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| **NUCL 355 Experiment 9** |
| Air-Water Two-Phase Flow Patterns in Vertical Pipe  Professor M. Bertandano |
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| School of Nuclear Engineering  Purdue University  Report of the Experiment By:  Weston Cundiff, Stephen Cox, Kara Luitjohan, Patrick Burk, Dominic Ghering, Michael Stryker, Austin Curtis, Matt Metzger, et. Al. |
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| **3/29/2011** |
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# Executive Summary

Two-phase flow is an important problem for reactor physics. The momentum of the system is not straightforward as in single-phase flow cases, and must be defined in other ways. The void fraction of the system is important, as it will affect not only the mass flow rate of the system, but the phase of the system. The phase of the system can be annular, whispy annular, developing, or slug, and is defined by its quantitative properties. The Mandhane chart is generally used to describe these properties.

A system was created using pumps for air and water and a vertical column. A section of the column was partitioned as a testing section. Using the separate pumps, the flow velocities of both phases were varied, and measured using separate flow meters. The pressure drop was also measured across the test region. A phase diagram was drawn for each of 60 different flows, for use in data analysis.

The quantitative values for the system were used in several different ways. The total pressure losses (from 5162.31 to 9545.32 Pa/m) were compared to the flow rates in the system. The friction losses (from 0.00100 to 0.187 Pa/m) were also compared to the flow rates in the system. The dynamic heads of the system (with the maximum velocity value being 1.111 in air, .6822 m/s in water; minimum velocity values were .0114 and .0158 m/s air and water, respectively) were calculated to use in the charting of the Mandhane chart.

The Mandhane chart turned out to be unexpectedly inaccurate. Using reason and possible errors in the drawing as markers, the Mandhane chart was able to be described accurately. The friction losses were described as increasing with air flow rate, decreasing with water flow rate. This is intuitive as it has to do with annular flow, and the amount of water in the boundary region during annular flow. Total pressure losses were only partially because of friction, with the rest of these exponential trends (following the friction trends in direction) coming from the amount of turbulence within the system.

Although certain parts of this experiment could be improved with different quantitative ways to measure the system, the experiment was generally performed well. With better drawings of the flow regions, the data would have been very accurate and physically intuitive.

# Introduction and Theory

Two Phase flow is especially important in reactor physics, because of the presence of evaporated gas within the coolant channels in nuclear reactors. Through the study of the fluid dynamics in these systems, many important things about two phase flow have been learned. This experiment does not deal with heat transfer in two phase flows, because it is a more simplified version of two phase flow experimentation. It clearly describes a system with two phases by its fluid momentum properties.

Two phase flow is governed by the amount of mass moving in the fluid system. Because the density is different for the gaseous element than the fluid element, it will change the flow parameters of the system. In general, the gaseous element with the lower density will move upward faster. This will help to move the fluid itself along the upward direction, because of the forces associated. The total mass rate of the system is given by the below equation, and is simple the super position of the two elements flow rates through the control volume.

Using the mass rates, the defining quality of the system can be defined, which is the void fraction. The void fraction defines, at a certain zero thickness slice of the system, the fraction of void (gas) to liquid. This can then be used to define the flow rates of air, the superficial velocities, and other system-wide parameters. The equation for the void fraction is given below, and it will give its output in a dimensionless quantity. The void fraction can also be computed from the quality of the flow, which is simply the ratio between the gas and fluid in the system.

Using the mass rates and the area of the tube system, the mass flow rate can be defined, which is by definition the amount of mass moving a distance in the system over a certain amount of time. This can be used in conjunction with the density to give volumetric flow rates for each of the different elements.

In single-phase flow systems, the volumetric flow rates are often used to determine the velocity of the system. Using the volumetric flow rate of the phases in two-phase flow, the velocity of each element can be determined, but it is not an accurate indicator of system properties. Instead the superficial velocity must be calculated, shown below. The superficial velocity uses the void fraction to calculate the velocity of only a fraction of the system. For the liquid, the quantity must be used because the void fraction is by definition the amount of gas divided by the amount of liquid.

