Measurement of NOx and CO Emissions in Natural Gas Flames

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1. Introduction

Owing to recent strict legislation [1], environmental impact of combustion processes is nowadays one of the most important problems involving both scientific community and burner manufacturers. In the case of natural gas combustion, nitric oxides (NOx) reduction is the most critical aim to achieve, often requesting for industrial applications heavy and high-cost plant revamping (for instance, adoption of low-NOx burners or burned gases de-NOx treatment [2, 3]). Moreover, although NOx formation mechanisms are today quite understood [4], many unsolved questions are connected to the interaction between fluid dynamic and chemistry inside the burner device [5] and this makes the CFD codes not yet fully predictive.

This paper presents the results obtained as for pollutant emissions (nitric oxides and carbon monoxide) upon two different natural gas burner typologies: a swirl burner equipped alternatively with two different fuel injectors (co-axial or transverse with respect to the rotating air stream) and a premixed burner with a flame generated downstream a metallic grid. The analysis has been carried out varying the operating conditions of the devices (equivalence ratio, swirl number).

For both burners, burned gases have been sampled for analysis of the pollutant emissions through chemiluminescence for NOx and infrared analysis for CO.

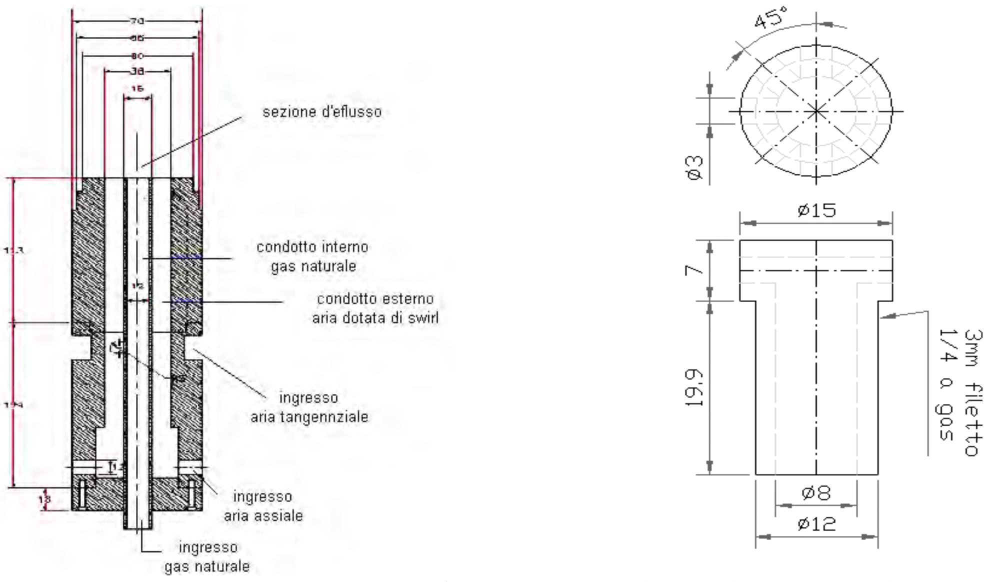

Figure 1: schematic view of the swirl burner inlet and of radial nozzle; dimensions are in millimeters.

1.1. Burner Geometries

As for diffusion flames, the experimental apparatus is a laboratory-scale swirl burner (Fig. 1). The fuel is delivered by a central tube, while the swirling air flow is provided by a coaxial annulus. Details regarding the investigated burner typology are reported in [6]. Air swirl motion was imparted through an axial plus tangential air entry. The variation of the relative amounts of axial and tangential air flow controls the intensity of the swirl. All tests were performed at ambient pressure, with the flame confined by a cylindrical quartz chamber

(192mm in diameter, 300mm in height). The burner can be alternatively equipped with an axial or a radial injector that provides fuel admission transversal to the air stream and it is designed with eight circular holes. The radial injection creates a more stable flame in comparison to the axial injection [6].

The premixed burner is mainly constituted by a mixing duct in which air + natural gas are injected and mix together: the duct terminates in a fine metallic grid equipped with an electrical ignitor. The premixed flame stabilizes downstream the grid and is confined inside a radiant tube oven. Fig. 2 reports a frontal and lateral view of the premixed flame. Nominal input thermal power of the burner is about 20 kW.

