SPRAY CHARACTERISTICS OF A MULTI-CIRCULAR JET PLATE IN AN AIR-ASSISTED ATOMIZER USING SCHLIEREN PHOTOGRAPHY

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ABSTRACT

This study investigates the effects of a multi-circular jet plate on the spray characteristics of an air-assisted atomizer in a burner system. Schlieren photography is used to capture spray images, and different parameters, such as spray tip penetration, spray angle, and spray area, are analyzed. Three types of plates with different geometries and open area ratios are studied at equivalence ratios of 0.5 to 0.9 (lean condition) and 1.0 (stoichiometric condition). Results show that a high fuel flow rate increases the spray penetration and spray area but reduces the spray angle. Application of the multi-circular jet plate in the burner system affects spray behavior and contributes to the combustion performance and emission of the burner system.

Keywords: multi-circular jet plate, turbulence generator, air-assisted atomizer, burner, Schlieren photography.

INTRODUCTION

Atomizers are widely utilized in industrial applications, particularly those involving combustion equipment. In air-assisted atomizers, a relatively slow-moving liquid is exposed to high-velocity air originating from the compressor; this high-velocity air produces atomization. The droplets produced possess a larger surface area than the mass, and this large surface area enables the fuel to evaporate at a very high rate. This factor contributes to the improvement of combustion efficiency [1].

Fuel spray has been studied intensively by many researchers by using the macroscopic approach [2–4]. Spray characteristics can be defined in physical parameters, such as spray penetration, spray angle, and spray area. The detailed characteristics of spray, including drop size, density, drop velocity, and drop size distribution, have also been examined. Several studies have concluded that spray behavior is influenced by nozzle diameter [3–4], internal geometry of the atomizer, properties of the gas medium, and physical properties of the liquid fuel [1].

Turbulence generators usually generate high-intensity turbulence travelling in an extended region at some distance downstream of the grid with a relatively a small pressure drop [4–5]. In other words, the turbulence generator in fuel spray facilitates the formation of a fuel–air mixture. Swirl is a component used in industries to improve the mixture of diesel fuel and air. The presence of a swirled mixture improves combustion and reduces harmful gases [6]. Increasing the swirl number to approximately unity can improve the mixture of diesel fuel and air [7].

Quantitative Schlieren techniques are utilized to measure refractive index distributions and related quantities in transparent media [8–10]. This study used indirect photography; a Schlieren system with a digital video camera was used to capture spray images and the detailed behavior of mixture formation. Spray penetration, spray angle, and spray area can be clearly determined from images with this method [11–12].

In this study, the effects of a multi-circular jet (MCJ) plate on the spray characteristics and mixture formation of fuel–air were investigated. An experiment was conducted in a closed chamber system with Schlieren Z-type indirect photography using diesel fuel.

METHODOLOGY

Air-assisted atomizer and burner system

The atomizer shown in Figure-1 was used as a component of fuel and air mixing during combustion [8]. It has eight holes, and the diameter of the nozzle is 1 mm. Diesel fuel with a density at 837 kg/m³ was utilized in the experiment (Table 1). A multi-circular jet plate was installed inside the premix chamber. Three different geometries, namely, MCJ 1 (8 holes with 2 mm diameter), MCJ 2 (6 holes with 2 mm diameter and 4 holes with 1.5 mm diameter), and MCJ 3 (4 holes with 2 mm diameter and 8 holes with 1.5 mm diameter), were investigated. The physical appearance of the MCJ plate is described as an open area (A_e). The percentage of the plate open area to the plate total area is $\%A_e = (A_e/A_p) \times 100$. A_p is defined as the plate's total area. The percentage of open area was calculated for MCJ 1, MCJ 2, and MCJ 3 at 17.82, 13.92, and 10.03 (Figure 2), respectively.

The investigation was conducted at five different equivalence ratios: from 0.6 to 0.9 (lean) and 1.0 (stoichiometric). The studied parameters included spray penetration, spray angle, and spray area. The working condition was characterized by ambient temperature T of 303 K, flow rate of primary air at 40 l/min, and air pressure of 1 bar from the air compressor (Table-2). Fuel flow rate was calculated from the constant air flow rate at 40 l/min at different equivalence ratios.

VOL. 12, NO. 4, FEBRUARY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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Optical setup

The spray was observed with the Schlieren Z-type method. A schematic of the method and the optical equipment are shown in Figure-3. In this method, parallel light from an LED lamp is focused on the first concave mirror, transmitted through the test region, and reflected to a focal point where the knife edge was located. Flat reflecting mirrors were used to save space. A video was recorded with a digital single-lens reflex (DSLR) camera for 20 s and further processed for analysis.