Using the superficial velocities, the entire mass flow rate of the system is possible to be calculated. Using this parameter, it’s possible to see if the inclusion of the second phase has increased the mass flow rate of the system. This value will be useful when heat and mass transfer analyses are done on the system, thus is an important key to the values used for reactor safety. The equation defining this factor is given below.[[1]](#footnote-1)

# Experiment Description

To correctly analyze a two phase flow system, there are many parts of the system that must be considered. Air must be able to be introduced into the system easily, the flow rates of both the fluid and the air must be able to be varied and measured independently, and the water must be able to be returned to the bottom and pumped upward again. This lab cleverly solved all these design constraints.

The setup is cleverly simple, with a water tank and an airtank attached to a vertical column through valves with pumps. There is a mixing section, which is where the water and air are fed in at prescribed flow rates and then pushed upward using pumps through the observation region. This observation region reaches the separator, which returns the water to its tank, and the air to atmosphere. The setup is shown below.

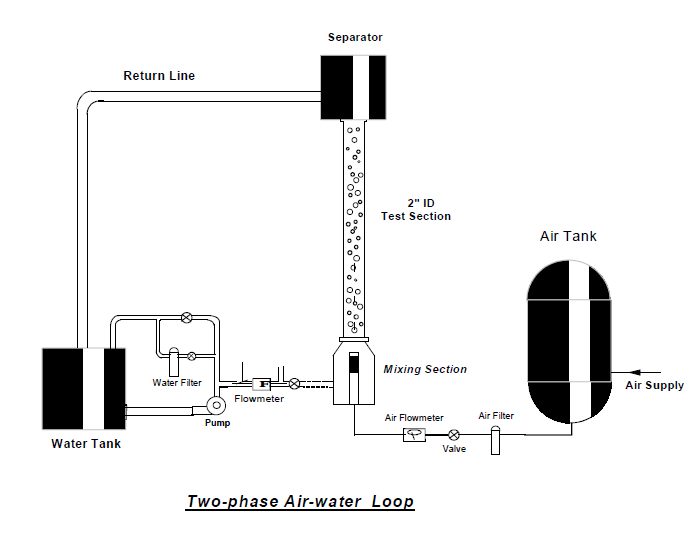


Figure .1 Two-Phase Air-Water Loop

The instrumentation in this experiment is also very important. The pressure correct for the air flow rate must be recorded, as well as the air flow rate itself. The air flow rate was measured using a rotameter. The water flow rate was measured using the flow meter that has been used in past experiments. The pressure drop across the entire testing length was taken using the pressure transducer used in past experiments and hooked up to a digital multimeter. The details of these apparatuses are shown below.

Table .1 Equipment Properties

|  |  |  |  |
| --- | --- | --- | --- |
| Equipment | Manufacturer | Model #/Serial # | Range |
| Pressure Transducer | Honeywell | STB 924-E1A-00000-1C.MB.AN+XXXX | 0-130 inH20, 1-5V |
| Flowmeter | Honeywell | MGG1 4C-CB4H-XBXX-SHA | 0-10 m^3/hr |
| Small Air Rotameter | King Instrument Co. | N/A | 0-4 SCFM |
| Large Air Rotameter | King Instrument Co. | N/A | 2-20 SCFM |
| Air Pressure Correction Gauge | Span | N/A | 0-100 PSI |

# Data Acquisition

Data was acquired in this lab in a way such that error could be correctly calculated and minimized. Because several of the instruments have precision error (the DMM and also the Flow Meter), several values were taken on these instruments.

The water flow rate was set at differing values as full sets. For each different air flow rate within those full sets, the pressure drop was read five times, as well as the flow rate of the water. The pressure gauge was read to determine the pressure drop. After this was completed, the air flow rate was increased 9 different times, giving us 10 subsets.

The sets were performed 6 times, giving 60 total subsets of data through a wide range of air and water flow rates. For each subset, the flow regime in a recording region was observed and drawn. Using these drawn flow regimes, the type of two phase of flow was qualitatively determined. Using the multiple readings as well as providing a full range of data allowed for error to be minimized within this experiment.

