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Water Hammer Analysis

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ABSTRACT

Washington River Protection Solutions (WRPS) is in charge of performing waste transfer operations at the DOE Hanford Site in Washington State. When a rupture disc on a pipeline failed, was replaced, and failed again, it was postulated that the new failure was caused by water hammer in the pipe. The design team at WRPS was then charged with creating a model to simulate the events that took place and discern if water hammer was the cause of the failure. The conditions which were present at the time of the pressure test were simulated along with other scenarios which were requested by WRPS management. AFT Impulse™, a software package which is designed for modeling and analyzing water hammer, was used. All of the drawings for the various sections of the pipeline were obtained and various details were taken from them.

Evaluation of the results of the water hammer analysis will help WRPS determine what changes to the pipeline are necessary and appropiate, including which components should be replaced and which operational parameters should be modified to avoid future incidence of this problem. This report will give an overview of the tasks performed, focusing on the modeling conducted as well as the details of the analysis and its results.

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1. INTRODUCTION

One of the tasks which Washington River Protection Solutions (WRPS) is in charge of is that of performing waste transfer operations. The SL-167 pipeline going to the evaporator facility had a rupture disc fail on its own due to age. It was replaced with a new inconel rupture disc and a pressure test was performed on the pipeline on April 29, 2010. When the test was performed, the new rupture disc failed. An engineering evaluation was performed and data readings were taken. It was then postulated that the new failure was caused by water hammer in the pipe. For this reason, the design team at WRPS was charged with creating a model to simulate the events that took place and discern if water hammer was the cause of the failure. The conditions which were present at the time of the pressure test were simulated along with other scenarios which were requested by WRPS management. AFT Impulse™, a software package which is designed for modeling and analyzing water hammer, was used. All of the drawings for the various sections of the pipeline were obtained and various details were taken from them. These include the elevations at multiple points, pipe lengths, pipe elements, Cv values for valves, and k factors. All of these factors were input into the program. Appendix A illustrates the AFT Impulse™ model.

In order to better understand the event which took place and the analysis of it, it is necessary to have an understanding of what water hammer is. In general, the phenomenon is actually called "fluid hammer," due to the fact that it can happen with any fluid, not just water. In general, it takes place when a fluid that is in motion is suddenly forced to change direction or stop altogether. Even though a valve downstream of the flow is shut, the fluid will continue to move forward with some velocity. If the flow is suddenly interrupted, this momentum is converted into pressure. The higher the velocity of the flow, the larger the momentum it will have (momentum is the product of mass and the velocity squared). As a result, the pressure will be higher if the velocity is higher. This will lead to a sudden surge in pressure and a pressure wave will be formed. The wave will then travel in the opposite direction and if it hits something else it may reflect back to the starting point. The velocity at which it reflects back and forth can be as high as 1440 meters per second in some cases. This wave can literally hammer fittings in the pipeline and create considerable damage ranging from burst seals to ruptured pipe. Many people are unknowingly acquainted with fluid hammer in their homes. For example, when a shower is shut off and a hammering or banging noise is heard from the piping in the wall, the cause of the sound is water hammer. This sound is also the source of the phenomenon's name.

There are other issues associated with water hammer. One such issue is what takes place with the water which has already moved past the valve. This water will continue to move forward and, as it does, it can create a vacuum between it and the valve. When the pressure wave on the other side of the valve reflects and hits the valve, the vacuum downstream of it will aid in blowing out the valve. There are many ways of controlling the occurrence of fluid hammer. Pressure loss caused by the pipe walls will help to stop the water hammer; however, it is not enough in most cases. Increasing the pipe diameter will help to alleviate the problem as it allows more room for the pressure to dissipate. Another measure is to reduce the speed at which valves open and close. The best measure is to eliminate the problem altogether by lowering the fluid velocity/supply pressure.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2010, a DOE Fellow intern (Mr. Jose Matos) spent 10 weeks doing a summer internship at the DOE Hanford site in Washington State. He worked for Washington River Protection Solutions under the supervision of Eric Nelson. Jose's initial role was to read and revise "calcs" or calculation documents. This task consisted of carefully going over calculation documents performed by outside contractors and verifying their engineering assumptions, calculation approach, mathematical formulation, and numerical results. Once revised, Jose filled out comment forms and returned them to the contractors in order to have them fix any errors found in the documents. Upon completion of various calculations, Jose was given a new role, to assist the in-house design team in the modeling and analysis of a possible water hammer event which was believed to have taken place in a transfer line. Jose assisted in collecting data from various drawings of the pipeline sections and in putting together a calculation document.

3. INPUTS AND ASSUMPTIONS

3.1 Input Data

The following data were used in the modeling and analysis:

1. Elevation, fittings, and pipe lengths (see Appendix B).
2. Purex Connector to nozzle interfaces modeled as 90° mitre bends.
3. Properties used are for water at 100 psig, 70°F from 1997 ASME Steam/Water tables which are built into Impulse.
4. Valve lineup and cycle logic.
5. HV-CA1-2A cycle time conservatively modeled at fastest cycle time of 5 seconds.
6. Pressure safety valves of the raw water (RW) system have a relief pressure of 150 psig
7. The discharge piping to the sump from the PSE-PB2-1 rupture disc does not interface directly with liquid in the sump and is free flowing.
8. P-B-2 pump is modeled as being offline but allowing flow through, as this was the condition present in the actual scenario.
9. The Cv curves used are linear which is a conservative measure.
10. Assuming runaway Hanford Water distribution pumps, the maximum worst case RW system supply pressure is 274 psig.
11. The RW supply pressures tested are 100, 150, and 274 psig. This supply pressure is modeled as a reservoir capable of providing infinite flow at a set pressure. The model uses a flow restriction between the supply pressure and the CA1-2 valve. This is a K based restriction set such that a 100 psig pressure at the inlet results in 100 gpm through the flush piping. This K based restriction was left as is for all scenarios tested.

