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Experimental study of the fuel jet combustion in high temperature and low oxygen content exhaust gases

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Abstract

The performance of high temperature air combustion (HiTAC) depends on the heat regenerator efficiency and on the way fuel is mixed with furnace gases. In this work, combustion of a single fuel jet of gasol (>95% of propane) was investigated experimentally. Experiments were carried out in steady-state conditions using a single jet flame furnace. The jet of fuel was co-axially injected into high temperature exhaust gases generated by means of a gas burner also fired with gasol. Thus, instead of highly preheated and oxygen depleted air, which was normally used by other researches for such studies, this work has used high temperature and low oxygen content exhaust gases as the oxidiser. A water-cooled fuel nozzle was used to control fuel inlet temperature. Influence of the oxygen content in the oxidiser, at temperatures of 860–890 °C, on the flame visibility and the reactants composition was investigated. The combustion of gasol in hot flue gases appeared to be very stable and complete even at very low oxygen concentration. The oxygen concentration in the oxidiser was found to have a substantial effect on flame size, luminosity, colour, visibility and lift-off distance. Reduced oxygen concentration increases the flame size and lift-off distance, and decreases luminosity and visibility. The HiTAC flame first became bluish and then non-visible at sufficiently low concentration of oxygen in the oxidiser. In this work, results are presented for the constant ratio between fuel jet velocity and velocity of co-flowing flue gases. This ratio was equal to 26.

1. Introduction

The interaction between the fuel jet and the hot furnace gases during high temperature air combustion (HiTAC) determine combustion stability, combustion efficiency and pollutant emission. For this reason, combustion of a single fuel jet was investigated experimentally in

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conditions that are typical for HiTAC, that is low oxygen content and a temperature level above the fuel auto-ignition temperature. However, in an HiTAC furnace, both the air and the fuel injection points are switched from one burner of the regenerative system to the other. The time for fuel and air injection is sometimes as short as 10–30 sec. This means that only during this time can the fuel jet be observed and measured. Additionally, since the temperature of the preheated air slightly decreases during combustion, the fuel jet is developing in a non-steady-state environment. Thus, it is very difficult to perform observations and measurements particularly as the flame also fluctuates. The experiments presented in this work were performed in steady-state conditions to allow time-averaged observations and measurements.

2. High temperature air combustion of single gas fuel jet—literature review

Under leadership of the late Tanaka [1], a very successful research and development program on HiTAC was undertaken in Japan. Although HiTAC is already applied commercially in different types of furnaces as reported by Yasuda et al. [2], fundamental research is still needed on this combustion method. The very positive experiences that were reported from Japan led to new ideas on HiTAC applications, such as waste gasification, gas turbines or steam reformers.

The properties of a single gas jet flame during combustion in a preheated mixture of air and inert gas were the subject of experimental and numerical studies from the beginning. The experimental studies of a single gas fuel jet were the basis for discovering and measuring unique features of the gas fuel jet flame during HiTAC.

Some of the phenomena, for example very low NO_x emissions, flat temperature profile of flame, low luminosity, green colour of propane flame, higher flame stability and large volume of flame were reported by Hasegawa et al. [3,4]. In these works, the preheated air was diluted with carbon dioxide or nitrogen gas. Much higher levels of NO_x were obtained with N_2 as the dilution gas as compared to CO_2 at any degree of air preheats. The authors stress that use of natural products of combustion can be more effective in controlling NO_x. Gupta et al. [5] observed a significantly different structure of the propane flame than that of methane at HiTAC, in this case the preheated air was also diluted with inert gas.

Many researchers have also investigated the lift-off mechanism of a single flame. This has been performed in a flow of preheated air mixed with inert gas in order to obtain a correct level of oxygen. These investigations cover different flow configurations but mostly co-axial flow of air and fuel were studied. The flame size, the visibility, the colour and the lift-off distance were investigated. However, the fuel jet combustion in a main flow created by hot flue gases was not looked into.

Kishimoto et al. [6] reported a large ignition delay of natural gas flames as well as lift-off flame due to combustion air dilution with nitrogen. The authors also measured the reduction of the flame lift-off height with higher temperature of preheated air. Bolz and Gupta [7] and Gupta et al. [8] also noted a decrease of the flame standoff distance (ignition delay) from the nozzle exit with an increase in the air preheat temperature. Gupta [9] also observed that the ignition delay was smaller for methane than for propane flames. Kitagawa et al. [10] noted that the flame fluctuations were reduced with the use of high temperature air. A similar conclusion was presented by Konishi et al. [11]. In all the above-mentioned works, preheated air diluted with inert gas