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CFD study on influence of fuel temperature on NOx emission in a HiTAC furnace☆

Abbas Khoshhal [a], Masoud Rahimi [a,*], Ammar Abdulaziz Alsairafi [b]

[a] CFD Research Center, Chemical Engineering Department, Razi University, Kermanshah, Iran
[b] Faculty of Mechanical Engineering, College of Engineering and Petroleum, Kuwait University, Kuwait

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ABSTRACT

The influence of the fuel temperature on NOx formation was investigated numerically. For this purpose CFD modeling of NOx emission in an experimental furnace equipped with high temperature air combustion (HiTAC) system was studied. The comparison between the predicted results and measured values have shown good agreement, which implies that the adopted combustion and NOx formation models are suitable for predicting the characteristics of the flow, combustion, heat transfer, and NOx emissions in the HiTAC chamber. Moreover the predicted results show that increase of the fuel temperature results in a higher fluid velocity, better fuel jet mixing with the combustion air, smaller flame and lower NOx emission.

1. Introduction

In a world increasingly concerned with sustainability and the environment, energy efficiency improvements are indispensable. Improving energy efficiency is often the most cost-effective way to reduce pollution emissions in the industrial combustion systems. In this framework, high temperature air combustion (HiTAC) technology, developed by Tanaka and Hasegawa [1], can play a significant role in the mitigation of combustion-generated pollutants, whilst meeting thermal efficiency needs. The HiTAC technology, also called moderate and intense low oxygen dilution (MILD) combustion [2], or flameless oxidation (FLOX) [3]. HTAC processes try to control the pollutants formation, in particular NOx emissions, in combustion applications reducing the residence time of gases in high temperature regions of the burner, or avoiding high oxygen concentration in these regions. In the HiTAC technology, fuel is mixed with a highly diluted and heated air to create a distributed reaction zone with a reduced peak temperature. These flames have attractive features such as a uniform temperature field, yielding better product quality, higher radiation flux, and low emission of NOx.

The published experimental works on HiTAC flame properties come from studies focusing on small laboratory-scale furnaces featuring a single-gas-jet combustion in high temperature preheated and oxygen deficient air [4–7]. For example, the influence of fuel-jet dilution on combustion stability and flame structure was investigated by Prasad et al. [8]. The results obtained with low temperature air and coaxial fuel jets, which were highly diluted by nitrogen, showed increased flame liftoff distances.

Although the concept of HiTAC technology has been extensively studied, mathematical modeling of this regime has received little attention. The numerical modeling of the HiTAC technology and combustion process is a three-dimensional problem that involves turbulence, combustion, and radiation in addition to NOx modeling. Due to progress in computer hardware and software and the increase of the calculation speed, the computational fluid dynamics (CFD) modeling technique is a powerful and effective tool for understanding the complex hydrodynamics in many processes. The CFD models are founded on fundamental physical principles, and can thus predict fluid flow and heat transfer within the combustion chamber and under specific operational conditions. Moreover, submodels such as combustion, turbulence, and NOx formation can be employed for the modeling of combustion chambers [9–13]. The CFD modeling of NOx emission, HiTAC, and heat transfer in an industrial boiler was numerically studied by Khoshhal et al. [14]. The comparison between the measured values and the CFD predicted results showed good agreement, which implied that the adopted combustion and NOx formation models are suitable for correctly predicting characteristics of the HRSG boiler.

NOx formation during the combustion process is formed mainly by the oxidation of nitrogen in the combustion air (thermal NOx), by oxidation of nitrogen with the fuel (prompt NOx), and from molecular nitrogen (N_2) via N_2O (N_2O-intermediate mechanism). The research in the literature showed that NOx emission formed by a N_2O-intermediate mechanism is the main one during the HiTAC, and about 90% of the NOx formed in this condition is based on this mechanism [15,16].

NOx formation during the HiTAC conditions is very complicated, and is affected by physical and chemical phenomena such as flow, mean heat and mass transfers, mixing processes, and chemical reactions. Integrated information relating such complex phenomena to NOx formation are difficult to obtain experimentally. Therefore, it is necessary to conduct an advanced numerical study combined with experiments to obtain

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* Corresponding author at: Chemical Engineering Department, Razi University, Taghe Bostan, Kermanshah, Iran.
E-mail address: masoudrahimi@yahoo.com (M. Rahimi).

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