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Combustion Characteristics and Application of Cyclon Combustor

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Key Words: Cyclon Combustor, Combustion, NOx, Ignition

Abstract

This paper concerns lean gas cyclone combustion system adopting distributed inlets with different velocity to promote ignition and burnout properties. Detailed temperature measurements have been achieved under different operating conditions and flue gas compositions and NOx have been measured. Experimental results show that cyclone combustor provided increasing combustion stability and reduction NOx emission level to negligible level.

1. INTRODUCTION

Cyclone combustor have been adopted as a favorable device for coal combustion because of good combustion capacity and removal efficiency of ashes. However, for the better development of powerful power plant and more environmental demand, its application has been limited.

Main advantages of the cyclone combustor, when retrofitted for burning gas, are high scope of air coefficients and a wide range of fuel adoptability (1,2).

Combustion limit of gas depends normally upon pressure and temperature in combustion system(3). For practical devices, the ignition of fuel and air mixture is also affected by preheat temperature, gas concentration, outlet velocity and geometric shape of burner. For cyclone combustor that uses premixed gas as a fuel, swirl of inlet gas jet provides increasing fuel and air mixing resulting in promotion of combustion characteristics and strong inner heat transfer (1,2,3).

Najim et al (1) studied combustion and NOx emission with different air coefficient

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and concluded enlarged the combustion scope of gas fuel as shown in Table 1.

Recently for the environmental consideration, the combustion of low heating value gas including waste gas have been considered to reduce pollution and to find application of new energy resources. Cyclone combustion chamber can improve mixing of gas by changing inlet gas angle and velocity, resulting in different combustion effects but the ignition of gas that is a key problem for stable combustion is still not resolved with it.

Ignition depends upon the heat exchanging condition - the hot flue gas heats the fresh gas or the premixed gas. In free jet condition, the heat transfer condition is affected by the convection of gas jet and ambient flue gas ; as the jet flow is strong, heat transfer between jet and flue gas increases. Therefore relatively low flow jet can be resulted in better ignition and combustion stability, although it is in conflict with the combustion intensity and burn-out.

Current study reported here is to find a methods to promote cyclone combustion characteristics by separating the inlet gas in two parts.

2. THEORETICAL CONSIDERATION

Combustion can be concerned in three ways ; ignition, propagation and burnout. For proper design of combustor, it is useful to consider the three terms and arrange them coherently. Gas ignition is affected by following parameters ; flue gas temperature, heat release rate, reaction activation energy, heat loss rate to ambient.

For identical ambient temperature condition, the higher heat release rate, the easier ignition, resulting in high reaction temperature. For different gases, the reaction is quite different and can be determined by fuel type and chemical medium (the existence of catalytic agent) due to different activated energy.

Heat loss rate also determines the reaction rate. In the case of open reaction system, heat losses depend upon the convection of reaction jet and the flue gas.

After ignition, heat generated from the combustion will be transferred to ambient combustible gases and thereafter flame propagates. Its difference with ignition is that turbulence plays a important role ; turbulent flame normally propagates faster than of laminar. In turbulence case, high turbulent intensity is beneficial for fuel and air mixing. The mixture of gas and air needs proper contact and the premixed gas with flue gas requires high enough temperature for reaction start.

Flameout can be occurred by high turbulent intensity in the case of short resident time and by low chemical reaction rate. For industrial utilization, in the other hand, increasing turbulent intensity can be resulted in rapid reaction for compact device. It is, therefore, necessary to provide continuos ignition and stable combustion. Under the light of combustion stability technology employed with gas or solid fuel (3,4), "additional ignitor" adopting premixed gas can be employed ; low inlet velocity and is high temperature of the hot flue gas would be beneficial for the continuos ignition. With the additional ignitor adopting premixed gas in the cyclone combustor using lean gas, combustion of the low caloric value gases could be promoted.

