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AIP Conf. Proc. 2062, 020026 (2019)
https://doi.org/10.1063/1.5086573

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The Effect of Nozzle Diameter on The Flow Characteristics of Air Entrainment Phenomenon in Vertical Plunging Jets

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Abstract. Bubble has an important role in separation processes such as desalination and flotation. The one way to produce bubble is air entrainment. Air entrainment phenomenon on vertical plunging jet has been studied with the aim to know the effect of nozzle and downcomer size on bubble penetration depth, gas entrainment rate, and bubble dispersion area. Experimental setup is in the form of water piping system consisting of pump, nozzle, downcomer, water flowmeter, air flowmeter and water pool. The visual data in the form of video and photograph taken by using digital camera and high speed camera with backlighting method. The visual data is then processed with the image processing program to obtain quantitative data. The results show that the nozzle diameter affects the air entrainment. Depth of bubble penetration, area of bubble dispersion, air entrainment rate, and liquid height entering into downcomer values are affected by the nozzle size.

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INTRODUCTION

Bubbles have a role in purification and separation of substances found in liquid. In the flotation process, bubbles have a role to separate minerals by utilizing the mineral surface properties of its hydrophilic and hydrophobic properties [1]. One way to produce bubbles is air entrainment. Air entrainment is a phenomenon in which a two-phase flow causes a gas bubble to occur when a collision of a fluid plunges vertically against a stagnant fluid [2]. This is due to the momentum energy of the velocity of fluid flow that flows vertically. Several studies show that air entrainment with plunging jet models of nozzles occurs when the jet impact velocity exceeds a characteristic velocity [2]. This velocity is a function of inflow conditions [3].

The phenomenon of vertical liquid jet that falling to the surface of the water in the water pool will drag the surrounding air into the water pool and produce small air bubbles. If the jet impact velocity is high enough, the air bubbles will be dragged downward following the fluid movement and then rising up to the liquid surface of the water pool. Low jet velocity will not form a significant amount of air bubbles, but the high jet velocity will form bubbles that cause cloud of bubbles [4]. In this phenomenon there will be a process of mass transfer of air into the liquid. The velocity of the liquid flow is also depends largely on the shape of the nozzle, the diameter of the nozzle, and the distance of the nozzle to the surface of the water [5]. Similar to many other natural event observations, the phenomenon of air entrainment has been studied and then applied for the human's importance. A recent exploitation of air entrainment is Jameson Cell which is a flotation device used in the mining industry to extract mineral deposits from waste water in the form of foam. It is consists of a water jet wrapped in downcomer, Jameson Cell relies on air entrainment to create a vacuum. It results a suction of liquid into the downcomer. The wave of water flows into this liquid, creating air bubbles. Mineral sediments attach to these bubbles floating to the surface, forming a layer of foam and finally separating sediment from water [6].

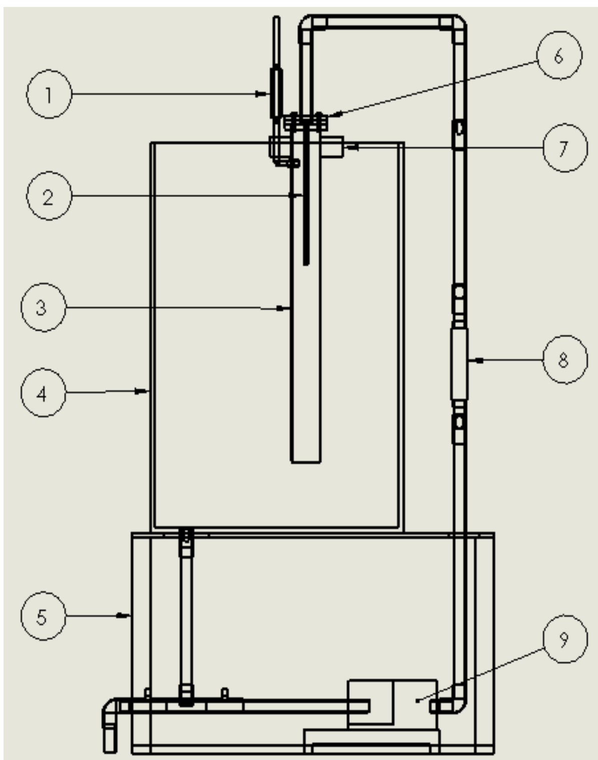
In the case of air entrainment, there is a two-phase flow in which the liquid coming from the water pool then is pumped through the pipeline to the nozzle then falls welcome into the water pool together with the gas coming from

