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Experimental Investigation of Blending Acetylene with Iraqi LPG to Determine a Flame Stability Map

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Abstract

The difficult challenges facing the designers and engineers of combustion systems are the flame stability (flame stability map) represented by the limits of flashback and blow-off. In this study, acetylene gas was combined with Iraqi liquefied petroleum gas at rates (10% - 50%). The reason for choosing these two components is the low cost and ease of access to it. Where the flashback limits (critical velocity gradient) were obtained from (40-485) 1/sec, while the blow-off limits were (265-2510) 1/sec with a diameter of 25 cm for the burning nozzle diameter only for Iraqi LPG without mixing acetylene. While in the case of mixing 10% acetylene, the flashback limits (critical velocity gradient) were from (30-520) 1/sec and the blow-off limits (440-3985) 1/sec for the same diameter of the muzzle of 25 cm. Whereas, when mixing 30% of the acetylene, the flashback limits (critical velocity gradient) were from (55-575) 1/sec and the blow-off limits (570 - 4050) 1/sec. From the above three cases, noticed a relative expansion of the flame stability map for the flashback boundaries, while at the blow-off limits the amplitude was clear and large, which indicates the confidence in mixing acetylene with Iraqi LPG and obtaining a larger flame stability map. Thus, it stimulates its use in industrial fields and gas turbine power stations.

Keywords: Acetylene, Flame velocity, LPG Iraqi, Map of stability, Swirl burner.

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التحقيق التجريبي لمزج الأسيتيلين مع غاز البترول المسال العراقي لتحديد خريطة استقرار اللهب

الخلاصة:

تتمثل التحديات الصعبة التي تواجه مصممي ومهندسي أنظمة الاحتراق في استقرار اللهب (خريطة استقرار اللهب) التي تمثلها حدود الومضة الراجعة وانطفاء اللهبة. في هذه الدراسة تم دمج غاز الاسيتيلين مع غاز البترول المسال العراقي بنسب تتراوح من (10٪ - 50٪). سبب اختيار هذين المكونين هو التكلفة المنخفضة وسهولة الوصول إليهما.

حيث تم الحصول على حدود الومضة الراجعة (انحدار السرعة الحرجة) من (40-485) 1/ثانية، بينما كانت حدود انطفاء اللهبة (265-2510) 1/ثانية بقطر 25 سم لقطر فوهة المحرق لغاز البترول المسال العراقي بدون خلط الأسيتيلين. بينما في حالة خلط 10٪ أسيتيلين، كانت حدود الومضة الراجعة (تدرج السرعة الحرجة) من (30-520) 1/ثانية وحدود انطفاء اللهبة (440-3985) 1/ثانية لنفس قطر الفوهة. وعند خلط 30٪ من الأسيتيلين، كانت حدود الومضة الراجعة (تدرج السرعة الحرجة) من (55-575) 1/ثانية وحدود انطفاء اللهبة (570-4050) 1/ثانية.

من الحالات الثلاث المذكورة أعلاه لخلط النسب، لوحظ توسع نسبي في خريطة استقرار اللهب لحدود الومضة الراجعة، بينما عند حدود انطفاء اللهبة كانت منطقة استقرار اللهب واضحة وكبيرة، مما يشير إلى الثقة في خلط الأسيتيلين مع غاز البترول المسال العراقي والحصول على استقرار أكبر لخريطة اللهب. وبالتالي، فإنه يحفز استخدامه في المجالات الصناعية ومحطات الطاقة التوربينية الغازية.

1. Introduction

Determining the type of fuel is the basic and economic criterion in the field of fossil energy, as well as pollution resulting from combustion reactions resulting from external combustion systems. Therefore, it is necessary to use environmentally friendly fuel that is low in cost and with high efficiency for use in industries that need to use thermal energy. The discovery of alternative energy and environmentally friendly fuels is one of the challenges necessary to face the decrease in the depletion of traditional fossil fuel sources [1, 2] . Where researchers have made great efforts to find multiple types of alternative fuels, such as gaseous fuels, alcohol blends, and biofuels[3–5]. LPG and acetylene are a promising fuel in the field of internal combustion engines because they have unique advantages in combustion without the formation of any hindrance[6]. The characteristics of acetylene gas combustion are close to hydrogen in terms of high flame speed as well as in terms of flammability. Therefore, it is used in cutting and welding[7]. Many studies have been conducted in mixing diesel fuel with acetylene in a compression ignition engine, and thus the efficiency has been increased by 2% instead of using diesel only[8]. It is known that acetylene cannot be used alone in applications of internal combustion engines due to its low octane count, but it is characterized by wide flammability and ease of preparation from crude oil at low costs[9]. Studies have shown that the use of hydrogen, liquefied petroleum, acetylene and natural gas as a secondary

