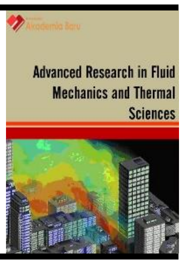
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Spray Formation in the Multi-Hole Nozzle of Twin-Fluid Atomizers

Open Access

Amir Khalid[1], Shahrin Hisham Amirnordin[2,*], Uthayakumar Vasuthavan[2], Azian Hariri[2], Mas Fawzi[2]

[1] Automotive and Combustion Synergies Technology Group, Faculty of Engineering Technology, Universiti Tun Hussein Onn Malaysia, Pagoh Higher Education Hub, 84600 Pagoh, Muar, Johor, Malaysia
[2] Combustion Research Group (CRG), Centre for Energy and Industrial Environment Studies (CEIES), Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 5 October 2018
Received in revised form 20 December 2018
Accepted 5 January 2019
Available online 9 January 2019

Keywords:
Internal mixing twin-fluid atomizer, multi-circular jet plate, open area ratio, breakup length, air-fuel mixing

ABSTRACT

The atomization of internal-mixing twin-fluid atomizers is highly dependent on the internal geometry of the mixing chamber. Many studies have been conducted on the air entrance geometry influencing the air-fuel mixing. This paper aims to determine the effects of a multi-circular jet (MCJ) plate on the spray formation of twin-fluid atomizers. Plates 1, 2 and 3 with different open area ratios were used in the experiments. A swirler was used for comparison. The spray images were captured at different equivalence ratios using a direct photography method. ImageJ software was used to analyse the breakup length of spray formation. Results corroborate that, as the open area ratio of an MCJ plate increases, the break-up length decreases. The opening area for primary air entrance into the mixing chamber contributes to the air-fuel mixing, thereby affecting the spray performance of twin-fluid atomizers.

1. Introduction

Fuel atomization is a critical process in determining the performance of atomizers in a burner system. Many atomizers are commercially available for various industrial applications, including pressure, rotary and twin-fluid type. High quality of atomization ensures the fast evaporation of fuel and good mixing between fuel and air, thereby resulting in high combustion efficiency and the reduction of emissions [1-3].

Internal mixing twin-fluid atomization has been studied intensively by many researchers [4-6]. Its advantages include good spray quality at low pressure, easy-to-control spray performance and low primary air consumption compared with the external mixing of different atomizers [7,8].The atomizer nozzle geometry plays an important role in the characteristics of spray atomization and mixture formation of fuel and air which contribute to enhancing the combustion performance [1,9].

[*] *Corresponding author.*
E-mail address: shahrin@uthm.edu.my (Shahrin Hisham Amirnordin)

Several studies involving the different operating conditions of atomizers include gas-to-liquid ratio, air and liquid injection pressure [10].

Many factors influence the spray performance including the liquid properties [11] and geometry of atomizers [1, 6, 12]. Investigation on geometrical parameters on the spray formation, especially their effects on the interaction of fuel and air in a mixing chamber, was conducted. In this study, the diameter of air channel and liquid ports play a major role to influence the Sauter mean diameter. A decrease in air injection area and injection length can reduce the droplet size [7] of a spray.

2. Methodology

Table 1 shows the diesel properties used in this experiment. Figure 1 exhibits the equipment setup and cross-sectional view of twin-fluid atomizers. Diesel fuel entered through the side channels, whereas the primary air entered through the multi-circular jet (MCJ) plate into the mixing chamber. The plate functions as a turbulence generator to improve the mixing of fuel and air before spraying into the atmosphere. The experiments were carried out using four different types of plates which are plate 1, plate 2, plate 3 and swirl (Table 2). The spray nozzle at the top of the chamber is 1 mm in diameter and has eight holes.

The atomizer was equipped with an air compressor to supply the primary air at 1 bar. The fuel pump was used to supply diesel to the atomizer. The fuel was controlled by the Ono Sokki mass flow meter. Table 3 shows the equipment and experimental conditions. The investigation was conducted at five equivalence ratios (ER) from 0.8 to 1.2.

