Comparison of Spray Characteristics between Conventional and Electrostatic Pressure-Swirl Nozzles

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Key words: Spray characteristics, Electrostatic pressure-swirl nozzle, charge injection mechanism, Breakup length, Spray angle, Sauter mean diameter

Abstract

Spray characteristics produced by conventional and electrostatic pressure-swirl nozzles for an oil burner have been studied, using kerosine as a test liquid. The charge injection mechanism is used to design the electrostatic nozzle, where specific charge density, breakup length, spray angle and mean diameter are measured and analyzed. Three nozzles with orifice diameters of 0.256, 0.308 and 0.333 mm at injection pressures of 0.7, 0.9, 1.1 and 1.3 MPa are used in the study. In case of the electrostatic nozzle, voltages ranging from −5 to −12 kV are applied. Comparison of the spray characteristics is made between the conventional and electrostatic nozzles. The results showed that, the electrostatic nozzle is superior to the conventional nozzle. This is due the effect of voltage on the liquid surface tension.

1. Introduction

Burners are used to generate heat in many areas such as agricultural and industrial applications. Although the conventional atomization techniques employed in oil burners are working well using pressure-swirl nozzles, they cause pollutant emission to the environment due to high amount of unburned fuel. Many studies on spray characteristics of pressure-swirl nozzles have been carried out especially with conventional type.(1-5) Many researchers are finding out an improved technology and methods that may possibly improve the atomization quality of oil fuel sprays. It is known that one of the methods to improve atomization quality using liquid fuel is by using electrostatic atomization.

Electrostatic techniques have been applied in the field of agriculture, medicine and other related industries, but the practical burner applications are very limited due to many factors such as low throughput, high viscosity and resistivity of the fuel. The difficulty in the liquid fuel disperse may be due to its long charge relaxation time. Kerosine having a resistivity of 10^{12} Ωm was atomized electrostatically, by adding 3% of active surface agent (ASA-3) which reduced the resistivity to 10^{6} Ωm.(7) Many works on electrostatic fuel atomization using the charge injection mechanism have been discussed elsewhere.(6-12)

The charge injection mechanism is known to be superior to other charging methods in terms of liquid fuel atomization. The charge injection mechanism used in combustion system is of three categories, differentiated by the number of electrodes it consist in the design (single, diode and triode).(9-11) Owing to insufficient charge carriers in hydrocarbon fuel and low flow rates, the electrostatic atomization technique has not been exploited for commercial application. Recently, works had been carried out to integrate pressure-swirl nozzle for electrostatic practical application at injection pressures above 0.6 MPa.(5, 6, 12-15)

This paper presents comparison of the spray characteristics produced by conventional and electrostatic nozzles.

This work is part of the electrostatic nozzle development scheme for practical oil burner which could be used for drying and heating processes in the agricultural fields.

2. Experimental methods and materials

A small oil burner (SH G8 F60, Shinheung, Korea) widely used in Korea to dry agricultural products and industrial heating was selected for this study. The specification of the burner used for this experiment can be found elsewhere.(5) The property of the tested fuel is

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presented in Table 1. Three commercial pressure-swirl nozzles with orifice diameters of 0.256, 0.308 and 0.333 mm, and injection pressures were varied at 0.7, 0.9, 1.1 and 1.3 MPa for the conventional and electrostatic nozzles. The nozzle adaptor was connected with nylon snap - lock fittings and high voltages with negative polarity ranging between 5 to 12 kV were applied to the electrostatic nozzle. In order to calculate specific charge density, the spray current was measured by using Keithley electrometer 6514 which has been connected to the Faraday pail. The pail contains some wire-wool which collects all the spray, and prevents rebouncing. Spray characteristics such as breakup length, spray angle and mean diameter were measured under the above conditions. The results from the experiment would be used as an input data to study the combustion characteristic of the electrostatic pressure-swirl nozzle.

