ERJ
Engineering Research Journal
Faculty of Engineering
Minoufiya University

EXPERIMENTAL STUDY OF INTERNAL AND EXTERNAL TWIN-FLUID ATOMIZER USING DIFFERENT HELICAL GROOVED PATHWAYS

M. A. O. Shehata
Mechanical Power Engineering Department, Faculty of Engineering,
Suez Canal University, Port Said, Egypt

ABSTRACT

The aim of this work is focusing on the behavior of internal and external twin-fluid atomizer using different helical grooved of air and water pathways, respectively. The present atomizer comprising a liquid inlet, an gas inlet arranged to receive a pressurized flow of air. A water flow path extending from the liquid inlet to a liquid stream outlet, and a helical air flow path extending from the gas inlet to a location adjacent the liquid stream outlet, which impinges on a liquid stream passing out through the liquid stream outlet for atomizing the liquid stream.

There are many parameters affecting the behavior of that spray. The spray performance of that atomizer has been studied by investigating the discharge coefficient of the liquid, the mass concentration and the spray cone angle. Therefore, an experimental test rig is built-up.

The effects of air injection pressure, helical geometry, length to diameter ratio (l/d) of mixing zone and air water ratio (AWR) have been considered. The injection pressure of air varies up to 0.5 MPa, the l/d ratio of the mixing zone varies up to 3.0 and the air to water ratios varies up to 17.

The results show that, as the air mass flow rate increases in all difference water pressures, the discharge coefficient decreases, but it increase by increasing the l/d. The triangle shape of helical groove has gross effect on spray characteristics. Spray cone angle increase with the air pressure increase, while it decreases with l/d increases at the same air pressure. As l/d is decreased the mass concentration has a wider radius as compared with first one.

ان الهدف الرئيسى لهذا البحث هو دراسة معمليه لسلوك مزرر تتم فيه عملية التزرية داخليا وخارجيا باستخدام تجاويف حلزونيه تأخذ أشكال مختلفه (مربع-مثلث-دائرى) حيث يمر الهواء المضغوط أفقيا حاله (١) خلال التجاويف الحلزونيه ليلتقى بالماء الذى يتدفق رأسيا لتتم عملية التزريه. أما الحاله (2) يمر فيها الماء أفقيا خلال التجاويف الحلزونيه والهواء المضغوط رأسيا.

ومن خلال الدراسه لبعض العوامل التى تؤثر علي أداء عملية الرش وهى:

- نسبة الهواء إلى الماء حتى القيمه ١٧
- نسبة طول إلى قطر منطقة الخلط حتى القيمه ٣ (عندما تكون هذه النسبة صفرا معنى هذا أن عملية الخلط تحدث خارجيا)
- ضغط الهواء حتى ٠,٥ ميجابسكال
- الفرق بين الحاله (١) والحاله (٢)

ومعرفة تأثيرها علي كلا من معامل التدفق للسائل وزاوية مخروط الرش وتوزيع الحبيبات على المحور الأفقى على بعد ثابت (٦٥ سم) من فوهة المزرر. وجد أن الزياده فى كمية تدفق الهواء عند فرق ضغط ثابت للماء تقلل من معامل التدفق لكنه يزيد بزيادة نسبة طول/قطر منطقة الخلط. ووجد أيضا أن شكل المثلث للتجويف الحلزونى والحاله (٢) يعطيا قيما أعلى من الأشكال الأخرى ومن الحاله (١). أما زاوية مخروط الرش وجد أنها تزيد بزيادة ضغط الهواء وتقليل نسبة الطول إلى قطر منطقة الخلط وعندما تقل هذه النسبه يزيد معها توزيع الحبيبات على المحور الأفقى.

Keywords: Atomization, discharge coefficient, helical flow path.

1. INTRODUCTION

Atomization is the process in which a certain volume of liquid is broken into many small drops generating a much increased surface area. The atomization of liquids has many important applications in the delivery of liquid fuels in internal combustion engines, jet engines and oil burners, in industrial processes such as spray drying and medical applications such as the delivery of drugs to the lungs.

