Experimental and Numerical Investigation of a Parallel Jet MILD Combustion Burner System in a Laboratory-scale Furnace

by

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Abstract

In a world increasingly concerned with fuel prices, sustainability and the environment, energy efficiency improvements are indispensable. In this framework, Moderate or Intense Low-oxygen Dilution (MILD) combustion technology can play a significant role in the mitigation of combustion-generated pollutants and greenhouse gases, whilst meeting thermal efficiency needs. Under MILD conditions, reactants are highly diluted with combustion products causing reactions to occur in a distributed reaction zone with a reduced peak temperature. As a consequence, the temperature distribution is nearly uniform, and pollutant emissions, nitrogen oxides (NO_x) in particular, are lower than from conventional flames.

Over the past few decades, MILD combustion technology has been implemented at full scale in various industrial sectors and tested at pilot scale in other applications. Nevertheless, despite considerable industrial success, many important issues of MILD combustion remain unresolved. The current research seeks to characterise the MILD regime in a furnace environment burning gaseous fuels through a combined experimental and numerical modelling approach.

This study describes the performance and stability characteristics of a parallel jet MILD combustion burner system in a laboratory-scale furnace, in which the reactants and exhaust ports are all mounted on the same wall. In-furnace temperatures and global emissions are measured, respectively with fine-wire thermocouples and a gas analyser, for a wide range of operating conditions. In addition, velocities for selected cases are measured using laser Doppler anemometry (LDA). The detailed experimental data set is then used to validate a computational fluid dynamics (CFD) model. In combination, the experimental and numerical data reveal details of the passive and reactive scalar fields, and enable not only the investigation of the parameters that influence their structure and pollutant formation, but also insight into the contribution of flue gas recirculation to flame stability under MILD conditions.

The present furnace/burner configuration proved to operate without the need for external air preheating, and achieved a high degree of temperature uniformity. The analysis of the furnace aerodynamics and qualitative observations of the burner exit region revealed that effective mixing is essential in order to increase dilution before reaction to ensure stability of this multiple jet system. Unlike in previous investigations, the fuel jet momentum is found to control the stability of this multiple jet system. The CO formation is found to be related to the mixing patterns and furnace temperature rather than reaction quenching by the heat exchanger.

It is found that, although heat extraction, air preheat, excess air, firing rate, dilution, and fuel type all affect NO_x emissions, they do not control NO_x scaling. The combined effects of these global parameters can be ultimately characterized by a furnace temperature and a global residence time. The quantitative analysis of NO_x emissions demonstrated the nondominant role of the thermal-NO pathway in the present MILD combustion conditions. It has been revealed that the N_2O-intermediate pathway is the dominant NO_x formation mechanism, while the prompt-NO mechanism is negligible. There is potential for NO reburning for this parallel jet burner configuration.

Despite the complexity of the recirculating flow inside the furnace, the CFD model agrees reasonably well with the experimental data. It is noted from the CFD analysis that finite-rate chemistry must be included for accurate predictions of MILD combustion conditions.

The fundamental aspects revealed by this study provide unique advancements in the understanding of MILD combustion that will assist in the effort to extend this technology to other heat and power systems.

Contents

List of Figures

List of Tables