# Analysis and Discussion of Data

The Mandhane Flow Map is the standard on which two-phase flow systems are plotted. It correctly shows the regions of flow and how they will appear in a two-phase flow system. To determine the properties needed for the Mandhane Flow Map to be correctly plotted, a long data transformation process must be used. The specifics of this process can be seen under the sample calculations section.

The process starts with the transformation of measured flow rates of air and water into units compatible. After compatible units are calculated, the quality of the flow can be determined, and from there the void fraction can be calculated. The void fraction is calculated using the quality relation formula under the homogenous equilibrium model. Using the equation for superficial velocity shown above, the superficial velocities of the system can be calculated, and then squared and multiplied by the density of their material to be plotted on the flow map. The experimental flow map is shown, followed by the accepted flow map. For a discussion of the differences in these flow maps, please see the Unexpected findings section.

Figure .1 Mandhane Flow Map (Calculated)

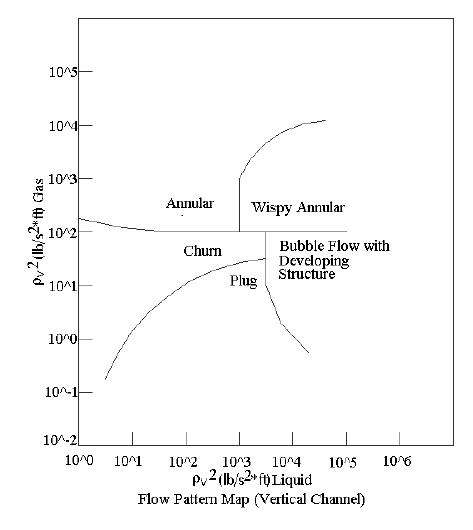


Figure .2 Mandhane Flow Structure Map

After the Mandhane flow map was generated, more quantitative results could be shown and discussed. The first was the pressure drop across the entire testing region. This pressure drop will be a mixture of the difference in the height, as well as friction loss and the loss to turbulence within the flow. The totals of these can be shown in the chart below.

The general trend for water is shown as an exponential decay of flow rate as the pressure drop over a distance increases. From a physical standpoint, this is understandable. As the flow rate of water drops, the flow rate of air tends to increase, and the void fraction. With a higher void fraction, the flow will move towards annular flow. In annular flow, most of the liquid moving is within the friction boundary region, creating a higher drop of pressure.

The trend for air also follows a physically intuitive pattern. As the pressure drop increases, so does the air flow rate. For higher pressure drops, the amount of air must be higher (to generate the higher void fraction and annular flow). This is shown in an exponential fashion on the chart of air flow rate against the pressure drop over a distance. After the discouraging results from the Mandhane chart, it is good to see that the quantitative values fit a physical model.

Figure .3 Flow Rates vs. dP/dx

The chart above, showing the total values for pressure drop, do not show the entire story. Although friction plays a part, as described above and also shown in the chart below, it is not the largest component of pressure loss. The chart below shows the relations described before, but instead of being exponential in value, in linear relationships. What exactly causes the exponential relationships?

This has to do with turbulence. As air increases in a system, there is increased energy that is put into non-conservative terms, from the turbulence in the system. This is evident especially in churn and bubbly flow, showing motion in many other ways than just straight upwards. Even in annular flow, it is shown, when the water cascades down periodically. Although the chart below shows the friction losses in the pipe and correctly physically describes the system, the bulk of the pressure loss comes from the different types of flow that occur because of the presence of air in the system.

Figure .4 Flow Rates vs. Friction Loss

## Error Analysis

Error analysis has been done throughout sample calculations, using bias error as well as precision error recorded in the experiment. The error bars are included on all charts, even if not apparent.

# Unusual and Unexpected Findings

This experiment yielded many unexpected findings, generally with the inaccuracy of the data. The Mandhane flow chart is significantly different than how the chart should appear. This happened because of the inaccuracy of the data collection. In the qualitative section of data analysis, the flow regimes were not correctly identified. It is apparent from the chart that what was defined as bubbly flow is actually flow with developing structure. The churn and slug flow were incorrectly identified, with many of the slug flows actually being annular flow, and many of the churn flows being developing annular flow. If these had been correctly identified, the data would’ve been more intuitive. See recommendations for more details on how to improve these unexpected findings.

