Effect of Air Velocity on Combustion Characteristics in Small-Scale Burner

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ABSTRACT

This paper presents the combustion characteristics of hydrocarbon fuel from a conventional pressure-swirl nozzle of a small-scale burner. The nozzle has orifice diameters of 0.256 mm and liquid flow rates ranging from 50 to 64 mL/min were selected for the experiments. The furnace temperature distribution along the axial distance, the gas emission such as CO, CO_2, NOx, SO_2, flue gas temperature, and combustion efficiency were studied. The local furnace and flue gas temperatures decreased with an increase in air velocity. At injection pressures of 1.1 and 1.3 MPa the maximum furnace temperatures occurred closer to the burner exit, at an axial distance of 242 mm from the diffuser tip. The CO and CO_2concentrations decreased with an increase in air velocity, but they increased with an increase in injection pressure. The effect of air velocity on NOx was not clearly seen at low injection pressures, but at injection pressure of 1.3 MPa it decreased with an increase in air velocity. The effect of air velocity on SO_2 concentration level is not well understood. The combustion efficiency decreased with an increase in air velocity but it increased with an increase in injection pressure. It is recommended that injection pressure less than 0.9 MPa with air velocity not above 8.0 m/s would be suitable for this burner..

Key Words : Air Velocity, Combustion Characteristics, Local Furnace Temperature, Flue Gas Temperature, Gas Emission

1. INTRODUCTION

Combustion has remained in modern world as the source of energy that governs our daily activities. In Korea, small-scale burners with pressure-swirl nozzles are widely adopted to generate heat for drying the agricultural products. It has been noted that combustion is controlled by several phenomena including atomization of the liquid jet, droplets evaporation, mixture between reactants and combustion [1].

The study of spray and combustion characteristics is highly required in order to improve upon the efficiency of a burner or a combustor. Spray characteristics of hydrocarbon fuel by using both conventional and electrostatic pressure-swirl nozzle have been studied [2-5]. Also results of combustion characteristics have been reported [6, 7]. Some of the methods that can be used to improve upon combustion efficiency include oxy-fuel combustion application [8, 9].

One of the parameters which are needed for energy efficiency improvement in burners is air velocity. Improper control of air velocity may lead to combustion instability or failure of the whole system and heat waste due to increased stack loss [10].

Industrial heating applications are

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classified into higher and lower temperatures. In the case of higher temperature applications, the furnace temperatures are well over 1400K. For lower temperature applications such as dryers, process heaters, and heat treating, typical temperatures are below 1400K [11].

This is an on-going project for the development of electrostatic nozzle for burner applications. The purpose of this study is to find the effect of air velocity on combustion characteristics, and to select suitable parameters that could be found useful for electrostatic nozzle development.

2. EXPERIMENTAL METHODS AND CONDITIONS

A small-scale oil burner (SH G8 F60, Shinheung, Korea) for drying agricultural products, industrial heating processing equipment, boiler and incinerators was selected for the experiment. The specifications of the burner and the property of the tested hydrocarbon fuel are presented in Tables 1 and 2 respectively. The air velocity supplied to the furnace was varied at 2.75, 5.94, 8.0, 9.5 and 10.24 m/s respectively for the five different damper openings. Those were measured by anemometer (TSI 8360-M-GB, USA) in front of the slit.

A pressure-swirl nozzle with hollow cone spray pattern having orifice diameter of 0.256 mm and injection pressures of 0.7, 0.9, 1.1 and 1.3 MPa were used for this experiment. The liquid flow rate was measured by using a flow meter (Macnaught, M 1SSP-1R, Australia). The injection pressures discharged corresponding flow rates of 50, 55, 60 and 64 mL/min respectively.

A schematic diagram of the combustion test rig used for the experiment is a steel rectangular ceramic-lined tunnel furnace

Table 1. Burner specification

Kerosine/Light Oil	
Power Source [V]	AC 220V/50Hz, 60Hz
Motor [W]	110
Oil Pump	Gear pump
Ignition Trans[kV]	8.5 kV/18 mA
Pump Pressure [MPa]	1.5
Flow rate [mL/min]	50 ~ 140
Dosage [MJ/h]	125.6 ~ 293.1

Table 2. Property of tested fuel at 295 K

Surface tension [kg/s2]	$2.6x10^{-1}$
Dynamic viscosity [kg/m s]	$1.04x10^{-3}$
Density [kg/m3]	790

shown in Fig. 1. The burner fires horizontally into the furnace chamber of a rectangular shape with dimensions of 1.2 m (L) x 0.76 m (W) x 0.76 m (H) and 0.11 m in refractory wall thickness. The rig is fitted with a stainless steel and a quartz window to enable access to the combustion chamber for in-flame visualization. The front and end views of the oil burner are shown in Fig 2.