Many studies of twin-fluid atomization have involved the direct injection of the liquid jet into a high velocity air stream. Some atomizers accomplish this by discharging the liquid at slow moving stream into a relative high velocity of air stream [1-3]. Another further twin-fluid method is effervescent atomization [4-6]. In effervescent atomizers, a small amount of air is introduced into the bulk liquid in a mixing chamber upstream of the discharge orifice. Karnawat et al [7] studied the controlled spray pattern that can be obtained with a novel twin-fluid internally mixed swirl atomizer. The atomizer can be used to provide a wide range of spray patterns in terms of spray cone angle and solidity of spray cone by adjusting the factors like liquid supply pressure, liquid flow rate and air-liquid ratio (ALR). An experimental studied by [8] into the production of fine drops of water by twin-fluid atomization using two types of atomizer, an internal mixing type atomizer and a novel type of prefilming air-blast atomizer. The applications of spray and combustion systems, the pressure swirl atomizer has attracted the attention of many research works and has been the subject of considerable theoretical and experimental studies. The most of researches concerning the twin-fluid atomizers can be found in [9-17]. The helical path pressure atomizer [18] considers as one of the pressure swirl atomizers where pressurized water flows inside the atomizer through a helical path and is issued from a nozzle hole as a spray to the atmosphere.

From the previous works, it can be concluded that there is few information about the twin-fluid atomizer using helical or curved pathway.

Therefore, in the present work, a twin-fluid atomizer using different helical grooved pathways was designed and manufactured in order to study the spray performance. This study includes the discharge coefficient of water, mass concentration, and spray cone angle issued into different air flowpath pressures. The effect of air injection pressure, air to water ratio (AWR), helical grooved shape and l/d of the mixing chamber are studied.

2. EXPERIMENTAL TEST RIG

An experimental test rig was constructed to measure the discharge coefficient, mass concentration and spray cone angle for different helical flowpath geometry, air mass flow rate at the same different water pressures and length to diameter (l/d) of mixing zone. A schematic diagram of the test rig is shown in Fig. 1 and photo (1). In the experiments, the supply water pressured by the gear fuel pump in order to offer the pressure needed was controlled by a valve and measured by Bourdon pressure gauge. The compressed air was supported by the air compressor depending on the required pressure, through an air chamber a filter control valve into the atomizer. The atomizer is mounted downwards on a vertical plane, so that the water spray is injected directly into a chamber at the ambient conditions. In all experiments, water and air have been used as atomized and atomizing fluids, respectively.

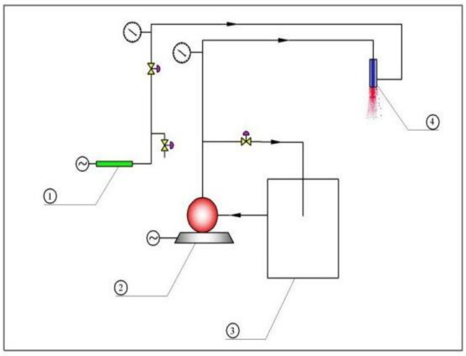


Fig.1 Schematic diagram of the test-rig

1- air compressor 3- water tank

2- gear fuel pump 4- atomizer

Photo (1) The experimental test- rig

The tested atomizer figures (2a and 2b) preferably comprise a housing defining a pressurized air inlet opening and a liquid inlet opening. Pressurized air inlet opening is preferably threaded so as to sealingly accept a suitably threaded pressurized air nipple assembly. Water inlet opening communicates with a multiple stepped axial bore, which communicates with pressurized air inlet opening. Water flows through a successively narrowing bore from a threaded water inlet which receives a water inlet nipple assembly to an outlet adjacent end portion and elongate outlet bore portion of housing impinge obliquely on the water flow and produce atomization thereof. Photo (2) shows the atomizer assembly.

Overall, it is reasonable to divide the twin-fluid atomizer into the following categories:

- Contacting of air and fluid within the nozzle head (internal mixing) at l/d equal 2, 2.5 and 3.
- Contacting of air and fluid outside the nozzle head (external mixing) at l/d equal zero.

