# 1. APPLICATION 1: SURGE ANALYSIS IN PRODUCT EXPORT LINE FROM A PETROCHEMICAL PLANT TO A JETTY

## 1.1 The Problem

In our first application we consider an engineering company that had been contracted to design the product export pipeline from Product Storage Tanks in a petrochemical plant to a Jetty into loading tankers. The environmental implications were of major concern in the design because leakage of the product into the sea could have serious consequences. An important aspect of the design was ensuring that pressure surges arising from the closure of valves would not cause damage to the pipework resulting in product spillage. The design of the section under consideration is sketched below.

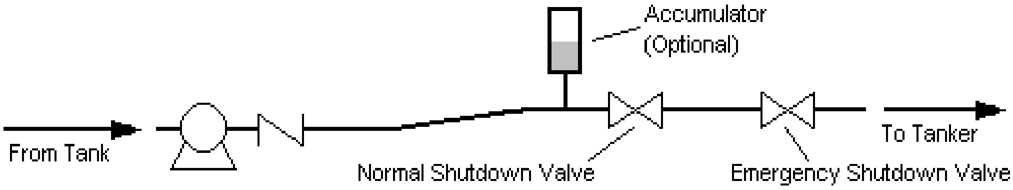


Figure 1-1 Sketch Of The Engineer's Problem

This example illustrates not only how easy it is to predict pressure surges using PIPENET Transient Module, but also how quickly one can appraise a proposed solution to the problem. Most of the techniques used in this simple case are also applicable when solving other problems with PIPENET Transient Module. As this is the first example, the methods used here are discussed in some detail.

The objectives of the study are the following:

- To establish if the pressure surges experienced by the existing valves due to valve closures are below the allowable limit of 25.5 bar G.
- To investigate the effect of an acumulator in reducing surge pressure.

### 1.1.1 The Scenarios

Two basic scenarios are considered:

#### 1.1.1.1 Planned Shutdown

This is an everyday occurrence effected by the closure of shutdown valve HV-5002 by a local manual switch or from the control room. In this scenario a number of cases are considered:

- Two stage valve closure type 1 without an accumulator
- Two stage valve closure type 1 with an accumulator
- Two stage valve closure type 2 without an accumulator
- Two stage valve closure type 2 with an accumulator
- Single stage valve closure without an accumulator

- Single stage valve closure with an accumulator

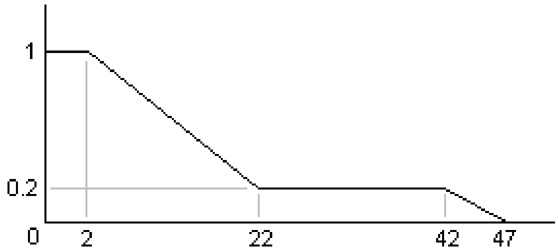
### 1.1.1.2 Emergency Shutdown

This is an infrequent occurrence that takes place if the shutdown valve HV-5002 fails to close, when the hydraulically operated ERC (Emergency Release Connection) comes into effect.

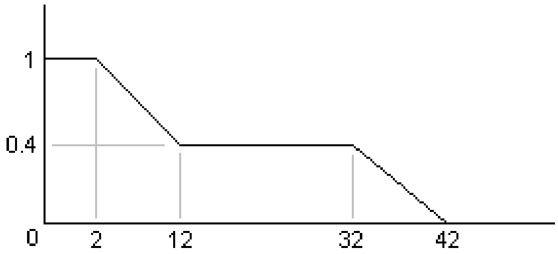
- Single stage closure of ERC valve without an accumulator
- Single stage closure of ERC valve with an accumulator

## 1.1.2 The valve closure patterns

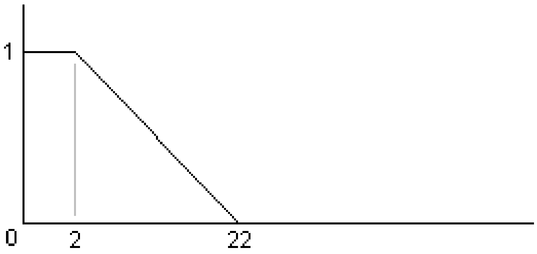
### 1.1.2.1 Two stage valve closure type 1 (HV-5002):



