

Peach Bottom Drain Tank Dynamic Analysis Using RELAP5

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Introduction

Turbines that use steam at saturated or near saturated conditions have Moisture Separators (MS), which remove large quantities of water at saturated temperatures. The MS vessels are located on each side of the turbine. Drainage from the MS vessels is by gravity alone. Gravity drain systems require some means of controlling the flow to the feedwater heaters. A simple and reliable means of controlling drain flow utilizes a drain tank to establish a steam-water interface. A level control system on the drain tank (DT) along with a drain valve in the line to the drain receiver, control the flow from the tank to match the uncontrolled gravity flow into the tank. Failure of the MS/DT drain system to dispose of the drain flow would result in a backup of water into the MS vessel. This would not result in immediate damage to the MS, but continued operation could result in turbine trip after a thirty second time delay. At the Peach Bottom plant, the water level in the DT is controlled by a control valve and a dump valve. The control valve sends water to the high pressure feedwater heaters and the dump valve sends water directly to the condenser. For the Peach Bottom plant the set points for these valves are shown in Figure 3.

Peach Bottom's proposed modifications to the Moisture Separator would increase the effectiveness of the MS from 85% to greater than 97%. Drain flows would increase accordingly with these modifications. Since the conditions represent two-phase phase flow that could flash when undergoing even slight pressure changes, choke points are difficult to predict. Additionally, the pipe size that drains the MS is not large enough to allow self venting flow. Therefore, the question of adequate venting from the MS/DT drain system must be addressed. The objective of this report is to determine, using a RELAP5M3.3 model, whether the drains will be able to accommodate the increased volume of water caused by the Moisture Separator modifications under steady state and transient conditions.

Discussion of the System

Peach Bottom (PB) has six drain tanks that receive flow from six MSs. A schematic of the MS/DT drain system is shown in Figure 2. If the water level in the MS becomes too high, the turbine will trip following a 30 second time delay. Each MS/DT system is independent from the others. Each drain tank has piping that exits the bottom of the MS through an 8" pipe and enters into a 20" standpipe. A 6" vent pipe that exits at the top of the standpipe allows steam that was trapped in the MS drain flow to flow back to the MS. A liquid water level is maintained in the standpipe while water flows to the associated DT and ultimately out through the control valve. Condensate is also fed into the flow exiting the standpipe. This condensate cools the water to ensure that local flashing does not occur in the flow to the control valve. The water levels in the standpipe and the DT are maintained by the manometer effect between the standpipe and the DT,

which balances the pressure between the two tanks. The standpipe acts as a buffer to the DT for pressure and flow transients in the MSDT drain system. At the bottom of the DT, the flow enters and leaves through two different pipes.

The MS/DT drain system simulated for this report is the 'D' loop for Peach Bottom Unit 3. The 'D' loop was chosen since it has exhibited the highest flow rate during steady state operation. The system is depicted by Figure 1 and Figure 2. Liquid drainage from Moisture Separator D flows down into the top of the stand pipe. Non-self-vented steam in the drain flow is vented back to the MS through a 6" vent line at the top of the standpipe. As the remaining water exits at the bottom of the standpipe on the way to the drain tank, subcooled condensate is injected. The condensate and MS drain flow combine and flow through an 8" pipe until it reaches the Drain Tank, at which point the water is divided by two 10" tees. Some of the water is routed into the DT and the remaining water flows downstream of the tees to the control valve. In the steady state case, only 30% of the total flow enters and leaves the DT. The other 70% of the flow from the standpipe and condensate flow pass by the DT directly to the control valve. Under normal conditions, the water from the DT flows to Feed Water Heater B-4. If the water level of the DT is sufficiently high, a dump valve, CV3013D, opens to Condenser B. Both the stand pipe and the drain tank have vent paths that first combine and then run up to the top of the Moisture Separator. The normal water level in the DT is controlled by CV3012D (See Figure 4). When the water level in the DT is high, dump valve V3013D will reduce the water level in the drain tank by allowing addition flow through the dump valve into the condenser.

Drainage must be continuous during steady-state operation of the turbine as well as during transients. Reduction of the turbine load results in a decrease in pressure and the generation of steam from water at saturation temperature in the drain systems. This steam formed can impede the gravity drainage of water unless the drain system piping and vents are properly designed. All moisture separator vessels for non-reheat turbines are designed with a large drain connection for direct attachment of drain tank. Precautions that must be observed in designing drain lines for gravity drainage fall into two categories, depending upon whether the flow is self-venting or nonself-venting. Self-venting flow exists when the relationship between the pipe internal diameter and the liquid flow rate is such that vapor is not carried down the drain pipe with the liquid, but can rise counter to the liquid flow continuously venting the pipe. In nonself-venting flow the liquid flow is too great for this venting action to occur and vapor pockets become trapped in the pipe and are carried downward with the liquid. Based on Reference 9, a drain line with gravity flow will be self-venting if the liquid Froude Number is less than approximately 0.3; with higher values of the Froude Number the flow will not be self-venting. In the Peach Bottom design, with the 8" drain pipe, the Froude Number for the 100% power/85% efficiency and for the 100% power/100% efficiency cases are .76 and .90, respectively. (See Appendix A for calculations) Both of these flow situations are above the threshold for self vented flow. Therefore, the vapor's buoyant force cannot overcome the speed at which the water is flowing down the pipe. The result is the introduction of vapor into the drains that are designed for liquid. The MS/DT drain system for Peach Bottom is thus a non-self-venting system.