3. EXPERIMENTAL SETUP

Experimental system employed in the currently work includes cyclone combustor as a main device, gas and air supply system and measurement system shown in Fig. 1. The cyclone combustor body was made of castable refractory material powder. Six gas inlets were prepared and each was angled in 30° to induce swirling motion. Shown in Table 2 is details of the cyclone combustor employed in present study. Fuel used was industrial propane.

4. RESULTS

Temperature measurements adopting CA type thermocouple and gas sampling employing GC and NOx analyser were achieved. Effects of low inlet velocity on combustion stability were evaluated with different combustion cases.

4.1. The role of small velocity gas inlet on normal cyclone combustion.

According to normal combustion velocity of premixed gas, a 20 lpm premixed gas was introduced through small hole of pipes in each different combustion cases, then their combustion limit was studied as shown in Fig. 3.

From this experimental results, it was found that, by this cyclone geometry, combustion stability or air coefficients decrease verse air flow rate, and with low velocity of inlet premixed gas, combustion stability increased. Growth rate seemed to affected by total air flow rate. Combustion stability of this growth rate was lower as it might be due to effect of high inlet air velocity on low jet velocity.

In design of this cyclone combustor, tangential inlet of each pipe was limited to avoid strong jet that might be resulted in bleach of combustion stability.

4.2 The temperature distribution.

Temperature obtained from experiments were compared with theoretical calculation of adiabatic flame temperature with different operating conditions. As shown in Fig. 4, temperatures depended upon air coefficients ; when air coefficients $\Phi>1$, as the air coefficients decreased combustion temperature increased. Measured temperature values shown here were higher than calculations due to the combustion processes of which local temperature was higher than average one. And in some positions the combustion condition might be in super adiabatic combustion due to hot flue gas. Temperature change was decided not only by air coefficients but also by flow type and combustion state. In the case of high air coefficients, if flow rate is not large, its combustion temperature might be high. This results coincided with those of the combustion, as shown in Fig. 3.

Shown in Fig. 5 is temperature distribution at Φ=2.27 and 380 lpm of the total air flow rate. Calculated combustion temperature was 1484K in the near of bottom of combustor where the temperatures at almost all measuring points reached to it.

Averaged temperature in the cyclone was high while temperature at some points near inlet position was about 700° C.

For a case of large air flow rate with less fuel rate as shown in Fig. 6, combustion temperature level was decreased to 1295K. As moved to the wall radially, temperature decreased ; the measured temperature at combustor center was higher than that from the calculation and its difference in center along the vertical direction was smaller than 50° C. This implied turbulent might affect to combustion ; large turbulence generated from large flow rate provide intensified combustion but in the point of ignition high inlet velocity would not be helpful.

Fig. 7 shows a case of small velocity ; it is clear that its combustion stability is better, compared with results in Fig. 6. As can be seen, high value of temperature was achieved in the near of center almost of all points. From this temperature distribution, it is known that temperature near inlet rises faster than the case in Fig. 6. This is due to a proper convection and flame propagation caused by relatively small inlet flow rate.

The difference of operation of this case is that all premixed gas was all-premixed input in two small pipes, therefore inlet velocity was very large, and also inlet turbulence was larger than the case of Fig. 6.

4.3 Measure of gas composition.

Distribution of gas CO, O_2, and NOx was acquired. CO distribution wasd shown in Fig. 8 ; CO concentration was low at center place and in the near of the wall different place provided different values - near inlet position, CO was very large and after proper combustion, mainly when the temperature has been promoted, CO concentration decreases. It also coincided with the combustion case, high temperature low CO value as O_2 concentration was enough to oxidize the CO if temperature is proper. O_2 concentration distribution was similar to that of CO, as shown in Fig. 9. Oxygen concentration near the cyclone combustor center was almost constant. Shown in Fig. 10 is NOx concentration distribution at the near bottom and the combustor center ; NOx concentration was relatively high. The NOx concentrations in row 8 and 7 were less than 50ppm, but others were low at positions of high CO and O_2.

