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# Impacts on Blowoff by a variety of CRZs using various gases for Gas Turbines

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## Abstract

Fuel flexibility will drive the energy demand in the near future. The use of different syngas compositions from various sources will play a major role in the global fuel mix. CO2 in the blends will also be added as a mechanism to improve carbon capture and storage technologies. However, this can trigger instabilities such as thermoacoustics, flashback, autoignition and blowoff. In terms of blowoff, the phenomenon is still not entirely understood. This project presents a series of experiments to determine the behaviour and impact on the blowoff process at various swirl numbers, nozzle geometries and gas compositions. The Central Recirculation Zone was analyzed just before blowoff. The results show how the strength and size of the recirculation zones are highly influenced by these parameters. However, it seems that the CRZ dimensions/strength does not play an important role in the blowoff, whilst the composition of the mixture shows high correlation. Nevertheless, the CRZ intensity using these compositions can increase residence time, important for combustion improvement of other blends.

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Keywords: Blowoff, Swirling Flow, Central Recirculation Zone

## 1. Introduction

The use of new alternative fuels in the energy mix at large scale will be a reality in the near future. However, this contrasts with recent experiences of global operators who report increasing emissions and difficult combustion dynamics with even moderate variations in the fuel supply [1]. Most of current gas turbines use swirl stabilized combustion to anchor the flame and stabilize the combustion process [2]. The crucial feature of swirl burners is the formation of a central recirculation zone (CRZ) which extends blowoff limits by recycling heat and active chemical species to the root of the flame in the burner exit [3-5]. Usually, a Swirl number is used to define the swirling features of any flow [2]. Simplified momentum equations indicate that a radial pressure gradient is produced by the centrifugal force arising from the swirling effect [6], thus producing a Vortex Breakdown phenomenon.

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Although the topic has been studied for decades, there is still space for investigation on the fundamental behaviour underlying combustion stability with alternative blends [7-8]. As explained by some authors [9], there are different theories about blowoff. Current theories are based on a flamelet based description upon local extinction by excessive flame stretch [5, 10-11]. However, it is also recognised that this mechanism is not the one causing the final blowoff, as it is clear from data that the flame can withstand some extinction. Therefore, it is considered that the "critical extinction level" must be somehow influenced by the entrainment of reactants, the cooling of regions and the CRZ, thus confirming some relation between the phenomenon of blowoff and the existence of the CRZ [9]. In order to predict the event, some researchers have developed various empirical correlations. Zukoski and Marble [12] presented a criterion based on a characteristic chemical and residence time using as characteristic length the length of the CRZ. Thus, the coherent structure seems to have an important role in the blowoff event. Regarding the central recirculation zone, the use of different configurations has demonstrated that the shape and strength of the CRZ can change drastically depending on the geometry [3]. Syred et al [13] showed that for three different specific designs of premixed swirl burner (with specified geometries) with swirl numbers ranging from 0.8 to 4.0 that blowoff was solely a function of the inlet swirl velocity, not the swirl number. This surprising conclusion indicated that despite the variation in the CRZ the crucial factors arising from considerations of blowoff are the initial shear layer around the base of the CRZ. Thus, the objective of this paper is corroborate these finding and observe the crucial factors of the CRZ that alter the blowoff phenomena using different fuel blends. The fuel blends analysed are potential candidates for Carbon Capture and Storage due to their CO2 composition.

## 2. Setup

A swirl burner constructed from stainless steel was used to examine the flame stability limits at atmospheric conditions. A geometrical Swirl number, Sg, of 1.0 was used [2]. The recirculation zone was also distorted using a 45° and 90° nozzles, as observed by Valera-Medina et al [4]. Confined and unconfined conditions were tested. Confinement was done using a pair of quartz cylinders with diameters of 2D and 3D, respectively, being D the external nozzle diameter of 0.028m. Experiments were run to define the blowoff limits and swirling frequency shift of different configurations using different gases under confined conditions. Premixed combustion was used. The gases used were a mixture of CO2 and CH4, as these gases represent a high percentage in the composition of pyrolysis/gasification syngases. Measurements were done using a Stereo PIV system which consists of a dual cavity Nd: YAG Litron Laser of 532 nm capable of operating at 5 Hz. The inlet air was seeded with aluminum oxide Al2O3. The entire system was triggered at 1/100 of the precessing vortex core mode recognised from the signal of a microphone condenser positioned at the outlet of the burner nozzle. 300 PIV pair of images was used to create an average phase locked velocity map.