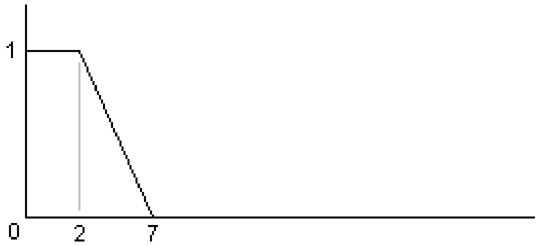
### 1.1.2.2 Two stage valve closure type 2 (HV-5002):



### 1.1.2.3 Single stage closure of valve HV-5002:



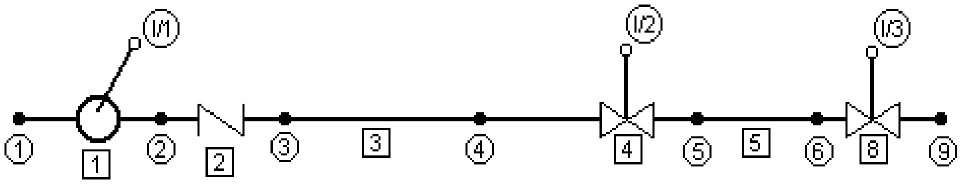
### 1.1.2.4 Single stage closure of ERC valve:



## 1.2 The Schematic Diagram

The first step is to draw schematic diagrams representing the network in question:

Without Accumulator:



With Accumulator:

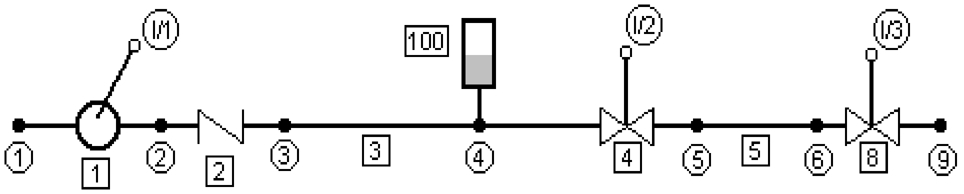


Figure 1-2 Schematics Of The Networks

At every junction between components or pipes, there is a "flow node" (encircled in the diagrams). Every pump and valve in any network has a single "information node" associated with it (labelled I/1, I/2 or I/3) which will be used to tell PIPENET how the device is to operate during the simulation. Every item in the network and every node must be labelled. The pump includes a non-return valve to protect it from flow reversal and so this is inserted between the pump and the first pipe.

## 1.3 Summary of Data Used

When approaching a new problem, it is useful to start by collating all of the required data for each of the components. In this section we will gather and enter all the information that PIPENET needs to perform the simulation.

The information entered is stored in four files: the Network Data File (or DAT file), the Pipe Schedule File (or PDF), the Pump Library (PLB) and the Valve Library (VLB). Different applications which use the same pipe schedules, pumps or valves can share the same library files, as the data contained in these files is independent of the application. We shall first set up the setup, then we can enter the supporting libraries, then the network itself.

All the information which is specific to a particular problem is stored in a Network Data File, or DAT file. This file contains general information, such as what sort of fluid is being used and what units are to be used throughout the simulation. The DAT file also includes information on the connectivity of the network; which components are included in the network and how they are connected to other components in the network.

- Pipe Data:

| Size | i.d.,mm | o.d.,mm | Length m | Elevation m | Fittings k-factor |
|---|---|---|---|---|---|
| 250 | 260.35 | 273.05 | 5697.33 | 1.45 | 197 |
| 250 | 260.35 | 273.05 | 150 | 0 | none |

Young's modulus = $29.6 \times 10^6$ psi

Poisson's ratio = 0.292

Pipe roughness = 0.0475mm

- Fluid Properties:

Density = 867 kg/m$^3$

Viscosity = 33.8 Cp

Bulk modulus = 178,400 psi

- Valve Characteristics (HV-5002, ERC Valve):

| Valve Position | $C_v$ (m$^3$/ s, Pa) |
|---|---|
| 0 | 0 |
| 0.1 | $4.058 \times 10^{-6}$ |
| 0.2 | $2.629 \times 10^{-5}$ |
| 0.3 | $6.231 \times 10^{-5}$ |
| 0.4 | $1.094 \times 10^{-4}$ |
| 0.5 | $1.694 \times 10^{-4}$ |
| 0.7 | $3.366 \times 10^{-4}$ |
| 1.0 | $6.854 \times 10^{-4}$ |

- Pump Data:

| Flow Rate (m$^3$/ s) | Pressure/ bar |
|---|---|
| 0 | 12.15 |
| 100 | 11.48 |
| 240 | 10.81 |
| 320 | 9.19 |

## 1.4 Solving the Problem

The data concerning the network can be entered in any order, but a consistent strategy is useful, so that no data is omitted. In this example the menu items are dealt with sequentially.