The 10th International Meeting of Advances in Thermofluids (IMAT 2018)
AIP Conf. Proc. 2062, 020026-1–020026-8; https://doi.org/10.1063/1.5086573
Published by AIP Publishing. 978-0-7354-1790-8/$30.00

the air in the downcomer area. When the liquid is pumped to the nozzle, the velocity of the liquid increases due to the gravity of the earth so that the liquid that plunge into a water pool will impact to the water surface in the water pool. This study intends to observe the hydrodynamic aspects of the jameson cell flotation device. Main goal is to determine the effect of nozzle diameter on the flow characteristics of the air entrainment phenomenon.

EXPERIMENTAL METHOD

The study was conducted with experimental method. The fabricated tools using acrylic material are nozzle, downcomer, and flange. The position of the downcomer and nozzle is at the center point of the pool and the water pool was made using transparent glass material in order to facilitate in observation and data collection using DSLR camera and high speed camera when the bubbles appear. The water pool was filled the water with a height according to the variations of the size of the specified jet height. The water was pumped to the nozzle to create a vertical flow with the jet velocity that able to produce bubbles when impacted with the surface of the pool. Air flowmeter installed at the downcomer side to measure air entrainment rate and water flowmeter installed at the vertical PVC pipe to measure water volumetric rate. Experimental setup can be seen in figure 1 below



1. Air Flowmeter
2. Nozzle
3. Downcomer
4. Water pool
5. Table
6. Flange
7. Buffer
8. Water Flowmeter
9. Pump

FIGURE 1. Design and Schematic Experimental

Data collection includes depth of bubble penetration, area of bubble dispersion, and rate of air entrainment. Measurements using image processing software include dept of bubble penetration, area of bubble dispersion, and the heigh of liquid being sucked upward into the downcomer. The depth of bubble penetration was measured from the surface of the water in the water pool to the point where the bubbles stop to move downward.

This study uses a vertical plunging jet model where the liquid moved downward into the water surface of the pool. The process of air entrainment involves the air entering through a downcomer pipe that was installed vertically. Before entering into downcomer, the air through the air flowmeter first to determine the air entrainment rate then into the downcomer pipe. At the bottom of the water pool there was a hole that delivers water to the drainage of the building for disposal or to the pump to recharge the water pool when conducting the experiment.

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Independent variables include nozzle diameter, downcomer diameter, jet height, and water volumetric rate. The independent variables can be seen in the table below

TABLE 1. A tabulation of experimental data

No.	Independent Variable	Range	Unit
1.	Nozzle Diameter	6, 8, 11	mm
2.	Downcomer Diameter	26, 36, 46	mm
3.	Water Flowrate	6, 8, 12, 16	lpm
4.	Jet Height	160, 210, 260, 310	mm

RESULT AND DISCUSSION

The results of this study are qualitative data that was processed into quantitative data using image processing software. Measurements which using image processing software include depth of bubble penetration, area of bubble dispersion, and the height which is sucked upward into the downcomer. For the results of air entrainment rate was obtained by air flowmeter. The results of measurement obtained was then presented in chart form that describes the characteristics of the relationship between the independent variables and the dependent variables.

