AER 210 Lab 1: Introduction to Microfluidics  
Robert Purcaru  
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**Introduction**

        This report follows a lab which studied microfluidics by passing a small volume of liquid, which suspended microscopic fluorescent spheres, through channels in microfluidics chip comprised of four different features of interest and photographing the fluid to observe the streaks formed by the fluorescent spheres. The information gathered in this lab is not only relevant to the study of fluid mechanics, it also sees applications in other fields, particularly chemistry and biology, where microfluidics is used in processes like DNA sequencing. This lab demonstrates the use of Bernoulli's equation, equation eq.[1], and the continuity equation, equation eq.[2], as the gravitational potential, direction of flow and area of channel are varied. The objective of this experiment is to not only confirm the models put forward by equations eq.[1] and eq.[2], but also to introduce the students performing the experiment to fluid mechanics.

Bernoulli's Equation: eq.[1]

Continuity Equation: eq.[2]

Error propagation through equation: eq.[3]

Uncertainty in the mean: eq.[4]

**Experimental Procedure and Results**

Chart, treemap chart

Description automatically generated        The procedure outlined in the lab manual [1] was followed with all pictures used in the analysis being taken using the 10x objective lens on the microscope. Using a hemocytometer, pictures were taken using the 10x objective lens to determine that the resolution of our pictures was 0.924 ± 0.004µm/px.

Figure 1 | Picture of hemocytometer using 10x objective lens with pixel distances on 25µm squares.

The technique shown above is the same technique used in subsequent calculations for measuring the displacement of the fluorescent sphere, the main difference being the measurement error is greater than 0.5px because measurements are taken on moving streaks which partially exposed some pixels - as opposed to the hemocytometer which was static when the picture was taken.

        To measure individual streaks, the images were imported into Microsoft Paint and 3 streaks were measured at each area of interest. These values were then averaged with the error of each average being derived from the uncertainty in the measurement for each streak. These results can be seen in Figure 2.

Figure 2a shows the fluid velocity at the edge of the channel (Edge), the quarter distance across the diameter (Between) and the center of the channel (Middle) for various heights of the reservoir above the reference height (0mm). These effects are elaborated on in figure 3.

Figure 2b shows that the velocity of the fluid increases as the diameter of the channel is constricted abruptly, with the fluid speed increasing abruptly as well.

Figure 2c shows the velocity of the fluid increasing as the diameter of the channel is constricted gradually, with the fluid speed increasing gradually as well.

Figure 2d shows that the fluid velocity before and after a bend is relatively constant but the fluid speeds up measurably on the outside radius of the turn and slows down measurably on the inside radius of the turn.

A picture containing table

Description automatically generated Figure 2e shows the fluid speed remaining relatively constant through the radius of a gradual bend.

Figure 2 | All set ups used with annotated flow lines and measured averaged (left of each subfigure). Tables showing average velocities and their respective uncertainties.

The relationship between velocity and gravitational potential can be derived from Bernoulli’s equation, indicating that they scale according to:

eq.[5]

Chart

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Figure 3 | Measured fluid velocity with reservoir at various heights. Measurements taken close to channel wall (left), halfway between wall and center of channel (center), and at center of channel (right). Fluid velocity scales quadratically as height scales linearly, as is expected from eq.[1].

**Error Analysis**

        The error for each measurement was inconsistent because judging where a streak ended could not be done consistently. Each streak was marked and measured twice, with the reported length being taken as the average of the measurements and the error as half the distance between measurements (since 2 measurements were taken per streak). Three of these measurements were taken for each region of interest and averaged to find the values reported in figure 2. The uncertainty was calculated using the uncertainty of an average formula, eq.[4].

eq.[4]

The camera we used was set to an exposure of 50.6ms for the trials in figure 2a, 2b, and 2c and 78.4ms for the trials in figure 2d and 2e within 0.05ms. This was assembled into the formula for velocity

With uncertainty:

Our data was likely skewed by our inability to account for the fluid proximity to the wall in the axis perpendicular to the viewing plane. This means that we could have been measuring samples that were closer to the top or bottom of the slide – and therefore moving slower - without knowing it. This error can be reduced by only measuring samples that were in relatively similar focus, however this was not always possible to do.

Defects in the channels could have also caused some error as they would interrupt the flow through the channel, resulting in small eddies or otherwise turbulent flow around the defects. Examples of these defects can be seen in figure 3.

A screenshot of a computer

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Figure 4 | Defects in channels.

The most significant source of error was likely the measurement error inherent to our group’s technique for measuring the length of each streak. Since the data was collected relatively haphazardly by placing the cursor in Microsoft paint where it seemed like a streak started or ended, the error from the repeatability of these measurements was likely around 4 to 6 pixels per measurement. As a result, the errors for our measurements were large, which propagated into the values we calculated for velocity using eq.[3].

