Jurnal Teknologi

Full Paper

Effect of Geometrical Parameters Interaction on Swirl Effervescent Atomizer Spray Angle

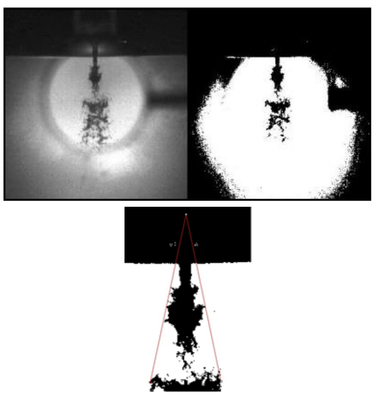
Zulkifli Abdul Ghaffar, Salmiah Kasolang*, Ahmad Hussein Abdul Hamid, Ow Chee Sheng, Mimi Azlina Abu Bakar

Faculty of Mechanical Engineering, Universiti Teknologi MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia

Article history
Received
15 February 2015
Received in revised form
30 April 2015
Accepted
31 May 2015

*Corresponding author
salmiahk@salam.uitm.edu.my

Graphical abstract



Abstract

A wider spray angle produced by an atomizer is often required in providing a better spray dispersion. The formation and wideness of the spray angle were reported to be affected by the changes in geometrical parameters. In the present study, the effect of the interaction between two geometrical parameters (swirl-generating vane angle and discharge orifice diameter) on the swirl effervescent atomizer spray angle was studied. A newly-designed swirl effervescent atomizer was developed with 30°, 45° and 60° swirl-generating vane angle and 1.5, 2.0 and 2.5mm discharge orifice diameter. The atomizer performance tests were carried out using water as the working fluid and nitrogen gas as the atomizing agent. High-speed shadowgraph technique was deployed to record the resultant sprays produced. Video recordings, acquired using a high-speed video camera, were converted to a sequence of images for further analysis using image processing software. It was found that geometrical parameters of the newly designed atomizer have a great impact on the formation and characteristics of the spray angle. The combined effect of both swirl-generating vane angle and discharge orifice diameter has produced an increase in the spray angle. The largest spray angle was observed at the largest dimension of both geometries.

Keywords: Swirl effervescent atomizer, spray angle, geometrical parameters

1.0 INTRODUCTION

The spray angle is an important spray characteristic of an atomizer since a wider spray angle provides a wider spray dispersion. This is an important spray features for various applications such as food coating, spray painting and pesticide sprays. Furthermore, Ibrahim [1] and Khavkin [2] have denoted that the one of the main parameters of the swirl-related atomizer are the spray angle beside the droplets size.

Spray angle depends on physical properties of the fluid as well as the geometry of the atomizer [3]. One of the generator of spray angle is the swirl-generating vane. Rho *et al*. [4] have constructed a twin-fluid atomizer with attached swirl-generating vane. They have varied the swirl-generating vane angle and observed that a more intense swirling produces a wider spray angle. Ghaffar *et al*. [5] have conducted an experiment on the characteristics of swirl effervescent atomizer spray angle. They found that an increase in swirl-generating vane angle tends to increase the spray angle. Jedelsky and Jicha [6] have also found that swirling the gas-liquid mixture in an effervescent atomizer led to a significant increase of the spray cone angle at low gas to liquid ratio by mass (GLR). Other parameters reported to influence the enlargement of spray angle is discharge orifice diameter as discussed by Hussein *et al*. [7].

Swirl effervescent atomizer is one of the atomizers which potentially applied in various machines and instruments due to the low injection pressure required to achieve good atomization and wideness of spray angle. Basically, the mechanism of this type of atomizer encompasses the combination of mechanisms of two types of atomizers which are swirl atomizer and effervescent atomizer. Particularly, in swirl effervescent atomizer, gas bubbles are injected into the atomizer which produces a gas-liquid mixture in the chamber. The gas-liquid mixture passes through the swirl-generating vane before exiting the atomizer through the discharge orifice. This has produced a spray with a cone type.

The study on the wideness of the cone or specifically, the spray angle of this atomizer is hardly available. This has resulted in the behavior of spray breakup of this type of atomizer hardly understood and further investigations are required. Our previous work concern only on the effect of one geometry at a time and neglecting the interaction between geometries. Understanding the interaction of the geometries is very important in determining whether the simultaneous changes of the geometries improve the widening of the spray angle.

