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Research paper

Effect of Rotating Burner Rim on Flame Stabilization: Blow-off and Flash Back

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Abstract

In present research, Schlieren photography has utilized to determine flame stabilization efficiency of methane–air mixture by tube burner method. The investigation is based on experiments carried out to identify the effect of varying the burner edge speed on the flame stabilization limits, and the blow-off and flash back limits of Schlieren cone at the high range methane-air premixing flows is studied. The flame was recorded using a high-speed digital camera and digital image processing techniques were applied on the captured frames. Two parameters are used in the method to characterize the flame stabilization on burner edge, the flame stabilization efficiency, and the flame stabilization coefficient. Data are presented for methane-air mixtures in wide ranges of equivalence ratios and burner edge speeds of ($0.665 \leq \varphi \leq 1.733$) and ($0 \leq Ne \leq 38$ r.p.m) respectively. The experimental results appear that rotation increases the flame stability coefficient, on the other hand, it's decreasing the flame stability efficiency.

Keywords: *Laminar flame, Rotate burner edge, and Burner efficiency.*

1. Introduction

The theme of flame stability conduct is determining the design of combustion tools i.e. burners among others Lewis and Von-Elbe [1] and Boulanger [2]. The matter is focus on the flame front enhancement and reestablished out of the burner or far from its edges due to of high speed of the unburned gases comparing to the velocity of the flame front. More so, flame stability limits in combustion tools and burners usually includes more interest for turbulent flame fields, while literatures on stability of laminar flames are also helpful since the facilitate to understand the turbulence flame behavior by changing different factors in turbulent heat transfer fields Williams [3]. Flame stability limits can have carried out by many techniques such as application of local low-velocity zones by different objects design and apply hydrodynamics (double counter flows) or by formation local different temperature zones using different designs of flame burners and ignitors.

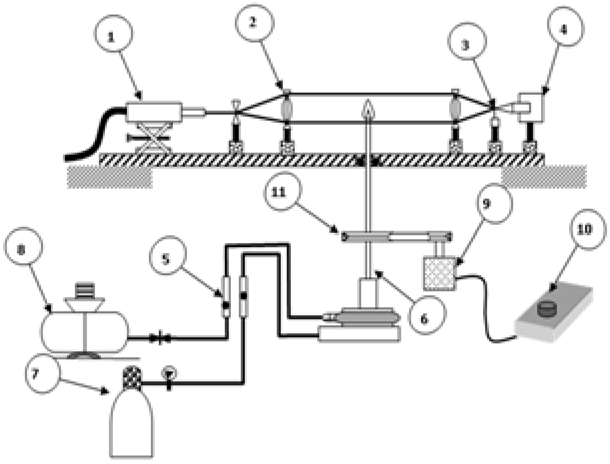
The laminar flame stability limits were widely studied by Lewis and Von Elbe [1]. They concentrated on associating the relation of flame blow-off results with the level of flame stretch, Karlovitz number, at the burner tube. And they were suggested that the Karlovitz data number is important factor to study the reverse fire on the high wire technique. After that, Esquiva et al. [4] were validated by following many experiments and performed on double corner flames on thin plates within rectangular slit burners. Other detailing for flame stability limits is followed on the cold reactant and hot combustion products by Kumar and Maruta [5]. The important influence of the hydrodynamic for unburned gases on stability flame limits has been highlighted in recent studies Kawamura et al. [6] and Navarro and Kronenburg [7]. So far, it has been identified on the potential benefits of the use of the vortex in the design of industrial stabilizers, flame tools Khirtatat Sohrab and Law [8].

In modern theoretical investigations by Mazlan and Ahmad Faiza [9]; Sheu and Sivashinsky [10]; Cha and Sohrab [11], the influence of burner rim rotation on flames stabilization and new design of rotating tubes that are located inside Bunsen burners is addressed. The authors noticed that the flame stability limits were reduced by the rotation of the gas since flame flash back had an effect with the increasing of flow velocity through the burner. In this work the influence of burner edge rotation on stability limits of Bunsen flames are studied. The blow-off and flashback limits are found for premixed of methane and air flames under different conditions of the burner tube rotation speed. The mechanism of Flame stability was described by depend on several real parameters, namely the mean gas velocity, the rotation speed at the burner rim, and the mass gas fraction in the combustible region.