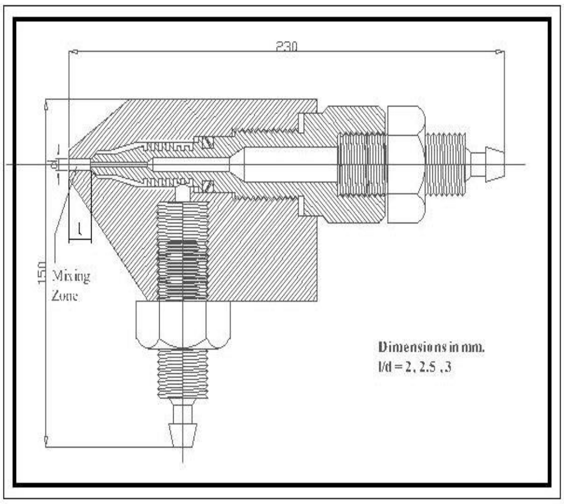


Fig. 2-a Internal twin-fluid atomizer assembly

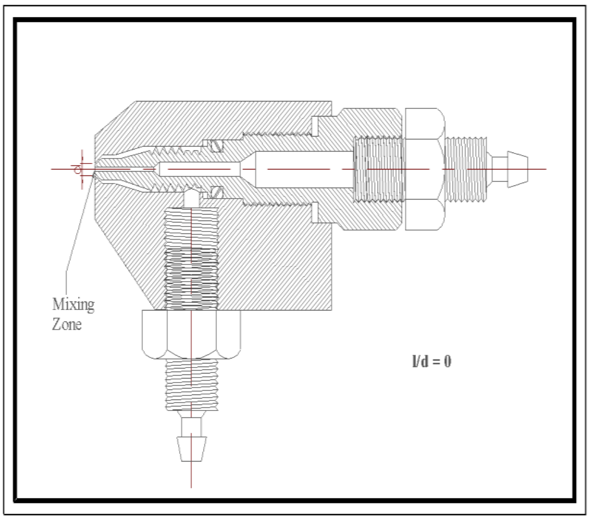


Fig. 2-b External twin-fluid atomizer assembly

Photo (2) The atomizer assembly

The experimental program involves three helical geometry of grooved pathways they are; circle, triangle and square shape. The geometries of helical flowpaths have been tested in the test rig shown in photo (3).

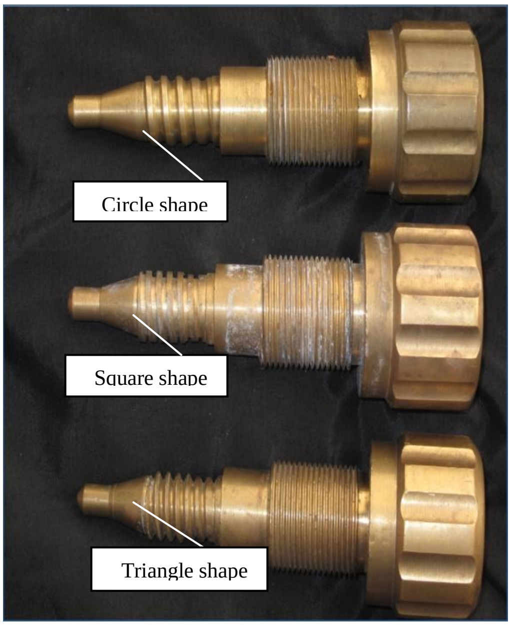


Photo (3) Geometry of helical shapes

There are two cases of helical flowpaths are shown in Fig. 3. In case (1), a water flowpath is extending vertically from the liquid inlet to a liquid stream outlet, and helical air flowpath extended horizontally from the air inlet. In the second case (2) a helical water flowpath is extending horizontally from the liquid inlet and the air flowpath extending from the vertical bore to a location adjacent the air stream outlet.

Case (1):

The sampling distance (Y) was set to 650 mm from the tip of nozzle. The inner diameter is equal 4 mm. As a fluid, the water was used with the flow rate in the range from approximately 80 L/h to 140 L/h, the l/d various up 3, the air to water ratio (AWR) was adjusted from 1.6 to 17 and the air injection pressures were set to 0.2, 0.3, 0.4 and 0.5 MPa.

The determination of the discharge coefficient of the atomizer is an important task when the atomizer is designed, and it directly decides the success or failure of the design. If the discharge coefficient is much big, the outlet area will be much bigger than the fact needed so as to influence the spray quality of the atomizer. If the discharge coefficient is small, it may not get to the designed mass flow rate and cannot satisfy the need of the temperature. So for all the atomizers determining the formula of the discharge coefficient of the atomizer is an important task. As water flow can be considered to be incompressible, ρ_l is assumed constant for all the calculations. The mass liquid flow rate $\dot{m}_l$ is defined as:

$$\dot{m}_l = \dot{V}_l \, \rho_l$$

Where $\dot{V}_l$ is the measured volumetric flow rate for the water fluid.

The air-to-water mass flow ratio is calculated by:

$$\text{AWR} = \frac{\dot{m}_a}{\dot{m}_l} = \frac{\dot{V}_a \rho_a}{\dot{V}_l \rho_l}$$

Here $\dot{V}_a$ is the inlet volumetric air flow rate, and ρ_a is the air density corresponding to the inlet pressure and temperature conditions. As the air volumetric flow is measured to standard conditions, the readings have to be corrected by the actual pressure and temperature values.