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fuel for combustion engines that run on diesel fuel is highly efficient and low in pollution[10]. The ignition temperature of acetylene is high, so it has great properties that make it more reliable for diesel engines[11]. Through the above literature, acetylene gives advanced hope in combustion technology as a good alternative fuel mixed with diesel[12]. For gasoline combustion engines, acetylene mixed with ethanol alcohol can be used, as it can be obtained from non-petroleum sources for a four-stroke engine, where high efficiency and low emissions are observed from those found in gasoline[13]. The properties of acetylene gas is characterized by its high-speed flame and it needs small amounts of oxygen compared to other gases, but it is a colorless, odorless and highly flammable gas, thus giving it advantages in use in internal combustion engines[14]. Studies have shown that the use of liquefied petroleum gas is much better than the use of liquid fuels in terms of emission, efficiency, and cheapness in Iraq. However, the problems of using gases in external combustion systems represented in safety and control of flame stability made designers an obstacle in its use, but it is considered a reliable, future and promising source in the field of Modern energy [15]. In terms of properties with respect to acetylene, hydrogen and liquefied petroleum, we note a convergence of specifications in their use in external combustion systems, and thus they can be mixed without any hindrance as shown in the following Table (1) [16–18].

Table (1) Standard Specification for LPG Iraqi and Acetylene Fuel.

Properties	Unit	LPG	Acetylene	Hydrogen
Density	Kg/m3	1.85	1.092	0.09
Flammability Limit (Volume %)	-	4.1-74.5	2.5-81	4-75
Low Calorific Value	MJ/Kg	42.790	48.22	120
Octane Number	-	+105	-	>120
Flame Velocity	m/s	0.48	1.5	1.85
Stoichiometric air–fuel ratio (A/F)	-	0.064	0.075	0.029

Flame instability is one of the important challenges in drawing a flame stability map represented by a flashback for the boundary layer that can be predicted [19]. Theoretical and experimental studies of the return ability of a pre-mixed flame to the airflow and fuel stream with a fixed equivalence ratio show a model for the propagation of the flame in the boundary layer[20]. Scientific investigations have shown that the inclination of the flashback has an

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important effect on the swirl number as when reducing the swirl from 0.66 to 0.53 it did not affect the blow-off and it has a clear effect on the inclination of the flashback [21]. The structure of the jet burner has a major role in influencing the flashback of mixed gases in turbulent streams [22]. Representation of flame instability in four mechanisms: (1) flame instability, (2) flashback boundary layer, (3) combustion vortex collapse (CIVB), and (4) core flow flashback through the use of a glass tube that shows the flame transfer to Burner nozzle [23]. The flashback mechanism of the boundary layer through the critical velocity gradient can be defined from the following equation [19].

$$g_f = \frac{4Q}{\pi R^3} \qquad (1)$$

A modern technology has been devised to counter the flashback in the boundary layer by simulating engineering using fine surfaces (metal mesh) placed on the walls of the burner from the inside [24]. Vortex combustion technology has spread to stabilize combustion used in gas turbines where geometric shapes can play an important role in the flow field inside the combustion chamber that allows the flame to stabilize under pre-mixed conditions [25]. Flame instability often occurs due to two techniques, which is the flashback that occurs due to the collapse of the combustion vortex in the center of the flame nozzle and thus attacks the mixing chamber of the fuel, as well as the flashback occurs through the boundary layer of the walls of the burner where the speed of the flame prevails over the velocity of the fuel flow [26]. The geometry of the burner nozzle had a major role in drawing a flame stability map for using different length nozzles with a fixed diameter and determining the blowing and flashback limits using LPG [27–29]. It is necessary to draw a flame stability map for the burner, define the safety zone, define the flashback and blow boundaries, and in this study we highlight the flame stabilization zone by mixing acetylene in certain proportions with Iraqi liquefied petroleum gas.

