Examining the Turbulence of a Buoyant Plume in a Flume

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Introduction

Buoyancy is the ability to float in a fluid or gas. In this experiment, we observe the turbulence of a buoyant plume in moving water with a boundary layer. A flume is a deep narrow channel or ravine with flow of water through it. In order to properly gather data for this experiment, we used a controlled flume to construct an experiment with a buoyant plume. This experiment was observed through color concentrations of the plume, as well as 3D velocities using a Vectrino. A Vectrino profiler is an acoustic doppler current profiler that can measure the 3D velocity at rates up to 100 Hz. MatLab is a programming platform that is used to analyze the image and velocity data, which is further used to quantify and describe the flow patterns associated with the buoyant plume.

Methods

Materials:

- Flume
- Flow meter
- Tubing
- Water
- 99% isopropyl alcohol
- Blue dye
- Beakers with mL measurements
- Stirring rod
- Camera
- Vectrino Profiler

Methods for Part 1

1. Create buoyant solutions, including 9 parts water and 1 part alcohol and approximately 5mL of blue dye
2. Place blue solution in a beaker with a tube attachment and attach to flow meter
3. Place a marking on the flume so that the flow will begin 2m down from the start of the flume
4. Have another tube go from the flow meter down the flume so that the flow will point directly upward
5. Set up a camera to capture the flow from 2m to 3m along the flume at 0.1m/s and started the flow meter at 10mL/min
6. After capturing 1 minute of the flow, increase the flow meter to 50mL/min, 100mL/min, and 140mL/min for 1 minute each
7. After completing the 0.1m/s series, we then measured the same flow rates by changing the flume speeds to 0.2m/s, 0.3m/s and 0.04m/s.
8. User MatLab to analyze concentrations of blues in the water
9. We then created concentrations of the dye in the water and captured pictures in the same lighting as the flume videos were taken

Methods for Part 2

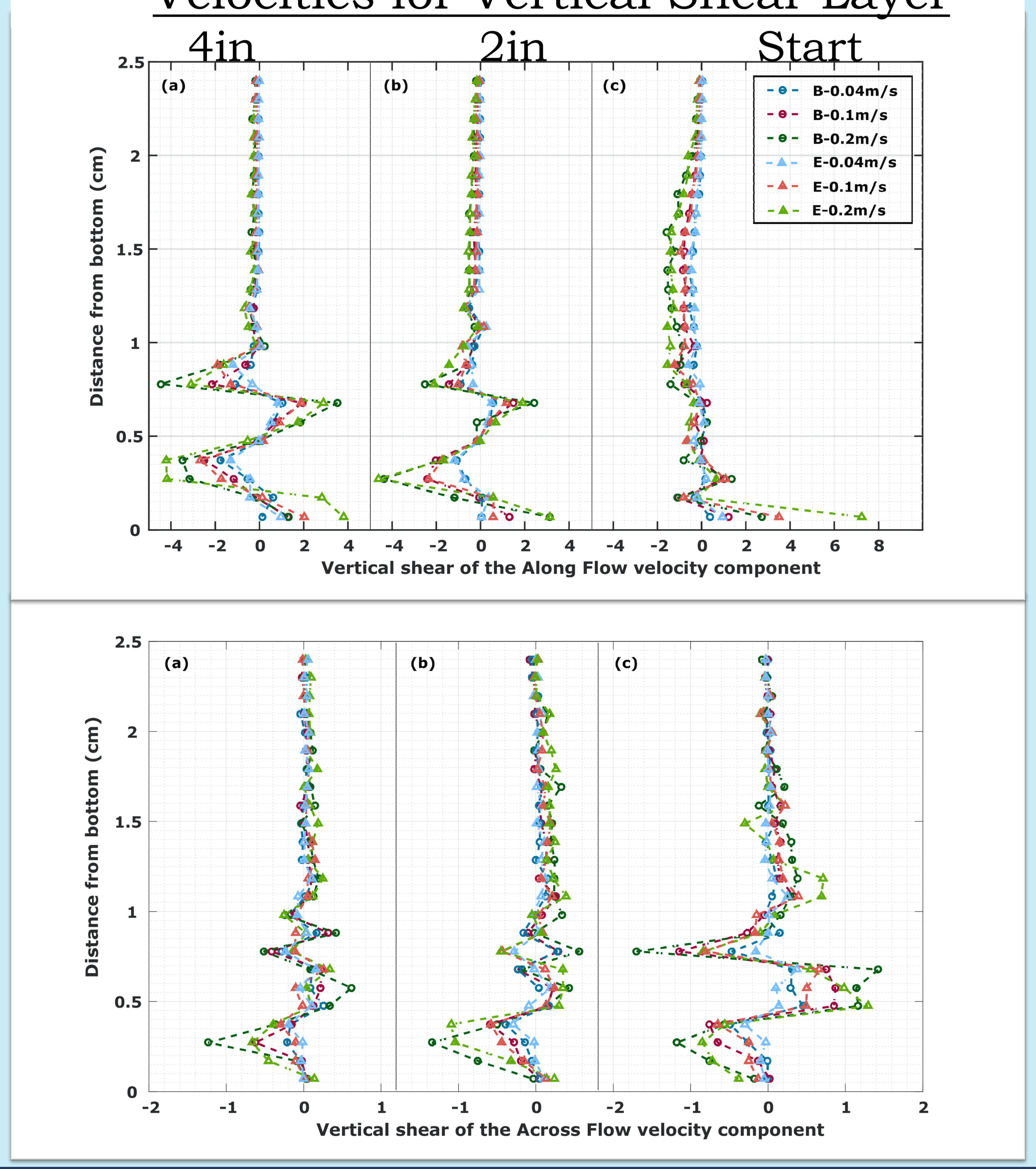
1. Set up Vectrino profiler submerged in the flume approximately 7cm from the bottom of the tank, standing directly straight upward
2. Using the same buoyant solutions, run Vectrino at three different flow rates and flume flow speeds
3. The flow rates and speeds were as followed: 11Hz at 40mL/min, 0.1m/s at 100mL/min, and 0.2m/s at 140mL/min for 1 minute each
4. Once we recorded this series, we moved the Vectrino Profiler down the flume by two inches and then four inches, recording the same series of flow speeds
5. We then used the data at the three locations to compare the turbulence through the velocities in both the X, Y, and Z directions