$$\dot{V}_a = \dot{\bar{V}}_a \sqrt{\frac{P_{at}.T_a}{P_a.T_{at}}}$$

Where $\dot{\bar{V}}_a$ is the measured air volumetric flow rate and P_{at} and T_{at} are the atmospheric pressure and temperature, respectively. For the present operating conditions, the air flow has to be regarded as compressible, and its density is calculated using the ideal gas relation. The air-to- water mass ratio is written as:

$$\text{AWR} = \frac{\dot{V}_a P_a M_a}{R_a T_a \dot{V}_l \rho_l}$$

Where R_a is the universal gas constant, M_a, T_a and P_a are air molecular weight the absolute air flow temperature and pressure, respectively. Just like the twin-fluid atomizer, the formula for the mass flow rate of the liquid is written as,

$$\dot{m}_l = C_d A_o \sqrt{2 \rho_l \Delta p_l}$$

Where, A_o is the cross-sectional area of the discharge nozzle.

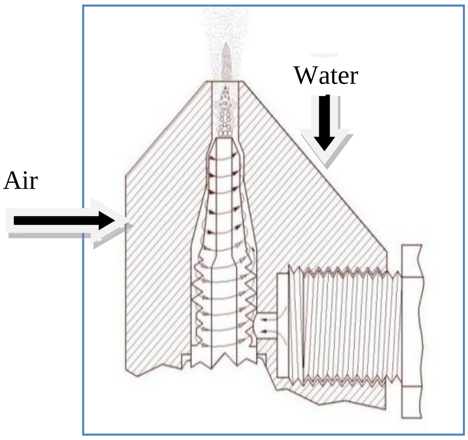
Then the discharge coefficient of the liquid can be written as:

$$C_d = \frac{\dot{m}_l}{A_o \sqrt{2 \rho_l \Delta p_l}}$$

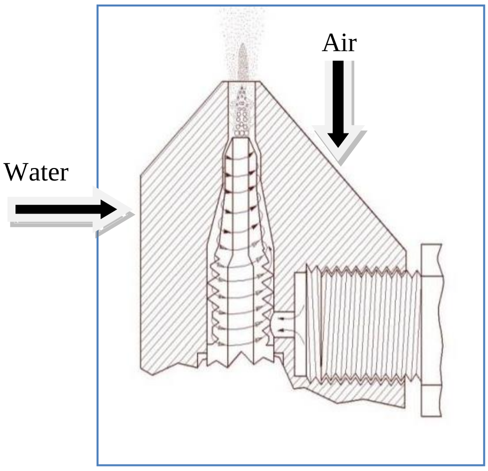
A collector at 65 cm vertically from the nozzle tip can estimate the water distribution of the spray. The liquid patternator for measurement of mass distribution is designed in two ways and it consists of test tubes, which located in the cross.

The spray cone angle is important parameter for atomizer and can influence the combustion and the flame length directly. It must be determined based on the size of the combustor and the mixing conditions of the air and fuel.

To measure the spray cone angle, a digital camera was used. Initially an automatic flash were used to obtain the best possible instant picture. Using the Photoshop software, the pictures were converted to negative forms, in order to improve clarifying the spray boundaries. Then, using the AutoCAD software, the spray cone angles were determined.



Case (1) Water is vertical



Case (2) Water is horizontal

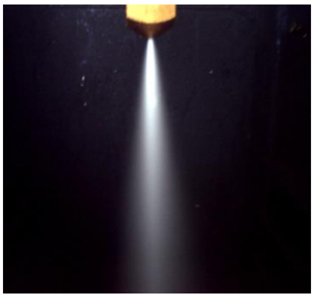
Fig. 3 Two cases of helical flowpath

3. RESULTS AND DISCUSSION

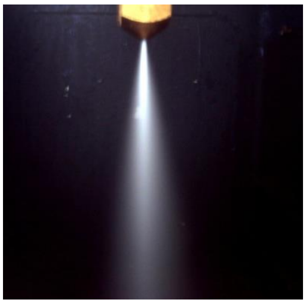
In the present experiments, for a constant water flow, different air flows have been established. For each experimental condition, the resulting water and air pressures, as well as ambient air temperature, have been simultaneously measured.

The photographs of the spray pattern produced by the present atomizer with different l/d are shown in Photo (4).

Figure 4 represents the volumetric water flow rates versus the difference water pressures using air mass flow rates. It is noticed that, the increasing the difference water pressure, increases the volumetric water flow rate, but by increasing the air mass flow rate, the volumetric flow rate is decreased.



l/d= 3



l/d =2

l/d =0

Photo (4) Photograph of the spray pattern produce by the present atomizer with different l/d

Figure 5 illustrates the effect of different air mass flow rates on the discharge coefficient for difference water pressure. It is seen from the figure, the increase of air mass flow rate and decrease the difference water pressure, decreases the discharge coefficient.

