

Working Design Map of Alternative Fuel for High Swirl Burner

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Abstract:

Gas turbine operation encounters many difficulties in real work. Some of these problems are flashback and blowoff, which are mainly caused by instabilities inside the burner. These phenomena restrict the operation of the gas turbine burner. In circumventing these unwanted phenomena it helps to guess the operative diagram area of the gas turbine combustor. Two types of fuel blends, methane enriched with 15% and 30% hydrogen, have been taken in this investigation to accomplish the required operative pattern plot. Using alternative fuel with hydrogen gives efficient combustion with high energy as hydrogen has higher calorific value and gives low undesirable emissions. These tests were carried out with two different high-swirl numbers. The results show the operation area decreases with high hydrogen content in fuel and with higher swirl number values.

Keywords: hydrogen, swirl, flashback, blowoff.

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I. INTRODUCTION

Recognizing the gas turbine working area is important for both designer and operator. This may involve computing and identifying a relationship that is suitable for expecting and interpreting the data. Computational fluid dynamic (CFD) codes use some of these correlations, but in many cases these correlations do not provide thoughtful analysis of the combustion phenomena and the impact on all parameter variations[1-4].

Premixed combustion results in low emissions and high complex correlation because of the effect of the low composition of fuel [5, 6]. Gas turbine undesirable emissions reduce using lean premixed (LP) combustion which is normally done by previous mixing of both fuel and air in a mixing room before the combustion chamber and this will

enhance the combustion efficiency and the latter would increase as the air and fuel mixed well. Swirl combustor one of method to achieve that and it is familiar to use[7-9]. Flashback tendency increases in lean mixture as instability increased and then the blowoff can also effected. Those two phenomena unlikely appear in partially or diffused premixed combustion.

Lean premixed combustion for alternative fuel contain a percentage of hydrogen more that 20% can makes a huge problem leads to flashback as burning instability increased. Many ways inside combustor to have flashback some of them happened via core of the burner and other take place as the flame propagate along the boundary layer and there is other mechanisms[10-12].

Blowoff is another crucial factor that can affect combustor performance as the designer needs to

fire each time it happens and needs to avoid too much lean mixture. However, lean premixed contain hydrogen blends also increased blowoff. Moreover, the higher instability and rich combustion can also leads to blowoff[13, 14].

To achieve low emissions goal to keep the level of emissions down, using alternative fuel blends, such as adding a percentage of hydrogen to methane, will minimise the undesirable emissions, especially reducing NO_x and other unwanted emissions[15, 16].

Using hydrogen increase the operation limitation and increase technical complication; these can include a high cost would be add and also increase running cost. Flame speed either laminar or turbulent will increase which is gives higher instabilities leading to flashback and blowoff. Eventually, this analysis will show that an significant variance between the flashback boundary for the fuel contain a percentage of hydrogen and with a fuel just a pure methane or natural gas as the flame speed will differ from using both fuels [17-20].

Geometrical limitations can also affect strongly on the combustion properties likes the shape of the mouth of the burner where the flame goes out which is confined or unconfined and also the shape of confinement. The other important parameters is the excitation degree which is measure by the swirl number. Several worries have been raised by the gas turbine designer concerning combustor designs technology that emphasis on flashback, blowoff, instability, and the opportunity of fuel swapping [10, 11].

This experimental study will perform the working region of a gas turbine combustor that is located between the blowoff and flashback limits using two types of alternative fuel and two types of swirl numbers with three different configuration confinements.

II- EXPERIMENT SETUP

Experiments done though out this study has investigated the flashback and the blowoff boundaries for two types of alternative fuels and two high swirl numbers using three types of confinements, all these tests done on a generic swirl burner in atmospheric conditions.

Burners with swirl insert communally recognized. The target of using these kind of combustors to generate central recirculation zone and reverse flow zone which is help to stabilized the flame as the hot chemical gases recycled to the flame root and resulting in very good flame stability and wide range of blowoff limit [11, 20, 21].