3.2 Assumptions

The following assumptions were used in the modeling and analysis:

1. RW supply pressure measured 5 ft upstream of CA1-2 in the 100 and 150 psig scenarios. In reality, the RW source is hundreds of feet away and as such, it can be said that the above measure is conservative.
2. For the 274 psig trial, the RW supply pressure is taken as being 50 ft upstream of the CA1-2 valve. The extra length as compared to the other scenarios is to account for an elevation change. However, as previously stated, the water source is really hundreds of feet away so this measure is still conservative.

4. RESULTS AND ANALYSIS

This analysis is limited to the SL-167 pipeline configuration as it existed on April 29, 2010. There have been several modifications performed on the pipeline before this date and many more are possible in the future. It is beyond the scope of this analysis to test all of these configurations. As such, only the various conditions and cases present on the date of the pressure test have been modeled.

Although 100, 150 and 274 psig raw water supply pressures have been tested, in reality 100 psig is the normal operating pressure and there are two pressure control valves set to maintain this pressure. These two valves are the PCV-RW-2A and PCV-RW-1 valves. There are also pressure relief valves in the system which are set to relieve pressure at 150 psig. This means that if the pressure control valves fail while the pressure relief valves remain in normal operation, the 150 psig scenario would be possible. This is the reason 150 psig has been included. Should all of the components regulating the raw water supply fail, the pressure could reach 274 psig, making that scenario possible. There are extra cases tested in the model in which the rupture disc is disabled until the CA1-2A valve is cycled. This was done in order to test what could have happened if the rupture disc did not fail due to the initial transient pressure variation when the valve was initially cycled.

By varying valve flow coefficients as a function of time, AFT Impulse™ can simulate a valve opening and closing. When the valve is closed, the Cv has a value of 0 and this is increased to the Cv value of the fully open valve. It was not possible to obtain the Cv values relative to the opening percentage for the CA1-2A and CA1-2 valves. The manufacturer makes similar ball valves which have a parabolic flow curve. Using this curve will result in lower transient pressures than using a linear relationship. In an effort to be conservative in all of the calculations of this analysis, linear flow curves have been used.

There are several components and fittings between the PCV-RW-1 and PCV-RW-2A valves which result in unrecoverable losses between them and the CA1-2A and CA1-2 valves. Under a static condition in which there is neither flow nor resulting pressure drop, the pressure in the piping will increase. Once the valve is cycled and flow is established, the pressure drops take effect and the overall pressure is much lower. The flow rate that was observed in the pipeline is 80 gpm. A K value of 100 has been added to P13 such that the flow rate is 100 gpm with 100 psig pressure. This larger flow rate is another measure taken in order to be conservative. It creates higher fluid velocity and transient pressures and the results are closer to conditions in the actual system as compared to no unrecoverable loss and 100 psig water supply through a short pipe.

The maximum transient pressure obtained from the analysis happened in the case of the 150 psig water supply and was 602.2 psig. This pressure happens when the valves complete the flush cycle and are returned to blocking the flow. V-214 did not close until 10 seconds after the maximum pressure took place. Once V-214 closes, HV-CA1-2A cycles from blocking to flushing and the pressure test begins. As it reaches the flushing configuration, the level in the pump sump room is raised because the bursting of the rupture disc has established a flow path from the raw water supply to the sump room. Table 1 provides a summary of the results of the analysis.

Table 1. Results of Analysis

Scenario	Raw Water Pressure (psig)	Maximum Trans. Pressure (psig)	Location of Max Trans. Pressure in Model	Maximum Pressure in P19(psig)	Flow Rate (GPM)
Base	100	575.7	Pipe 15	421.7	103.3
Delayed Rupture Disc	100	296.3	Pipe 19	296.3	103.3
Varied RW Supply Pressure	150	602.2	Pipe 17	461.2	125.6
Delayed Rupture Disc	150	447.8	Pipe 19	447.8	125.6
Varied RW Supply Pressure	274	600.3	Pipe 17	420	161.8
Delayed Rupture Disc	274	420.9	Pipe 19	421	161.8

These results are about as expected. The SL-167 pipeline is under constant review and there are several modifications planned for it. Overall, the results indicate that almost regardless of the scenario, the pipeline will experience pressures that are above what the pipe is rated for. The only exception is when the supply pressure is within parameters (stays at 100 psig) and the rupture disc failure is delayed. The conditions of this scenario can be recreated by using a pressure relief valve in place of the rupture disc, setting it such that it relieves pressure in the same way as the disc when it delays. It should be noted that high flow rates contribute to water hammer issues and that the flow rates experienced were all above 100 gpm. It should also be noted that AFT Impulse™ takes into account transient cavitation so the effects of bubble formation and collapse are accounted for in the results. The AFT Impulse™ program provided a considerable amount of extra data for the conditions that are present in the pipeline during these pressure transients. This includes fluid pressures, flow rates, temperatures, and densities. This information is included in Appendix C. Appendix D provides the information obtained from the vendors.