Table 1 Property of the tested fuel (kerosene) at 295K

Property	Value
Surface tension [kg s^{-2}]	2.6x10^{-1}
Dynamic viscosity [kg m^{-1}s^{-1}]	1.04x10^{-3}
Density [kg m^{-3}]	790
Electrical conductivity [Ωm]$^{-1}$	1.69x10^{-11}
Relative permittivity	2.2

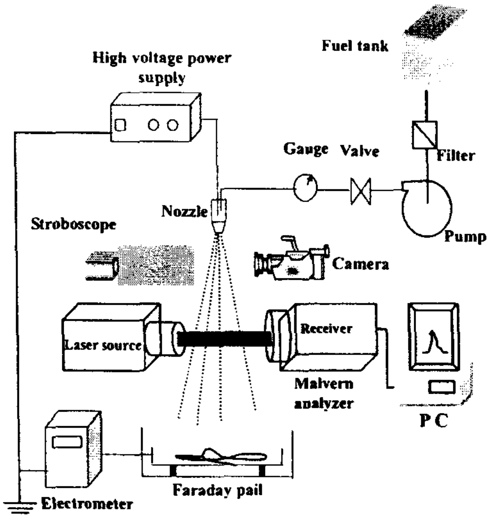


Fig. 1 Schematic diagram of experimental setup

A 3-CCD video camera (Sony DCR-VX, Japan) is used to capture multiples of spray images for measurement purpose. A direct lighting source from a stroboscope was employed to illuminate the spray field from a dark background. The captured images are stored in the computer for off-line analysis. Twenty images are processed with the photoshop image analysis software. The image processing gives geometrical information to analyze the spray characteristics such as breakup length and spray angle. The mean diameter (SMD) is measured using a Malvern Particle Size Analyzer (Master Sizer S)at axial distance of 20 mm from the nozzle exit. A schematic diagram of the experimental setup is shown in Fig. 1. In order to evaluate the nozzles performance, comparisons were made between the conventional and the electrostatic nozzles.

3. Results and discussion

3.1. Effect of applied voltage on specific charge density

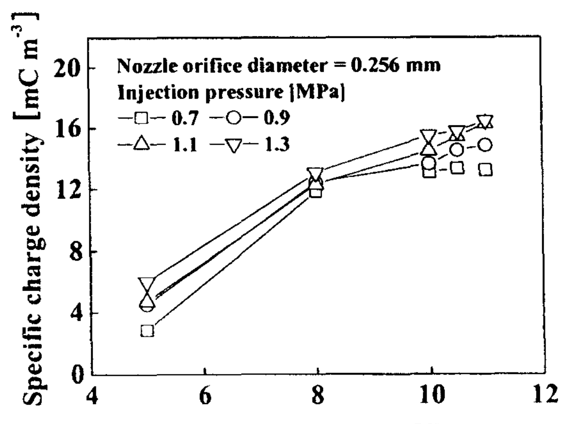
It is known that increase in injection pressure produces the increase of the inherent current caused by triboelectric effect through rubbing of the liquid on metal surface.$^{(6, 16)}$ The spray current increased with an increase in applied voltage until electrical breakdownoccurred causing the high voltage power supply to tripped off. The critical applied voltage depends on injection pressure for individual nozzle. The specific charge density was calculated by

$$\rho_s = \frac{i_s}{Q_v} \qquad (1)$$

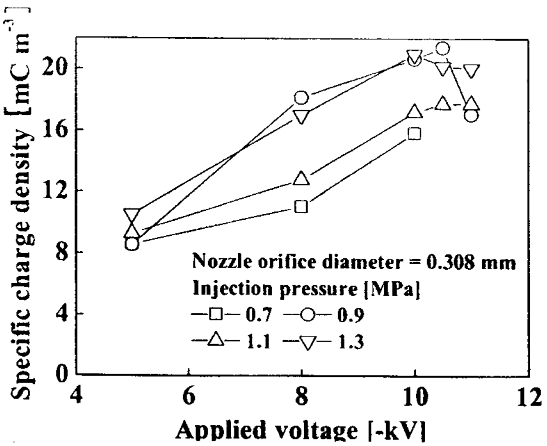
where i_s is the spray current (A) and Q_v is the volumetric flow rate (m^3/s).

The influence of applied voltage on specific charge density for the different nozzles is presented in Fig. 2. The figure indicates that, the specific charge density increased with an increase in applied voltage until electrical breakdown occurs.