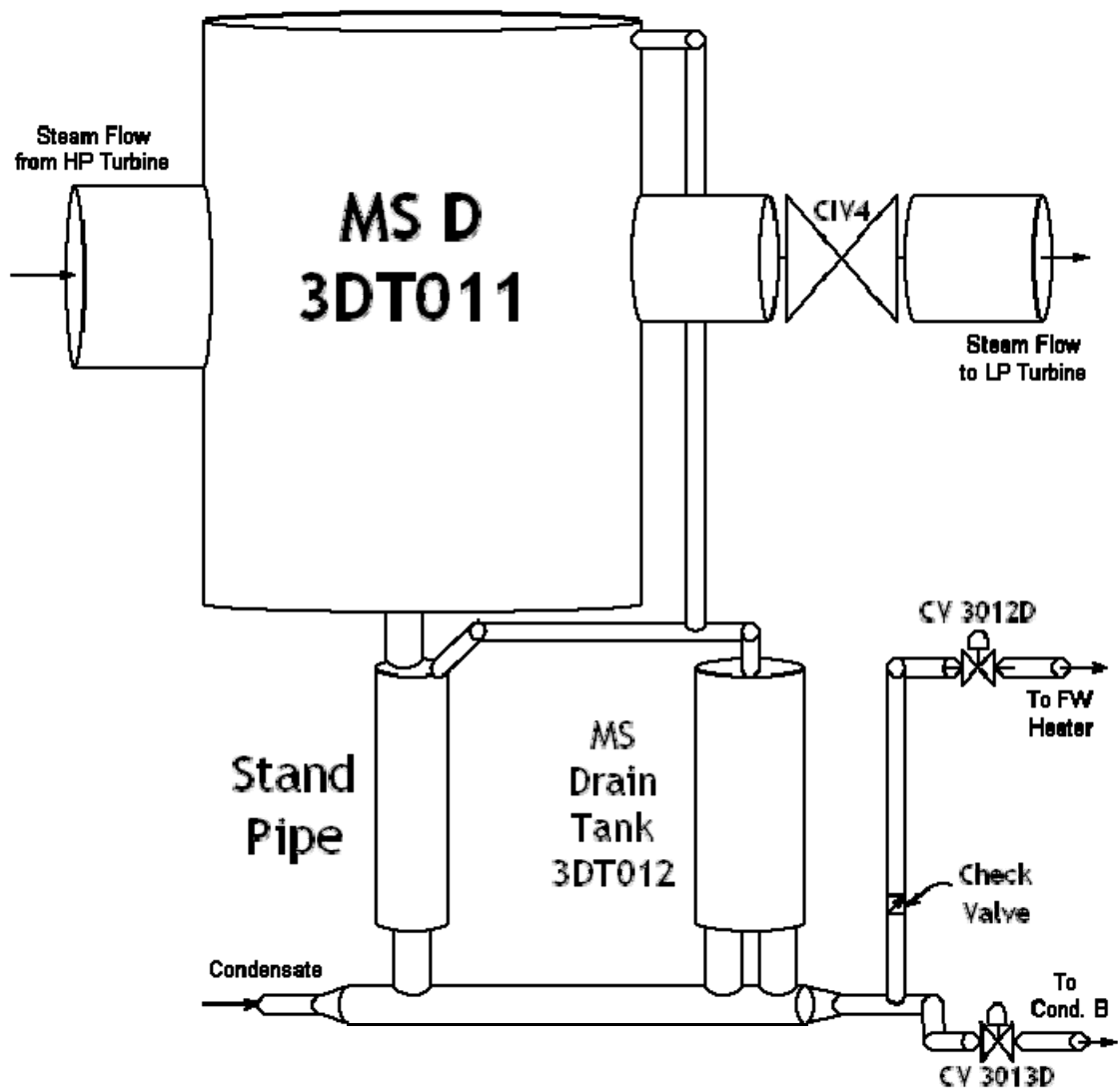


Figure 2: Simple depiction of the model

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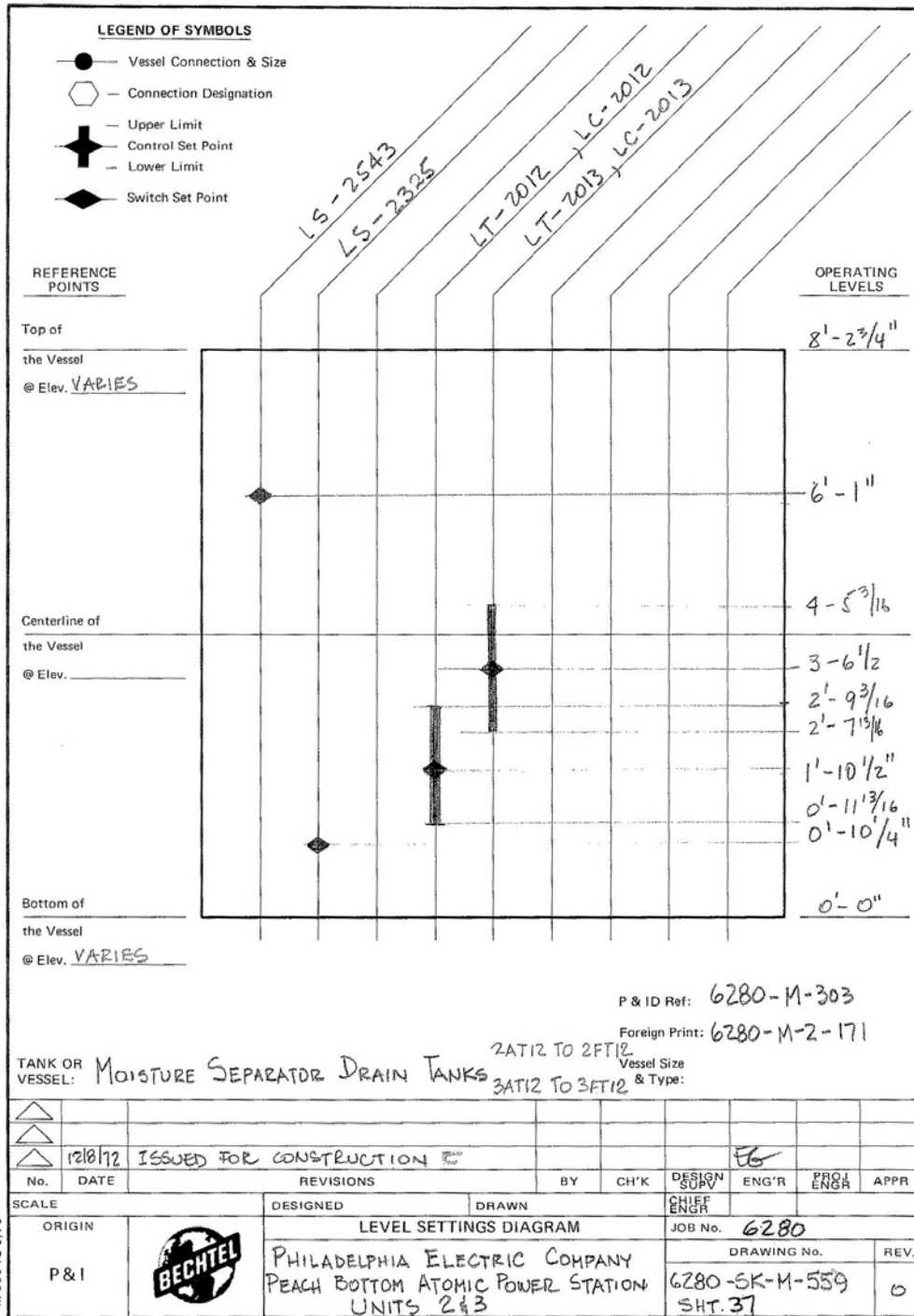


Figure 3: Drain Tank Control Valve Levels

Description of Model

A RELAP5/M3.3 model was constructed to simulate the fluid in the drain system. It starts at the moisture separator and culminates at the feed water heaters. RELAP5/M3.3 is a computer program used for the thermal-hydraulic analysis of transients and small-break accidents and transients in light-water nuclear power plants. It uses a one-dimensional, two-phase fluid model, consisting of steam and water, with the possibility of the vapor phase containing a non-condensable component and the liquid phase containing a nonvolatile solute.

The RELAP5 model was constructed as shown in Figure 4. The model starts at the moisture separator (component 401) and ends at Feedwater Heater 4B (component 93) and Condenser B (component 95). There is condensate added to the junction at the bottom of the stand pipe (component 504). To ensure that the flow through the moisture separator during transients was simulated correctly, the MS was divided into four volumes as shown in Figure 5. The vent system is incorporated into the model, with pipes beginning at both the stand pipe and the drain tank, converging at component 503 and running up to the top of Moisture Separator D (401). A description of all volume and junction components is presented on Tables 1 and 2.

The model is dependent on three main valves. CV3012D (component 319) controls the flow out to the feedwater heater. CV3013D (component 321) controls the flow out to Condenser B. CV3013D is not opened unless the level in the drain tank is over 2' - 7 3/16". Both of these valves are controlled the level of Drain Tank D. Finally, CIV4 is modeled as component 601, and controls the steam outlet that goes to the low pressure turbine. Loss coefficients in the valves were modeled as per Ref. 1.

Table 1: RELAP Model Components

Vol #	Description	Area	Diameter	Length	Elev. *
91	HP turbine, Time Dpndnt Volume, conditions: P=219.1, H=1095.7	Arbitrary	Arbitrary	Arbitrary	Arbitrary
92	LP turbine, Time Dependent Volume, conditions: P=219.1, x=1.0	Arbitrary	Arbitrary	Arbitrary	Arbitrary
93	FW Heater, Time Dependent Volume, conditions: P=122.0, x=0.0	Arbitrary	Arbitrary	Arbitrary	Arbitrary
94	Condensate In, Time Dpndnt Volume, conditions: P=567.8, T=93.5F	Arbitrary	Arbitrary	Arbitrary	Arbitrary
95	Condenser B, Time Dependent Volume, conditions: P=5psi, x=0.0	Arbitrary	Arbitrary	Arbitrary	Arbitrary
401	Moisture Separator, 3DT011	113	11.995	18	-9.5000
402	MS and Stand Pipe connector	0.3474	0.6651	4.817	-14.3172
403	Stand Pipe	2.18	1.666	11.9296	-25.7468
404	7' of pipe, condensate and drainage go to Drain Tank, ends with elbow	0.3474	0.6651	7	-25.7468
405	6' of pipe, condensate and drainage go to Drain Tank, ends with elbow	0.3474	0.6651	6	-25.7468
406	3' 11.25", condensate and drainage go to Drain Tank, ends with elbow	0.3474	0.6651	3.9376	-25.7468
407	9' 6.5", condensate and drainage to Drain Tank, ends with elbow, has dz	0.3474	0.6651	9.544	-25.7468
408	40804 has 1' section of area .4475 (simulating a reducer), ends w/ elbow	0.3474	0.6651	5	-25.0801
409	MS Drain Tank D, 3DT012	7.068	2.9999	8.2262	-25.0801
411	41101 has 1' section of area .3474 (simulating a reducer), ends w/ elbow	0.2006	0.5054	23.088	-25.0801
412	15', water to FWHeater and Cond.B, ends w/ elbow	0.2006	0.5054	15	-25.0801
413	36' 5.625", contains split of FWHeater and Cond.B at 41336, ends w/ elbow	0.2006	0.5054	36.432	-25.0801
414	2' pipe, split to FWHeater, ends w/ elbow	0.2006	0.5054	2	-25.0801
415	contains a check valve in 41501, has dz, ends w/ elbow	0.2006	0.5054	12.336	-25.0801
416	25' pipe, no dz, ends w/ elbow	0.2006	0.5054	25	-12.7468
417	14' 10.25" pipe, vertical, has dz, ends w/ elbow	0.2006	0.5054	15.42	-12.2329
418	6' 1.375", contains a check valve in 41801, ends w/ elbow	0.2006	0.5054	6.114	2.6699
419	6' 2.5", pipe before CV3012, ends w/ elbow	0.2006	0.5054	6.21	2.6230
420	15' pipe out to TDV 93 (FW Heater)	0.2006	0.5054	15	2.1074
454	11.75" pipe, start Stand pipe vent line, 45 deg. Angle, ends w/ 45deg elbow	0.2006	0.5054	0.9792	-13.4710
455	5' 7.25" pipe, no dz, ends w/ elbow	0.2006	0.5054	5.604	-13.1248
456	6' 8" pipe, ends w/ elbow	0.2006	0.5054	6.666	-13.1248
457	2', to branch 503, other 9" from isometric drawings part of branch 503	0.2006	0.5054	2	-13.1248
471	1' 8.5" pipe, combined vent line, branch 503 out, ends w/ elbow	0.2006	0.5054	1.7082	-12.6979
472	3' 3.25" pipe, slight dz, ends w/ elbow	0.2006	0.5054	3.291	-11.3750
473	19' 2(11/16)" pipe, completely vertical (has dz), ends w/ elbow	0.2006	0.5054	19.228	7.8490
474	4' 3" pipe, slight dz, ends w/ elbow	0.2006	0.5054	4.248	7.9336
475	3' 4" pipe, Vent to top of Moisture Separator, has slight dz	0.2006	0.5054	3.333	8.0000
476	48' 10.25" split pipe to condenser B, has horizontal and vertical sections	0.2006	0.5054	48.8545	-25.0801
477	5' pipe out to condenser B	0.3474	0.6651	5	-27.6635
481	2' 3/4" start of vent line from Drain tank, vertical pipe (has dz), ends w/ elbow	0.2006	0.5054	2.062	-16.8541
482	5' 10" pipe, no dz, ends w/ elbow	0.2006	0.5054	5.8332	-14.7916
483	1' 8" pipe, vertical (has dz) ends w/ elbow	0.2006	0.5054	1.6666	-14.7916
484	5', to branch 503 (other 2.25" from isos part of branch 503)	0.2006	0.5054	5	-13.1250
499	separated steam from MS	7.069	3.0001	8	8.5000

