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SWIRL NUMBER INFLUENCE ON POLLUTANT EMISSIONS IN A TWO PHASE SWIRL COMBUSTOR

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Abstract. *This paper deals with an alternative Low-NOx combustor configuration to possible application in gas turbine. The combustion structure allows the conciliation of low NOx emissions and partial oxidation combustion products, as carbon monoxide (CO), unburned hydrocarbons (UHC). The combustion conditions for emissions reduction are reached through the dynamics control of reactants mixing process. This control is obtained by the operational parameters: fuel jet Reynolds number, primary chamber length/diameter and air flow swirl number. Swirling flows are widely used in gas turbines to improve reactants mixture and stabilize the flame, so this work analyses, meanly, the influence of swirl number influence on pollutant emissions, being the other parameters considered. The results that swirl number increase provide CO and UHC reduction. However, NOx higher values are found for high swirl number. Nevertheless, the levels obtained are acceptable. It is also observed that the correct combination of the analyzed parameters is contributory for reducing emissions.*

Keywords: *combustion, gas turbine, pollutant emissions.*

1. INTRODUCTION

Swirling flame are widely used in a variety of combustion applications, and their dynamics has been a subject of a continuous scientific interest (Candel *et al*., 2014). This flame is obtained by aerodynamic swirlers that presented as a way of controlling the intensity, size and shape of a flame, and its use in gas turbines is quite common.

In conventional gas turbine combustion chambers, swirlers are commonly used so that the flow directed to the reaction zone has not only axial velocity but also tangential and radial components. Swirl provides recirculation of the hot gases near the combustor inlet for a better mixing between the reactants and flame stability. A recirculation zone is created downstream of the swirler, where a reverse flow results in the mixing of the hot combustion products with the incoming air stream. This dynamic allows high and uniform temperatures in the combustion zone as in a well-stirred reactor. This hot mixture provides the energy required for the fuel to ignite and stabilize the flame (Khalil *et al*., 2011). According to Syred and Beér (1974); Gupta et al. (1984) and Sloan et al., (1996), cited by Elkady (2005), swirl flows in gas turbines create a recirculation zone in the combustor dome around the fuel injector, which in turn recirculates a portion of the hot combustion products. This recirculation zone acts not only as a heat reservoir, but plays an important role in the reagent mixture improvement, reducing blowout limits and pollutant emissions levels. The results of Tangirala et al. (1987) showed that the mixture and flame stability can be improved by increasing the swirl number to values close to stoichiometry. According to Syred (2006), the use of a high swirl number produces stronger and more regular recirculation zones and, consequently, a more homogeneous mixture of the reactants. Jeong et al. (2004), studying the effects of swirling and recirculating gases on unmixed flame characteristics, shown that the central toroidal recirculation zone caused by high swirl numbers resulted in a much larger NO reduction when compared to non-swirl situations.

This paper presents a double-stage swirl combustor that uses parts of RQL and LP concepts to control NO_x emissions; however, without premixing in a preliminary duct as LP combustors and without staged air addition as RQL combustors. The favorable conditions to NO_x reduction are achieved by the flow dynamic control of reactants and burned gases inside the chamber. The combustion takes place in two stages, each one in a separate chamber. At first stage the fuel is injected through a central spear and the total air of the combustion process crosses a swirler, where acquire a tangential component of velocity. The air, which because of the tangential velocity component produced by swirler, flows concentrated near the wall of the combustion chamber and develop a film cooling from the wall of the chamber and flame. At the end of this primary zone, which is called transition zone, there is a sudden increase in the chamber diameter and the rotating air flow loses the wall effect, expanding itself radially. This causes the pressure decrease in the central region, which in turn allows the reversal of the air flow and consequently the creation of an intense recirculation zone mixing the remaining air with the combustion products of the primary zone. So that, in the secondary chamber a lean pre-mixed flame is established.

