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BLUFF BODY EFFECT ON THE STABILIZATION OF PREMIXED FLAME

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ABSTRACT
The effect of bluff body on stabilization of liquid petroleum gas (LPG) - air premixed burner flame has been experimentally investigated. One of the objectives of this experimental work was to perform an analysis on the effect of the bluff-body shape on flame stabilization. A method of aerodynamically stabilizing lean premixed natural gas flames on a conventional burner was investigated. The analysis of premixed flames stabilization process was focusing mainly on the shape and sizes of flame holders. To study the influence of the bluff-body shape on the stabilization process, four flame-holders were considered: a rod, a wire and rings of several diameters. Flames were anchored in the wake behind a small ring placed in the exit plane of a conventional burner. The stabilization conditions were based on the description of the stability domain and of the characteristic flame modes. Direct visualizations allow a better knowledge of these different regimes: laminar stable flame, transition and unstable flame. An aerothermodynamic description of the reacting flow in the bluff-body wake was performed over a range of Reynolds numbers and mixture equivalence ratios. The objective was to extract from this analysis, the differences in the flame structure due to the bluff-body geometry and their consequences on the stabilization diagram. Results show the existence of various types of flames, according to the classical premixed burner flame, but the influence of the bluff-body shape on these stabilization regimes is also demonstrated. Comparison between the flow without bluff body and with bluff body on flow as well as flame stabilization was discussed. It was found that the stabilization of the flame is improved by having bluff bodies on downstream of the flow. Without bluff body the stability region of the flame is limited or in general the flame is easier to blow off and flashback. The overall with bluff body stability regime of the burner was significantly increased, permitting stable lean premixed combustion. The influence of the ring with different diameters on flame stability limit was also investigated.

Keywords: Bluff body, stabilization, premixed, flame

1.0 INTRODUCTION

The main purpose of the study of the flame stabilization is to maintain the flame at the burner port. Without the stabilizer, the flame will not stay at the burner port. The blow-off phenomenon will occur where the flame is not stabilized and disappear. Although flame stabilization in ramjets and afterburners involved turbulent fields, studies on stabilization of laminar flames are useful since they help the understanding of the turbulent problem through the change of transport coefficients such as heat and mass diffusivity to turbulence ones.

The effect of bluff body on stabilization of (butane-propane)-air premixed burner flame has been experimentally investigated. The investigation will begin with the preparation of the premixed burner which is the main part of the experiment apparatus. The premixed burner is designed and fabricated which will be use for this experiment. The main matter about this burner is about the flow of the fuel mixture which arises from the burner port. The flow must be in the laminar stream, so we can properly investigate the laminar premixed flame in this experiment.

The first objective of the study is to investigate the possibilities of using ring as bluff body for the flame stabilization. It is believe that by using ring as bluff body, the stability regime of the flame can be extended. It is because if the flame was stabilize by the burner rim, the flame will be unstable and blow-off easily under fuel lean and high flow rate condition. Although the similar types of bluff body stabilization can be use, but the ring stabilizer is somewhat unique. The ring is to fit inside the burner exit port and can be highly effective in stabilizing the flames.

The second objective is to study the flame characteristics by changing several parameters. The three important parameters in the experiment are the types of bluff bodies, the equivalence ratio for the fuel and the different Reynolds numbers.

2.0 EXPERIMENTAL SETUP AND PROCEDURE

The schematic drawing of the experimental apparatus is shown in figure 1. The burner consists of a long 45 cm stainless steel tube with inner and outer diameter is about 23mm and 25 mm. This stainless steel tube was fixed properly about 4 cm deep in the burner body. A piece of ceramic honeycomb 1cm thick with large number of small holes is place 5cm from the bottom side the stainless steel tube. The ceramic honeycomb is acting as a flow straightener and also as a flame arrester. This is to avoid flame from going into the burner tube if the fuel flow is turned to a lower velocity.

The burner body was made of aluminium square (3in x3in) with the shape shown in the schematic drawing in figure 1. A burner stand was build to ensure that the burner can stand properly and the fuel can enter to the burner from the burner base.A bunch of aluminium tubes which function as a flow straightener is fixed inside the burner. The flow of the fuel that enters the burner is not purely laminar. So the flow straightener will guide the fuel to rise up to the burner tube in the laminar stream.

