Experimental investigation on fuel flexibility of a cyclonic burner performed in MILD Combustion

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Introduction

The interest in the improvement of the performance in power generation systems, aiming to reduce costs, increasing the efficiency and fuel flexibility and reducing pollutants emissions has driven the combustion community to study and develop new technologies [1].
MILD Combustion [2, 3] (often identified also as FLameless Oxidation-FLOX® [4] or Colorless Distributed Combustion [5]) is a rapidly developing technology to obtain high-energy savings with enhanced heat transfer combined with the advantages of low pollutant emissions and low noise without flame instability phenomena. Demonstration and industrial implementation of MILD or Flameless technologies has been realized for furnace applications worldwide where the thermal intensity is very low (about 0.1–1 MW/m^3-Atm) and large combustion volume is available to achieve stable combustion [6]. On the other hand, one of the main limitations to the large deployment of internal recirculation based combustion devices is the difficulty in stabilizing the oxidation in small-scale systems due to the high heat losses and very low flow residence times inside the combustor. An effective method to create recirculation zone in small scales involves the use of cyclone like configuration [7].
In this context, the present study investigates the fuel flexibility and stability characteristics of a novel Laboratory Unit CYclonic (LUCY) burner operating under MILD combustion conditions [8].
In order to enhance the internal recirculation of burnt gas into the fresh fuel/oxidant mixture, a cyclonic flow configuration was chosen, while the fuel flexibility of LUCY burner was investigated by performing experimental tests with propane, methane and biogas at different thermal power levels. Such analysis is therefore very important for scaling methodologies, in order to ensure that MILD combustion mode is achievable in scaled combustors for higher or lower thermal intensities.

Experimental set-up

LUCY burner is a prismatic (20x20x5 cm^3) chamber [8]. Two injection systems feed the combustion chamber in an anti-symmetric configuration realizing a centripetal cyclonic flow field with a top-central gas outlet. The injection system is made of a main duct (where a mixture of oxygen and diluent gases is fed) and an adjacent smaller duct used to inject the fuel. The burner is located within electrical ceramic fiber heaters to minimize heat exchange towards the surroundings. The cyclonic burner, made in vermiculite, is provided with a set of N thermocouples (T_1, T_2, T_3 corresponding to the central, intermediate and lateral position) and an optical access (a quartz window). The exhaust gases are sampled using an in-house built cooled probe and analyzed by means of an inline flue gas analyzer and a Gas chromatographic system. The burner is designed to have very long residence times to permit the complete oxidation of diluted mixtures. The high gas recirculation rates promote the attainment of high temperature low oxygen concentration condition required for the stable autoignition of MILD mixture.

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Results and Discussions

Experimental campaigns were performed with C_3H_8, CH_4, and Biogas mixtures at different thermal power in order to evaluate the fuel flexibility and the process stability of the cyclonic burner. The performance of LUCY burner in terms of CO and NO_x emission have been evaluated in the experimental tests.
Firstly, experimental tests were carried out to value the maximum theoretical thermal power that the burner can sustain without compromising pollutants emission operating with C_3H_8 mixtures. Figure 1 reports the CO and the NO_x emissions obtained performed the cyclonic burner with C_3H_8–Air mixture at $\Phi = 0.85$. Such a value of the equivalence ratio has been chosen because, by the previous analysis [9], CO emissions present a minimum value.

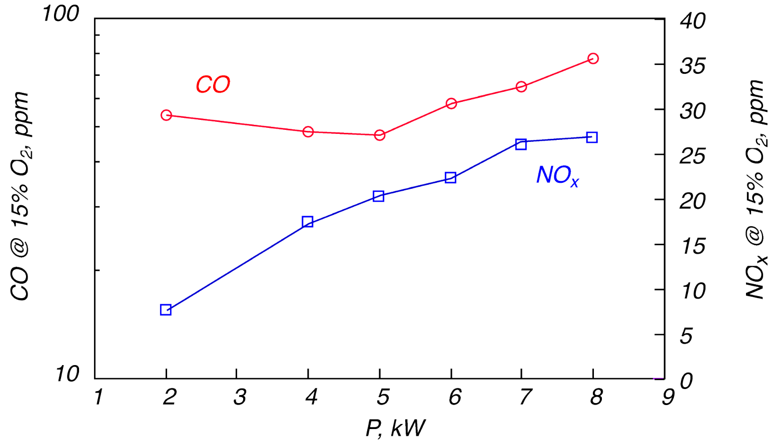

Fig. 1 CO and NOx emissions for C_3H_8-Air mixtures as a function of P. $\Phi = 0.85$.

