DILUTED COMBUSTION OF LOW CALORIFIC, ALTERNATIVE FUELS ON A 30 KW FURNACE

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Introduction

Diluted combustion, known as Flameless Oxidation or MILD Combustion too, 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. Diluted 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, diluted combustion allows larger fuel flexibility compared to conventional burner.

Experimental tests have been performed on a 30kW, laboratory scale furnace, designed to operate in diluted combustion and able to reproduce some of the main features of industrial furnaces (injection system, geometry, variable load). An electrical air preheater is used to get the desired air inlet temperature and a mixing unit supplies the desired composition of the fuel from gas bottles. 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 [2] through an optical access.

The furnace was designed to work with natural gas and was deeply tested with this fuel [3]. During test campaign 2013 the behaviour of blends of CH4, CO, H2, CO2, N2 (coke oven gas and its mixtures with blast furnace gas) with lower heating value than natural gas has been investigated and compared in terms of powers balance, combustion efficiency, emissions, shape and position of the reaction zone, and effect of air preheating temperature [6].

Test campaign 2014 is focused on the study of other blends: Biogas and Synthetic gas. The idea is to continue to enrich the database of experimental tests in diluted combustion of low calorific, alternative fuels, to determine their working conditions limits in this specific furnace configuration and to understand the main phenomena and behaviour which are linked to these fuels when they burn in flameless mode.

The effect of the inlet fuel speed by changing the fuel injectors diameter has been investigated in detail for Biogas and pure CH4, selected as reference fuel. Concerning the syngas, only a single test at reduced power (15kW) has been performed to check if this blend is able to burn in mild combustion mode. The test was a success but it is not reported herewith because it requires further investigations.

Comparisons are always realized in terms of temperatures, powers balances, combustion efficiencies, combustion products contents and emissions, and OH images.

Operating conditions

The 30kW combustion chamber has been used to burn in flameless mode biogas (60% CH4, 40% CO2) and pure CH4. For all the tests the air has been preheated at 800°C. Its flow rate has been set in order to have 15% excess air into the furnace with the selected fuel. For each fuel and each injectors diameter (2.8mm and 4.5mm) three different immersions of the load has been tested and stable state has been reached. Moreover, for the biogas tests have been repeated with the optical access closed to reproduce real working condition of industrial furnaces and to evaluate the losses through the quartz window.

Analysis methods and main results

Biogas and CH4 have similar trends in terms of temperatures and combustion efficiencies. As expected, pure methane has always higher wall and flue gases temperatures (respectively +20-25°C and +35-45°C on average). For the Biogas, CO2 leads to a temperature reduction of the furnace walls as an effect of the higher inert gases content inside the chamber. At high temperature CO2 has higher specific heat if compared to N2, thereby it has an important cooling effect, absorbing radiation from the main reaction zone and enhancing the heat distribution throughout the furnace. This is in perfect agreement with studies of other researchers [7].

The performances of the fuels are very close: CH4 has a combustion efficiency on average only +2-3% higher than the one of Biogas. Once again CO2 has an important function: it improves radiation properties and heat capacity of flue gases. As a consequence heat exchange has generally a better performance, and the differences in terms of efficiencies between Biogas and pure methane are reduced [7].

OH images, recorded by the camera and post-processed through a homemade Matlab code, are used to catch the position of the main reaction zone. Fig. 1 shows some results of this analysis. On the left it depicts for the Biogas the lift of the reaction zone to the top of chamber when load immersion is moved from 20 cm to 30 cm. Biogas is more sensitive to the load than CH4 due to its CO2 content which increases the dilution and cools down the reaction. On the right the figure shows for two CH4 cases at the same immersion the effect of the increased momentum rate of the jets due to the reduction of fuel injectors diameter. The asymmetry of two main reaction zones, consequence of the interaction of the two fuel jets with the central air one, is an expected result. This diameter has been chosen for fuels with lower LHV than CH4, which therefore require higher flow rates to satisfy the 30kW inlet power.

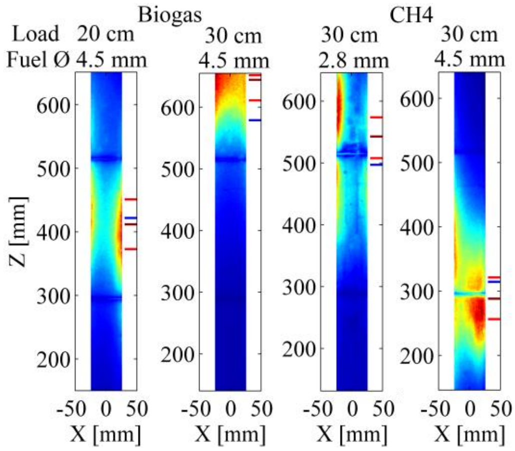

Fig. 1: Some images of mean OH count for Biogas and CH4 at different load and fuel injectors diameter

The study of the images is enhanced with the extraction of the profiles of the maximum OH and their comparison with the wall temperatures profiles. Outlet speeds of the jets are also determined using the experimental values of the upstream chamber conditions and taking into account compressibility effects. Recirculation ratios are estimated using the GrandMaison's theory [10] in order to improve the understanding of the main phenomena.

A sample of flue gases is taken at the exhaust and on dry basis the main species (O2, CO2, CH4, CO, NOx) are measured. NOx emissions are lower than 30ppm: the more the load is immersed into the chamber, the more NOx decreases till values close to the zero, 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 about the half of the CH4 ones, thanks to the cooling effect of the CO2 on the reaction zone [8].

Conclusions

Diluted combustion has been successfully used to burn several low calorific, alternative fuels in different conditions on a 30kW laboratory-scale furnace. In the last test campaign Biogas and CH4 has been tested using two different fuel injectors diameter for three positions of the variable load. The cooling and dilution effect of the CO2 content introduced by the Biogas on the main reaction has been confirmed by temperatures, OH images and NOx levels. Moreover very close combustion efficiencies between the two fuels have been recorded, proving the good performance of the Biogas thanks to higher CO2 concentration of the flue gases, which determines better heat capacity and radiation properties.

NOx emissions decrease according to the temperature reduction (caused by increasing load immersion) from 30ppm in the CH4 case and 15 ppm in the Biogas one till values very close to zero.

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