A Review Paper on Experimental and Numerical Investigation of Parametric Study on Gaseous Fuel Flow Parameters: Flame Length and Diameter

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Abstract— Flame is an important parameter for any combustion process which is responsible for either the complete or incomplete combustion process. There are certain factors which influence the flame length and diameter such as fire source diameter or nozzle diameter, equivalence ratio, quality of fuel, heat release rate etc. Investigation of flame length and diameter is more relevance in the rational design of combustion chamber, be it for an internal engine or for a furnace. The flame represents the zone of combustion, its length is a measure of the intensity of combustion and therefore of heat release. So, this paper reviews about the flame behavior on the basis of flame length and diameter.

Key words: Flame, Gaseous Fuel, flame velocity

I. INTRODUCTION

Combustion is a rapid oxidation generating heat and light and flame is the chemical reaction between one chemical substance called a fuel, and another chemical which is an oxidizer (or oxidant). The size and shape of flame depend on its type, namely, premixed or diffusion, laminar or turbulent and also on the burner dimensions.[16][17]

The structure of the diffusion flame is determined mainly by the process of mixing of gas and air and not by the velocity of flame propagation. The mixing is achieved by either molecular diffusion or eddy diffusion, depending upon the laminar or turbulent condition of flame. A laminar diffusion flame is converted into the turbulent type by increasing the gas velocity beyond a critical value.

A freely burning flame is considered stable when there is no flash-back or blow-off. The essential condition for flame stability is that the normal velocity of flame propagation is equal and opposite to the velocity of fuel-air mixture at a flame front. A consideration of all the factors affecting these two velocities is necessary for evaluating the condition of flame stability.

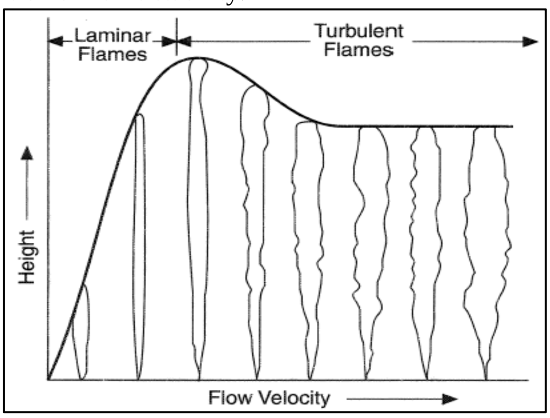

Fig: Progressive Change in Flame Type with Increase in Jet velocity [16]

This is the transition stage. In the turbulent region the flame length remains practically constant with increasing jet velocity. Above a critical velocity the flame is lifted and finally it blown of when the jet velocity increases further. [16]

II. LITERATURE SURVEY

A brief summary of the vast amount of material that has been published on flame would be well beyond the scope and intention of this paper. Instead, attention is focused on a few key aspects of flame that are considered important and relevant.

Chu yan-yan, Dong Wen-li, Liang Dong[1] presented the theoretical and experimental analysis of laneway flame length. Analysis indicated that the flame length relates with the heat release rate, fire source diameter, combustible matter diffusivity, etc. Based on that the experiment plant of laneway fire has been setup. Experiment indicated that the flame length is directly proportional to heat release rate, fire source diameter and combustible matter diffusivity. Also the impact of fire source, velocity etc to flame length has been developed through theoretical and experimental study resulted that average flame length is always proportionate to heat release rate of fire source, velocity and fire source diameter but it is independent in velocity and fire source diameter when the fire develops rapidly.

Byung Chul Choi and Hyung Taek Kim[2] experimentally investigated the visible length of coal-derived syngas jet diffusion flames. The nozzle diameter of the lab-scale combustor was varied at 1.23, 1.96 and 2.95mm and the flame length of each condition was studied to determine the flame length characteristics of flame. Various compositions of CO and H_2 used as fuel gases for simulating the composition of coal synthetic gases and examined with different compositions and result of experiment were compared with the characteristics of a pure methane flame using dimensionless flame length(L^*). An experiment were performed and concluded that the nozzle diameter would appear as the key parameter for determining the flame length because the flame lengths of small diameter were longer and heating rate and CO/H_2 ratio did not affect the flame length but the calculated flame lengths for various gaseous fuel compositions were slightly smaller than the actual flame lengths.