Table 1
Properties of diesel fuel (No. 2)

Property	Unit	Value
Density at 15° C	kg/l	0.8296
Flash point	°C	62
Kinematic viscosity at 40°C	cST	3.4

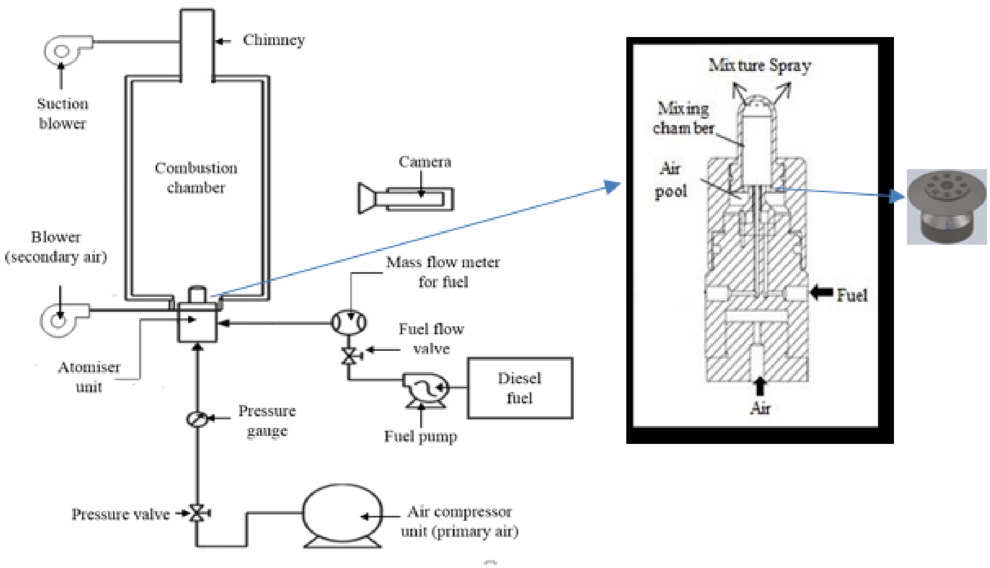


Fig. 1. Schematic diagram of the experiment

Table 2
Specification of the plates

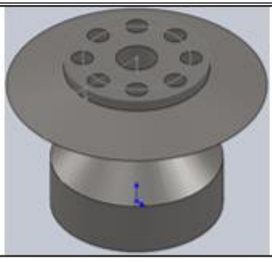
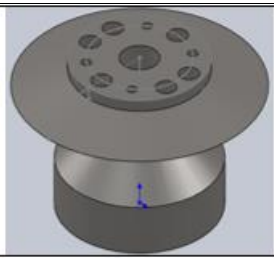
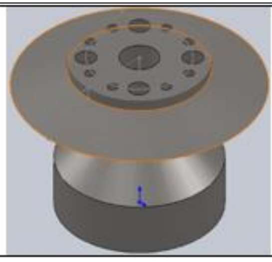
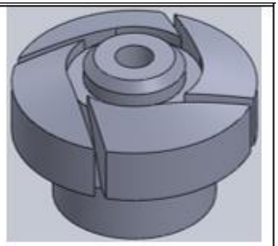
Plate 1	Plate 2	Plate 3	Swirl
Diameter 2 mm x 8 holes; Open area ratio, Ae =17.8	Diameter 2 mm x 6 holes; Diameter 1.5 mm x 4 holes; Open area ratio, Ae =18.4	Diameter 2 mm x 4 holes; Diameter 1.5 mm x 8 holes; Open area ratio, Ae =18.9	Slit-width 0.45 mm Outer diameter 5.5 mm
			

Table 3
Equipment specifications and operating conditions

Air Compressor	Model	PUMA XN2040	Operating Conditions	Plate	1, 2, 3 and swirl
	Capacity, l/min	400		Air pressure, bar	1.0
	Pressure, kg/cm²	8		Air density at 30°C, kg/m³	1.184
Fuel Pump	Model	CNY-3805		Ambient temperature, K	300
	Pressure, bar	3		Fuel mass flow rate, kg/hr	4.941-7.412
	Flow rate, l/hr	115		Equivalence ratio, ER	0.8 - 1.2

A digital single-lens reflex camera (Nikon D5) with FX-format 20.8 MP CMOS sensor and EXPEED 5 image processor was used to obtain the visual of the spray. It has 12 fps continuous shooting rate with full time AF and AE, 4K UHD video recording at 30 fps and shutter speed at 1/8000 to 30 s. The images were focused on the plane of the central nozzle using a 10 cm height scale for image length calibration from a perpendicular view of a fix side of the chamber. The constant lighting was from the 6 units of the 20 W spotlight with a dark background of the chamber.