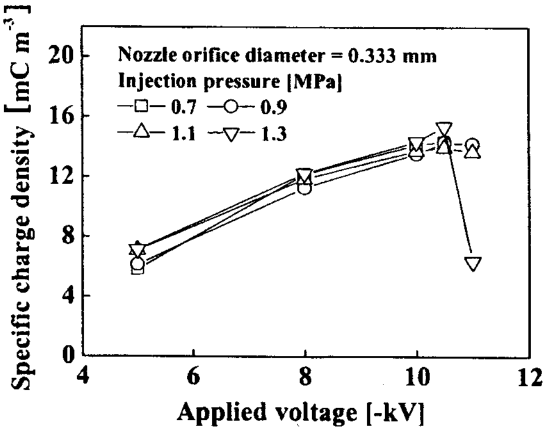
The specific charge density for nozzle with orifice diameter of 0.308 mm was not consistent with an increase in applied voltage.



a) Nozzle orifice diameter : 0.256mm



b) Nozzle orifice diameter : 0.308mm

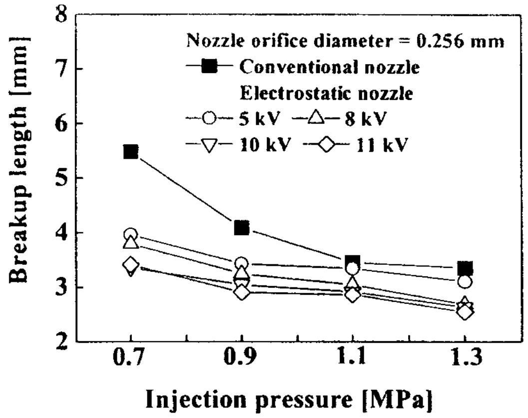


c) Nozzle orifice diameter : 0.333mm

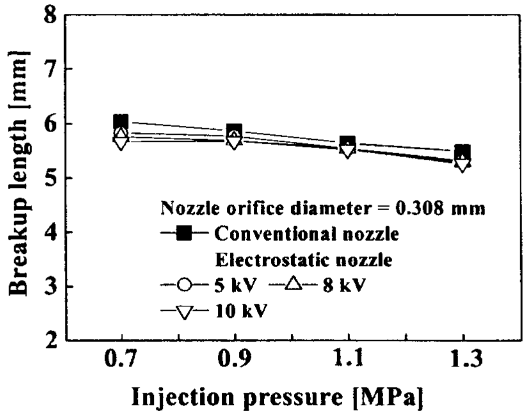
Fig. 2 Effect of applied voltage on specific charge density for three different orifice diameters

At high injection pressure which means high flow rate, the effect of voltage was insignificant. At low injection pressures, a complete electrical breakdown occurred due to the accumulation of the charged liquid inside the nozzle and an increase in current leakage to the grounded nozzle body.

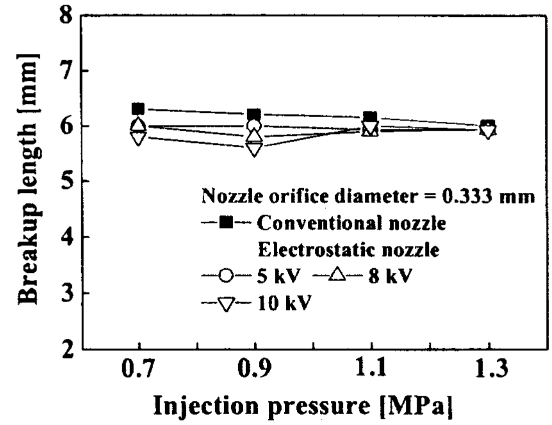
3.2. Comparison between the conventional and electrostatic nozzles on breakup length



a) Nozzle orifice diameter : 0.256mm



b) Nozzle orifice diameter : 0.308mm



c) Nozzle orifice diameter : 0.333mm

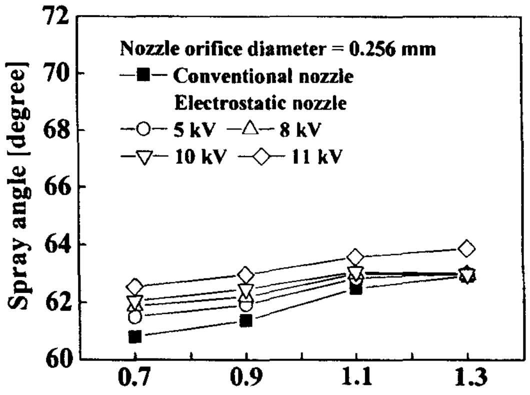
Fig. 3 Variation of injection pressure on breakup length for conventional and electrostatic nozzles