Ibrahim, I. A., Shabaan, M. M., Shehata, M. A., and Farag, T. M[3] presented an experimental study to improve the spray combustion by using dual fuel (diesel and N.G. fuels) combustion. For burning dual fuel together a burner head is designed it was fitted coaxially with a water–cooled combustor of 0.2 m inner diameter and 1 m in length.

The flame characteristics of dual fuel (diesel and N.G.) in which the natural gas, with and without swirl, is added into the combustion chamber with different thermal heat percentages of 5, 10, 15, and 20% of the total thermal load. Such that the experimental results shows that, increasing the natural gas thermal heat percentage when the N.G. used with and without swirl leads to decrease the flame length. The NOx and CO2 concentrations increase but CO and O_2 concentrations decrease at the same operating conditions. The effect of using N.G. with swirl has stronger effect than that of without one. The flame size in its diameter and length is larger for N.G. with swirl than that of without one.

Peter B. Sunderland, James E. Haylett, David L. Urban, Vedha Nayagam[4] experimented lengths of laminar jet diffusion flames on circular burners and for that there are two prevalent scaling relationships. Experimental studies of earth-gravity and microgravity flames which invoke a linear relationship between normalized flame length and Reynolds number also elevated gravity have correlated flame lengths with a function of Reynolds and Froude numbers. In that the Reynolds scaling indicates that stoichiometric flame length is independent of gravity level, whereas the Reynolds–Froude scaling indicates that length decreases with increased gravity. They examined the ability of both approaches to correlate laminar hydrogen, methane, ethane, and propane flame lengths for a range of 1–15 times earth gravity. The Reynolds scaling is shown to accurately correlate the length measurements at both earth gravity and elevated gravity. The Reynolds–Froude scaling also correlates the measurements, but its theoretical basis is less rigorous, it does not account as accurately for variations in fuel flow rate. Also concluded that Measured and computed flame lengths are well correlated according to the Reynolds scaling of L/d ~ Re. This scaling has strong theoretical and empirical support for microgravity, normal gravity, and elevated gravity flames.

Babak Kashir, Sadeg Tabejamaat and Mohammad baig moheamadi[5] experimentally investigated the effects of oxidant preheating and diluting of propane/oxygen and natural gas/oxygen diffusion flames within laminar regime in two parts that is effect of oxygen dilution with nitrogen and carbon dioxide gases. Combustion of natural gas and propane with pure oxygen can increase the flame stability .Oxidant stream preheating upto 480k and diluting with nitrogen or carbon dioxide are investigated and results were compared with non preheating process. An investigation concluded that diluting oxidizer with CO_2 and N_2 eventually causes lift off and blow out. For diluting oxygen with carbon dioxide this lift off occurs in lower percent of dilution. Also propane flame is so longer than natural gas flame through presence of more carbon radicals that enlarges reaction zones and these flames were more luminous than their natural gas counterparts because of more heat release.

Kazunori Kuwana, Santoshi Morishita, Ritsu Dobashi, Keng H. Chauh and Koro Saito[6] discussed about the behavior of visibly determined flame length of a weak fire whirl compared with the corresponding pool fire without spin. To apply a flow circulation to a 3cm diameter methane burner flame and 3cm diameter ethanol pool fire split cylinders were used. Little change was observed in flame length of the methane burner flame while the flame length of ethanol pool fire increased about three times after applying the flow circulation because the burning rate of methane burner flame was fixed constant whereas the ethanol pool fire increased due to the increased heat input to the fuel surface. The experimental observation shows that the burning rate effect can significantly increase the flame length even under a weak circulation condition and concluded that the flame length does not depend on fluid dynamics but only on fuel characteristics such as fuel type, pool diameter and burning rate.