The most vital parameters used to symbolize swirl flows, the swirl number (S), is defined as the ratio of axial flux of swirl momentum divided by the axial flux of axial momentum, and the half of equivalence nozzle diameter [22, 23]:

$$S = \frac{G_{\theta}}{G_x D_o / 2}$$

Nevertheless, the profile of the flow is extremely complex. Because the flow shapes are extremely multifaceted, it is immensely challenging to specify the exact experimental swirl number, unless very comprehensive 3D speed measurements are available (rare existence). The practical figure of swirl number is initiate from the geometric swirl number (S_g), which uses inlet conditions and later can ignore pressure differences across the flow. For isothermal conditions and constant density, it has to be assumed that the swirl number for the generic swirl burner will be as shown in figure 1.

After some simplification:

$$S_g = \pi(D_o^2 - D_p^2)(D_i - t) / ((1/4) \cdot t \cdot h) D_o,$$

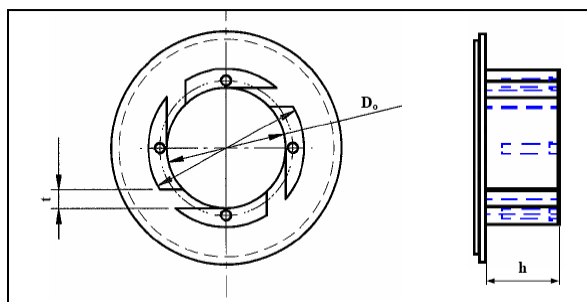


Fig. 1: Blade swirler burner configuration

Where,

D_o is the diameter of the combustor outlet,

D_i is the inlet diameter of the combustor,

D_p is the diameter of the injector,

t is the gap between the blades, and

h is the vertical length of the mixing zone

The generic swirl has a fuel central injector, which passes through the whole body of the burner axially and in most cases is used to help conform the central recirculation zone (CRZ), which stabilises the premixed flow inside the burner (figure 2).

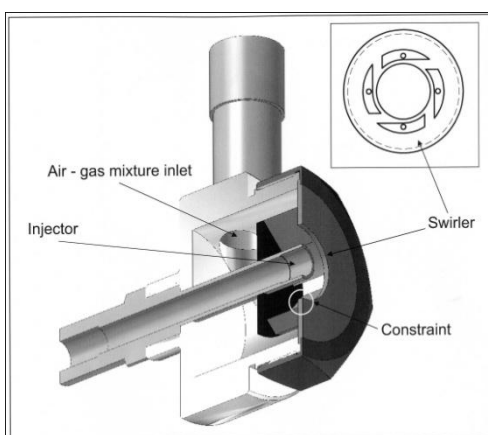


Fig. 2: Generic swirl burner

The generic swirl burner has a mixing room and a single tangential inlet that allows the body of this chamber to feed the burner with a mixture of air and fuel, which directly passes through the swirler insert into two swirl numbers. Figure 3 shows all the parts of the burner exploded.

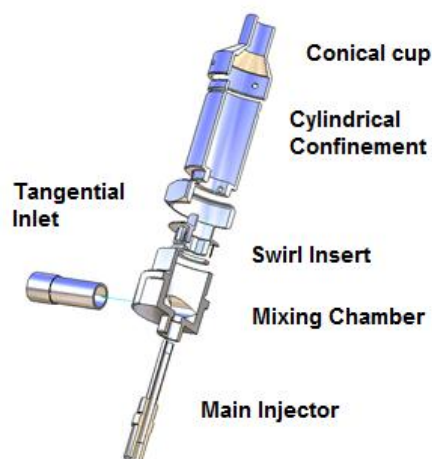


Fig. 3: Exploded swirl burner

The use of different swirl numbers achieved by using the same shape of generic swirl burner except the swirl insert shows in figure 1 can be changed to get the required swirl number. Figure 4 shows the experiment setup and this arrangement give ability of having any kind of fuel mixing (non-premixed, premixed and partially premixed). Coriolis flow meters used to measure the mass flow rate of both fuel and air separately (figure 4).

