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3/15/06
MCEN 5228

Air bubble trapped under flowing water

Introduction

The purpose of this image is to illustrate basic fluid dynamics with an image that is both interesting from a visual perspective, as well as a scientific perspective. The image of interest is one of an air bubble trapped under flow over a broad crested weir (figure 1).

Figure 1: Photo of bubble trapped beneath water flowing over broad crested weir.

The stream of water flowing off the weir is called a nappe. The nappe in fig. 1 is classified as a "Springing Flow"[1]. This flow is cause by two physical reasons. First, the momentum of the water doesn't let it turn the sharp corner. The water overshoots the corner and forms an arc. Second, the water flows over the edge so quickly that the air is trapped beneath the water.

Setup

The setup for this photo is fairly simple. The equipment needed is listed below (table 1). There are many different shapes of weirs available; the rectangular weir was used because of the 90 degree drop on the back side. This sharp drop is important because this is what allowed the bubble to be trapped by the water flowing over the block.

Table 1: Equipment needed to perform experiment

Flow equipment /testing setup	**Photographic/lighting**
Flume	Camera
Rectangular block weir (broad crested weir)	Two 500 W halogen lamp
Water	Whiter cloth (background)

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The first step in the setup of this experiment is to secure the block to the bottom of the flume. This is necessary because the block will slide down stream of float to the top if not secured properly. The block was placed 23 in. from the inlet of the flume. The block itself is 13.5 in. long, which means that the flow occurs about 36 in. from the inlet. Lights were placed above the block at an angle of about 45 degrees. The camera was located below, at an angle of –15 degrees, and about 5 in. behind the back of the block (figure 1).

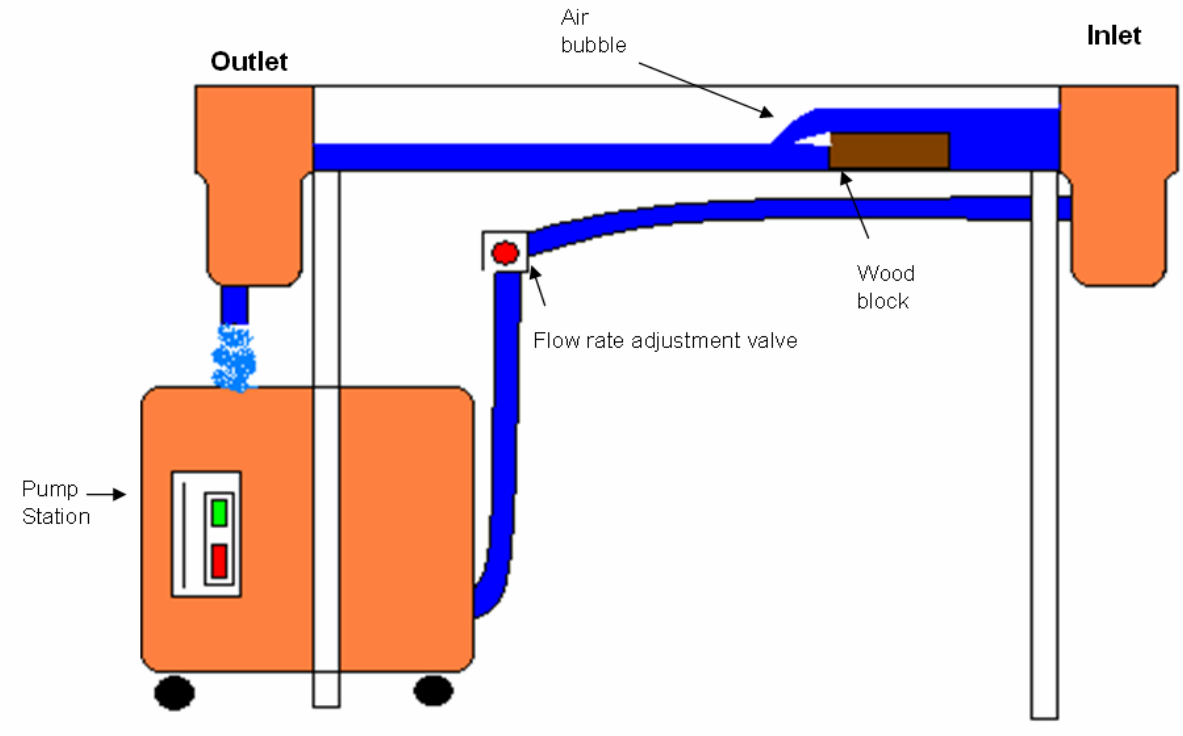

Figure 2a)