Figure 1 demonstrates the type of pressure stagnation that was produced in the pipeline over time. As the figure shows, there was a sudden, large spike in pressure followed by several smaller pressure spikes- generally indicative of a water hammer event. The figure presented is for the 100 psig scenarios; however, it is representative of the pressure vs. time relationship throughout all of the cases tested.

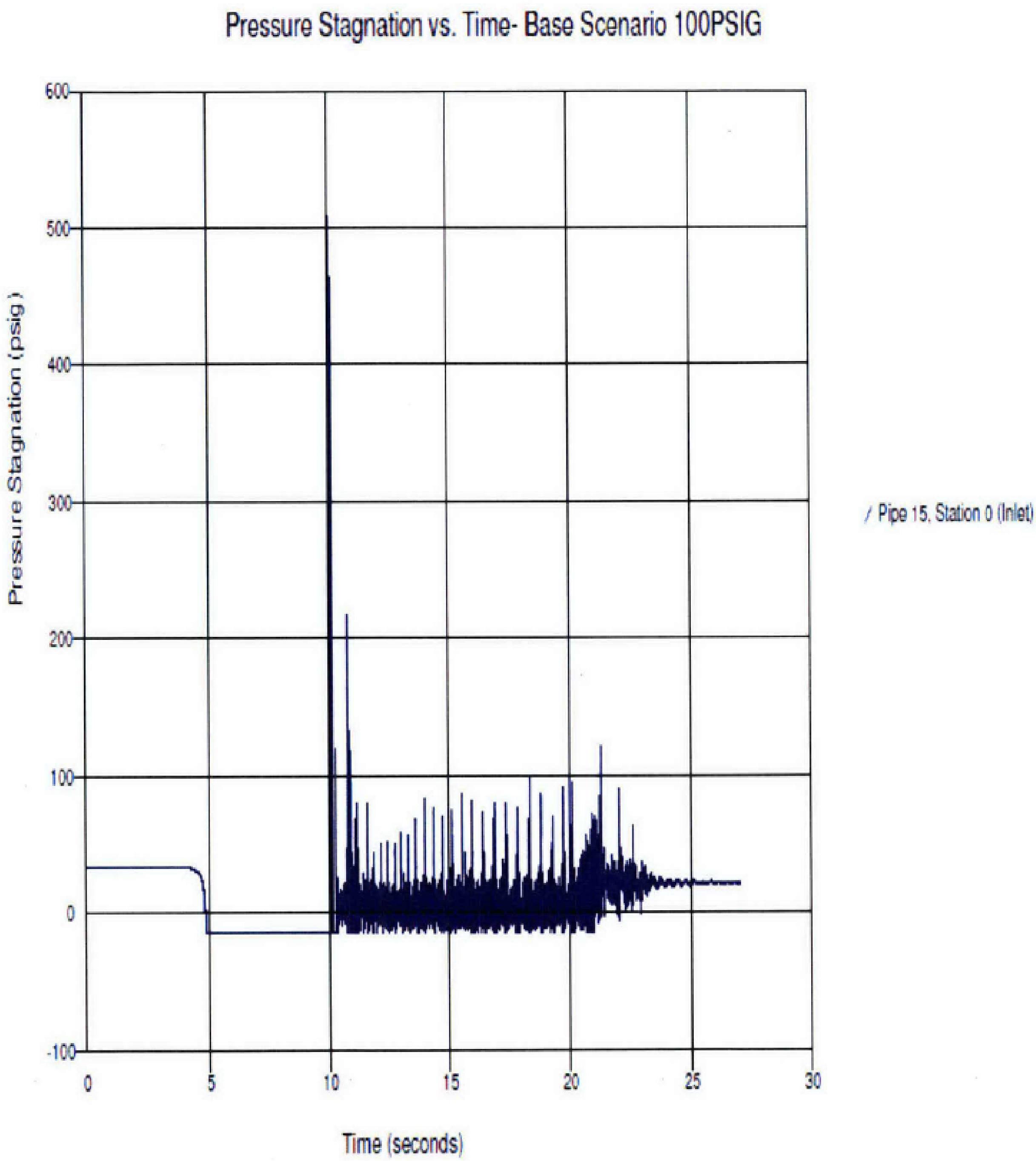

Figure 1. Pressure Stagnation vs. Time.

5. CONCLUSION

The maximum transient pressure experienced by the system was 602.2 psig in the case of 150 psig supply pressure. Even considering the other cases, all of the maximum transient pressures experienced by the system were considerably higher than the burst pressure of the PSE-PB2-1 rupture disc (the disc was set to go at 240 psig). Despite these results, there is still not enough evidence to prove that the rupture disc failed when the CA1-2A valve changed from flushing to blocking while V-214 was open or vice versa. The pipes are all rated to 400 psig, and realistically, it would take a much higher pressure to cause the pipes themselves to burst. However, it is safe to assume that various components and fittings attached to the pipeline may have been affected by the high transient pressures generated by water hammer in the pipeline on the day of the pressure test.