5. DISCUSSION AND CONCLUSIONS

From temperature distributions, it was found that high combustion temperature could be obtained due to proper heat transfer conditions for premixed gas combustion. It was possible to optimize position and raw rate of small velocity gas inlet to promote combustion stability.

Considering the turbulence and flow jet itself in cyclone combustor, jet rigidity was provided in the small geometry. This was a parameter that affected to proper combustion. By changing the structure and inlet position, stability of the cyclone combustor could be improved.

For gas composition analysis, it was clearly noticed that the NOx formation generated from prompt and thermal NOx formation mechanism decreased due to low temperature. Combustion processes of propane can be simplified as;

$$C_3H_8+O\rightarrow C_{iH_j}+HO+CO \tag{1}$$

$$C_iH_j+O\rightarrow CO+H_2O \tag{2}$$

$$CO+O\ (+OH)\rightarrow CO_2+(OH) \tag{3}$$

In all reaction step, step(3) is a rate limit reaction and determined by potential of oxidation and reduction of environment. In the case of lack condition of CO oxidization, CO can be emitted. Except for step(3), other reaction is fast, even in low temperature. Therefore in cyclone combustor, CO can be oxided to CO_2 due to relatively high temperature at the center of cyclone combustor. In the near of inlet, however, the formed CO cannot be oxided due to low temperature.

NOx was formed mainly by prompt and thermal mechanism. High temperature contributed to the thermal NOx formation and therefore decreasing combustion temperature could be one of best ways to reduce thermal NOx.

In cyclone combustion experiment, enlargement of combustion air coefficient introduced not to high temperature of overal temperature followed by reduction of NOx formation.

For combustion of hydrocarbon fuel, it is important to consider prompt NOx ;

$$C_iH_j+N_2\rightarrow C_iH_j+N \tag{4}$$

$$C_iH_jN+O\rightarrow HCN+HO \tag{5}$$

$$HCN+O\rightarrow N \tag{6}$$

$$N+OH\rightarrow NO \tag{7}$$

$$N+NO\rightarrow N_2+O \tag{8}$$

Reaction coefficients of step(7) and (8) are:

$$K_7=1.0\times10^{11}\exp(-2.805\times10^{8}/RT)$$

$$K_8=3.0\times10^{12}\exp(-2.512\times10^{8}/RT)$$

Also reaction (7) is a key step of the prompt NOx formation but reaction (8) is occurred easily.

In the center of cyclone combustor, NOx concentration was high, (as shown in NOx profile in Fig. 10) due to high temperature and ample O_2 concentration. N atom formed from prompt mechanism, when N contact NOx formed in center part, would react to generate N_2. Then NO would be reduced.

By these analysis, as premixed gas was separated into two parts through different inlet, cyclone combustion could be prompted. Also by optimization of location and their flow rate, combustion stability would be promoted more. Strong input turbulence had a available effection on combustion. In way of NOx emission, because of low combustion temperature near premixed gas inlet and a potential of reduction, NOx was formed less and finally reduced more by N and NO reaction.

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Table 1 Combustion Condition in Cyclone Combustor(1)

Gas Flow Rate (Kg/h) CH_4	Air Flow Rate (Kg/h)	Air Coefficient
3.1	35	0.86
	60	1.1
	89	1.68

Table 2. Specification of cyclone combustor

Combustor diameter D_o	100 mm	
Exit diameter of cyclone D_e	56 mm	
Main inlet diameter D_t	12 mm	
Additinal inlet diam. D_{thlp}	8 mm	
Length of Cyclone L_o	250 mm	
Length of Vortex Sleeve L_s	100 mm	
D_e/D_o	0.56	0.45 - 0.65
L_o/D_o	2.5	1.5 - 1.8
A_t/A_o	0.062	0.1 - 0.3