2. Experimental Work

All tests were conducted under the supervision of a specialized scientific cadre at the Technical College of Engineering, Najaf, taking all occupational safety precautions using high-quality electrical control in the event of any emergency for the system, which consists of a cylindrical burner, rotometers and an air impeller with an electrical control panel, as well as using a high-precision camera.

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The burner was designed and manufactured in the workshops and laboratories of the College of Engineering Technology, Najaf, from welding, cutting, and examination using an old oil filter for the car and exploiting its cylindrical shape to make it a swirl burner by inserting two tubes from the bottom of the burner in two tangents with a diameter of 14 mm, one of which is used to enter compressed air and the other is used to enter acetylene gas and from the bottom a 6 mm tube was placed for the introduction of LPG, and the burner nozzle was made from the top with three nozzles with diameters (2.5, 3,3 and 5) cm respectively, and the nozzle from the inside was grooved to prevent the flashback from occurring on the boundary layer. The dimensions of the burner body are 150 mm in height, 105 mm in diameter, and 40 mm in nuzzle height. The design idea of the burner body is taken from the University of Cardiff in Britain[30], but the design and dimensions are different, as well as the ease of manufacture, as shown in the Figure (1, a & b).

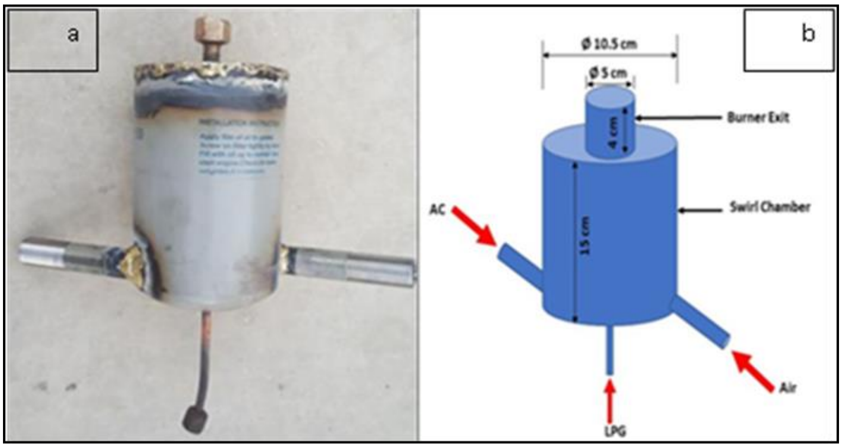

Fig. (1): Geometric design of tangential swirl burner (a) photograph (b) schematic.

The followed steps that were studied in this research were as follows:

1. Starting to supply LPG with a low flow rate for the purpose of first ignition.
2. Control the flow rates of air, acetylene, and liquefied petroleum, through rotometers and at specific mixing rates.
3. Increase the air flow rate slowly and continuously until the flame rises from the edge of the burner until blowing occurs and the flow rate is recorded.
4. Repeating the previous steps above from 1 to 3.

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5. Reducing the rate of air flow slowly and continuously until the flame drops to the edge of the burner and goes to the fuel stream until the flashback occurs and the flow rate is recorded.
6. Repeating the previous steps with equivalence rates from (0.6 to 1.4) and mixing rates for acetylene from (0 - 50%).

An analysis of the recorded values was used by repeating the experiment five times at least and taking the average values for the sake of accuracy of the information.

3. Results and Discussion

In this study experiments were conducted to determine the flame stability limits of flashback and blow-off using Iraqi LPG fuel with different mixing ratios of acetylene gas and air (equivalence ratios). Figure (2) shows the flame stability zone limits for acetylene gas LPG mixing group. Note that the flame stability map is narrow in the lean state and broad in the rich state. The reason for the difference in the stability map in the rich state is to increase the blow-off limit with the increase in fuel, while the flashback limit decreases with the increase in fuel due to the high flammability of acetylene gas. It was also observed that the flashback increased with the increase in acetylene mixing due to its high flame speed compared to the velocity of the Iraqi LPG.