This paper aims to investigate the influence of swirl-generating vane angle and discharge orifice diameter and their simultaneous interaction on the characteristic of the spray angle of a newly developed swirl effervescent atomizer. The image of spray angle, a of resultant spray characteristics produced by an atomizer is shown in Figure 1.

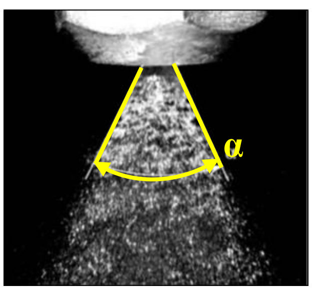


Figure 1 Image of spray angle, a (adapted from [8])

2.0 EXPERIMENTAL METHODS

2.1 Atomizer Geometries and Operating Principles

The swirl effervescent atomizer deployed has an inside-out gas injection configuration that enables gas bubbles coming out from the aeration tube to mix with the bulk liquid in the mixing chamber. The atomizer has two inlets in which liquid enters the mixing chamber through the side inlet and gas enters through the central inlet. The gas-liquid mixture passes through the swirl-generating vanes which create swirling effects on the mixture before exiting the atomizer through the discharge orifice.

The swirl motion of the liquid pushes the flow close to the wall to create a zone of low pressure along the center line. This results in air back flow in the nozzle and hence the formation of air-cored vortex is established. The convergent section near the discharge orifice accelerates the flow prior to exiting the atomizer [1]. The liquid spreads out in the form of a conical sheet as soon as it leaves the atomizer and a hollow cone or a solid cone spray is formed due to the breakup of the sheet [9].

The atomizer main body is made up of Perspex to facilitate internal flow visualization. The schematic of the swirl effervescent atomizer is shown in Figure 2.

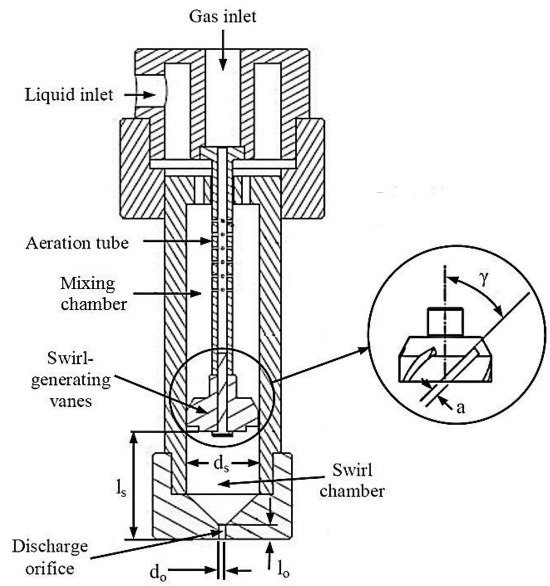


Figure 2 Schematic of a newly designed atomizer with the nomenclature of atomizer geometries

2.2 Experimental Test Rig

An experimental test rig was constructed to perform the atomizer performance test. Water was used as the working fluid and nitrogen as the atomizing gas. A line diagram of the test-rig is shown in Figure 3.