It is clear that the intensity of the recirculation zone has a strong influence on the mixture and consequently on the pollutant emissions. The intensity of the recirculation zone formed is quantified by a parameter named swirl number. Thus, this work aims to analyze the influence of this parameter not only on NOx, but also on CO and UHC emissions. Since the recirculation zone is influenced, also, by the other parameters that control the mixing process between the reactants, i.e. fuel jet Reynolds number, primary chamber length/ diameter and swirler angle blades, these will also be considered in the analysis.

2. METHODOLOGY (EXPERIMENTAL SETUP)

The camera used in this work was fabricated in stainless steel and is divided into two zones, no refrigeration is necessary, since the air coming from the swirler works as film cooling. The primary chamber has length of 10, 20 and 30 cm, and diameter of 10 cm (L/D = 1, 2 and 3), and the secondary, 50 and 40 cm, respectively. The air from two blowers is axially conducted to the swirler, positioned at the primary chamber entrance and composed of 8 blades that form angles between 50º and 80º with the axial direction (the primary chamber and swirler have the same diameter). So, it was possible to study the swirler blades angle influence on emissions without changing the air flow passing through the swirler. The maximum air flow was 70 g/s. The fuel mass flow rate was kept constant at 1 g/s, and the different Reynolds number of the fuel jet were obtained changing the injector nozzle diameter: 2.35, 3.20 and 7.8 mm, providing jets with Reynolds numbers of 50,000, 40,000 and 15,000, respectively. Both mass flow rates were obtained through orifice plate systems, resistive sensors pressure and LabVIEW software. For these flow values the equivalence ratio varied between 0.2 and 0.9. The combustion gases concentration acquisition was carried out by GreenLine 8000. The flue gas sample probe was coupled to the exhaust duct. The Greenline 8000 is accompanied by the DBGas 2004 software that assists data management and storage. The gases concentration is corrected to 12% of O2. Figure 1 shows a schematic diagram of the experimental setup.

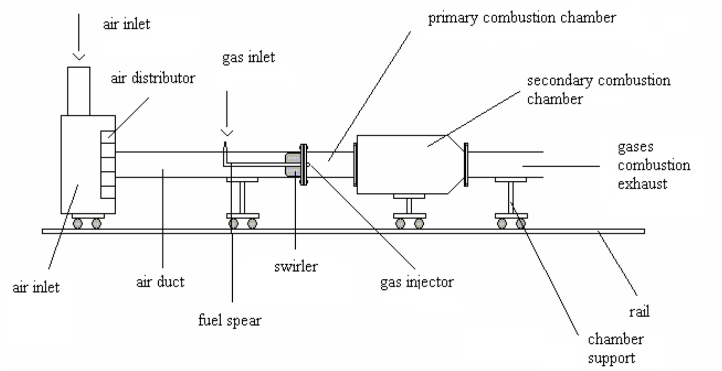

Figure 1. Experimental Setup

3. RESULTS

This section presents the results obtained through the tests developed, as well as the description and discussion of them. The presentation of the results follows the execution sequence of the experimental tests. For a given chamber length (fixed ratio L / D), a given gas injector diameter (fixed Re) and a given swirler blade angle (α fixed) varied at the air flow rate (varied ϕ). Subsequently α, Re and L / D were varied, with concentrations of the combustion gases being obtained for each of these conditions.

As noted by Figures 2 to 7, high swirl numbers provide CO and UHC reduction. However, CO concentration is more affected by swirl flows than UHC. CO depends on a longer residence time to complete the combustion than the hydrocarbons since they are formed in the first step of the burning of the fuel and CO after such a step. According to Li (2005) in a highly turbulent flow, provided by high swirl numbers, there will be a higher rate of reaction and combustion efficiency and, thus, the decrease of CO emissions.