Six R-type (0.5 x 500L x SSA S13 x 1/2″ PT) thermocouples were installed on the combustion test rig at axial distances of 142, 242, 392, 542, 692 and 842 mm from the diffuser tip in order to record the furnace temperatures. The temperatures were recorded at 5 mins after start of combustion, by using a hybrid recorder (KONICS KM 100, Yokogawa, Japan).

A sampling port was provided at the furnace outlet to enable access for gas analyses. The flue gases emission such as CO, CO_2, NOx and SO_2 as well as combustion efficiency were recorded at 5

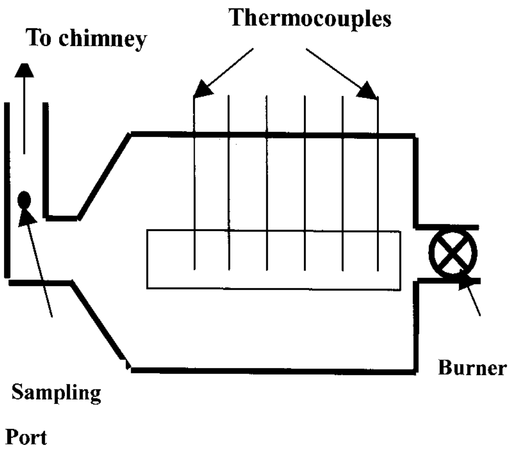

Fig. 1 Schematic diagram of a steel rectangular ceramic-lined tunnel furnace

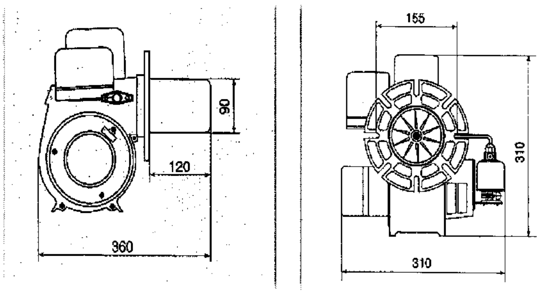

Fig. 2 Front and end views of oil burner

mins intervals, by using a gas analyzer (Quintox KM9106, Kane-May, UK).

3. RESULTS AND DISCUSSIONS

3.1 Effects of air velocity and axial distance on local furnace temperature

In this experiment, the air velocity and axial distance effects on local furnace temperature distributions have been discussed. The mean values are plotted in Fig. 3. It shows that the furnace temperature decreased with an increase in air velocity and axial distance. The decrease in furnace temperature was due to the disappearance of droplet along the attributed to a fast rate of vaporization and cooling effect from excess air.