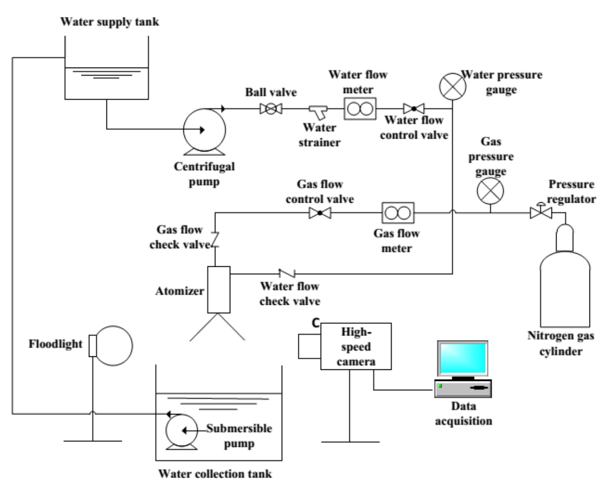


Figure 3 Line diagram of test rig

A centrifugal pump delivers water from the water supply tank to the atomizer through the water-line. The amount of water flowing out of the pump controlled by the ball valve. Pressure regulator controls the amount of gas flow from the nitrogen gas. Measurement of water and gas flow rate in the system is obtained through water and gas flow meter respectively. The flow of both water and gas are controlled by globe valves. Water strainer is installed at the inlet of water flow meter to prevent unwanted debris passing through the meter which could cause malfunctioned [10]. Water and gas injection pressures are measured by digital pressure gauges. Water flow and gas check valve were installed at the inlet of the atomizer to allow only one-direction flow. The atomizer fixed in vertical downward position produce water sprays into a water collection tank. A submersible pump delivers the water back into the water supply tank to complete the cycle. The water flowrate was held at a constant value. Video recordings of the resultant sprays produced were captured by a high-speed video camera with 800x600 resolutions at 1000 frames per second. The shutter speed was set to maximum value of 5μs. Shadowgraph technique was applied in acquiring the resultant sprays video recordings.

During the atomizer performance test, the swirl-generating vane angle was controlled by changing the swirl-generating vane. There are three swirl-generating vane fabricated with different angle as shown in Figure 4. The control method of the discharge orifice diameter is the same as the swirl-generating vane. Three different discharge cap with three different orifice diameter were fabricated.

Figure 4 Swirl-generating vane with three different angle

2.3 Spray Angle Measurement

Acquired videos were converted to a sequence of images. These sequences of images were processed via image processing software for further analysis. In measuring the spray angle, the spray images were converted to binary form to facilitate the visualizations of the spray boundary as shown in Figure 5. Angle measurement tool was utilized in determining the spray angle as depicted in Figure 6.

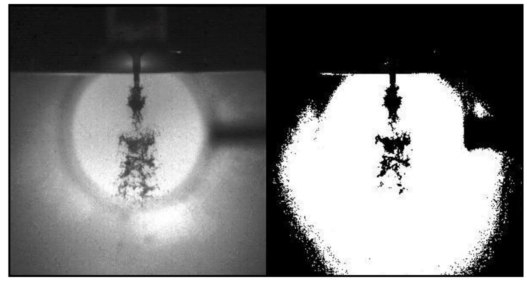


Figure 5 Binary conversion

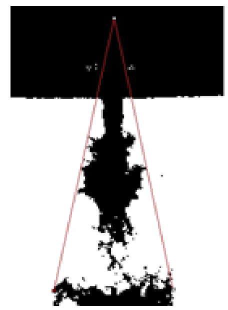


Figure 6 Angle measurement using the angle tool in ImageJ (red triangular line)

3.0 RESULTS AND DISCUSSIONS

3.1 Effect of Swirl-generating Vane Angle on Spray Angle

Figure 7 illustrates the effect of swirl-generating vane angle on the spray angle. It is observed that the spray angle visualizes an upward trend with the increased of the vane angle. The spray angle increase up to 11.23° with 60° swirl-generating vane angle to achieve a 25.01° angle. This is probably occurring because swirl-generating vane angle associated with the swirl intensity of a liquid/liquid-gas mixture flowing in the atomizer. Yang *et al*. [11] stated that the conversion of the centrifugal pressure produced by the swirling liquid sheet to the axial velocity component tends to increase the wideness of the spray profile. A higher swirl intensity associated with a higher centrifugal pressure and hence, widens the spray profile.

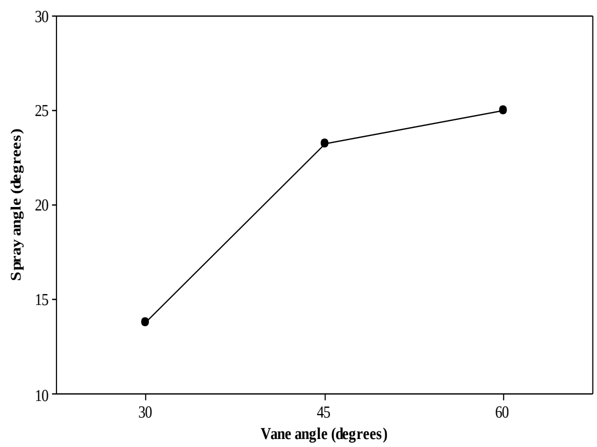


Figure 7 Effect of swirl-generating vane angle on spray angle (GLR = 0.0006 and d_o = 2mm)

3.2 Effect of Discharge Orifice Diameter on Spray Angle

The relation of the discharge orifice diameter to the spray angle is shown in Figure 8. The spray angle shows a small increment with the increase of discharge orifice diameter. The increment rises slightly at larger discharge orifice diameter. The diameter of the discharge orifice has produced an increment of 4.93° to the spray angle to reach 24.6° as the discharge orifice enlarged from 1.5mm to 2.5mm.

