EXPERIMENTAL INVESTIGATION OF THE FLAME STABILITY MAP (OPERATING WINDOW) BY USING A TANGENTIAL SWIRL BURNER FOR THE CONFINEMENT AND UNCONFINEMENT SPACE

Karrar S. Hasan1*, H. H. S. Khwayyir1, Wisam A. Abd Al-wahid1

1 Engineering Technical College, AL-Furat Al-Awsat Technical University, Al-Najaf 31001, Iraq

eng.karrarsalah@atu.edu.iq
ahmedqom90iq@gmail.com

ABSTRACT

Despite the development in the field of energy usage and the ways to reach it to meet the needs of human life, the energy is the actual measure of development in any society. The hydrocarbons fuel is the main energy source in the world and the increments in consumption hydrocarbons lead to an increase in the pollutants and increase global warming. To obtain economical combustion systems that have more stable, the present work used a new design for LPG tangential swirl burner to clarify the extent of the combustion stability for with and without confinement space (flashback, and blowoff). Moreover, study the produced heating power for both confinements and without confinement. The experiments were performed with four constant values of gas (2, 4, 8, and 10) L/min at different airflow rates for individual gas value. The results demonstrated that the flame stability behavior of the confinement burner was clear when Ф verify from 0.39 to 1.4, while without confinement the flame stability was clear when verifying from 0.34 to 1.7. For the same operation parameters the values of heating input (2.63, 6.56, 10.55, and 13.19) kW.

Keywords: Burner, Blowoff, Confinement, Flashback, Operation window, LPG
INTRODUCTION

The increase in energy consumption in the world led to an increase in research and development in its production methods and how to maintain and develop it through the development of the systems used as heat exchangers and boilers as well as combustion systems (1) (2) (3). The combustion system has a direct impact on the environment as a result of emissions and pollutants. Therefore, the combustion system must be designed with the lowest emission and less expensive products, which are used in many gas turbines, boilers, and factories. One of the things that designers should focus on is to achieve stability in the work by knowing the operational conditions of the blowoff and flashback limits for this design because of its impact on the percentage of pollutants, fuel consumption, and combustion efficiency.

When the flame moves away from the edge of the burner, the blowoff phenomenon occurs and the flame extinguishes due to the separation of the flame from the source. It is affected by the type of fuel used, the mixing ratio, and the geometry of the burner (4). As a result of the development of combustion systems, the use of a swirl burner reduced NOx emissions, but it increased the possibility of a blowoff problem (5) (6) (7) (8). The carbon content of single fuel cases is relatively higher than in dual-fuel cases, resulting in a significant increase in CO2 emissions Raheem (9) (10). Moreover, the flashback phenomenon occurs when the turbulent flame movement in the direction of the combustion source is faster than of fuel flow trying to penetrate this system (11) (12). As the flashback phenomenon is considered the most dangerous and the most visible to combustion systems and thus flame instability. As it depends on the type of fuel used and thus has an effective effect on the flashback mechanism, depending on if the fuel has a higher hydrogen number, the velocity of its vortex flow is much higher than natural gas (13) (14). Hence, the speed of the fuel mixture in the tangential swirl burner is less than the speed of the flame and thus the flashback phenomenon occurs (15) (16). The flashback is divided into four mechanisms according to the location of the turbulence and the change in the flame speed, including flashback due to Combustion Induced Vortex Breakdown (CIVB), Boundary-Layer Flashback (BLF), Turbulent Core Flashback, and Combustion instability induced flashback (17).

The CIVB is of interest to researchers and designers, among other types of flashback, because it is the dominant type in swirl combustion, especially in fuels with high reaction mixtures (18). A sudden change in the nozzle of the burner creates a central recirculation area. Which increases the heat release in this region and thus the flame is directed mainly towards the source of the fuel and works to break down the swirl. The type of fuel has a direct impact on CIVB as mentioned in many studies that have shown that increasing the hydrogen content leads to a reduction in the CIVB (19).

