Analyze open channel for continuously low speed used carbon dioxide bubbles

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Abstract
Designing a recirculating open-channel for continuously low speed in place of a towing tank required checking on its flow characteristics. There are many methods for checking the flow characteristics such as food coloring techniques, using buoys and hydrogen gas bubbles, etc. For this research, we use carbon dioxide bubbles which are caused by the reaction between sodium bicarbonate (NaHCO3) and hydrochloric acid (HCl) that is diluted in water until the acidity is equal to pH 3. Our experiments were carried at the area near the wall and the center of the test range at depths 6, 8 and 10 centimeters from the free surface level respectively. From the experimental results, the trend of water flow patterns in the center of the channel using food coloring needles technique tends to form the fluid flow close to the computational fluid dynamics (CFD) while the results from the carbon dioxide bubble technique are different compared with the two previous techniques by less than 20 percent, and the trends of the water flow pattern results of the numerical method, the food coloring needle, and the carbon dioxide bubble techniques. The tendency of the flow pattern in the same direction.

Keywords: Carbon dioxide bubble technique, Food coloring technique, Open-channel for continuously low speed

1. Introduction
Testing a specimen to know the pattern of flow through that specimen can be done in various ways, such as wind tunnels or water tunnels. However, we will encounter problems with noise and relatively large wind tunnel sizes to resolve the issue where the boundary layer thickness will increase as the test distance increases. As for the water tunnels, the barriers are mostly structural and usually encounter leakage problems. This includes the water tunnels that have to be closed systems [1] while the hulls are formed like an open gutter and the specimen must be dragged back and forth. The problem with this test suite is if the test length is insufficient, deviation of the actual flow pattern on the object to be tested or even
obtained data extremely deviates from the actual operating conditions [2]. In this research [3], the concept of a low cost, small, recirculating open-channel, continuous water flow was developed. The system can be simply set up and maintained. The flow patterns of the sample specimen can also be easily observed. However, this type of water tunnel is suitable for relatively low speed flow. Other than the development of a recirculating open-channel flow tunnel, we also developed various relatively low-cost techniques to obtain flow patterns for the tunnel. The paper starts from theory and measuring procedures related to open-channel flow pattern. There are two methods of flow velocity measurements, i.e., food coloring and carbon dioxide bubble techniques. Next section, we provide details of our experiments from various methods. Details of the experiments’ set up such as the position of instruments and substance with respect to the tunnel, experimental procedures and results are also provided. We then compare our experimental results with numerical simulations. Finally, we conclude our results from the different methods.

2. Theory

2.1 Measuring fluid velocity in an open-channel flow apparatus

To find appropriate fluid measurement and flow visualization methods, the research focused on flow visualization in irrigation engineering. There are three main groups for measuring water currents:

1. Mechanical measuring instruments, such as water flow meters rotated around a vertical axis, etc.
2. Electronic water flow meters such as a tidal speed meter, electromagnet (Electromagnetic Velocity Meters) etc.
3. Special tools, which are not in the first 2 groups, for example, float method, Dilution (Dye) method, etc.

In this paper, we measured flow pattern of the water flow using dilution method and carbon dioxide bubble comparing to numerical calculations.

2.2 Measuring fluid velocity using dilution method

Measuring flow velocity in different depths can be done via timing specific distance that released paint moved. Before experiments started, we placed a few hypodermic syringes in different depths in the open-channel areas. Food coloring was then injected through the syringes. The movement of the paint was recorded and processed as follows. When the colored water header reached the first landmark the timer was started and when the colored water header reached the second landmark the timer was stopped. The capture time(t) was obtained from the timer. The following equations were utilized to calculate velocity and flow rate of the flow:

\[ Q = AV \]  

And

\[ V = \frac{L_d}{t} \]  

Where

- \( Q \) = volume flow rate (\( m^3/s \))
- \( A \) = flow cross-section area (\( m^2 \))
- \( V \) = velocity of flow (\( m/s \))
- \( L_d \) = distance of 2 measuring positions (m.)
- \( t \) = time of water flow through both measurement positions (s)

