Influence of natural gas injection procedure in a swirl burner

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ABSTRACT

This paper presents the experimental results obtained comparing different natural gas injection typologies in a swirl burner. Particularly, both co-axial and radial (i.e.: transverse) injection, with respect to the rotating air stream, have been characterised through different techniques: particle image velocimetry and laser Doppler anemometry for flow field analysis, emission spectroscopy of the flame front. The burner has been operated in lean condition (equivalence ratio $\phi=0.69$), with an input thermal power of 17 kW, and a swirl number of the air stream equal to 0.82. The results put into evidence that, although the global mixing process is mainly governed by the swirling air stream, in the region close to the reactants efflux the fuel injection procedure plays an important role for flame stabilization and development in the primary mixing zone of the device.

INTRODUCTION

Non-premixed swirling flows are widely used in industrial combustion systems, particularly gas turbines, boilers and furnaces, for safety and stability reasons. Swirl motion of the air flow increases flame stability and has strong influence on the combustion efficiency and on the pollutant emissions. The basic principle of the swirl flow is that above a certain swirl level ($S > 0.6$), there is the generation of a recirculation bubble in the vicinity of the fuel jet outlet, the CTRZ (Central Toroidal Recirculation Zone) [1]. The combustion process is strongly influenced by the dimension and shape of the recirculation zone, because the combustion products recirculate backwards and supply energy for the ignition of the incoming fuel-air stream. Moreover, the recirculating regime provides efficient mixing between the reactants and a rapid homogenisation of the combustible mixture [2].

This paper deals with the experimental characterization of a natural gas swirl combustor, analysing by different techniques (flame visualization, emission spectroscopy, particle image velocimetry) the influence of fuel injection typology (coaxial or transverse with respect to the swirling air stream) upon the flame behaviour (morphology and flow field).

EXPERIMENTAL SET-UP

Fig. 1 reports a schematic view of the investigated burner (for more details, see [3]). Fig. 2 is referred to the two different injectors (axial or radial) tested during the research programme. As it can be seen, the burner is equipped with an axial+tangential swirl generator: it is a configuration quite similar to those used for typical industrial appliances (diffusive atmospheric pressure burners). A cylindrical quartz combustion chamber (internal diameter=192 mm) has been used for flame confinement, making possible flame visualization and measurements by laser anemometry.
Radial injector has been designed so as to reproduce (with respect to axial one) similar Reynolds and momentum ratio. Tab. 1 reports the main operating conditions used for the experimental measurements described in this paper.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>Air flow rate [g/s]</td>
<td>8.8</td>
</tr>
<tr>
<td>Reynolds number of air jet</td>
<td>20700</td>
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<tr>
<td>Natural gas flow rate [g/s]</td>
<td>0.35</td>
</tr>
<tr>
<td>Reynolds number of natural gas jet</td>
<td>5600</td>
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<tr>
<td>Input thermal power [kW]</td>
<td>17</td>
</tr>
<tr>
<td>Air swirl number S</td>
<td>0.82</td>
</tr>
<tr>
<td>Fuel/Air Momentum ratio MR</td>
<td>0.91</td>
</tr>
<tr>
<td>Fuel/Air Equivalence ratio Φ</td>
<td>0.69</td>
</tr>
</tbody>
</table>

Tab. 1: main operating conditions of the investigated burner.

MAIN RESULTS

Fig. 3a, b reports the image of the flame for the different injection typologies. It can be observed the typical calyx shaped flame, due to swirl, and, for the axial injector, the formation of a central luminous region connected to fuel penetration inside the recirculating
bubble, generating a fuel rich zone and giving rise to soot formation. This phenomenon, anyway sporadic for axial injector, is always absent for radial one.

![Fig. 3a: image of the flame for axial injection.](image1)

![Fig. 3b: image of the flame for radial injection.](image2)

The higher stability and compactness of the flame in the case of radial injection is proved also by the results obtained by CH* emission spectroscopy from the flame front, resumed in Fig. 4. In fact, reaction zone (identified by the peak of CH* emission intensity) for radial injector is closer and more concentrated at the burner head (peak at h/Rb=1.3, where Rb=radius of the burner head=18 mm), with an initial steeper gradient.

![Fig. 4: CH* emission intensity as a function of the distance h/Rb from the efflux.](image3)
The different behaviour of the two injectors is put into evidence also by flow field measurements in reacting conditions performed by particle image velocimetry. In this case, different seeding conditions have been analysed:

- Silicon oil droplets (mean diameter=1 µm) dispersed in the fuel flow, to reproduce the central jet penetration (in the case of axial injector) and obtaining “conditional” velocity measurements referred to the “cold” natural gas jet interacting with the recirculating central bubble;
- Alumina particles (mean diameter=5 µm) dispersed in the corner region at the base of the combustion chamber, reproducing mainly the recirculating flow of already burned gases;
- Both oil droplets and alumina particles, to have the complete characterization of the flow field.

Fig. 5 reports the number of validated vectors obtained seeding the central fuel jet (axial injector) with oil droplets: the penetration and progressive decreasing of fuel concentration by interaction with the coaxial swirling air stream and central recirculating region is clearly visible.

**Fig. 5: number of validated vectors for axial injector (oil droplets dispersed in the fuel flow).**

Measurements performed by LDV close to the region of interaction between the central jet and the recirculating central region gave rise to bi-modal distributions, putting into evidence the possibility of sporadic penetration of the fuel jet inside the bubble, a phenomenon originating the luminous zone visible in Fig. 3a.

The difference between the two injectors is visible also in Fig. 6, which reports the axial velocity profiles deduced by PIV measurements, close to the reactants efflux (at the traverse h/Rb=0.46). The use of the radial injector, obviously, avoids the possible interaction of the central jet with the formation of the recirculating region, which is generated just downstream the efflux. Moreover, in Fig. 7, 8 the 2-D flow field measured by PIV averaging 200 double-exposed images (double seeding), confirms the generation for radial injector of the recirculating regime very close to the burner head, contributing to flame stability and reactants mixing (with already burned gases too) enhancement with respect to axial injection.
Finally, Fig. 9 describes the axial velocity decay along the burner axis (axial injector), for cold condition and for the different seeding procedures for the reacting flow. Acceleration
due to thermal expansion in combustion conditions is clearly visible, while measurements with oil droplets put into evidence central jet penetration.

![Fig. 9: axial velocity decay along the burner axis (axial injector).](image)

**CONCLUSIONS**

The measurements performed through different techniques upon a model of a natural gas swirl burner varying the gas injection procedure (axial or transverse with respect to air stream) put into evidence how this procedure plays an important role in flame stabilization and development close to the reactants efflux, being the global mixing process governed by swirl effect imparted to the air. Particularly, it has been deepened the knowledge about the possible interaction (for axial injection) between the central fuel jet and the recirculating bubble, which can induce fuel penetration and formation of a sooting luminous region. This phenomenon is obviously absent in the case of radial injection, which gives rise to a flame quite similar to a partially premixed one.

**REFERENCES**


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