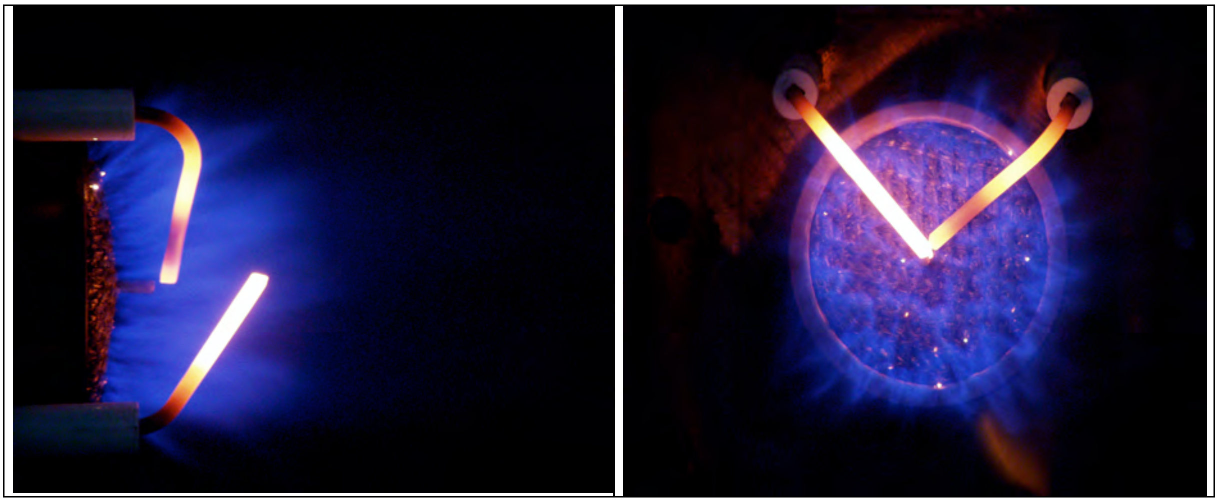

Fig. 2: lateral (left) and frontal (right) view of the premixed investigated flame.

2. Experimental Results

As for the swirl burner, pollutant emissions (CO and NOx) at the exhaust have been measured for the two injectors in different operating conditions, that is varying equivalence ratio, and for different values of air swirl number. Swirl number variation is possible modifying the axial-tangential split ratio in the swirl generator. Variation of the equivalence ratio has been obtained changing fuel flow rate and, consequently, input thermal power and momentum ratio, but maintaining constant the air flow rate and, as a consequence, the Reynolds number and the macroscopic fluid dynamic of the flow. Results are reported in Figgs. 3, 4, 5 and 6. As it can be seen, the graphs start from the blow-off limit for the lean flame and are also useful to define the possible operability range of the burner.

Blow-off limit in lean conditions is mainly dictated by swirl intensity rather than injection procedure: in this case, the lower swirl number allows the extension of blow-off limit towards leaner conditions, to the detriment of CO emissions which become very high. Probably, the higher value of swirl number can enhance flame local stretching inducing instability phenomena (such as the PVC, Precessing Vortex Core) clearly observed in isothermal conditions. The radial injector presents lower NOx emissions (up to 50% in lean condition) with respect to axial one and its behaviour under the point of view of pollutant emissions is strictly dependent from equivalence ratio rather than swirl number. In fact, for the radial injector, a steep increase of NOx emissions has been pointed out approaching stoichiometric flames. At the same time, a relevant increase of CO formation is noticeable in lean conditions. At the contrary, especially for high swirl number, the axial injector seems quite insensitive to equivalence ratio and a slight decrease in NOx emissions can be revealed close to stoichiometric flame, associated with increase of CO emission (probably connected to strong penetration of central fuel jet with subsequent possible mixing deficiency).

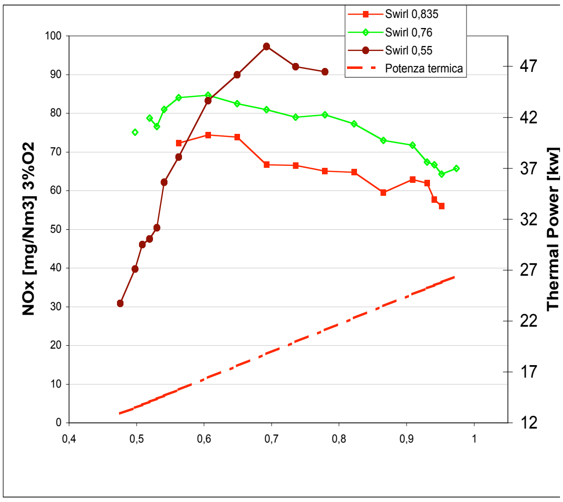

Fig. 3: NOx emissions for the axial injector.

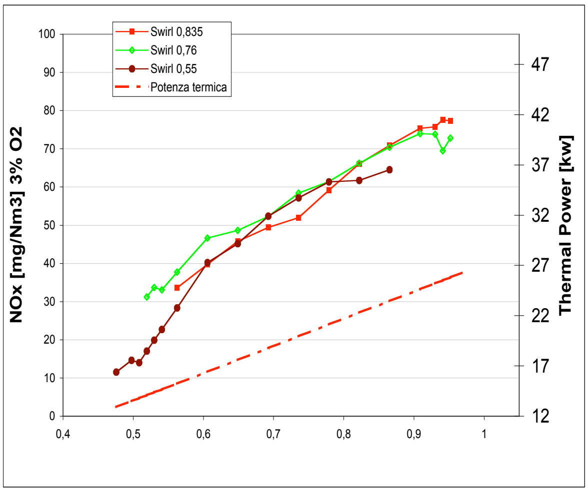

Fig. 4: NOx emissions for the radial injector.

