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Flame Structure Characteristics of Diffusion Flame in Low Calorific Value Coal Syngas by Using Regression Analysis

Byung-Chul Choi and Hyung-Taek Kim
Department of Energy Studies, Ajou University

1. INTRODUCTION

According to recent energy consumption trends in Korea, the demand for electric power generation by gaseous fuel will be further increased in the future. However, with the finite outlook of natural gas resource, electricity generation utilities have to largely depend upon coal-derived syngas from IGCC (integrated gasification combined cycle) system since it ensures cost-effective and environmentally sound options for supplying future power generation needs. In IGCC system, coal is gasified inside high-temperature, high-pressure gasifier with oxygen and steam, then produced gas is transferred into gas cleaning unit, where fly ash and noxious gaseous products, such as H_2S and NH_3 are removed from the gas stream. Cleaned gas is burned at the gas turbine combustor with pressurized air, and then exhaust gas is transported to gas turbine to generate electricity. Cooled gas can be further utilized in the steam turbine with exhaust heat recovery boiler. For the performance improvement of IGCC power system, gas turbine combustor should be developed to satisfy the stability with various input combustion condition. Turbulent non-premixed flames are widely utilized in the practical combustion systems, principally because of the ease with which such flames can be controlled. Turbulent jet flames are usually characterized by flame luminosity and flame length according to their combustion parameters such as fuel types, amount of swirl and input jet velocity. The shape of the flame represents visual image of brushy or fuzzy edges. However, the non-premixing usually increases the flame luminosity since some soot usually presents within the flame. Flame stability in the fuel-lean condition is important issue in these days since this condition produce temperature high enough to utilize for gas turbine as well as save the amount of the fuel used.

The coal-derived gas produced from the O_2 blown, entrained-type coal gasifier has a calorific value as low as 1/5 of natural gas, so that its combustion behavior is different from that of natural gas. The most important parameter of gas turbine combustor operation is to maintain stable flame with variation of air and fuel flow rate. In the present investigation, combustion stability of coal-derived syngas is examined with lab-scale combustor while varying CO/H_2 ratio, percentage of excess air, swirl number, ratio of axial and tangential air, and type of the nozzle. The amount of air for combustion is first calculated by stoichiometric mixing ratio, and then total amount of air is also varied from 100 to 200 percent of stoichiometric amount. Therefore, stability study of coal-derived syngas in fuel lean condition is established. In the present study, detailed measurements of temperature were made in six different types of flames formed around a fuel jet surrounded by swirling air flow, and effects of a wide range of combustion parameters on temperature formation were examined in order to interpret the characteristics and processes of temperature formation by regression analysis.

2. THEORY AND METHOD

Various compositions of coal-derived syngas are manufactured by mixing the CO and H_2 from the gas cylinder tank and air is delivered through commercial air compressor. Predetermined flow rates of fuel and air passed through flowmeter and introduced into burner arrangement. The entire experimental system is illustrated in Figure 1. The goal of the burner design was to incorporate realistic industrial burner characteristics while maintaining experimental flexibility in regard to the burner geometry and input flow parameters. The burner was designed to be upfired, coaxial, and fueled by pure methane as well as simulated coal syngas. The burner consists of five components: the axial air plenum, the swirl module, the air contraction, the quarl, and the fuel injector. All of these components are threaded and changeable such that different geometries can be installed and investigated. This was done for maximum flexibility in addressing interesting research ideas as well as responding to the directions proposed by industry.