Figures 1 & 2:
The top figure depicts the buoyant blue solution within the flume. The bottom figure shows the blue concentrations that were picked out using MatLab image processing software.

Abstract

The study of buoyant plumes is crucial to understanding fluid dynamics within an environment. This can often be applied to real world events when discussing the spread of buoyant pollutants in air and water. In this study, we investigated the turbulent nature of a buoyant plume within a background flow. In order to do this, we used a flume to create the background flow and a flow meter to create a buoyant plume. The flow meter pushed a buoyant blue liquid solution through a tube into the flume. The different flume speeds used were 0.04m/s 0.1m/s, 0.2m/s, and 0.3m/s. The size of the plume was controlled by the flow meter, and we used flows of 10 ml/min, 20 ml/min, 30 ml/min, 40ml/min, 50ml/min, 100ml/min, and 140 ml/min. We used the programming platform MatLab to quantify the results into dark, medium, and light shades of the blue solution, to determine the light, medium, and high concentrations of the plume as it is dispersed within the flume. With the Vectrino profiles, we measured 3D velocities which allowed us to create velocity maps at three locations down the flume and away from the plume source. The results of this study have shown that the highest concentration of the plume is located near the source of the plume with an increase of mixing as the plume moved down the distance of the flume. We also found that most of the 3D mixing occurred within 1cm of the bottom boundary, due to the large vertical shear seen in the along and across flow velocity components. The shift in shear between the along and across velocity component along the flume, could be due to the vortices's created downstream of the buoyant plume point source. Data from this study can provide a background for further investigation of buoyant plumes of varying buoyancies, from different source configurations and within different background vs plume flows environments.

