The Effect of Diameter Downcomer in Air Entrainment Process from Vertical Plunging Water Jet with Downcomer

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Abstract. The development of technology for flotation in water-waste treatment is happening rapidly this environmentally friendly technology uses air bubbles to separate the material into hydrophilic or hydrophobic factions as a result of a bubble’s characteristics and additional chemicals. Air entrainment events occur when bubble formation takes place. At the time of bubble formation, air entrainment events occur. This study aims to determine the parameters that affect air entrainment; those are the relationship of the downcomer diameter and jet velocity to air entrainment from a fluid mechanics aspect. The apparatuses used in this study were a pump, nozzle, downcomer, flow meter, reducer, and glass water tank; these items were all connected with pipes. Data was collected via a camera to obtain photos and videos. Quantitative and qualitative data was derived from these images using an image processing program; ImageJ. The results of this research indicate that the diameter of the downcomer affects the volume of the air entrainment, and jet velocity affects air entrainment rate.

1. Introduction

The development of technology is occurring at a fast pace. This remains true for flotation technology and water-waste treatment technology, such as microbubble technology. Microbubble technology is growing rapidly as human needs for flotation and desalination processes rise. The Jameson cell is one of the flotation technologies currently used.

The Jameson cell was developed by Professor G. J. Jameson of the University of Newcastle and Mount Isa Mine Ltd. This cell is used in the mining industry as a mineral extractor. The cell uses a downcomer to dictate where the first point of contact between the bubbles and particles takes place; the high-pressure jet causes the air to entrain the water and produces bubbles [1]. Hydrophilic and hydrophobic characteristic from bubbles it used to floatation and water-waste treatment.

Bubbles, particularly microbubbles, are used as a medium for flotation. A microbubble is an air bubble with a diameter of 10-50μm [2]. The microbubble is seen as an environmentally friendly technology because they produce highly reactive free radicals without using harmful chemicals.

In every microbubble forming process, there is an air entrainment phenomenon. Air entrainment occurs naturally when air is immersed into water by an external stream of water. A natural occurrence of air entrainment in water can be seen in bodies of water with waterfalls. An example of a naturally occurring air entrainment is found in rivers, especially in areas with waterfalls. Air entrainment is responsible for the infusion of oxygen into the water; this oxygen source is intended, and necessary, for the living things in the water.

In regard to bubble formation, many studies on water entrainment have been carried out. One of these studies stipulated that the diameter of the downcomer did not affect the air entrainment rate [7], and Zhu et al. [3] characterized the jet profile shortly before and after hitting the surface of the water to determine
the jet’s contribution to the formation of bubbles. Although the usefulness of bubbles in the industrial world is vast, the study of bubbles is not. Until now research about the characterization of air entrainment has not been comprehensively studied, despite it being important parameters in the formation of bubbles.

This research was conducted as a first step towards the development and identification of hydrodynamic bubble aspects because these characteristics have not been fundamentally discussed. The downcomer contributes for trapping the air so the air is not being interfered with by air outside downcomer, along with other variables and constants discussed in the following sections. The properties of the water jet stream are vital because the contact point for the incoming air occurs within it. The stream’s properties will affect the level and momentum of the air below the surface and ultimately, bubble formation. This air entrainment study on microbubbles was conducted in the Fluid Mechanics laboratory of the Department of Mechanical Engineering at Universitas Indonesia. This study aimed to identify the characteristics of air entrainment from the perspective of fluid mechanics.

2. Methods

This study used a model of vertical air entrainment where the water jets plunged the liquid directly downwards towards the surface of the water in the tank. The air for the entrainment process was injected into the vertical downcomers pipe where the process occurred. Factors affecting air entrainment are the size of the nozzle and downcomers diameter, the distance between the water surface and the nozzle tip, the physical properties of the fluid, the jet turbulence and the jet velocity during the collision with surface water. The variables used in this study are nozzle diameter, downcomers diameter, water jet height and jet velocity. The tools used in this study are outlined below.

![Figure 1. Schematic Apparatus](image)

Information:
1. Air flowmeter
2. Nozzle
3. Downcomer
4. Water flowmeter
5. Water tank
6. Pump

The following equipment was used for this study: glass water tank, pump, water and air flowmeters, downcomers, nozzle, pipes, reducer, and flanges. The water tank was 910 mm long, 610 mm wide and 620 mm tall and its glass was 2 mm thick. The tank was filled with water. The pump capacity was 10–18 L / min with an engine pump rotation of up to 2900 rpm.

The piping system was composed of PVC pipes with a diameter of 1”. In the suction section, the pipe was vertically connected to the drain, and it had length of 20 cm. Drainage pipe was connected with a ‘T’ connector; one side flowed to the gate valve, which was parallel to suction section and drainage of the laboratory, and the other side connected to a 70 cm long horizontal pipe that included an additional connection to the inlet 1.5”.

The pipe in suction section was reduced to a diameter of 1" in the discharge section. The pipe extended for 70 cm before the gate valve was installed. Gate valve was used to regulate the water
discharge coming out of the pump; this allowed the water discharge to be easily adjusted. After the water had passed through the flowmeter, it would be passed through a 1" pipe with a flange installed at the end. The nozzle was connected with to this pipe and covered with a downcomer of 700 mm to trap the air inside.

