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Abstract

Title	Realization of a Low-NOx Combustion System using a Small Cylindrical Furnace

(800 words)

The several detrimental impacts of nitrogen oxides (NOx) on the environment and human health have led to the designing of an effective combustion system with minimum emissions. Among the several combustion techniques that have been proposed to reduce the NOx emission, burnt gas recirculation (BGR) combustion has attracted a great deal of attention because of its unique ability to increase thermal efficiency, whereas simultaneously resulting in ultra-low NOx emission. These features make BGR combustion an exceptional combustion technique because most other NOx reduction methods reduce the thermal efficiency. In BGR combustion systems, a high degree of preheating of the reactants is coupled with a high degree of dilution by the burnt gases, such as CO_2, H_2O, and N_2. The higher specific heat capacities of the burnt gases lead to a decrease in flame temperature and consequently, NOx emission. However, an intense dilution of reactants in the BGR combustion system may cause flame instabilities, such as flame extinction or flame blow-out, because of the low availability of an oxidizer or fuel. Such instabilities should be avoided by supplying a great deal of enthalpy externally. Among the several BGR combustion configurations in previous studies, two of them seem to be widely used. The first method is characterized by a central jet of fuel, and a number of air jets, which are located circumferentially around the central fuel jet, supplying the preheated-diluted combustion air. In this configuration, the air jets entrain large quantities of the recirculated burnt gases, before mixing with the fuel jet. However, the starting procedure of this burner configuration has become much complex. In order to achieve the stable flame, initially, turbulent premixed flames are used through the air-jet nozzles, and then, the furnace is heated up, and consequently, it makes the preheated-combustion air to maintain stable flameless combustion. In the second method, the combustion air is provided by a central high-momentum air jet, and that is surrounded by a number of low-momentum fuel jets. These weak fuel jets are injected into recirculated burnt gases, and consequently, the fuel is diluted before it mixes with the combustion air. However, in this configuration, overall furnace efficiency may go down because fuel jets are not surrounded by air-streams, and hence, un-burnt fuel particles may be contained in the exhaust gases. Consequently, the designing of a simple burner configuration, which can achieve a low-NOx combustion system, is still increasingly important objective.

In the meantime, a comprehensive experimental investigation of EINOx characteristics, which gives NOx emission in terms of the emission index, of turbulent non-premixed flames in Pyrex-glass cylindrical furnaces was conducted by Noda et al., and showed that the EINOx significantly decreases by the increasing in the inner diameter of the furnace (D), air inlet velocity difference, (ΔU_a), and global equivalence ratio, (ϕ). This decrease in the EINOx may be related to the dilution of combustion mixture by burnt gases and flame stretch. The EINOx of confined non-premixed flame was scaled by the parameter $DU_F\Delta U_a$, which is proportional to $Re_{,c}\ Da^{-1}$, and the increase in the parameter, $DU_F\Delta U_a$, leads to linear reduction of EINOx. Here, U_F is the fuel velocity, $Re_{,c}$ is the furnace Reynolds number, which reflects the turbulence in the furnace, and Da is the Damkohler number, which represents the flame stretch through the air velocity difference.

In this study, it is found that the radiation effect on EINOx is small and almost constant with respect to above three parameters in confined flames by comparison of EINOx emissions in Pyrex glass and insulated-stainless steel furnaces.

In confined jet flames, an inadequate supply of surrounding fluids induces the formation of the recirculation structure between the jet and furnace wall. Confined jet flows undergo the entrainment of recirculated fluid at jet boundaries. The recirculation transports high-temperature burnt gases upstream, and induces a mixing process that is related to flame stabilization and dilution. Consequently, a small cylindrical furnace, which is proposed to place in a large industrial furnace room, paves the way to combine the dilution and pre-heating phenomena because of the self-recirculation characteristics. Therefore, the enhancement of the self-dilution in confined flames should lead to the peak temperature reduction in the furnace, and thereby, considerable NOx abatement.

Hence, this study describes a numerical evaluation to characterize the effect of self-dilution in confined flames, in terms of the furnace geometry, the global equivalence ratio, and the air velocity difference, on NOx emission properties. In this study, the total flame dilution quantitatively evaluated through the integration of local dilution factors along the axial direction. The local dilution factor is defined as the burnt and inert gases mass quantity entrained into the flame at each axial cross section with respect to total jet zone mass flow rate. The study found that the increase in inner diameter increases the flame dilution, and the enhancement of the self-dilution in confined combustion system lead to the peak temperature reduction in the flame, and thereby considerable thermal NOx-abatement. The EINOx characteristics of confined flames exhibit a liner reduction with the increase in flame self-dilution.

In a confined combustion system, two main exemplificative asymptotic conditions can be considered. In the first case; air, which issued from the annular nozzles, starts to mix with the high-temperature burnt gas, including residual oxygen, which is transported upstream in the furnace, and this yields hot diluted oxidant, which mixes and reacts with the fuel issued from the central nozzle at the room temperature. In the second case; both the fuel and the air can mix with the high-temperature burnt gases, including residual oxygen, because of strong turbulence, and this yields hot diluted fuel/oxidant stream. Consequently, in confined flame, the internal recirculation should generate the variable composition fuel and air streams along the axial direction. Thus, in this study, the confined flame-structures, in terms of the axial distance, in the mixture fraction domain, are examined using a counter diffusion configuration to emphasis the effect of self-dilution on NOx abatement.

Eventually, this study heads to present a low-NOx combustion system in a small cylindrical furnace, and to provide a better alternative for the BGR combustion systems.