2.3 Numerical Model

It is very important to predict fluid flow through computer calculations. Since it can reduce the time of trial and error in design, save costs, resources and time to build in the research facilities for open-channel
flow. A computational method was applied using the ANSYS CFX Release 15.0 program. The flow was a multi-state flow type which was selected in the mode of a homogeneous flow. Initial conditions such as height variables for upstream and downstream, and output pressure were also specified. The main equation related to our calculation was a homogenous flow equation given as follows:

\[
\frac{\partial}{\partial t}(r_a \rho_a \varphi_a) + \nabla \cdot (r_a \rho_a \vec{U}_a \varphi_a) - \nabla \left( r_a \left( \rho_a D_a^{(e)} + \frac{\mu_a}{S_{\text{eff}}} \right) \nabla \varphi_a \right) = S_a^{(e)} + T_a^{(e)}
\]

Where \( \rho_a \) = density of state \( a \)

\( \varphi_a \) = Mass of state \( a \)

\( \varphi_a \) = Volume of state \( (\varphi_a = \rho_a \varphi_a) \)

\( D_a^{(e)} \) = Kinematic viscosity of the state \( a \)

\( S_a^{(e)} \) = External volume from state \( a \)

\( T_a^{(e)} \) = Sum of \( \varphi_a \)

\( \varphi \) = Exit of State \( a \)

\( a \) = Volume Fraction

Equation 3 [5] is a Eulerian-Eulerian multiphase equation which is used in ANSYS CFX Release 15.0. The equation is a single state flow with the density and viscosity of the combined states added. In our research, two types of fluids were used, water and air, and the turbulent homogeneous flow equation were used to solve the problem in the case of water and air mixtures. We also defined various constants ranging from water inflow rate, outlet pressure, pressure equivalent to the atmosphere in the open surface, moreover, all losses that were proportional by the volume of air and water in different areas for example air and water inlet and an outlet of pipes were added.

2.4 Measuring fluid velocity using carbon dioxide bubbles method

Using carbon dioxide bubbles in the measurement started from adding acid to the water in the open-channel flow until the mixture reached a pH of 3. We then added sodium bicarbonate (NaHCO3) to produce carbon dioxide bubbles. The carbon dioxide foaming mechanism could be described from the chemical equation as follows:

\[
\text{NaHCO}_3(s) + \text{HCl}(aq) \rightarrow \text{NaCl}(aq) + \text{H}_2\text{O}(l) + \text{CO}_2(g)
\]

It can be seen that when sodium bicarbonate reacts with hydrochloric acid (HCl), the resulting product contains salt, water, and carbon dioxide as shown in equation 4. The resulting product is carbon dioxide which forms as spherical bubbles. Very small bubbles which have low buoyancy move along the flow with a relatively low floating speed. However, with a clear boundary of the bubble, we could then achieve more accurate measurements of the flow with relatively low cost. The experiment to measure the velocity of the fluid in open-channel flow could be performed as shown in Figure 1, the arrangement of sodium bicarbonate in water mixed with hydrochloric acid to prepare for the flow test.
3. Experiment

3.1 Experiment model in open-channel for continuously low speed experiment set-up using carbon dioxide bubble and food coloring techniques.

Figure 2 shows the position setting for both experiments in the open-channel flow, using food coloring and carbon dioxide bubble techniques. The experiment was conducted in 2 areas: the middle of a low vortex open gutter and the area near the wall. The red dot areas were the places where the calcium carbonate located to generate the bubbles. The green dot areas were the location of the syringes for releasing the dilution for food coloring techniques. We monitored the movement of the bubbles at water levels 10, 8, and 6 cm measuring from the bottom of the channel respectively. Notice that in the technique of carbon dioxide bubbles, the subsequent addition of water caused the pH to change, which directly affected the rate of the chemical reaction, resulting in the change in the size of the carbon dioxide bubbles. For the technique of food coloring, abruptly disturb the system, e.g., adding water too quickly, might result in variation of released positioning depth.