# Conclusions, Recommendations and Comments

## Conclusions

The conclusions for this lab are split into two separate categories. The conclusions for the quantitative parts of this lab are generally intuitive and straightforward, while the conclusions for the qualitative part show that the turbulence problem in two phase flow is still a difficult problem to grasp. The two separate conclusion sets will be discussed below.

The quantitative part of the lab included the calculation of many flow parameters. The superficial velocities of water and air in the system were calculated and compared, with the maximum value being 1.111 in air, .6822 m/s in water. The minimum values were .0114 and .0158 m/s air and water, respectively. These correlated to the flow regimes annular, developing annular, and developing structure (see Unexpected findings for explanation). The dynamic head was also found for this system.

These values were compared against each other, and used to plot the pressure drops throughout the system. The pressure drops in the system ranged from 5162.31 to 9545.32 Pa/m. These pressure drops showed the different types of loss that occurred within the system, as well as showing a good description of the Bernoulli equation that could be set up for the system. The friction losses that occurred, increasing with void fraction (because of annular flow) ranged from 0.00100 to 0.187 Pa/m. These are small compared to the total pressure drops, showing that most of the energy in the system is lost in non-conservative turbulence.

Besides the quantitative relationships shown, the qualitative map was a very important part of this experiment. While the flow regimes were misidentified originally, through some reasoning (explained in the Unexpected results section in this lab), the correct map was able to be identified. This map shows the regions of the flow that happen in two-phase flow. On a log-log plot, the lower right corner of this chart (of dynamic head in air vs. dynamic head vs. water) shows developing flow. This region is developing because the Reynold’s number of each different phase is still low enough to have the flow in laminar or transition systems. When the amount of air or velocity of air moves upward, the turbulence increases, creating churn or whispy annular flow. This is mostly air with some water moving through the air pockets. In the top left section of the chart, where both dynamic heads are high, the air region through the middle is surrounded by an annulus of water. Moving down in air dynamic head from here, slug flow is shown. This flow does not have enough energy in the air to keep the water in an annulus permanently, so periodically the water collapses into turbulent flow. This flow creates annular flow for regions, followed by bubbly flow for regions, oscillating back and forth. To be able to generate this chart, correct description of each phase must be taken, and the amount of each phase should be able to be altered in many aspects, as done in this experiment.

## Recommendations

The main problem with this experiment was the interface between the quantitative and the qualitative parts of the lab. Because the observation region was so long, annular flow tended to look like slug flow, and because the observation was made at an instant, developing flow looked more like bubbly or churn flow. These could be changed with several easy changes. The observation region should have been blocked off to only a one foot region of pipe, so as to only see one foot, which will look like annular flow instead of slug flow. This should be observed using a video camera, as a way to have a transient description of the flow. This could allow for the developing flows to be correctly identified. It would also be helpful to have the observation region in the same area as the instrumentation.

## Comments

There are no additional comments for this lab.

# Works Cited

Fox, R. W., McDonald, A. T., & Prichard, P. J. (2004). *Introduction to Fluid Mechanics* (6th ed.). New York: Wiley.

Munson, Y. O. (2009). *Fundamentals of Fluid Mechanics.* Hoboken, NJ: Wiley and Sons, Inc.

Revankar, S. T. (2011). *Experiment 9: Air-Water Two-Phase Flow Patterns in Vertical.* West Lafayette, IN: Purdue University School of Nuclear Engineering.