Once the analysis was completed, the management at WRPS sought a second opinion in order to verify beyond doubt that these results were accurate. Dominion Engineering, Inc, a company with experience in modeling and analysis for water hammer, was contracted to perform their own analysis. They were provided with the AFT Impulse™ model, the calculation document put together by the in-house design team at WRPS, as well as all of the inputs, pipe design, and readouts from the pipeline instrumentation. Upon completion of their analysis, their findings concurred with those of the WRPS design team.

In order to avoid future trouble with the pipeline, it will be necessary to modify the configuration in order to reduce the pressures generated. One of the measures necessary to improve the pipeline is already underway. This is the replacement of the rupture disc with a pressure relief valve. A pressure relief valve will allow for finer control of pressure spikes in the pipeline. This modification was planned before the pressure test which led to the rupture disc failure; however, modifications to pipelines take some time because several calculations must be performed and approved before it is safe to install. Another measure to avoid this problem is to reduce the speed of the valves in the pipeline or to replace them altogether with slower moving valves. Reducing the flow velocity of the raw water may not be an option at the moment as the pipeline may require certain transfer rates.

6. REFERENCES

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APPENDICES

Appendix A: Model

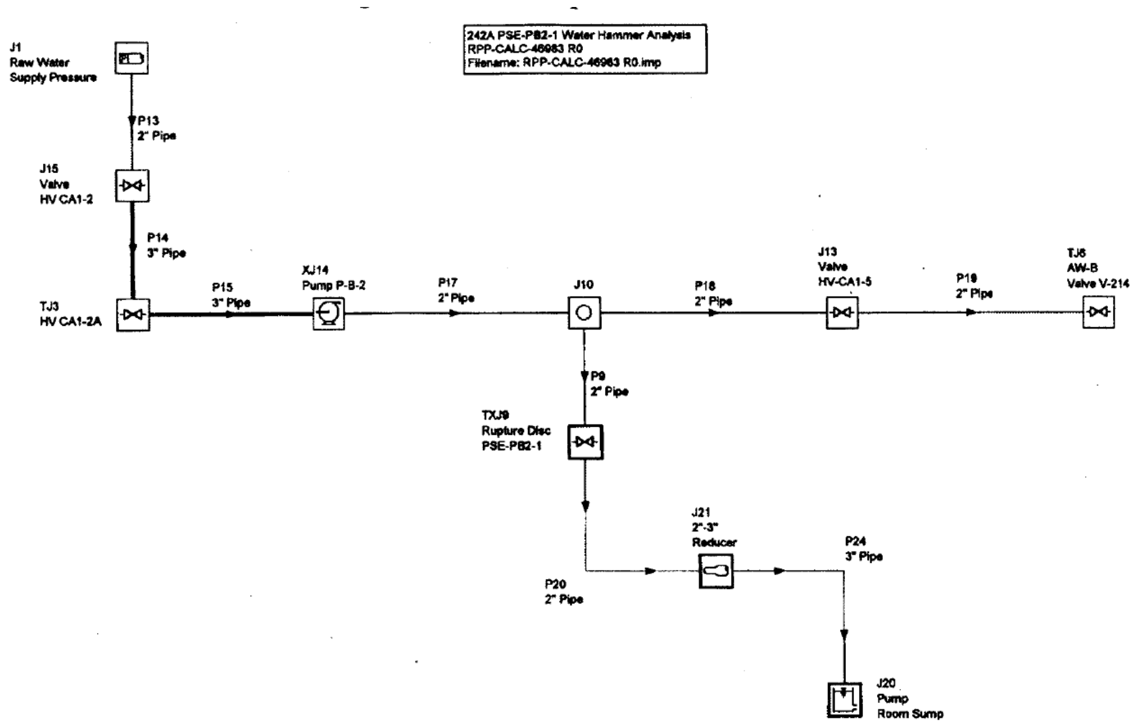


Figure 2. AFT Impulse™ Model

Appendix B: Program Inputs

Table 2. Fittings Located in Pipes

Pipe Number	Fittings
P9	Rupture Disc and T-branch
P13	n/a
P14	3" 90° LR elb(x3), 3" 45° elb(x1)
P15	3"-2" reduction, 2"-3" expansion, Purex Connector 13, 1'-3" radius 90° bend(x1), 90° LR elbow(x1)
P17	1.5"-2" expanding elbow, Purex Connector C, 90° LR elb(x5)
P18	90° LR elbow(x4) 90° SR elbow(x2)
P19	90° LR elbow(x12), Purex Connectors 5,19,R3
P20	90° LR elbow(x3), Purex Connector 21
	Straight pipe, 2"-3" expansion
P24	90° LR elbow(x1), Purex Connector 36
	90° LR elbow(x4),90 1'-3" radius bend(x2)

Table 3. Individual Pipe Lengths

Pipe Number	Notes	Length (ft)
P9	T- branch to Rupture disc	0.5
P13	Assumed length	5
		50
P14	HV-CA1-2 to HV-CA1-2A	3.583
P15	HV-CA1-2A to P-B-2 Pump	6.541
P17	P-B-2 Pump to T-branch	6.167
P18	T-branch to HV-CA1-5	4.0625
P19	HV-CA1-5 to V-214	371.75
P20	PSE-PB2-1 Rupture Disc to Connector 21	4.917
	Connector 21 to 2"-3" reducer	2.583
P24	2"-3" reducer to connector 36	5.083
	Connector 36 to Sump	26.625