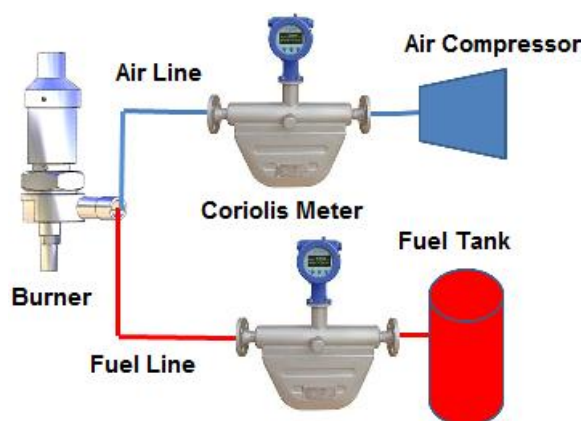


Fig. 4: Test arrangement

II. RESULTS AND DISCUSSION

In this study swirl numbers used two values, $SN=1.2$ and $SN=1.5$, and two different alternative fuels contain two percentage hydrogen with pure methane as brief in table. Using three

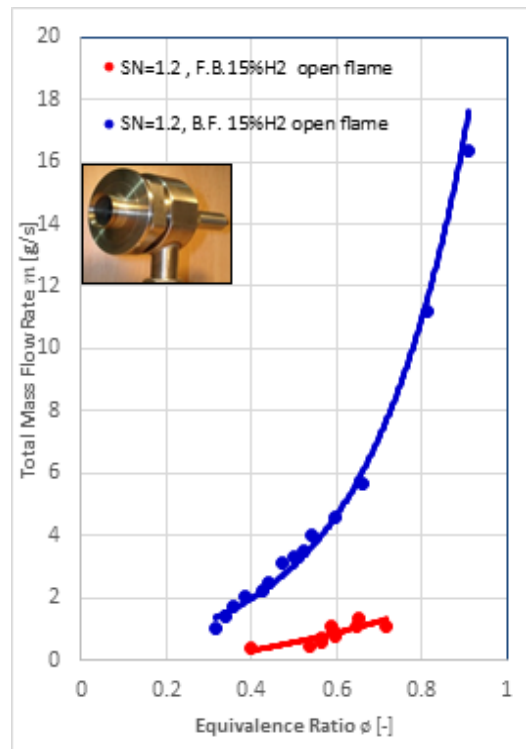
configurations were used to find flashback and blowoff point results. The flame goes freely out of the burner into the air in all tests.

Table 1: Hydrogen percentages in fuel

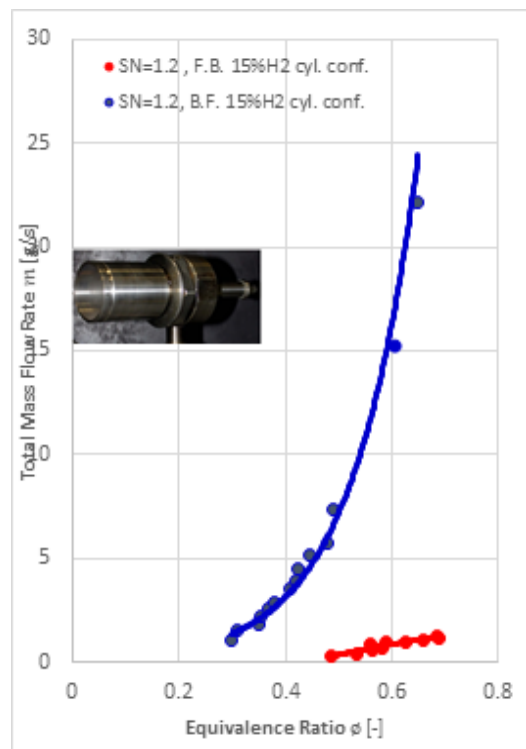
Fuel Name	Pure methane percentage	Pure hydrogen percentage	Higher heating value [MJ]	Maximum Temperature [K]
15%H2	85	15	57.36	2245
30%H2	70	30	59.89	2253

Four sets of curves were plotted on which to perform the operation area of each case of swirl relay, on the swirl number and type of alternative fuel and the mouth of the burner open flame (unconfined), cylindrical confinement, and conical cup.

