Flashback and combustion stability in swirl burners: review paper

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Abstract

Flame flashback phenomena and combustion stability in a swirl burners represent the major of instability problems that lead to causing a considerable damage to combustion systems as well as the pollution troubles. Recently, researchers suggested many techniques in order to enhancing flame flashback resistance especially against a combustion induced vortex breakdown mechanism in addition to boundary layer flashback. Therefore, the present paper represent a general review about flashback and combustion stability in swirl burners to be as a scientific reference for researchers in this field.

Key words: Flashback, swirl burner, CIVB, BLF, flame stability, swirl flow

Introduction

In the previous decades, emissions had a clear and worrying impact on climate change as a result of human activities such as using gas turbine in power plant. One of the most serious problems in designing gas turbine engines is how to reduce emissions of pollutants such as carbon dioxide and nitrogen oxides. Once of solutions that used to reduce these emissions was advanced design propulsion systems. Besides, alternative fuels and biofuels can be used as a successful
alternative to reduce emissions compared with the case of oil fuels and its derivatives (1, 2). New applied combustion strategies, for example, flameless burning and lean premixed vaporized, can improve combustion process and lessen undesirable emissions. However, these methods are accompanied by serious stability problems, which are blowoff, auto ignition and the most critical one flashback, especially in fuels that have a high content of hydrogen which has a high combustion speed. Hydrogen gas combustion remains undoubtedly a difficult problem (3). Compared to hydrocarbon fuels, the reaction velocity and ignition of hydrogen are much higher due to its various physical and thermal properties such as its higher diffusivity, high flame speed, smaller quenching distances, and broadly flammability (4). Consequently, there is a high risk that the flashback will return to the source above the burner rim. This concerns to areas with low flow velocity, as in waking areas or boundary layers. Flash back can lead to instability of combustion and damage to devices that not designed for high temperatures and thus corrosion, and this may cause hardware failure and shutdown. To obtain combustion systems with more stability and safety, there must be a thorough and detailed understanding of the mechanisms of flashback (5).

**Swirl Flow**

To obtain swirl flow two different types of swirl generators are used: a swirl guided at a specific angle to mix the air with fuel. The vane guide used in this work has 16 slots and $30^\circ$ (6), as shown in Fig.1 and the second one is a tangential swirl to enter the air with fuel as shown in Fig.2 (7). These two types create a swirling mixture to lift the flame from the edge of the burner, especially in the external combustion systems of gas turbines. In terms of performance the transverse entry system has a better performance in forming a spiral at the heart of the internal wall of the burner. However, the transverse system of the swirl has defects in a high degree of contrast as well as the associated effects of swirls formed on the inner wall of the burn (8).

**Swirl strength**

Mixing flow generates a large thrust (centrifugal force) directed to the inner wall of the burner. To maintain equilibrium with centrifugal force, the gradient is formed when pressed in the radial direction, and this flow is called simple radial equilibrium (9). From the aerodynamic point of view, it is concluded that the
strength of the vortex will decrease with increase length due the friction with burner inner walls. As a consequence, the swirl flow will turn to jet or diffusion like flow (10)

![Swirl vane guide](image1)

![Tangential swirl burner](image2)

It was found that when the flow flows and the azimuth decomposes at an increasing axial distance, pressure resumes in the lower region. A positive gradient of pressure is created along the axis, thus forming a recirculation area, providing a high vortex force. In some gas turbine systems, the vortex breakdown occurs in relation to the pressure gradient due to the sudden expansion of the cross-section: the vortex core grows rapidly and produces a harmful gradient of pressure, which is further enhanced by the restoration of pressure due to the general decrease in axial speed (11). Several types of eddy breakdown emerged that were described as turbulent lamellar flows (12, 13). The way in which the flow was created (ie. the use of guided blades), as well as the geometry of the burner, has a significant impact on the collapse of the vortex and thus affects the flow field (11, 14). Several parameters are proposed in the description of turbulent circulation flow, such as vortex, Strouhal number, swirl number, Reynolds number, circulation number, geometrical swirl number (15, 16). Swirl numbers were selected to determine and evaluate vortex strength in the flame probes in the burner. It is known as the axial flow ratio of the axial impetus to the axial flow of the distinctive longitudinal impetus and the radius of the burner output (17)

\[
S = \frac{3}{2} \tan \propto \frac{1-R^3}{1-R^2+\left[\frac{1}{R^2} - 1\right]^2 R^2} \tag{1}
\]

