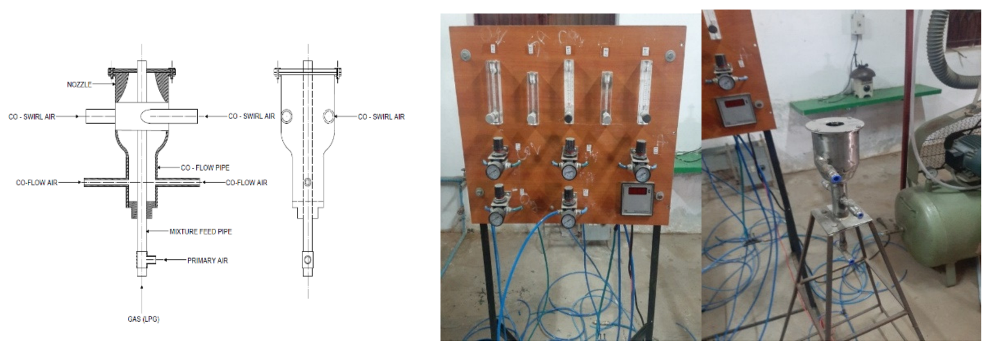

Figure 1 Schematic diagram of a coaxial burner assembly Photographic view of experimental rig

IV. RESULTS AND DISCUSSION

The experiments were conducted as two sets. First set of experiments were conducted to investigate the flame characteristics such as flame length, width and color. The effect of primary aeration on flame characteristics and the effect of balance gas N_2 and CO_2 has been carried out. [6] proposed a principle in which another NN yield input control law was created for an under incited quad rotor UAV which uses the regular limitations of the under incited framework to create virtual control contributions to ensure the UAV tracks a craved direction. Utilizing the versatile back venturing method, every one of the six DOF are effectively followed utilizing just four control inputs while within the sight of un demonstrated flow and limited unsettling influences. Elements and speed vectors were thought to be inaccessible, along these

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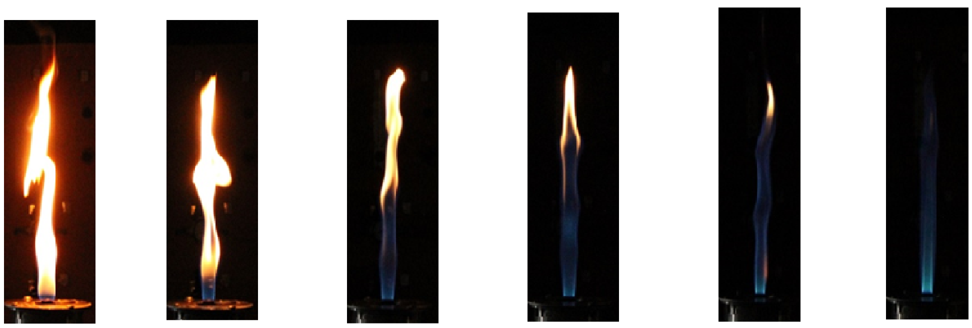
lines a NN eyewitness was intended to recoup the limitless states. At that point, a novel NN virtual control structure which permitted the craved translational speeds to be controlled utilizing the pitch and the move of the UAV. At long last, a NN was used in the figuring of the real control inputs for the UAV dynamic framework. Utilizing Lyapunov systems, it was demonstrated that the estimation blunders of each NN, the spectator, Virtual controller, and the position, introduction, and speed following mistakes were all SGUUB while unwinding the partition Principle.

