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| **NUCL 355 Experiment 13** |
| Blowdown Experiment  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

Loss of coolant accidents are important to understand within the nuclear industry. Amongst design basis incidents, they are the worst. The problems with the LOCA are that they release pressure and coolant at high rates. This can damage the containment, as well as strip the reactor vessel of necessary coolant.

It is important to understand the flow of this water as it is released from the pressure vessel to be able to design against these accidents. Because of the high pressure and velocity of the two phase flow, the flow can become choked. A choked flow allows pressure within the chamber to still build because the flow cannot move as fast as it would like to.

Choked flow comes from nucleation theory and relates the boiling of water to the flow out of the chamber. It can also be determined experimentally for the chambers using an orifice meter and the void fraction of the flow leaving the chamber. The equation for choked flow using nucleation theory is shown below.

The experimental setup being used is very similar to a reactor loop in a BWR style power plant. There is a pressure chamber, which is close to 2 meters tall, and can be heated by a heating element at the bottom. This is attached to a release valve at the top to release any extra gas so only two-phase flow is examined. There are two different valves that simulate the LOCA, and can be opened extremely quickly. One is in the steam dome at the top of the chamber, which only allows for steam to be released. The other is under the minimum water level, and when both are opened, two phase flow is released. There is also an orifice to measure flow velocity out of the LOCA, and an observation chamber for this flow.

The experiment is performed by heating the chamber so that the pressure increases. When it is sure that there is enough vapor to fill the steam dome, some pressure is let out to remove all excess air. It is continued heating until there is a high pressure within the chamber. After this occurs, the LOCA is simulated and the flow is allowed to escape the chamber. This goes hand in hand with the start of a data acquisition system, which takes three different dP cell readings and two different thermocouple readings.

This experiment should successfully demonstrate a LOCA as well as explain choked flow through its flow parameters and characteristics.

# Analysis and Discussion of Data

Using heating of the water within the pressure chamber in the experimental apparatus, the pressure within the chamber is raised. This originally fills the chamber with vapor, and when the chamber is filled with vapor, air is released to make sure there is no gas within the two phase mixture. With more heating, the steam cell pressure increases to several thousand Pa. When the break occurs, this is released very quickly. For the case where steam only is released, the pressure is released exponentially, as expected. This should be exponential because the rate relates to the amount of relative pressure, which decreases as the pressure is released.

The case for two phase is not as straightforward. There seems to be three regimes in this pressure drop. The first drops linearly at a shallow slope, then again at a faster linear slope. Finally, after a certain point, it turns into an exponential decrease. Obviously, when the exponential starts, the mixture leaving the chamber is only steam. In those two regimes, the two phase mixture is creating different phenomena within the release. Slow originally because the void fraction is small, and then higher as the void fraction increases.

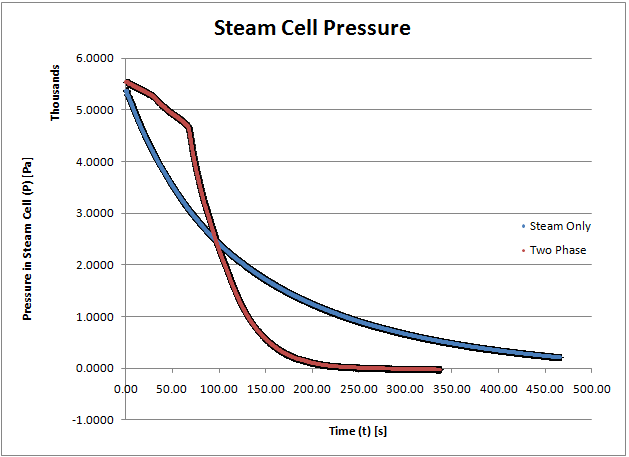


Figure 2.1 Steam Cell Pressure

The analysis is similar for the water level transience as for the steam cell. The water level, during heating, increases because of the density decrease. When the pressure is released, this level will decrease again as it reaches back to ambient pressure. For steam, the water level will decrease exponentially because it is related to the ambient pressure. The ambient pressure is shown above, as an exponential decrease.