The spray images (Figure 2) were captured using macro 105 mm macro lenses, aperture at 2.8 and ISO 800 at 4 to 10 fps. The camera was located at 0.8 m from the object using a tripod. The transient images were captured at 30 fps at continuous height with f3 aperture. Eight images were captured for each reading. The images, which were 60 MB in raw format and 20 MB in JPEG format, were processed further using Photoshop. Eight images were analyzed using ImageJ for stable spray formation. The calibration of the images referred to the bar located next to the nozzle, and measurement was conducted on the break-up length of the spray (Figure 2).

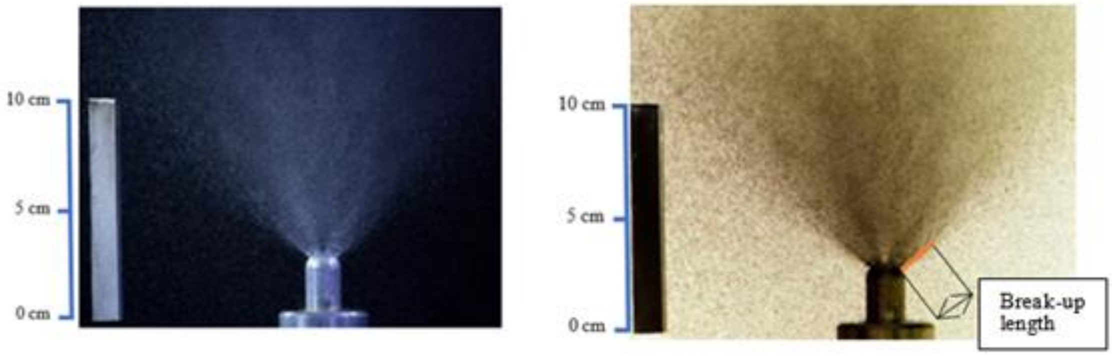


Fig. 2. Instantaneous and inverted images of spray formation

3. Results and Discussion

3.1 Spray Observation of Multi-Hole Nozzle

The atomization process must successfully break up all particles to make them fine for a complete combustion to occur. This study involves an introduction of diesel into the gaseous environment through an eight-hole nozzle of a twin-fluid internal mixing atomizer. The diesel interacts with the surrounding air and breaks up into droplets. Figures 3 to 6 show the inverted images of instantaneous spray dispersion from plate 1 to swirl at increasing ER from 0.8 to 1.2. Observation affirms that the spray formation occurs when the droplets detach from the outer surface of liquid core extending from the orifice of the nozzle. In all nozzles, primary breakup occurs when the liquid core disintegrates into the ligaments or large droplets. The liquid ligaments and large droplets break further into small droplets as a secondary breakup. The density of droplets near the nozzle produces the high-density region, which enters the dilute spray region as it travels further away from the nozzle. It agrees with the spray characteristics of the near nozzle flow described by a single nozzle [9,13]. However, each nozzle produces different break-up lengths at different ERs. The results of analysis are discussed further in the next sub section.