V.H. Moros and Y.M. Abdel Rahim[7] studied the flame length characteristics of light-fuel oil burned inside horizontal straight and swirl burners working below their minimum conventional operating fuel pressure of 0.3 MPa. To examine the effects of primary air-fuel mass flow rate ratio, fuel-air pressure ratio, burner geometry, fuel mass flow rate and degree of swirling on flame length, tests were carried out. The analysis of data shows that the flame length generally decreased with increasing primary air-fuel mass flow rate ratio, axial distance between combustor exit, burner tube diameter and entrance of burner tube, fuel-air pressure ratio and degree of swirling represented by air tangential angular speed. Also the flame length increased with increasing burner tube length but the flame length of straight burner behaved almost the same as that of a swirl burner.

D.Y. Kiran and D.P. Mishra[8] experimented to measure the lift-off height (H_L), flame length (L_f) and blow-off velocity for simple LPG (liquefied petroleum gas) jet diffusion flames and it is observed that the lift-off height is proportional to the fuel exit velocity (U_f). The jet froude number is used to differentiate between momentum dominated and buoyancy-dominated regimes in LPG jet diffusion flames. From that it can be observed that the flame length increases with fuel jet velocity and remains almost invariant at higher Froude number which happens to be towards the flame blow-off. The NO_x emissions, expressed in terms of emission index ($EINO_x$) which is decreases with fuel exit velocity (U_f).

T.S. Cheng, C.Y. Wu, C.P. Chen, Y.H. Li, Y.C. Chao, T. Yuan, T.S. Leu[9] discussed about the measurements of temperature, major species concentrations (O2, N2, H2O, H2), and hydroxyl radical concentration (OH) in laminar hydrogen jet diffusion flames (Re = 30 and 330) and performed using nonintrusive UV Raman scattering coupled with the laser-induced predissociative fluorescence (LIPF) technique for assessment of combustion models. Effects of thermal diffusion and chemical kinetics on the flame structure are investigated by comparing computed results with experimental data. The numerical simulations, using the Miller and Bowman mechanism, indicate that thermal diffusion affects the flame structure for the Re = 330 flame, whereas its influence becomes minor for the Re = 30 flame. Effects of chemical kinetics on the flame structure are investigated in the Re = 30 flame using five different H2/air reaction mechanisms. Where comparison of the measured and calculated data using five mechanism reveal thet the computed flame structures are in reasonable agreement with one another and with experimental data. This indicates that this flame, unlike the highly stretched tubular flames and is not be sensitive for examining the effect of chemical kinetics of flame structure.

T. Boushaki, J. C. Sautet, L. Salentey, B. Labegorre[10] presented an investigation into turbulent, confined, oxy-flames generated by a burner consisting of a central natural gas jet surrounded by two oxygen jets also focused on the identifying the influence of burner parameters on the flame characteristics and topology, stability, lift-off height and flame length. The effects of the natural gas and oxygen jet exit velocities, the distance separating the jets and the deflection of oxygen jets towards the natural gas jet are examined and resulted that the lift-off heights increase when jet exit velocities and the distance separating the jets are increased. The deflection of oxygen jets decreases the lift-off height and increases the volume of flame in the transversal plane. The flame length increases principally with the oxygen exit velocity and the separation distance, and decreases considerably when the angle of oxygen jets is increased.

Shuichi Tore, Toshiaki Yano Masatatsu Iwashita and Hideki Nishinohara[11] performed an experimental study on hydrogen jet diffusion flames from vertical circular nozzles burning in free air and direct photographic method was employed to investigate the influence of fuel flow rate and nozzle diameter, d, on the flame morphology also the determination of the flame length (L_f), over a wide range of the fuel flow rate. From that it became clear that until a laminar-to-turbulent transition occurs the flame burning mixing with air is induced and its length is monotonically increased as the nozzle velocity is increased from zero and after the transition takes place, the turbulent flame length is substantially independent of further increase in fuel jet velocity. A few relationships were proposed and examined pertinent to the flame length which were L_f versus Uj, L_f/d versus Re, and L_f/d versus d, and concluded that In the case of the laminar flame, the flame length is increased with an increase in the nozzle velocity. In contrast, the corresponding length for the turbulent flame is constant in the wide range of the flow rate and the flame length, Lf/d, is independent of the Reynolds number and the nozzle size if the flame becomes turbulent.