### 1.4.1 The Init Menu

For the example problem the following information must be entered into PIPENET:

#### 1.4.1.1 The Problem Title

The first item on the **Init** menu is **Title**, which allows the user to define up to four lines of text to describe the problem. This is important as this title information is inserted into the output file, and helps the user to identify one set of results from another. The title for this problem is:

Transient Module
Application Manual
Example 1: Lube Base Oil Tanker Loading Problem
Planned and Emergency Valve closures

#### 1.4.1.2 Units chosen

PIPENET Transient Module allows the user to specify the units used. This is done by selecting **Units** from the **Init** menu. This opens a dialog box which contains a selection of 'radio-buttons' with which the user can select the units he wishes. The following table shows the units chosen for this example.

| Item | Unit |
|---|---|
| Length | m |
| Diameter | mm |
| Pressure | Bar |
| Velocities | m/s |
| Flowrate Type | volume |
| Flowrate | $m^3$/hr |
| Density | kg/$m^3$ |
| Viscosity | Cp |
| Bulk Modulus | psi |
| Volume | l |
| Time | s |
| Force | N |
| Mass | kg |
| Temperature | °C |
| Torque | Nm |
| Inertia | kg.$m^2$ |

(Some of the above units will not be used by the program in this example, but they will still be specified.)

#### 1.4.1.3 Time Controls

The user must specify the length of the simulation, and how frequently to output the results. The simulation will be run for 120 seconds in the network with no accumulator, and for 750 seconds in the network with the accumulator, and the Time Step will be calculated by PIPENET. Clearly a longer simulation time and shorter time steps would be required for more detailed analysis. To enter this information, **Time** should be selected from the **Init** menu, and the start and stop times set as 0 seconds and 120 seconds or 750 seconds, respectively (depending whether an accumulator is present in the network). At this stage, it may not be obvious how long the simulation should last, but as with all variables in PIPENET, if it is found after a simulation that a parameter was wrong it is very easy to change it.

| Accumulator | Start Time (s) | Finish Time (s) |
|---|---|---|
| No | 0 | 120 |
| Yes | 0 | 750 |

### 1.4.1.4 Fluid properties

In order to simulate the system, the following data about the fluid used (in this case Lube base oil, grade 500N) must be given to the program, under **Fluid** on the **Init** menu:

| Quantity | Value |
|---|---|
| Density | 867 kg/m$^3$ |
| Viscosity | 33.8 Cp |
| Temperature | (not used) |
| Bulk Modulus | 1.23 GPa |
| Vapour Pressure | (not used) |

The temperature and vapour pressure are not used in this problem, so their values are irrelevant and left at their default values.

