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# The Effects of Water Flow Rate On The Air Entrainment Process From Vertical Plunging Water Jet With Downcomer

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**Abstract.** This study is intended to research the characteristics of bubbles produced by the phenomenon of air entrainment. This phenomenon is used in the Jameson cell, a flotation system used to separate valuable minerals from impurities. This process has proven successful in providing high separation efficiency. However, the characteristics of hydrodynamic bubbles and water entrainment have not been widely described. Research was set up in the form of a water loop consisting of a pump, flow meter, nozzle, downcomer, and water box. Data collection is done by using a digital camera and a high-speed digital video camera with a backlighting system. The resulting image is processed with software to obtain quantitative data. Results indicate that increasing the water flow rate also causes the ratio of air to water to increase (air entrainment). Air Entrainment is a natural phenomenon air carried out as a result of a fluid jet stream. Mass transfer deepens penetration because a high jet speed produces bubbles and tends to force those bubbles towards the flow. Increasing the water flow rate will expand the surface roughness to produce more bubbles. Thus, it can be concluded that there are three phenomena that will affect whether or not the discharge will increase the air entrainment process: depth of bubble penetration, area of bubble dispersion, and air entrainment rate.

## 1. Introduction

Flotation is used to separate minerals by utilizing hydrophilic and hydrophobic surface properties [1]. Floating hydrophilic molecules can be absorbed or dissolved in water so these hydrophilic substances remain in the water phase, while flotation will cause hydrophobic substances to be bound to air bubbles, which will be brought to the surface of the solution and result in foam, so it can be separated from the liquid. Additionally, the froth containing the mineral concentrate is separated for further processing and using bubbles as separation media.

Bubbles can be produced using the phenomenon of air entrainment, a natural phenomenon brought about by using free vertical jets to introduce air mass into the water's surface to form bubbles. Through experimentation, an innovative flotation device called the Jameson Cell was developed. The Jameson Cell is a flotation tool used in the mining industry to extract mineral deposits in the form of foam from waste water. Furthermore, the flotation device has proved effective in separation processes.

The scheme of the Jameson cell flotation device is a water jet wrapped in a downcomer that has been submerged in water, which creates a vacuum [2,3]. The phenomenon of air entrainment occurring within the downcomer sucks air into the downcomer and the water jet falls into the stagnant fluid to create bubbles [2,3]. The resulting bubbles separate sediment, causing it to float on the water, and the sediment can be swept from the water's surface [3].



There are several factors that affect bubbles produced by the mechanism of air entrainment: the jet velocity at the collision point, the physical properties of the fluid (viscosity, for example), the jet nozzle design, the length of the downcomer, and jet turbulence [4]. Based on the theory of developing fluid, jets falling vertically into a stagnant fluid will create air bubbles that become trapped when the impact speed exceeds the critical speed. The critical speed is change in flow properties from laminar flow to turbulent flow and there are several factors such as viscosity, density, pipe size, roughness, etc. that affect this number. This collision process will cause air to enter surface cracks in the second liquid, and the air will be trapped. This collision process will also create vortex currents that occur in the downcomer column and the collision can be as mixing energy [5].

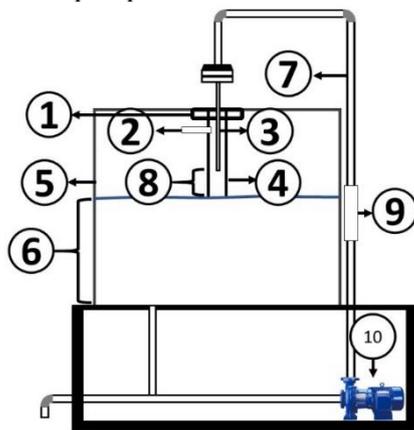
Referring to a previous study that used the vertical plunging jet method with a downcomer, this study was intended to determine the effects of water flow rate on the air entrainment phenomenon, as well as to study the characteristics of bubbles, such as area bubble dispersion, bubble depth of penetration, and the air entrainment ratio.

## 2. Methodology

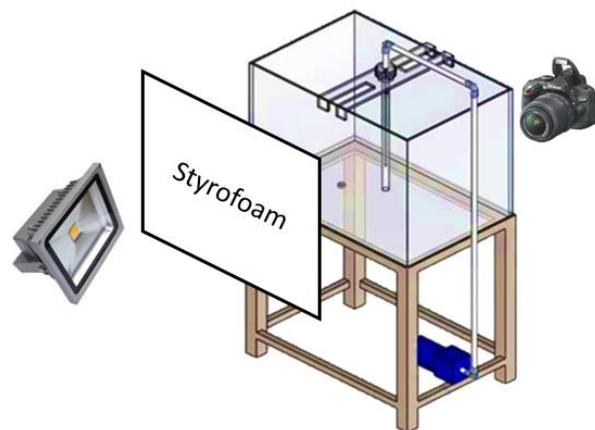
### 2.1. Experimental apparatus

Downcomer is partially submerged in water box. The water is pumped back by the pump to the nozzle. The nozzle ejects a water jet in downcomer. The air bubbles go in the direction of the air coming from the jet. Figure 1 shows a simple diagram of equipment and measuring tools used to watch the phenomenon of water. The experimental setup utilizes variable volumetric flow rates, achieved by adjusting the valves on the pipes. The water entrainment equipment, water tank, and pumps have been used in previous studies.