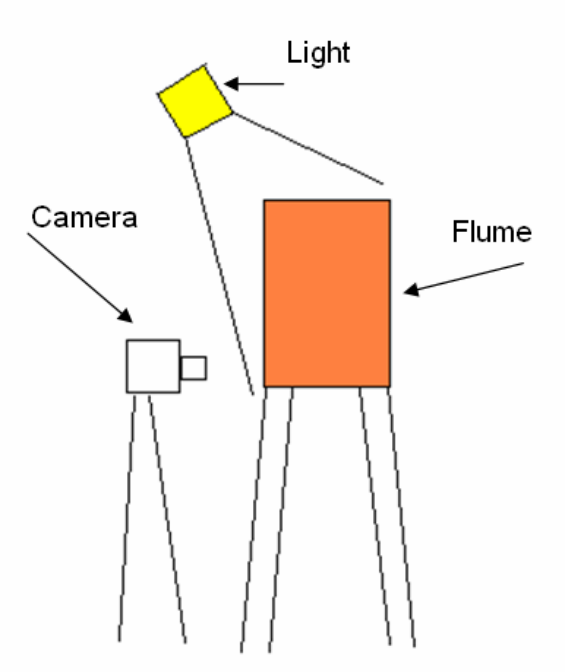

Figure 2b)

Figure 2: a) Front view of test set up (top), b) Side view set up (bottom).

The water in the flume was changed to get rid of any color or particulate matter that might add distracting elements to the photo. The flume was then turned on and the flow rate set at about 80% of the maximum possible rate. If the flow rate is too low the bubble will be smaller and less interesting. If the flow rate is too high the flow will be too chaotic to allow good photographic opportunity.

Flow Physics

The flow in this image is fairly easy to understand what is going on, but almost impossible to describe analytically. When the flume is turned on the area in front of the block is filled up with water, causing the water to flow over the broad crested weir. When the water reaches the back of the block it flows over the block forming a waterfall. Two things cause the air to be trapped under the flowing water. First the momentum of the water doesn't allow it to flow down the sharp 90 corner. This alone is not what causes the bubble to form. Just to test this theory air was pulled out of the bubble with a straw while the flow was set up. The space left behind by the leaving air filled with water. The water in this space, like the air, is not moving due to the momentum of the water above it. The bubbles are formed from the water pouring over the block so quickly that the air doesn't have time

to escape. The air wants to rise through the water because of its much lower density, but the pressure of the water above is too great for the air to overcome.

Weirs are used to measure flow rate in open channel flow. A broad crested weir is a rectangular shaped block of wood with a rounded front edge (figure 2).

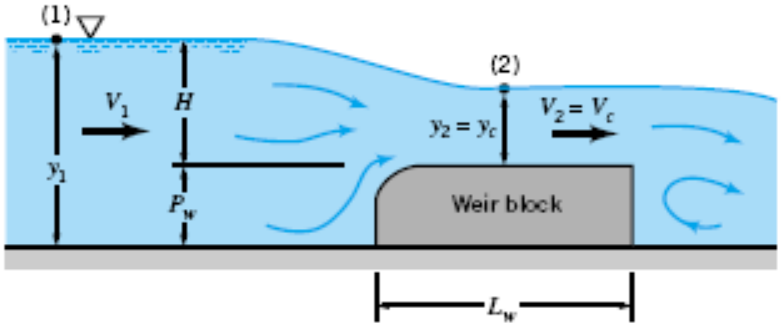

Figure 2: Figure of a boade crested weir with flow. [2]

From the figure we see how the flow forms the bubble. The area on the bottom right of the block where the water is spinning in a turbulent manner is where the bubble is formed and allowed to remain. The arrow right above that shows the laminar sheet of water that keeps the bubble from rising to the surface (figure 3).