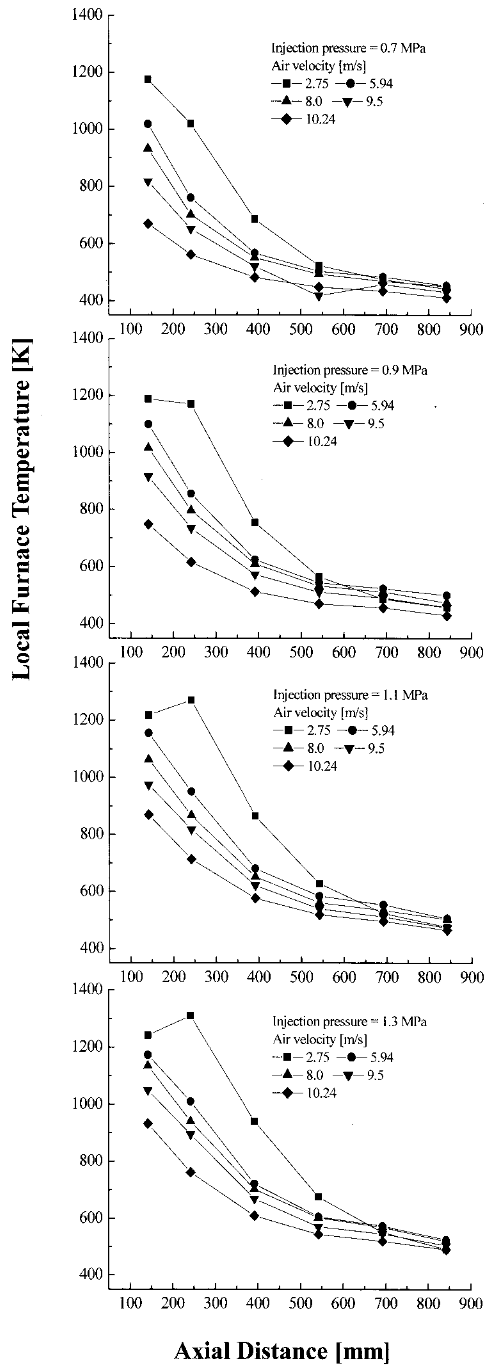

Fig. 3 Effect of air velocity on furnace temperature at various injection pressures

Figure 3 also shows that at high injection pressures of 1.1 and 1.3 MPa, the furnace temperature increased as the distance from the diffuser was increased to 242 mm and then decreased with an increase in axial distance. This may be due to the effect of 3-D structure of flame according to swirl.

3.2 Effects of air velocity on flue gas temperature

The analyzer probe was inserted for sampling measurements at various positions in the stack. It was found that, minimum values were at the center of the stack. Under this note, all the measurements were taken at one point (i.e. at the center of the stack).

Figure 4 shows the effect of air velocity on flue gas temperature. The flue gas temperature decreased with an increase in air velocity but increased with an increase in injection pressure. This means, an increase in air velocity forced the exhaust gas to move faster out of the stack. It also has a cooling effect on the exhaust flue gases. Flue gas temperature above 673 K is too high and. it is not recommendable or a heat recovery system is required.

3.3 Effect of air velocity on flue gas emissions

Emission analysis is of much importance in combustion processes. There are two methods of obtaining gas samples: extractive and *in situ* [11]. In this experiment, the *in situ* method was used for the emission gas analysis due to time saving. The results of the flue gases analyses such as CO, CO_2, NOx and SO_2 concentration levels have been presented in Fig. 5a, b, c, and d respectively.

From Fig. 5a, it was observed that, at injection pressure of 0.7 MPa, the CO decreased with an increase in air velocity, but it increased with an increase in injection pressure. The decreased in CO means that, the ratios of the air/fuel

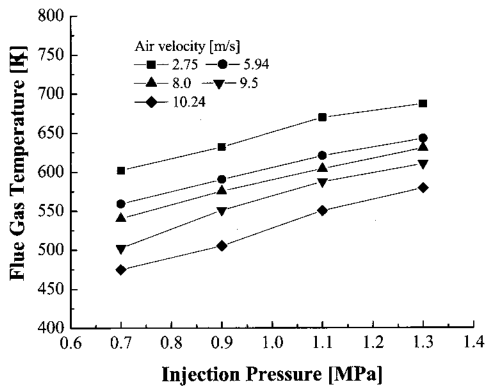

Fig. 4 Effect of air velocity on flue gas temperature

supplied to the burner were in good proportions. The CO increased gradually at air velocity of 8.0 m/s. It was also noted that, at high injection pressure of 1.3 MPa, the air velocity has less influence on the CO concentration level.

In Fig. 5b, the CO_2 concentration level decreased with an increase in air velocity but it increased with an increase in injection pressure. The decrease in CO_2 concentration level showed that sufficient oxygen was available to reduce the unburned fuel.

From Fig. 5c, it was observed that at low injection pressures, the air velocity effect on NOx can not clearly be seen, but at injection pressure of 1.3 MPa, the NOx concentration level decreased with an increase in air velocity. At air velocity of 2.75 m/s, the NOx concentration level increased with an increase in injection pressure.

In Fig. 5d, the effect of air velocity on SO_2 concentration level is not well understood. It therefore requires further studies in this area.