Figure 6 illustrates the effect of l/d on the discharge coefficient for different air mass flow rates. It is seen that the curve of the l/d equal 2 has the lowest discharge coefficient and when the l/d increases the discharge coefficient slightly increases at the same air mass flow rate. Calculated values for C_d are presented in Fig. 7 for different air mass flow rates and different helical shapes with difference water pressure at 0.2MPa and l/d equal 2. It should be noted that higher values of discharge coefficient have been obtained for the triangle helical path of air. Inspection of this figure has shown that for the triangle helical path, the maximum air mass flow rate that is reached higher than those for the other two paths.

Figure 8 represents the air to water ratio versus the air mass flow rates using different volumetric water flow rates. Increasing the air mass flow rate from 200 to 1400 kg/h, the AWR at same l/d and triangle shape increased to about 3.5 and 5.7 times of this AWR for volumetric flow rate 80 and 140 L/h respectively.

The mass concentration is the quantity of accumulated water during a certain time in a graduated tube divided by the total injection water flow rate. The radial mass concentration was measured for different air pressures, helical geometry and length to diameter (l/d) of mixing zone.

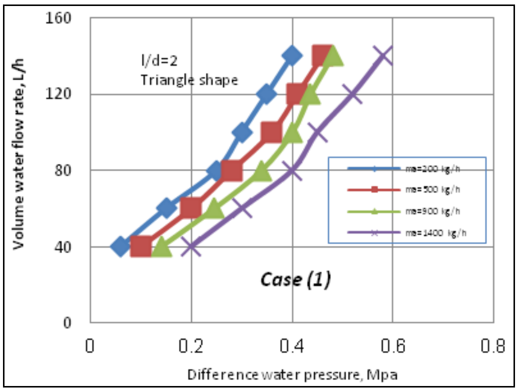


Fig. 4 Effect of volumetric water flow rate for different air flow rates with difference water pressure

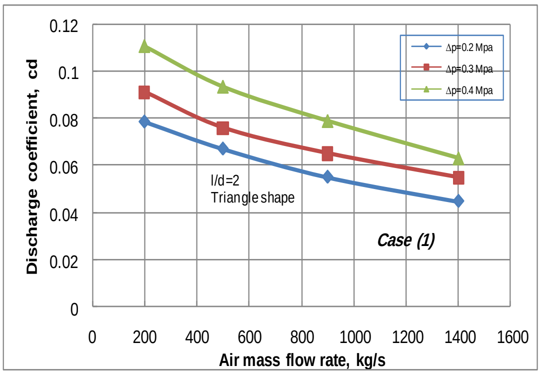


Fig. 5 Effect of air mass flow rate and difference water pressures on discharge coefficient

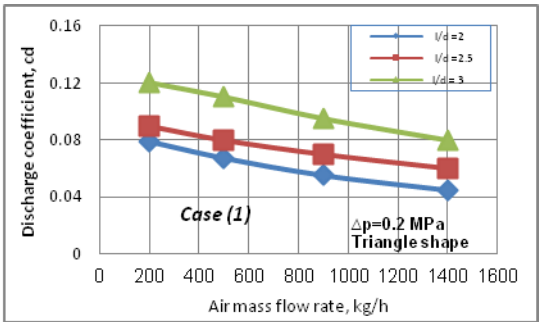


Fig. 6 Effect of l/d on the discharge coefficient with different air mass flow rates

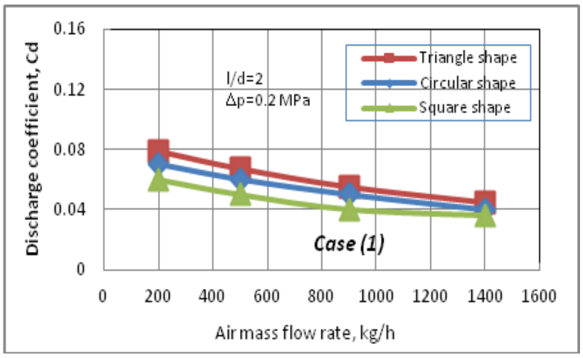


Fig. 7 Discharge coefficient for the different helical shapes for various air mass flow rate