* Elevation is recorded from the bottom of the volume

Table 2: RELAP Model Junctions

Jun #	Description*	Area (ft ²)	Diameter (ft)	Kf	Kr
201	From HP Turbine, MS steam/water in	1.12E+01	3.769529589	0	0
202	Condensate In, 1.5"	1.41E-02	0.133987602	0	0
301	MS drain to 402, 8"	3.47E-01	0.665073994	0.5	1
302	402 to top of Stand Pipe, 8"	3.47E-01	0.665073994	1	0.5
50401	Stand pipe bottom to branch, 8"	3.47E-01	0.665073994	0.84	0.84
50402	branch to 404, 8"	3.47E-01	0.665073994	0.28	0.28
304	404 to 405, 8"	3.47E-01	0.665073994	0.28	0.28
305	405 to 406, 8"	3.47E-01	0.665073994	0.28	0.28
306	406 to 407, 8"	3.47E-01	0.665073994	0.28	0.28
307	407 to 408, 8"	3.47E-01	0.665073994	0.28	0.28
308	408 to first 10" tee (501), 10"	5.48E-01	0.835000584	0.24	0.23
50101	Branch 501 to Drain Tank, 10"	5.48E-01	0.835000584	0.84	0.84
50102	Branch 501 to Branch 502, 10"	5.48E-01	0.835000584	0.28	0.28
50201	Branch 502 to Drain Tank, 10"	5.48E-01	0.835000584	0.84	0.84
50202	Branch 502 to 411, 10"	5.48E-01	0.835000584	0.21	0.25
311	411 to 412, 6"	2.01E-01	0.505382877	0.3	0.3
312	412 to 413, 6"	2.01E-01	0.505382877	0.3	0.3
313	413 to 414, 6"	2.01E-01	0.505382877	0.3	0.3
314	414 to 415, 6"	2.01E-01	0.505382877	0.3	0.3
315	415 to 416, 6"	2.01E-01	0.505382877	0.3	0.3
316	416 to 417, 6"	2.01E-01	0.505382877	0.3	0.3
317	417 to 418, 6"	2.01E-01	0.505382877	0.3	0.3
318	418 to 419, 6", MOV 3024D	2.01E-01	0.505382877	0.424	0.424
319	CV 3012	1.04E-01	0.364590467	CV	CV
320	420 to Feedwater Heater, 6"	2.01E-01	0.505382877	2	1.5
321	CV 3013	4.51E-02	0.239631182	CV	CV
353	Vent from Stand Pipe, 6"	2.01E-01	0.505382877	0.24	0.24
354	454 to 455, 6"	2.01E-01	0.505382877	0.24	0.24
355	455 to 456, 6"	2.01E-01	0.505382877	0.3	0.3
356	456 to 457, 6"	2.01E-01	0.505382877	0.3	0.3
50301	combined vent, goes to MS, 6"	2.01E-01	0.505382877	0.9	0.9
50302	Stand pipe vent branch, 6"	2.01E-01	0.505382877	0.3	0.3
50303	Drain Tank vent branch, 6"	2.01E-01	0.505382877	0.3	0.3
371	471 to 472, 6"	2.01E-01	0.505382877	0.3	0.3
372	472 to 473, 6"	2.01E-01	0.505382877	0.3	0.3
373	473 to 474, 6"	2.01E-01	0.505382877	0.3	0.3
374	474 to 475, 6"	2.01E-01	0.505382877	0.3	0.3
375	475 to Moisture Separator, 6"	2.01E-01	0.505382877	1	0.5
376	split to Condenser B (with check valve), 6"	2.01E-01	0.505382877	0.775	0.775
377	477 to Condenser B	8.84E-02	0.335491245	2	1.5
380	Drain Tank D Vent, 6"	2.01E-01	0.505382877	0.5	1
381	481 to 482, 6"	2.01E-01	0.505382877	0.3	0.3
382	482 to 483, 6"	2.01E-01	0.505382877	0.3	0.3
383	483 to 484, 6"	2.01E-01	0.505382877	0.3	0.3
398	Steam out of MS, 36"	7.07E+00	3.000088389	0	0
399	499 to LP Turbine, 36"	7.07E+00	3.000088389	0	0