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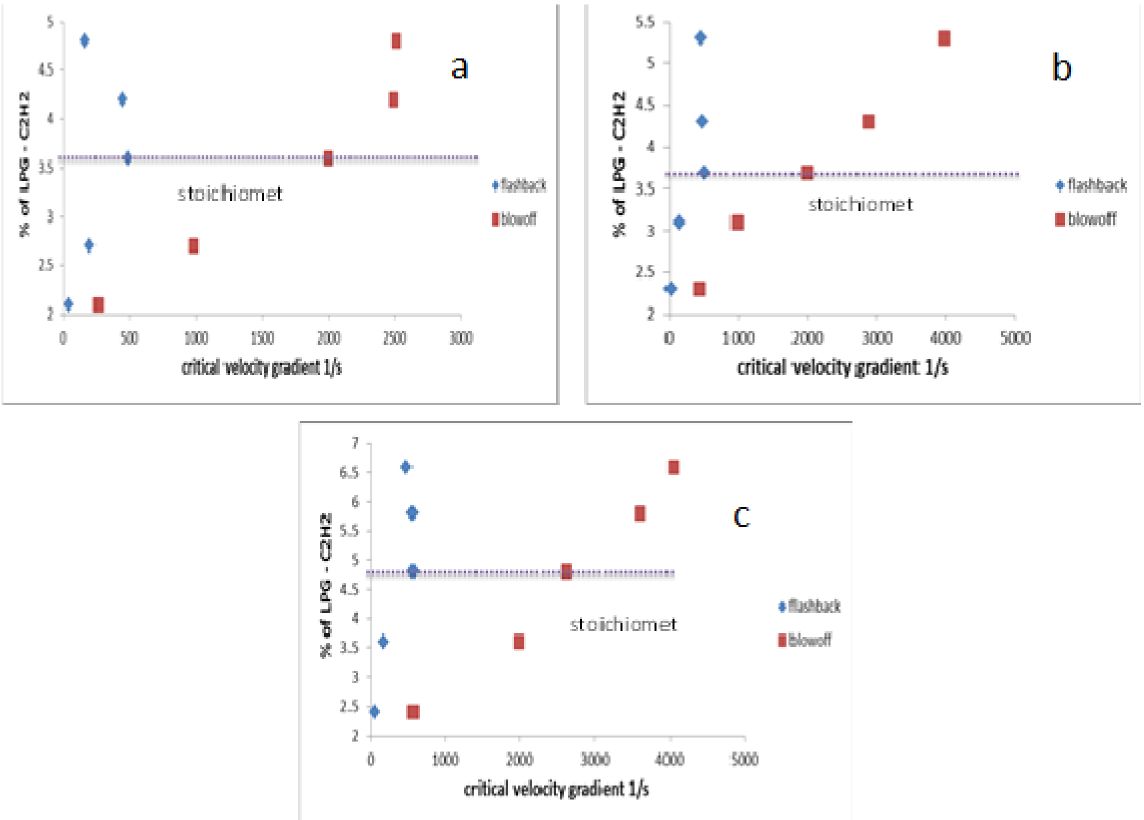

Fig. (2): The relationship between the flame stability map (flashback limits and blow-off) in certain proportions with a critical velocity gradient (a) 0% acetylene - 100% Iraqi LPG and (b) 10% acetylene - 90% Iraqi liquefied petroleum and (c) 30% acetylene - 70% of Iraqi liquefied petroleum.

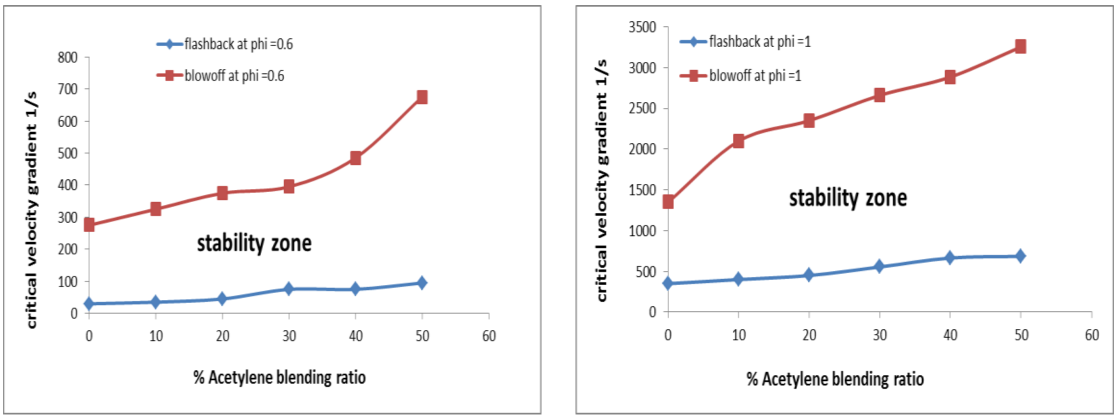

Fig. (3): Demonstrates flame stabilization area (flashback and blow-off limits)