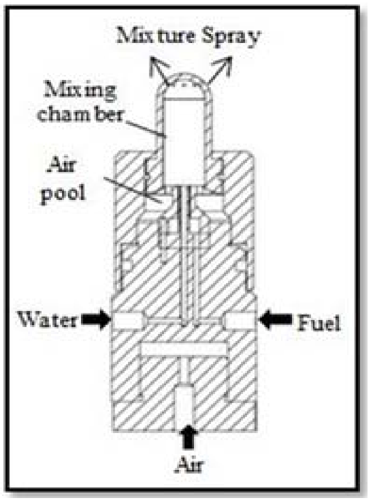

Figure- 1. Cross-sectional view of air-assist atomizer.

Table-1. Diesel fuel properties.

Properties	Value
Density (g/cm^3)	0.83374
Kinematic viscosity (Cp)	3
Flash point (°c)	80
Water content (%)	0.00796
Acid value (mgKOH/g)	0.423

(a) MCJ 1	(b) MCJ 2	(c) MCJ 3
%Ae = 17.82 Diameter 2 mm x 8 holes;	%Ae = 13.92 Diameter 2 mm x 6 holes; Diameter 1.5 mm x 4 holes	%Ae = 10.03 Diameter 2 mm x 4 holes; Diameter 1.5 mm x 8 holes

Figure-2. Geometrical configurations of MCJ plates.

Table-2. Equipment and experimental condition.

Air Compressor	Model	QUASA HDC-D3050
	Capacity, L/min	200
	Pressure, kg/cm^2	8
Water Pump	Model	SFDP1-014-080-22-Seaflo
	Voltage, V	12
	Flow rate, L/min	5.1
Fuel Pump	Model	CNY-3805
	Pressure, bar	3
	Flow rate, L/hr	100
DC Voltage Regulator	Model	Teletron TC-1206A
	Current, A	64 (max)
Operating condition	Air Pressure, MPa	0.1
	Air Density, kg/m^3	1.16
	Ambient Temperature, K	300
	Equivalence Ratio	0.6 - 1.0

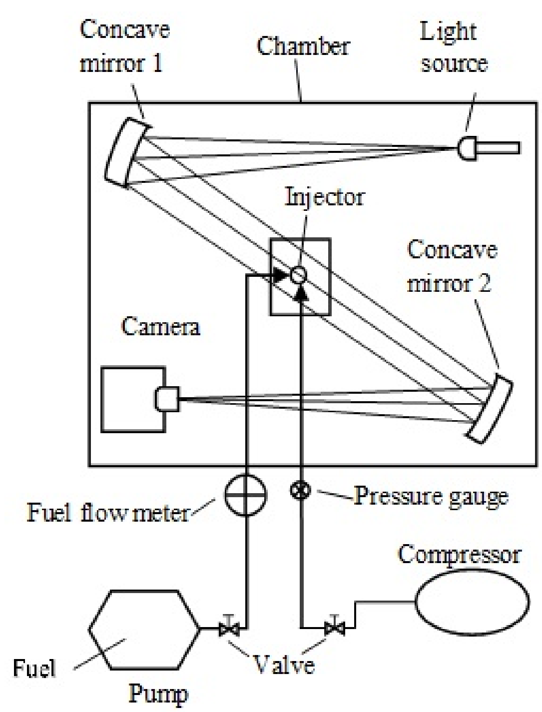

Figure-3. Schematic diagram of experimental setup.

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Image analysis method

The image of the spray (Figure-4) was initially recorded with a DSLR camera. The video was obtained at a set duration time of 20 s from the initial fuel and air supplied until maximum penetration was reached. The video was then converted into real images by using GomPlayer software. An image of a spray is shown in Figure-5 at different equivalence ratios using MCJ 1. Solidwork was utilized to measure the length penetration, angle, and area of the spray. The eight spray jets visually produced increasingly consistent and homogeneous sprays as the equivalence ratio increased. This result is due to the fact that an increase in fuel flow rate improves the atomization of the two-phase atomizer [13].

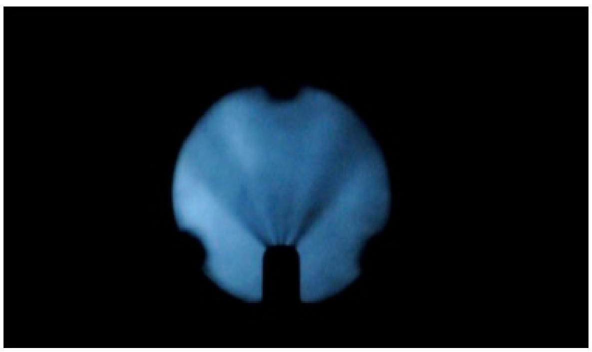


Figure-4. Image captured using MCJ 1 at equivalence ratio 1.0.

