IN-FURNACE MEASUREMENTS OF MILD COMBUSTION OF A BLEND FROM INDUSTRIAL BY-PRODUCTS ON A 30 KW CHAMBER

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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. Thanks to a specific configuration of air and fuel injectors a strong recirculation of flue gases inside the chamber is guaranteed, 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. Therefore 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, it allows larger fuel flexibility compared to conventional burner.

Experimental tests have been performed on a 30 kW, laboratory scale furnace, designed to operate in MILD 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. The chamber is equipped with an optical access which can be used to take images of the main reactions zones by recording the OH* chemiluminescent emissions [2]. However, in the test campaign (TC2015) discussed here this optical access has been closed to simulate conditions as similar as possible to a real furnace.

The chamber was designed to work with natural gas and was deeply tested with this fuel [3]. The combustion group of the University of Mons has then decided to start to investigate the behaviour of low calorific, alternative fuels in this particular combustion regime, thanks to the increasing interests of the industrial partners and the community. In 2013 a particular blend (B50: 28% N2, 12% CO2, 14.25% CH4, 32.5% H2, 13.25% CO), obtained by mixing 50% of coke oven gas with 50% of blast furnace gas, has been tested: the effect of the air preheating on its MILD combustion has been investigated in terms of powers balances, combustion efficiency, emissions, shape and position of the reaction zones, and temperatures [4].

In 2015 (TC2015) a further important step has been accomplished: the detailed in-furnace measurements of the MILD combustion of this fuel. Making use of gas sampling and temperature probes, a mapping of 154 internal points of the chamber has been carried out. H2, CO, CH4, O2, CO2, NO concentrations of the sampled volumes (on dry basis) and temperatures have been successfully measured respectively by chromatographic, infrared, paramagnetic, chemiluminescent gas analysers and a suction pyrometer.

The knowledge of the temperature and concentration experimental fields on a section of the combustion chamber represents an important goal to help the researchers to understand the real behaviour of the MILD combustion technique and to better validate the performed numerical simulations and the actually used codes for the 30 kW furnace [5].

Operating conditions

The in-furnace measurement process has required 8 test days. The 30 kW chamber has been completely checked before the campaign and prepared to be used with probes: 14 levels (from 0.10 to 0.62 m) have been settled along the Z height of the furnace on X-Z plane at Y = 0 m, where the 2 fuel injectors and central air nozzle are positioned. On this plane, in the X direction, 11 points (from -0.15 to 0.15 m) have been selected as reference positions for the probe immersion. The resulting 154 mapped points cover 3 main zones of the MILD combustion of B50: the one of the jets and their interaction/mixing, the main reaction zones, and the recirculation zones.

In all tests the general setup has been kept as similar as possible: air has been preheated at 800°C and its flow rate has been set in order to have 15% excess air into the furnace with a B50 flow rate able to guarantee 30 kW combustion power; the B50 flow rate has been prepared and guaranteed by gas bottle and a homemade mixing system coupled with several mass

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flow controllers; the immersion of the water cooled tubes which simulates the presence of a load inside the chamber has been kept at 35 cm, in agreement with previous MILD combustion tests of this fuel performed in 2013 [4].

Main results

The post-processing required to analyse all data has not been straightforward. Algorithms have been developed in order to collect all data from gas analysers and acquisition card (676 samples), and to sort, correct and show them in a proper way. Figure 1 depicts an example of H2 concentration field during the B50 MILD combustion. It has been obtained by the means of two samples taken one after the other using the gas sampling probe and the chromatograph gas analyser. Figure shows a decrease of H2 concentrations along the chamber height from a peak of ~16% to values close to zero. The two H2 streams come from the two fuel injectors, 11° tilted from the vertical line and symmetrically positioned in respect with the central air nozzle. The main reaction zones determined on the interaction lines of fuel/air jets partially mixed with the flue gases are extended from 0.25 m to 0.5 m, in agreement with the OH* chemiluminescent emissions recorded during TC2013 [4].