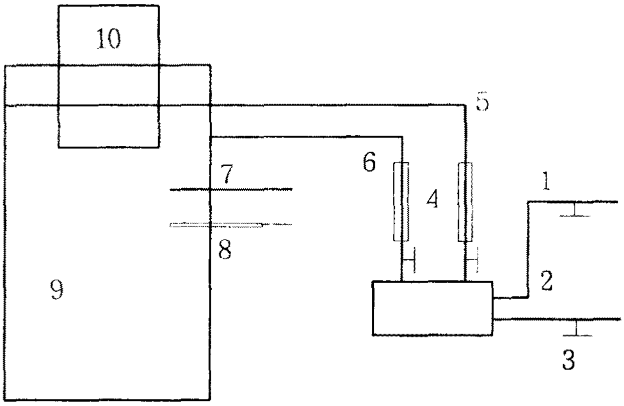

Fig. 1 Scheme of experimental system

1. Inlet pipe for gas 2. Inlet pipe for air
3. Flow rate valve 4. Flow meter
5. Inlet pipe 6. Inlet pipe 7. Thermo couple.
8. Gas sampler 9. Cyclone body 10. Vortex sleeve

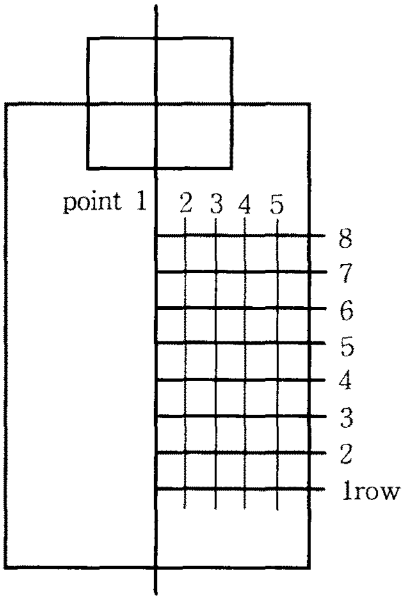

Fig. 2 The sampling point
Point 1 in all rows is the center of cyclone

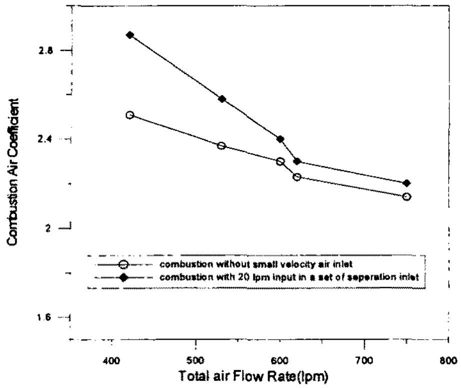

Fig. 3 The effect of small velocity inlet of premixed gas on normal combustion stability

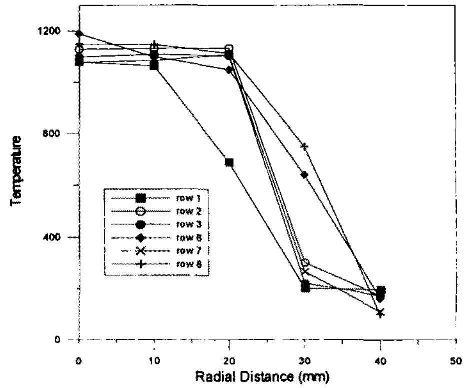

Fig. 6 Temperature distribution in radial direction of cyclone combustor in operation condition of Φ =2.45 (Qgas=6.8lpm, Qair=390 lpm), Fuel:LPG

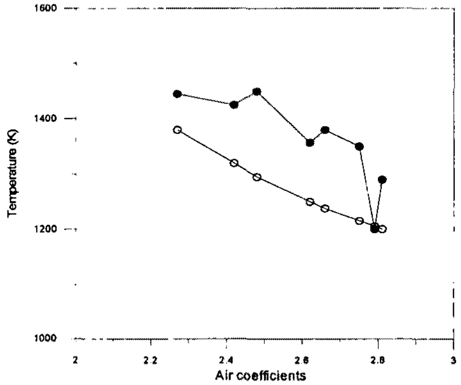

Fig. 4 Comparison of by temperature measurement and calculation of adiabatic combustion