## 1.4.2 The Libraries Menu

### 1.4.2.1 The Pipe Schedule

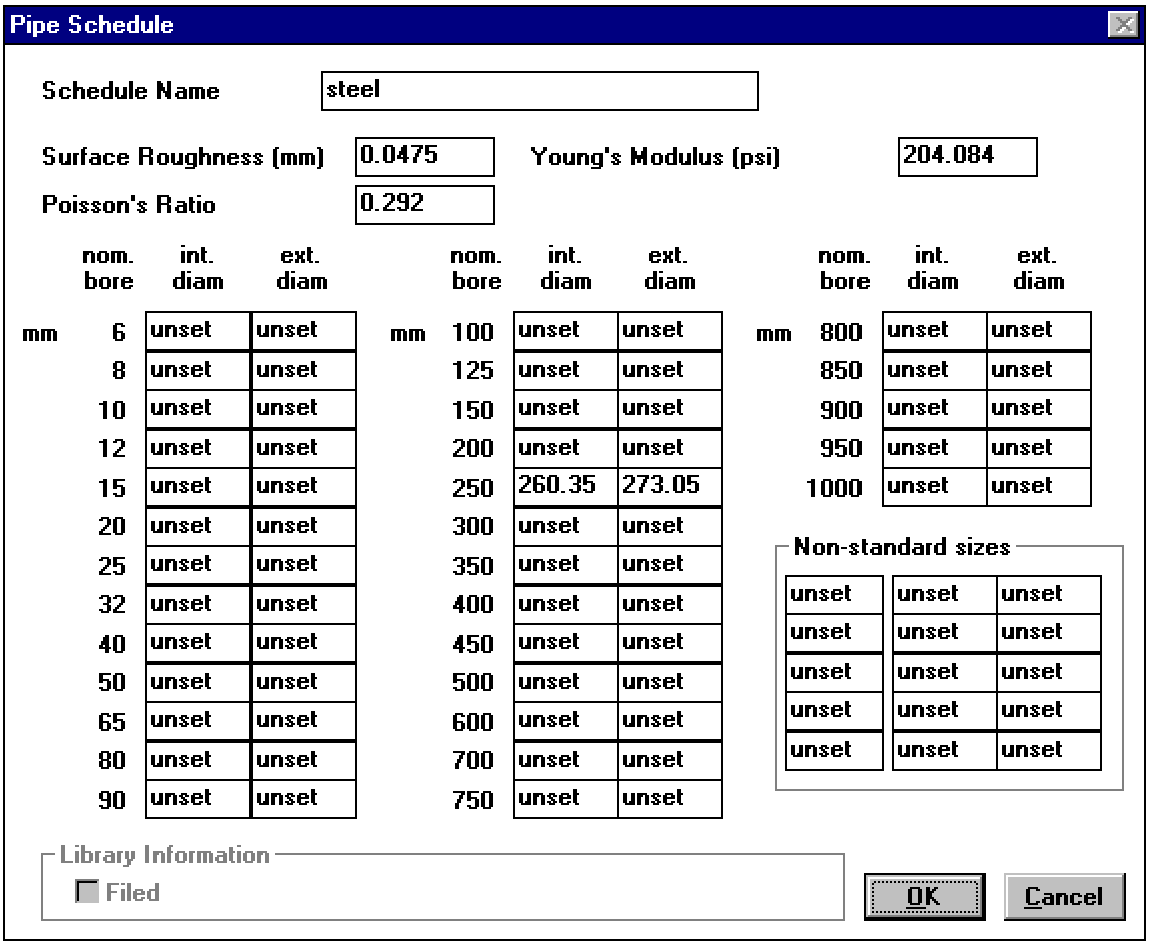
The pipe schedule file, or PDF, is where the data on the pipe schedules and materials is stored. PIPENET requires information about the pipes in order to calculate the wave speed. If the necessary data is not available then the PDF can be omitted and an approximate (constant) value for the wavespeed in the pipes given. In PIPENET, pipes are always referred to by their nominal diameter. As only one size of pipe is used in the refinery, much of the data is redundant for this problem. However, as has already been mentioned, private data files are not usually specific to any one problem, but are normally general to a project. Once this data has been entered into a particular file, it can be used whenever pipes from this pipe schedule are involved. In this case, the Pipe Schedule is as follows:

| Nominal Diameter | Internal Diameter | External Diameter |
|---|---|---|
| 250 | 260.35 | 273.05 |

The pipes are made of steel with the following properties:

| | | |
|---|---|---|
| • Roughness | 0.0475 | mm |
| • Young's modulus | 204.1 | GPa |
| • Poisson's ratio | 0.292 | |

Selecting **Pipe Schedule** from the **Libraries** menu opens a dialog box which allows the data for this particular pipe to be entered. The cursor can be moved between the entry boxes by clicking on the appropriate box with the mouse, or by pressing **TAB**. When all the data has been entered into the dialog box it looks like figure 1-4.