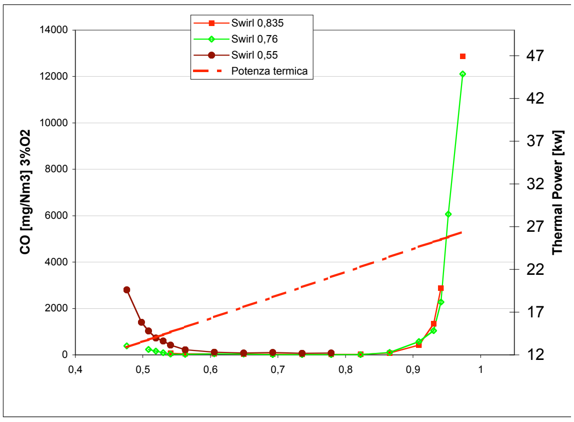

Fig. 5: CO emissions for the axial injector.

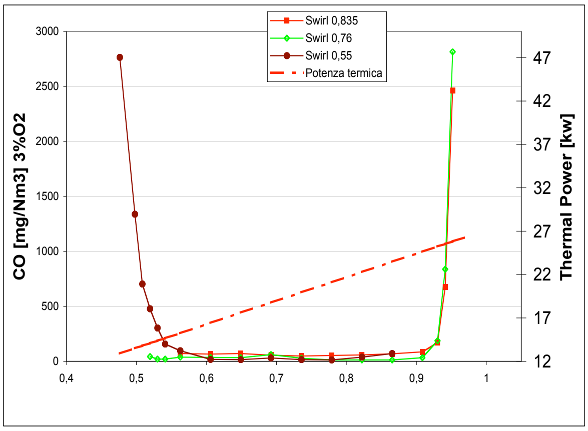

Fig. 6: CO emissions for the radial injector.

The general behaviour of the two different injectors as for pollutant emissions seems to reflect the generation of two different flame typologies: a partially premixed one for the radial injector and a purely diffusive flame for the axial one.

Results of pollutant emissions measured in the purely premixed burner are represented in Figgs. 7 and 8.

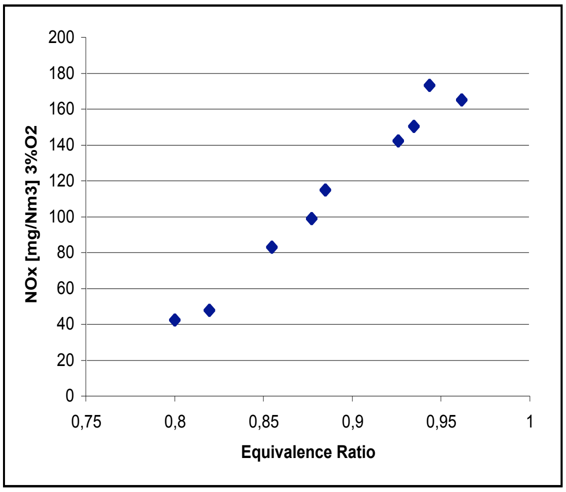

Fig. 7: NOx emissions for the premixed burner.

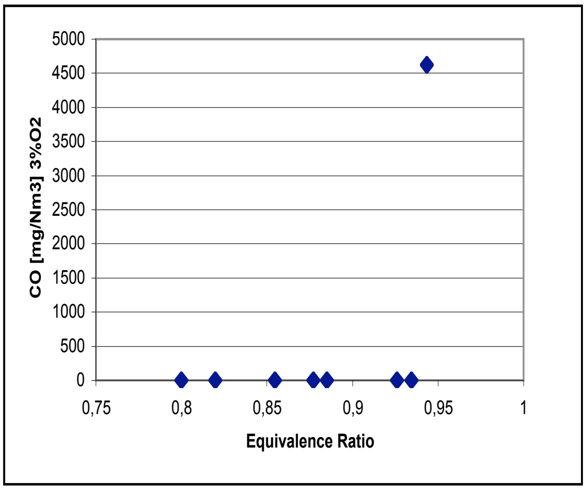

Fig. 8: CO emissions for the premixed burner.

As it can be observed, the behaviour of the premixed burner presents the classical trend for pollutant emissions: a steep increase of nitric oxides as a function of equivalence ratio (with a maximum close to the stoichiometric value, where temperature values are higher). At the same time, an almost sudden rise of CO emission in stoichiometric condition could be due to carbon dioxide dissociation owing to high temperature levels in the premixed flame front.

3. Conclusions and Future Work

Different natural gas burner typologies (a swirling burner and a purely premixed one) have been characterised under the point of view of pollutant emissions (NOx and CO). The obtained results put into evidence the dependency of pollutant formation on the operating conditions of the device (swirl number, equivalence ratio) and could be of interest to identify, from a practical point of view, the optimal operating conditions of the burner and to support, under a theoretical aspect, the validation of CFD codes. Off course, the results here described have to be considered as a preliminary aspect of the flame behaviour, that has to be deepened through further application of experimental techniques (for instance, local temperature, velocity and mixture fraction measurements).

4. Acknowledgements

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5. References

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