## 3. Results and Discussions

During experiments regular periodic motion was observed with frequencies which increased quazi-linearly with flowrate. The Strouhal number showed a constant trend, as previously observed with other swirl burners [2]. Thus, a clear appearance of the recirculation zone/precessing vortex core system was evident as to be expected [2]. Confinement improves the limits due to the reduction of air interaction with the flame, as expected. The equivalence ratio of the open flame case was $\phi$~0.6 while the blowoff with confinement reduced up to $\phi$~0.4. An increase of the flowrate would increase the intensity of the shear layer, which would converge into a new structure called High Momentum Flow Region (HMFR), highly correlated to the CRZ [14]. This would increase the strength of the CRZ but reduce its dimensions. Experiments using both nozzles with different blends were performed, Fig. 1. It is evident that there is a minor impact due to the geometry of the nozzle. Although the CRZ is different [4], blowoff limits are not affected by this factor. This confirms previous assertions [13], linking the phenomenon to other effects.

In order to observe the progression of the CRZ close to blowoff, experiments with the same blends were carried out using only the 45° nozzle. PIV measurements were obtained, Table 1 and Fig. 2. The total velocity in the system increases during the first experiments, being reduced in the last case due to the high, negative velocity of the CRZ. The addition of CO2 affects the velocity of the flow. Moreover, the CRZ has also increased its strength, size and negativity when compared to pure methane, Table 1. The increase of carbon dioxide from 0.13g/s to 0.89g/s clearly shows the progression and movement of the limits of this instability, reducing the resistance of the flame as the diluent is augmented.

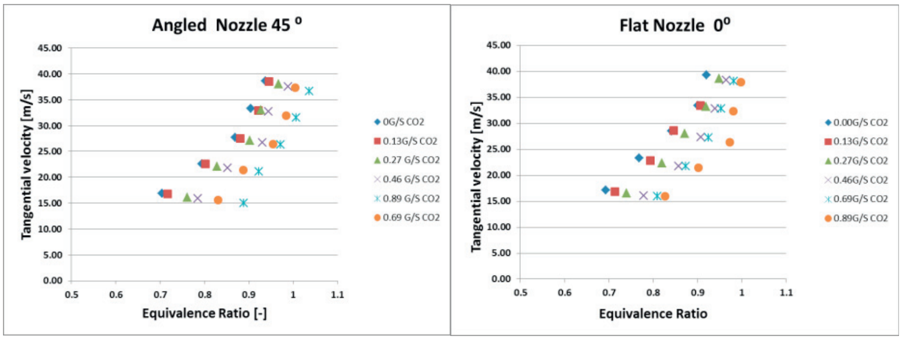

Fig.1. Blowoff comparison with different geometries. Minor changes in the trends are observed.

These results show that the CO2 increases the strength of the CRZ whilst keeping almost the same equivalence ratio before blowoff, compare T1a with T5b. This could enhance the recirculation of other products in the field augmenting their residence time whilst keeping the similar power outputs. It seems from the results that the higher density of the CO2 increases the centrifugal forces which in turn increases the CRZ. It is obvious that the use of CO2 increases in almost 16% the axial-radial turbulence intensity of the structure (i.e. TIAR% CRZ), whilst augmenting its width and length in more than 6%, compare T1a and T5b. The length of the recirculation zone increases due to the reduced reaction time of the blend and the higher turbulence inside of the structure, Fig.2. However, this also leads to less blowoff resistance. Therefore, the excess of turbulence at the boundaries of the CRZ, which could be produced by lower diffusivity of CO2, seems to be highly impacting on the phenomenon.