Flame characteristics experiment

(1) Effect of Primary aeration on the flame characteristics (Q_{fuel} = 0.4 lpm in O_2/N_2)



0 20 40 60 80 100

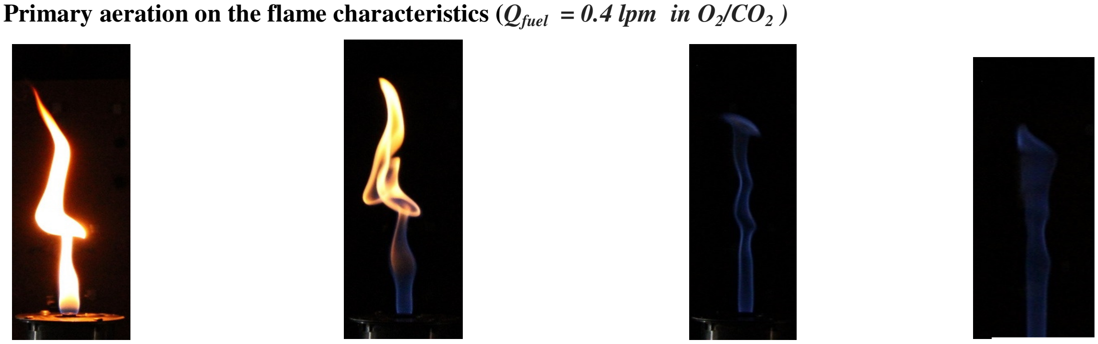
Figure 2 Flames with varying primary aeration

The experimental results show that the flame height decreases with increase in the primary aeration. The flame color also changed from sooty orange to blue. The same trend has been followed in oxy cases as well. The width of the flame has also been found to be shrinking with increase in oxygen availability closer to the flame.

Table 1 Height and Width of Flames with Air cases

Primary Aeration	0%	20%	40%	60%	80%	100%
Height (cm)	29	26	26	25	23.5	23
Width (cm)	3	2.5	2.2	1.6	1.5	1.2

Effect of Primary aeration on the flame characteristics (Q_{fuel} = 0.4 lpm in O_2/CO_2)



0 60

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Available online at www.ijarmate.com

International Journal of Advanced Research in Management, Architecture, Technology and Engineering (IJARMATE)
Vol. 7, Issue 4, April 2021

20 40

Figure 3 Flames with different equivalence ratio

The flame characteristics as observed from the flame images and videos has shown the same trend as in air case in the presence of nitrogen.

Table 2 Height and Width of Flames with oxy cases

Primary Aeration	0%	20%	40%	60%
Height (cm)	30.5	30	25	24
Width (cm)	3	2.5	1.6	1.6

Flame Temperature between the air and oxy cases

The temperature of flame at top, middle and bottom of the flame are noted by using thermocouple. It shows that the temperature of oxyflame is always lesser than the air flame.

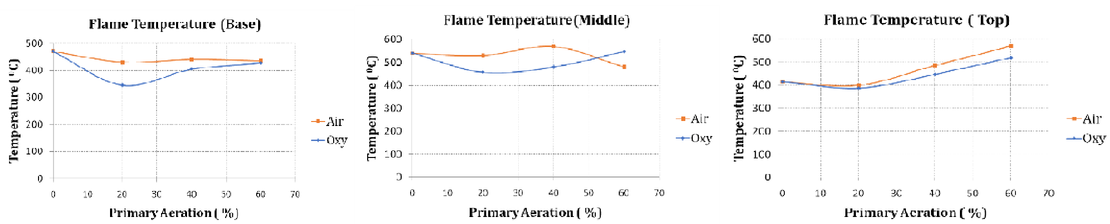

Figure 4 Temperature difference at the Base, Middle and Top

Stability Experiment

AIR CASES(O_2/N_2)

Q_{fuel} = 0.25 lpm in O_2/N_2 Environment

Flame Stability in Air case

PA %	Incipient lift (VN_2)m/s	Lift Off (VN_2) m/s	Blow Off (VN_2)
0%	0.5	0.85	0.87
20%	0.84	0.934	1.061
40%	1.02	1.06	1.08
60%	1.27	1.38	1.58
80%	1.29	1.48	1.7
100%	1.59	1.69	1.71

OXY CASES(O_2/CO_2)