Table 4. Elevations

Model Junction	Element	Elevation
J1	Raw Water Supply Pressure	698'-4"/ 662.52'
J15	HV-CA1-2 valve	698'-1"
J3	HV-CA1-2A valve	697'-2"
J14	P-B-2 Pump	693'-10"
J10	T-branch	696'-3"
J9	PSE-PB2-1 Rupture Disc	696'-9"
J18	Connector 21	695'-10"
J21	2"-3" Reducer	694'-10"
J19	Connector 36	692'-4"
J20	Pump Sump Room	675'-8"
J13	HV-CA1-5 valve	696'-9"
J6	V-214 valve	685'-3"

Table 5. Flow Coefficients

Model Junction	Flow Coefficient
HV-CA1-2 valve	Cv=259
HV-CA1-2A valve	Cv=449
V-214 valve	Cv=309
HV-CA1-5 valve	K=1.697
PSE-PB2-1 Rupture Disc	K=5.3

Appendix C: Sample AFT Impulse™ Readouts

100 PSIG Raw Water Supply Pressure

```
Scenario: Base Scenario: 242-A Water Hammer Models
Output File: U:\sitedata\IHDEProj\PROJECTS\200746 (Phase I 242-A_Water
Hammer Analysis)\Final 8-4-10\Impulse Files\RPP-CALC-46983 R0_1.out

Steady-State Execution Time= 0.02 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 4
Number Of Pipes= 9
Number Of Junctions= 10
Matrix Method= Gaussian Elimination

Transient Execution Time= 5:49.32 (349.32 seconds)
Model Start Time= 0 seconds
Model Stop Time= 27 seconds
Time Step Size= 1.11058E-04 seconds
Total Number of Time Steps= 243116
Transient Cavitation Model= Discrete Vapor Cavity Model
Artificial Transient Criteria= 0.5%
Artificial Transient Criteria Minimum Flow= 0 gal/min
Time Step Output Written to File= 2
Psi= 0.5

Pressure/Head Tolerance= 0.00001 relative change
Flow Rate Tolerance= 0.00001 relative change
Flow Relaxation=  (Automatic)
Pressure Relaxation=  (Automatic)

Constant Fluid Property Model
Fluid Database: ASME Steam/Water Tables
Fluid: ASME '97 Water
Temperature= 70 deg. F
Pressure= 100 psig
Max Fluid Temperature Data= 337.8822 deg. F
Min Fluid Temperature Data= 32.00002 deg. F
Density= 62.32087 lbm/ft3
Viscosity= 2.357836 lbm/hr-ft
Bulk Modulus= 318185.4 psia
Vapor Pressure= 0.3633404 psia
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 103.3 gal/min
Total Outflow= 103.3 gal/min

Maximum Static Pressure is 99.34 psig at Pipe 13 Inlet
Minimum Static Pressure is -0.5442 psig at Pipe 19 Outlet
Maximum Transient Pressure is 575.7 psig at Pipe 15 (3" Pipe) Station 0.
Minimum Transient Pressure is -15.49 psig at Pipe 20 (2" Pipe) Station 13.
```

100 PSIG Raw Water Supply Pressure/Delayed Rupture Disc

```
Scenario: Base Scenario: 242-A Water Hammer Models/Delayed Rupture Disc
(100 PSIG)
Output File: U:\sitedata\IHDEProj\PROJECTS\200746 (Phase I 242-A_Water
Hammer Analysis)\Final 8-4-10\Impulse Files\RPP-CALC-46983 R0_2.out

Steady-State Execution Time= 0.01 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 4
Number Of Pipes= 9
Number Of Junctions= 10
Matrix Method= Gaussian Elimination

Transient Execution Time= 5:24.97 (324.97 seconds)
Model Start Time= 0 seconds
Model Stop Time= 27 seconds
Time Step Size= 1.11058E-04 seconds
Total Number of Time Steps= 234112
Transient Cavitation Model= Discrete Vapor Cavity Model
Artificial Transient Criteria= 0.5%
Artificial Transient Criteria Minimum Flow= 0 gal/min
Time Step Output Written to File= 2
Psi= 0.5

Pressure/Head Tolerance= 0.00001 relative change
Flow Rate Tolerance= 0.00001 relative change
Flow Relaxation=  (Automatic)
Pressure Relaxation=  (Automatic)

Constant Fluid Property Model
Fluid Database: ASME Steam/Water Tables
Fluid: ASME '97 Water
Temperature= 70 deg. F
Pressure= 100 psig
Max Fluid Temperature Data= 337.8822 deg. F
Min Fluid Temperature Data= 32.00002 deg. F
Density= 62.32087 lbm/ft3
Viscosity= 2.357836 lbm/hr-ft
Bulk Modulus= 318185.4 psia
Vapor Pressure= 0.3633404 psia
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 103.3 gal/min
Total Outflow= 103.3 gal/min

Maximum Static Pressure is 99.34 psig at Pipe 13 Inlet
Minimum Static Pressure is -0.5442 psig at Pipe 19 Outlet
Maximum Transient Pressure is 296.3 psig at Pipe 19 (2" Pipe) Station 420.
Minimum Transient Pressure is -15.18 psig at Pipe 20 (2" Pipe) Station 13.
```