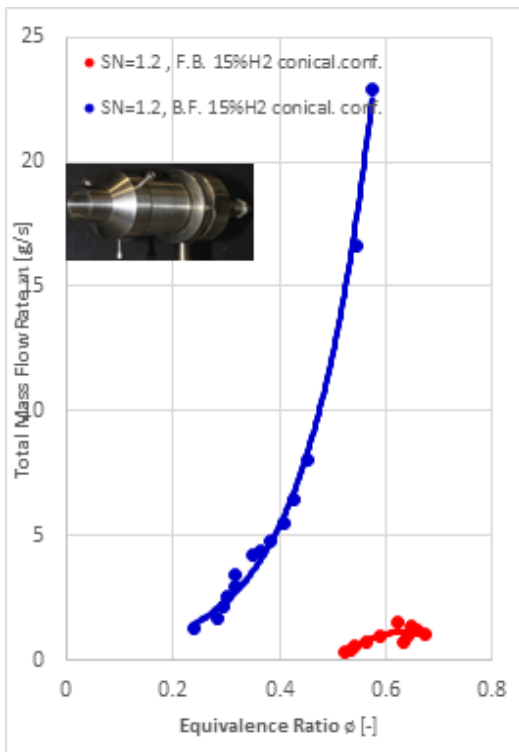
Figure 5 shows combustor operation and, for swirl number 1.2, fuel content of 15% H₂ and 85% CH₄ for three different cases of open-flame confinement (unconfined, cylindrical confinement, and conical cup). It reveals that the operation area increased with the confined burner compared with the unconfined by percentages of 10% to 40% of possible area and to 30% and 90% for confined burner. Furthermore, most results showed there was an unnoticed difference between confined cylindrical confinement and conical cup. Figure 6 for SN=1.5 also shows good results and gives a wide operation area, same as figure 5. However, Confinements help the swirl flow to keep its shape of central recirculation zone more stable than open flame.