* All pipes are Schedule 40

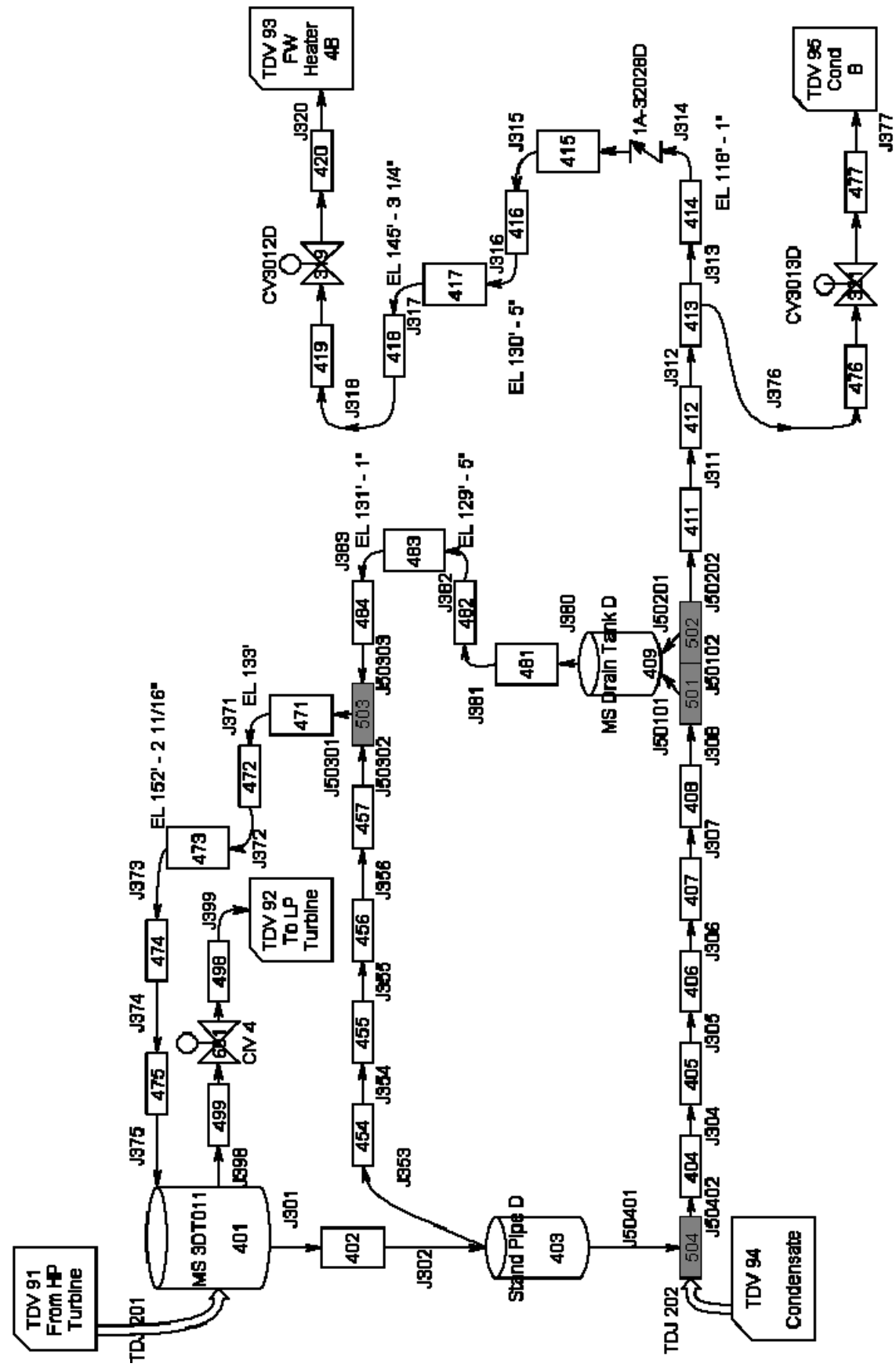


Figure 4: RELAP5 Nodal Diagram of Peach Bottom MS/DT Drain System

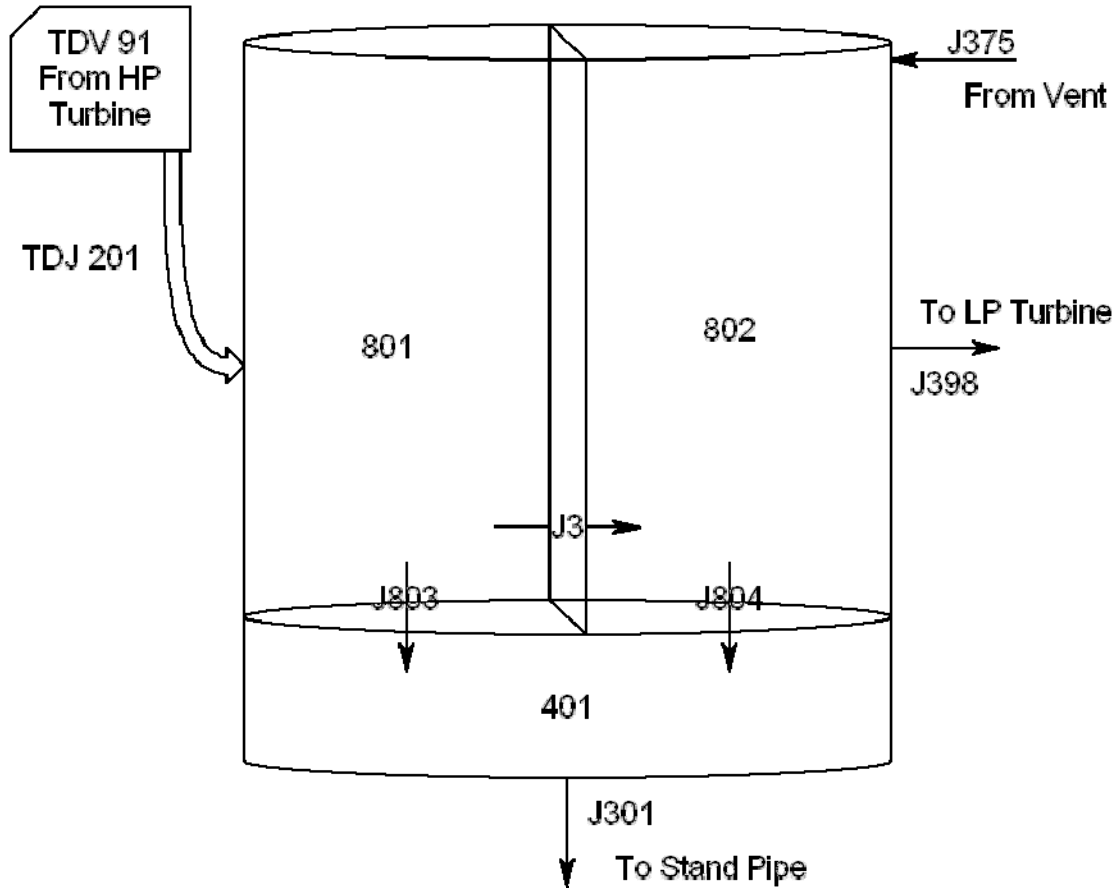


Figure 5: RELAP5 Nodalization of the Moisture Separator

Results

Eight cases were evaluated for this study. They are listed in Table 3 along with the details of each specific case. The first six are requested by Peach Bottom. The remaining cases are transients that were included to evaluate other possible scenarios.

Table 3: Case Descriptions

Case	RELAP File	Power	MS Effectiveness	Details
1	p185-v20r1	100	85	Current Plant Specifications
2	p185-v21r1	100	100	Proposed Upgrade Specifications
3	75pr1	75	100	Upgrade Specifications at 75% power
4	50pr1	50	100	Upgrade Specifications at 50% power
5	25pr1	25	100	Upgrade Specifications at 25% power
6	p185-v39r1	100	100	CIV4 Stroking
7	p185-v44	100 to 25	100	100% Power to 25% Power over 30 sec
8	P185-v25r1	100	100	Failure of CV2012D to open

The initial simulations were run to see what differences would exist in steady state operation before and after the MS modifications were performed to increase MS efficiency. Simulations were based on data obtained from plant PEPSE diagrams. For conservative results, the inlet flow was increased by 30% on both cases. Table 4 contains the output.

Table 4: Comparison of Steady State, MS Effectiveness 85% to 100% at 100% Power

	Component	MS Effectiveness	
		85%	100%
Drain Tank Level	c10	1.52 ft	1.61 ft
MS D Level	c40	0.0343 ft	0.0369 ft
CV3012D Stem Pos.	c20	0.277	0.328
CV3013D Stem Pos.	c21	0	0
Flow Out of MS	302	309500.0	363200.0
Flow to FW Heater	320	313017.9	367200.0
Stand Pipe Vent Flow (lbm/hr)	353	6859.0	6405.0
Drain Tank Vent Flow (lbm/hr)	381	0	0
Combined Vent Flow (lbm/hr)	371	6857.188	6404.804

The operating level of the drain tank increases from 1.52 ft to 1.61 ft. At different MS Effectiveness levels, there are differing amounts of flow leaving the MS. To remain at steady state, this is also the flow that must leave to the FW Heater. Since the control valve is modeled as per the level of the DT, the level must change for the flow rate to be different.

In the 100% case, the level is under the midpoint of the CV3012D range by about 3 inches and about one foot under the switch for dump valve actuation. The MS level also increases accordingly and has around a 7.6% rise in level for the 100% efficiency case.

In the proposed MS upgrade, the liquid flow to the stand pipe would increase by 17%. The Froude number of pipe 402, the pipe that connects the MS and stand pipe, is 0.76. It is increased to 0.90 when upgrading the MS from 85% to 100% efficiency. Both of these are well over the 0.3 threshold. The results of both cases using conservative flows show that the vents from the standpipe and drain tank more than compensate for the non-self venting characteristics of the drain pipe.

To analyze the effect of transients, several situations were simulated. The 100% efficiency case is used for all transients. The first included the stroking of CIV4 which shuts off the steam flow out of the Moisture Separator (Case 6). The 100% power and 100% efficiency case was used.

CIV4 closes in seven seconds and opens in 10.8 seconds. The CIV stroke times were based on Ref. 10. Therefore, the entire cycle took only 17.8 seconds. In that time, the drain tank undergoes a rapid level decrease of about 4 inches as shown in Figure 6. The drain tank water level decrease was caused by the decrease in drain flow from the MS and the continued flow through the drain tank control valve.

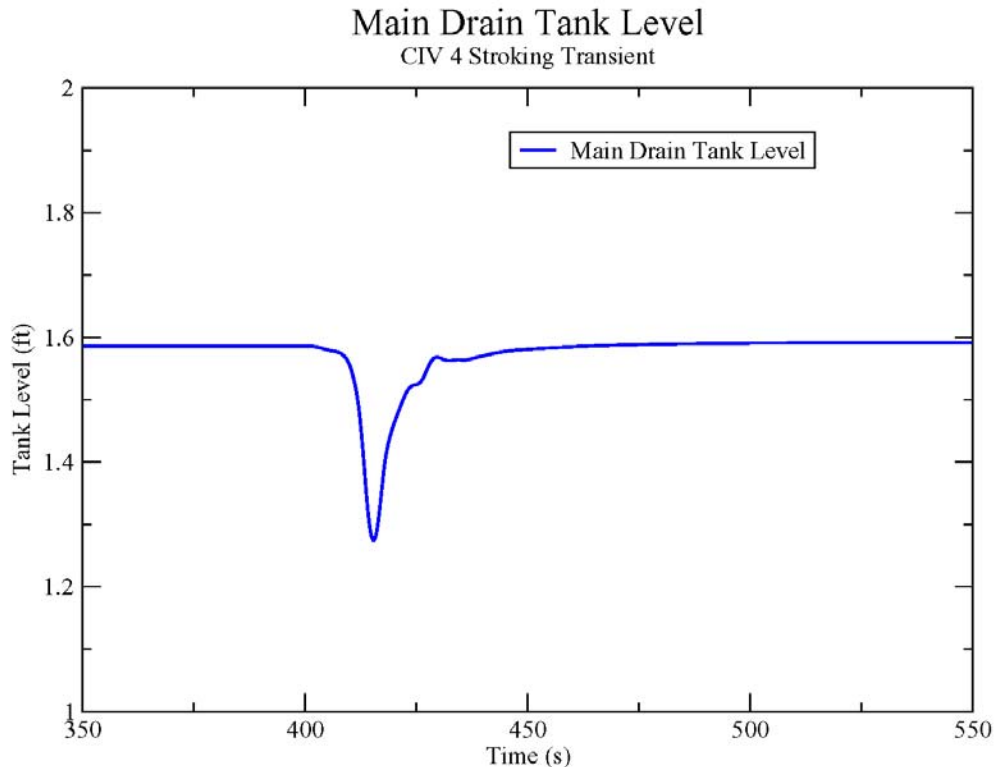


Figure 6: Main Drain Tank Level During the CIV Closure

The drain flow decreases slightly after the valve begins closure as seen in Figure 7. There is a minor discontinuity at 7 seconds which corresponds to the pressure spike

associated with the valve fully closing. The drain flow continues to decrease even as the CIV is reopened because the level in the moisture separator is still decreasing. Once the flow through the CIV becomes sufficiently high, the level in the MS increases as it returns to the original level and the drain flow begins to increase again.

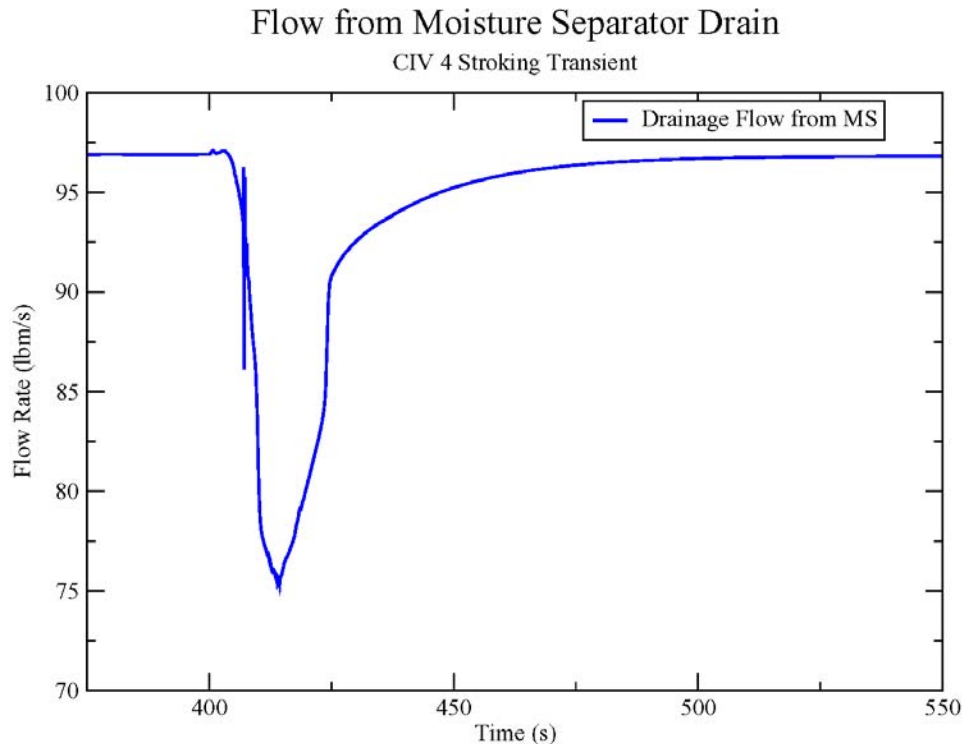


Figure 7: Drain Flow from MS During the CIV Closure

Another simulated transient was the ramping of power from 100% to 25% (Case 7). This was conservatively simulated in a 30 second time frame and causes a significant reduction of pressure and flow in the MS. The pressure is reduced by 166 psi. This results in the depressurization of the tanks, and therefore, backflow and flashing is likely to occur to compensate for pressure differences. This simulates a rapid increase in the level of the tanks. Both flashing and backflow are involved in the process.