To avoid the occurrence of CIVB, use a bluff body that works to increase turbulence at the mouth of the stove in the recycling area, thus reducing the tendency to occur CIVB (20). It is possible that the bluff body is an injector of air or fuel and works
to prevent the occurrence of CIVB, but it may lead to boundary layer flashback (21). The use of Mayer (22) axial fuel injection, improves the resistance of CIVB compared to the trailing injection. In the event of a BLF, the flame spreads in the direction of the current in the low-speed area near the walls of the burner or the walls of the bluff body (23). The lateral air injection helps push the flame to a higher speed zone, thus preventing flashback (24). Among the newest techniques for resisting BLF, Steel wire mesh within the inner wall nozzle was used at the edge of the stove (25). Besides, when the burner contains wire mesh technology with the central injector, the combustion is more stable and resists the occurrence of CIVB and BLF (26). It is possible to overcome the operational problems of a flashback by changing the shape and diameter of the burner nozzle and thus increasing the flashback limits when pre-mixing or partial combustion (27). Among the studies that were conducted, is the knowledge of the effect of the length of the stove neck on the area of the operating window, and it was found that increasing the length of the stove neck affects the vortex, weakens it and increases the occurrence of the flashback phenomenon (28) (29). Therefore, this study provides a statement of the stability of the operating window (flashback and blowoff limits) for a tangential swirl burner with and without confinement space.

**EXPERIMENTAL SETUP**

General view of a tangential swirl burner as depicted in Figure 1 was manufactured in the laboratories of engineering technical college/Al-Furat Al-Awsat Technical University- Najaf. The present burner consists of two side air intakes with 1.4 cm in diameter for each side, to create vortices inside the combustion swirl chamber. Where the air is mixed with the liquefied petroleum gas (LPG), which is supplied from the bottom of the swirl chamber with a diameter of 0.6cm (as shown in Figure 2), thus creating a homogeneous mixture of fuel and air ready for combustion at the burner exit. For control of the quantities of air and fuel needed in the combustion process. Rotometers are used to measure fuel and airflow rates.
Figure 1. Manufactured tangential swirl burner

Figure 2. Geometry specifications of the Tangential Swirl Burner a) top view b) front view
The study was conducted on the burner without confinement space as well as in confinement space by using it in the steam generation system (Boiler) as shown in Fig. 3.

![General View](image)

(a) (b)

**Figure 3.** General View. (a) burner, (b) experimental rig.

**RESULTS AND DISCUSSION**

In present work, the tangential swirl burner was used to clarify the stability of the zone between the limits of flashback and blowoff (operation window) at a variable equivalent with and without confinement space. Figure 4 shown the vortex nucleus emerging from the burner nozzle which obtained from the present work under unconfined study. Moreover, the mention phenomena are matched to the results of Syred study (30) which performed with the different burner.

![Helical Nature of the Processing Swirl Core](image)

**Figure 4.** Helical Nature of the Processing Swirl Core
The practical photo is shown in Figure 5a low swirl combustion which features a separate flame that is raised above the burner where it is more stable. Since the flame does not touch the burner, the low swirl combustion is also highly energy-efficient due to the non-loss of the burner energy. Figure 5b shows the flame approaches the sides of the burner nozzle, which creates a Boundary Layer Flashback (BLF), while the Combustion Induced Vortex Breakdown (CIVB) can be observed as the flame starts attacking the core of the burner as shown in Figure 5c. The blue color indicates that the fuel mixture is completely burned in this region due to the presence of a sufficient quantity of oxygen, which means clean combustion.

![Figure 5a](image1.jpg) ![Figure 5b](image2.jpg) ![Figure 5c](image3.jpg)

**Figure 5.** (a) Flame separation in low swirl combustion, (b) Boundary Layer Flashback (BLF), (c) Combustion Induced Vortex Breakdown (CIVB)

Figure 6 discusses the blowoff limits of the flame in with and Without Confinement Space, where notice that the blowoff limits for the without confinement space are less than the state of the confinement space and this gives the possibility of
working even at a few equivalent ratios in the without confinement. The boundaries of blowoff in without confinement space 0.341 and in confinement space 0.398.

**Figure 6.** Comparison of the Blowoff Limits In with and Without Confinement Space

Figure 7 discusses the limits of the flashback of the flame with and Without Confinement Space, where notice that the limits of the flashback in without confinement area have a wide range and this gives high stability of the flame, better cohesion, and not return to the source of the nozzle, which gives more safety to the combustion system, as the first point For the flashback occurrence in without confinement space is 1.365, while in confinement space it is 0.95.

**Figure 7.** Comparison of the Flashback Limits In with and Without Confinement Space
As shown in Figure 8 the stability area (operation window) of the tangential swirl burner was limits (0.543 - 1.365) for the without confinement space, while it was (0.597 - 0.95) in the confinement space as shown in Figure 9.