Here
R: radius ratio
m: mass ratio
α: the vane stagger angle

Swirl flow structures

As shown in Fig.3 which is described in (17), when the collapse of the central vortex is strong and the internal recirculation zone (IRZ) known the central recirculation zone is created. Flame stability in collapse vortices is enhanced by the presence of reverse flows as well as internal recessions. The collapse of the vortex is associated with the passive axial velocity field in the field of rotary flow, although the collapse structures that have emerged have appeared different (16). The collapse of the vortex is caused by the gradual negative pressure that grows along the burner walls during the high vortex Valdez (18). The inner shear layer (ISL) is formed between the recycling area and the main flow, and the outer shear layer (OSL) is formed between the recycling area.

Fig.3 flow structure in confined zone (17)

However, there is a type of swirl called spiral core processing. This type of vortex is the most common processing vortex core (PVC) (19, 20). As described above, in industrial applications of pre-mixed gas turbine systems as well as high-performance flame stabilization techniques, thus the application and development of low emission burner (DLE). Vortex flows of pre-mixed lean gas turbines are used to create a low-speed zone, so that the flame can be stabilized, and depends on the main role of the vortex Stein (21). Besides, the internal recirculation area of the vortex flow acts as a dynamic barrier in torch fixation. The balance between the recirculation area and the lost heat occurs in igniting the
flammable mix. Combustion products are recycled in the internal recirculation area, helping to ignite the fuel mixture continuously.

In recent years, flame types have been studied in the combustion of premixed gas turbine systems (called flame topology or total flame structures). Operating conditions have an important role in the effect of the shape of the flame, as well as the transfer of heat to the wall of the stove as well as forms of the stove and confinement (22-24). Liu et al. (23) as shown in Figure 4 (a, b, c), there are two basic types of flame form: the shape of the flame M- and Flame V- flame. The Flame M shape with reaction zones is formed in both the outer shear layer (OSL) with the inner shear layer (ISL), while the V-shaped internal shear layer (ISL) shape sudden transition from the M-shaped flame-flame is installed on M shape, so it is suggested to use a flashback for the brink of the flame in Figure V along the wall of the stove (24, 25).

Flame-shaped V is preferred because it is supported by numerical calculations indicating heat loss for the walls of the burner. Kempf et al. (26) In conclusion, it is possible to predict the transfer of the flame well by constant swirl force, small proportions of confinement, as well as the number of Karlovitz Stable flame structures are observed for other types

Fig.4 (a) A schematic of flow fields in a swirling jet flow with a central bluff-body; (b) the V-shape flame and (c) the M-shape flam. (23)

Flame instability refers to the rate of heat release from combustion as well as to harmful oscillations at pressure (27). In the gas combustion system, several mechanisms have been identified that can cause combustion instability in the swirl flow. The mechanisms are summarized according to the following points: (1) fuel line feed line connection, (2) parity ratio change, (3) breakdown oscillator, evaporation, mixing, (4) different flame oscillation zones and (5) fatigue spiral (15). It was observed that flame and flow structures change during the process of flame variability. (28, 29) The reason for the low frequency of the flammable
flame is the circular motion that occurs in the external recycling area around the center of confinement. Note that the severity of the flame infrastructure is associated with its instability. **Tong. Et al. (29)** The transition of the overall flame structures led to fluctuations in the flame because they found intermittent ignition of the outer recirculation areas as well as a sudden ignition. Other things related to flame instability are flashback, lean explosion and automatic ignition. A flashback occurs when the flame moves to the direction of the fuel source or to the fuel mixing area or along the border to the upstream area (30, 31).

**Swirl Burners**

In the past decades, technologies used in industrial fields have evolved where the swirl burner technology has been used. As is the case for combustion of gas turbines, internal combustion engines, pulverized coal plants, boilers, refineries, and process combustion. (32, 33). These swirls improve the mixing rate of the materials used in the combustion process, which increases the energy produced and reduces emissions. The combustion process includes a more stable range, such as flashback and blowoff levels, high levels of turbulent flame speed and low combustion volumes using these flows (32, 34-36).