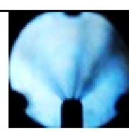
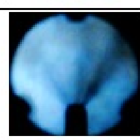
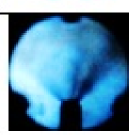
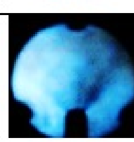
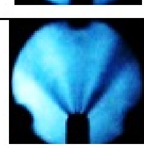
Equivalence ratio	Time 0.12 s
0.6	
0.7	
0.8	
0.9	
1.0	

Figure-5. Schlieren images using MCJ 1.

RESULTS AND DISCUSSION

Effect of equivalence ratio

The influence of equivalence ratio on different plate geometries was analyzed, as shown in Figures-6 to 8. Figure-6 shows that the spray area and spray penetration for MCJ 1 increase while the spray angle decreases at different equivalence ratios. This trend was also observed in Figures-7 and 8, which represent MCJ 2 and MCJ 3, respectively.

The results show that spray angle, spray area, and spray penetration depend on the flow rate of liquid fuel and primary air. At a very high flow rate, the two-phase mixture inside the orifice is fully dispersed and discharges from the orifice in the form of drops suspended in the atomizing air [13]. This phenomenon is due to the fact that an increase in fuel flow rate enhances the interaction between liquid and air. This enhancement causes air–fuel mixing to increase and become sufficient [14], thereby improving the spray formation. The other factors that contribute to the spray characteristics are diameter of the exit orifice, diameter of the mixing chamber, and liquid fuel viscosity [13].

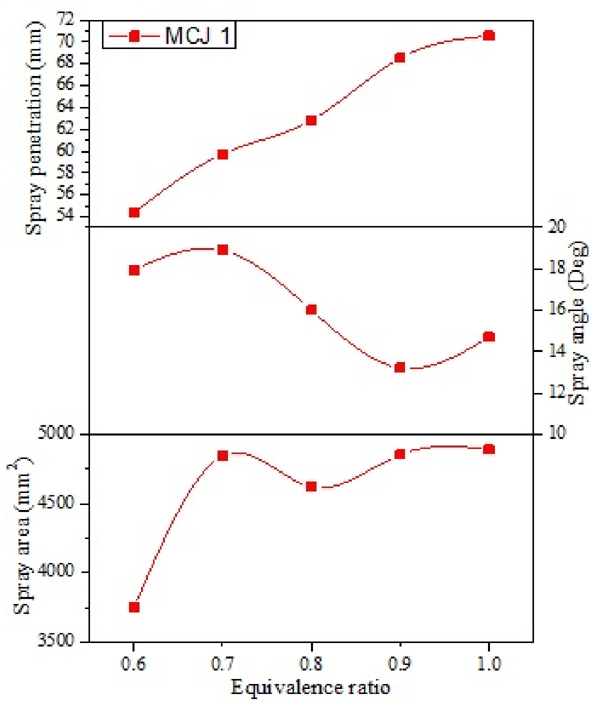


Figure-6. Spray characteristic of MCJ 1.

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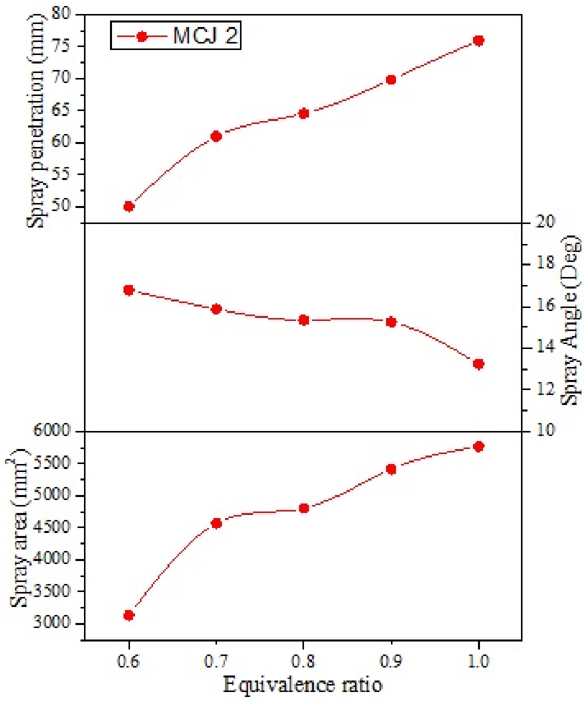

Figure-7. Spray characteristic of MCJ 2.