![Figure 8. Operation Window in without Confinement Space](image1.png)

![Figure 9. Operation Window in Confinement Space](image2.png)

By comparison of the operation window as clear in Figure 10, it was found to be larger and more stable in the without confinement space, while less in the confinement space. This variety is due to the presence or absence of oxygen in the vicinity of the flame.
At the same values of heat produced from the fuel burning in the confined and without confined spaces found that the blowoff points of the confined space are at higher mixing ratios than unconfined and that the return points of the confined space are at lower mixing ratios than unconfined as shown in Figure 1. This gives a clear idea of the importance of oxygen for combustion and the necessity of increasing its rate in the case of using the unconfined space so that the work window area becomes more stable.

Figure 10. Comparison of the Operation Window between the Confinement and Without Confine Space

Figure 11. Comparison of the Limits of Heat Input In with and Without Confinement Space
Table 1. $\Phi$ limit of flashback & blowoff comparative between present work and previous work as follow:

| Author       | $\Phi$ Flashback | $\Phi$ Blowoff | Swirl configuration | Fuel type | Burner state          |
|--------------|------------------|----------------|---------------------|-----------|-----------------------|
| (28)         | 0.82             | 0.38           | vane                | LPG       | Without confined      |
| (25)         | 0.6              | 0.43           | tangential          | NG        | Without confined      |
| Present work | 1.36             | 0.34           | tangential          | LPG       | Without confined      |

CONCLUSIONS

The important point reached in this paper is that the occurrence of flashback occurs in the place of confinement that can be expected to happen more quickly compared to the area of non-confinement, as a result of the reverse pressure (negative pressure) in the space confinement, it warns the occurrence of flashback, flame instability, more active, the operation window is largely confined compared to the non-inventory space. As for the blast, the process is not very significant, as the flame is only separated from the source of the flame by pumping a large amount of air. So, the limits of blowoff of a confinement space occur at a certain limit of the amount of air mixed at constant proportions of fuel, while the blowoff of without confinement space it can happen at lower air supply values than it was with the space confined to the same conditions of fuel supply. From this, the operating area of the un-confinement space is greater than the confinement space, taking into consideration the values of the flashback limits for the confinement space that are closer to the case of lean mixing than un-confinement space. From the foregoing, the air in the vicinity of the flame in the case of un-confinement space and the lack of it in the case of confinement space has this effect on the change in the stability zone (operating window).

NOMENCLATURE

- LPG: Liquefied petroleum gas
- NG: Natural gas
- BO: Blowoff
- FB: Flashback
- CIVB: Combustion induced vortex breakdown
- BLF: Boundary layer flashback
Greek symbols
Φ Equivalence ratio