A white LED light was placed behind the glass water tank to illuminate it. The back of the tank was covered by 2 mm thick polyfoam. This coating was useful as it allowed the LED light to be scattered well. The photography technique used was backlighting. To obtain the most accurate data, ImageJ was used to process the data; this was an open source Java image processing software. The software was capable of filtering the image with 2048 x 2048 pixels and 8-32 bits in RGB colour with a wide format in 0.1 seconds. 'ImageJ' offered image enhancement that was essential for this study due to the speed required to capture the necessary images of this process.

3. Results

Air entrainment was visually observed through photography in this study. Air entrainment from a vertical plunging water jet is a phenomenon that generates bubbles [4]. When the jet hits the water’s flat surface, it forms a depression in the meniscus at the water’s surface [5]. As jet velocity increases, the depression in the meniscus also increases. Air pockets becomes trapped in the water because air entrainment occurred. Eventually, air pockets will burst to produce bubbles.

![Figure 2. Visualization of air entrainment](image)

Figure 2. Visualization of air entrainment

![Figure 3. (a)-(d) show subsequent phases of the phenomenon as a disturbance in the water’s surface as the stream moves downward [6]](image)

An air cavity is created on the water’s surface when the jet stream makes contact with it. The force with which the stream hits the surface causes a stress rupture and creates a vacuum in the form of a cavity [3]. The broken surface tension causes the meniscus to form a pouch that will break off into the water as air enters into it; this produces the bubbles

![Figure 4. images of the formation and bursting of the air pouch. a. the jet stream creates a cavity in the water surface b. the cavity breaks off into an air pouch c. the pouch bursts releasing the air and forming bubbles.](image)

a. First  
b. Second  
c. Third
The diameter of the downcomer and jet velocity were used to determine the volume value of air entrainment that occurred. Downcomer diameters used in these tests measured 26 mm, 36 mm and 46 mm. Results graphed in figures 4 through 7 were obtained using a 6 mm nozzle and jet velocities between 3.53 m/s and 9.44 m/s. Figure 4 indicated that air entrainment tends to rise when the jet velocity is increased, and a 36 mm downcomer diameter, jet water brought less air than in downcomers with 26 mm and 46 mm diameters. For each jet height, the downcomers with a 36mm diameter also experienced smaller air entrainment values. Overall, the higher the jet velocity, the more air entrainment occurred. The results obtained with nozzle diameters of 8 mm and 11 mm mimicked those obtained with the 6 mm diameter nozzle.

The relationship between jet velocity and downcomer diameter to depth penetration is shown in Figure 5. Depth penetration with a downcomer diameter of 26 mm and 46 mm diameter stayed relatively similar as velocity increased, but an increase with the 36 mm downcomer. Many anomalies occurred with the 36 mm downcomer diameter. Stagnant graph trends were shown in the results from the 8 mm and 11 mm nozzle diameters.

In Figure 6, the bubble spread decreased because of the increase in the amount of water entering the downcomer. For the 46 mm diameter downcomer, the graph declined as velocity increased. This
decreasing occurred for all trials of this downcomer diameter regardless of the other variables in this study. Decreasing bubble dispersion area was occurred because the air was not brought into the water, so water entrainment is less effective. For the 36 mm downcomer diameter, the bubble dispersion area increased under all tested conditions. With increasing jet velocity, the bubble dispersion area also increased in this condition. The nozzle diameter values of 6 mm, 8 mm and 11 mm indicated that both jet and downcomer diameter do not significantly affect the dispersion width distribution of the bubbles.

Figure 7 shows that the height of the water that goes into the downcomer tends to rise in every condition. This is because the difference of downcomers are immersed with the air flow into the downcomer through the feed. Consequently, water from water tank enter to downcomer. Another factor is the difference in the diameter of the nozzle, the diameter of the downcomer and the height of the jet. The results increased only the difference in height values in each condition. The water that enters the downcomer affects the pressure difference between the inside downcomer and environment outside downcomer. Pressure variance increased when the diameter of the downcomer decreased as a result of the change in water volume that entered the downcomer. The amount of water present is influenced by the pressure and jet velocity.

Downcomer affects bubble production because it influences the volume of air available for air entrainment. Where, air entrainment occurs and produces bubbles. According to the diameter of the downcomer does not affect the water entrainment, this is contrary to the results of this study [7]. In order for bubbles to be produced as desired, changing the geometry of the experimental apparatus is a must. Changing the nozzle diameter, the height of the jet, the jet velocity and the diameter of the downcomer.

4. Conclusions
Air entrainment occurred when the jet stream hit the water level in the tank. The entry of air into the water’s meniscus, enlarged by the jet stream, caused the formation of air pouches which were then divided into bubbles of air as it goes deeper into the water. Many factors affected the air entrainment rate. Those factors are the diameter of the downcomer, jet velocity, water jet height, and nozzle diameter. The diameter of the downcomer determines the volume of air that is present in the jet stream therefore, it affected the air entrainment rate. Jet velocity affects air entrainment because the faster the velocity, the more air that gets sucked into the downcomer thus, more air entrainment occurs. The velocity of the jet and the downcomer diameter also determine the amount of water that goes into the downcomer. Jet velocity and downcomer diameter do not affect depth penetration, or the area of bubble dispersion.

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