Figure 8 is the level of the drain tank during the reduction in power event. Figure 9 shows the flows in and out of the drain tank. At 400 seconds, the transient begins and almost instantly the level in the tank jumps (See Figure 8) because of sudden pressure drop, which causes a reduction and flow reversal in the water flowing to the Feed Water Heater as shown in Figure 9. Water flow from the standpipe initially increases due to the pressure in the discharge piping of the standpipe, which is initially much higher than the pressure in the drain tank. The vent path in the drain tank allows the pressure to decrease much quicker in the DT than the pressure in the standpipe discharge piping since the standpipe provides a buffer for the pressure drop in the standpipe discharge piping. The level in the drain tank raises high enough, which results in dump valve actuation while CV 2012D is fully open as shown in Figure 8. Since the reduction in outflow lasts only for a limited time, after the first few seconds of the transient it subsides. The valves are still open which leads to the overcompensation of the tank level as shown in Figure 9,

explaining why it dips below one foot and begins to rise. Finally, the drain tank water level steadies to a new equilibrium level.

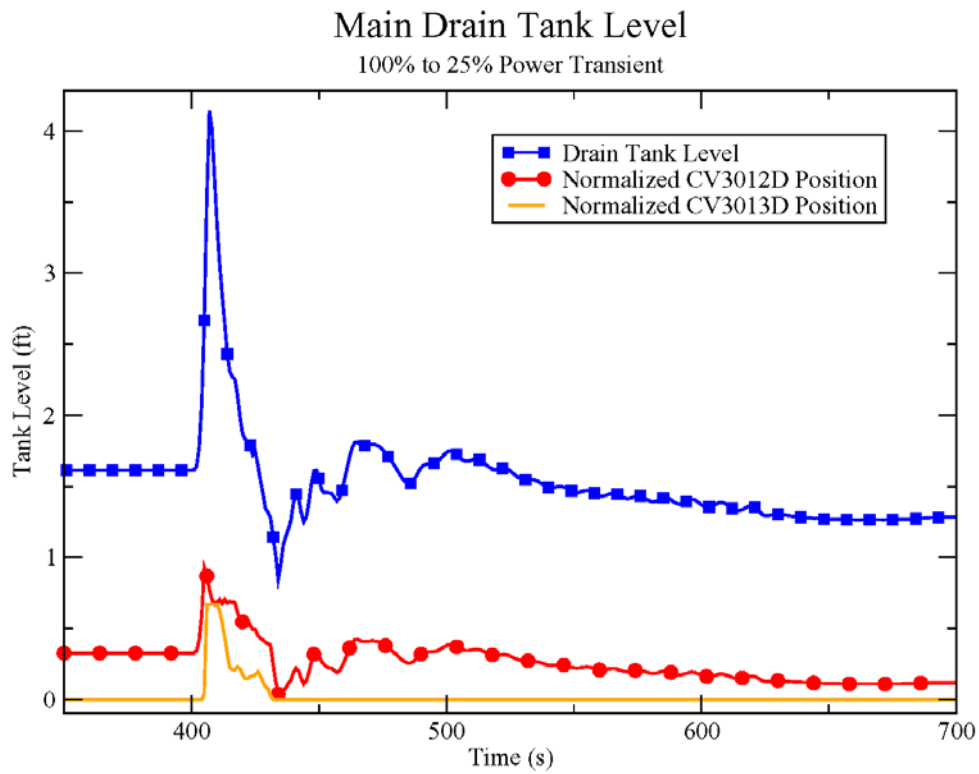


Figure 8: Main Drain Tank Level During Reduction in Power Event

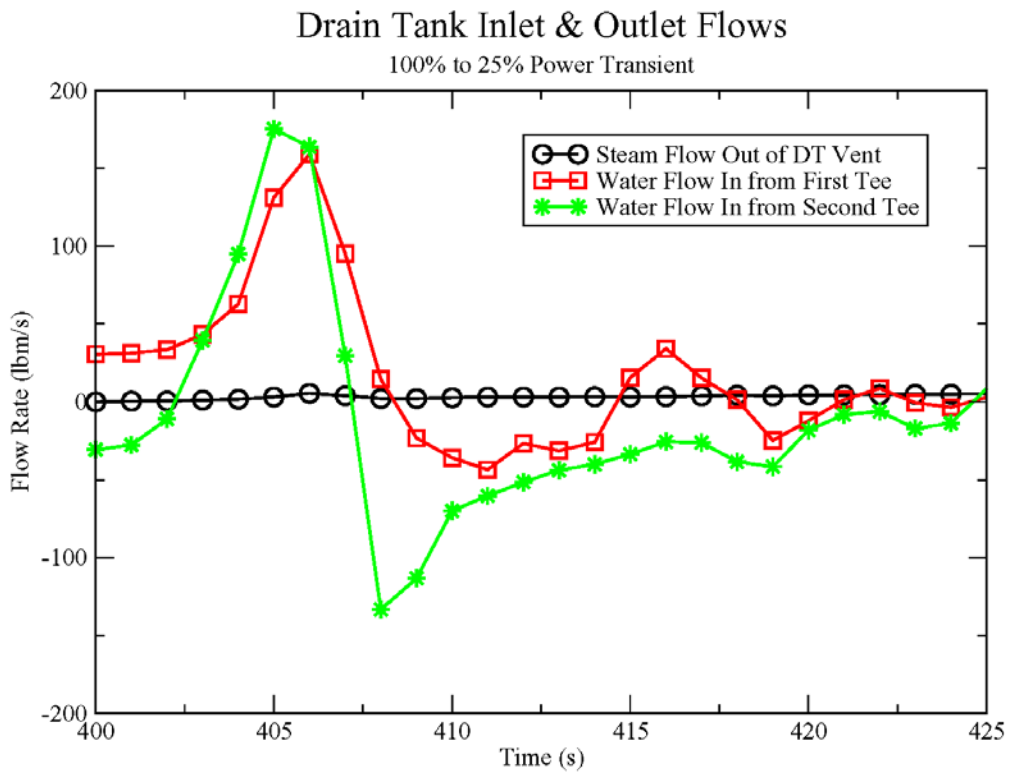


Figure 9: Main Drain Tank Flows During Reduction in Power Event

For the power reduction event, the drain flow out of the Moisture Separator, as seen in Figure 10, decreases dramatically at first because of the high pressure in the drainage system down stream. For about ten seconds, flow reverses back into the MS, resulting in about 20 gallons being added to the MS vessel. The flow then reverses again and drains the excess to return to a new steady state level as shown in Figure 10.

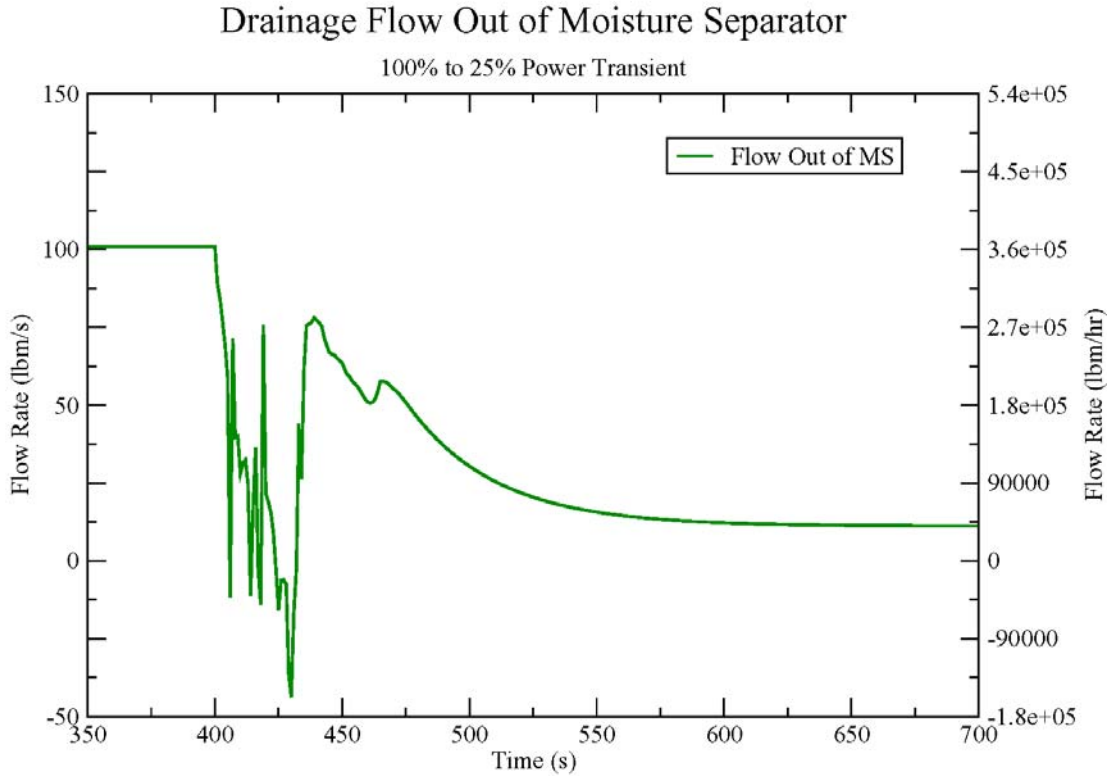


Figure 10: Flow Out of MS During Reduction in Power Event

The final transient involved the failure of the control valve to the feedwater heaters, CV3012D (Case 8). The case simulated is the 100% power and 100% efficiency case at steady state. At 800 seconds, the control valve CV3012D closes due to some failure. The failure results in a rapid increase of the water level in the main drain tank as shown in Figure 11. Actuation of the dump valve occurs about 4 seconds into the transient and limits the level to slightly more than 3.5 feet, shown in Figure 11.