REFERENCES
1. Baqir AS, Mahood HB, Kareem ARJTS, Progress E. Optimisation and evaluation of NTU and effectiveness of a helical coil tube heat exchanger with air injection. 2019;14:100420.
2. Bălănescu D-T, Homutescu V-MJPM. Study on condensing boiler technology potential accounting various fuels. 2019;32:504-12.
3. Al-Fahham M. A modelling and experimental study to reduce boundary layer flashback with microstructure: Cardiff University; 2017.
4. Jameel Al-Naffakh. <experimental investigation of the effect of burner geometrey on flame stability.pdf>, al-furat al-awsat technical university 2019.
5. Lieuwen T, McDonell V, Santavica D, Sattelmayer TJCS, Technology. Burner development and operability issues associated with steady flowing syngas fired combustors. 2008;180(6):1169-92.
6. Li Y, Li R, Li D, Bao J, Zhang PJICih, transfer m. Combustion characteristics of a slotted swirl combustor: An experimental test and numerical validation. 2015;66:140-7.
7. Durbin MD, Ballal DR. Studies of lean blowout in a step swirl combustor. 1996.
8. Lieuwen TC, Yang V. Combustion instabilities in gas turbine engines: operational experience, fundamental mechanisms, and modeling: American Institute of Aeronautics and Astronautics; 2005.
9. Raheem DG, Erdem K, Hasan KJAAT. Techno-environmental studies on a reciprocating internal combustion engine fired with syngas produced by gasifying different types of Turkish lignites. 2018;2(3):137-42.
10. Gül M, Köten H, Yılmaz M, Savcı İjo. ADVANCED NUMERICAL AND EXPERIMENTAL STUDIES ON CI ENGINE EMISSIONS. 2018.
11. Kalantari A, McDonell V, Samuelsen S, Farhangi S, Ayers D, editors. Towards Improved Boundary Layer Flashback Resistance of a 65 kW Gas Turbine With a Retrofittable Injector Concept. ASME Turbo Expo 2018: Turbomachinery Technical Conference and Exposition; 2018: American Society of Mechanical Engineers Digital Collection.
12. Baumgartner G, Boeck LR, Sattelmayer TJJoEffGT, Power. Experimental investigation of the transition mechanism from stable flame to flashback in a generic premixed combustion system with high-speed micro-particle image velocimetry and Micro-PLIF combined with chemiluminescence imaging. 2016;138(2):021501.
13. Syred N, Abdulsada M, Griffiths A, O’Doherty T, Bowen PJAE. The effect of hydrogen containing fuel blends upon flashback in swirl burners. 2012;89(1):106-10.
14. Benim AC, Syed KJ. Flashback mechanisms in lean premixed gas turbine combustion: Academic press; 2014.
15. Abdulsada M, Syred N, Bowen P, O’Doherty T, Griffiths A, Marsh R, et al. Effect of exhaust confinement and fuel type upon the blowoff limits and fuel switching ability of swirl combustors. 2012;48:426-35.
16. Marco Osvaldo V-Z, Nicholas S, Agustín V-M, Daniel DIR-U. Flashback Avoidance in Swirling Flow Burners. Ingeniería, Investigación y Tecnología. 2014;15(4):603-14.
17. Lieuwen T, Torres H, Johnson C, Zinn BJEGTP. A mechanism of combustion instability in lean premixed gas turbine combustors. 2001;123(1):182-9.
18. Baumgartner G, Sattelmayer T, editors. Experimental investigation on the effect of boundary layer fluid injection on the flashback propensity of premixed hydrogen-air flames. ASME Turbo Expo 2013: Turbine Technical Conference and Exposition; 2013: American Society of Mechanical Engineers Digital Collection.

19. Dam B, Love N, Choudhuri AJ. Flashback propensity of syngas fuels. 2011;90(2):618-25.

20. Lasky IM, Morales AJ, Reyes J, Ahmed KA, Boxx IG. The Characteristics of Flame Stability at High Turbulence Conditions in a Bluff-Body Stabilized Combustor. AIAA Scitech 2019 Forum2019.

21. Hoferichter V, Hirsch C, Sattelmayer TJJoEfGT, Power. Prediction of confined flame flashback limits using boundary layer separation theory. 2017;139(2).

22. Mayer C, Sangl J, Sattelmayer T, Lachaux T, Bernero SJJoEfGT, Power. Study on the operational window of a swirl stabilized syngas burner under atmospheric and high pressure conditions. 2012;134(3):031506.

23. Lovett JA, Mick WJ, editors. Development of a Swirl and Bluff-Body Stabilized Burner for Low-NOx, Lean-Premixed Combustion. ASME 1995 International Gas Turbine and Aeroengine Congress and Exposition; 1995: American Society of Mechanical Engineers Digital Collection.

24. Heeger C, Gordon R, Tummers M, Sattelmayer T, Dreizler AEiF. Experimental analysis of flashback in lean premixed swirling flames: upstream flame propagation. 2010;49(4):853-63.

25. Al-Fahham M, Hatem FA, Alsaegh AS, Valera Medina A, Bigot S, Marsh R, editors. Experimental study to enhance resistance for boundary layer flashback in swirl burners using microsurfaces. ASME Turbo Expo 2017: Turbomachinery Technical Conference and Exposition; 2017: American Society of Mechanical Engineers Digital Collection.

26. Hatem FA, Alsaegh AS, Al-Faham M, Valera-Medina AJEP. Enhancement flame flashback resistance against CIVB and BLF in swirl burners. 2017;142:1071-6.

27. Janna H, Abdulssada MJA-QJfES. Experimental Investigation of the Confinement Effect on Flashback in Multi Combustion Modes Tangential Swirl Burner. 2019;12(3):161-6.

28. Jameel Al-Naffakh MA-FaQAA. Experimental Investigate the Effect of Burner Geometry on the Operation Window of the Burner. Energy Research Journal. 2019.

29. Jameel Al-Naffakh, Al-fahham M, Abed QA. The blowoff limits and flashback limits for different diameter to length ratio burner. 2019.

30. Syred NJPIE, Science C. A review of oscillation mechanisms and the role of the precessing vortex core (PVC) in swirl combustion systems. 2006;32(2):93-161.