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| **NUCL 355 Experiment 8** |
| Two Phase Natural Circulation  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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# Introduction and Theory

Two phase flow occurs in many systems involving coolant loops. This is particularly important to BWRs in the nuclear industry. The BWR environment may be the most prototypical environment for evaporation while cooling. In a PWR, the water is kept from boiling by high pressure. It is important for the industry to understand exactly the kinematics and dynamics of a system involving these flows so that they can properly design the reactor to cool the core.

As stated, the kinematics of the system are very important, and many models have been created to solve for this. The most important of these equations is the momentum equation for a two phase flow. This equation is related to the Bernoulli’s equation, but this time takes into account the changes that occur by the introduction of a second phase. The equation is shown below, with its dependence on not only the major losses, but on the different densities, and the dynamic head. It is important to understand that this will hold true not only for two phase flow, but for any flow where some of the liquid is hotter than the remaining fluid.

Because the equation above is generalized for use with any system where one of the fluids is heated, several factors must be defined to use when one fluid actually enters another phase. These factors help correctly define the system through its characteristic differences in motion from one phase flow. The most important of these factors is called the void fraction, and is simply the volumetric fraction of the air to water in a fluid system. Its analytical definition is given below.

The void fraction is very useful, but sometimes it is needed to use the convection motion equation given above to calculate the motion of the system. Thus it must be given a way to understand the connection between two phase flows and one phase flows with a heated state. This connection is given below, and allows for direct substitution into above momentum equation.

With a correct understanding of the theory behind two phase flow, a simple experiment can be done to see the correlation between the void fraction and the motion in a system, as a way to simulate a reactor coolant type situation.

# Analysis and Discussion of Data

The data collected in this lab shows some of the properties of two phase flow. The pressure drops across the orifice and the riser are shown in the table below. It is notable that the drops in the riser were much higher because of the distance between the taps, but the pressure drops in the riser also display a different distribution. The chart below the table shows normalized values for the pressure in the orifice and in the riser. It can be seen that the distributions are of the same shape, but that the pressure drop in the riser rises quicker than in the orifice. This is because of the evolution of bubbles in the riser. The amount of bubbles will generate a higher pressure drop, because they do not have the density that water does to create pressure in the dp cells.

|  |  |  |  |
| --- | --- | --- | --- |
| Pressure (Orifice) [Pa] | Pressure Error (Orifice) [Pa] | Pressure (Riser) [Pa] | Pressure Error (Riser) [Pa] |
| 25.564 | 0.839 | 1838.87 | 59.90 |
| 41.440 | 1.149 | 3072.85 | 66.50 |
| 63.780 | 0.758 | 4916.65 | 61.81 |
| 74.660 | 1.056 | 5890.40 | 98.44 |
| 81.315 | 1.019 | 6419.74 | 96.94 |
| 87.927 | 1.354 | 7094.75 | 118.16 |
| 90.366 | 3.808 | 8062.58 | 258.26 |

Figure .1 Pressure Drops in Orifice and Riser

Figure .2 Normalized Pressure Drop vs. Flow Rate

Knowing that the rates are different for flow of water in the orifice and the riser, the system can be analyzed better. The mass flow rate across the orifice will display information about how much water is in the flow through the orifice, and the void fraction will display information about how much water is in the flow across the riser. The distribution between the two is shown below. It can be seen that there is a root type distribution between the mass flow rate and the orifice. As the amount of water in the flow through the orifice increases (mass flow rate increases), the void fraction in the riser will start to increase towards infinity.

This has a physical interpretation that as water moves faster across an orifice, bubbles will be introduced into the flow. There is a value where the flow will transform from laminar or transition flow towards turbulent flow, at very high rates through the orifice. At these high rates, much air will be introduced into the flow, and the void fraction in the riser will increase exponentially once past this point. This has specific implications to nuclear reactors.