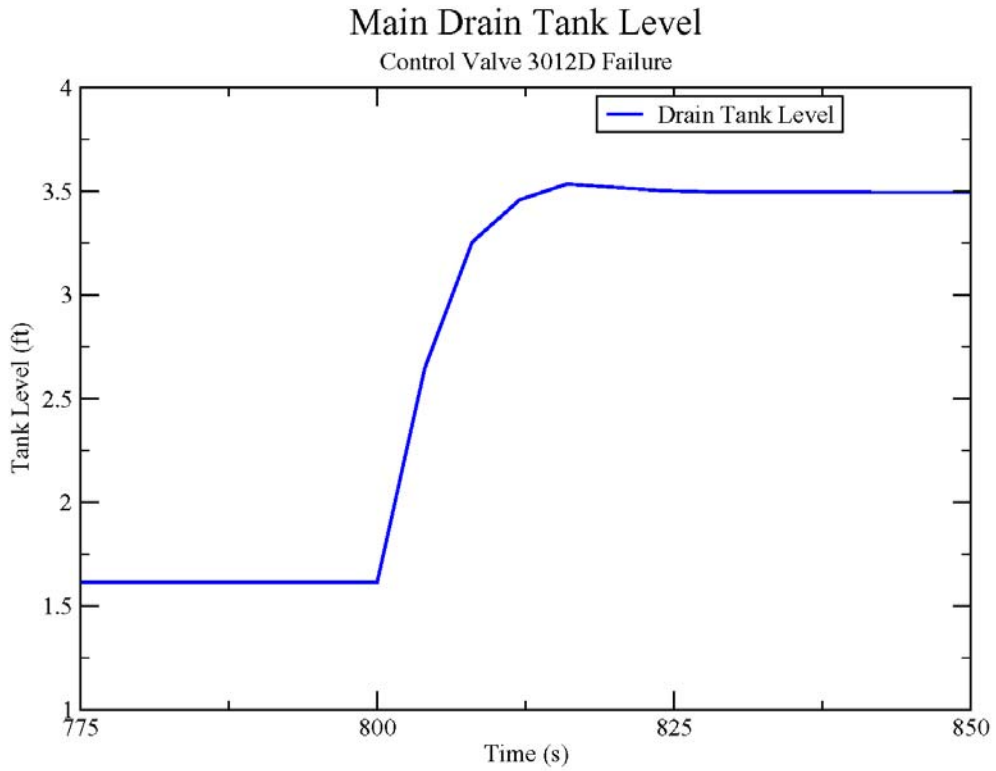


Figure 11: Drain Tank Level for CV3012D Failure

The associated valve flow rates are shown in Figure 12. Immediately after CV3012 is shut, the drain tank fills since there is no flow leaving the drain tank. Four seconds into the transient, the dump valve begins to open and flow exits the drain to the condenser. By 30 seconds the system has reached equilibrium at a higher level in the drain tank with all flow leaving through the dump valve.

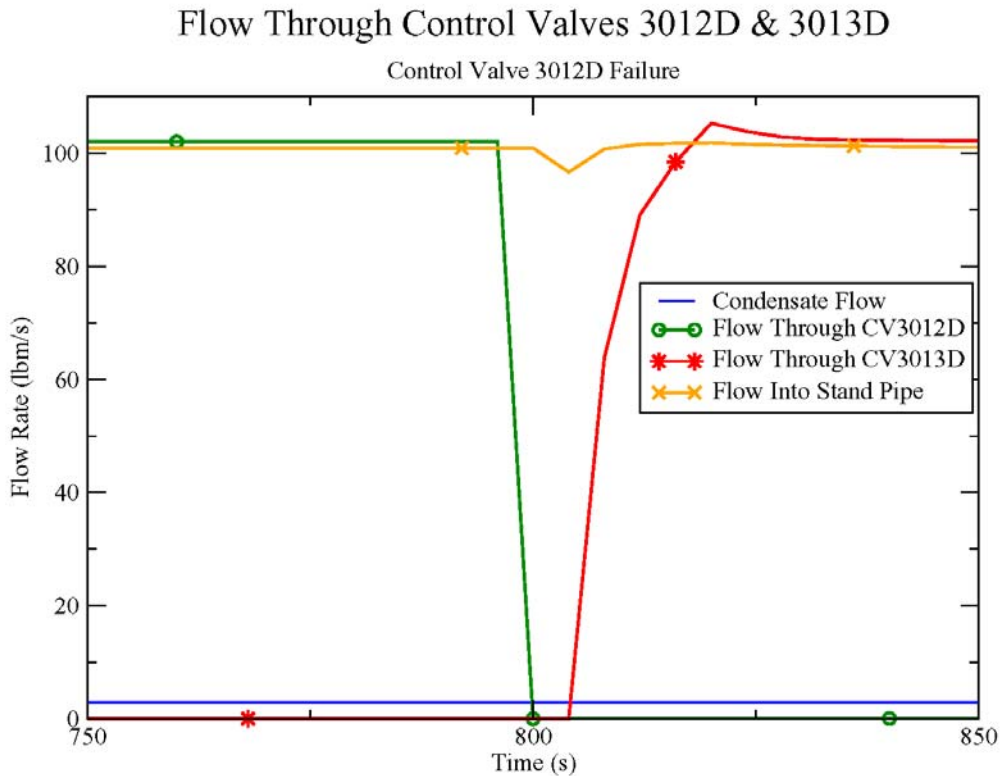


Figure 12: Flow Through Control Valves in CV3012D Failure Event

Conclusions

Based on the evaluations presented in this report, the Peach Bottom MS/DT drain system is designed with sufficient venting from the stand pipe and the drain tank, and therefore, can accommodate significant vapor flow through the MS drain. According to GEK 37949A (Ref. 9) the system has a favorable configuration. The pipe leading from the Moisture Separator to the Stand Pipe is short and regular and is void of any abrupt discontinuities. The vent pipes leading from the stand pipe and drain tank have a backwards pitch so that any condensate will flow back into the drain system. These standards laid out in the GEK are followed reasonably well, and suggest a level of stability suitable for moisture separator modification.

Following the descriptions of the GEK (Ref. 9), the stand pipe in the Peach Bottom MS/DT drain system is what resembles the GEK drain tank. This is not actually the case, as the drain tank is downstream of the stand pipe. The Peach Bottom configuration actually provides two significant venting opportunities, which are vents from the standpipe and venting from the DT. This double vent configuration assures the vapor that entered the system from the MS will not impede the operation of the MS/DT drain system. With vents on each tank (standpipe and drain tank), the likelihood of vapor

lock occurring in the MS/DT drain system is of more concern with transients, when the behavior of the system is harder to predict.

The simulations presented here provide a good basis of whether or not the system can handle an upgrade to the MS internals. The five steady state runs and the three transient runs provide a good scope on the normal operation of the plant, along with worst case scenarios.

The steady state runs were within plant operating guidelines. As shown in Table 5, none had a drain tank level higher than the 100% case, which had a value of 1.61ft. The lowest steady state level was 1.16ft, occurring in the 25% power case. No abnormalities exist in the steady state cases. As expected, as the power increases, so does the tank level and flow out of the MS. The steady state analyses show no problems in flow related to upgrading the moisture separators.

Table 5: Steady State Values for 25%, 50%, 75%, and 100% Power Cases

	Component	Core Thermal Power			
		25%	50%	75%	100%
Drain Tank Level (ft)	c10	1.25	1.31	1.45	1.61
MS D Level (ft)	c40	0.0044	0.0113	0.029	0.0369 ft
CV3012D Stem Pos.	c20	0.092	0.141	0.23	0.328
CV3013D Stem Pos.	c21	0	0	0	0
Flow Out of MS (lb/hr)	302	27972	91800	210000	364000
Flow to FW Heater (lb/hr)	320	37800	100800	216000	368000
Stand Pipe Vent Flow (lbm/hr)	353	623	1523	4000	6400
Drain Tank Vent Flow (lbm/hr)	381	0	0	0	0
Combined Vent Flow (lbm/hr)	371	623	1523	4000	6400

The CIV 4 stroking transient presents an interesting challenge to the system. It must restrict steam flow while stabilizing the drainage. While it is stressful on the system, the stand pipe acts as the buffer to protect the drain tank.

The reduction in power event depressurizes the components and disrupts the system. According to the simulation, some backflow occurs in spots without check valves (such as the MS-stand pipe connector), but the magnitude is small enough that no flooding of the MS tank will occur.