For two phase, the water level has a very different relationship. The water level will decrease linearly, because there is a certain amount of water leaving the chamber in the two phase mixture being shot out. This will even out with the pressure decreasing and creating a drop when there is a higher void fraction. There is a limit where the water level will stay, which is much lower than in the steam only analysis.

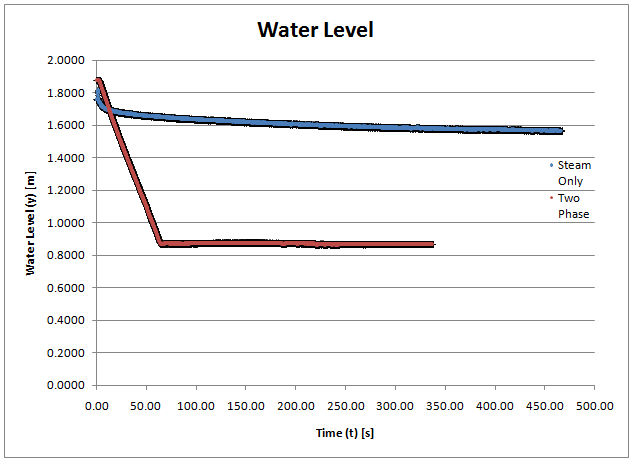


Figure 2.2 Water Level

The previous two analyses are important as the critical mass flux for choked flow is determined. It is estimated that this choked flow occurs at about 40 seconds in the experiment created. A simple calculation of the mass flux using the velocity through an orifice as well as the void fraction found using the ratio of phases in the pressure chamber. This mass flux is shown below.

This can also be calculated using nucleation theory and the temperature of the two phase mixture. The calculation shown below gives this calculated value. It is within 3% of the experimental value, showing the success of the experiment as well as the model’s accuracy.

## Error

Error in this lab is defined by propagation of the bias error from uncertainty in the instruments. Propagation of error has been plotted on the charts (black error bars) as well as listed as uncertainties in tables (THESE ARE LISTED AS UVALUE, AND ARE QUANTITATIVE ERROR).

## Recommendations

Although the experiment was obviously well performed with the data being close to predictive models, there was a problem in finding the void fraction of the two phase flow. A huge assumption had to be made. Perhaps it would be possible to add a dP cell to help determine the void fraction within the two phase flow through the orifice.

# Conclusions

Conclusions in this lab have to do with a qualitative demonstration of the process that occurs when a LOCA occurs, as well as the modeling and calculation of the critical mass flux needed for choked flow. The qualitative assessment of the pressures and water height within the chamber was successful.

These assessments show that the pressure steam decreases exponentially with time for a steam only test. This happens because of the relative pressures which decrease, making it exponential. For a two phase flow, there are two linear regions of decrease in pressure, followed by an exponential decrease. These linear regions occur because of the change in void fraction that occurs as the pressure decreases. The exponential decrease occurs because the void fraction has risen to 1, and is effectively an all steam flow as in the steam only experiment.

The assessment of water level also shows similar concepts. The exponential decrease occurs in steam only just as before, because of the amount of steam being drawn out of the chamber through the jet being released. In two phase flow, there is a linear drop until a point where it is even from then on. This linear drop occurs because it is much faster with the actual liquid water being released. It is linear because the amount of steam evens out with the amount of void fraction being lost in the flow.

Choked flow occurs at 40 seconds. An estimation of this critical mass flux can be made using nucleation theory, as shown below. This was compared to the experimental value that was found using the reading through the orifice meter and an estimation of the two phase density. This is also shown below. These values are within 3%, therefore showing that the model is a good one, as it holds to the experimental setup.