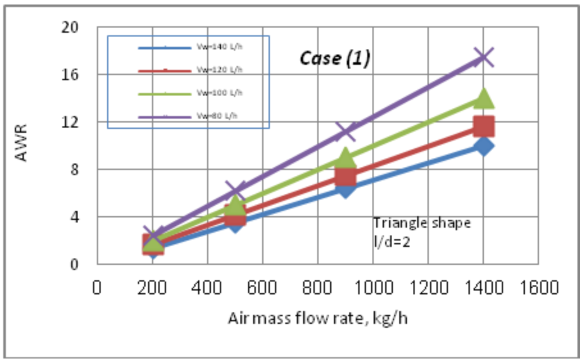


Fig. 8 Air to water ratio for different air and volumetric liquid flow rates

Figures 9 to 11 show a sample of the results of the measured radial mass concentration at different air pressures, helical geometry pathways and l/d. Because of the issued spray is a solid cone type, one peak of the maximum mass concentration is formed around near the spray axis. Figure 9 shows that, as air pressure for all results decrease, the mass concentration of liquid at the spray core increased, while the concentration become less at wider radial distance and the peak mass concentration moved outwards, as its value decreased.

Figure 10 indicates the effect of different shape of flow paths on the mass concentration at Y=65 cm from the tip of nozzle, air and water pressures are the same at 0.3 MPa and l/d equal 2. This figure shows that the peak value of the mass concentration is located near the center of the spray and then it decreases with increasing the radial distance. Also this figure shows that, the triangle shape have wider spray than the other two shapes.

Figure 11 presents the effect of l/d for different helical shapes on the radial of the water mass concentration at water and air pressures are the same at 0.3 MPa and the axial distance (Y) equal 65 cm. This figure shows that, as the l/d decreases, the radial profile of the liquid mass concentration tend to be more uniform. Also shows that, the maximum value of the mass concentration is located near the center of the spray up to the midradius and then decreases with increasing the radial distance.

The spray cone angle for different air pressures, l/d of the mixing zone and helical shape of air are shown in Figs. 12 and13. The effect of l/d on the spray cone angle for different air pressures is shown in Fig. 12. Increasing the l/d and air pressure, the spray cone angle also increases to about 2 to 3 times.

Figure 13 illustrates that the effect of air pressures is stronger on the spray cone angle than the effect of the geometry path of air flow. Also this figure shows that, the triangle shape have big spray cone angle than the other two shapes.

Case (2):

The cone shape of spray is one of the studied characteristic and used determine the efficient atomization or combustion of fuel, Referring to Fig. 14, it can be concluded that the increase in air pressure increased the spray angle. It is clear also found from Fig. 15 that the spray angle is largest for l/d equal zero and lowest for l/d equal 3 with water pressure 0.3 MPa and triangle shape. Figure 15 shows that, as l/d ratio increased, the concentration of water at the spray core increased, while the mass concentration becomes less at wider radial distance.

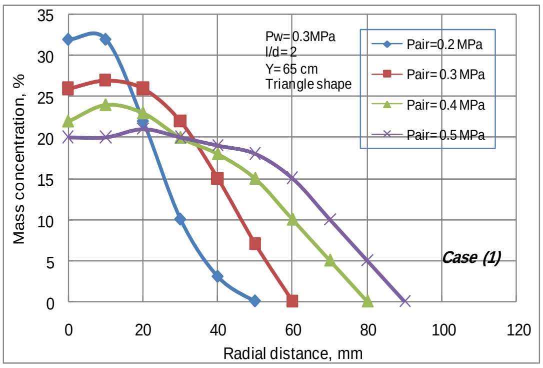


Fig. 9 Effect of air pressures on the mass concentration

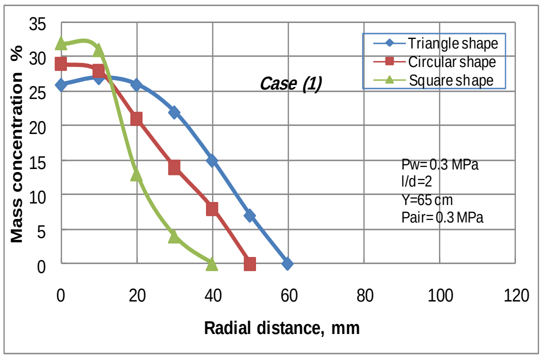


Fig. 10 Effect of helical shape flow path on the mass concentration along spray axis