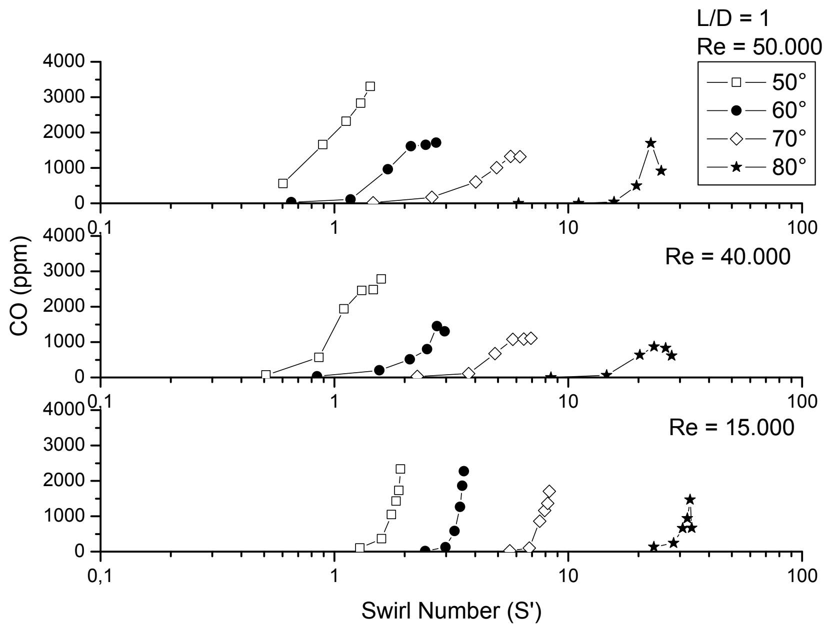

Figure 2. Swirl number effect on CO emissions for L/D = 1

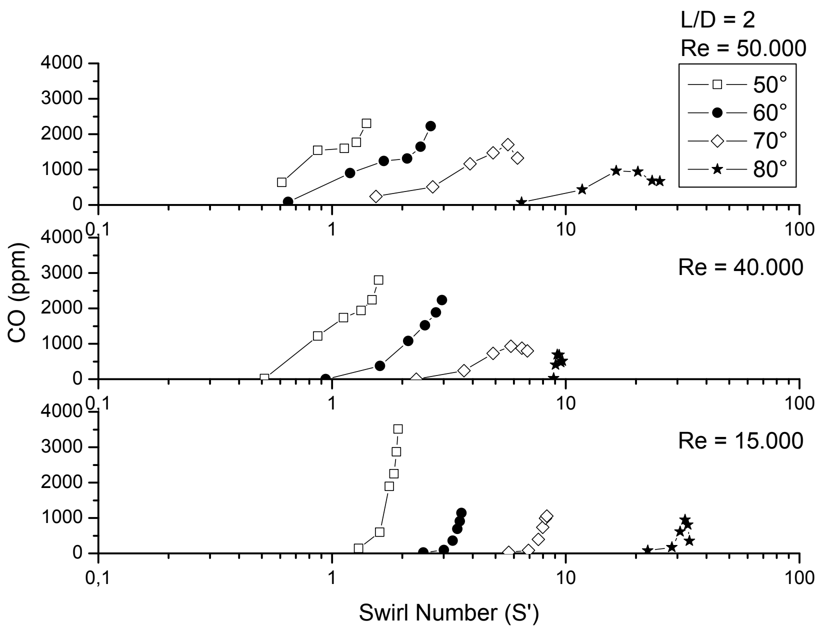

Figure 3. Swirl number effect on CO emissions for L/D = 2

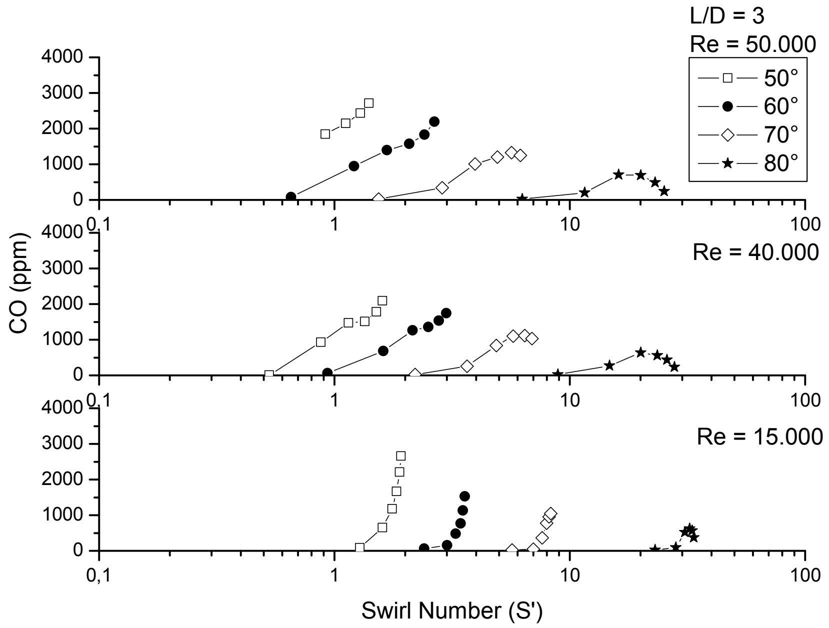

Figure 4. Swirl number effect on CO emissions for L/D = 3

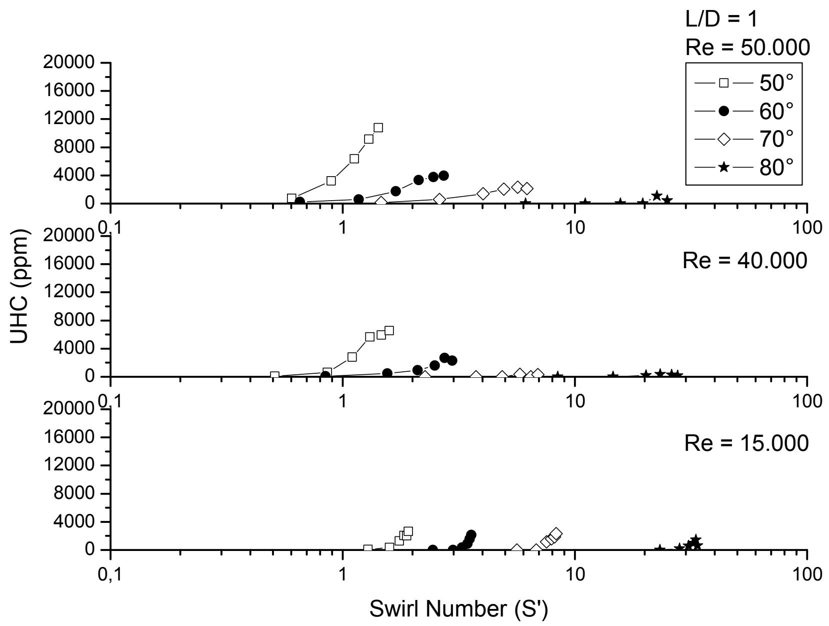

Figure 5. Swirl number effect on UHC emissions for L/D = 1

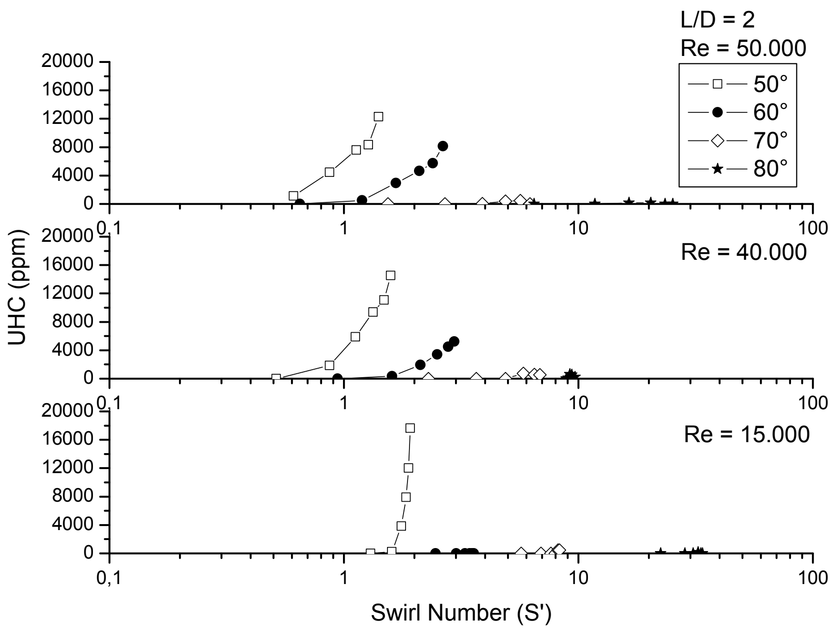

Figure 6. Swirl number effect on UHC emissions for L/D = 2

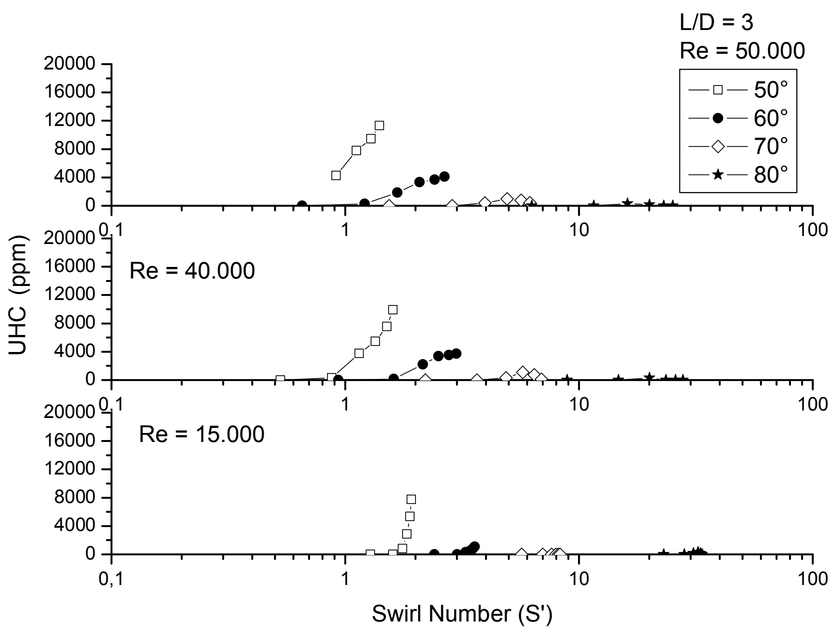

Figure 7. Swirl number effect on UHC emissions for L/D = 3

Still analyzing the results for CO and UHC, it’s clear that for higher swirl number, such as obtained for angles of 80°, the increase of emissions up to a maximum value followed by a reduction, in some situations, abrupt. This is due to the fact that the global impoverishment of combustion combined with high swirler blades strengthens the recirculation structure and, consequently, minimizes the favorable conditions for the formation of the pollutants in question. As shown in the Figure 8, increasing the swirler angle increases exponentially the swirl number. With less influence, the reduction of the equivalence ratio (air flow increase) also increases the swirl number, since more fluid is passing through the swirler blades. It is important to note that the ratio L / D = 1 was arbitrarily chosen for the results to be presented, since the swirl number model is applied to the condition at the exit of the primary combustion chamber, that is, the addition of tangential velocity component exactly at the exit of the swirler, and the length of the primary chamber does not interfere with the result. Similar results are obtained for the L / D = 2 and 3 ratios.

In addition, high swirl numbers tends to increase the turbulence intensity and consequently the reaction rate, which in the case of lean combustion may partly compensate for the reduction of speed due to the low temperature, which in turn, allows the acceleration of the intermediate reaction mechanisms and, consequently, the reduction of CO and UHC.