2. Experimental Apparatus and Procedure

The apparatus used in the present work consists of two systems: Combustion system and Schlieren optical system. By the first system the stationary flame front is prepared; fuel and air flow rates are measured, rotate burner edge and measured. Recording Schlieren cone required for the study is performed by the second system. The apparatus components are illustrated in Figure 1.
Combustion system involves tube burner containing premix chamber. The chamber including a (0.44 mm) diameter nozzle of jetting fuel, and other six tubes (10mm diameter) distributed on the circumference of the chamber for entering air. The burner contains, in addition, a copper tube of (810mm) length and (12mm) diameter. Two ball bearings are used on the burner tube to help it on rotating and used belt system drive by vary speed motor.

Schlieren optical system consists of laser light (He-Ne) low power 0.11mWatt and wave length of (633nm), and a group of lenses. By this system, pictures with high contrast have been obtained by using thin wire as cut-off plane instead of using traditional knife edge. The stationary flame front of Methane-Air for wide ranges of equivalence ratios (0.665< φ < 1.733) and at blow-off and flash back limits. They also involve depicting Schlieren cone for equivalence ratios themselves and burner edge speeds (Ne = 0, 15, 27, and 38 r.p.m).



No	Part
1	Laser Light Source (He-Ne)
2	Group of Lenses
3	Cut-off Plane (thin wire)
4	Camera
5	Rotometers
6	Tube burner
7	Fuel (CH_4)
8	Compressor
9	motor
10	Current Changer
11	Belt system

Fig. 1: Schematic diagram of the experimental setup: combustion system and Schlieren optical system.

3. Results and Discussion

Figure 2 shows samples of Schlieren cone of Methane-Air at blow-off and flash back for burner edge speeds under study, the digital processing sequence of the images is shown in this figure. Image subtraction was utilized prior to the sequence shown in Figure 2 in order to reduce the background noise and a calibration image was obtained with no flame front. These images contained light distribution information regarding the camera noise and background. The calibration image was subtracted from each image to provide an image of the flame fronts with reduced background noise.

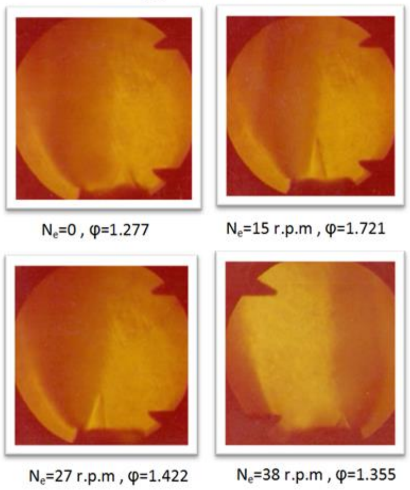
Morphological functions were also used to improve the quality of the image and the flame shape. Finally, the processed images were analysed to determine the blow-off and flash back of each flame front. By counting the number of pixels in the flame and scaling them to physical dimensions, the area of each flame front was calculated.

Depended on critical limited theory for speed drop from measuring unburnt gases flow rate at blow-off and flash back limits was calculated (*gb, gf*) Reed [12]; Lewis and Von Elbe [1]:

$$g = \frac{8Vo}{Dt} \tag{1}$$

Vo is unburned gas velocity; *Dt* is burner pipe diameter. Used equation (1) to calculate stability limits of Methane-Air at change burner edge speed (0, 15, 27, 38 r.p.m). Figure 3 shows variation of stability limits with equivalence ratio. In experiments, a mean gas velocity through the tube (*Vo*) is taken and a premixed flame is stabilized on the burner tube.

(a) Flash Back



(b) Blow-Off

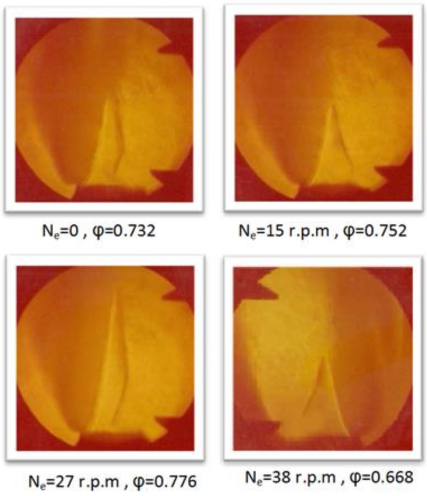


Fig. 2: Samples of Schlieren cone of Methane-Air (a) flash back; (b) blow-off for burner edge speeds under study.