Breakup length can be measured based on two criteria: perforation and drop formation.(17) It is defined as the distance from the nozzle exit to where perforation or drop formation begins to occur. In this experiment, the breakup length based on drop formation has been used. Mean values obtained at 80% threshold level are illustrated in Fig. 3 for different nozzle orifice diameters. It can be observed that, the breakup length decreased with increase in injection pressure. Also in the case of the electrostatic nozzle, the breakup length decreased with increase in applied voltage especially at low injection pressure.

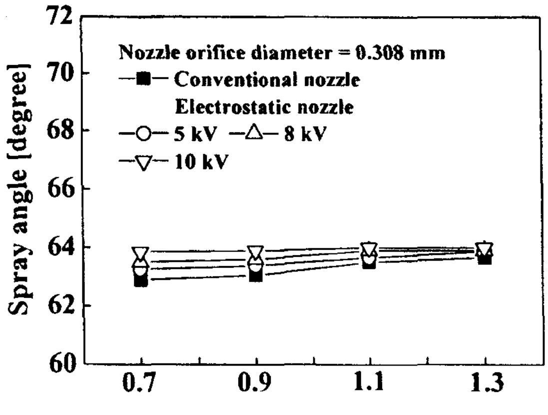
The figure indicates that, the electrostatic nozzle issued sprays with shorter breakup length than that produced by the conventional nozzle. This is due to the voltage effect that overcomes the pressure exerted on the liquid's surface tension. Effect of voltage on breakup length for nozzle with orifice diameter of 0.333 mm was not consistent due the high liquid flow rate. High injection pressures are therefore not recommended for electrostatic atomization.

3.3. Comparison between the conventional and electrostatic nozzles on spray angle

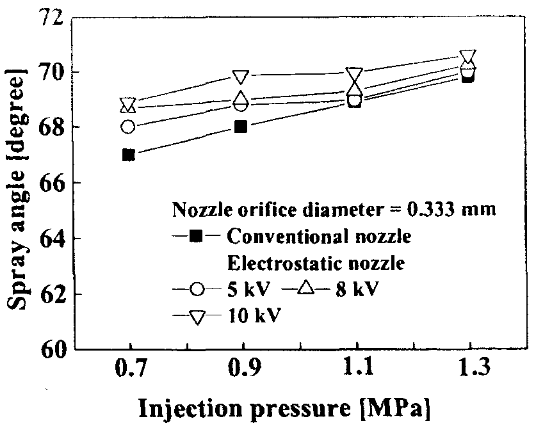
The spray angle was measured by drawing two lines on the captured images from the nozzle's exit to cut the contours at the liquid breakup points. The relationship between the injection pressure and the mean values are presented in Fig. 4. The figure revealed that, the spray angle increased with an increase in injection pressure and also with an in applied voltage for the electrostatic nozzle. This can clearly be seen especially at low injection pressure. The difference in spray angle may be due to the creation of additional electrical forces acting on the charged droplet. This caused the droplet to repel and dominates the spray trajectory. It was assumed that, an increase in voltage caused the bulk liquid temperature to increase which affected ionic mobility by the change in fuel viscosity.