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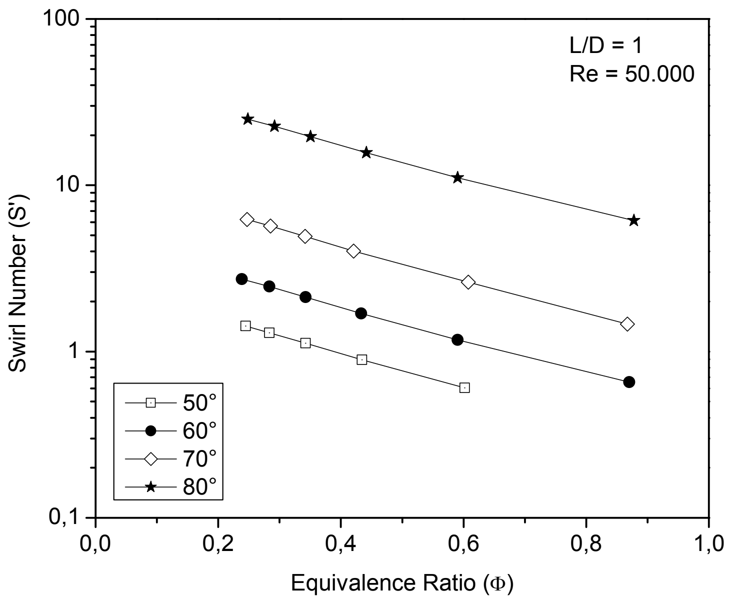

