MILD COMBUSTION OF BIOGAS ON A 30 KW AND 200 KW LAB FURNACES: SCALE EFFECTS AND INFLUENCE OF THE GEOMETRICAL CONFIGURATION

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Introduction

MILD combustion is a very high efficiency combustion technique, successfully applied on industrial furnaces to have very low NOx emissions, stable working conditions and significant energy savings by high air preheating. A specific configuration of air and fuel injectors guarantees a strong recirculation of flue gases inside the chamber, with consequent high dilution of reactants into the flue gases and a temperature increase above the fuel auto-ignition threshold. The formation of hot-spots is significantly prevented: the result is a reduction of NOx and carbon monoxide emissions [1].

This combustion technique is particularly interesting for alternative fuels such as biogas, gasified waste or by-product gases, for which the generation of a stable flame can be difficult due to their highly variable calorific value. MILD combustion avoids the formation of a flame front because fuel and oxidizer are continually mixed with recirculating combustion products and the combustion occurs in homogeneous and extended way once the auto-ignition temperature is reached. Without constraints due to the stability of a flame front, MILD combustion allows larger fuel flexibility compared to conventional burner.

Experimental tests have been performed on a 30 kW and 200 kW laboratory scale chambers, designed to operate in diluted combustion and able to reproduce the main features of industrial furnaces (injection system, geometry, variable load). The 30 kW chamber is equipped with an electrical air preheater able to return the desired air inlet temperature and a simple inject system positioned on the bottom composed by two fuel injectors, 11° tilted from the vertical line, symmetrically disposed in respect with the central air nozzle. The 200 kW semi-industrial furnace on the contrary has an auto-regenerative FLOX REGEMAT® 350 burner [2], positioned on a side of the chamber and usually fed with natural gas (NG). It uses 80% of the extracted flue gases to preheat the combustion air with effectiveness higher than 90%, thanks to 6 ceramic matrixes (3 used to preheat, 3 to get heat).

The 30 kW chamber is fed by gas bottles through an appropriate system of mixing units and mass flow controllers. The 200 kW furnace uses natural gas of the town and CO2 can be added thanks to a dedicated pipeline coming from the 30 kW chamber feeding system. Thermocouples, suction pyrometer, gas analysers, and intensified UV camera have been used to respectively measure wall and recirculation temperatures, flue gases temperature, O2, CH4, CO2, CO, NOx flue gases contents on dry basis, and OH chemiluminescent levels [3] through an optical access. Additional information can be found in literature [4][5].

The test campaign has been focused on the study of the MILD combustion of Biogas on the two mentioned furnaces. The main target is a first comprehension of the scale effects and the influence of the different geometrical aspects related to the chambers.

Operating conditions

For the 30 kW chamber a Biogas given by 60% CH4 and 40% CO2 by vol. has been used. Air has been preheated at 800°C and its flow rate has been set in order to have 15% excess air. A 2.8 mm diameter for fuel injectors (optimal one for CH4, used as reference fuel) has been selected and two different immersions of the load (20-30 cm from the top) have been tested. The 200 kW furnace has been fed with a Biogas given by 60% NG and 40% CO2 by vol. (about 54% CH4, 40.8% CO2, 1.2% N2, 4% other CxHy compounds). Its flow rate has been set to get a 180 kW combustion power, with an excess air of ~25%. Two different immersions of the water cooled tubes (WCT) at 30 and 50 cm have been tested and natural gas has been used as reference fuel.

Main results

Biogas and CH4/NG have similar behaviour in all the performed tests on both the furnaces. The CO2 addition leads to a general temperature reduction of the walls (about -2% on average). More homogeneous conditions are guaranteed inside the chamber thanks to the increased inert gases content and momentum rates of the fuel jets for Biogas cases ~4.5 times than the CH4/NG ones, which determine a general improvement of the recirculation. Moreover, CO2 has an important cooling effect due to its high specific heat, absorbing radiation from the main reaction zone and enhancing the heat distribution throughout the furnace, in agreement with studies of other researchers [6]. The flue gases temperature for the Biogas (in the range 1080-1190°C) as expected has a 4% relative decrease compared to the CH4 one on the 30 kW chamber, on the contrary a ~1% increase has been recorded on the 200 kW furnace. This effect is probably related to the change of the fluid dynamic conditions inside the chamber: the highest

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momentum rates in the Biogas cases determine a more extended reaction zone and recirculation paths; the flue gases can reach higher temperature before the extraction by the burner, thereby the resulting air preheating increases. Indeed, the calculated air temperature from the experimental conditions is 1073°C (+2.7% than NG) and 985°C (+4% than NG) respectively for immersion of the load at 30 and 50 cm.