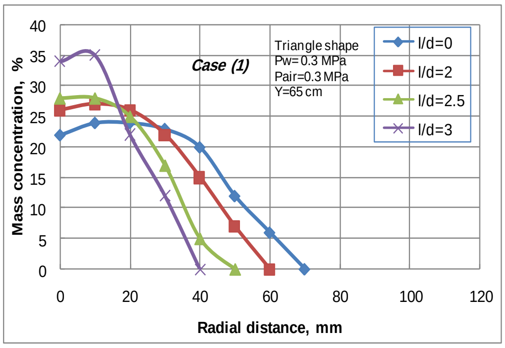


Fig. 11 Effect of l/d on the mass concentration along the spray axis

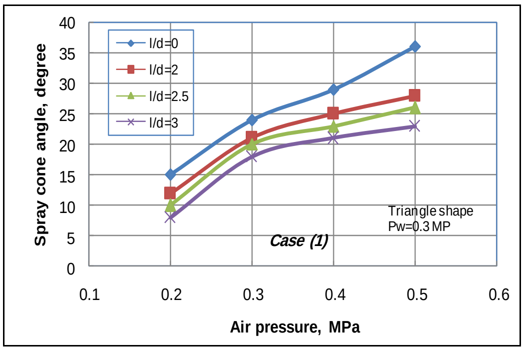


Fig. 12 Effect of l/d on the spray cone angle with different air pressures for case (1)

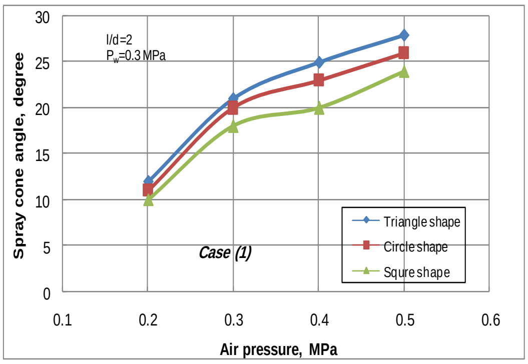


Fig. 13 Effect of helical shape flow paths on spray cone angle with different air pressures

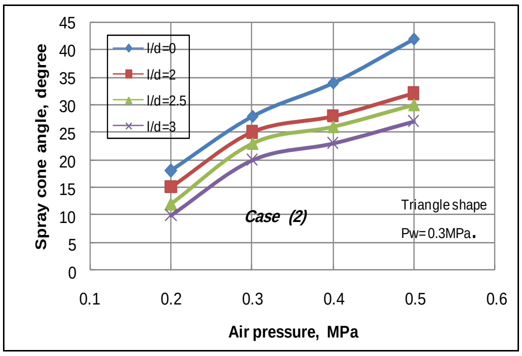


Fig. 14 Effect of l/d on the spray cone with different air pressures for case (2)

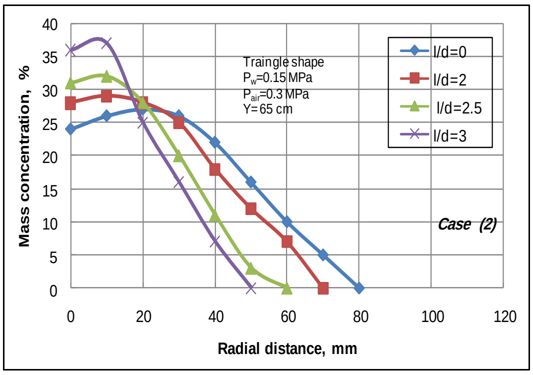


Fig. 15 Effect of l/d on the mass concentration

Figures 16 and 17 show the comparison between the two cases for triangle shape at water pressure equal 0.3 MPa and l/d equal 2. It is clear from the both figures to found, that the maximum values and the spray cone angle from case (2) great than the other one.

4. CONCLUSIONS

The discharge coefficient, the mass concentration and the spray cone angle are studied experimentally. The influence factors considered are as follows: the helical grooved shape, AWR, water pressure difference, air pressure, volumetric water flow rate, and l/d.

The results of the experimental study are summarized as the follows:

- As the l/d decreased, the C_d of liquid decreased for all helical shapes, while for the triangle helical shape have the maximum values.
- As the l/d increased the mass concentration of liquid at the spray core increased, while the mass concentration becomes less at wider radial distance. But when the air injection pressure increases the peak value decreases.
- The spray cone angle widened with the decrease in l/d ratio and the increase of air injection pressure.
- The higher values of spray angle and wider spray and uniform shape found by the triangle shape.
- In case (1), where water flow path extends vertically and helical air flow path also extends horizontally from the air inlet. But the case (2) has greater values compared with case (1) as the helical water flow path extends horizontally and the air flow path also extends vertically from vertical bore.
- For case (2), at the lowest air pressure tested 0.3 MPa, the spray cone angle lies between 15 and 32 degrees, while the concentration become great at wider distance.