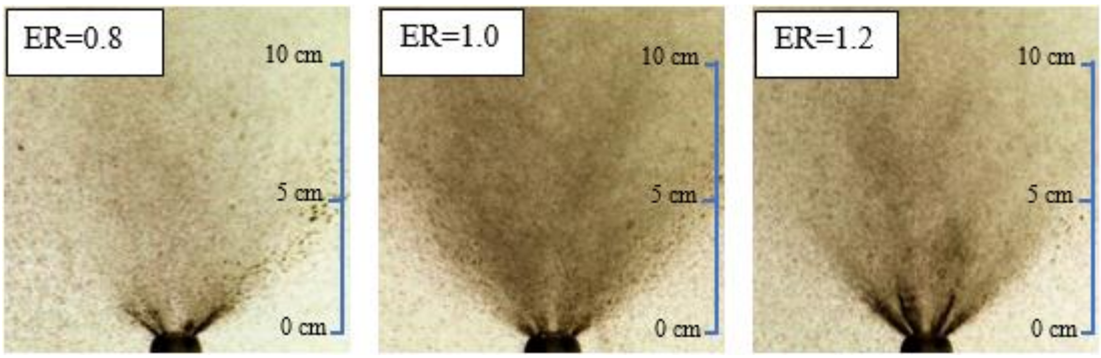


Fig. 3. Instantaneous images of spray generated using plate 1

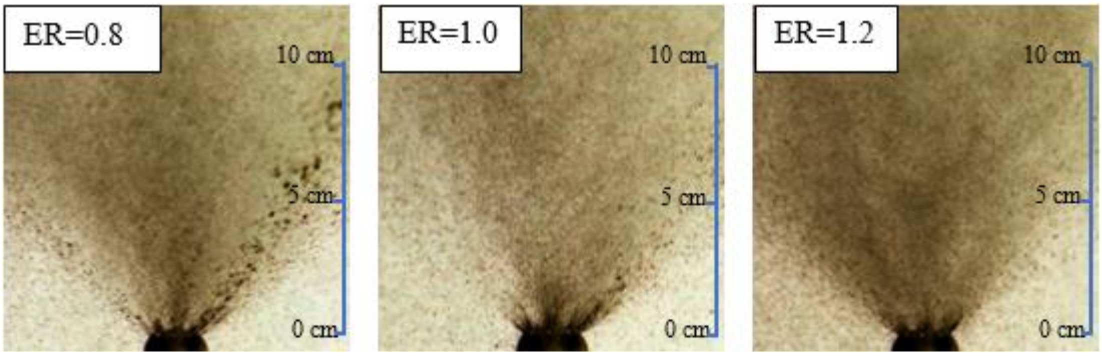


Fig. 4. Instantaneous images of spray generated using plate 2

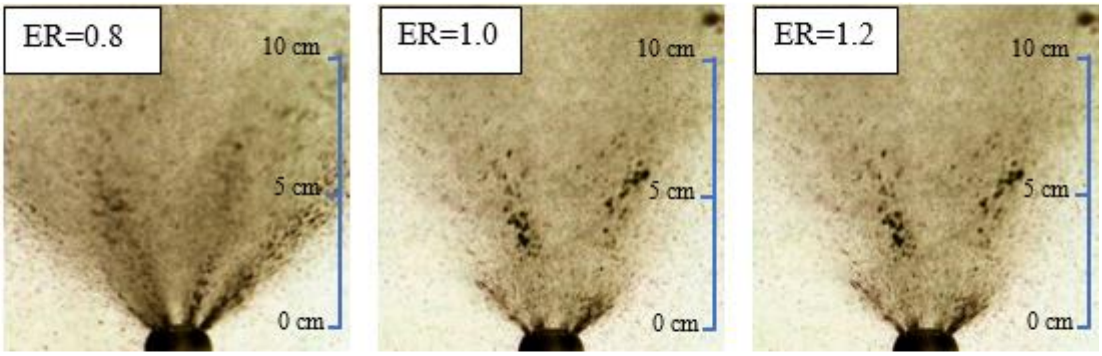


Fig. 5. Instantaneous images of spray generated using plate 3

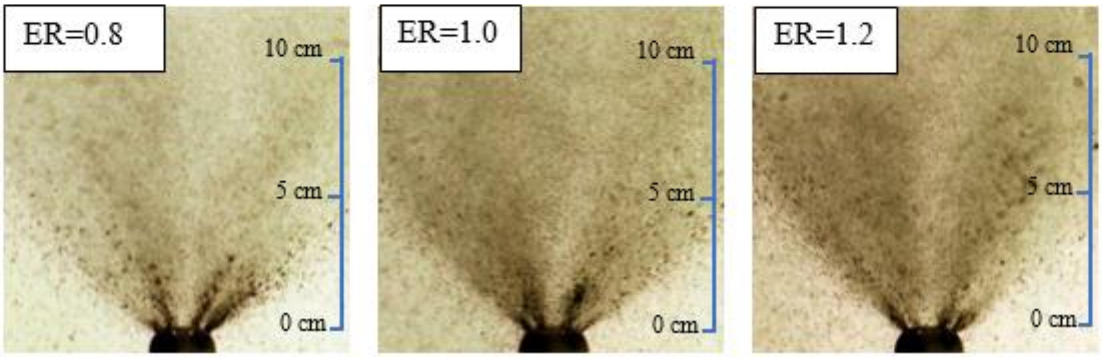


Fig. 6. Instantaneous images of spray generated using swirl

3.2 Effects of Equivalence Ratio and Open Area Ratio

Figure 7 illustrates the break-up length of plate 1, plate 2, plate 3 and swirl at different ERs. The break-up length of nozzle 1 slightly increases from ER 0.8 to 1.2. However, the break-up length of plate 2, plate 3 and swirl decreases from ER 0.8 to ER 1.2. The overall comparison depicts that at low ER, a large difference of break-up length is observed for all plates. As the ER increases, the difference is reduced significantly until it reaches the range within 5 to 7 mm for all plates. At the initial stage of ER, the primary atomization occurs as the gas liquid interacts and momentum exchanges between the fuel and air. The formation of liquid films near the nozzle is caused by fierce interactions in this area. As the liquid exits the orifice, the gas expands and creates unsteady flow. This condition generates fine and large droplets.

Nevertheless, as the ER increases, the diesel mass flow rate also increases. This will increase interaction and momentum exchange between the liquid and gas particles, thereby producing high kinetic energy of sprayed particles for all nozzles. The break-up length then decreases, thereby producing several droplets in this area which agrees with findings by other researchers [1,9,7].