Figure .3 Mass Flow Rate Across Orifice vs. Void Fraction

A chart that shows better the implications to a nuclear reactor is the chart of the mass flow rate vs. the air flow rate. In a nuclear reactor, it is important for the coolant to move through the reactor quickly enough to cool it sufficiently. Ideally, the coolant water could move extremely fast through the reactor, but as the mass flow rate increases, much of the liquid will become gas. Because the convection coefficient of air is much lower than the conduction coefficient of a fluid, a higher void fraction will drastically reduce the heat transfer characteristics of the fluid. This means that at a limiting value of around 20 SCFH for the air in the mixture, the mass flow rate reaches an asymptotic value of just above 20 kg/s. Designs for reactors must be made to use rates below this for cooling.

Figure .4 Mass Flow Rate Across Orifice vs. Air Flow Rate

## Error

The error in this experiment was calculated in several different ways. Ten values of voltage were taken for every flow rate, allowing standard deviation to be calculated and used as error, as well as the error inherent in reading values off of a DMM. These errors much be squared and added, then rooted to get the total error for the voltage readings. Because the voltage readings were the only readings taken in this lab, and the rest of the data is taken from texts and references and assumed accurate, only the error in the voltage is propagated through. This error propagation and calculation is shown in each calculation step under sample calculations.

## Recommendations

While the execution of this lab was mostly seamless, there are still areas where it could be improved. Perhaps a data acquisition software could be used to minimize the error propagation throughout the calculations. Also, it could be useful to get an entire distribution using this data acquisition and a continuum of values for the flow rate instead of specific values.

# Conclusions

This lab successfully highlights some of the important aspects and restrictions of natural circulation, especially as it is related to the use of this concept in nuclear technology. In a nuclear reactor, two phase flow is present in many different aspects, and must be well understood. Using a riser and an orifice natural circulation loop, these aspects can be investigated.

The pressure drops of the orifice and the riser were compared. The pressure drops in the riser ranged from 1838.87 Pa to 8062.58 Pa, whereas the pressure drops in the orifice ranged from only 25.564 Pa to 90.366 Pa. When normalized, the distributions of these values were compared. The pressure drop of the riser seemed to increase faster than that across the orifice as the air flow rate increased. This is likely because of the creation of bubbles through the orifice, which add to the air flow. This addition to the air will create a higher pressure drop.

The mass flow rate through the riser was calculated, coming to values from 11.278 kg/s up to 21.204 kg/s. The void fractions were also calculated, and ranged from 0.082 to 0.36. This shows a huge increase in the void fractions compared to the change in mass flow rates. The distribution of this chart showed that there is a root type relationship that the void fraction increased but leveled off after around 20 kg /s. This shows that there is some threshold that the void fraction approaches and cannot exceed.

This was echoed in the graphing of the air flow rate against the mass flow rate, with the air flow rate leveling off at around a mass flow rate of 22 kg/s. This shows the limitation that must be taken into account when boiling water reactors are designed. It also shows a limitation to these type reactors. Overall, the lab gives a brief but intuitive overview of natural circulation and the effects of two phase flow on this phenomenon.

# Works Cited

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

Revankar, S. (2011). *Experiment #8: Two Phase Natual Circulation.* West Lafayette, IN: Purdue University School of Nuclear Engineering.

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# Appendices

## Original Data

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Flow Rate (SCFH) | 2 | 5 | 10 | 15 | 20 | 30 | Flow Rate (SCFM) | 1 |
| DP Cell 1 (V) | 1.456 | 1.770 | 2.143 | 2.344 | 2.451 | 2.538 | **DP Cell 1 (V)** | 2.555 |
|  | 1.450 | 1.719 | 2.118 | 2.346 | 2.472 | 2.612 |  | 2.610 |
|  | 1.451 | 1.729 | 2.142 | 2.335 | 2.436 | 2.564 |  | 2.583 |
|  | 1.445 | 1.737 | 2.147 | 2.347 | 2.461 | 2.548 |  | 2.704 |
|  | 1.444 | 1.741 | 2.131 | 2.316 | 2.431 | 2.586 |  | 2.631 |
|  | 1.444 | 1.719 | 2.137 | 2.345 | 2.457 | 2.572 |  | 2.515 |
|  | 1.437 | 1.700 | 2.140 | 2.311 | 2.472 | 2.582 |  | 2.551 |
|  | 1.432 | 1.732 | 2.124 | 2.320 | 2.473 | 2.581 |  | 2.680 |
|  | 1.426 | 1.730 | 2.136 | 2.321 | 2.464 | 2.575 |  | 2.667 |
|  | 1.420 | 1.719 | 2.146 | 2.360 | 2.440 | 2.603 |  | 2.709 |
| Average (V) | 1.441 | 1.730 | 2.136 | 2.335 | 2.456 | 2.576 | **Average (V)** | 2.621 |
| Standard Deviation (V) | 0.012 | 0.018 | 0.010 | 0.016 | 0.016 | 0.023 | **Standard Deviation (V)** | 0.069 |