The mass gas fraction (*XF*) of the lean mixture is decreased, however its reduction depends on the occurrence of the flame blow-off from the burner edge happen. Also, for the flash back experiments (*XF*) of lean mixture is increased until the flame beings to enter the burner rim. All these experiments are then repeated at a larger value of the average velocity (*Vo*). Thus, the boundaries of flame flashback and blow-off are found as a function of the Reynolds number:

$$\mathrm{Re} = \frac{RVo}{\vartheta} \tag{2}$$

The kinematic viscosity of methane-air mixture is gas ϑ = 0.16 cm^2/sec. For a rich flame instead of a full flame, the partial vent is defined as the case when at least one third of the flame is raised by 0.5 cm above the edge. An adequate interval is provided between the flash back experiments to ensure that the burner edge temperature is reduced to its normal temperature 32 ^oC. Also, the lean and rich flash back boundaries are defined as the point when the flames move in the burner rim completely. Figure 4 shows the features of rapid flame flare and flash recovery by detecting experiments on glazed pre-methane and air with Ne = 0, 15, 27 and 38 rpm.

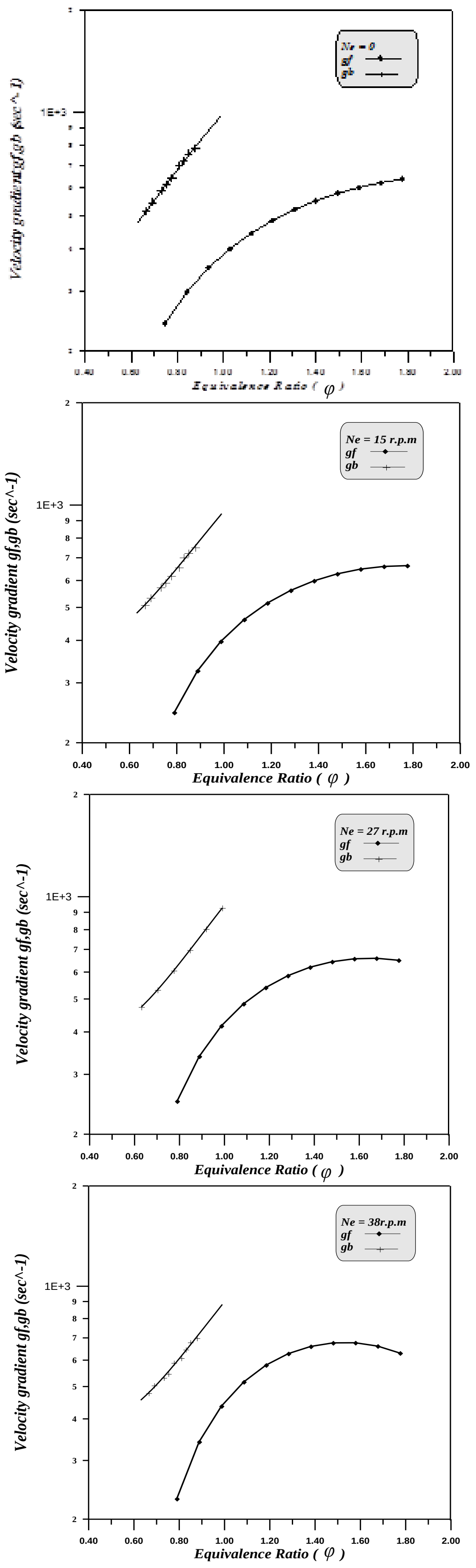


Fig. 3: Variation of stability limits with equivalence ratio.