150 PSIG Raw Water Supply Pressure (Worst Case Scenario)

```
Steady-State Execution Time= 0.02 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 4
Number Of Pipes= 9
Number Of Junctions= 10
Matrix Method= Gaussian Elimination

Transient Execution Time= 5:44.61 (344.61 seconds)
Model Start Time= 0 seconds
Model Stop Time= 27 seconds
Time Step Size= 1.11058E-04 seconds
Total Number of Time Steps= 234112
Transient Cavitation Model= Discrete Vapor Cavity Model
Artificial Transient Criteria= 0.5%
Artificial Transient Criteria Minimum Flow= 0 gal/min
Time Step Output Written to File= 2
Psi= 0.5

Pressure/Head Tolerance= 0.00001 relative change
Flow Rate Tolerance= 0.00001 relative change
Flow Relaxation=  (Automatic)
Pressure Relaxation=  (Automatic)

Constant Fluid Property Model
Fluid Database: ASME Steam/Water Tables
Fluid: ASME '97 Water
Temperature= 70 deg. F
Pressure= 100 psig
Max Fluid Temperature Data= 337.8822 deg. F
Min Fluid Temperature Data= 32.00002 deg. F
Density= 62.32087 lbm/ft3
Viscosity= 2.357836 lbm/hr-ft
Bulk Modulus= 318185.4 psia
Vapor Pressure= 0.3633404 psia
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 125.6 gal/min
Total Outflow= 125.6 gal/min

Maximum Static Pressure is 149.0 psig at Pipe 13 Inlet
Minimum Static Pressure is -0.8051 psig at Pipe 19 Outlet
Maximum Transient Pressure is 602.2 psig at Pipe 17 (2" Pipe) Station 2.
Minimum Transient Pressure is -15.95 psig at Pipe 20 (2" Pipe) Station 11.
```

150 PSIG Raw Water Supply Pressure/Delayed Rupture Disc

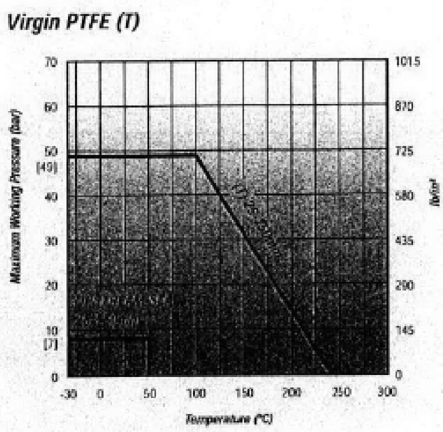
```
Scenario: Base Scenario: 242-A Water Hammer Models/150 PSIG Raw Water
Supply Pressure/Delayed Rupture Disc (150 PSIG)
Output File: U:\sitedata\IHDEProj\PROJECTS\200746 (Phase I 242-A_Water
Hammer Analysis)\Final 8-4-10\Impulse Files\RPP-CALC-46983 R0_4.out

Steady-State Execution Time= 0.66 seconds
Total Number Of Head/Pressure Iterations= 0
Total Number Of Flow Iterations= 4
Number Of Pipes= 9
Number Of Junctions= 10
Matrix Method= Gaussian Elimination

Transient Execution Time= 5:43.95 (343.95 seconds)
Model Start Time= 0 seconds
Model Stop Time= 27 seconds
Time Step Size= 1.11058E-04 seconds
Total Number of Time Steps= 243116
Transient Cavitation Model= Discrete Vapor Cavity Model
Artificial Transient Criteria= 0.5%
Artificial Transient Criteria Minimum Flow= 0 gal/min
Time Step Output Written to File= 2
Psi= 0.5

Pressure/Head Tolerance= 0.00001 relative change
Flow Rate Tolerance= 0.00001 relative change
Flow Relaxation=  (Automatic)
Pressure Relaxation=  (Automatic)

Constant Fluid Property Model
Fluid Database: ASME Steam/Water Tables
Fluid: ASME '97 Water
Temperature= 70 deg. F
Pressure= 100 psig
Max Fluid Temperature Data= 337.8822 deg. F
Min Fluid Temperature Data= 32.00002 deg. F
Density= 62.32087 lbm/ft3
Viscosity= 2.357836 lbm/hr-ft
Bulk Modulus= 318185.4 psia
Vapor Pressure= 0.3633404 psia
Viscosity Model= Newtonian

Atmospheric Pressure= 1 atm
Gravitational Acceleration= 1 g
Turbulent Flow Above Reynolds Number= 4000
Laminar Flow Below Reynolds Number= 2300

Total Inflow= 125.6 gal/min
Total Outflow= 125.6 gal/min

Maximum Static Pressure is 149.0 psig at Pipe 13 Inlet
Minimum Static Pressure is -0.8051 psig at Pipe 19 Outlet
Maximum Transient Pressure is 447.8 psig at Pipe 19 (2" Pipe) Station 732.
Minimum Transient Pressure is -16.01 psig at Pipe 9 (2" Pipe) Station 0.
```

Appendix D: Vendor Information

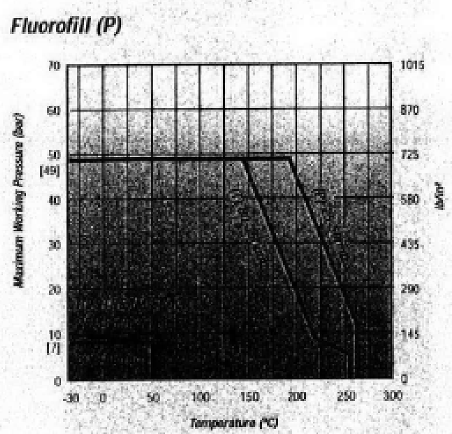
Many of the values, such as flow coefficients, for the valves were made available to Hanford engineers at the time they were installed and were available from the Hanford database at the time of the analysis. Others had to be taken from information on the vendor websites. They have been included here for traceability.