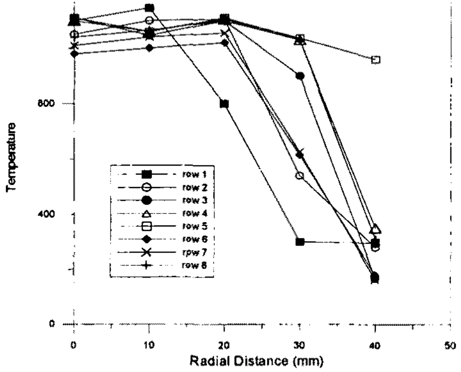

Fig. 7 Temperature distribution in radial direction of cyclone combustor in operation condition of Φ =2.67 (Qgas=4.8lpm, Qair=300 lpm), Fuel:LPG

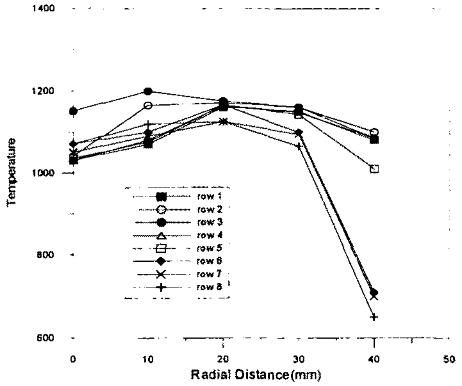

Fig. 5 Temperature distribution in radial direction of cyclone combustor in operation condition of Φ =2.27 (Qgas=7.36lpm, Qair=380 lpm), Fuel:LPG

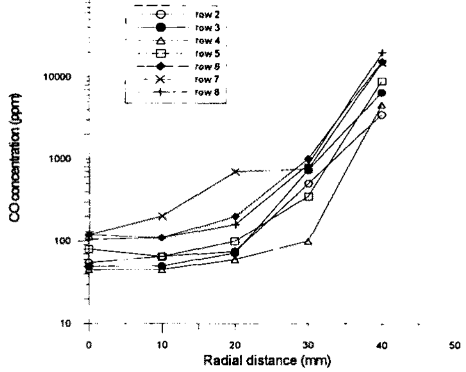

Fig. 8 CO concentration distribution in radial direction of cyclone combustor in operation of Φ =2.27 (Qgas=7.36lpm, Qair=390 lpm), Fuel:LPG

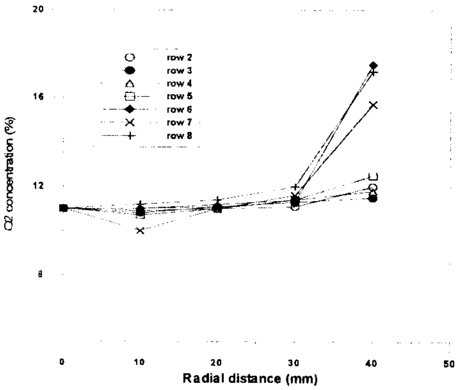

Fig. 9 O_2 concentration distribution in radial direction of cyclone combustor in operation of Φ =2.27 (Qgas=7.36lpm, Qair=390 lpm), Fuel:LPG

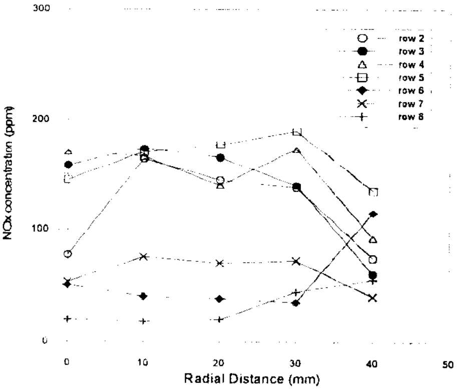

Fig. 10 NOx concentration distribution in radial direction of cyclone combustor in operation of Φ =2.27 (Qgas=7.36lpm, Qair=390 lpm), Fuel:LPG