The entrainment process for water involves air coming through a vertically mounted downcomer pipe. Air entrainment using vertical plunging jets which liquid will move into the water. Before entering the downcomer pipe, air passes through a flow meter to determine the volumetric rate of airflow into the downcomer pipe. In addition, at the bottom of the box, there is a hole for releasing water in the box. This setup uses closed-loop system which the water in the box is reused and pumped by the water pump to the nozzle.



**Figure 1.** Schematic diagram of experimental in side view



**Figure 2.** Lighting conditions for capturing the process image and video using camera

#### Information:

- |                  |                             |
|------------------|-----------------------------|
| 1. Flange        | 6. Water level              |
| 2. Airflow meter | 7. PVC pipe                 |
| 3. Downcomer     | 8. Height of jet from water |
| 4. Nozzle        | 9. Water flow meter         |
| 5. Water box     | 10. Pump                    |

## 2.2. Collecting data

In this research, data was retrieved using a camera to take images of bubbles that resulted from the phenomenon of air entrainment. The camera was positioned so it aligned horizontally with the point of jet collision on the surface. To obtain the clearest images, dark fabric was installed around the box at distance adjusting. In addition, there were lights around the box to allow the camera to take more images and clearer images. With a backlit design, image processing software can be used to analyse the bubbles that appear.

To get the desired image results when shooting air entrainment, room lighting needed to be kept to a minimum. Light is needed only from the light opposite the camera in the pool (the backlight) to allow the images of water entrainment to be captured as clearly as possible for easy observation. Outside lights had to be minimised by covering window with a tarp so it was not translucent. Light emitted by the firing lamp had to be prevented because it result an unfavourable image. Therefore, an intermediary was used to disperse the light as shown by the scheme that follows. Light was spread by white polyfoam as thick as  $\frac{1}{2}$  mm. Polyfoam is capable of spreading the light so the light captured by the camera was white and the bubbles were visible. The camera was placed at the front of the observation pool on a tripod to keep the camera steady. The resulting image was processed with the help of software on the computer.

To calculate the air entrainment rate generated by downcomer suction, the water flow rate was measured two flow meters, one measuring 1–10 lpm, and one measuring 0.1–1.5 lpm, because it is difficult to read the incoming airflow when only one larger flowmeter is used. The type of flow meter used was a rotameter.

## 2.3. Data processing

To collect the data as accurately as possible, a data processing (image processing) application was used. The 'ImageJ' software used is a Java-based open source image processing software. This software is the image processing software used to analyse photos that have already been taken and it can be able to filter images with pixels 2048 x 2048 and 8-32 bits in RGB colour in wide format, and ImageJ offers image improvement as an option, because of the need to take pictures at high speeds (high speed photo capturing). The procedure required for shooting in ImageJ is as follows:

1. Preparing the image to be analysed: change the image type to 8-bit to increase the effectiveness of the picture contrast; add contrast to get clearest image in software and to prepare the image for binary conversion; calibrate the scale comparison on the image in ruler scale.
2. Obtaining bubble characteristics: determining the area of bubble dispersion requires the use of a free hand tool or it is tool for moving hands freely to create the circumference of the bubble dispersion. Determining the depth of penetration and the water level in the downcomer both require the line tool; point the line from the water's surface towards the lowest end of the bubble dispersion, and the line tool will ensure the angle of water surface comes to 90°.