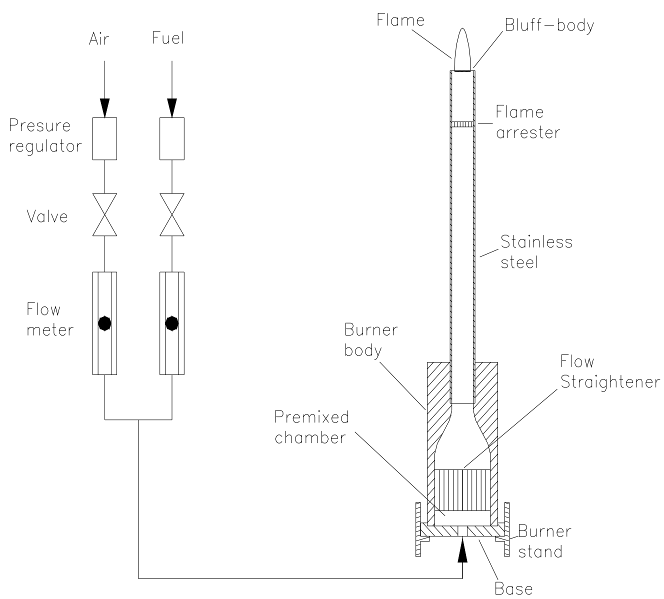

Figure 1: Schematic drawing of the experimental setup for premixed laminar flame burner

In this experiment, the fuel that will be used is (LPG) which comprises of propane and butane (40% propane and 60% butane). The fuel will be mixed with air. Fuel and air are supplied from the fuel tank and the air tank respectively. The pressure from the tank will be controlled by the pressure regulator. Valves on each flow meter will control the flow rate of air and fuel supplied. The flow rate of air and fuel are displayed at the flow meter. The flow meter was calibrated before the experiment to ensure the correct reading.

The fuel and air will mix properly at the premixed chamber. Then the flow of the mixed fuel and air will be straightened by the flow straightener inside the burner before entering the burner tube. At the top of the burner tube, the fuel flow pass through different bluff bodies. The mixture was lighted up and the flame was stabilized on the bluff body.

The characteristic of the flame can be seen at the top of the burner tube. The characteristic of the flame is different if the parameter of this experiment is change. In this experiment the flame stabilization mechanisms are described in terms of three important parameters, namely the fuel velocity (R_e) at the burner, the fuel equivalent ratio and the bluff bodies. The experiments will do in different coalition of parameter and in every changing of parameter; the characteristic of flame will be analyze. The types of bluff bodies that will be used in this experiment are ring, vertical rod, horizontal rod, wire and the burner port it self.

The experimental process will be done in the dark environment. It is to ensure that the flame characteristic will be seen clearly. The data of the fuel flow ratio will be collected from the starting flame attach at the bluff body until flame was disappear (blow off). The video of the flame will be recorded by camcorder and the photograph of the flame will be captured by the digital camera. The graph of the velocity (R_e) vs. equivalent ratio will be plot after the experiment.

3.0 RESULTS AND DISCUSSIONS

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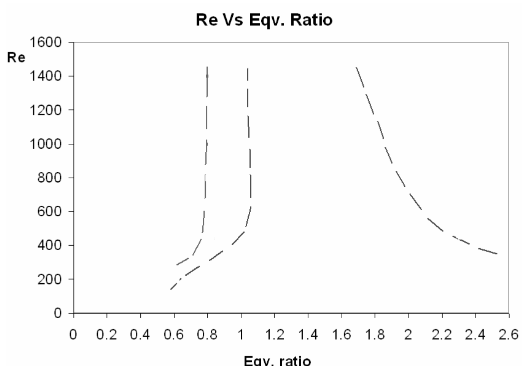
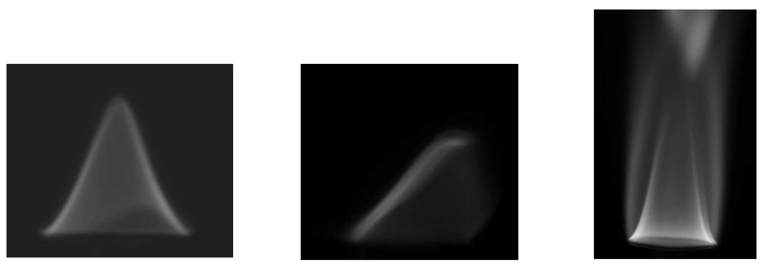