Air Entrainment Phenomenon

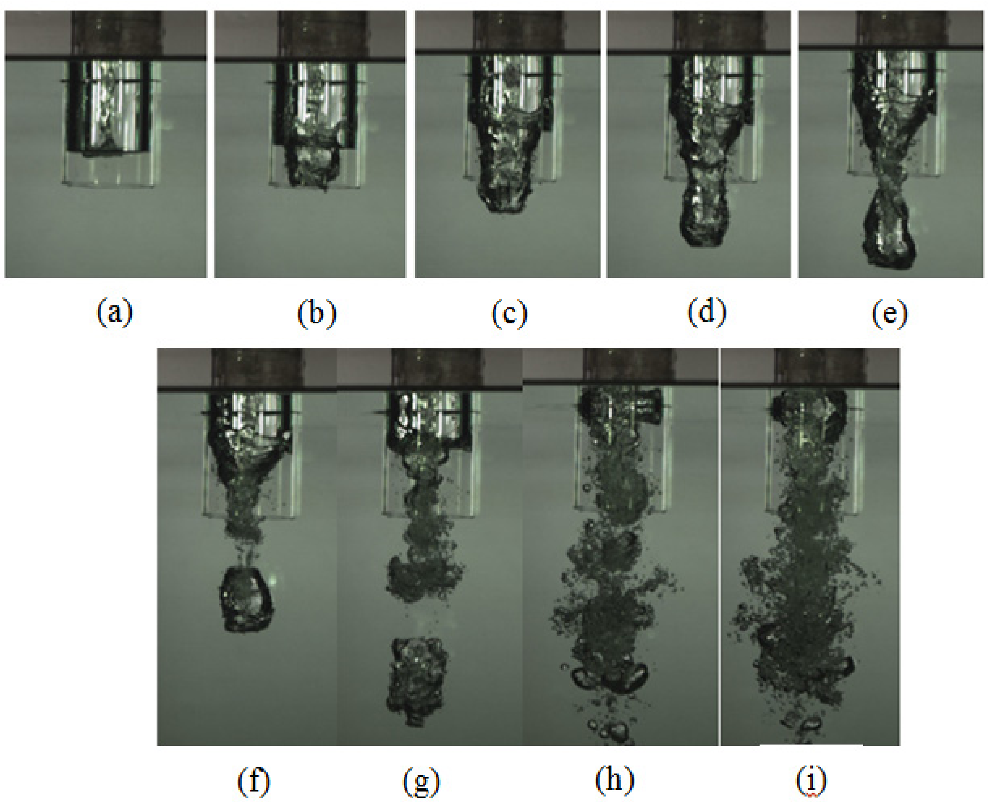

FIGURE 2. The process of Air entrainment phenomenon

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Figure 2 shows the initial process of air entrainment until the appearance of bubbles below the surface of the water. In the initial conditions, there was no bubbles appeared (a-e) and then some bubbles appeared after a certain period of time and are trapped beneath the surface of the water and then disappeared within a certain period of time (f-h). After that, there is a continuous of air entrainment when the air cavity and bubbles continuously appeared (i).

Depth of Penetration

The depth of bubble penetration was obtained by processing qualitative data in the picture form taken during the experiment through Image processing software. The depth of bubble penetration was measured from the surface of the water in the water pool to the point where the bubbles stop to move downward.

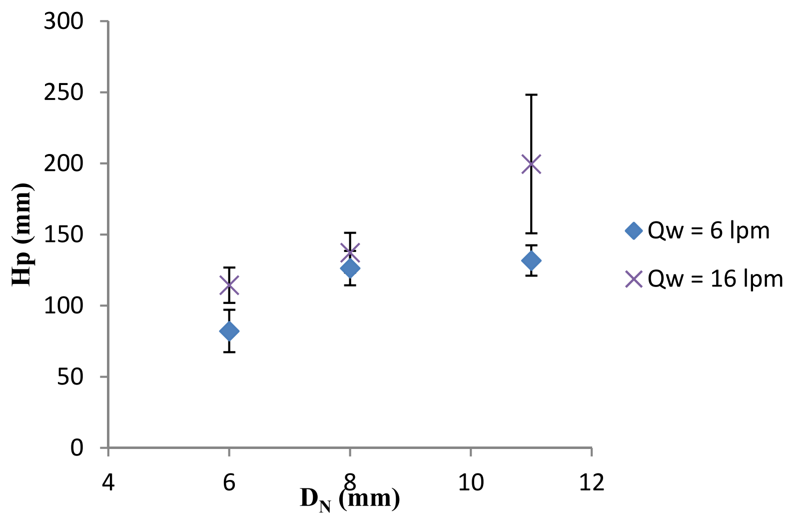

FIGURE 3. Relationship between depth of bubble penetration with nozzle diameter

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The value of depth of bubble penetration increased with increasing nozzle diameter for several conditions. The highest penetration depth value occured at the water volumetric rate of 16 lpm. It is occurred because of the momentum energy and the velocity of fluid flowing from the nozzle vertically into the water surface in the water pool and giving a curve form of meniscus so that the surface tension cannot maintain the condition and the jet plunges into the water surface. The depth of bubble penetration also occurred because of the effect of gravity.

The larger nozzle diameter gives more mass of fluid to be carried. It is also related to the momentum energy generated that when the fluid velocity s constant with increasing fluid mass so the momentum gets larger then the jt plunges deeper. But in this study, the value of water volumetric rate is constant so that the jet velocity decreased with increasing nozzle diameter. The depth of bubble penetration also increased with increasing jet velocity. But due to the downcomer was used in this study, when the jet plunged into the pool so the downcomer was filled water because of the pressure difference so that depth of bubble penetration at higher jet velocity became decreased.