# Appendices

## Original Data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Air Flow Rate (SCFM) | Air Pressure Correction (psi) | Water Flow Rate (m^3/s) | DP Cell Reading (V) | Water Flow Bias Error (m^3/s) | DP Cell Bias Error (V) | Flow Type |
| 0.40 | 3.00 | 1.003 | 2.171 | 0.00212 | 0.0226 | Bubbly |
| 0.80 | 3.00 | 1.019 | 2.350 | 0.00207 | 0.0358 | Bubbly |
| 1.20 | 3.00 | 1.040 | 2.628 | 0.00207 | 0.0723 | Churn |
| 1.60 | 2.50 | 1.045 | 2.756 | 0.00694 | 0.0350 | Churn |
| 2.00 | 2.00 | 1.064 | 2.997 | 0.00702 | 0.0804 | Slug |
| 2.40 | 2.00 | 1.068 | 3.108 | 0.00550 | 0.0856 | Slug |
| 2.80 | 2.00 | 1.071 | 3.244 | 0.00374 | 0.113 | Slug |
| 3.20 | 2.00 | 1.075 | 3.286 | 0.00620 | 0.0760 | Slug |
| 4.00 | 2.00 | 1.081 | 3.437 | 0.00488 | 0.138 | Slug |
| 5.00 | 2.50 | 1.081 | 3.466 | 0.00308 | 0.0425 | Slug |
| 0.40 | 3.00 | 1.834 | 1.793 | 0.00594 | 0.0269 | Bubbly |
| 0.80 | 3.00 | 1.924 | 2.301 | 0.00594 | 0.0269 | Bubbly |
| 1.20 | 2.50 | 1.944 | 2.500 | 0.00598 | 0.0514 | Churn |
| 1.60 | 2.50 | 1.972 | 2.620 | 0.00476 | 0.0379 | Churn |
| 2.00 | 2.50 | 1.984 | 2.798 | 0.01153 | 0.0358 | Churn |
| 2.40 | 2.50 | 2.002 | 2.833 | 0.00706 | 0.0823 | Slug |
| 2.80 | 2.50 | 2.004 | 3.016 | 0.00887 | 0.0687 | Churn |
| 3.20 | 2.50 | 2.015 | 3.031 | 0.00332 | 0.110 | Churn |
| 4.00 | 2.00 | 2.033 | 3.196 | 0.00942 | 0.0748 | Slug |
| 5.00 | 2.50 | 2.043 | 3.276 | 0.00590 | 0.0978 | Slug |
| 0.40 | 3.50 | 2.590 | 1.662 | 0.00863 | 0.0072 | Bubbly |
| 0.80 | 3.00 | 2.712 | 2.186 | 0.00863 | 0.0072 | Bubbly |
| 1.20 | 3.00 | 2.762 | 2.382 | 0.00638 | 0.0353 | Churn |
| 1.60 | 3.00 | 2.775 | 2.423 | 0.00507 | 0.0800 | Churn |
| 2.00 | 3.00 | 2.827 | 2.688 | 0.00791 | 0.0587 | Churn |
| 2.40 | 3.00 | 2.847 | 2.828 | 0.00989 | 0.0605 | Slug |
| 2.80 | 2.50 | 2.855 | 2.897 | 0.00940 | 0.0596 | Slug |
| 3.20 | 3.00 | 2.886 | 3.004 | 0.00857 | 0.0603 | Slug |