Velocities for Vertical Shear Layer

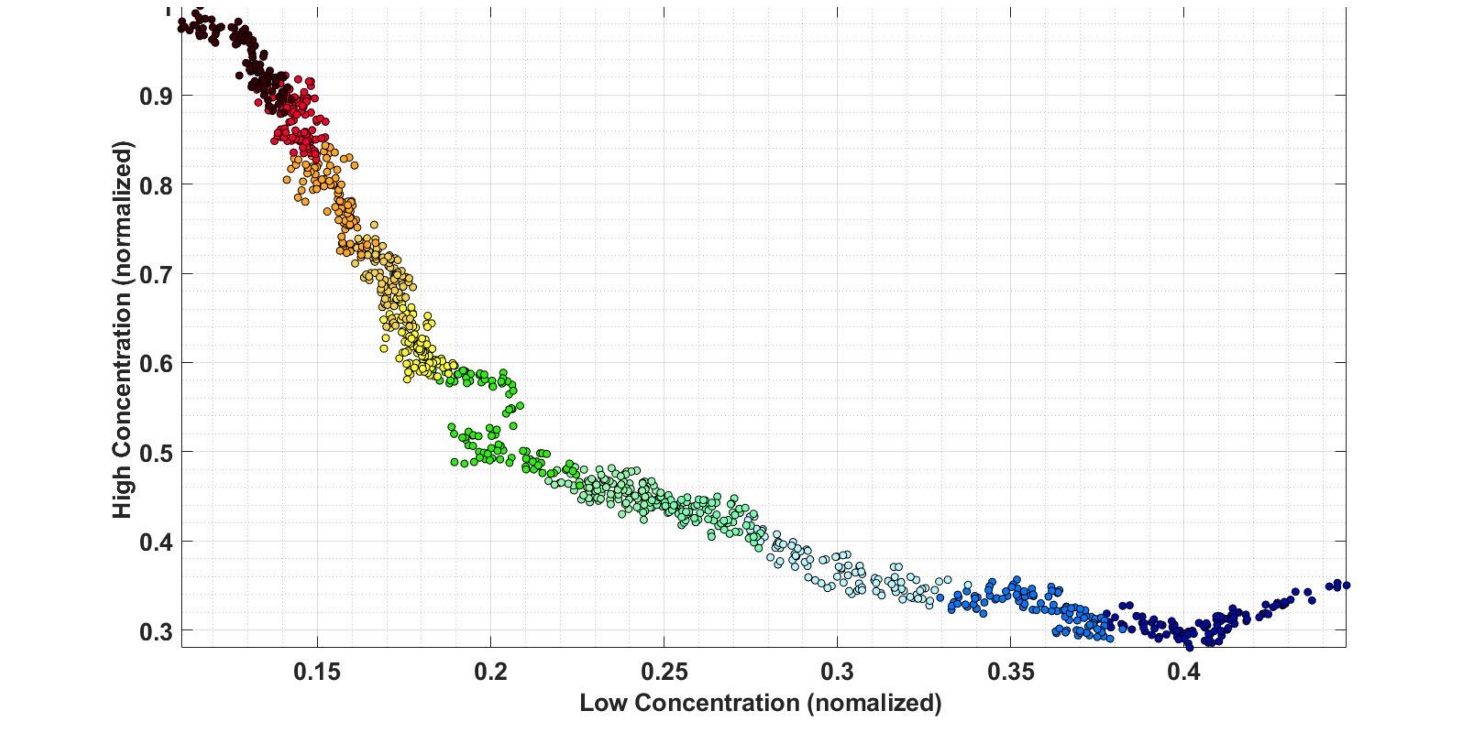


Figures 3: The above figure details the vertical shear of the along and across flow components in relation to depth at the start, 2in down flume and then 4in down flume. Background values are indicated as "B" and experiment values are "E".

Results

We were able to determine three levels of blue concentrations, later referred to as "low", "medium", and "high" values. The low concentration is 18.3PPM, medium is 37.6PPM and the high ranges from 79-178ppm. The density difference between our solution and the water in the flume was 0.022 g/cm^3. General trends depict that as the high concentration decreased, the medium and low concentrations increased. (Figure 4) There was a clear trend in each of the experiments that showed that the point of the source of the plume had the greatest concentration of the blue, decreasing as the water traveled down the flume. In analyzing the velocities from the Vectrino profiler data, we found large changes in the vertical shear of the along and across the flow within the bottom 1cm. This creates a large potential for mixing within this region, which we observed in all of the experiments. Above this layer, stratification occurred, where the buoyancy of the plume lessened the mixing. Based on our flow speeds, the Reynold's numbers ranged from 286 to 1420, which corresponds to Strouhal numbers between 0.1995 and 0.2129.

