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Analysis of a 20 kW flameless furnace fired with natural gas

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Abstract

An experimental and computational investigation of a MILD industrial burner, fed with natural gas, is presented. The experimental tests are performed at a constant inlet excess air of 17%, two power levels and two different furnace temperatures. Comparisons are presented in terms of energy balance, thermocouples measurements, OH* self-emission images, and NO_x/CO content. After a first validation based on the global energy balance, different combustion models, i.e. EDM, ED/FR and EDC are tested. Finally, the comparisons between the predicted and measured NO emissions indicates a good quantitative agreement adopting a simple NO formation mechanism based on the thermal, prompt, N_2O and NNH routes.

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1. Introduction

Over the last twenty years, moderate or intense low oxygen dilution (MILD) combustion, also known as flameless combustion, has attracted increasing attention because of its capability of enhancing thermal efficiency as well as reducing NO_x emissions [1]. The technology needs the reactants to be preheated above their self-ignition

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temperature and enough inert combustion products to be entrained in the reaction region, in order to dilute both reactants and flame. The system is characterized by a more uniform temperature field than in traditional non-premixed combustion, and by the absence of high temperature peaks, thus suppressing NO formation [1,2] through the thermal mechanism, while ensuring complete combustion and low CO emissions [3].

Recently it has also been suggested for oxy-fuel combustion, a technology able to provide a step-wise reduction of greenhouse gases emissions through the CO_2 capture and storage (CCS). However, what makes such technology very attractive is the large fuel flexibility, being suited for, industrial wastes, biogas [4,5] and low-BTU fuels [6]. These non-conventional fuels are blends of CH_4, CO, H_2, N_2 and CO_2 in variable proportions. In normal non-premixed flame, the generation of a stable flame can be difficult in presence of highly fluctuating compositions and low CH_4/H_2 contents. Flameless combustion can be a solution, since there is no need to stabilize a flame front, which can turn out to be complicated when the LHV of the burnt fuels is subjected to wide variation.

Achieving maximal heat recuperation efficiency is one of the main reasons of interest in flameless combustion. However, these results are possible only in combination with regenerative exchanger or self-recuperative burners. More frequently, industrial communities are interested in using flameless combustion with limited air preheating temperature, especially if the use of regenerative systems is not possible as retrofit process of existing plants [2].

The research is focused on the experimental and numerical analysis of a 20 kW flameless furnace fired with natural gas. Comparisons are carried out in terms of powers and efficiencies of the system, wall, flue gases and furnace temperatures, measures of flue gases content on dry basis (CO, NO_x, O_2, CO_2), and OH* images of the reaction zone.

Nomenclature

$\dot{m}$	mass flow rate	[kg/s]
$\dot{Q}$	Flow rate	[Nm^3/h]
k_R	recirculation degree	[-]
OD	outlet diameter	[mm]
A	area	[m^2]
T	temperature	[K]
Re	Reynolds number	[-]
Da	Damkölher number	[-]
C_τ	EDC time scale constant	[-]
C_γ	EDC volume fraction constant	[-]
P	Power	[kW]
I	Chemiluminescent emissions	[Counts]

Subscript

fg	flue gases
f	fuel
a	air
N	nozzle
C	chamber
f	furnace
c	cooling
w	walls
b	bias
s	statistical