The performances of the fuels are very close: CH4/NG has higher combustion efficiencies (up to 54% and 60% respectively for the 30 and 200 kW furnaces), but the difference compared to Biogas cases is lower than 5%. Moreover, the 30 kW chamber results more sensitive than the 200 kW one to changes of immersion of the load: the efficiency shows a 16% relative rise switching from 20 to 30 cm, on the contrary the 200 kW has a mean 9% relative increase when the immersion is moved from 30 to 50 cm. Losses are in the 3-4 kW and 36-45 kW ranges respectively for the small and semi-industrial furnace, which correspond on average to ~25% and ~22% of the combustion power. Higher losses on the 30 kW chamber are expected since its input power density is about 3.9 times than the 200 kW furnace one.

OH images (Figure 1), taken by an intensified UV camera, have been used to catch the position of the main reaction zone. On the left averaged images from a sample of 50 depict the lift of the reaction zone for the Biogas to the top of the 30 kW chamber when immersion of WCT is moved from 20 cm to 30 cm. A similar but limited lift is shown by the CH4 too. Biogas is more sensitive to the load than CH4 due to its CO2 content which increases the dilution and cools down the reaction. The position of the main reaction zone close to the top can enhance the heat transfer to the load but there is a risk of unburnt gases at the exhaust, placed near the roof. On the right averaged images from a sample of 120 show the main reaction zone along the 200 kW chamber length. Again there is a downstream shift of the reaction zone, more pronounced for the Biogas than the NG, when the immersion of the load is increased.

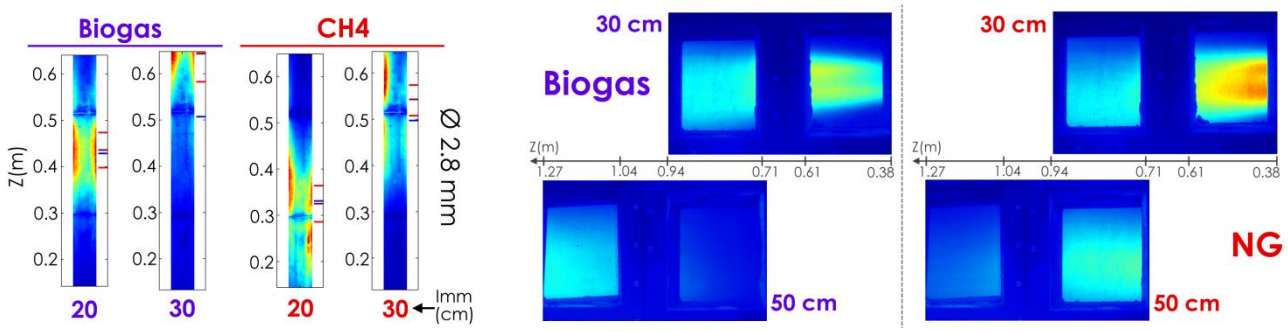

Figure 1: Averaged OH images of tests on the 30 kW (left) and 200 kW (right) furnaces. The Z direction is the distance from the injection system/ burner.

The maximum recorded NOx emission at 3%O2 for all the tests is 38 ppm: the more the load is immersed into the chamber, the more NOx decreases, as a consequence of reduction of temperature and hot-peaks in the furnace. Moreover, a direct comparison between NOx levels measured for the two fuels shows that NOx emissions when Biogas is burnt are always lower than CH4 ones, thanks to the cooling effect of the CO2 on the reaction zone [7] and a better recirculation inside the chambers. The mean CO levels are 35 and 65 ppm respectively for the 30 kW and 200 kW chamber. No remarkable differences on CO emissions between Biogas and CH4/NG cases can be pointed out.

Conclusions

MILD combustion has been successfully used to burn Biogas and CH4/NG in different conditions on a 30 kW and 200 kW furnaces. The cooling and dilution effects of the CO2 introduced by the Biogas on the main reaction zone have been confirmed by temperatures in both cases. On the 200 kW furnace different operating conditions have been found when Biogas was used: a rise of the air preheating has been calculated, resulting in increased flue gases temperature. Thanks to OH images a lift/shift of the main reaction zone has been shown for deeper immersions of the load inside the furnaces. In both the chambers the Biogas performance has been found close to the CH4/NG ones, with a difference in combustion efficiencies lower than 5%.

A decrease of NOx emissions when Biogas was used has been pointed out, as a consequence of more diluted conditions. Maximum recorded levels at 3% O2 have never exceeded the 38 ppm.

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