Figure2: Stability limit for without bluff body



(a) Φ = 0.8 Lift off

(b) Φ = 1.1 Tilted Flame

(c) Φ = 2.2 Dual Flame

Figure 3: Different type of flame at different zone when Re = 1200 (without bluff body)

Figure 2 shows the region of flame stability when there was no bluff body used. For lean mixture, he flame was more stable than the flame from rich mixture. Increasing the equivalence (Φ) exceed the stoichiometric value, the flame start to tilted (Fig.3b) . When the equivalence value reached value of 1.8, dual flame appeared (Fig. 3c).

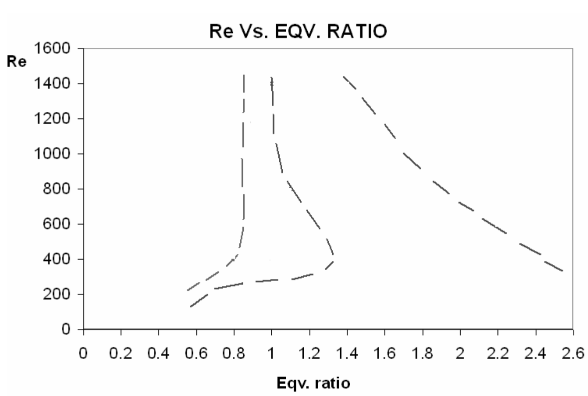
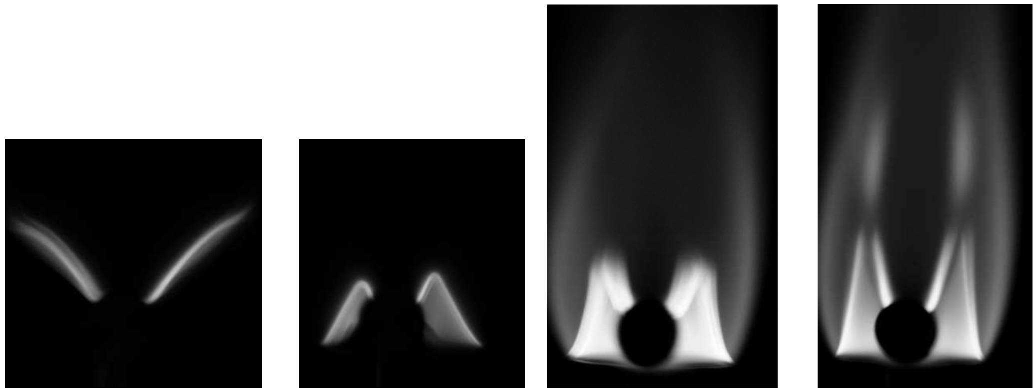


Figure 4: Stability limit for horizontal rod as bluff body



(a)	(b)	(c)	(d)
Φ = 0.9	Φ = 1.0	Φ = 1.8	Φ = 2.2

Figure 5: Different type of flame at different zone when Re = 1000 (horizontal rod as bluff body)

In the figure 4 the stability region for horizontal rod is larger than burner rim but if we compare with ring as a stabilizer, which is not good enough also. The region of stable flame is small. By using horizontal rod the flame is more easily blow off especially at the higher flow rate. The flame will blow off until the equivalence ratio 0.9 for the higher Re (<600). For the flash back phenomenon, the flame, which is stabilized by the horizontal rod, is not easily flash back at the lower Re (>400) compared by using ring stabilizer. But after reached the Reynolds number more than 600, the flame is easily flashback and at the Re more than 1200 the area of stable flame is quite thin compare than before.