a)Nozzle orifice diameter : 0.256mm



b) Nozzle orifice diameter : 0.308mm

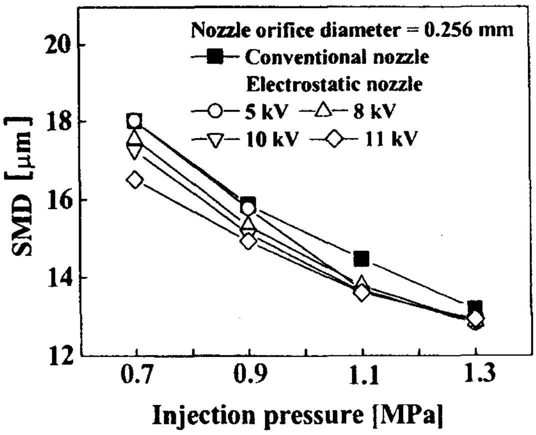


c) Nozzle orifice diameter : 0.333mm

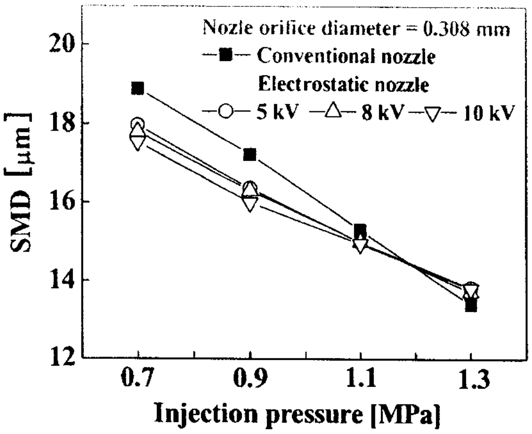
Fig. 4 Variation of spray angle with injection pressure for conventional and electrostatic nozzles

3.4. Comparison between the conventional and electrostatic nozzles on mean diameter

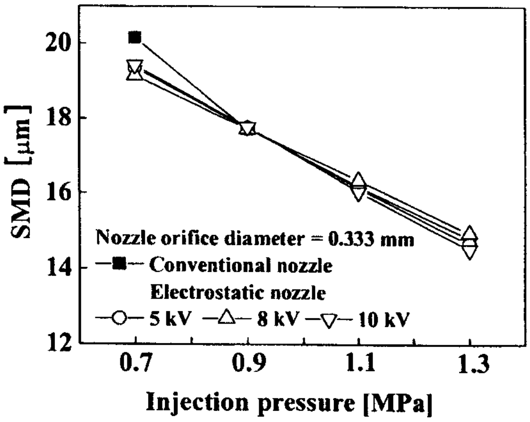
The mean diameter was measured at axial distance of 20 mm from the nozzle exit to the center of the laser beam. The measured mean diameters (SMD) are shown in Fig. 5. It can be seen from Fig. 5 that, the mean diameter decreased with an increase in injection pressure for the conventional nozzle and decreased with an increase in applied voltage for the electrostatic nozzle. In our previous experiment, it was revealed that, the electrostatic nozzle showed high spray volume than the



a) Nozzle orifice diameter : 0.256mm



b) Nozzle orifice diameter : 0.308mm



c) Nozzle orifice diameter : 0.333mm

Fig. 5 Variation of injection pressure on mean diameter for conventional and electrostatic nozzles for orifice diameters of a) 0.256, b) 0.308 and c) 0.333 mm respectively

conventional nozzle under the same experimental conditions. The increase in spray volume was due to the effect of high voltage which overcame the surface tension of the liquid.(6)

At injection pressure of 0.7 MPa, the mean diameter decreased by 8.4, 7.1 and 3.6% for the nozzle with orifice diameters of 0.256, 0.308 and 0.333 mm respectively, 12.3% for orifice diameter of 0.308 mm at injection pressure of 0.9 MPa. This means by using this nozzle under this condition, the amount of unburned hydrocarbon fuel may be reduced. The nozzle with orifice diameter of 0.333 mm is not recommended for electrostatic atomization process. It can be concluded from the figure that, the electrostatic is superior to the conventional nozzle.

4. Conclusion

The following conclusions are drawn from this experimental study.

The spray characteristics comparison between the conventional and electrostatic nozzles showed that, the electrostatic nozzle has a shorter breakup length than the conventional nozzle. The spray angle produced by the electrostatic nozzle is wider than that of the conventional nozzle. This is due to the charge on individual droplets that in effect causes the droplet to repel in the presence of electrical field. Also the measured mean diameters (SMD) from the electrostatic nozzle are smaller than the one sprayed by the conventional nozzle. In addition, high spray volume can be obtained by using electrostatic nozzle especially at low injection pressures. The electrostatic nozzle is more superior to the conventional nozzle due to the high voltage effect that acts on the surface tension of the liquid.

Acknowledgement

This work was supported by Chungbuk National University Research Grant in 2005.

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