# Works Cited

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# Appendices

## Original Data

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| Sample Number | Date/Time | CHANNEL0 | CHANNEL1 | CHANNEL2 | CHANNEL3 | CHANNEL4 |
| 1 | 09:29.4 | 169.1794 | 23.2689 | 4.1146 | 1.5361 | 1.0002 |
| 2 | 09:29.5 | 169.1794 | 23.5695 | 4.1167 | 1.538 | 0.9996 |
| 3 | 09:29.6 | 169.2982 | 23.5695 | 4.1186 | 1.5395 | 0.9996 |
| 4 | 09:29.7 | 169.3576 | 23.4944 | 4.118 | 1.541 | 0.9996 |
| 5 | 09:29.8 | 169.3576 | 23.5695 | 4.1164 | 1.5386 | 0.9999 |
| 6 | 09:29.9 | 169.2388 | 23.4944 | 4.114 | 1.5367 | 0.9996 |
| 7 | 09:30.0 | 169.2982 | 23.6481 | 4.1143 | 1.5377 | 0.9996 |
| 8 | 09:30.1 | 169.2982 | 23.4192 | 4.1173 | 1.5392 | 0.9987 |
| 9 | 09:30.2 | 169.3576 | 23.7949 | 4.1176 | 1.5407 | 0.9996 |
| 10 | 09:30.3 | 169.3576 | 23.7198 | 4.1158 | 1.5392 | 1.0005 |
| 11 | 09:30.4 | 169.1199 | 23.5695 | 4.1137 | 1.5367 | 0.9996 |
| 12 | 09:30.5 | 169.1172 | 33.4606 | 4.1128 | 1.5364 | 1.0018 |
| 13 | 09:30.6 | 169.0605 | 65.1373 | 4.1152 | 1.5377 | 1.0176 |
| 14 | 09:30.7 | 168.6417 | 70.1654 | 4.1106 | 1.5215 | 1.1473 |
| 15 | 09:30.8 | 168.6417 | 70.6486 | 4.0957 | 1.4476 | 1.3295 |
| 16 | 09:30.9 | 168.6363 | 74.6107 | 4.0774 | 1.4263 | 1.649 |
| 17 | 09:31.0 | 168.8119 | 85.866 | 4.0682 | 1.4379 | 2.0681 |
| 18 | 09:31.1 | 168.8658 | 91.1215 | 4.0649 | 1.4614 | 2.4681 |
| 19 | 09:31.2 | 168.8037 | 95.0776 | 4.0642 | 1.4916 | 2.7907 |
| 20 | 09:31.3 | 168.8604 | 107.5827 | 4.0633 | 1.5193 | 3.0379 |
| 21 | 09:31.4 | 168.9171 | 113.7494 | 4.0618 | 1.5349 | 3.2741 |
| 22 | 09:31.5 | 168.7982 | 121.3129 | 4.0591 | 1.5431 | 3.4804 |
| 23 | 09:31.6 | 168.736 | 125.4696 | 4.0609 | 1.5541 | 3.6394 |
| 24 | 09:31.7 | 168.7333 | 128.1041 | 4.0636 | 1.5608 | 3.8277 |
| 25 | 09:31.8 | 168.7306 | 126.5371 | 4.0649 | 1.5669 | 3.9757 |
| 26 | 09:31.9 | 168.79 | 126.1634 | 4.0612 | 1.5688 | 4.1106 |
| 27 | 09:32.0 | 168.7306 | 126.2262 | 4.0581 | 1.5721 | 4.2074 |
| 28 | 09:32.1 | 168.6711 | 120.2374 | 4.0578 | 1.5749 | 4.3029 |
| 29 | 09:32.2 | 168.6684 | 115.5974 | 4.0603 | 1.5749 | 4.381 |
| 30 | 09:32.3 | 168.5495 | 119.6645 | 4.0594 | 1.5734 | 4.4509 |
| 31 | 09:32.4 | 168.5495 | 121.3129 | 4.0557 | 1.5718 | 4.5089 |
| 32 | 09:32.5 | 168.4305 | 126.791 | 4.0502 | 1.5657 | 4.5501 |
| 33 | 09:32.6 | 168.5495 | 128.4199 | 4.0444 | 1.5645 | 4.5879 |
| 34 | 09:32.7 | 168.5467 | 128.7953 | 4.0423 | 1.5712 | 4.6154 |
| 35 | 09:32.8 | 168.4873 | 125.7209 | 4.0417 | 1.5789 | 4.6401 |