Pressure Temperature Ratings

Virgin PTFE (T)



Fluorofill (P)



Notes

1. Both 90° and 180° can be actuated pneumatically or electrically.
2. Alternative seat/seal materials are available.
3. Installation, Operating and Maintenance Instructions are available on request.
4. Some flanges have tapped bolt holes.
5. If required, dissimilar flange materials to body can be supplied.
6. Non preferred face to face dimensions can be accommodated.
7. All sizes shown are for full bore B18/19 Series valves. For reduced bore use one size down, i.e. 1" reduced bore use ¾" dimensions.
8. The bottom port of ½" to 2" B19 Series is a fabricated (welded) construction.

Standards of Compliance

Testing	Valves are tested to the requirements of BS 6755 Part 1 in the downstream sealing mode only and are firesafe to the external leakage requirement only of BS 6755 Part 2
Face to Face Dimensions (of 2 opposed flanges on a 3-way valve) (See Note 6)	BS EN 558 - Table [illegible] ISO 5752 - Table [illegible] ANSI B16.10 - [illegible] API 6D - [illegible] DIN 3202 - [illegible]
Flange Dimensions (See Note 4)	BS EN 1759 Class 150/Class 300 BS EN 1092 PN 10/16/25/40

NOTE:

Stainless steel valves are CE Marked in accordance with the Pressure Equipment Directive 97/23/EC conformity assessment Module H and are classified in Category III (not end of line duty).

Carbon steel valves are classified as SEP (Sound Engineering Practice) and, in accordance with the Pressure Equipment Directive, are not CE Marked. These valves may be used within the limitations defined in Annex II of the Directive.

Flow Coefficients

Valve Size (Full Bore)		Straight Through Flow		90° Branch		Double 'L'	
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
25	1	44	38	25	22	16	14
40	1½	104	90	60	52	38	33
50	2	194	169	112	97	71	62
80	3	449	390	259	196	160	139
100	4	820	713	474	412	280	243
150	6	1965	1708	1135	986	658	571

Cv – Flow in US GPM Pressure – psi
Kv – Flow in M³/hr Pressure – bar

FLOWSERVE

Flow Control

Worcester Controls

Torque Output Series 0539 (in-lb/N m)
Two-Spring-Return Actuator

	Operating Pressure psi (Bar)					
	50 (3.4)		60 (4.1)		70 (4.8)	
	Start	End	Start	End	Start	End
Air	28 (3.2)	16 (1.8)	35 (4.3)	30 (3.4)	50 (5.7)	41 (4.6)
Spring	42 (4.7)	32 (3.6)	42 (4.7)	32 (3.6)	42 (4.7)	32 (3.6)

Torque Output Series 0539 (in-lb/N m)
Four-Spring-Return Actuator

	Operating Pressure psi (Bar)	
	80 (5.4)	
	Start	End
Air	45 (5.1)	30 (3.4)
Spring	53 (6.0)	41 (4.6)

Torque Output Series 0539 (in-lb/N m)
Double-Acting Actuator

Operating Pressure psi (Bar)								
30 (2.0)	40 (2.7)	50 (3.4)	60 (4.1)	70 (4.8)	80 (5.4)	90 (6.1)	100 (6.8)	120 (8.2)
33.6 (3.8)	48.6 (5.5)	59.7 (6.8)	73.5 (8.2)	86.3 (9.8)	97.4 (11.0)	106 (12.0)	126 (14.2)	148 (16.7)

Engineering Data

Air Flow Requirements

Actuator Size	Under 4 ft. Run	Over 4 ft. Run
0539, 1039, 1539, 2039, 2539	¼" Tubing	¼" Tubing
3039, 3339, 3539, 4039, 4239, 4539, 5039	¼" Tubing	⅜" Tubing

Actuator Weights*

Actuator Model	Double-Acting lb. (kg)	Spring-Return lb. (kg)
0539	1.7 (.77)	2.0 (.90)
1039	3 (1.3)	3.5 (1.6)
1539	6 (2.7)	7 (3.1)
2039	10 (4.5)	12 (5.5)
2539	16.25 (4.5)	18.5 (8.4)
3039	24.6 (11)	27 (12)
3339	50.6 (23)	54.5 (24.7)
3539	58 (26)	65 (30)
4039	70 (32)	80 (36)
4239	158 (67)	192 (83)
4539	213 (97)	253 (115)
5039	304 (138)	355 (161)

*without solenoid

Stroke Time (seconds)

	Minimum (Unloaded)		
Model No.	D/A Actuator	SR Actuator	With Max.* Speed Control
0539	Less than 1	Less than 1	10
1039	Less than 1	Less than 1	10
1539	Less than 1	1	15
2039	1	1-2	15
2539	2-3	2-3	18
3039	3-4	3-4	20
3339	4-5	7-8	25
3539	4-5	8-9	25
4039	5-6	9-10	30
4239	10-11	11-12	36
4539	10-12	11-13	40
5039	12-14	13-15	60

*Average times under 50% load conditions, 80 psi (with standard solenoid).