In order to obtain a combustion system appropriate to the nature of work and more efficient and with low fuel and maintenance costs and fewer pollutants, there was a significant development in the design and manufacture of swirling burners, and therefore there are different types of swirling burners and differ according to the nature of its use as in the aviation sector or fixed gas turbines or propulsion systems Marine or boilers. Multi-input combustion systems and rotary burner furnace systems can burn low-quality fuels and low calorific value (1.3-1.4 MJ / m³) without any improved fuel (37).

**Combustion instability**

The main challenge for any successful, safe and reliable design of the burner is to reach a stable flame position, especially with the use of hydrogen-rich fuel (38). However, some major challenges arise while the burner is on (2):

- Blow off indicates the extinction of the flame. Therefore, to install a combustion flame use different systems of rapid expansion or deceptive
objects. Regardless of which mounting mechanism is used, there is a range of situations in which the flame can settle.

- Auto ignition indicates that the fuel mixture used is automatically ignited inside the combustion chamber.
- Unstable combustion refers to the fluctuations and harmful changes caused by the change in the rate of combustion heat emitted.
- Flashback refers to the return state and spread of the flame at the source, and is supposed to be based on previous sections not designed for warming.

Flashback mechanisms:

There are four mechanisms to summarize Flashback: flashback due to combustion induced vortex breakdown (CIVB), flashback in the boundary (FBL), automatic ignition in the primary feed area in the upstream direction and flame spread in the high-speed primary flow M. Lee et al. (31). In addition, a fifth factor is that the flashback is a flame instability. There are two theories that explain the lean explosion phenomenon of premixed combustion systems: (39) The explosion phenomenon occurs when there is not enough time to continue the flow of fuel and thus separate the flame syred (27, 30, 40, 41).

Flashback due to combustion induced vortex breakdown:

The collapse of the combustion spiral has been identified as one of the sources of rapid flame transmission and its reflection in the combustion spiral. An abrupt change will lead to serious system setback due to the possibility of overheating the burner components at the source. This kind occurs mainly in continuous swirl combustion without a central body in a stable process owing to slight vicissitudes in the stream field and turbulent reactions and chemistry at the end of the central recycling area. (42-44). It will happen even though the speed of the flow is greater than the speed of the turbulent flame (45). Early studies indicating this phenomenon were carried out by Kroner et al. (46). Within the context of previous snapshots, the group accomplished swirl burners with cylinder-shaped mixing tubes deprived of centrifugal use. They originate that the cooling influence of chemicals played a dominant role within the limits of flashback. In another study (42) they has been found that flame spread is ruled by joint interactions between chemical responses and flow. In additional words, the
flashback has a high responsiveness to the transfer of energy in the center of the vortex, while the chemical response contributes to a decrease in the pressure limits at the entrance to the burning chamber, thus facilitating the propagation of the vortex collapse. The axial jet effected also investigated by (47) who observed that the growth in the diameter of the axial jet contributes to denser vortex centers. Thus, vortex collapse will be turned down, thereby installing the fireplace operation window.

Vortex transfer equations were used by (45, 47, 48) to analyze source conditions for azimuth components in the flow domain. They argue that the baroclinic torque crops a large aggregate of negative axial velocity at the core of the vortex which in shot leads to the return of the CIVB flash. They too associated the stagnation of the recirculation region with the influence of fluctuating the parity ratio of the axial location. Founded on his studies, the upstream fire cover and recession point play a major part at the beginning of CIVB. Condition the recirculation region can traverse the stagnation point in the path of the source, then increasing the source size in the recirculation area generates a positive vortex and thus a positive axial velocity. Thus a stable flame prevents CIVB from occurring. However, when the flame spread increases at the source (another increase in the parity ratio) the baroclinic torque will rise, thus increasing the great probability of a CIVB happening.