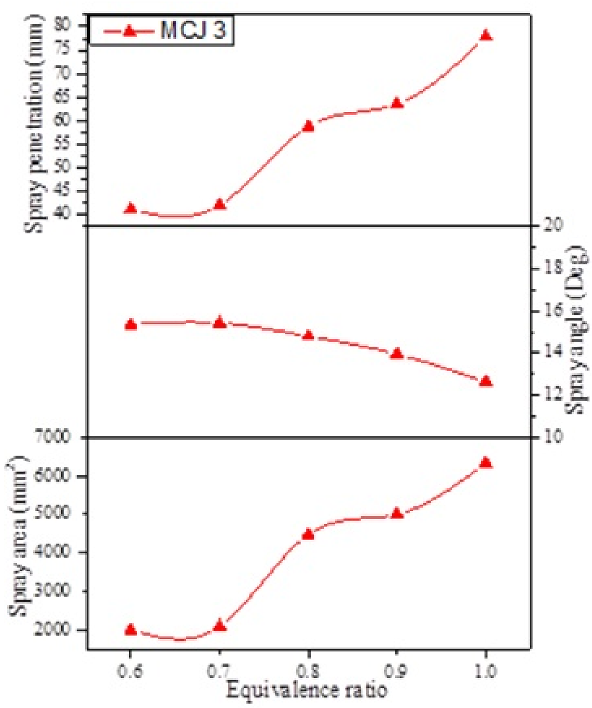

Figure-8. Spray characteristic of MCJ 3.

Effect of plate geometry

Figure-9 shows the comparison of all plates at different equivalence ratios. Analysis indicates that the largest spray area is exhibited by MCJ 2, followed by MCJ 1 and MCJ 3. MCJ 3 possesses the lowest spray area at 0.6 and 0.7, but the value increases to the values of MCJ 1 and MCJ 2 from 0.8 to 1.0. This increase is contributed by an increase in fuel flow rate as the atomization becomes more consistent, thereby easily increasing the spray area. This result shows that a plate with a small open area can operate in a nearly stoichiometric condition beginning from 0.8 up to 1.0 [13]. The high blockage of MCJ 3 requires a certain flow rate to overcome the resistance before achieving good atomization. As a result, MCJ 2 with the second largest open area produces the best spray quality in terms of area, angle, and penetration.

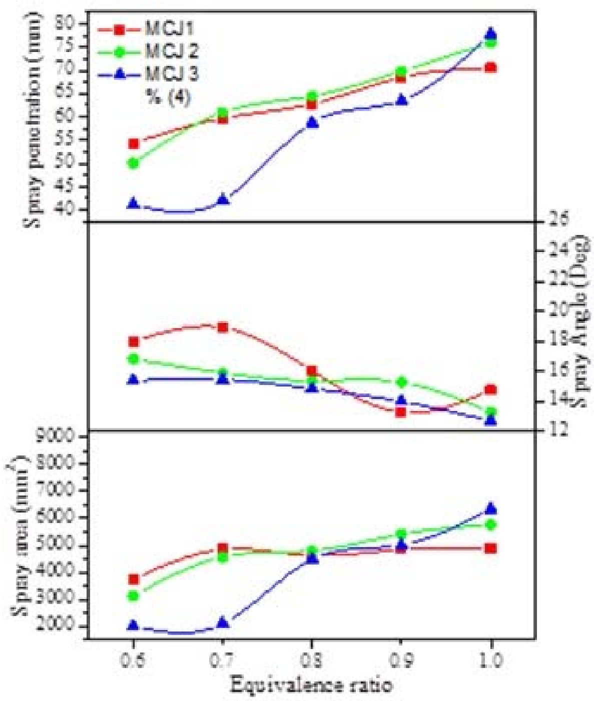

Figure-9. Spray characteristic of all plates.

CONCLUSIONS

First, an increase in fuel flow rate enhances air–fuel interaction and increases penetration length and spray area with a slight decrease in the spray angle. Second, the presence of the MCJ plate in the atomizer generates high-intensity turbulence, which contributes to an increase in penetration length and spray area. These criteria help produce high burning velocity compared with the existing system.

Third, MCJ 2 with an open ratio of 13.92 is consistent in producing a large spray area and large spray penetration compared with MCJ 1 and MCJ 3. However, in the stoichiometric condition, MCJ 3 performs better than the others in terms of spray quality.

ACKNOWLEDGEMENTS

The authors would like to thank the Ministry of Higher Education Malaysia for supporting this research under Exploratory Research Grant Scheme (ERGS) Vot E033.

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