Table 5.1 Sample Data from Steam Only (if more sample data is needed, please email ahagen@purdue.edu)

## Reduced Data

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Time (t) [s] | dP Steam Cell (Pa) | dP Steam Cell Error (Pa) | Water Level (m) | Water Level Error (m) |
| 0.00 | 5539.0778 | 0.172369 | 1.8772 | 0.000051 |
| 0.10 | 5543.7318 | 0.172369 | 1.8775 | 0.000051 |
| 0.20 | 5545.8002 | 0.172369 | 1.8781 | 0.000051 |
| 0.30 | 5544.2489 | 0.172369 | 1.8787 | 0.000051 |
| 0.40 | 5540.6291 | 0.172369 | 1.8782 | 0.000051 |
| 0.50 | 5538.0436 | 0.172369 | 1.8779 | 0.000051 |
| 0.60 | 5540.6291 | 0.172369 | 1.8773 | 0.000051 |
| 0.70 | 5545.2831 | 0.172369 | 1.8781 | 0.000051 |
| 0.80 | 5545.2831 | 0.172369 | 1.8785 | 0.000051 |
| 0.90 | 5541.6634 | 0.172369 | 1.8787 | 0.000051 |
| 1.00 | 5537.5265 | 0.172369 | 1.8779 | 0.000051 |
| 1.10 | 5537.5265 | 0.172369 | 1.8770 | 0.000051 |
| 1.20 | 5541.1462 | 0.172369 | 1.8779 | 0.000051 |
| 1.30 | 5544.2489 | 0.172369 | 1.8784 | 0.000051 |
| 1.40 | 5541.1462 | 0.172369 | 1.8784 | 0.000051 |
| 1.50 | 5537.0094 | 0.172369 | 1.8775 | 0.000051 |
| 1.60 | 5535.8028 | 0.172369 | 1.8775 | 0.000051 |
| 1.70 | 5539.0778 | 0.172369 | 1.8775 | 0.000051 |
| 1.80 | 5542.6976 | 0.172369 | 1.8782 | 0.000051 |
| 1.90 | 5541.1462 | 0.172369 | 1.8784 | 0.000051 |
| 2.00 | 5537.5265 | 0.172369 | 1.8779 | 0.000051 |
| 2.10 | 5533.7344 | 0.172369 | 1.8775 | 0.000051 |
| 2.20 | 5535.2857 | 0.172369 | 1.8775 | 0.000051 |
| 2.30 | 5539.0778 | 0.172369 | 1.8784 | 0.000051 |
| 2.40 | 5541.1462 | 0.172369 | 1.8787 | 0.000051 |
| 2.50 | 5537.0094 | 0.172369 | 1.8781 | 0.000051 |
| 2.60 | 5532.7002 | 0.172369 | 1.8748 | 0.000051 |
| 2.70 | 5527.0120 | 0.172369 | 1.8723 | 0.000051 |
| 2.80 | 5524.2541 | 0.172369 | 1.8735 | 0.000051 |
| 2.90 | 5519.6001 | 0.172369 | 1.8745 | 0.000051 |
| 3.00 | 5511.6711 | 0.172369 | 1.8745 | 0.000051 |
| 3.10 | 5506.5001 | 0.172369 | 1.8731 | 0.000051 |
| 3.20 | 5502.1908 | 0.172369 | 1.8705 | 0.000051 |
| 3.30 | 5504.7764 | 0.172369 | 1.8689 | 0.000051 |

Figure 5.1 Sample Reduced Data from Two Phase (if more sample data is needed, please email ahagen@purdue.edu)

## Sample Calculations

### Steam Cell Voltage to Pressure Translation

### Steam Cell Voltage to Pressure Error

### Water Level Voltage to Pressure to Water Level Translation

### Water Level Voltage to Pressure to Water Level Error

### Mass Flux at 40 Seconds (Experimental)

### Mass Flux at 40 Seconds Error (Experimental)

### Mass Flux at 40 Seconds (Calculated)

### Mass Flux at 40 Seconds Error (Calculated)