Because vortex flows are characterized by highly complex stormy flows, CIVB flashback cannot be linked only to the equilibrium among flow velocity and fire speed. Thermodynamic properties and fluids are too necessary for a even reaction while a fire spreads upstream. Great expansion amounts and heat harm in the reaction area can too suppress or suppress the flame, while as the expansion rate increases, heat release is narrow by response kinetics and as a result, the equilibrium between product group and exclusion since the reaction region is disturbed. Kroner, et al.(49) Suggest a novel relationship to set flashback bounds. This relationship specified that flame suppression happens at a serious value of the quenching factor ($C_{\text{quench}}$) which signifies the ratio among the typical chemical time scale ($\tau_c$) and the stream or mixing time ($\tau_d$)
\[ \frac{\tau_c}{\tau_u} \geq C_{\text{quench}} \]

Where

- \( C_{\text{quench}} \): slake parameter [ - ]
- \( \tau_c \): chemical time scale = \( \alpha / S_L^2 \) [s]
  - \( \alpha \): thermal diffusivity [m²/s]
  - \( S_L \): laminar burning velocity [m/s]
- \( \tau_u \): flow time scale = \( d / \bar{u} \) [s]

And

- \( d \): mixing tube diameter [m]
- \( \bar{u} \): mean axial velocity [m/s]

Therefore, the cooling constant can too be determined as follows;

\[ \frac{\alpha \bar{u}}{S_L^2 d} \geq C_{\text{quench}} \]

According to the Peclet Number approach the above equation has been modified

\[ \frac{\bar{u}d}{\alpha} = C_{\text{quench}} \cdot Pe_{SL^2} \]

Wherever (Peu) is the flow Peclet number and (PeSL) is the flame Peclet number.

Therefore, according to the flashback behavior of the above bond of a particular stove, it can be distinguished by the cooling limit, or in another meaning, by significant the cooling parameter or the cooling distance of the mixing pipe, the flashback can be evaded. The overhead links have been changed by Kroner, et al. (50) The chemical time scale was determined rendering to the relationship among the thickness of the reaction region and the transport owing to thermal diffusion. In this relationship, the timescale is the amount of the residence of hot reaction gases within the reaction region with a thickness \( \delta_R \), where
\[
\delta_R = \frac{\alpha}{S_l}
\]

Therefore, chemical time scales can be determined rendering to the following formula,

\[
\tau_c = \frac{\delta^2_R}{\alpha}
\]

Nearly all of the overhead works have shown that the stability system near the stove rim is a function of the communication among the stream field and the thermal issue from the combustion progression. This reaction controls the type of fuel, its composition, the conditions of the non-combustible mixture and local topical chemistry, which means that it is important to understand the effect of the fuel type and the geometry of the spiral stove in relation to its effect on turbulence properties near the stove mouth. The type of fuel or fuel mixture plays an important role in the CIVB mechanism, while the use of high hydrogen increases the appearance of CIVB. Several studies (1, 3, 51) have stated that the behavior of fuel mixtures can differ significantly from the behavior of individual components, while (52-54) have shown important changes in flashback bounds when cumulative the hydrogen comfortable in the fuel.

Confined vortex flow properties and valence ratios directly affect the reaction in the burner nozzle, and henceforth the governing circumstances for CIVB flashback. Certain studies have examined the influence of eddy strength and degree of mixing, and Baumgartner and Sattelmayer (55) originate that with an increase in the valence ratios in a low spiral density, the flashback mechanism was changed from the flashback layer from the front boundary layer to the flashback CIVB.

Sayad, et al. (56) originate that CIVB flashback happens in higher vortex numbers than those in the flashback boundary layer. The impact of engineering problems on the CIVB flashback has been examined, and several studies have been carried out on the effect of changing geometric shapes on enhancing resistance to CIVB backlight. Central trick bodies or spears are widely used in spiral burners to evade spreading upstream fire or CIVB flashback. Although it is possible to work
with partial mixing and reduce the number of eddies, some axial injection works are used to increase the flashback resistance.

Richelle et al. (57) It has been found that axial air injection in large quantities reduces the defect in the axial speed, which affects vortex breakdown (VB) and thus enhances the resistance of CIVB.

Konle and Sattelmayer (47) discovered that an raise in the injector of the central diameter would rise the thickness of the vortex centers and strengthen the axial flow velocity. Therefore the downstream spiral collapse is transformed, resulting in improved flame stability. The results were too illustrated by (48, 58) who originate that axial injection leads to a wider vortex nuclei that result in lower pressure gradients and then lowering the baroclinic torque, and successful the system resistance to the CIVB flash system.