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Figure (3) shows the flame stability zone, with the effect of the flame stability zone, by mixing acetylene with air and Iraqi LPG, which is indicated by the critical velocity gradient of flashback and blow-off. Where it was observed that blow-off in the critical velocity gradient increased with the increase in the mixture of acetylene due to the high flammability compared with Iraqi liquefied petroleum. Likewise, with flashbacks, an increase in the critical velocity gradient was observed with flashback, with the increase in acetylene mixing due to its high ignition speed. This event is necessary for the safe operation of the combustion system in a gas turbine. The different flow rates (gf) were calculated for the different burning nozzles of Iraqi Liquefied Petroleum with mixing of 30% acetylene as shown in Figure (4).

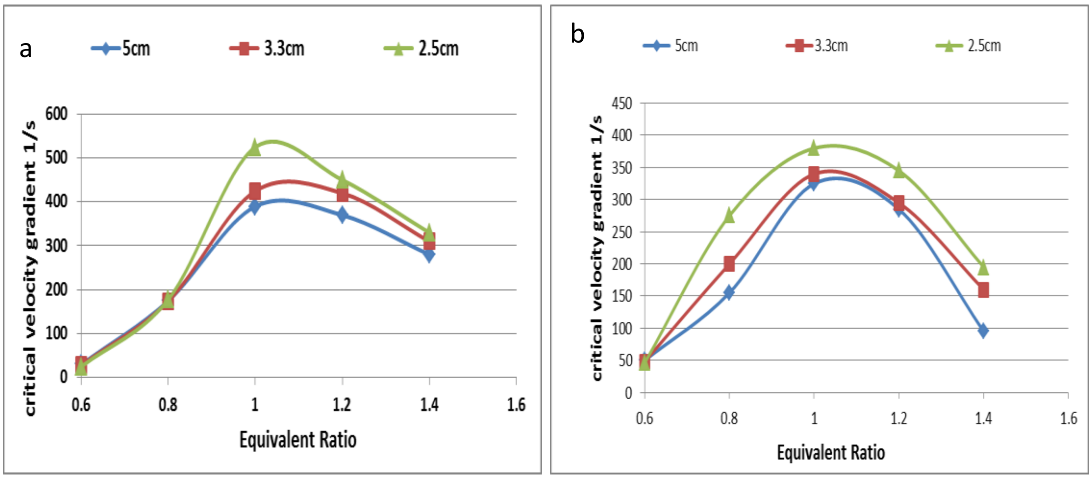

Fig. (4): It shows the equivalent ratio of the mixture with the critical velocity gradient for different burner nozzle diameters (a) 100% Iraqi LPG, (b) Acetylene 30% - 70% Iraqi LPG.

It was observed that the maximum flashback occurred in the vicinity of the stoichiometric mixture, which decreased with the increase of the burner diameter in an increased proportion of the acetylene mixture due to the cooling effects at the burner edge and the higher the combustion temperature of the acetylene. The big challenge facing the Flame Stability Map is to prevent flashbacks. Figures (5, 6 and 7) show the flashback function of the critical velocitygradient for different firing nozzle diameters with different mixing ratios for acetylene. It was also noted that the flashback increased with the increase in the percentage of acetylene mixing due to the high flame speed of acetylene gas and the high combustion

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temperature. As for the phenomenon of blow-off, this has a major impact on the flame stability map. As the blow-off was determined by increasing the flow rate of the unburned mixture to a value greater than the flame velocity, and thus the flame moves away from the burner edge, which leads to the retention of air at the base of the flame, which reduces the equivalence ratio and thus affects the blow-off of the flame. Also, it has been observed that in the case of increasing the mixing of acetylene, the blow-off limits are increased due to the high flammability of acetylene compared to Iraqi Liquefied Petroleum.