Q_{fuel} = 0.25 lpm in O_2/CO_2 Environment

Flame Stability in oxy case

PA %	Incipient lift (VCO_2)m/s	Lift Off (VCO_2) m/s	Blow Off (VCO_2)
0%	0.46	0.91	1.05
20%	0.87	1.06	1.08
40%	0.95	1.06	1.08
60%	1.01	1.38	1.08
80%	1.06	1.27	1.3
100%	1.16	1.27	1.3

Stability curve at lift off, blow out and blow off

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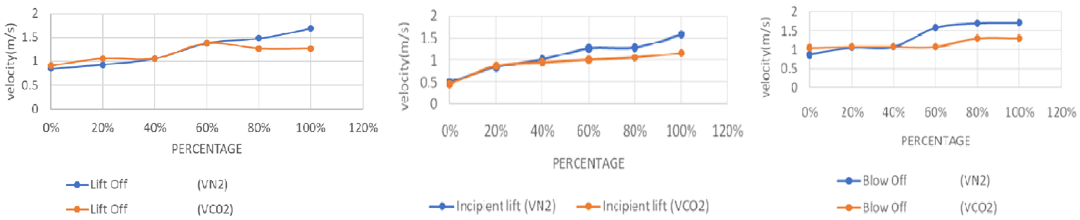

Stability curve for lift off, incipient lift and blow off

The experimental results

- The height and width of the LPG/O_2/N_2 and LPG/O_2/CO_2 flames were noted over ranges of equivalence ratio from 0 to 1 and oxygen fraction 21%. Flame height decreases with increasing primary aeration in both air and oxy cases.The height and width of the flame in both oxy case and air case are more or less same but the flame in oxy case is weaker compared to the air case flame.
- It is observed that the flame colour changes from sooty orange to deep blue with primary aeration in air and oxy cases. It can be observed that there is a reduction in the visible flame length of diffusion flame with increase in air jet velocities for a constant fuel jet velocity. Interesting to note that length of the lower portion of blue flame known as the premixed zone is increased while the length of the upper zone of yellow flame, known as the luminous zone is shortened.
- The temperature of both air and oxy case were measured by using thermocouple over ranges of equivalence ratio 0 to 1 and oxygen fraction 21%. The temperature of oxy flame is lower than the air flame in all cases (top, middle and bottom). It shows that increasing the concentration of CO_2 also affect the temperature of the flame, because specific heat capacity of CO_2 is greater than the N_2 is the main physical factor that enables the CO_2 dilution to be more efficient in lowering the temperature rise, thus promoting the occurrence of the mild state of flame in oxycase. So, the temperature of flame in oxycase is always lower than the air flame.
- The flame lifts off, incipient lift and blow off in oxy cases occurs at smaller velocity than the air case. It shows that the burning velocity of LPG/O_2/CO_2 decreases with increase the CO_2 fraction in the oxidiser. It proves that increase in the CO_2 fraction decreases the burning velocity and affects the flame stabilisation. We know that the burning velocity and the flow velocity are the important factor that the flame stability depends on. So, increase in CO_2 concentration leads to lift off and further increase in CO_2 concentration leads to blow off.
- Replacing CO_2 in the place of N_2 affects the flame temperature and the flame stability.The flame temperature and flame stability of oxy cases may be matched with air case by increasing the O2 concentration from 21%.

V. CONCLUSION

An experimental investigation on the characteristics of air and oxy fuel LPG flame was carried out. The flame height, flame width and temperature of flame are noted for both air cases and oxy cases. The flame images of air cases and oxy cases are compared with to find out the effect of replacing CO2 in the place of N2.Finally, Flame Stability test were carried out in both air case and oxy cases. There are five main flame stability issue namely flashback, lift off,

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blow off, blow out and drop back. However, the scope of this work is only limited to flame incipient lift off, and blow off happen for both air cases and oxy cases.

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