Bubble Dispersion Area

The values of area of bubble dispersion for certain conditions changed along with the increasing nozzle diameter. Area of bubble dispersion increased with increasing nozzle diameter. The highest value of bubble dispersion area occured at a water volumetric rate of 16 lpm. At a nozzle diameter value of 11 mm nozzle, it was clearly that area of bubble dispersion increased with increasing water volumetric rate. Then at the nozzle diameter of 6 mm and 8 mm, the area of bubble dispersion did not change if the water volumetric rate increased.

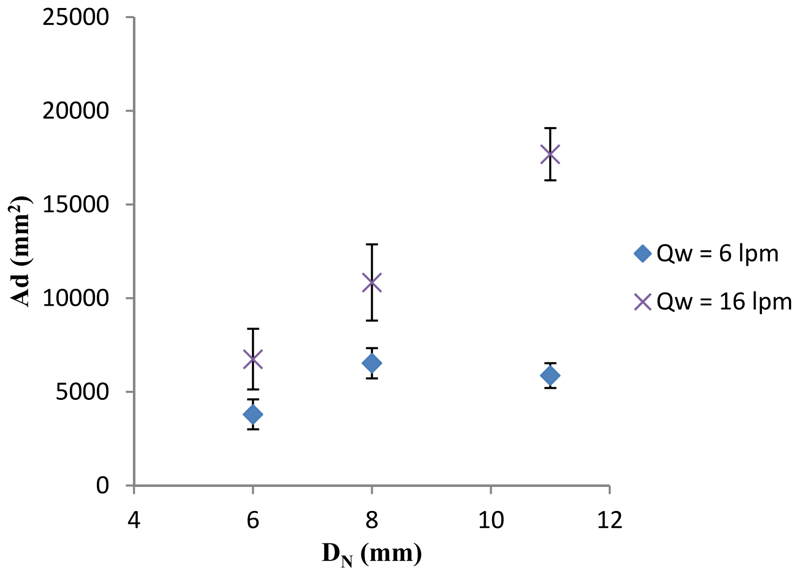

FIGURE 4. Relationship between Area of bubble dispersion with nozzle diameter

The area of bubble dispersion was formed due to the momentum of the jet plunging continuously, so that the bubbles formed below the surface of the water head up at the side of the jet plunge center. The size of the jet plunge that impacted to the liquid in the water pool also affect the shape and size of the produced of bubbles, so that also influenced the pattern of movement of bubbles that rise to the top and the area of bubble dispersion formed.

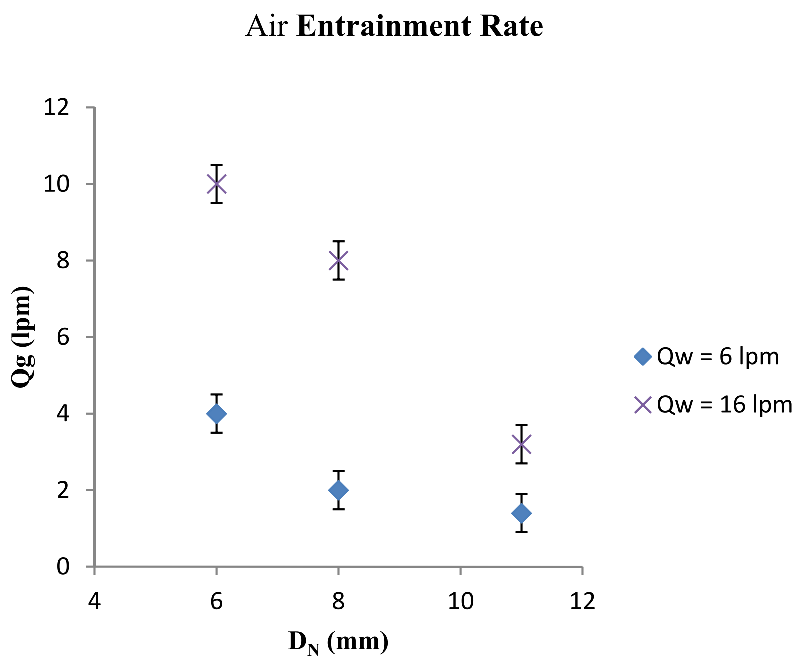

FIGURE 5. Relationship between Air entrainment rate with nozzle diameter

The results of this variable were obtained by reading the numbers listed on the air flow meter with units of lpm. There were two types of flowmeter used, because in certain conditions it could not be read by a large-scale flowmeter. The air entrainment rate decreased with increasing nozzle diameter and decreasing the volumetric water