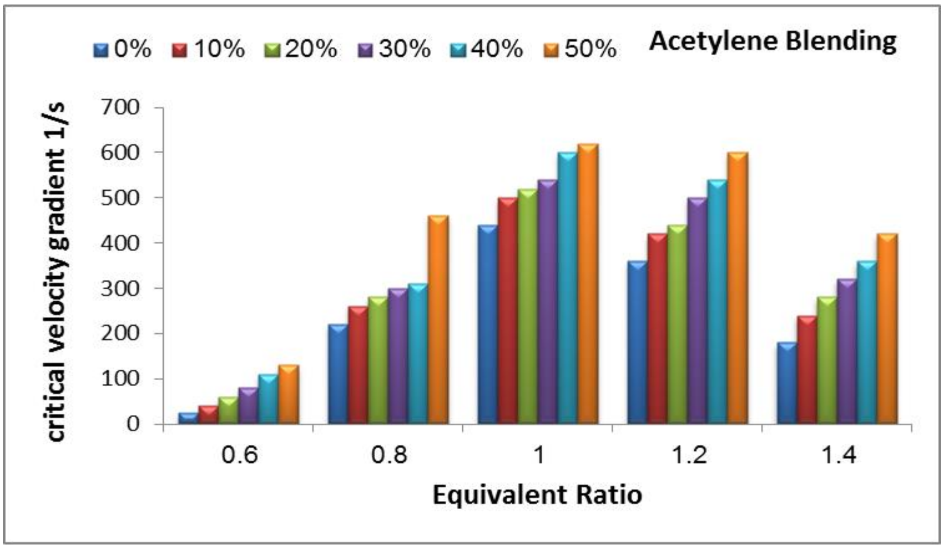

Fig. (5): Shows the critical velocity gradient at flashback of the 2. 2 cm burner nozzle

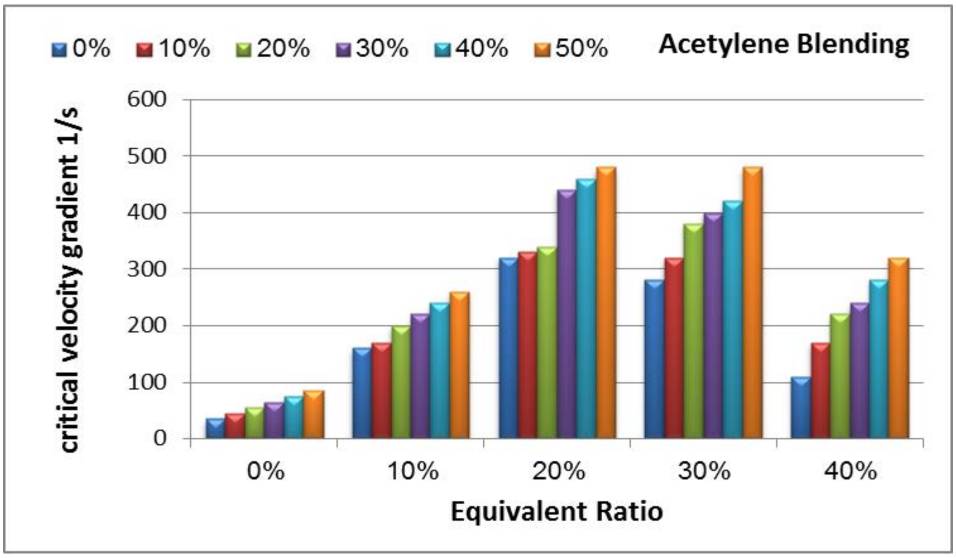

Fig. (6): Shows the critical velocity gradient at flashback of the 3. 3 cm burner nozzle