The final transient involves the failure of the CV3012D valve. Upon failure, the drain tank fills quickly and actuates the dump valve to Condenser B. With correct triggering of CV3013D, the transient is handled with ease. The tank assumes a new level almost two feet higher, which is still about a foot below the range of the dump valve.

Overall, the system is robust. It can handle all steady state operating conditions along with transients that are very taxing on the system. As expected, the stand pipe acts as a buffer to shield the drain tank from major oscillations in level. At no point was the drain tank empty or full.

References

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3. Transmittal, Jeff Marion to Joe Miller, EDA, Inc. Subject: Peach Bottom Atomic Power Station Units 2 & 3, Moisture Separator Drains Capability Analysis. Date: January 24, 2007. Attachments: PEPSE Diagrams for 25%, 50%, 75%, 100% Power, 100% Efficiency Cases, 100% power 85% efficiency case, Plant Isometric Drawings, M-304 Sheet 2
4. Email Transmittal, Jeff Marion to Joe Miller, EDA, Inc. Subject: RE: Condensate Addition, Date: February 1, 2007
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6. P&ID provided by Exelon (Attachment of Ref. 5)
7. Email Transmittal, Jeff Marion to Joe Miller, EDA, Inc. Subject: PBAPS Moisture Separator Drains Capability Analysis. Date: February 12, 2007. Attachments: 6280-SK-M-559 sheet 37
8. Moisture Separator Drain Tanks, Drawing 6280-SK-M-559 Sht. 37 (from ref. 17)
9. GEK 37949A Revision A, June 1977. Moisture Separator and Reheater Drain Systems
10. Email Transmittal, Jeff Marion to Joe Miller, EDA, Inc. Subject: RE: CIV Stroke data, Date: March 9, 2007.

Appendix A: Mathcad Calculation File

A) Pipe Internal Diameters (ft) and Areas (ft²) [1]

$$\pi := 3.14159$$

$$D2 := \frac{2.067}{12} \quad A2 := \pi \cdot \left(\frac{D2}{2}\right)^2 \quad A2 = 0.0233$$

$$D4 := \frac{4.026}{12} \quad A4 := \pi \cdot \left(\frac{D4}{2}\right)^2 \quad A4 = 0.0884$$

$$D6 := \frac{6.065}{12} \quad A6 := \pi \cdot \left(\frac{D6}{2}\right)^2 \quad A6 = 0.2006$$

$$D8 := \frac{7.981}{12} \quad A8 := \pi \cdot \left(\frac{D8}{2}\right)^2 \quad A8 = 0.3474$$

$$D10 := \frac{10.02}{12} \quad A10 := \pi \cdot \left(\frac{D10}{2}\right)^2 \quad A10 = 0.5476$$

$$D20 := \frac{18.81}{12} \quad A20 := \pi \cdot \left(\frac{D20}{2}\right)^2 \quad A20 = 1.9297$$

$$D36 := \frac{34.5}{12} \quad A36 := \pi \cdot \left(\frac{D36}{2}\right)^2 \quad A36 = 6.4916$$

B) Loss Coefficients by Pipe Diameter

(using chart on Crane, page A-26) [3]

$$Ft2 := .015$$

$$Ft6 := .015$$

$$Ft8 := .014$$

$$Ft10 := .014$$

$$Ft20 := .012$$

C) Loss Coefficients in Elbows by Pipe Diameter

(using chart on Crane, page A-26) [2][3]

$$K2_90_el := Ft2 \cdot 20 \quad K2_90_el = 0.38$$

$$K6_90_el := Ft6 \cdot 20 \quad K6_90_el = 0.3$$

$$K8_90_el := Ft8 \cdot 20 \quad K8_90_el = 0.28$$

$$K10_90_el := Ft10 \cdot 2C$$

$$K10_90_el = 0.28$$

$$K6_45_el := 16 \cdot Ft6$$

$$K6_45_el = 0.24$$

For use on J353, J354

D) Loss Coefficients in Branches [3]

$$K6_br := 60 \cdot Ft6 \quad K6_br = 0.9$$

$$K6_run := 20 \cdot Ft6 \quad K6_run = 0.3$$

$$K8_br := 60 \cdot Ft8 \quad K8_br = 0.84$$

$$K8_run := 20 \cdot Ft8 \quad K8_run = 0.28$$

$$K10_br := 60 \cdot Ft10 \quad K10_br = 0.84$$

$$K10_run := 20 \cdot Ft10 \quad K10_run = 0.28$$

E) Loss Coefficients in Reducers [5][6][7]

Contraction [5]

From 10" to 6"

$$F1 := .547t \quad F0 := .200t \quad \frac{F0}{F1} = 0.3663 \quad \text{areas of pipes, } F1 \text{ is } 10" \text{ } F0 \text{ is } 6"$$

$$\alpha_{10_6} := 2 \operatorname{atan}\left(\frac{2}{8.25}\right) \quad \alpha_{10_6} = 0.4757 \quad \frac{\alpha_{10_6} \cdot 180}{\pi} = 27.2548$$

using Diagrams 3-5 and 5-2 on Ref. 5

$$\zeta_{10_6pr} := .15 \quad \zeta_{10_6fr} := .01 \quad \text{used interpolation for these values}$$

$$K10_6 := \zeta_{10_6pr} \left(1 - \frac{F0^2}{F1^2}\right) + \zeta_{10_6fr} \quad K10_6 = 0.1399$$

From 10" to 8"

$$F_{-1} := .547t \quad F_{-0} := .347t \quad \frac{F_{-0}}{F_{-1}} = 0.6344 \quad \text{areas of pipes, } F_{-1} \text{ is } 10", \text{ } F_{-0} \text{ is } 8"$$

$$\alpha_{10_8} := 2 \operatorname{atan}\left(\frac{1}{8.25}\right) \quad \alpha_{10_8} = 0.2412 \quad \frac{\alpha_{10_8} \cdot 180}{\pi} = 13.8229$$

using Diagram 3-5 and 5-2 on Ref. 5

$$\zeta_{10_8pr} := .26 \quad \zeta_{10_8fr} := .02$$

$$K10_8 := \zeta_{10_8pr} \left(1 - \frac{F_{-0}^2}{F_{-1}^2}\right) + \zeta_{10_8fr} \quad K10_8 = 0.1754$$

Expansion [6]

6 in to 10 inch

$F1 = 0.5476$ $F0 = 0.2006$ areas of pipes, F1 is 10", F0 is 6"

$$n1 := \frac{F1}{F0} \quad n1 = 2.7298 \quad \frac{1}{n1} = 0.3663$$

use α_{10_8} from above and Ref. 6:

$\zeta_{8_10exp} := .2$ $\zeta_{8_10fr} := .02$ these values are interpolated

$$K_{8_10} := \zeta_{8_10exp} + \zeta_{8_10fr} \quad K_{8_10} = 0.22$$

8 in to 10 inch, source not correct, added 0.1 as a correction factor

$F_{_1} = 0.5476$ $F_{_0} = 0.3474$ areas of pipes, F_1 is 10", F_0 is 8"

$$n_{_1} := \frac{F_{_1}}{F_{_0}} \quad n_{_1} = 1.5763 \quad \frac{1}{n_{_1}} = 0.6344$$

use α_{10_6} from above and Ref. 6:

$\zeta_{6_10exp} := .19$ $\zeta_{6_10fr} := .01$

$$K_{6_10} := \zeta_{6_10exp} + \zeta_{6_10fr} \quad K_{6_10} = 0.2 \quad \text{this number is adjusted as per above}$$

F) Loss Coefficients in Valves [3]

found using CRANE

Check Valve [3]

$Ft6 = 0.015$ based on 5.5" pipe, Ft is average of 6" and 5" value

$Ft5 := .01\epsilon$

$$Ft55 := \frac{Ft6 + Ft5}{2}$$

$F_{_chv} := 50 \cdot Ft55$ $F_{_chv} = 0.775$ Modeled as a swing check valve, $\theta = 0$, flow area based on 5.5" pipe, put on pipe 415 and Pipe 418

Motor Operated Valve [3]

$F_{_mov} := 8 \cdot Ft55$ $F_{_mov} = 0.124$ Modeled as a Gate valve, $\theta = 0$, flow area based on 5.5" pipe, put on J318 (added to elbow loss)

Calculated Steam Inlet qualities

25% Case $h_{25} := 1098.4$

$$hf_{25} := 250.7$$

$$hfg_{25} := 923.4$$

$$x_{25} := \frac{h_{25} - hf_{25}}{hfg_{25}} \quad x_{25} = 0.918$$

50% Case $h_{50} := 1095.4$

$$hf_{50} := 301.4$$

$$hfg_{50} := 886.4$$

$$x_{50} := \frac{h_{50} - hf_{50}}{hfg_{50}} \quad x_{50} = 0.8959$$

75% Case $h_{75} := 1095.6$

$$hf_{75} := 335.8$$

$$hfg_{75} := 859.1$$

$$x_{75} := \frac{h_{75} - hf_{75}}{hfg_{75}} \quad x_{75} = 0.8836$$

Control Valves 2012 and 2013 Areas

CV201:

From Ref 17 cv3012 has 4 3/8" port and CV 3013 has a 2 7/8 " port

$$\text{AreaCV3012} := \frac{3.1415 \left(\frac{4 + \frac{3}{8}}{12} \right)^2}{4} \quad \text{AreaCV3012} = 0.1044 \quad \text{ft}^{**2}$$

$$\text{AreaCV3013} := \frac{3.1415 \left(\frac{2 + \frac{7}{8}}{12} \right)^2}{4} \quad \text{AreaCV3013} = 0.0451 \quad \text{ft}^{**2}$$

Drain Flow Evaluation, Peach Bottom

Froude Number Calculation:

85% Moisture Separator Effectiveness $e_{MS_{85}} := .85$

From Steam Tables:

$$\rho_{w_psat_220} := \frac{1 \cdot \text{lb}}{.01850 \text{ft}^3}$$

$$\rho_{w_psat_220} = 54.0541 \frac{\text{lb}}{\text{ft}^3}$$

$$\rho_{v_psat_220} := 1 \frac{\text{lb}}{2.0863 \text{ft}^3}$$

$$\rho_{v_psat_220} = 0.4793 \frac{\text{lb}}{\text{ft}^3}$$

$$h_{in_85} := 1095.7$$

$$h_{lat_vap_85} := 835.4$$

$$h_{liq_85} := 364.1$$

Constants:

$$D_8 := .665 \text{ft} \quad A_8 := 0.3474 \text{ft}^2$$

$$D_{10} := .835 \text{ft} \quad A_{10} := .5476 \text{ft}^2$$

$$g = 32.174 \frac{\text{ft}}{\text{s}^2}$$

increase flow by 30%

$$\text{Factor} := 1.3$$

$$W_{85} := 2241663 \frac{\text{lb}}{\text{hr}}$$

$$x_{\text{flow}} := \frac{h_{in_85} - h_{liq_85}}{h_{lat_vap_85}} \quad x_{\text{flow}} = 0.8756$$

$$v_{1_85} := W_{85} \cdot \text{Factor} \cdot (1 - x_{\text{flow}}) \cdot e_{MS_{85}} \cdot \frac{1}{\rho_{w_psat_220}} \cdot \frac{1}{A_8} \quad v_{1_85} = 3.5055 \frac{\text{ft}}{\text{s}}$$

$$FR_{85_D8} := \frac{v_{1_85}}{\sqrt{g \cdot D_8}} \cdot \sqrt{\frac{\rho_{w_psat_220}}{\rho_{w_psat_220} - \rho_{v_psat_220}}} \quad FR_{85_D8} = 0.7612 \quad \lll\lll\lll\lll\lll\lll$$

back calculate to find pipe diameter corresponding to FR=0.3

$$FR_1 := 0.3$$

$$D_{\text{calc}_1} := \left[\frac{4 \cdot W_{85} \cdot \text{Factor} \cdot (1 - x_{\text{flow}}) \cdot e_{MS_{85}}}{\rho_{w_psat_220} \cdot \sqrt{g} \cdot \pi \cdot FR_1} \right]^{\frac{2}{5}} \quad D_{\text{calc}_1} = 0.9635 \text{ft}$$

Checks

Water Level

$$WLi = (\rho_{hi} \times HTi / TH) \times Vol \times (1 / (AREA \times RHOe / 2.2046)), \text{ ft/kg}$$

where ρ_{hi} is density in height segment of tank - taken from RELAP, kg/m^{**3}

HTi is height of segment in feet

TH is total height of tank in feet

Volume of tank in m^{**3}

AREA of the inside cross section of the tank, ft^{**2}

$RHOe$ is expected density in the tank, lb/ft^{**3}

2.2046 lb per kg

WLi is water level in height segment, feet

WLT = Total Water Level in Tank, feet

$$WLT = WL1 + WL2 \dots WLn, \quad n = 10$$

$$TH := 8.226 \quad \text{ft}$$

$$Vol := 58.3028 \quad \text{Vol} = 1.6499 \quad \text{m}^{**3}$$

$$AREA := 7.068 \quad \text{ft}^{**2}$$

$$RHOe := 54.5 \quad \text{lb/ft}^{**3}$$

$$HT1 := .984 \quad HT2 := .834 \quad HT3 := .834 \quad HT4 := .115$$

$$HT5 := .835 \quad HT6 := .835 \quad HT7 := .9482 \quad HT8 := HT7$$

$$HT9 := HT7 \quad HT10 := HT7$$

From RELAP5 run

$$\rho_{h1} := 875 \quad \text{kg/m}^{**3} \quad \rho_{h6} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{h2} := 871 \quad \text{kg/m}^{**3} \quad \rho_{h7} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{03} := 682 \quad \text{kg/m}^{**3}$$

$$\rho_{04} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{05} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{08} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{09} := 7.6 \quad \text{kg/m}^{**3}$$

$$\rho_{010} := 7.6 \quad \text{kg/m}^{**3}$$

Water Level

$$WL_i = (\rho_{0i} \times HT_i / TH) \times Vol \times (1 / (AREA \times RHO_e / 2.2046)), \text{ ft/kg}$$

$$WL_1 := \left(\rho_{01} \cdot \frac{HT_1}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_1 = 0.9861 \quad \text{ft}$$

$$WL_2 := \left(\rho_{02} \cdot \frac{HT_2}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_2 = 0.8338 \quad \text{ft}$$

$$WL_3 := \left(\rho_{03} \cdot \frac{HT_3}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_3 = 0.6529 \quad \text{ft}$$

$$WL_4 := \left(\rho_{04} \cdot \frac{HT_4}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_4 = 1.0033 \times 10^{-3} \quad \text{ft}$$

$$WL_5 := \left(\rho_{05} \cdot \frac{HT_5}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_5 = 7.2671 \times 10^{-3} \quad \text{ft}$$

$$WL_6 := \left(\rho_{06} \cdot \frac{HT_6}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_6 = 7.2671 \times 10^{-3} \quad \text{ft}$$

$$WL_7 := \left(\rho_{07} \cdot \frac{HT_7}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_7 = 8.2726 \times 10^{-3} \quad \text{ft}$$

$$WL_8 := \left(\rho_{08} \cdot \frac{HT_8}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHO_e}{2.2046}} \right) \quad WL_8 = 8.2726 \times 10^{-3} \quad \text{ft}$$

$$WL9 := \left(\rho_{09} \cdot \frac{HT9}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHOe}{2.2046}} \right) \quad WL9 = 8.2726 \times 10^{-3} \quad \text{ft}$$

$$WL10 := \left(\rho_{010} \cdot \frac{HT10}{TH} \right) \cdot Vol \left(\frac{1}{AREA \cdot \frac{RHOe}{2.2046}} \right) \quad WL10 = 8.2726 \times 10^{-3} \quad \text{ft}$$

$$WLi := WL1 + WL2 + WL3 \quad WLi = 2.4728 \quad \text{ft}$$

$$WLj := WL5 + WL6 + WL7 + WL8 + WL9 + WL10 \quad WLj = 0.0476$$

$$WLT := WLi + WLj \quad WLT = 2.5205$$

Calculate Valve 2013 control fraction

From RELAP5 $FRAC = .73$, $WTf = 2.34$

$$WT := HT2 + HT3 + HT4 \quad WT = 1.783$$

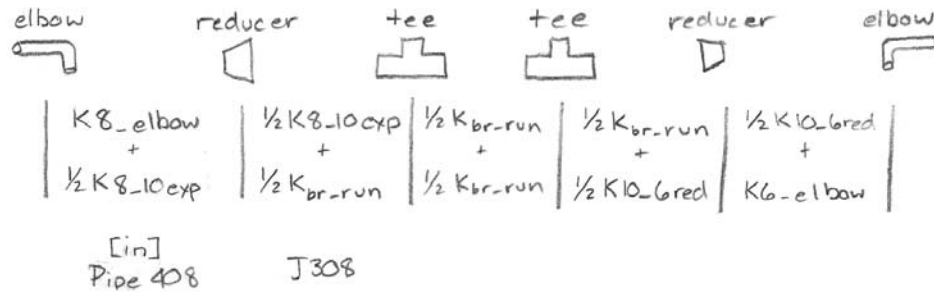
$$Frac := \frac{2.34 - HT1}{WT} \quad Frac = 0.7605 \quad \text{close enough to } .73$$

Appendix B: Angles of Non-Horizontal Pipes

#	description	pipe length	Elevation Change	From	To	Angle (rad) Sin ⁻¹ (elevation change/pipe length)	Angle (deg)
401	Moisture Separator					Vertical	
402	MS stand pipe connection					Vertical	
403	Stand pipe					Vertical	
407		9.541666667	0.666666667	117' 5"	118' 1"	0.069925967	4.006462798
409	Drain Tank					vertical	
415						vertical	
417						vertical	
419		6.208333333	-0.5625	145' 10"	145' 3.25"	-0.09072845	-5.198357255
454						0.785398163	45
471						vertical	
472		3.2917	0.041666667	132' 11.5"	133'	0.012658438	0.725275056
473						vertical	
474+475		7.583333333	0.151041667	152' 2 11/16"	152' 4.5"	0.0199189	1.141268878
474						0.0199189	1.141268878
475						0.0199189	1.141268878
481						vertical	
483						vertical	

Appendix C: Loss Coefficients of 10" Tees

Loss Coefficients for Drain Tank D Piping



Coefficients

rev	0.28 + $(\frac{1}{2})(0.20)$	$(\frac{1}{2})(0.20)$ + $(\frac{1}{2})(0.28)$	$(\frac{1}{2})(0.28)$ + $(\frac{1}{2})(0.28)$	$(\frac{1}{2})(0.28)$ + $(\frac{1}{2})(0.14)$	$(\frac{1}{2})(0.14)$ + 0.3
fwd	0.38	0.24	0.28	0.21	0.37
rev	0.28 + $(\frac{1}{2})(0.1754)$	$(\frac{1}{2})(0.1754)$ + $(\frac{1}{2})(0.28)$	$(\frac{1}{2})(0.28)$ + $(\frac{1}{2})(0.28)$	$(\frac{1}{2})(0.28)$ + $(\frac{1}{2})(0.22)$	$(\frac{1}{2})(0.22)$ + 0.3
fwd	0.37	0.23	0.28	0.25	0.41

* note* in reverse coefficients, expanders become reducers and vice-versa