Mayer et al.(59) an evolution in reflux resistance was found by injecting the axial fuel associated with the rear injection because the back injection was made by adding rows of injector holes placed on four excess edges of the padded vortex.

Lewis et al. (60) deliberate impact the axial injection of methane, air and carbon dioxide, and found that the injected gas type significantly altered the coherent structures. In addition, they suggested a relationship among the mutual influence of the high momentum flow region (HMFR) and the central recirculation region (CRZ). Affording to this relationship, CIVB flashback happens when CRZ is pressed through the high momentum flow region HMFR that develops through the flow.

Sattelmayer et al. (61) They originate that the widespread use among stove mixing tube and stove could change the flashback procedure from flashback to the boundary layer flashback of the wall BLF. In addition, they claimed that the flashback limits are close to BLF and that the limits set by CIVB for certain vortex content can be met by changing aerodynamics, which is the optimal condition in terms of flashback resistance. However, any digression from the strongest source of degradation of the two-type flashback resistance, which will exacerbate the limits of recovery. However, although a lot of work has been done to deeply understand the CIVB flashback mechanism, there are up to this time several
unknowns. The influence of different geometrical shapes and fuels on flashback phenomena is still normally expected in a specific sense.

**Boundary layer flashback:**

The Boundary layer flashback (BLF) tilt instruments were discussed in laminar burner flames in 1943 by Lewis and Von Elbe (62, 63), and they presented the concept of widely passable critical gradient velocity. Figure 2 below defines their explanations. At a sufficiently high speed, a stable flame happens at the outlet of the burner fig.5(1). Close to the stove, the reaction is extinguished due to the heat loss of the wall and the flame root curvature out. If the speed decreases, then this external curvature increases in some different parts so that the flame front becomes orthogonal to the arriving flow.

![Fig.5 BLF of the tube burner flame (1) constant flame, (2) flame in flashback conditions, (3) upstream spread flame Hoferichter (63)](image)

If this position extends behind the wall distance in yFB, then the backlight flashes (1), the recovery border is reached(2). Reducing the flow velocity increases the flame spread to the source near the burner wall at yFB, l (3). In this type of flashback, the flow gradually flows near the wall due to the non-slip boundary layer, even in the case of high-speed flow, the flame speed can exceed the local flow rate in the boundary layer(64).

Advertise recent investigations and studies avoiding early flashback decades ago announced in the written works round the effect of flame confinement, the tip
temperature and the composition of fuel and pressure (65-67). Flame containment has been found to significantly increase the retraction of the flashback layer within the boundary. In addition, the rear flashback instruments rely on various parameters, such as heating values, reaction speeds, etc., which render it incredibly difficult for other fuels to be used. Several authors tested with CO2 and N2 diluents to control the flame spread of these fuels. Several authors tested with CO2 and N2 diluents to control the spread of flame for these fuels. The system engineering is an additional significant parameter in the spread of flashback inclination. Minor fluctuations in the engineering structure of the feedstock mixing tube, such as contrast sections, steps, surface outages, or fuel injection methods, such as counterflow injection, diffuse penetration, etc., allow serious fluctuations in flashback behavior Marco (68).

6.2.1 Factors affecting the BLF

Many factors affect the tendency of flashbacks, but it is difficult to separate its effects. Therefore, these comprehensive factors can be distributed in the following groups:

- Flame configuration and heating boundary layer
- Flowing and combustion properties.

Flame configuration and heating boundary layer

Most researchers have discovered that the confined flame is extra suffering than the flashback, and the interaction between the confined flame and its wall has found great interest in its study in recent years through numerical and experimental studies. When the flame arises at the top of the confined area, the front of the flame has a convex edge and approaches the reactants, which increases the effect of the flame extension and the flow of the approach begins to slow down.

Burner heads made of modified materials have an erratic propensity to flashback, and it has been found that the influence of the thermal coupling between the flame and the burner head on the flashback instrument is an important parameter in the effect. Notes the relationship between flashback and variables associated with burner process and development. The type of the product and the
temperature of the flame to change with the composition of the fuel, then it affects the heat transfer between the edge of the flame and the edge of the burner. Fig.6 (a) illustrates a graph of a stable flame, and too when BLF limits are reached, the flame at source is spread to pre-mixed reactors in Fig.6 (b)(69).