| 4.00 | 3.00 | 2.897 | 3.070 | 0.0121 | 0.0399 | Slug |
| 5.00 | 3.00 | 2.921 | 3.214 | 0.00904 | 0.0614 | Slug |
| 0.40 | 3.50 | 2.997 | 1.764 | 0.00261 | 0.0147 | Bubbly |
| 0.80 | 3.00 | 3.125 | 2.199 | 0.00261 | 0.0147 | Bubbly |
| 1.20 | 3.00 | 3.175 | 2.400 | 0.00701 | 0.0506 | Churn |
| 1.60 | 3.00 | 3.203 | 2.524 | 0.00654 | 0.0979 | Slug |
| 2.00 | 3.00 | 3.225 | 2.565 | 0.0148 | 0.0497 | Slug |
| 2.40 | 3.00 | 3.263 | 2.760 | 0.0107 | 0.0372 | Slug |
| 2.80 | 3.00 | 3.282 | 2.827 | 0.0110 | 0.0679 | Churn |
| 3.20 | 2.50 | 3.291 | 2.831 | 0.01357 | 0.0568 | Churn |
| 4.00 | 3.00 | 3.328 | 3.058 | 0.00858 | 0.0282 | Slug |
| 5.00 | 2.00 | 3.355 | 3.108 | 0.0150 | 0.0839 | Slug |
| 0.40 | 4.00 | 4.541 | 1.556 | 0.00879 | 0.00713 | Bubbly |
| 0.80 | 3.50 | 4.750 | 2.027 | 0.00879 | 0.00713 | Bubbly |
| 1.20 | 3.50 | 4.861 | 2.224 | 0.00950 | 0.0390 | Churn |
| 1.60 | 3.50 | 4.878 | 2.323 | 0.00809 | 0.0233 | Churn |
| 2.00 | 3.00 | 4.926 | 2.442 | 0.00994 | 0.0305 | Slug |
| 2.40 | 3.00 | 4.987 | 2.557 | 0.0144 | 0.0470 | Slug |
| 2.80 | 3.00 | 5.027 | 2.713 | 0.01668 | 0.0641 | Slug |
| 3.20 | 3.00 | 5.040 | 2.714 | 0.00906 | 0.1031 | Churn |
| 4.00 | 3.00 | 5.088 | 2.880 | 0.0125 | 0.0977 | Churn |
| 5.00 | 3.50 | 5.148 | 2.925 | 0.0222 | 0.0706 | Churn |
| 0.40 | 4.00 | 5.621 | 1.415 | 0.0103 | 0.00152 | Bubbly |
| 0.80 | 3.00 | 5.919 | 1.894 | 0.0103 | 0.00152 | Bubbly |
| 1.20 | 3.00 | 6.005 | 2.059 | 0.00967 | 0.0283 | Bubbly |
| 1.60 | 3.00 | 6.064 | 2.149 | 0.00867 | 0.0189 | Churn |
| 2.00 | 3.00 | 6.179 | 2.327 | 0.0278 | 0.0091 | Slug |
| 2.40 | 3.00 | 6.205 | 2.420 | 0.0191 | 0.0152 | Slug |
| 2.80 | 3.00 | 6.291 | 2.504 | 0.0136 | 0.0650 | Slug |
| 3.20 | 3.00 | 6.330 | 2.613 | 0.0362 | 0.0421 | Slug |
| 4.00 | 3.00 | 6.382 | 2.741 | 0.0188 | 0.0508 | Churn |
| 5.00 | 3.50 | 6.482 | 2.821 | 0.0494 | 0.0702 | Churn |