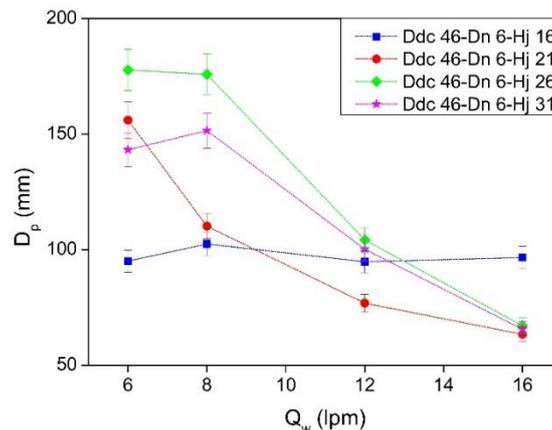
## 3. Results and discussions

### 3.1. Bubble penetration depth

For the 46 mm diameter downcomer, the results of the graph show that a higher water flow rate causes the depth of penetration to be closer to the water's surface. This result is caused by the downcomer enclosing the free vertical jet and having jets crash into the surface, which the collision causes a higher occurrence of aeration of water in the downcomer. This collision process will also cause a vortex current that occurs in the downcomer column and the collision can be as mixing energy [5]. In addition, a greater water flow rate causes the current vortex (water sucked) to increase in the downcomer, which increases the area of collision between the jet and the water's surface.

The other results are obtained from 36 mm and 26 mm diameter downcomers. The larger water flow rate causes penetration to extend deeper from the surface of the water. A high velocity jet stream that produces a bubble drag force tends to force the bubbles in the direction of the jet stream. This

result can also be attributed to the impact force between the jet stream and the surface of the water. When associated with the equation of momentum law where mass is multiplied by velocity, each point of contact between the jet and the water's surface causes the profile of the jet velocity to decrease, and the jet mass will increase to fulfil the same momentum value in each point of contact momentum between jet stream and water surface. The jet attracts air around it to increase the mass of water.

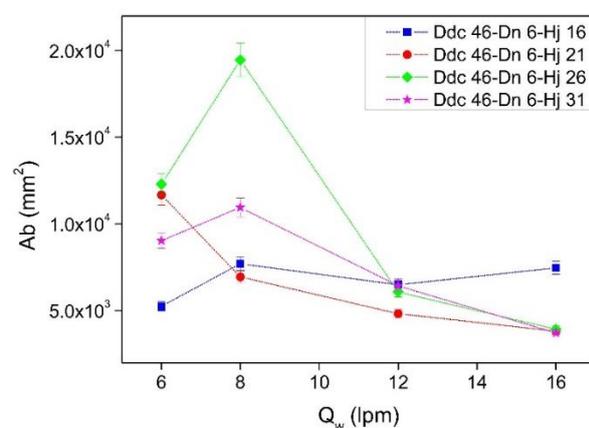


**Figure 3.** Bubble penetration depth for 46 mm downcomer

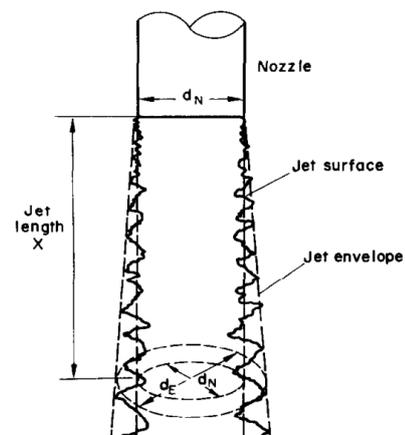
Penetration depth is defined as the lowest point of a bubble, where its velocity becomes zero and the force of buoyancy becomes dominant [6]. The small surface area of a microbubble causes its buoyancy force to be smaller; therefore, the microbubble will drift steadily along its flow direction [7].

### 3.2. Area bubble dispersion

The results concerning the 46 mm downcomer show that a larger water flow rate gives a smaller area of bubble dispersion. The resulting bubbles are visibly sucked into the downcomer more than those coming out of the downcomer column, and dispersed as bubble clouds. However, the 36 mm and 26 mm downcomers had results that opposed those of the 46 mm downcomer; the graph shows an uptrend, which means that when the water flow rate is larger, the area of bubble dispersion also becomes larger. It can also be explained visually that so many bubble were not sucked up into the downcomer.



**Figure 4.** Bubble dispersion area for 46 mm downcomer



**Figure 5.** Specifications of jet surface roughness [8]

The above results are supported by previous research demonstrating that many bubbles are produced and the area of bubble dispersion increases significantly with an increase in water flow rate

[9]. However, in this study, the size of the downcomer enveloping the vertical jet affected the results of the 46 mm downcomer differently from the 36 mm and 26 mm downcomers.

From the above results, it can also be explained well that the higher jets falling from the nozzle will affect the area of the jet surface contact with the surface. It can expand the area of occurrence of the water entrainment phenomenon, thus making the quantity of bubbles higher and higher. Increasing the jet height also causes increasing the surface roughness of the jet stream, so the friction between the stream jet and the water's surface is greater. The jets will bring more air into the fluid and the surface contact of the impact is wider. The theory is described in Figure 5.