![Flame configuration](image1)

**Fig.6 Flame configuration:**(a) Without confined flame stabilized downstream of the pre-mixer tube (69),  (b) Confined flame stabilized in a tube (69)

This changes the temperature of the burner tip according to the fuel composition to obtain a certain neutral ratio. The heat is applied toward the source at the side of the burner, adds heat from the wall to the received reactants. Border layer heating creates a contrast point in the velocity profile, which may result in separation of flow. Later, the tendency to return is more pronounced for unrefined burns. Unstable shift in operating conditions For example, a sudden decrease in the reactive flow rate can lead to BLF production (69).

**Flowing and combustion properties.**

The speed of flow directly effects on the BLF by varying the flow force in the wall area. As the average flow velocity rises, the local flame velocity must rise to reproduce the source, and therefore, the flashback tendency in fuel/air ratios occurs near the proportions associated with the highest flame velocity with a significant increase in the flow velocity. Additionally, the incoming flow velocity profile, where the flame settles, disturb the limits of flashback. For example, it should be noted that when the received flow is not fully developed, the tilt of the flashback reductions owing to the high pressure of the wall fixation, which is a
function of the length of the inlet. BLF threshold varies completely under turbulent and turbulent boundary conditions. This changes the temperature of the burner tip according to the fuel composition to obtain a certain neutral ratio. The heat is applied toward the source at the side of the burner, which adds heat from the wall to the received reactants. Boundary layer heating creates a contrast point in the velocity profile, which may result in the flow leaving. Later, the tendency to return is more pronounced for unrefined burning. Unstable shift in operating conditions For example, a sudden decrease in the reactive flow rate can lead to BLF production (69).

The reaction of the flame wall is an additional complication in turbulent conditions. Depending on the Reynolds turbulent number, the turbulent combustion system dictates the structure of a flame and determines how small swirls relate to the flame. Thus, turbulent flame velocity is also a function of the severity of the turbulence. Consequently, the higher severity of the disturbance leads to a higher tendency to flashback. The combustion properties of mixed fire also depend on the composition of the fuel. The combustion velocity mixture plays an important role in activating the flashback, which is often the function of chemical kinematics. Also, the thermal and radical cooling of the wall varies greatly with the change of fuel combinations that change slope limits. The high inclination of the previous mixture of hydrogen mixtures is due to the small cooling area and the very high combustion velocity (69).

Mitigation strategies to avoid BLF

Flexibility in the usage of different fuels to boost the performance of a gas turbine engine is a major challenge for manufacturers and designers to fix reliability concerns. The flashback phenomenon is a major challenge for the development of pre-low combustion of nitrogen oxides of high-hydrogen. In this section, describe some of the parameters and mechanisms that can survive the regression layer flashback from the most recent available literature.

The well-known concept of a gradient known as Louis and Von Elbe used these assumptions as stove diameter, laminar burning speed, and wall distance from flashback, but neglected the importance of flame expansion to the combustion velocity explain by hoferichter et al., 2018. For this purpose, updated prediction models were developed for confined and unregulated flames. Nevertheless, they argue that the influence of an extension of the blaze is an
important parameter for the determination of boundary layer reflux limits, especially for highly reactive fuels such as hydrogen. Some of the additional parameters included in the updated predictive model is that a certain weak oxidase is used to stretch the blaze along Markstein (70).

Fig. 7 (a) The flashback limits for pneumatic and hydrogen flame layers calculated by the amend foretelling model and associated to the critical gradient concept of changed burner diameters (b) The flashback bounds for methane-laminar flame are calculated using a changed prediction model and associated to the critical gradient concept in changed diameters (70).