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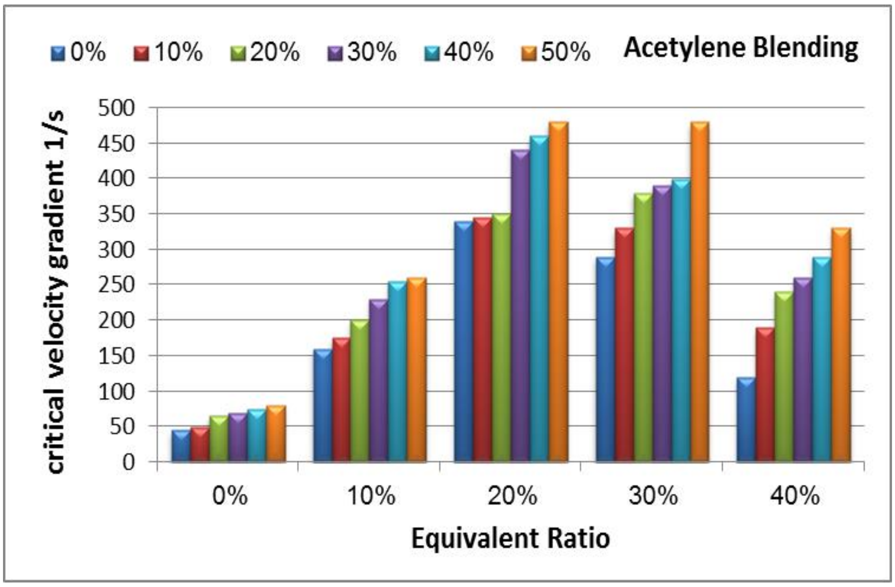

Fig. (7): Shows the critical velocity gradient at flashback of the 5 cm burner nozzle

Knowing the flame stability map represented by the flashback and blow-off phenomena is necessary to define the safety zone in which the area must be worked. Figure (8) shows the practical images that were taken using a high-resolution camera, the occurrence of the flashback in the boundary layer, as well as the flashback illustrating the collapse of the vortex. It also shows the occurrence of the phenomenon of separation of the flame from the burner nozzle (blow-off). The critical velocity gradient was calculated when blowing using equation (1) so that the flame must be kept in the stable zone for safe and smooth operation of the combustion system.

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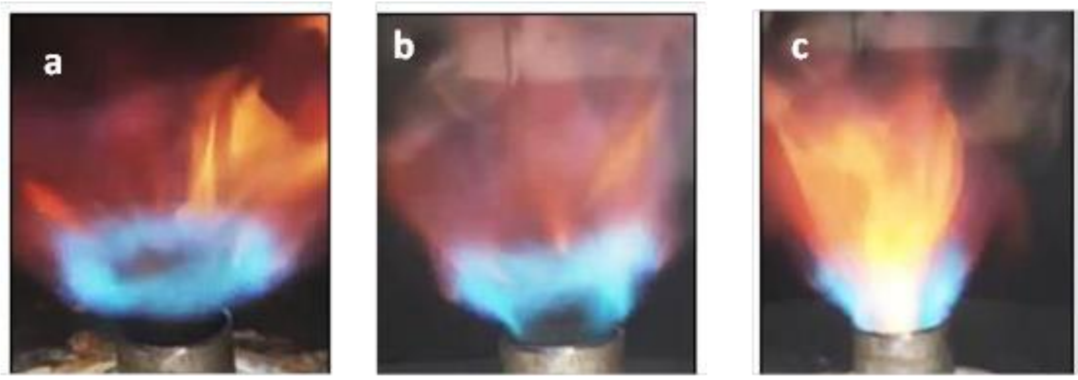

Fig. (8): It shows laboratory images taken of the burner nozzle where (A) shows the separation of the flame from the source (blow-off) and (B) shows the occurrence of the flashback phenomenon in the boundary layer(BLF) and (C) shows the collapse of the flame vortex (CIVB)

4. Conclusions

This paper describes a set of experiments conducted to analyze and define a flame stability map for combustion mixed from Iraqi LPG with acetylene in a swirl burner using different diameters of a nozzle upstream for a set of acetylene mixing ratios and a set of equivalence ratios. The following important points were concluded:

1- The flame stabilization map (flashback and blow-off) mixed with LPG and air with mixing ratios of acetylene gas (0% - 50%) for different diameters of the burner nozzle (2.5, 3.3 and 5) cm, and a set of equivalence ratios (0.6-1.4) that were measured. As all the tests were conducted in the conditions of atmospheric air and ambient temperature. Where it was found that the maximum flashback occurred at the stoichiometric ratio and decreased on both sides of the stoichiometric ratio.

2- Increasing the acetylene mixing ratio further improved the flame stability area and thus the flashback limits were slightly increased due to the high acetylene flame speed. As for the blow-off limits, it has been greatly increased and thus the flame stability zone has been expanded, which is an important indicator for the safe operation of the combustion system.

3- The large burner diameter (5 cm) nozzle improved the flame stabilization area by reducing the flashback limits compared to the lower diameter.

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