Low break-up length shows the good atomisation of a spray. Figure 7 shows that plate 1 produces the lowest break-up length at an open area ratio of 0.178. As the open area ratio increases, the break-up length also increases. This is displayed by the plates 2 and 3 with open area ratios 0.184 and 0.189, respectively. An increase in an open area ratio reduces the air velocity into the mixing chamber because of less restrictions or blockages imposed by the plate. A reduction in air velocity also reduces the shear force that it exerts upon the liquid, delaying the formation of droplets from the liquid. Consequently, a reduction in the kinetic energy of air and liquid are observed, resulting in long break-up lengths which agrees with the related work by Kushari [7] on the twin-fluid atomizer. However, at high ER, the effects of a jet plate open area are reduced on the break-up length formation. At this stage, a high diesel flow rate produces high kinetic energy of air and liquid, which accelerate the droplet formation of all nozzles, reduce the break-up length and significantly improve the spray atomization [13-15].

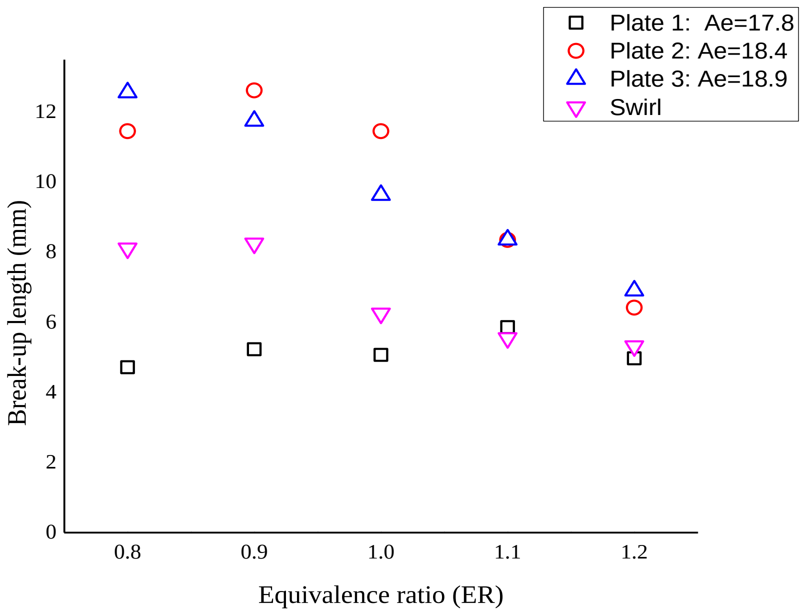


Fig. 7. Breakup length of multi-hole nozzle

4. Conclusions

The effects of using a MCJ plate as a turbulence generator for air fuel mixing in twin-fluid spray atomization were investigated experimentally. Plate 1 with the lowest open area ratio produces the lowest break-up length compared with plate 2, plate 3 and swirl. A low open area ratio produces short break-up lengths and improves the spray atomisation of twin-fluid atomisers at a low range of ER. However, the effects of an open area ratio on the break-up length formation decrease at high ER (ER 1.1 and 1.2).