Schedule Name: steel

Surface Roughness (mm): 0.0475

Young's Modulus (psi): 204.084

Poisson's Ratio: 0.292

|  | nom. bore | int. diam | ext. diam |  | nom. bore | int. diam | ext. diam |  | nom. bore | int. diam | ext. diam |
|---|---|---|---|---|---|---|---|---|---|---|---|
| mm | 6 | unset | unset | mm | 100 | unset | unset | mm | 800 | unset | unset |
|  | 8 | unset | unset |  | 125 | unset | unset |  | 850 | unset | unset |
|  | 10 | unset | unset |  | 150 | unset | unset |  | 900 | unset | unset |
|  | 12 | unset | unset |  | 200 | unset | unset |  | 950 | unset | unset |
|  | 15 | unset | unset |  | 250 | 260.35 | 273.05 |  | 1000 | unset | unset |
|  | 20 | unset | unset |  | 300 | unset | unset |  |  |  |  |
|  | 25 | unset | unset |  | 350 | unset | unset |  |  |  |  |
|  | 32 | unset | unset |  | 400 | unset | unset |  |  |  |  |
|  | 40 | unset | unset |  | 450 | unset | unset |  |  |  |  |
|  | 50 | unset | unset |  | 500 | unset | unset |  |  |  |  |
|  | 65 | unset | unset |  | 600 | unset | unset |  |  |  |  |
|  | 80 | unset | unset |  | 700 | unset | unset |  |  |  |  |
|  | 90 | unset | unset |  | 750 | unset | unset |  |  |  |  |

Non-standard sizes

|  |  |  |
|---|---|---|
| unset | unset | unset |
| unset | unset | unset |
| unset | unset | unset |
| unset | unset | unset |
| unset | unset | unset |

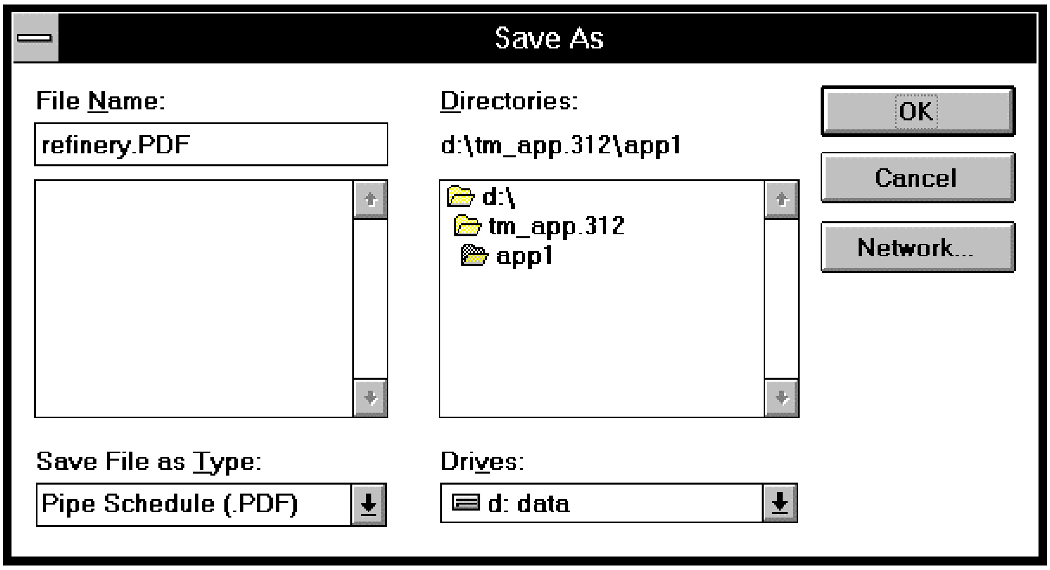
Library Information

☐ Filed

Figure 1-4

Clicking on **OK** accepts this data, and PIPENET checks the data to see if any obvious mistakes have been made. If none is found, the dialog box closes and the name of this pipe schedule is added to the **Pipe Schedules** listbox. This listbox can now be closed by selecting **Close** from the menu, or by double clicking on the system menu.

If desired, the pipe schedule can be saved before continuing data entry. If the user tries to exit PIPENET or to save a network that uses this schedule, PIPENET will issue a reminder that the schedule has not been saved. Selecting **Save As** from the **File** menu opens the **Save As** dialog box. This can be used to save all of the different types of PIPENET file.



File Name: refinery.PDF

Directories: d:\tm_app.312\app1

Save File as Type: Pipe Schedule (.PDF)

Drives: d: data

Figure 1-5 The Save As Dialog Box

The **Pipe Schedule** option enables a Private Data File to be saved. The **Directories** listbox can be used to move to the directory in which the PDF is to be saved. The name refinery.pdf should be entered into the **File Name** box and then **OK** clicked on to save the PDF.

### 1.4.2.2 Valve Characteristics

The pressure/flowrate relationship for a valve which is opened by a fraction *s* can be defined in terms of the flow coefficient $C_v$, where

$$C_v = \frac{Q}{\sqrt{P}}$$

and $Q$ is the (volumetric) flowrate through the valve
$\Delta P$ is the pressure drop across the valve

$C_v$ is generally a function of s.