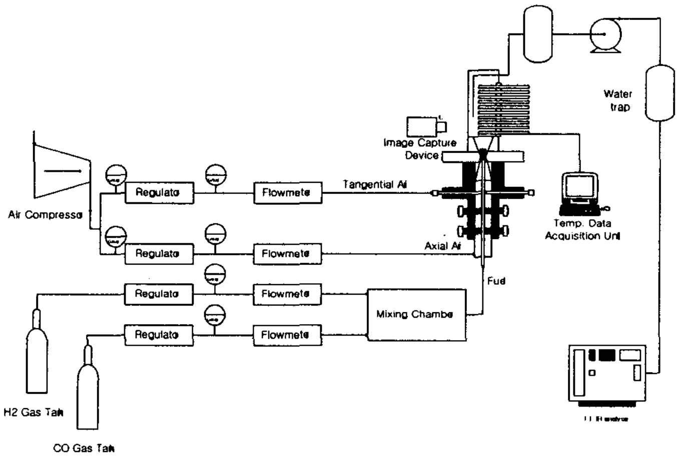

Figure 1. Schematic diagram of lab-scale burner system

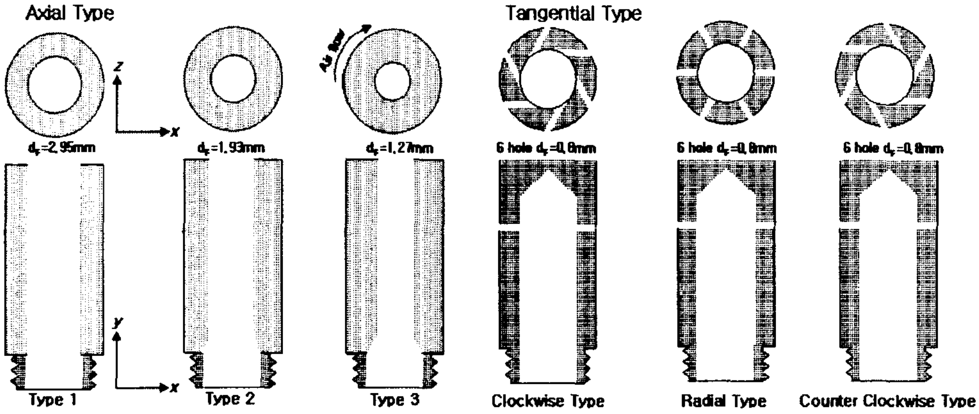

Figure 2. Specific configuration of nozzle

The components of burner swirl module, air contraction, quarl, and fuel nozzles are arranged into one unit and the burner specific configuration with installed fuel nozzles is shown Figure 2. While changing the fuel nozzle of the burner, fuel is also varied with different ratio of CO and H_2. Eights different mixtures of fuel were used for the experiment of flame stability and their physical properties are given in Table 1.

Table 1. Physical properties of fuel gaseous used in the flame stability experiment

Gas	Purity/ composition %v	Molecular weight	Dynamic viscosity, μ, at 0℃, micropoises	Maximum burning velocity in air, Su, m/s	Mass fraction in stoichiometric mixture with air, $\bar{\theta}_s$
CH4	99	16	102.7	0.39	0.055
H2	99	2	84.2	3.06	0.028
CO	99	28	166	0.136	0.289
H2 : CO	99/ (1:1)	15	182.5	1.66	0.179
H2 : CO	99/ (1:1.5)	17.6	184.8	1.41	0.204
H2 : CO	99/ (1:2)	19.42	185.7	1.23	0.220
H2 : CO	99/ (1.5:1)	12.4	178.7	2.02	0.153
H2 : CO	99/ (2:1)	10.58	174.7	2.20	0.133

Flashback safety device is also installed upstream of fuel gas inlet point since flame velocity of H_2 represents high value of about 0.3m/sec [1]. The swirl generator consists of four tangential air inlets that mix tangential air with axial air upstream of the tip of fuel nozzle. The swirling coaxial airflow surrounds a central fuel tube that injects fuel in the axial direction. During the experiment, swirl is also gradually reduced to zero, so that one recovers the important case of a jet flame with coaxial air that is documented in the literature [2]; thus the swirl and no-swirl cases can be properly compared. Two types of fuel injection nozzles were chosen for the initial burner facility tests: axial, tangential jet injectors. The axial injectors were chosen for the flames which have low swirl and a closed, off-axis recirculation zone; these flames have characteristic of higher fuel velocity comparing to air velocity [3]. The selection of nozzle diameter of axial type nozzles was based on the design operating conditions. With axial nozzles, most of the experiments were carried out because axial nozzles produce rather simple flame shape that can be analyzed through the variation of experimental parameter. The tangential nozzles were chosen to match the quarl angle and it used to determine the flame shape and stability only.

3. RESULTS AND DISCUSSIONS

The flame characteristics of axial nozzle type are investigated while the swirl numbers and nozzle type are varied and keeping the fuel heating rate, the fuel composition and total air flow rate constant. [4] The flame shape image is shown in Fig.3. The experimental condition of Fig.3 is constant fuel heating rate (1,000kcal/hr), fuel compositions (CO:H2= 1:1), and total air flow rate (13l/min: stoichiometric condition). The varied combustion parameters are noted in the figure caption. The decrease of the flame length is notified with increasing nozzle type number.