To ensure the validity of the advanced prediction model, the authors linked the calculated flashback limits for each model and linked experimental data of the mixtures of hydrogen, air, and methane in Figure 7 (a) above and fig. 7 (b). The influence of embedding the flame extension, the Markstein length, and the main parameters used in the sheet flux prediction model result in good reproduction of the experimental light reflection limits for hydrogen, air, and methane – jet (70). Though many previous studies absorbed on BLF, some experiments focused on flashback at high pressures, wherein high pressures the turbulent combustion speed is high as well as the cooling distances are small, so the flashback's tendency to increase. Therefore, the BLF prediction tools under the actual operating conditions of the gas turbine engine (high pressure and temperature) are of great importance. The author Calantari et al. 2018 conducted a trial to restore the Flashback boundary layer. The return of the injector back layer to the 65 kW microturbine generator is studied, For example, Capstone C-65 MTG, which works on hydrogen at pressures between 2-7 atmospheric pressure and temperatures among
In this method, use two injectors (a) original injector fig.8 and (b) Retrofit flashback resistance injector fig.8. In both designs, the fuel is injected into the axial direction in a series of jet planes that are inserted through the radial passages. The main objective was to encourage the rapid mixing of fuel. The original injector is primarily designed to create a uniform mixture of fuel / air at the exit level for the purpose of reducing emissions. However, the main goal of the retrofit injector is to avoid the appearance of flashing by reducing fuel near the outer wall (71).

![Fig.8 (a) pristine injector (b) Retrofit flashback resistance injector (71)](image)

The valence ratio of the flashback of the original injector works on pure hydrogen as a pressure function for different heating temperatures (420-620 K). The highest flow velocity in the injector is 50 m/s for all positions. Note that for a specific heating temperature, the increased pressure reduces parity when the flashback appears. That is due to a low cooling gap and a high instability in combustion at higher pressures. Investigators observed that increasing the average flow rate of the initial injector to the par value was not necessary to stop the flashback tilt. The change in flow speed has only fewer influence on reducing the BLF slope. The best is to dilute the fuel/air mixture near the wall, which has proven effective in an ideal pre-mixing tube (72). The tests for the flashback injector were done under different operating conditions, and in all of them the flashback was not recognized even for the extreme case (\( Pu = 7 \text{ atm}, Tu = 600 \text{ K}, \phi = 0.7 \)) (71).

In Fig.9 the hydrogen/air mass ratio calculated in CFD can be seen at the injector's exit level. The ratio of the hydrogen/air mass is roughly uniform across the original injector, indicating the appropriate level of mixing. However, the
original injector is subject to return in the actual operating state cause to the high hydrogen concentration in the area of the near wall. In contrast, the flashback anti-injector generates an irregular concentration of hydrogen/air in the exit jet. The focus is maximum at the midline, while it suddenly drops near the wall. This confirms that the flame no longer spreads to a region close to the wall, although there is a relatively little flow speed in that zone and evades the flashback tilt.

![Fig.9 The circumference of the hydrogen / air mass in the exit jet: (a) pristine injector,(b) flashback resistant injector (71)](image)

As discussed in the preceding section, fireplace engineering plays a role in stabilizing the combustion process. Owing to the association of geometric forms with rotational flows, the characteristics of the flow field can differ considerably. The methods used to tip the flashback are troublesome for achieving sufficient tolerance to vortex combustion reactions, and the improvement in technological improvements will be able to minimize the impact of the various flashback instruments.

al-Fahham et al. (73) develop a novel technique titled biomimetics to use microscopic surfaces to attain this purpose. The use of these biologically designed shapes can be seen in Fig.10 and Fig.11 below to achieve successful flow stability, allowing better control of the flashback layer.
One of the benefits of microscopic structures is that it reduces skin friction by regulating naturally happening turbulent speeds that tend to reduce shear stress and transfer momentum. It is directly related to the ability of tapes to reduce drag. In their research, three configurations were presented which are as follows: Formation a) Spiral burner without central air injection and no micromesh. Formation b) Spiral burner with no central air injection and a small surface present in the nozzle. Formation c) a spiral stove with central air injection and a partial surface in the nozzle. This concept has been studied numerically and empirically in
a symptomatic spiral burner of 150 kilowatts, when the grid stability zone between the range (0.4 = 0.45~0.65) is not used, the boundary flashback happens at higher transverse speeds, due to the lack of a damping instrument against the boundary layer flashback, Flashback happens earlier fig.12.

Fig.12 comparison the boundary layer flashback with and without grid(73)

Fig.13a,13b Demonstrates change in flashback reflection directions when covering the nozzle of the inner surface with a microscopic coating. The effect is best demonstrated to avoid flashback, at transverse velocities with $W_t = 2.8$. After that, there is no ignition of the flame over the ranges that were tried when using the miniature surface (73).