NOTE:
These figures are meant as an indication of obtainable speeds only. For more precise figures for any particular application, contact your Flowserve representative. Faster speeds are obtainable, if required, by using additional control equipment.

Speed control with spring-return actuators only available on exhaust air (spring stroke).

Operating Conditions

Pressure Range:	30–120 psi Double-Acting 40–120 psi All Spring-Return Versions* *Standard spring-return units require 80 psi minimum. Reduced-pressure versions are available.
Media:	Air or non-corrosive gas.
Temperature Range:	0° to 212°F (-18° to 100°C) actuator only To 100°F (38°C) continuous; actuator with G.P. solenoid To 175°F (79°C) continuous; actuator with Watertight Type 4, 4x or Hazardous Locations Type 4, 4x, 7 & 9 solenoid High-temperature option to 250°F continuous, to 300°F intermittent (without solenoid) Low temperature option to -40°F (without solenoid)
Rotation:	Actuators rotate in counterclockwise direction when the outer air connection is pressurized.
Movement: Sizes 10–35; Sizes 40–50:	90° with up to 2° each direction 90° with up to 2° overrun each end
Supply Air:	The Series 39 Actuator is factory lubricated. For optimum performance, standard filtered and lubricated air is recommended.

Series 39 Actuator Free Internal Volume

	Size	5	10	15	20	25	30	33	35	40	42	45	50
Open	Cubic Inches (in³)	3.0	10.4	21.4	42.1	74.4	113.5	206.9	239.8	410.7	732.3	824.4	1456.6
	Litres	0.05	.17	.35	.69	1.22	1.86	3.39	3.93	6.73	12.00	13.51	23.87
Close (DA only)	Cubic Inches (in³)	3.0	13.4	23.8	45.2	79.9	125.1	292.3	338.1	499.8	847.6	1220.5	1861.2
	Litres	0.05	0.22	0.39	0.74	1.31	2.05	4.79	5.54	8.19	13.89	20.00	30.50

Actuator air consumption is calculated using the free internal volume and supply pressure in the following equation.

$$\textit{Air Consumption per Stroke} = \frac{V}{1728}\left(\frac{\textit{Supply Pressure} + 14.7}{14.7}\right)$$

FLOWSERVE

Flow Control

Worcester Controls

How to Order

10	F	39	S	W	Z	120A	
Actuator Sizes	**Special Services**	**Series**	**Operating Mode**	**Solenoid**	**Limit Switches**	**Solenoid Voltage**	**‡Options**
05 10 15 20 25 30 33 35 40 42 45 50	**Blank** - None - (Male Shaft End) **F** - Female Shaft End (0539 Only) **9** - Fail-Open Mount **H** - High Temperature (N and SN models only) **E** - End-Mounted Limit Switch Module **R** - Rotary Switch† **T** - Travel Stops† (Sizes 10–30 only) **L** - Low Temperature**	39	**Blank** - Double-Acting **S** - Spring-Return*	**Blank** - General Purpose Solenoid (TYPE 1) **W** - Watertight Solenoid (TYPE 4) **X** - Hazardous Locations Solenoid (TYPE 4, 4x, 7 & 9) **N** - No Solenoid (No Block)	**Top-Mounted** **M1** - General Purpose Switch **M2** - Two General Purpose Switches **W1** - Watertight Switch **W2** - Two Watertight Switches **X1** - Hazardous Locations Switch **X2** - Two Hazardous Location Switches **Rotary** - (must specify "R" in Special Services Column)† **M1** - 1 SPDT **M2** - 2 SPDT **D1** - 1 DPDT **D2** - 2 DPDT **End-Mounted** - (must specify "E" in Special Service Column)† **Z** - Watertight/Hazardous Locations, SPDT Switches **ZD** - Watertight/Hazardous Locations, DPDT Switches **Z1** - Watertight/Hazardous Locations, 2-wire AC Proximity Switches **Z3** - Watertight/Hazardous Locations, 3-wire DC Proximity Switches	**12D** - 12 DC **24D** - 24 DC **24A** - 24/60 AC **120A** - 120/60 AC **240A** - 240/60 AC	**V-54** - S.S. Springs (Sizes 10–30 only) **V-55** - Rebreather Gasket **V-64** - Namur Solenoid End Cap

Code depicts Series 39 Spring-Return Actuator with watertight solenoid and watertight/hazardous locations end-mounted limit switches.

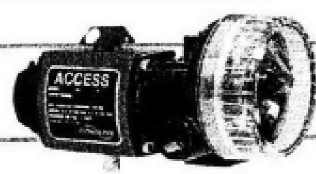
† Not available on Series 0539.

Due to continuous development of our product range, we reserve the right to alter the product specifications contained in this brochure as required.

***NOTE:** Specify air supply for spring-return actuators. Place appropriate code from below after Solenoid voltage when ordering.

4 - Prepared for 40 psi air supply
5 - " 50 "
6 - " 60 "
7 - " 70 "
Blank " 80 "

****NOTE:** Must have N (no solenoid) in Solenoid option column.



To Order ACCESS combined pneumatic actuator, limit switches and solenoid, refer to the ACCESS Brochure.

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(Part PB 302)

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