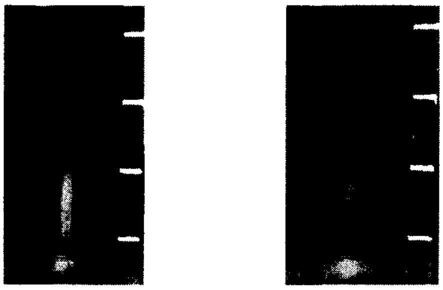

Fig. 3. Photographs of the axial type 3
(Left Side: Swirl number = 0, Right Side: Swirl number = 1)

Because of the relatively rapid fuel bulk velocity contributed to fuel mixing with air. The right side image of the Fig.3 is flames with higher primary air flow rate than that of the left side. Toshimi et al reported that the swirling primary air serves to form a recirculation zone and the position and the size of the recirculation zone of the reversed cone shape is drawn back into the primary air nozzle and extends downstream from the primary air nozzle tip for the flame.[5] However our experimental quarl equipment in combustor diminished in flame width expansion. In other words, the position of recirculation zone is relatively lower than that by Toshimi et al's experiment. Again, our flame recirculation zone was located in the divergent quarl. The recirculation zone is filled with high-temperature burnt gas to anchor the flame and the fuel flows mainly around the recirculation zone forming a fuel. Considering swirl number effects in Fig.3, increasing swirl number affected decreasing flame length and increasing flame width. Fig. 4 showed temperature profile of the flames with excess air variation for axial type nozzle experiments.

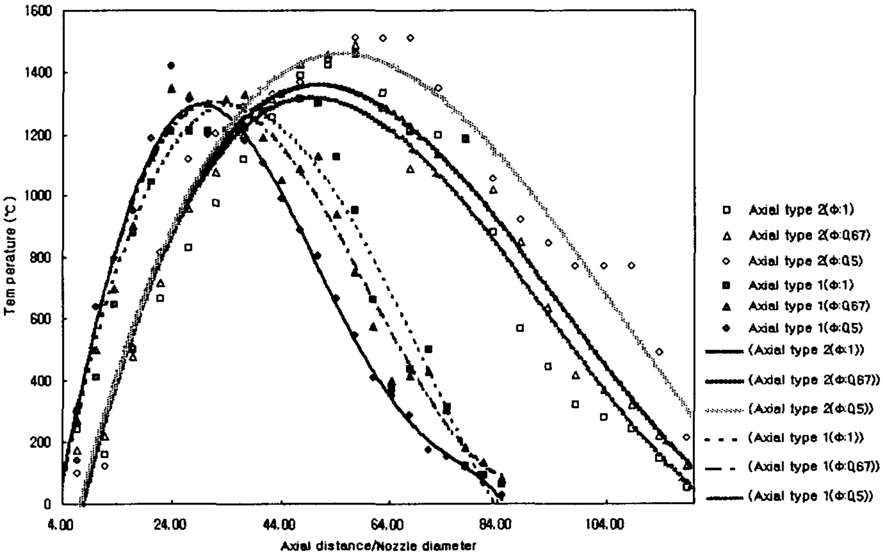

Figure 4. Temperature profile for the axial type nozzles at radial position, 0 (Heat rate : 1,000kcal/hr, S: 0)

The radial variation of temperature in Fig.4 was cited on a parenthesized passage. Considering the excess air variations, increasing excess air was accompanied with decreasing the flame length. Considering radial temperature profiles, the fuel layer burns to form flame around the recirculation zone that causes the sudden drop of the flame temperature in below radial position 1. Therefore, the fuel layer around the recirculation zone in quarl section burns at the downstream section after dilution by the excess air.

4. CONCLUSION

A study of flame structure was using conducted simulated coal-derived syngas. The experiments were performed using selected nozzles with different diameters and shapes, and operation conditions. The following conclusions were made: 1) The structure of the flame formed around a fuel jet surrounded by swirling air is characterized by the mixing and combustion of the fuel layer flowing around the high-temperature recirculation zone. The flame configurations arise according to the nozzle shapes. 2) In axial type nozzles, the flame heights of smaller diameter nozzles were longer and the flame widths relatively narrowed. Accordingly, the nozzle diameter would appear to be the key parameter determining the flame structure. 3) In tangential type nozzles, the flame structure is depended on the fuel heating rate and air flow rate. The swirl number variation affected the flame structure more or less. Accordingly, the fuel flow rate would appear to be the key parameter determining the flame structure. 4) Compared to nozzle types, the flame heights of the tangential type nozzles are about 3 times smaller than those of the axial type. The radial temperature profiles of the tangential type are more uniform than the axial type. The swirl effects on the flame structure are minor factor in our experimental conditions.

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