It is possible to note that CO slightly diminishes from 40 ppm at P = 2 kW to 35 ppm at P = 5 kW, then starts increasing. In any case, the CO emissions are lower than 100 ppm. The NO_x slightly increase with P, passing from 9 ppm for P = 2 kW to 20 ppm to 8 kW, that is a value much lower than the NO_x emission value in the traditional systems.
Once identified the optimal operating conditions for a C_3H_8-Air mixture, further experimental campaigns have been performed in CH_4-Air and Biogas-Air mixtures. The same conditions have been reproduced in order to verify the stabilization of the process even for different fuels. Thus, the burner has been performed to value the effect of the mixture equivalence ratio on the process stability and emission parametrically in the nominal thermal power P that was fixed to respectively 4 kW and 6 kW. Figure 2 shows the temperature profiles and CO/NO_x emissions obtained as a function of the equivalence ratio Φ for a thermal load equal to P = 4 kW and P = 6 kW operating with CH_4-Air and Biogas-Air mixtures.
The equivalence ratio Φ was changed from 0.6 to 1. For the case P = 4 kW and even for the case P = 6 kW T_3 is lower than T_1 and T_2 because are in front of the oxidizer inlets (at room temperature). The process is stable in the whole range of the equivalence ratio explored.
In addition, the CO and NO_x emission as a function of Φ for the thermal loads considered, P = 4 kW and P = 6 kW. Emissions reach a minimum value in the range $0.8 < \Phi < 0.9$ when the cyclonic burner has been performed in CH_4.
Then, LUCY burner has been performed with LCV fuels. In particular Biogas (60% CH_4, 40% CO_2) was used as fuel. The temperature profiles obtained as a function of the equivalence ratio Φ for the nominal thermal power equal to P = 4 kW and P = 6 kW have the same trend as the case CH4-Air. CO emissions rapidly drop from $\Phi = 0.7$ (250 ppm), then reach a minimum value in the range $0.85 < \Phi < 0.95$. They increase towards the stoichiometric value. The same trend is registered for the case P = 6 kW, but the minimum range is wider than the case P = 4 kW. CO emissions reach a minimum in the range of equivalence ratio $0.7 < \Phi < 0.9$, where is proximate to 0 ppm. In any case it is worth noting than for both P =

4 kW and P = 6 kW, the NOx emission levels are proximate to 0 ppm for the whole range of the equivalence ratio Φ here considered.