## Reduced Data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Superficial Air Velocity (m/s) | rho v^2 Air (kg\*m^2/s^2) | Superficial Water Velocity (m/s) | rho v^2 Water (kg\*m^2/s^2) | Flow Type |
| 0.0418 | 0.0022 | 0.0798 | 0.0081 | Bubbly |
| 0.117 | 0.0174 | 0.0576 | 0.0042 | Bubbly |
| 0.028 | 0.0010 | 0.180 | 0.0413 | Bubbly |
| 0.086 | 0.0093 | 0.150 | 0.0288 | Bubbly |
| 0.022 | 0.0006 | 0.277 | 0.0980 | Bubbly |
| 0.069 | 0.0061 | 0.242 | 0.0747 | Bubbly |
| 0.019 | 0.0005 | 0.331 | 0.1394 | Bubbly |
| 0.063 | 0.0051 | 0.292 | 0.1091 | Bubbly |
| 0.014 | 0.0002 | 0.537 | 0.3670 | Bubbly |
| 0.047 | 0.0028 | 0.499 | 0.3170 | Bubbly |
| 0.011 | 0.0002 | 0.682 | 0.5934 | Bubbly |
| 0.039 | 0.0020 | 0.651 | 0.5411 | Bubbly |
| 0.079 | 0.0080 | 0.604 | 0.4651 | Bubbly |
| 0.202 | 0.0520 | 0.0461 | 0.0027 | Churn |
| 0.293 | 0.1091 | 0.0379 | 0.0018 | Churn |
| 0.158 | 0.0317 | 0.126 | 0.0201 | Churn |
| 0.237 | 0.0716 | 0.109 | 0.0152 | Churn |
| 0.322 | 0.1318 | 0.0961 | 0.0118 | Churn |
| 0.499 | 0.3179 | 0.0777 | 0.0077 | Churn |
| 0.591 | 0.4450 | 0.0711 | 0.0065 | Churn |
| 0.132 | 0.0221 | 0.212 | 0.0571 | Churn |
| 0.203 | 0.0528 | 0.186 | 0.0441 | Churn |
| 0.280 | 0.0997 | 0.170 | 0.0367 | Churn |
| 0.121 | 0.0188 | 0.258 | 0.0849 | Churn |
| 0.423 | 0.2282 | 0.177 | 0.0397 | Churn |
| 0.508 | 0.3289 | 0.163 | 0.0339 | Churn |
| 0.092 | 0.0109 | 0.460 | 0.2699 | Churn |
| 0.148 | 0.0281 | 0.419 | 0.2239 | Churn |
| 0.426 | 0.2314 | 0.321 | 0.1313 | Churn |
| 0.585 | 0.4360 | 0.287 | 0.1053 | Churn |
| 0.793 | 0.8024 | 0.255 | 0.0832 | Churn |
| 0.129 | 0.0212 | 0.562 | 0.4027 | Churn |
| 0.529 | 0.3572 | 0.409 | 0.2135 | Churn |
| 0.725 | 0.6706 | 0.370 | 0.1748 | Churn |
| 0.385 | 0.1886 | 0.0331 | 0.0014 | Slug |
| 0.479 | 0.2929 | 0.0288 | 0.0011 | Slug |
| 0.575 | 0.4217 | 0.0256 | 0.0008 | Slug |
| 0.671 | 0.5749 | 0.0230 | 0.0007 | Slug |
| 0.866 | 0.9556 | 0.0192 | 0.0005 | Slug |
| 1.111 | 1.5739 | 0.0158 | 0.0003 | Slug |
| 0.409 | 0.2132 | 0.0864 | 0.0095 | Slug |
| 0.777 | 0.7700 | 0.0609 | 0.0047 | Slug |
| 1.015 | 1.3133 | 0.0514 | 0.0034 | Slug |
| 0.361 | 0.1660 | 0.154 | 0.0303 | Slug |
| 0.446 | 0.2534 | 0.141 | 0.0253 | Slug |
| 0.532 | 0.3603 | 0.131 | 0.0220 | Slug |
| 0.711 | 0.6444 | 0.113 | 0.0164 | Slug |
| 0.941 | 1.1280 | 0.0975 | 0.0121 | Slug |
| 0.189 | 0.0456 | 0.230 | 0.0676 | Slug |
| 0.263 | 0.0884 | 0.208 | 0.0551 | Slug |
| 0.341 | 0.1484 | 0.192 | 0.0468 | Slug |
| 0.682 | 0.5930 | 0.143 | 0.0262 | Slug |
| 0.908 | 1.0506 | 0.124 | 0.0196 | Slug |
| 0.211 | 0.0567 | 0.389 | 0.1927 | Slug |
| 0.278 | 0.0987 | 0.365 | 0.1697 | Slug |
| 0.350 | 0.1562 | 0.343 | 0.1497 | Slug |
| 0.184 | 0.0432 | 0.534 | 0.3630 | Slug |
| 0.246 | 0.0772 | 0.500 | 0.3184 | Slug |
| 0.311 | 0.1234 | 0.477 | 0.2901 | Slug |
| 0.381 | 0.1848 | 0.452 | 0.2611 | Slug |

## Sample Calculations

### Air Flow Rate Correction

### Voltage to Pressure Translation

### Voltage to Pressure Error

### Flow Quality

### Void Fraction

### Superficial Velocity Air

### Superficial Velocity Water

### Friction Loss in Pipe

1. These equations and assumptions were all made using the Homogenous Equilibrium Model. [↑](#footnote-ref-1)