High v. Low Concentration



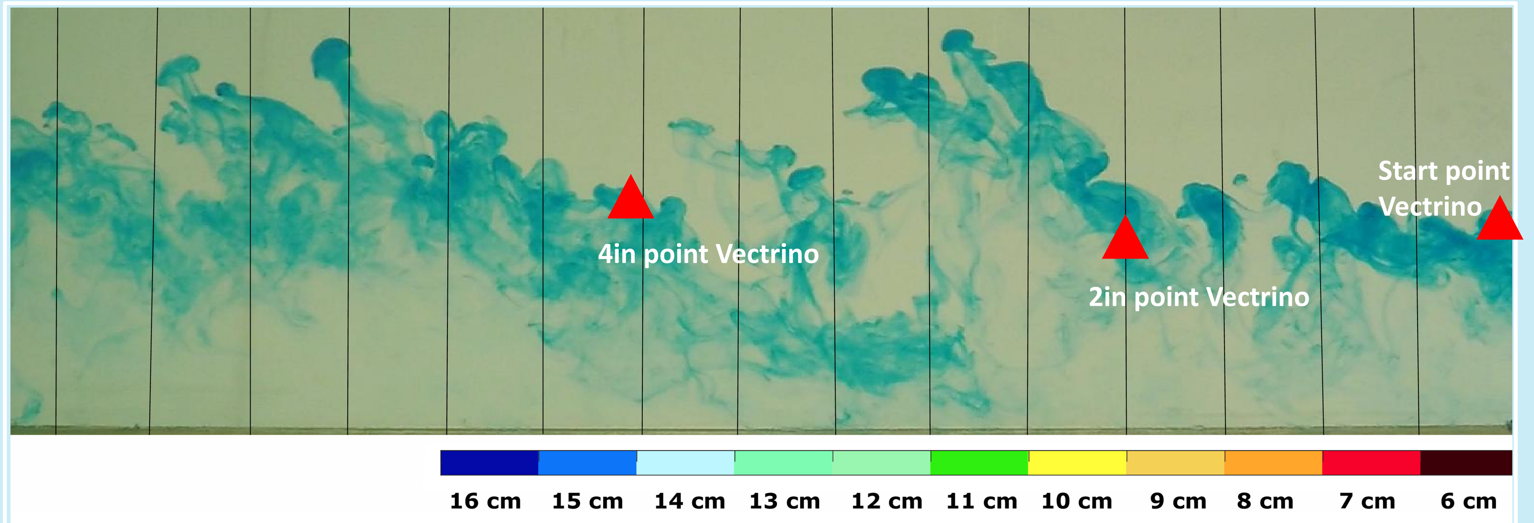


Figure 4 & 5:
Figure 4 shows the concentrations of the dye concentration compared to the light (18.3PPM), medium (37.6PPM) and dark (79-178PPM) concentrations as the plume moves down the length of the flume. Figure 5 shows the corresponding sections that correspond to the concentrations in figure 4.

Discussion

The concentration of the blue dye solution were examined to investigate variation in concentration levels downstream of the buoyant plume point source. Within the area of water that was analyzed, we were able to determine that there are greater concentrations of the dye in areas that are closer to the point source of the buoyant plume. We expected to find that as the dark concentrations were lowered, the concentrations of medium and light dye amounts would increase. By analyzing the data using MatLab, we were able to create graphs that depicted this trend. In relation to this, the measured velocities indicate that there is mixing due to vertical shearing and shedding of eddies from the incoming plume and its cylinder. (Fig 5) We also saw evidence of vortical structures created due to the introduction of a buoyant plume into a uniform stream (these show up as inconsistencies in the 'green' area in figures 4 and 5). Here, it is postulated that these wake vorticies originate in the laminar boundary layer of the wall, and in fact travel upward. Based on our Reynold's numbers, we found that our three experimental setups spanned three separate regimes, a wake-transition regime, fine scale 3D instability and lastly a shear-layer transition regime. (Williamson 488)

References

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