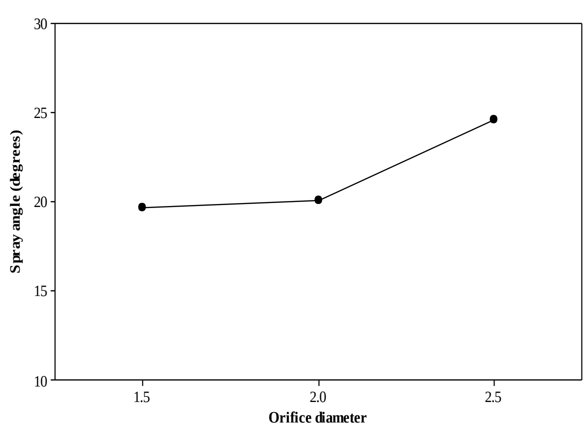


Figure 8 Effect of discharge orifice diameter on spray angle (γ = 45° and GLR = 0.0006)

A study conducted by Hussein *et al*. [7] have come to a conclusion that the discharge orifice diameter of jet-swirl atomizer affected the resultant spray angle. They have found that the enlargement of the discharge orifice diameter widens the spray angle. This verifies the relations of the discharge orifice diameter to the spray angle in the present research. The reason the increase of the discharge orifice diameter influences the increase of the spray angle is that a larger discharge orifice creates a larger air core which indicates a higher swirl intensity. The swirl intensities affect the widening of the spray angle hence, a larger discharge orifice contributed to a wider spray angle.

3.2 Effect of Geometrical Parameters Interaction on Spray Angle

Figure 9 shows the interaction plot between discharge orifice diameter to swirl-generating vane angle on spray angle. It shows that spray angle increases with increasing discharge orifice diameter in all cases of swirl-generating vane angle tested. The dominance of discharge orifice diameter on the widening of spray angle occurs at 30° swirl-generating vane angle. It is observed that the spray angle abruptly increases as the discharge orifice diameter approaching a highest value of 2.5 mm. It is also observed that neither parameter has interacted antagonistically which could lessen their influence on the spray angle.

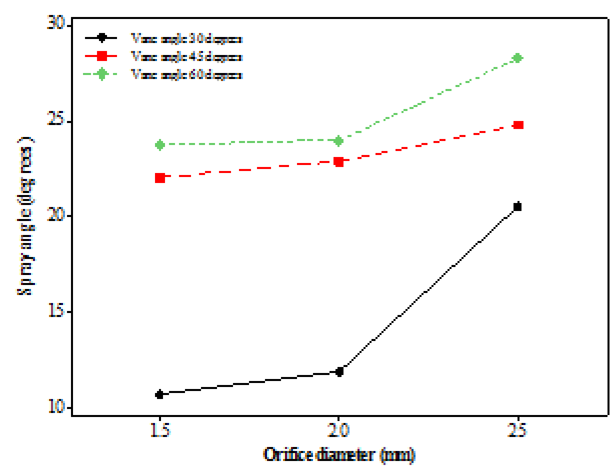


Figure 9 Interaction plot between discharge orifice diameter to swirl-generating vane angle on spray angle

4.0 CONCLUSIONS

This study was conducted for investigating the performance of a newly developed swirl effervescent atomizer. Performance evaluation in term of the spray angle revealed that the geometrical parameters have a significant impact on the formation and characteristics of the spray angle. The combined effect of both discharge orifice diameter and swirl-generating vane angle has resulted in an increasing spray angle. The largest spray angle was observed at the largest dimension of both geometries.

Acknowledgement

The authors thank the Ministry of Education (MOE) of Malaysia for their financial support of this study through the MyBrain, FRGS, and ERGS Grant awards. The authors are also indebted to the Research Management Institute of UiTM for facilitating this project.

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