In this experiment, the needle was installed in the center and near the wall of the channel with three level of depth for each location as shown in Figure 3.
As mentioned in the section 2, the experiments were recorded and processed. Since the color was very thin at the starting point, it therefore was difficult to identify its position correctly. In order for us to obtain better information, we waited for a second after we saw the color from our video before started collecting data for calculations. The following figure was an example of information obtained from the video capture.

For the carbon dioxide gas bubble technique, sodium bicarbonate powder would be arranged in the area before reading of the carbon dioxide bubble about 3-5 centimeters prior to the test section in order to make the carbon dioxide bubbles flow with the water. Figure 5 showed the arrangement of the sodium bicarbonate powder on the wall of the open-channel flow.
The size of the bubbles in the carbon dioxide bubble technique was the most important parameter to achieve accurate testing results, since the floating velocity component would contribute significantly to total velocity to the flow. We therefore had to limit the bubble size in order to limit effect of the floating velocity. The size of the bubble used to measure the fluid velocity is about 0.6 mm in spherical diameter. Figure 6 shows our set-up measurement axes. The bubble was measured with respect to y-axis only where at the top 105.6 mm to 106.2 mm at the bottom edge of the bubble as shown in figure 7. Notice that we did not consider the z-axis in this experiment. Using Adobe Photoshop CS 6, the measurements could be taken from the top left corner of the image as the origin, as shown in Figure 6-7.

**Figure 5.** Equipment installation point for open-channel for continuously low speed

**Figure 6.** Figure used to locate the resulting carbon dioxide bubbles.
Figure 7. Size of the carbon dioxide bubble that is formed

The experimental conditions led to the flow of food coloring or carbon dioxide bubbles. To calculate the velocity at any particular point, we relied on the time in the video. The point of interest was tracked for 1 second in case of food coloring or carbon dioxide bubbles. Floatation of more than 5 mm from the point of interest was not calculated in order to avoid the influence of the buoyancy force and the expansion of carbon dioxide bubbles, including the excessive spread of diffusion and the velocity of water at different depths were not the same.

3.2 Method for testing open-channel for continuously low speed using food coloring technique.
Before testing begun, we needed to turn on the small water pump to expel all the air in the syringe. The following steps were performed in the food coloring method:

1) Turn on the small pump and open the food coloring liquid valve. To let the liquid flow from the tip of the syringe, gently open the valve so that the liquid overcomes the loss of the hose, syringe system and the syringe exit pressure.

2) When the valve position according to the first procedure is found, mark the valve position. Turn off the small water pump and valve and wait for the color to fade away.

3) Turn on the main pump for a few minutes to allow the flow to reach its steady condition. We then turn on the liquid valve to position marked from the second procedure and record the flow. Close the liquid valve and turn off the small pump and then the main pump.

4) Post processing the data we obtain from the third procedure.

Notice that if water level in the open-channel flow is altered, we need to restart from the first step. If the water level is the same, we can start from third step by using the same liquid valve position since the pressure relating to the food coloring system is relatively unchanged.

3.3 Method for testing open-channel for continuously low speed using carbon dioxide gas bubbles
The following steps were performed in carbon dioxide gas bubbles method:

1) Mix approximately 100 cc of 12 mol hydrochloric acid with water in the open-channel flow to achieve a pH value of 3 using pH paper 0-14 to read the value.

2) Place the sodium bicarbonate powder in the desired location using paper. By placing the sodium bicarbonate powder before the area to be measured about 3-5 cm, with a width of 2-3 mm longer than the measurement and 5 cm in length of the sodium bicarbonate powder as shown in figure 8 to allow gas bubbles to form and flow in the area to be measured.

3) Turn the pump to the desired flow rate and beams of light to the area of interest to make the gas bubbles more prominent. Turn off all surrounding lights. Record the video of the area you want to record.