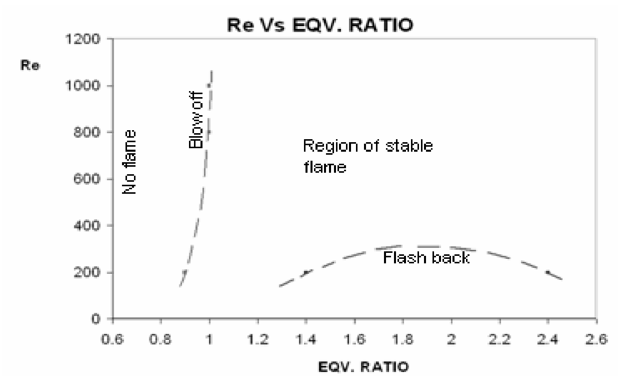
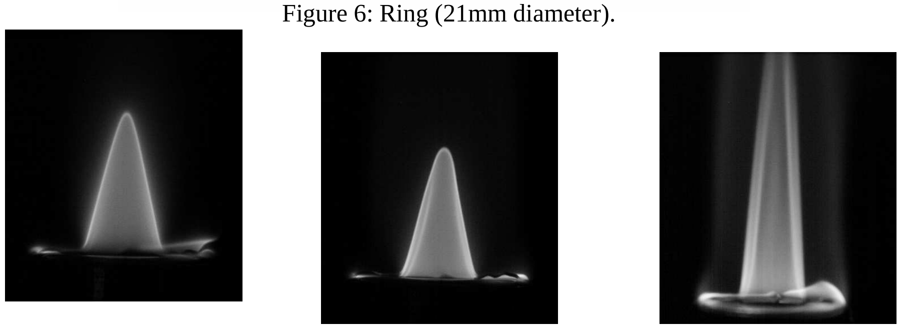


Figure 6: Ring (21mm diameter).



(a)	(b)	(c)
Φ = 1.2	Φ = 1.6	Φ = 2.0

Figure 7: The effect of increasing equivalence ratio for Re = 800 (ring 21mm diameter)

From figure 6, we can see that the stability region for each type of the ring size is different. For 21mm diameter ring, the flame is easily blown-off. The blow off limit is reach when the equivalence ratio is reduced until equal to 1. But the when the size of ring diameter is change to smaller, the flame can be stabilized at the ring stabilizer more properly and not blow off easily.

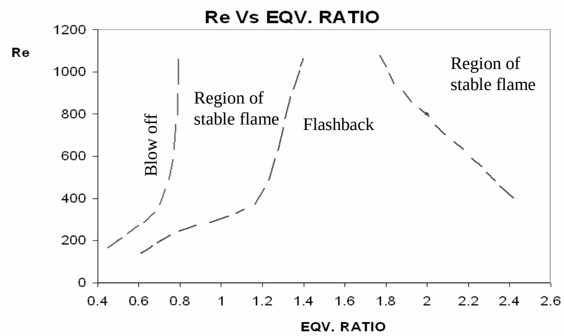
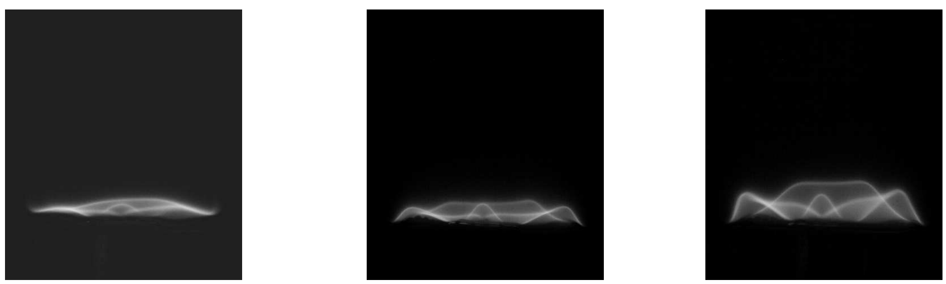


Figure 8: Ring (10mm diameter)



(a) Re=400 (b) Re=600 (c) Re=1000

Figure 9: The effect of increasing Reynolds number for $\Phi = 1.1$ (Ring (10mm diameter))

The blow off limit for 17mm, 13mm and 10mm diameter ring are at equivalence ratio 0.9, 0.85 and 0.8. Here we can say that the flame is not blow off easily if we used the small diameter of ring stabilizer rather than a large diameter.

For the flashback phenomenon, the decreasing of diameter of the ring will enlarge the flashback region. The flame is more easily flashback when the flame speed is greater than the flow velocity at the smaller ring stabilizer. As we can see on the figure 3, the upper limit of the flashback region is going higher from at Re = 300 for 21mm diameter ring to more than 1000 Reynolds number for 10mm diameter ring.