3.4 Effect of air velocity on combustion efficiency

Combustion efficiency can be measured by either using the oxygen content or

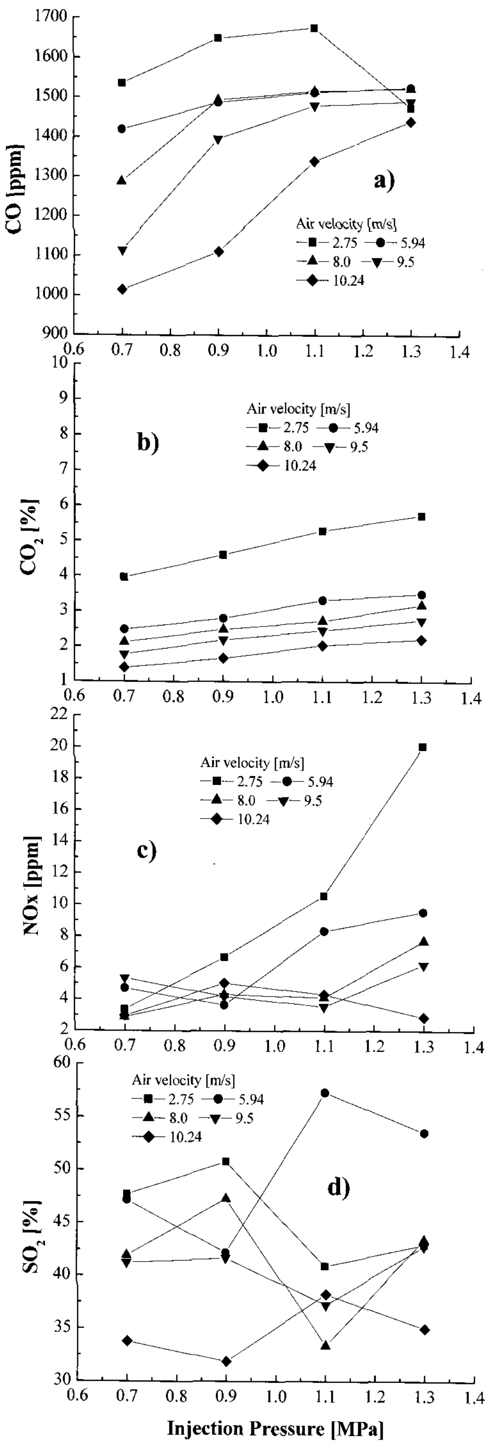

Fig. 5 Effect of air velocity on exhaust emission

carbon dioxide content in the flue gases.

In this experiment, the combustion efficiency is calculated directly by the gas analyzer that has in-built computer software by selecting the net combustion efficiency. The net combustion efficiency is given as

$$\eta_n = 100\% - dry\ flue\ gas\ losses$$

$$= 100\% - \frac{20.9K1_n(T_{net})}{K2(20.9 - \%O_{2m})} \quad (1)$$

where

K1n = 255x %Carbon in fuel/Qnet

K2 = % max theoretical CO_2 (dry basis)

Tnet = Flue temperature - Inlet temperature

Qnet = the net calorific value of fuel and

O_2m = the % oxygen in flue gas.

The combustion efficiency analysis is presented in Fig. 6. It can be seen from the figure that, the combustion efficiency decreased with an increase in air velocity but it increased with an increase in injection pressure. The decrease in combustion efficiency were due to the excessive air supplied and incomplete combustion.

4. CONCLUSIONS

The effects of air velocity on combustion characteristics of hydrocarbon fuel injected from pressure-swirl nozzles have experimentally been studied. The conclusions drawn from this study are:

The local furnace temperature decreased with an increase in air velocity and axial distance.

The flue gas temperature decreased with an increase in air velocity, but it increased with an increase in injection pressure.

The CO concentration level decreased with an increase in air velocity, but increased with an increase in injection pressure. At air velocity of 8.0 m/s, there was a slightly increase in the CO concentration level. At injection pressure of 1.3 MPa, the air velocity has less influence on the CO concentration level.

The CO_2 concentration level decreased with an increase in air velocity but increased with an increase in injection pressure.

At injection pressure of 1.3 MPa, the NOx concentration level decreased with an increase in air velocity, but it increased with an increase in injection pressure at air velocity of 2.75 m/s

The effect of air velocity on SO2 concentration level is not well understood.

The combustion efficiency decreased with an increase in air velocity.

It was concluded that the suitable parameters to be recommended were injection pressure less than 0.9 MPa with air velocity not above 8.0 m/s.

The effect of air velocity on SO2 concentration level requires further studies.

5. ACKNOWLEDGEMENT

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