### 3.3. Water level in downcomer

Figure 6 shows that the water level in the downcomer (water sucked into the downcomer) continued to increase along with a larger water flow rate. This result is the same for each downcomer. This happens because the continuous flow of air from jets carrying air mass into the water is not proportional to the air entering the small hose on the downcomer, resulting in a pressure difference between the atmospheric pressure and the pressure in the downcomer. A pressure difference between the atmospheric pressure and the pressure in the downcomer causes the water level or water sucked up into downcomer higher.

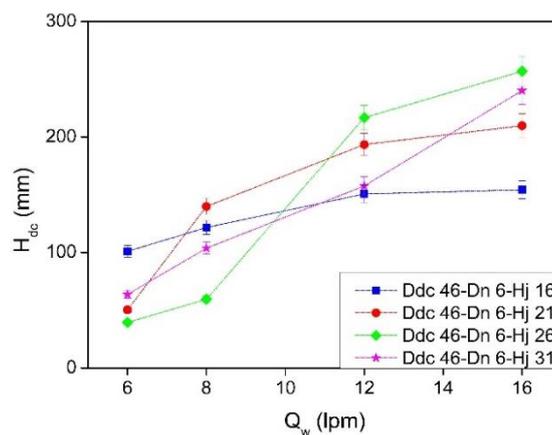


Figure 6. Water level in the 46 mm downcomer

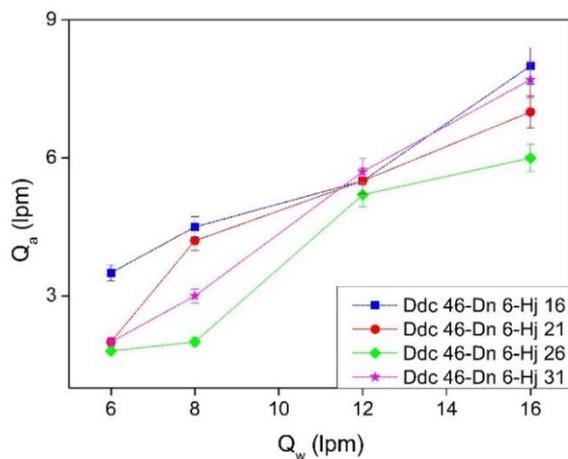


Figure 7. Graph of air entrainment rate for 46 mm downcomer

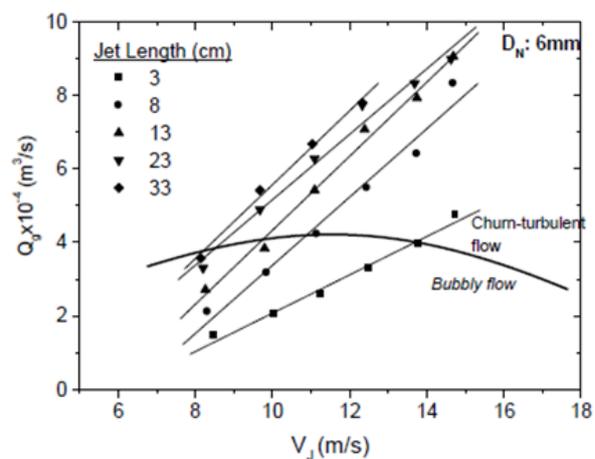


Figure 8. Graph of air entrainment rate [10]

### 3.4. Air entrainment rate

Figure 7 shows that the air entrainment rate increases along with a greater water discharge. This result is the same for each downcomer. The air entrainment rate is then calculated rotameter in litres per minute unit.

The results of Figure 6 are supported by previous studies [10]. In Figure 7, however, there is a unit difference in the y-axis, where the unit of air entrainment rate is expressed in  $\text{m}^3/\text{s}$ , and the x-axis, which represents the jet velocity in metres per second unit. However, it may support studies that show the effect of water flow rate on the rate of air entrainment.

An increased air entrainment rate is proportional to the increase in jet velocity due to increased kinetic energy of the jet, the roughness of the jet surface, and the momentum at the point of contact between the jet and the water's surface [11]. The bubble float to water's surface and it become a bubble mixture or as consisting of 2 phases.

## 4. Conclusions

A greater water flow rate will cause a decreasing trend graph pattern. This means that the penetration depth of bubbles gets shallow from the surface of the water. When the water flow rate is increased, the trend graph pattern indicates an increase in the water entrainment rate, the dispersion area of bubbles, and the height of the water in the downcomer. The resulting bubble characteristics due to variations in water flow rate can be used to separate pollutant substances from water. Although this must be increased in many aspects of hydrodynamics and also the bubbles must be added hydrophobic substances and hydrophilic substances to separate pollutants. Future research will require the use of a device that captures better images and improves visualization; one suggestion is a high-speed digital video camera with capturing capabilities of approximately 1000 frames per second. That way, the water entrainment process will be well documented.

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