Table 1. Axial-Radial (AR) Velocity Fluctuations and CRZ size using the 45° nozzle.

| Test | Gas composition (CH4 and CO2) | Field TI% | TI% CRZ | Φ [-] | Width of CRZ[m] | Height CRZ[m] | Width | Height |
|---|---|---|---|---|---|---|---|---|
| T1a | 0.13CH4+0.13CO2+2.57 AIR | 2.57 | 0.79 | 0.87 | 0.033 | 0.069 | 1.17D | 2.4D |
| T2a | 0.156CH4+0.156CO2+3.01AIR | 2.25 | 0.77 | 0.89 | 0.032 | 0.050 | 1.14D | 1.78D |
| T3a | 0.21CH4+0.21CO2+3.93AIR | 2.33 | 0.85 | 0.91 | 0.032 | 0.055 | 1.14D | 1.96D |
| T4a | 0.24CH4+0.24CO2+4.12AIR | 2.53 | 0.81 | 1.00 | 0.033 | 0.046 | 1.17D | 1.64D |
| T5a | 0.27CH4+0.27CO2+4.94AIR | 2.28 | 0.80 | 0.94 | 0.032 | 0.049 | 1.14D | 1.75D |
| T1b | 0.13CH4+3.2AIR | 3.18 | 0.68 | 0.69 | 0.030 | 0.052 | 1.07D | 1.85D |
| T2b | 0.156CH4+3.5AIR | 2.38 | 0.68 | 0.76 | 0.030 | 0.045 | 1.07D | 1.6D |
| T3b | 0.21CH4+4.69AIR | 2.16 | 0.68 | 0.77 | 0.032 | 0.042 | 1.14D | 1.5D |
| T4b | 0.24CH4+5.2AIR | 3.22 | 0.67 | 0.79 | 0.032 | 0.042 | 1.14D | 1.5D |
| T5b | 0.27CH4+5.58AIR | 2.14 | 0.68 | 0.83 | 0.030 | 0.042 | 1.07D | 1.5D |

## 4. Conclusions

Experimental results show how the addition of CO2 in the blend can be of great importance to the change of the CRZ. Although it is concluded that the size and shape of the CRZ seem to be minor players in the blowoff limit under the conditions analysed, it is clear that the CRZ is increased with the usage of CO2. This in return could be beneficial for new blends and the increase of the residence time of the products/reactants of these and other fuel/diluent compositions. The results will be used to evaluate mass recirculation and the fundamental process behind the increase of turbulence in the boundaries of the CRZ.

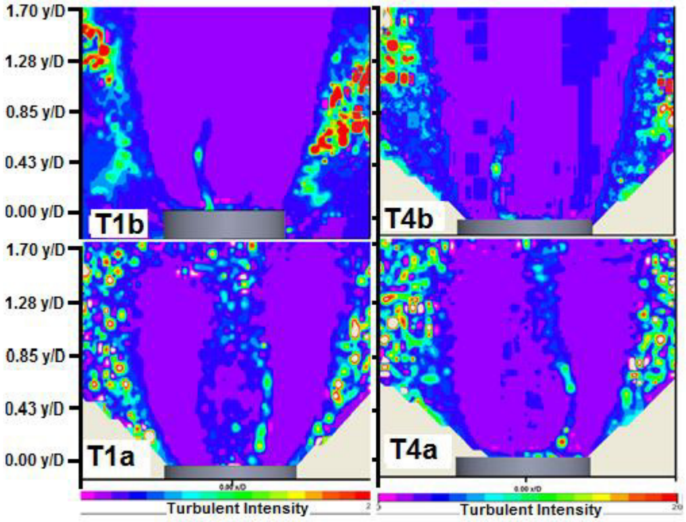

Fig.2. Comparison of turbulent intensity. Tests as in Tables 1. Colour band from 0 to 20%.

## 5. Acknowledgements

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