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rate for all conditions. It is due to the influence of decreasing kinetic energy on the jet, jet surface roughness, and the perimeter were connected between the jet and the surface of the water in the water pool. In the present study, the water volumetric rate was used as an independent variable in which the results will be constant for all sizes of nozzle diameters so that the jet velocity decreased when the nozzle diameter increased. This could be explained by the continuity equation below

$$Q = A \times V_J \tag{1}$$

Where Q is the water volumetric rate (m^3 / s), A is the area of the circle of the nozzle (m^2), and V_J is the jet velocity (m / s). of the equation, it can be seen that A is inversely proportional to V_J so that if the diameter of the nozzle is larger, the value of V_J will decrease where Q is constant. The chart between the nozzle diameter on the air entrainment rate can be seen in the figure below

Liquid Height In Downcomer

In this study, it can also be observed that there is a change of the height of liquid entering into downcomer affected by increasing nozzle diameter

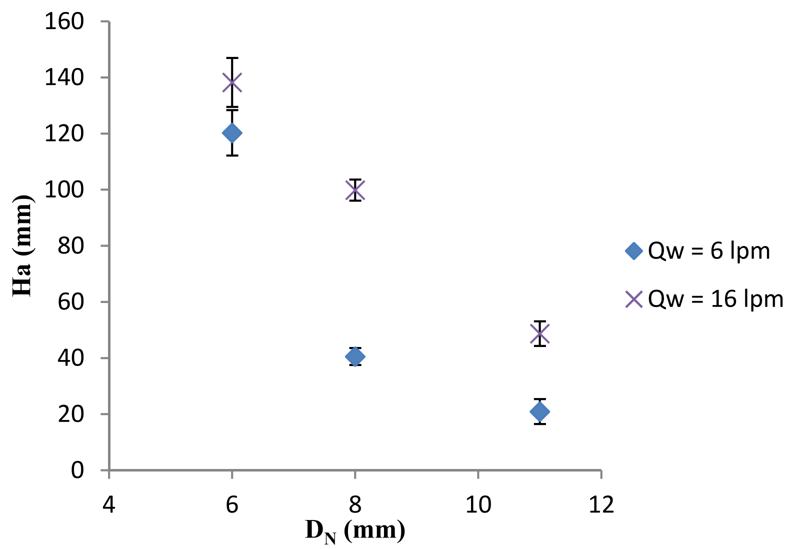

FIGURE 6. Relationship between Liquid height in downcomer with nozzle diameter

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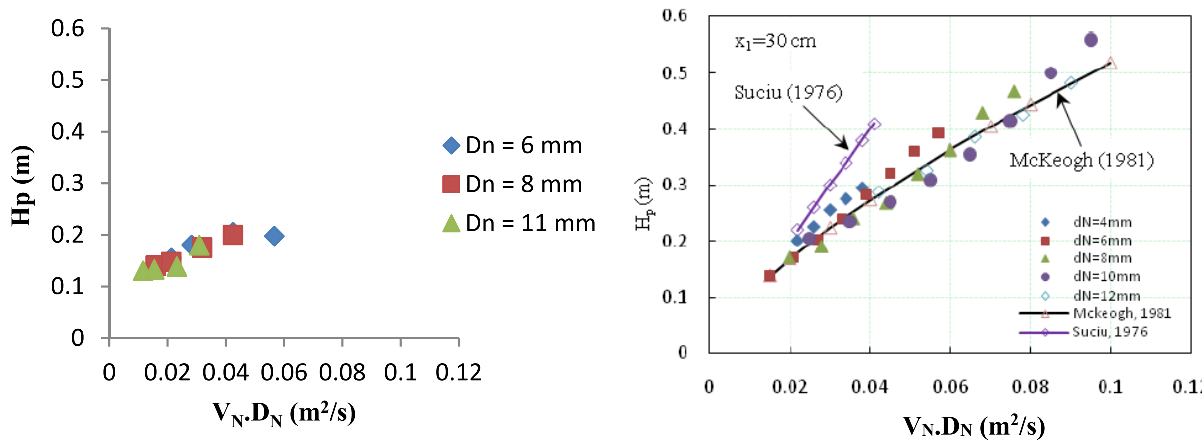
The relationship between these two variables has a downward tendency. In this study, it can not calculated gas holdup due to the capillary pipe was not installed at the experiment device. The height of the liquid entering into the downcomer decreased with increasing nozzle diameter. It is because of the pressure difference in the downcomer chamber with the pressure below the water surface. Beside that, the influence of the amount of momentum energy that enters into the water pool.