**Discussion**

The values measured in the first experiment which sought to measure, the relationship between the height of the reservoir and the velocity of the fluid through the channel showed, a vaguely quadratic relationship between the two. This is almost what was expected using Bernoulli’s Equation, where the velocity term is quadratic and the change in gravitational potential of the fluid is a linear term. However, as is shown in eq.[5], velocity should scale with the square root of height, not the other way around. This was likely due to a combination of the small number of data points used in the fit and the poor quality of measurements taken in the early part of the lab.

Likewise, the data showing the affect of proximity to the boundary also failed to match the expectation. At the reference fluid level, there appears to be a linear relationship between distance from the boundary and fluid velocity (figure 2a). However, the subsequent trials, at heights 280mm and 353mm, show no relationship between the fluid velocity and the distance to the boundary. This could be due to an error in how the microscope was focused for the picture. If the focus plane of the microscope was significantly above or bellow the center of the channel, all the streaks that were clear enough to be measured could have been relatively close to a boundary, resulting in the lack of variation in the measurements. Still, the flow appeared to be laminar throughout the channel. We would expect the fluid to travel slower near the boundary and fastest in the center of the channel with the most noticeable difference in velocity occurring near the edge of the channel. Unfortunately, the data collected in this experiment does not provide any insight into what kind of relationship there is between distance from fluid boundary and velocity.

In both cases where the fluid was forced through a constriction, the fluid velocity after the constriction had increased appreciably. For the abrupt constriction (figure 2b), the width of the channel decreased by a factor of about 3[[1]](#footnote-1). Since the depth of the channel remains constant, the area decreased by a factor of 3 as well. Eq.[2] tells us that area and velocity are inversely related. That is, if the area decreases by a factor of 3, the velocity of the fluid should increase by a factor of 3. Once again, the data collected fails to strongly reflect this relationship. Instead, the data collected at 2 different heights reflects a narrowing of area by a factor closer to 2. This may be a result of increased resistance to the flow in the narrower section of the channel; a greater proportion of the liquid is closer to the wall of the channel which would disrupt the flow of the fluid. The channel that narrowed more slowly narrowed by a factor of about 4. The data collected fails to exhibit this relationship, presumably for similar reasons as the channel that narrowed abruptly. It is worth noting however that the velocity of the fluid seems to decrease more gradually in this case when compared to the abrupt change in channel width; the length of streaks appears to increase consistently as the fluid approaches the constriction. In both cases, the flow appears relatively laminar, however the sudden narrowing channel had a large bubble, which could not be dislodged, that produced some visible non-laminar affects. Both of these experiments were also used to re-examine the affects of gravity on the fluid velocity. As was the case in the first set of experiments, increasing the gravitational potential of the fluid increased the velocity of the fluid through the channel.

The experiments with bends in the channel both showed the fluid velocity was statistically constant before and after the bend with the speed of the fluid changing depending on where it was in the bend. In both cases, the fluid passing through the inner radius moved slower and the fluid in the outer radius moved faster while fluid at the midpoint retained a near constant velocity. This is illustrated in figures 2d and 2e, where the length of the line represents the relative lengths of the tracks in that region. In both cases, the fluid seems to exhibit laminar flow. It is however worth noting that the height of the reservoir was relatively close to the height of the sample. When the reservoir was raised, the fluid speed increased and the flow immediately following the bend in the sharp corner became turbulent. The flow remained laminar in the sample with bends for all heights tested. This means that, remarkably, the experiments involving bends in the channel align with the model we were given.

In general, the results obtained did not match the models provided. This was likely a result of poor understanding of the experimental procedure and data collection along with the implications of the assumptions that need to be made to apply eq.[1] and eq.[2] (namely incompressible, nonviscous flow). These results could be refined in future experiments given the understanding of the apparatus and objectives that was developed during the course of the experiment. The results likely have a low degree of reproducibility because of the flawed method with which the data was collected.

**Conclusion**

Given our understanding of fluid mechanic, Bernoulli’s equation and the continuity equation should describe fluid flow when studying fluid velocity as it relates to gravitational potential and the size of the channel it is passing through assuming an incompressible and nonviscous fluid. This experiment did not show a strong degree of correlation with these models. In some cases, this seems to have been a result in error of experimental method and in others the result of the failure of the assumptions made by these models. This experiment did however provide valuable information about the procedure and techniques which can be used when studying microfluidics, like how to tune exposure, gain, saturation and gamma. The experiment was therefore successful in its goal to teach a student who has yet to study fluid mechanics formally about how Bernoulli’s equation and the continuity equation could be applied in a theoretical context (since an understanding of both was required to recognize the error in the experiments).

**References**

[1] B. Keith, E. Chung, T. Dell, E. Brisson, D. Temelli, A. Shukalyuk, and M. Binette,  
“Introduction to microfluidics,” 2013.

1. This value was obtained by diving the pixel width of the narrow part of the channel by the pixel width of the wide part of the channel. [↑](#footnote-ref-1)