Figure 8. Swirl number effect on UHC emissions for L/D = 3

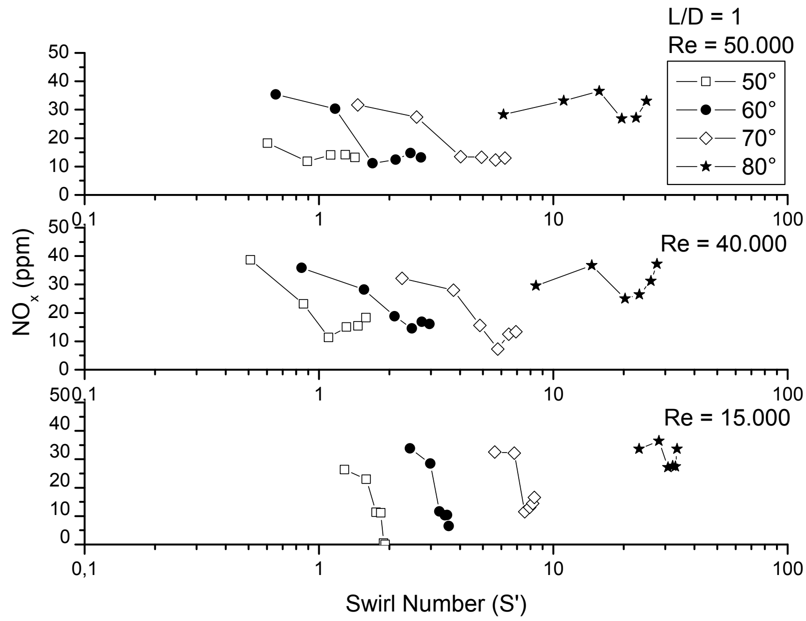

Figure 9. Swirl number effect on NO_x emissions for L/D = 1

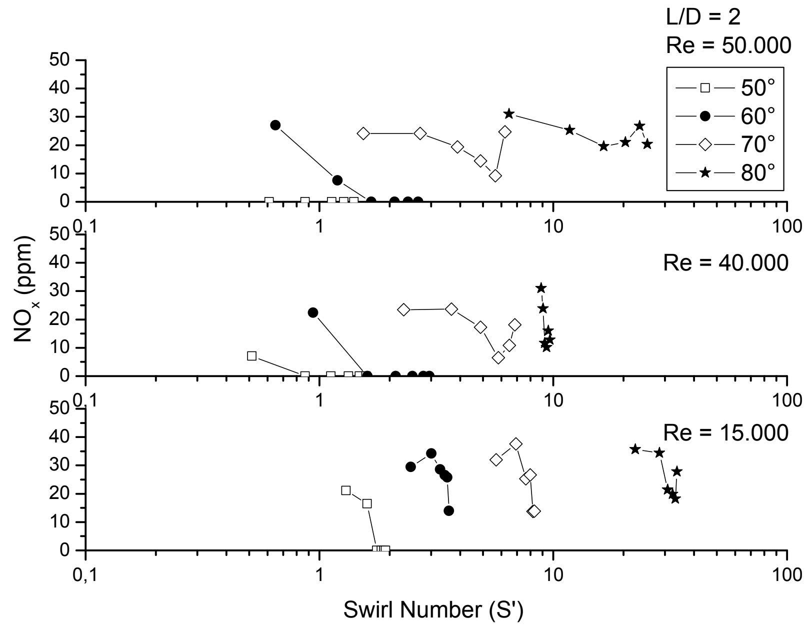

Figure 10. Swirl number effect on NO_x emissions for L/D = 2

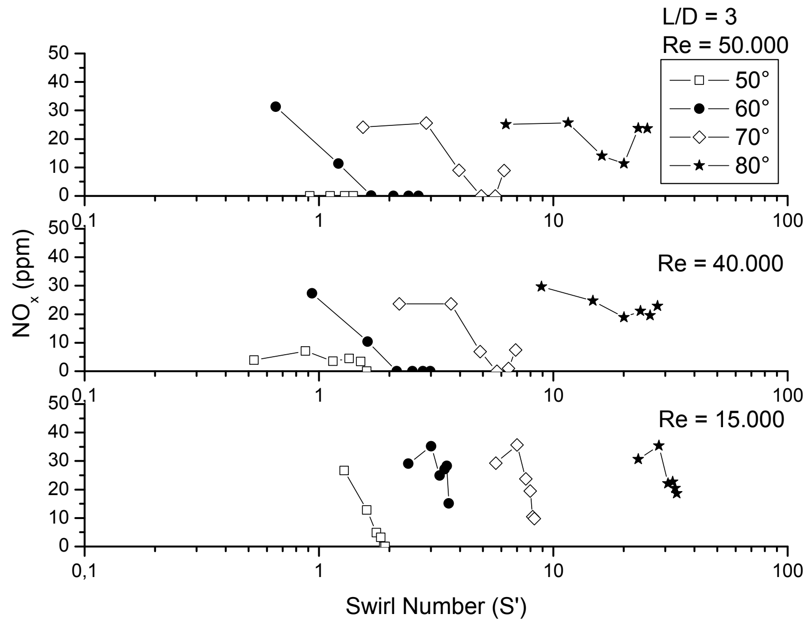

Figure 11. Swirl number effect on NO_x emissions for L/D = 3

With regard to NOx, the literature shows that in some situations, high swirls number increase their levels, in other cases, at least initially, they decrease them. This shows that the swirl number effect on NOx is complex and also indicates strong influence of other parameters on the same (Hill and Smoot, 2000). The NOx emissions variations with the swirl number undoubtedly are due to differences in the mixing pattern of the reactants. The mixture between the primary (fuel) and secondary (air) flows controls the conversion of nitrogen to NO.

In the present work, in addition to the swirl number, the equivalence ratio, the primary chamber L / D ratio and the fuel jet Reynolds number also control the physical and chemical processes that are developed along the combustor. However, in spite of the several parameters involved, the results for swirl number influence on the NO_x emissions show that in all operating conditions analyzed, NOx emissions present higher levels for larger values of this parameter, as observed in Figures 9 to 11. However, NOx levels are still considered relativity low.

In addition to improving the mixing process between the reactants and combustion gases, high swirl numbers increase the reaction rate of different elemental reaction mechanisms, which gives a higher flame temperature and, consequently, there is an increase in the NOx emissions. Kevin et al. (1977), analyzing the pollutant formation of confined turbulent diffusive flames, also observed the NOx levels increase with high swirl numbers.