P.C. Vena, B. Deschamps, G.J. Smallwood, M.R. Johnson[12] studied the effects of large-scale gradients in equivalence ratio on locally stoichiometric turbulent iso-octane/air V-flames using a novel stratified burner capable of producing transverse variations in mixture strength. Gradients in equivalence ratio had a dramatic effect on flame wrinkling, leading to enhanced corrugation of the flame front for the strongest gradients. However, the effect of increased flame surface density was more modest, balanced in part by an increase in flame brush thickness, and ultimately by a decrease in flame length. This suggests that although gradients in mixture strength may alter the overall structure and instantaneous behavior of globally stoichiometric combustion systems, their effect on the topology of locally stoichiometric flames may be limited.

H.S. Zhen, C.W. Leung, C.S. Cheung [13] were experimentally studied the combustion characteristics of a swirling inverse diffusion flame (IDF) upon variation of the oxygen content in the oxidizer. Experiment was conducted with constant oxygen content in the oxidizer. When the oxygen was varied, the changes in flame appearance, flame temperature, overall pollutant emission and heating behaviors of the swirling inverse diffusion flame were investigated. The swirling inverse diffusion flames with different O_2 content revealed that the flame structure involves an internal recirculation zone (IRZ) which is quite large and characterized by high temperature and thermal NO formation. The use of nitrogen-diluted air (O_2 content of 20%) allowed the IDFs to operate at lower temperature with reduced NOx formation, compared to the case of air/LPG combustion (O_2 content of 21%) but increases the CO emissions.

P. Griebel, P. Siewert, P. Jansohn[14] were experimentally investigated the effects of operating conditions and turbulence on flame front position, turbulent flame speed and flame brush thickness of lean premixed methane/air flames at high pressure. The turbulence intensity and the integral length scale at the combustor inlet were varied by means of turbulence grids with different geometry and by changing the grid position in the inlet channel. By investigated the effects, major results were; No influence of pressure on the most probable flame front position and on the flame brush thickness and an increase of the turbulence intensity and the integral length scale at the combustor inlet leads to shorter flames also A close relation between the flame front position and the flame brush thickness was observed.

James E. Usowicz[15] studied the flame structure, flame length, and emissions of ethylene jet diffusion flames over a range of injection times and duty-cycles with a variable air co- flow by using a pulse fuel injector. In all cases the jet was completely shut off between pulses (fully-modulated) for varying intervals, giving both widely-spaced, non-interacting puffs and interacting puffs. Imaging of the luminosity from the flame revealed distinct types of flame structure and length, depending on the duration of the fuel injection interval. Such that For short injection times, for long injection times and For compact Puffs, the flame structures were observed and resulted in burnout length of the puffs was at least 83% less than the steady-state flame length, The flame lengths of the elongated flames were generally comparable to those of the corresponding steady-state cases, the addition of co-flow for ducted flames generally resulted in an increase in the mean flame length, amounting to an increase in flame length of up to 30% respectively.

III. CONCLUSION

From the review of literature it analyzed that by experimentally and theoretically investigated the behavior of the flame length, flame lift off height, flame velocity etc., it can be increased or decreased by varying the different size of nozzle diameter or fire source diameter, different quality of fuel, different equivalence ratio etc. and different findings are concluded.

- Flame length is always proportionate to heat release rate of fire source, velocity and fire source diameter but it is independent in velocity and fire source diameter when the fire develops rapidly.
- The flame length increases with fuel jet velocity and remains almost invariant at higher Froude number which happens to be towards the flame blow-off.

- The flame length does not depend on fluid dynamics but only on fuel characteristics such as fuel type, pool diameter and burning rate.
- The flame length generally decreased with increasing primary air-fuel mass flow rate ratio, axial distance between combustor exit, burner tube diameter and entrance of burner tube, fuel-air pressure ratio and degree of swirling represented by air tangential angular speed.

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