Because of that, in the industrial application, we need to select the optimum stabilizer for our combustion equipment. In our case, the different type of ring will give a different region of stabilize flame. If we prefer more on the preventing flame from blow off rather than flashback, the smaller ring stabilizer is better than the large diameter of ring stabilizer. But if we more concern about the flashback phenomenon and we don't it happen, the large diameter of ring size is more suitable. In more cases, the optimum stable region is more important. We don't want the flame blow off easily and also flashback easily, so the optimum stabilizer needs to be chosen. In my experiment, the diameter of the optimum ring stabilizer for the 23 mm inner diameter of the burner tube is 17mm.

4.0 CONCLUSION

This project is focusing on the effect of bluff body in premixed laminar flame stabilization. The characteristic of flame stabilization is quite different for different type of bluff bodies. The observation of flame's stability region is the main emphasis of the study.

The effect of changing the velocity on gas mixture has been investigated. Reynolds number has represented the velocity. When the Reynolds number is increased, the stability region of flame is also changed. Some of bluff bodies such as ring, the flashback region for higher Reynolds number is not exits but for the others the region of the stable flame is decreased if we used the higher Reynolds number. When the Reynolds number is further increased the flame is more easily to blow off in the lean condition.

The possibility of using ring as a flame stabilizer has also been investigated. From the result we can see clearly that the ring is most suitable shape to be used as a flame stabilizer. It is because the region of the stabilize flame is larger compared to the other bluff bodies. The flame which is stabilized by ring is not easily blown off under the fuel lean condition and the flame will also not easily flashback if we increase the velocity of gas flow. By using the different type of ring diameter, we can see a lot of the different of the flame characteristic especially on the stability limit (blow off and flashback). When the percentage of fuel and air was changed the characteristic of flame also will be change.

From the result we can see that clearly the ring is very possible to use as a flame stabilizer. It is because the region of the stabilize flame is large. The flame which is stabilize by the small diameter of ring is not easily blow off under the fuel lean condition and the flame which is stabilize by the large diameter of ring will not flashback easily.

REFERENCES

1. W.C. Strahle, *An Introduction To Combustion,* Gordon and Breach Science Publishers, Pennsylvania, 1993.
2. A.G. Gaydon and H.G. Wolf Hard, *Flames*, Chapman and Hall Ltd., 3rd edition, London, 1970.
3. S.R. Torns, *An Introduction to Combustion*, Mc Graw Hill Inc., New York, 1996.
4. I. Glassman, *Combustion*, Academic Press Inc., New York, 1977.
5. B. Lewis and G. Von Elbe, *Combustion, Flames and Explosions of Gases*, Academic Press Inc., 3rd edition, New York, 1987.
6. F.J. Weinberg, *Optics of Flames*, Butterworths, London, 1963.
7. Thabet, *Ph.D Thesis*, London, 1951.
8. Barr and Mullins, *Fuel*, British Press, London, 1949.
9. B. Karlovitz, *Seventh Symposium on Combustion*, Butterworth, London, 1958.
10. K. Wohl, N.M. Kapp and C. Gazley, *Third Symposium on Combustion, Flame And Explosion Phenomena*, 1949.
11. D.T. Townend, J.A. Garside and G.W Culshaw, Institute Gas Engineering Comm., 1941
12. A.M. Kanury, *Introduction to Combustion Phenomena*, Gordon and Breach, New York, 1975.
13. E.E. Zukoski and F.E. Marble, *Combustion Research and Reviews*, Butterworth, 1955.
14. K.K. Kenneth, *Principles of Combustion*, John Wiley and Sons, New York, 1986.
15. D.B. Spalding, *Combustion and Mass Transfer*, Pergamon Press, Oxford, 1979.
16. F.A Williams, *Combustion Theory*, The Benjamin Publishing Company Inc., California, 1985
17. M. Drkos, C.W. Leung and C.S. Cheung, *Flammable Characteristics of the Rod-stabilized Laminar Premixed Flame,* The Seventh Asia-Pacific International Symposium on Combustion and Energy Utilization, Hong Kong, 2004