4. CONCLUSIONS

The present work had as objective to analyze, experimentally, the swirl number influence on pollutant emissions (CO, NO_x, UHC) in an alternative model of combustion chamber for application in gas turbines. Most of the pollutant emission control techniques of gas turbines have the direct objective of reducing NOx. Low levels of NOx are readily achieved by eliminating high temperature zones in the combustion chamber. The challenge is to keep the flame temperature low in high power conditions without incurring loss of performance when operating at low power.

Results show that high values of swirl number produce different effects on the studied pollutants. While higher swirl numbers are fundamental for CO and UHC reduction, since they provide a better mixture between the reactants, for the NOx these higher values promote the elevation of their levels. This is due to the fact that, with a better mixture, there is a higher reaction rate and also energy release, and thus a higher reaction temperature. However, NOx levels are still considered relativity low, which makes it possible to operate the camera at such swirl number.

With respect to the other operating parameters, in general, it can be said that for this chamber geometry one must use Re = 15,000, ratio L / D = 3 and = 80 °. This combination provides a better mixing between the partial oxidation compounds and the remaining air, and a higher reaction rate in the recirculation zone.

5. ACKNOWLEDGEMENTS

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6. REFERENCES

Candel, S., Durox, D., Schuller, T., 2014. Bourgoin, J.C. and Moeck, J.P. *Annual Review of Fluid Mechanics*, Vol. 46, p. 147-73.

Elkady, A.M., 2005. *Experimental Investigation of Aerodynamics, Combustion and Emissions Characteristics within the Primary Zone of a Gas Turbine Combustor*. Ph.D thesis, University of Cincinnati, Ohio, USA.

Jeong, Y.K.; Jeon, C.H.; Chang, Y.J., 2004. "Effects of a Swirling and Recirculation Flow on the Combustion Characteristics in Non-Premixed Flat Flames". *KSME International Journal*, Vol. 18, p. 499-512.

Gupta, A. K.; Lilley, D. G.; Syred, N., 1984. *Swirl flows*. Abacus Press.

Hill, S.C. and Smoot, L.D., 2000. "Modeling of Nitrogen Oxides Formation and Destruction in Combustion Systems". *Progress in Energy and Combustion Science*, Vol. 26, p. 417-458.

Kevin, O.F.; Spadaccini, L.J.; Bowman,C.T., 1977. "Pollutant and Energy Release in Confined Turbulent Difusion Flames". *Proceedings of 16th Symposium International on Combustion*, p. 105-117.

Khalil, A.E.E.; Arghode, V.K.; Gupta, A.K., 2011. "Distributed Combustion with Swirl for Gas Turbine Applicatios". In: *49th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*. Orlando, Florida, AIAA paper # 2011-64.

Li, G. and Gutmark, E.J., 2005. "Effect of Exhaust Nozzle Geometry on Combustor Flow Field and Combustion Characteristics". *Proceedings of the Combustion Institute*, Vol. 30, p. 2893-2901.

Sloan, D. G.; Smith, P. J.; Smoot, L. D., 1996. "Modeling of Swirl in Turbulent Flow Systems". *Progress in Energy and Combustion Science*, Vol. 12, p. 163-250.

Syred, N. A., 2006. "Review of Oscillation Mechanisms and the Role of the Precessing Vortex Core (PVC) in Swirl Combustion Systems". *Progress in Combustion and Energy Science*, Vol. 32, p. 93-161.

Syred, N. and Beér, J. M., 1974. "Combustion in Swirling Flows: A Review". *Combustion and Flame*, Vol. 23, p. 143-201.

Tangirala, V.; Chen, R.H.; Driscoll, J.F., 1987. "Effect of Heat Release and Swirl on the Recirculation within Swirl-Stabilized Flames". *Combustion Science and Technology*, Vol. 51, p. 75-95.

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