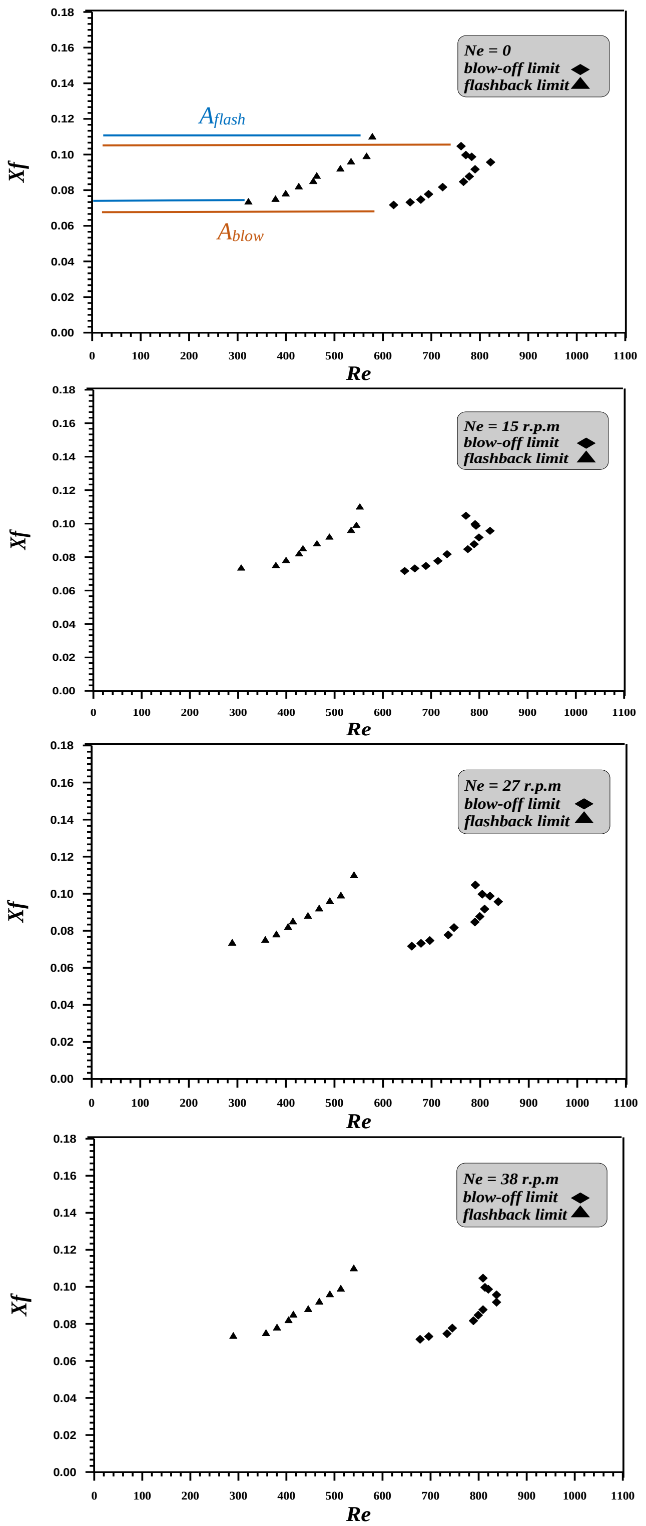


Fig. 4: Flame blow-off and flashback stabilization contours for experiments on Methane-Air premixed flames with Ne = 0, 15, 27, and 38 r.p.m.

Depend on the previous discussions, it was clearly understood that rotating of the burner causes in expansion of the area between the curves for flash back and the blow-off thus allow to flame stability at the larger limits of ($XF - Re$) parameters. The area within the blow-off limit and the flashback curves shown in Figure 4 are noticed by (A_{flash}) and (A_{blow}), respectively. The overall stability area is described as the difference between the blow-off area and the flashback area ($As = A_{blow}$-A_{flash}) on the ($XF - Re$) curves. Two parameters will be used that may notice to describe the flame stability efficiency for different burners types. The flame stability efficiency of the burner was defined as follwing:

$$\eta_s = 1 - \frac{A_{flash}}{A_{blow}} = \frac{A_s}{A_{blow}} \tag{3}$$

To describe the process in the stability limits ($A_{blow} \to \infty$) or ($A_{flash} \to 0$). Therefore, the flame stability efficiency can be decreased by increasing the blow-off area or reverse. The second parameter is used to determining the flame stability characteristics is the flame stability coefficient which can be defined as:

$$\beta_s = \frac{A_s}{A_{st}} \tag{4}$$

Where (A_{st}) is the ideal stability area under optimum conditions. In the current experimental study of the influence of rotation on flame stability (A_{st}) defines to the flame stability area when burner rim fixed ($Ne = 0$). From Table 1 shows results of stability parameters.

Table 1: The initial parameters and conditions for simulation.

Ne (r.p.m)	A_s	η_s %	β_s
0	26.44	81.44	1
15	31.14	76.33	1.177
27	36.66	73.11	1.386
38	39.11	69.82	1.479

4. Conclusion

We investigated the effect the burner rim rotation on stability of premixed flames experimentally. The flame blow-off and flashback limits are evaluated in mass gas fraction versus Reynolds number curve (*XF–Re*). In this work, the results showed that with the increase the flame stability coefficient, the burner rim rotation enhanced the total flame stability area, and decreasing the flame stability efficiency means that the increase of the flame stability area is factually littler than of the blow-off area. The parameters; the flame stabilization efficiency, η_s and the flame stabilization coefficient, β_s also can apply in combustion operations where they can be used to quantify and compare the stability efficiency of several types of burners.

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