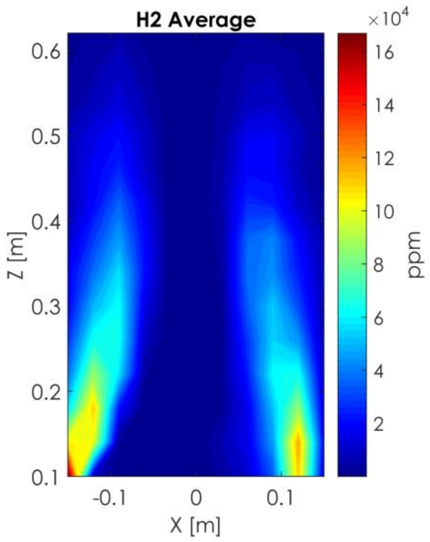

Figure 1: H2 concentration field

Measured temperatures on the mapped field are in the range ~825°C to ~1125°C (~975°C to ~1100°C if the smallest window of the main reaction zones is considered), confirming the typical characteristic of the MILD combustion to prevent hot-peaks. NO measured levels do not exceed the 7 ppm and CO concentrations reduce from ~6% to ~5000 ppm in the mapped range as the reaction occurs. At the exhaust CO drops at expected levels in the range 25 to 40 ppm, whereas NO concentrations are stable at 6÷8 ppm.

All mapped fields show asymmetries. Several sources which may have caused this behavior have been and still are under investigation. The non-perfect tilt angle of fuel injectors, the uncertainty on the probe position, the fluid dynamic behavior around the intrusive probe, and the lack of accuracy of some measurements are the main issues on which the researchers are working. For instance, a first analysis of uncertainty on the concentrations of the sampled volumes measured by the chromatograph system points out that the relative differences between two different samples increase on the fuel/air jets interaction zones and as the main reactions occur.

Conclusions

The MILD combustion of a low calorific fuel obtained by mixing coke oven gas and blast furnace gas has been successfully investigated in 8 separated tests, keeping constant the air preheating at 800°C, the fuel flow rate to get a 30 kW combustion power, the air flow rate to guarantee a 15% excess air and the immersion of the load at 35 cm. The main target of this campaign was the mapping of H2, O2, CO2, CH4, CO, NO concentrations and the temperatures on the plane where air/fuel injectors are positioned, making use of a gas sampling and a temperature probe. 154 points in a range of 0.52 m in height and 0.3 m in length around the main reaction zones have been measured following a very tight and reliable schedule in order to minimize the fuel wastefulness and to get the highest accuracy on the measurements.

Data show concentrations and temperatures distributions coherent with the jets and the expected behaviour of the MILD combustion. Nevertheless, some asymmetries are present but the reasons why they appear are still under investigation.

The determined concentration maps confirm one important feature observed in 2013 by OH* chemiluminescent images: even if this blend has a lower heating value equal to the 29% of the CH4 one, the H2 content guarantees a correct position of the main reaction zones inside the chamber (1 m high), demonstrating the well-known ability of H2 to reduce ignition delays [5].

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References

[1] J. A. Wünning and J. G. Wünning, Progress in Energy and Combustion Science 23 (1997) 81-94

[2] A. Gambale, D. Lupant, P. Lybaert, Turbulence, Heat and Mass Transfer 7 (2012)

[3] A. Gambale, D. Lupant, B. Pesenti, P. Lybaert, 11th ICCEU, 2012

[4] G. Mosca, D. Lupant, A. Gambale and P. Lybaert, INFUB10 (2015), Porto

[5] D. Lupant, P. Lybaert, Applied Thermal Engineering 75 (2015) 93-102

[6] A. Parente, C. Galletti, L. Tognotti, Int. Journal of Hydrogen Energy 33 (2008) 7553-7564