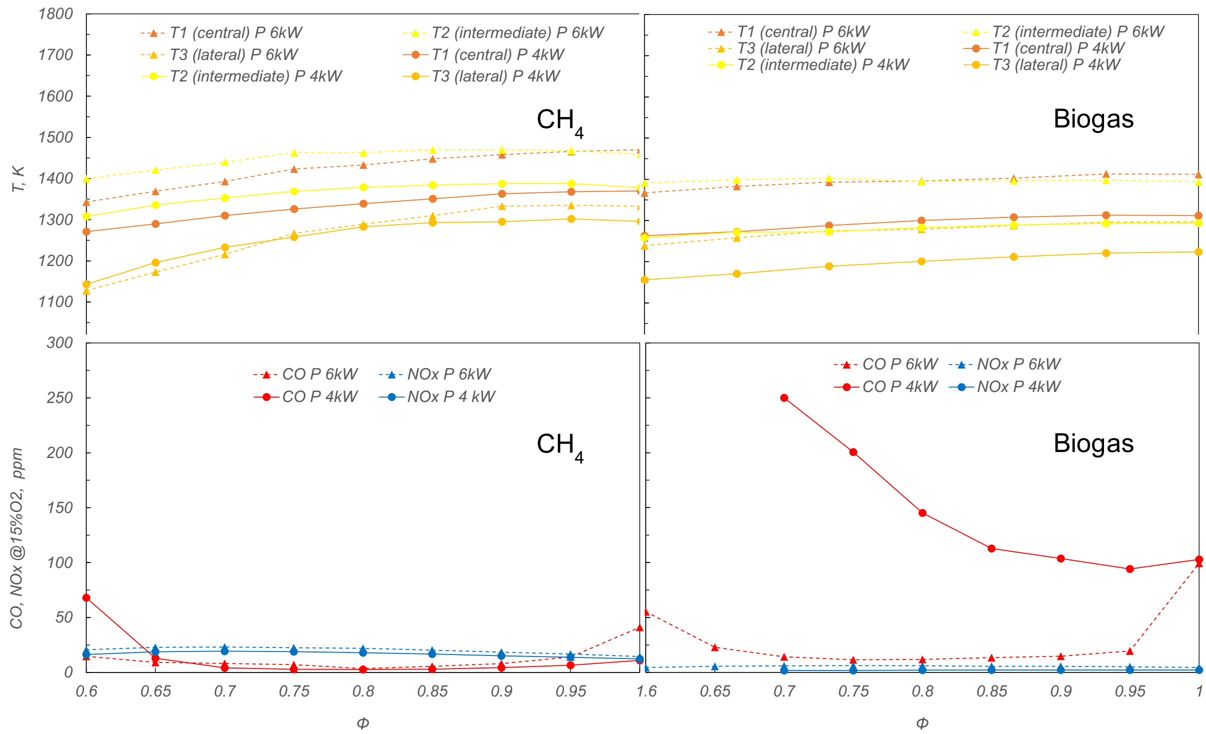

Fig. 2 Temperature measurements in T_1, T_2, T_3, CO and NO_x emissions for CH_4-Air and Biogas-Air mixtures as a function of Φ for different P.

Figure 3 reports CO and NO_x emissions for different thermal power when using CH_4 and Biogas as fuels. In CH_4 case, CO emissions are lower than 10 ppm, while in Biogas decrease from 70 ppm to 40 ppm. NO_x slightly increase with the thermal power in both cases, passing from 10 ppm for P = 2 kW to 25 ppm for 10 kW in CH_4 case, while they are lower than 10 ppm in the whole range of P_{th} explored in the Biogas case.

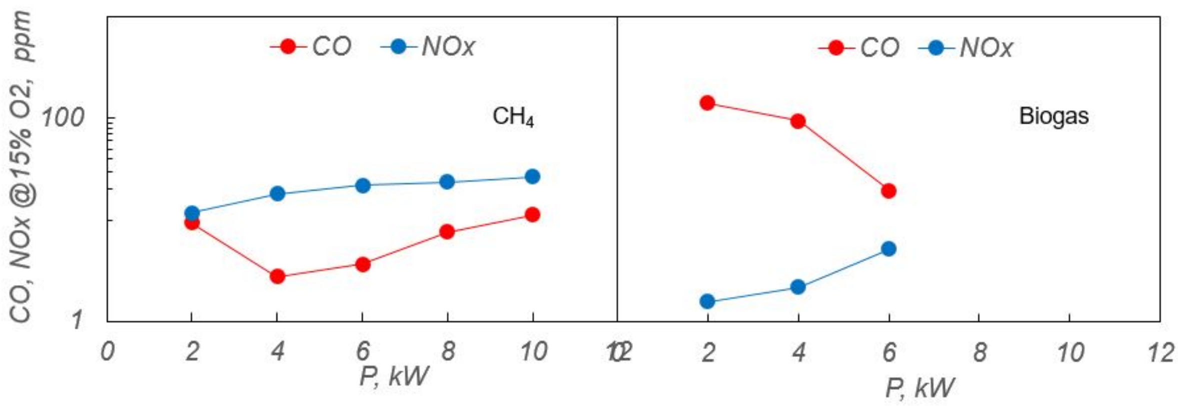

Fig. 3 CO and NO_x emissions for CH_4-Air (Φ = 0.8) and Biogas-Air (Φ = 0.9) mixtures as a function of P.

Conclusions

The work has aimed to verify the performance of a Laboratory Unit CYclonic (LUCY) burner in terms of working temperatures and pollutant emission with respect to mixture equivalence ratio, thermal power operating different fuels.
In particular, experimental campaigns have been performed with C_3H_8-Air, CH_4-Air and Biogas-Air mixtures for different thermal power. The analysis has suggested that mixtures with equivalent ratios in the range $0.7 < \Phi < 0.9$ show the best performance in terms of CO and NO_x emissions. Temperatures higher than 1200 K have to be reached to insure fuel full conversion with limited CO emissions for the considered residence times and system size.
In any case analyzed, NO_x emission were lower than 40 ppm with values lower than 10 ppm when temperatures do not exceed 1300 K.
The experimental tests suggested that the system working temperature should not exceed 1300 K to limit the NO_x emission to single-digit values, whereas CO emissions are limited for temperatures higher than 1200 K. In particular, slightly fuel-lean conditions resulted to be the optimal working point to minimize CO and NO_x, simultaneously independently from the fuel used. It has been showed that it is possible to achieve a complete fuel conversion and low pollutant emissions in a wide range of operative conditions, even for a nominal thermal power up to 10 kW.

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