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Publication date
2017

Document Version
Final published version

Citation (APA)
Huang, X., Tummers, M., & Roekaerts, D. (2017). *Flamelesss combustion characteristics in a lab-scale furnace*. Abstract from Combura 2017, Soesterberg, Netherlands.

October 11 & 12

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Flamelesss combustion characteristics in a lab-scale furnace

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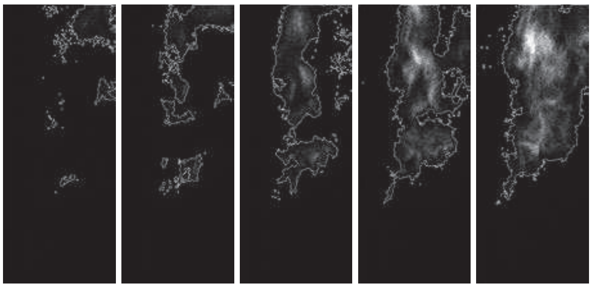
Flameless combustion, named as Moderate or Intense Low-oxygen Dilution (MILD) combustion or high-temperature air combustion (HiTAC), is a promising technology to improve the thermal efficiency while suppressing NOx formation in combustion systems. Flameless combustion can occur when fresh air (and/or fuel) streams are sufficiently diluted by entrained combustion products before reactions take place. It has recently been experimentally studied on laboratory-scale setups because of scientific challenges, environmental concerns and its potential industrial applications.

Some burning features in flameless combustion have been observed in jet-in-hot-coflow burners which use hot coflows generated by a secondary burner or diluting air with N_2 or/and CO_2 to mimic the diluted air which is actually diluted by burnt gases entrainment in furnaces. With the help of high-speed cameras, the time-resolved studies on such burners have been done experimentally. E. Oldenhof et al. [1] reported that the jet-in-hot-coflow flame is stabilized by autoignition kernels and the entrainment of hot oxidizer plays an important role in the formation of autoignition kernels[2]. As O_2 level in coflow is reduced, reaction zone becomes less intense leading to a greater degree of partial premixing in these flames[3]. P. R. Medwell et al.[4] also concluded that large-scale vortices can lead to a weakening of the flame front or even local extinction leading to a form of partial premixing, and may contribute to the stabilization of the flameless combustion reaction zone. With low level (5% by volume) hydrogen addition in the fuel, the flame also exhibits autoignition kernels, but this was not observed at higher level (10% and 25%) hydrogen addition cases[5]. However, how can these findings be related to the flames in a furnace is still unclear because of the lack of similar experimental observations in furnace.

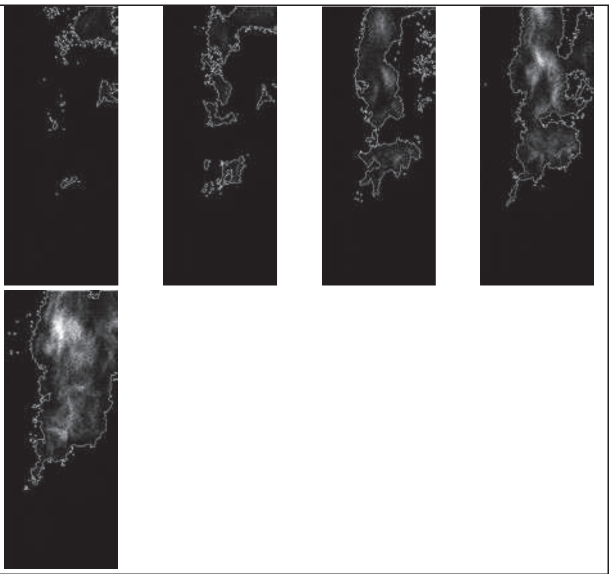
To simplify the complexity in industrial or semi-industrial scale furnaces, lab-scale furnaces are easier to do detailed measurements and also less computationally expensive for numerical simulations. There are several past and undergoing investigations on lab-scale furnaces. However, most of them are about the effects of operational conditions on performance of flameless combustion, such as jet velocity, equivalence ratio, air preheating temperature, burner configuration and so on. The flame behaviours are seldom reported. In view of these results, the aim of work is especially focusing on the ignition and flame stabilization behaviour in a new lab-scale flameless furnace. Compared to the observations in jet-in-hot-coflow flames, how the ignition happens and how the flames stabilize in the furnace are still unclear. To obtain more insights on flameless combustion and extend the operating range, ignition and flame stabilization behaviour in flameless regime need to be studied. In this study, we report on results of flame behaviour in the furnace.