Acknowledgement
The authors would like to thank the Ministry of Education Malaysia and UTHM for supporting this research.

References

[1] Ochowiak, Marek. "The experimental studies on atomization for conical twin-fluid atomizers with the swirl motion phenomenon." *Chemical Engineering and Processing: Process Intensification* 109 (2016): 32-38.
[2] García, J. A., A. Lozano, J. Alconchel, E. Calvo, F. Barreras, and J. L. Santolaya. "Atomization of glycerin with a twin-fluid swirl nozzle." *International Journal of Multiphase Flow* 92 (2017): 150-160.
[3] Etzold, M., A. Deswal, L. Chen, and F. Durst. "Break-up length of liquid jets produced by short nozzles." *International Journal of Multiphase Flow* 99 (2018): 397-407.
[4] Lefebvre, Arthur H. "Energy considerations in twin-fluid atomization." In *ASME 1990 international gas turbine and aeroengine congress and exposition*, pp. V003T06A002-V003T06A002. American Society of Mechanical Engineers, 1990.
[5] Ochowiak, Marek, Magdalena Matuszak, Sylwia Włodarczak, Andżelika Krupińska, Małgorzata Markowska, Anna Gościniak, and Tomasz Szulc. "The concept design and study of twin-fluid effervescent atomizer with air stone aerator." *Chemical Engineering and Processing: Process Intensification*124 (2018): 24-28.
[6] Mlkvik, Marek, Philipp Stähle, Heike P. Schuchmann, Volker Gaukel, Jan Jedelsky, and Miroslav Jicha. "Twin-fluid atomization of viscous liquids: The effect of atomizer construction on breakup process, spray stability and droplet size." *International Journal of Multiphase Flow* 77 (2015): 19-31.
[7] Kushari, A. "Effect of injector geometry on the performance of an internally mixed liquid atomizer." *Fuel Processing Technology* 91, no. 11 (2010): 1650-1654.
[8] Ferreira, Germán, Juan Antonio García, Félix Barreras, Antonio Lozano, and Eduardo Lincheta. "Design optimization of twin-fluid atomizers with an internal mixing chamber for heavy fuel oils." *Fuel processing technology* 90, no. 2 (2009): 270-278.
[9] Watanawanyoo, Pipatpong, Hirofumi Mochida, Teruyuki Furukawa, Masanori Nakamura, and Hiroyuki Hirahara. "Experimental study on the spray characteristics of an air assisted atomizer with internal mixing chamber." *European Journal of Scientific Research* 84, no. 4 (2012): 507-521.
[10] Yoon, Soon Hyun, Dong Keon Kim, and Bong Hwan Kim. "Effect of nozzle geometry for swirl type twin-fluid water mist nozzle on the spray characteristic." *Journal of mechanical science and technology* 25, no. 7 (2011): 1761.
[11] Li, Zhouhang, Yuxin Wu, Hairui Yang, Chunrong Cai, Hai Zhang, Kazuaki Hashiguchi, Keiji Takeno, and Junfu Lu. "Effect of liquid viscosity on atomization in an internal-mixing twin-fluid atomizer." *Fuel* 103 (2013): 486-494.
[12] Zaremba, Matouš, Lukas Weiß, Milan Malý, Michael Wensing, Jan Jedelský, and Miroslav Jícha. "Low-pressure twin-fluid atomization: Effect of mixing process on spray formation." *International Journal of Multiphase Flow* 89 (2017): 277-289.
[13] Basak, Arindam, Jitendra Patra, Ranjan Ganguly, and Amitava Datta. "Effect of transesterification of vegetable oil on liquid flow number and spray cone angle for pressure and twin fluid atomizers." *Fuel* 112 (2013): 347-354.
[14] Barroso, Jorge, Antonio Lozano, Félix Barreras, and Eduardo Lincheta. "Analysis and prediction of the spray produced by an internal mixing chamber twin-fluid nozzle." *Fuel Processing Technology* 128 (2014): 1-9.
[15] Lal, Suresh, A. Kushari, M. Gupta, J. C. Kapoor, and S. Maji. "Experimental study of an air assisted mist generator." *Experimental Thermal and Fluid Science* 34, no. 8 (2010): 1029-1035.