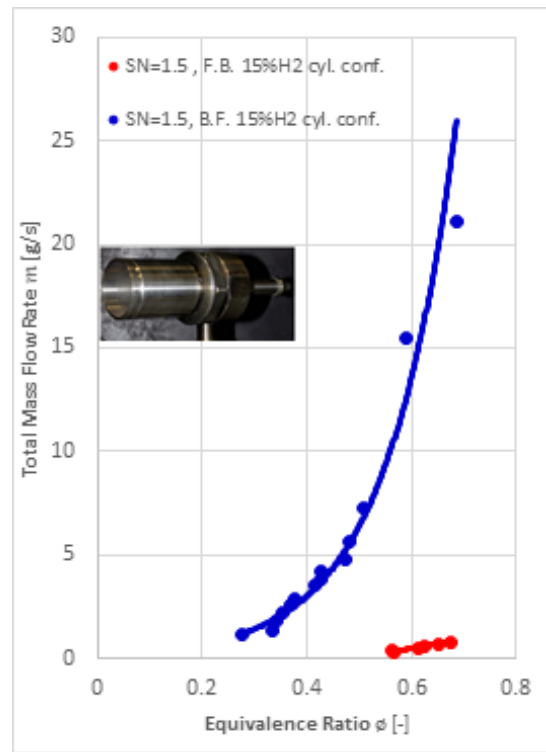
A- Combustor without confinement



B- Combustor using cylinder confinement

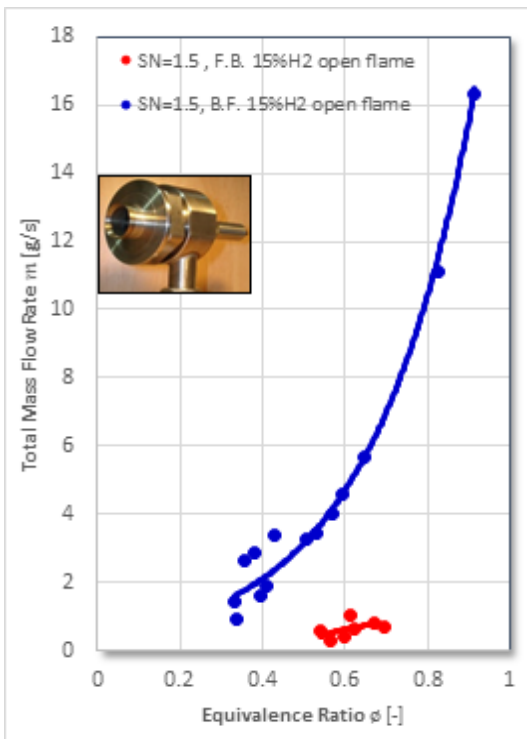


C- Combustor using conoid confinement

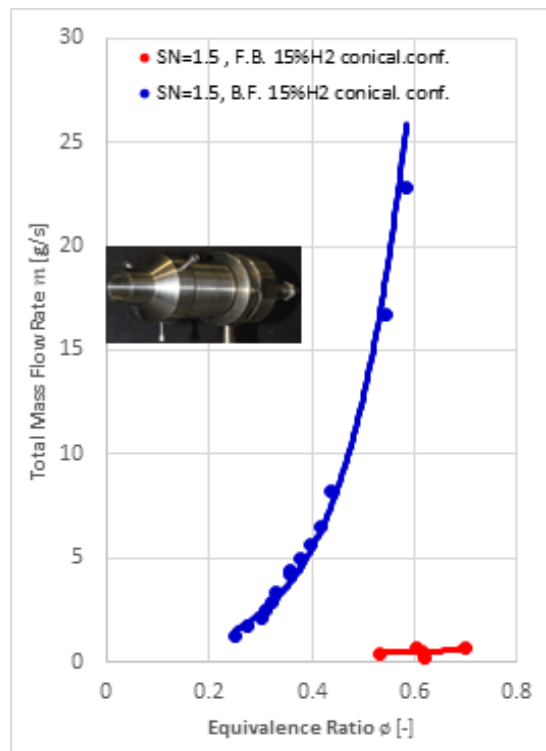


B- Combustor using cylinder confinement

Fig. 5. Burner working chart for combustor with swirl number SN=1.2 and 85% pure methane CH₄ with 15% pure hydrogen H₂.