4) Post processing the data we obtain form the third procedure.
There are various techniques for measuring fluid velocity for open-channel for continuously low speed. The proposed techniques have many advantages such as clear visualization and the point of interest can be specified for the food coloring technique. However, there are some disadvantages such as color diffusion and an uncontrolled diffusion pattern for this food coloring technique. The advantage for the carbon dioxide bubble technique is the ability to keep track of the carbon dioxide bubbles throughout the flow without confusion. The carbon dioxide bubbles are tiny, resulting in a fine flow path. The disadvantage of this technique is that we cannot specify any particular points needed. Due to buoyancy force on the bubbles, the bubbles rise to the surface of the flow. Moreover, the bubbles expand as they rise due to diminishing of surrounding pressure, this process could disturb the overall flow field in a way that we did not anticipate.

4. Results

4.1 Water flow patterns at 10 cm-depth in the middle of open-channel for continuously low speed.

A reverse calculation was performed from the water meter installed under the channel. The water flow rate in the test set was 53 L/hr. Therefore, reverse calculations were made to find the model's inlet velocity and set up the calculations, found that the result was as shown in Figure 8, and plotted the point of the flow velocity from both techniques are shown in Table 1

| Point  | Food coloring       | Carbon dioxide bubbles |
|--------|---------------------|------------------------|
| 1      | Faster (11.11 percent) | Slower (1.11 percent)  |
| 2      | Equal to the calculation result | Faster (2.78 percent)  |
| 3      | Equal to the calculation result | Equal to the calculation result |

Figure 8. Numerical calculation results at the water level of 10 cm in the center of open-channel for continuously low speed
4.2 Water flow patterns at 10 cm-depth at the wall of open-channel for continuously low speed.
The reverse calculation was performed from the water meter installed under the channel. The water flow rate in the test set was 53 L/hr. Therefore, reverse calculations were made to find the model's inlet velocity and set up the calculations, found that the result was as shown in Figure 9, and plotted the point of the flow velocity from both techniques are shown in table 2

Table 2. Comparison table of fluid velocity of each technique against Numerical calculation results at the water flow pattern at the water level 10 cm is on the wall of open-channel for continuously low speed.

|                | Food coloring        | Carbon dioxide bubbles |
|----------------|----------------------|------------------------|
| Point 1        | Faster (1.58 percent)| Slower (6.35 percent)  |
| Point 2        | Equal to the calculation result | Faster (1.52 percent) |
| Point 3        | Equal to the calculation result | Faster (3.06 percent) |

In all three techniques were performed in center and wall open-channel a continuously low speed was used. The velocity obtained from the techniques was calculated from the video recording data. The velocity of the flow at the middle of the channel was faster than the velocity of the flow near the wall.

5 Conclusion
From the experiments at different water levels, it was found that the fluid flow patterns for both techniques deviated from the numerical calculation results. By using depths of 10, 8, and 6 centimeters from the water surface in the middle of open-channel for continuously low speed. Techniques for using food coloring tend to have flow patterns close to numerical calculation results. While the carbon dioxide bubble technique tends to be faster and slower at different points, the plane and the height from the floor of the carbon dioxide bubble could not be determined exactly. Therefore, the experimental results of the carbon dioxide bubble technique were highly variable. Despite being highly variable, the results showed less than 20% error rate compared to the food coloring and the numerical calculation. For the bubble technique at 6 cm-depth, it was not possible to interpret the data at some point due to the limitations of the camcorder. The maximum frame rate of 30 frames per second making it impossible to clearly see the carbon dioxide bubbles moving fast and the expanding of the bubbles. At the wall of the low vortex open gutter, it was found that the results of the food coloring technique and the carbon dioxide gas bubble technique tended to agree with each other. The results from the numerical calculation showed less than 9% error rate when compared with the food coloring and the numerical calculation. Only at the depth of 6 cm provided the results of the carbon dioxide bubble flowing at a speed of 0.125 m/s over the 5 cm flow pattern have a 23.80% error rate which could be explained by the expanding and floating of the bubbles.

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