In this work, OH* chemiluminescence is used to determine burning characteristics in flameless regime. The OH* chemiluminescence was recorded by using an intensified high-speed camera. Time averaged and time resolved images were taken and processed to determine the burning behaviour. The furnace was working at 9 and 10 kW, with equivalence ratio 0.7, 0.8 and 0.9. As equivalence ratio increases, the reaction zone progressively moves further downstream. This shift of main reaction zone is due to the decrease in air jets momentum when increasing equivalence ratio, which slows down the entrainment of burnt gases into fresh jets resulting in slow preheating. When decreasing equivalence ratio, air jets momentum is increased and more hot burnt gases are entrained into fresh jets, therefore, fuel and air are preheated faster leading to earlier ignition and main reaction zone shifts upstream. The mean OH* chemiluminescence intensity (indicating the reaction intensity) decreases at the same time due to better dilution from stronger entrainment of burnt gases. With the intensified high speed camera, the ignition characteristics were studied. Three types of autoignition behaviour were observed in the current MILD furnace. One is individual autoignition kernel which appears, grows and soon be blown downstream, as shown in figure 1. This kind of ignition kernel was observed disappearing downstream and did not lead to intense reactions near the local region. As increasing the height, the individual ignition kernels become less. Fuel and air become hotter resulting in the second type of ignition behaviour, that is, multiple ignition kernels, as shown in figure 2. In this type of ignition, multiple ignition kernels appear at the same time in a region. All of them grow faster than individual kernels and merge with each other leading to a local intense reaction zone. The third ignition behaviour is ignition kernel cluster, as shown in figure 3. This is a very intense ignition process observed in the current furnace. Autoignition kernels are continuously formed and move downstream and merge with the upper flame base becoming a large intense reaction zone is formed in figure 3(e).



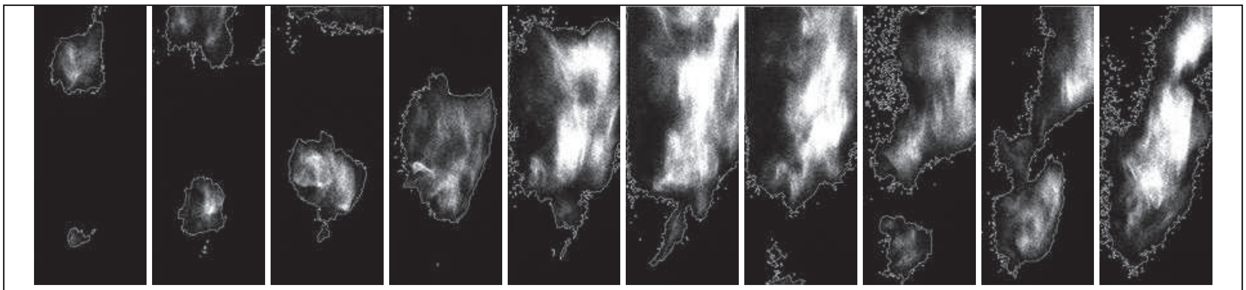
a) (b) (c) (d) (e)

Figure 1 Sequential images show individual autoignition kernel development during one ignition event. Time interval between above images is 2 milliseconds.



(a) (b) (c) (d) (e)

Figure 2 Sequential images shows multiple autoignition kernel formation and development during ignition process. Time interval between above images is 1 milliseconds.



(a) (b) (c) (d) (e) (f) (g) (h) (i) (j)

Figure 3 Sequential images show ignition kernel cluster formation and development during ignition process. Time interval between above images is 2 milliseconds.

Reference

[1] E. Oldenhof, M.J. Tummers, E.H. van Veen, D.J.E.M. Roekaerts, Ignition kernel formation and lift-off behaviour of jet-in-hot-coflow flames, Combustion and Flame 157 (2010) 1167-1178.

[2] E. Oldenhof, M.J. Tummers, E.H. van Veen, D.J.E.M. Roekaerts, Role of entrainment in the stabilisation of jet-in-hot-coflow flames, Combustion and Flame 158 (2011) 1553-1563.

[3] P.R. Medwell, P.A.M. Kalt, B.B. Dally, Simultaneous imaging of OH, formaldehyde, and temperature of turbulent nonpremixed jet flames in a heated and diluted coflow, Combustion and Flame 148 (2007) 48-61.

[4] P.R. Medwell, P.A.M. Kalt, B.B. Dally, Reaction Zone Weakening Effects under Hot and Diluted Oxidant Stream Conditions, Combustion Science and Technology 181 (2009) 937-953.

[5] L.D. Arteaga Mendez, M.J. Tummers, E.H. van Veen, D.J.E.M. Roekaerts, Effect of hydrogen addition on the structure of natural-gas jet-in-hot-coflow flames, Proceedings of the Combustion Institute 35 (2015) 3557-3564.