Table .1 DP Cell 1 Readings

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| DP Cell 2 (V) | 1.375 | 1.620 | 2.000 | 2.194 | 2.298 | 2.471 | DP Cell 2 (V) | 2.703 |
|  | 1.383 | 1.637 | 2.004 | 2.178 | 2.301 | 2.465 |  | 2.664 |
|  | 1.385 | 1.618 | 2.006 | 2.201 | 2.294 | 2.433 |  | 2.584 |
|  | 1.376 | 1.629 | 1.989 | 2.193 | 2.312 | 2.445 |  | 2.615 |
|  | 1.390 | 1.624 | 2.012 | 2.211 | 2.275 | 2.447 |  | 2.663 |
|  | 1.366 | 1.642 | 1.996 | 2.202 | 2.314 | 2.421 |  | 2.720 |
|  | 1.374 | 1.637 | 2.014 | 2.181 | 2.334 | 2.456 |  | 2.559 |
|  | 1.383 | 1.615 | 2.000 | 2.184 | 2.327 | 2.399 |  | 2.615 |
|  | 1.377 | 1.633 | 1.997 | 2.236 | 2.307 | 2.457 |  | 2.608 |
|  | 1.375 | 1.628 | 1.999 | 2.209 | 2.299 | 2.434 |  | 2.657 |
| Average (V) | 1.378 | 1.628 | 2.002 | 2.199 | 2.306 | 2.443 | **Average (V)** | 2.639 |
| Standard Deviation (V) | 0.007 | 0.009 | 0.008 | 0.017 | 0.017 | 0.022 | **Standard Deviation (V)** | 0.051 |

Table .2 DP Cell 2 Readings

## Reduced Data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Flow Rate [SCFH] | Pressure (Orifice) [Pa] | Pressure Error (Orifice) [Pa] | Mass Flow Rate (kg/s) | Mass Flow Rate Error (kg/s) |
| 2 | 25.564 | 0.839 | 11.278 | 0.185 |
| 5 | 41.440 | 1.149 | 14.359 | 0.199 |
| 10 | 63.780 | 0.758 | 17.814 | 0.106 |
| 15 | 74.660 | 1.056 | 19.273 | 0.136 |
| 20 | 81.315 | 1.019 | 20.114 | 0.126 |
| 30 | 87.927 | 1.354 | 20.915 | 0.161 |
| 60 | 90.366 | 3.808 | 21.204 | 0.447 |

Table .3 Orifice Flow Parameters

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Flow Rate [SCFH] | Pressure (Riser) [Pa] | Pressure Error (Riser) [Pa] | Void Fraction [ ] | Void Fraction Error [ ] |
| 2 | 1838.87 | 59.90 | 0.082 | 0.0027 |
| 5 | 3072.85 | 66.50 | 0.14 | 0.0030 |
| 10 | 4916.65 | 61.81 | 0.22 | 0.0028 |
| 15 | 5890.40 | 98.44 | 0.26 | 0.0044 |
| 20 | 6419.74 | 96.94 | 0.29 | 0.0043 |
| 30 | 7094.75 | 118.16 | 0.32 | 0.0053 |
| 60 | 8062.58 | 258.26 | 0.36 | 0.012 |

Table .4 Riser Flow Parameters

## Sample Calculations

### Voltage Error

### Voltage to Pressure Translation (Orifice)

### Voltage to Pressure Translation Error (Orifice)

### Voltage to Pressure Translation (Riser)

### Mass Flow Rate Across Orifice

### Mass Flow Rate Error

### Void Fraction

### Void Fraction Error