The Comparation of Experimental Results

In this study, the relationship between nozzle diameter on the depth of bubble penetration was obtained. To compare the results of this study with previous study, need to connect two independent variables which are the diameter of nozzle with the jet velocity on the nozzle by multiplying. It can be seen that the trend of both of the charts increased even though the conditions of the two charts are different. For the present study used a downcomer dipped 1 cm under the surface of the water while the previous study by Harby et al did not use a dipped downcomer. In addition, at the study by Harby et al the chart was applied at a jet height of 30 cm and at the present study at a jet height of 31 cm. Both of charts illustrate that depth of bubble penetration increased with increasing $V_N D_N$. Both of charts can be seen in the figure 7 below,



(a) (b)

FIGURE 7. Relationship between depth of bubble penetration with $V_N D_N$ of (a) present study and (b) previous study [7]

In addition, the relationship between jet velocity and air entrainment rate at this study with previous study by Tasdemir et al can be known. Both the present study and the previous study by Tasdemir et al was using a dipped downcomer. The result of this study are the same with previous study which that air entrainment increased with increasing jet velocity.

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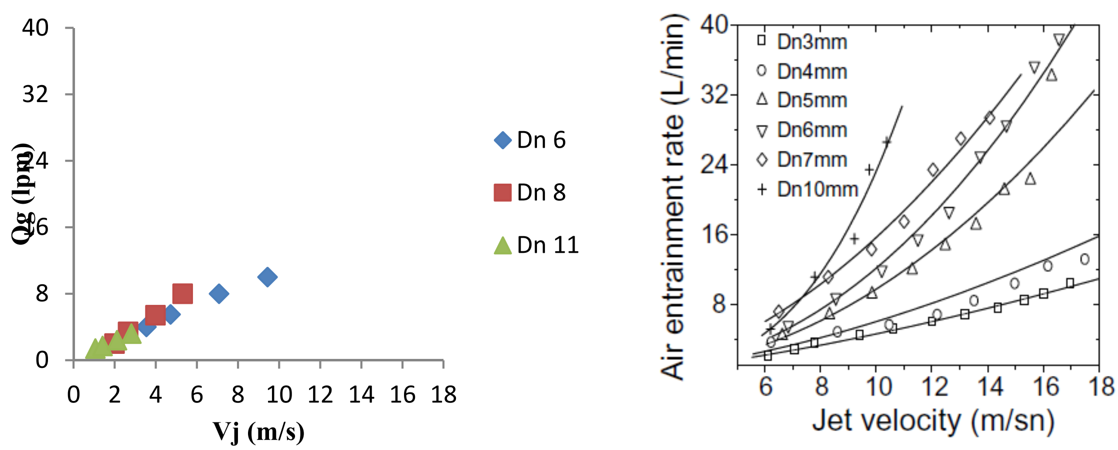

(a) (b)

FIGURE 8. Relationship between air entrainment rate with jet velocity of (a) present study and (b) previous study [8]

In figure 8 above, it can be seen that the trend of both charts increase. This shows that air entrainment rate increased with increasing jet velocity. However, the effect of nozzle diameter cannot be compared due to limited data in this study which only has jet velocity data up to 10 m/s. In this study, air entrainment decreased with increasing nozzle diameter for certain conditions, while for previous study by Tasdemir et al, air entrainment rate increased with increasing nozzle diameter. It is due to nozzle diameter is constant but jet velocity increased so that the air carried around the jet plunging layer increases toward the stagnant liquid in the water pool.

CONCLUSION

The air entrainment process occurs when the jet plunges into the water surface of the water pool which causes the meniscus pushed deeper so that air cavity formed then produced bubbles. From this study, it can be concluded that depth of bubble penetration and area of bubble dispersion increased with increasing nozzle diameter but air entrainment rate and height of liquid entering into the downcomer decreased with increasing nozzle diameter.

ACKNOWLEDGMENTS

This study was funded by a grant from the Directorate of Research and Community Service (DRPM) Universitas Indonesia grant no. 2556/UN2.R3.1/HKP.05.00/2018

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