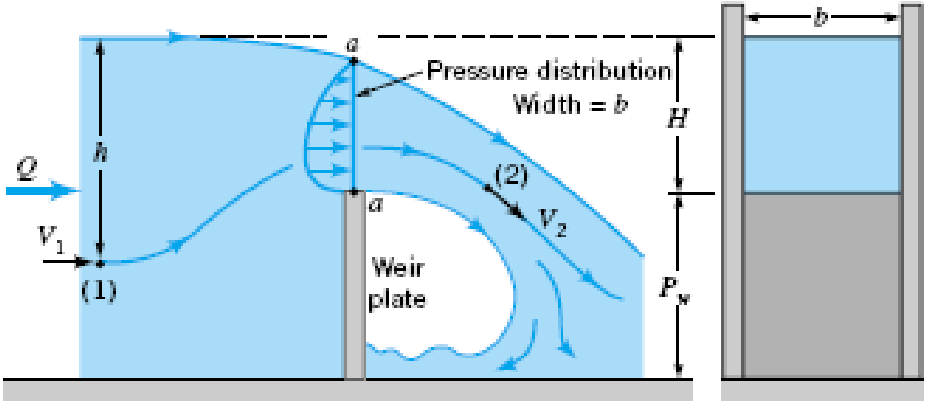

Figure 3: Shows the air bubble caught beneath the flow of water, in open channel flow [3].

The water in the in the laminar portion of the flow is flowing very quickly (around 30in/sec). The water circulating beneath the nappe moves relatively slowly, and for the most part the water in the circulating stay there trapped in that area similar to the bubble.

It is possible for the water to be able to make the sharp 90 degree corner. This is classified as “clinging flow” [2]. In order to get this type of flow the surface tension and gravity forces have to be great enough. If the flow is fast enough the water will overcome the gravitational force and the flow shown in the picture above will talk place.

Visualization Technique followed by Photographic Technique

The visualization technique used for this photo is simply flowing water and air interaction. The interaction between the two fluids allows us to see some of what is scientifically happening in the water flow and also makes for an interesting photograph. The flow took place in the ITLL flume and was illuminated from above using two 500 Watt halogen bulbs. This amount of light was needed because the flow was moving fast enough to cause motion blur of the image even using the most sensitive of ISO camera settings.

The camera used was a Canon Digital Rebel XT (8.2 MP). ISO sensitivity was set to 800 and a shutter speed of 1/1600 sec was used to eliminate any possible motion blur. An aperture of F/6.3 was used on the lens as well as a focal length of 33 mm. The distance from the lens to the flow was approximately 2 feet. The field of view we see in the image is approximately 10 inches in width and 8 inches in height. With the given camera resolution of 8.2 MP we have a resulting spatial resolution of .0029 inches. Assuming a flow speed of 30 in/sec, we calculate a temporal resolution of .0187 inches. In Photoshop we removed small debris and bubbles with the clone stamp tool. We also balanced the color to a more pleasant tone by placing a slightly blue filter on the image.

Conclusion

The purpose of this image is to illustrate an air bubble trapped under flow over a broad crested weir. The combination of these creates an image that is attractive from both a scientific and artistic perceptive. Overall, I was very pleased with the results of this experiment. My only complaint is the small amount of blurring, however, the image looks very clean, interesting, and beautiful.

References

[1] Johnson M. C. Discharge coefficient analysis for flat-topped and sharp-crested weirs. Irrig Sci (2000) 19: 133-137

[2] Fundamental of Fluid Mechanics, 5th Edition, Munson Young Okiishi, Wiley 2006

[3] http://www.jfccivilengineer.com/broad_crested_weir.htm

[4] http://www.aquatext.com/calcs/weir%20flow.htm