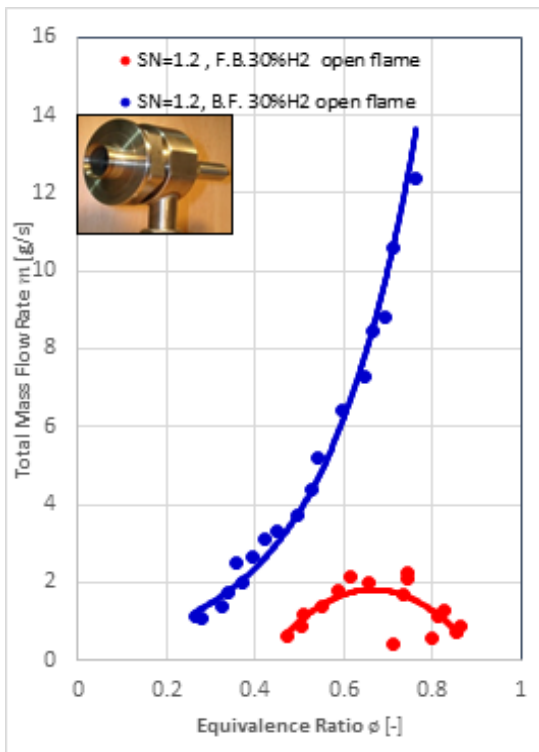


A-Combustor without confinement

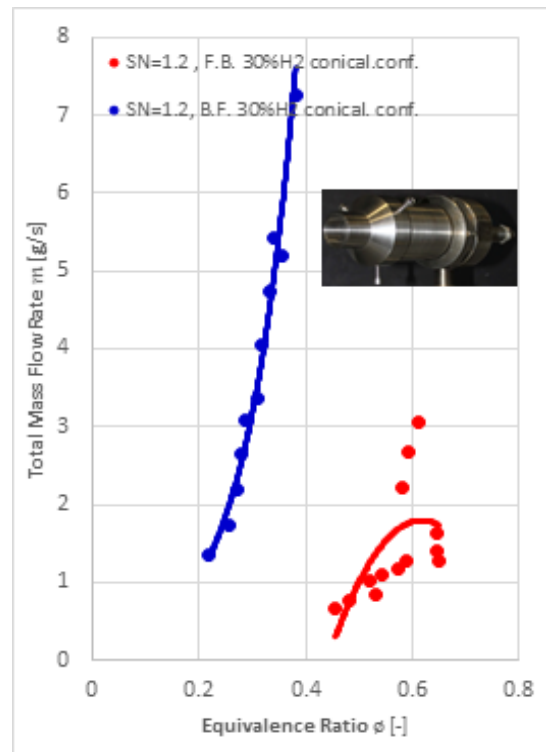


C- Combustor using conoid confinement

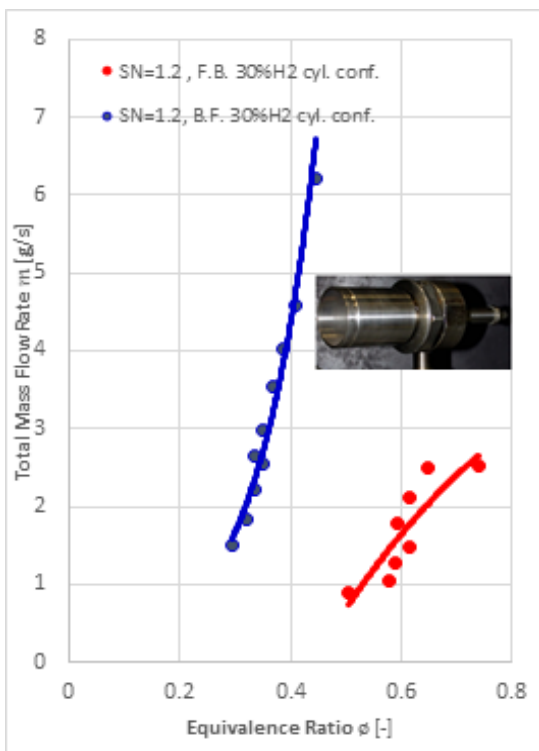
Fig. 6. Burner working chart for combustor with swirl number SN=1.5 and 85% pure methane CH₄ with 15% pure hydrogen H₂.