Fig.13 (a). Flashback direction using changed configurations. A) central air injection deprived of using a grid (73), (b). Combining central air injection with grid use (73)
Flashback Core flow

Flame spreading happens in the primary flow as the intermittent combustion rate equals the local flow velocity in the primary flow (2) (74). The sum of turbulent combustion velocity plays a key role in triggering the flashback of the primary spray, which is the mechanism of both the turbulent flame reaction and the chemical kinetics (75). As a result, the fuel composition and turbulence structure are essential parameters for the determination of flashback limits (76) (77). The typical combuster is designed to avoid flashback by raising axial speed. However, popular flame stabilization methods used in practical devices may lead to the return of the basic flash. For instance, Vortex significantly reduces the local axial velocity component. Besides, the flame expansion induced by the flame spiral reaction raises the velocity of the turbulent flame (78) (79) (80), Consequently, these two effects, high turbulence flame speed and low axial flow velocity, can lead to the return of the basic flash flow. The key characteristic of the reverse flashback is the turbulent combustion velocity, which has been widely studied in literature and is mostly viewed as a property of the flame velocity and turbulence properties of the shield (81–84). High flame-speed gases, such as hydrogen, raise the possible dangers in comparison to natural gas. Numerous correlations of turbulent combustion velocity have been shown to be promising as a tool for forecasting baseline return flow (3, 75). However, these similarities can not necessarily be applied to various materials, as the turbulent rate of combustion is highly dependent on night structures (76) (77) In addition, various definitions associated with describing turbulent combustion velocity lead to different principles, which can contribute to differences between literature evidence and challenges in interpretation (75).

Combustion instability induced flashback

Flashback is caused by combustion instability due to fluctuations in the large amplitude of the flow field (2) (85), instability can be created through the interaction of sound modes, unstable thermal release, and the flow structure. Volatility and pressure fluctuations associated with instability can trigger the flame and generate large swirls that cause flow reflection (86), which may lead to the return of the flashback. Figure 14 refer to instability of the flame that settled by a step facing it backwards (86).
The flow structure pulse cycle raises the flame from the edge of the step and eventually leads to the return of the flashback. Large spiral simulation (LES) performed by Thibaut et al. (85), investigations into flashback caused by flame instability. Effective interactions among sound, turbulence, and combustion are captured by forcing an external speed adjustment at the entrance to the computational field, as shown in Fig.15. Since reflection of the flux is improved by the instability process, the flame propagates upstream of the step.

Fig.14 Combustion stability of a backward-facing step and cyclic process of the flame-flow interaction investigated by Keller et al. (86)

Fig.15 Temperature distribution of premixed flames stabilized by a backward-facing step obtained from two-dimensional LES (85)
Geometry effect on flame stability

A vortex burner has been studied in an air pressure combustion system with a different burning length (5, 10 and 15) cm to the Diameter of the burner edge (5 cm) (L/D). Three ratios of (L/D) 1, 2 and 3 have been used to study the influence of stove geometry on the stability of the operation window. The results show that the location of the flame front mounting changes with the (L/D) ratio. The flame front stabilizes near the edge of the burner with the stove length increasing. The equivalence ratio of the mixture was constant for comparison. The flame settles near the edge with an increase in edge length Fig. 16 (87).

![Fig.16 The flame front height at changed rim length (L) a) 5cm b) 10cm c) 15cm. (87)](image)

The most important conclusion to be taken from the study indicates that the change in the length of the edge of the burner contributes to a larger decrease in the frequency of the vortex. This reduces the strength of the downstream flow and the mixing momentum. The most important point to be taken from the survey shows that the change in the length of the edge of the burner results in a greater degradation of the vortex power. This reduces the strength of the downstream flow and the mixing momentum (87). The operational window of three versions of the burner neck has been discussed above. The edge with a length of 5 cm was observed to have an equivalent ratio (0.38-0.82) and an equivalent ratio (0.39-0.84) for the edge of 10 cm as well as an equivalent ratio (0.4-0.83) for the edge of
15 cm with a steady air velocity. For the three models mentioned above, the corresponding ratio of the above pattern, it was found that the 10 cm edge gave a higher operating window and therefore higher stability than the other two models Fig.17 (88).

Fig.17 Operation window for all cases (88)
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