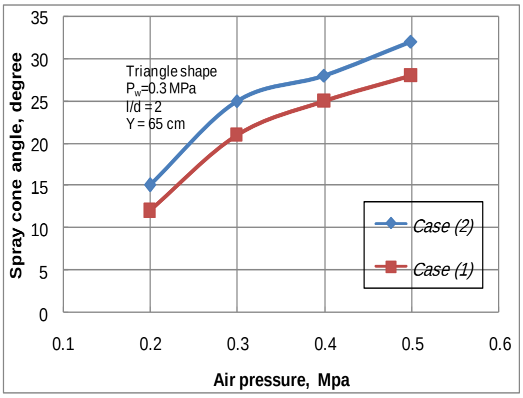


Fig. 16 comparison between the two cases on spray cone angle

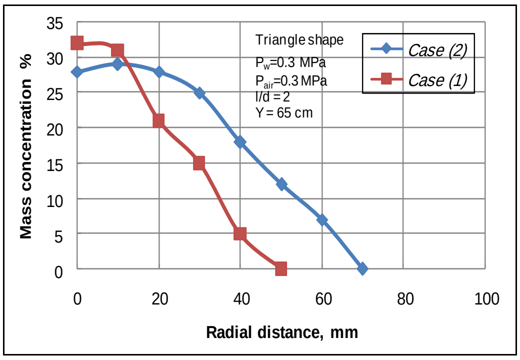


Fig.17 Comparison between two cases on the mass concentration

5. REFERENCES

[1] Shehata,M.A., " Spray characteristics of external mixing airblast atomizer", PSERJ, vol.13, No.2, Sept.2009.

[2] Shehata,M.A., " Characteristics of shear fuel airblast atomizer with air swirler", PSERJ, vol.10, No.1, March 2006.

[3] Stefan,M., Udo,F., Klaus, B., "Jet breakup of liquid metal in twin-fluid atomization", Materials Science and Engineering A32, pp.122-133, 2002.

[4] Sovani, S.D., Chou, E., Sojka, P.E., Gore,J.P., Eckerle, W.A.,Crofits, J.D.,"High pressure effervescent atomization: Effect of ambient pressure on spray cone angle", Fuel, vol.8, pp.427-435, 2000.

[5] Wade, R.A., Weets, J.M., Sojka, P.E., Gore,J.P., Eckerle, W.A., ' Effervescent atomization at injection pressures in MPa range", Atomization sprays, vol.9, pp. 651-667, 1999.

[6] Shehata,M.A., " Spray performance of an effervescent atomizer", PSERJ, vol.9, No.1, pp.222-237, March 2005.

[7] Karnawat, J., Kushari, A., "Controlled spray pattern factor using a twin-fluid swirl atomizer", AIAA, Joint propulsion conference& exhibit, July 2005, Tucson, Arizona.

[8] Nguyen, D.A., Rhodes, M.J., "Producing fine drops of water by twin-fluid atomization", Powder technology, 1998, pp.285-292, 1999.

[9] Levebvre, A.H., "Atomization and sprays", Hemisphere publishing corporation,1989.

[10] Kufferath,A.,Wende, B., Leuckel, W., " Influence of liquid flow conditions on spray characteristics of internal mixing twin-fluid atomizers", Internal journal of heat and fluid flow 20, pp. 513-519, 1999.

[11] Jing-Song Gong, Wei-Biao Fu, "The experimental study on the flow characteristics for a swirling gas-liquid spray atomizer", Applied thermal engineering 27, pp.2886-2892, 2007.

[12] Jung-Hyn Rhim, Soo-Young No, "Breakup length of conical emulsion sheet discharged by pressure swirl atomizer", International journal of automotive technology, vol.2, No.3, pp.103-107, 2001.

[13] Varga, C.M., Lasheras, J.C., Hoffinger, E.J., "Initial breakup of a small diameter liquid jet by a high- speed gas stream", J. Fluid Mech.497, pp.405-434, 2003.

[14] Marmottant, P., Villermaux, E., "On spray formation", J. Fluid Mech.498, pp.73-111, 2004.

[15] Barreras, B., Lozano, A., Barroso, J. and Lincheta, E., "Experimental characterization of industrial twin-fluid atomizers", Atomization and spray, vol.16, pp.127-145, 2006.

[16] Lacava, P., Bastos-Netto, D. and Pimenta, A., "Design procedure and experimental evaluation of pressure-swirl atomizers", 24^{th} international congress of the aeronautical sciences. ICAS, 2004.

[17] Halder, M.R., Dash, S.K. and Som,S.K., " On the coefficients of discharge and the spray cone angle of a solid cone swirl nozzle", Experimental Thermal and Fluid Science 28, pp.297-305, 2004.

[18] Farage, T.M., Abdel-Mageed, S.I., Ibrahim, EL-Sayed, A., "Spray performance of helical path atomizer", PSERJ, vol.5, No.2, pp.674-691, Sept.2001.