A-Combustor without confinement



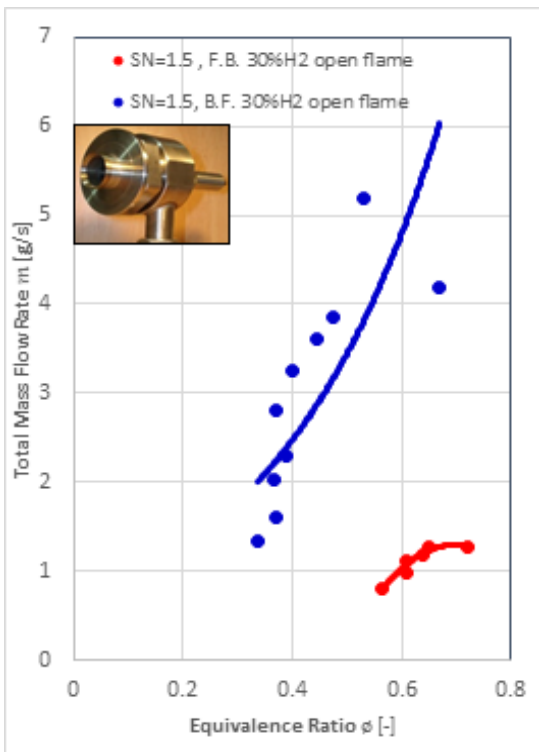
C- Combustor using conoid confinement



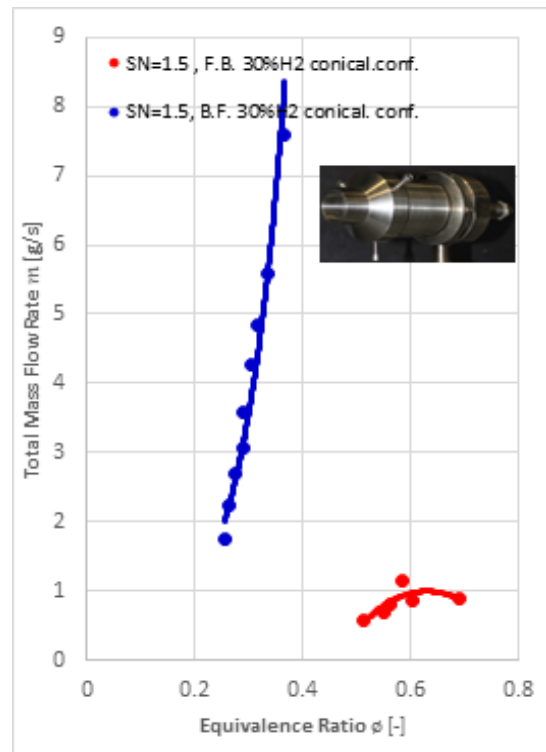
A-Combustor using cylinder confinement

Fig. 7. Burner working chart for combustor with swirl number SN=1.2 and 70% pure methane CH₄ with 30% pure hydrogen H₂.

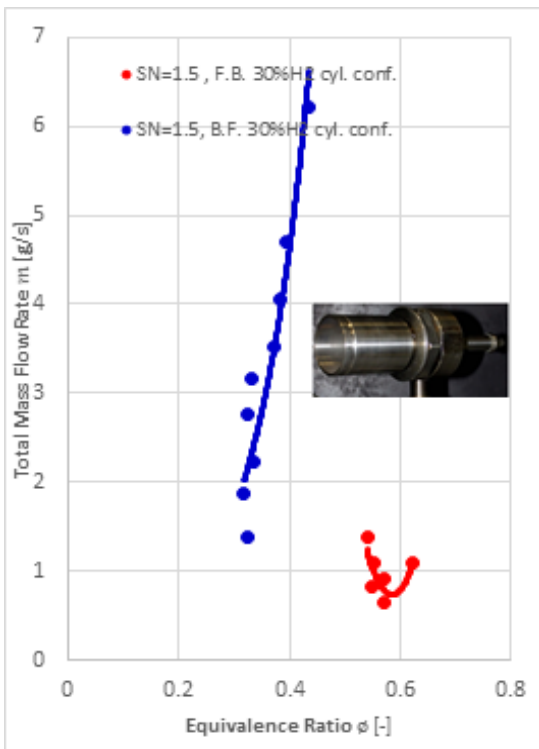
From the general view to these curves on the same fuel, it can be noted that increasing the percentage of hydrogen gives unstable combustion and this is clearly shown by the curves in figures 7 and 8. On the other hand, it can reduce that and widen the area of operation from 16% up to 90% of the possible area of operation.



A- Combustor without confinement



C- Combustor using conoid confinement



B- Combustor using cylinder confinement

Fig. 8. Burner working chart for combustor with swirl number SN=1.5 and 70% pure methane CH₄ with 30% pure hydrogen H₂.

IV. CONCLUSION

Flashback besides blowoff have been examined at two dissimilar geometrical swirl numbers and using two unlike fuel blends of H₂/CH₄, as mentioned previously.

Flashback bounds are conclusively prejudiced by fuel kind and particularly when blended with H₂ as well as swirl number. As the fuel used a pure methane 85% and pure hydrogen 15% hydrogen blends at the high swirl numbers of 1.2 and 1.5 give best flashback and blowoff boundary to generate an excellent operation map, which gives more reliability to designer and operator.

These working areas may reduce and change as the hydrogen percentage increases to 30% for the same above-mentioned swirl numbers, as a high percentage of hydrogen increases fuel-burning

instability, which gives unstable flashback and normal blowoff.

Confined burners reveal more stable flame and operation area as they reduce flame instability and mitigate CRZ break down.

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