The pressure/flowrate relationship can also be defined as:

$$\tfrac{1}{2} k\rho Q^2 = s^s A^2 \Delta P$$

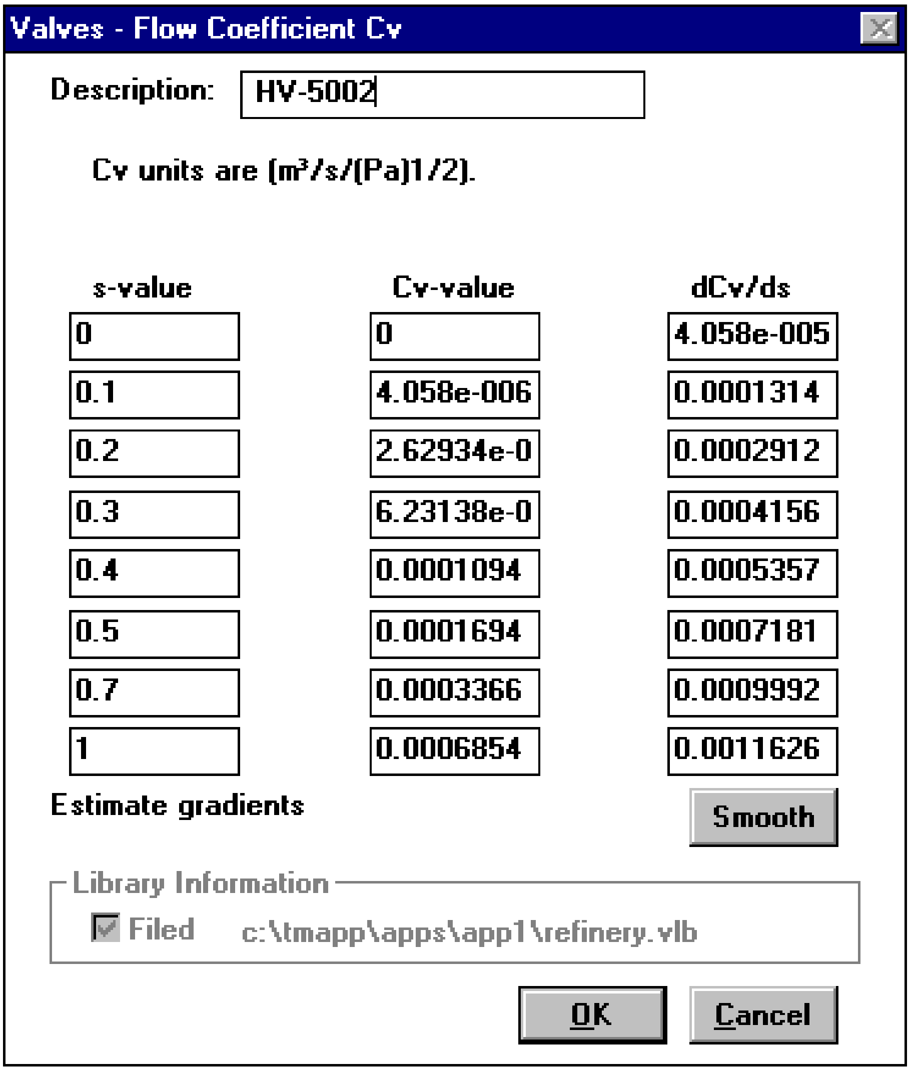
where
$A$ is the port area of the valve on which the k-factor is based
$\rho$ is the fluid density

The value of *k*, which is known as the velocity headloss, depends on the valve used and is generally a function of *s*, although it is often taken to be a constant for convenience.

The information required by PIPENET Transient Module to model any valve is its $C_v$ or *k* value (as a function of *s*) and the diameter of the area on which this value is based. Since the function of $C_v$ or *k* against *s* is often very complex, it is specified approximately in the Valve Library by a series of co-ordinates and gradients on the $C_v$-*s* or *k*-*s* line.

A full explanation of the models and definition of the valve types can be found in appendix A2 of the user manual.

The valve used in these simulations is the HV-5002, ERC Valve, whose $C_V$-$s$ relationship, taken from manufacturer's data, is as given in section 1.2 (Summary of Data Used). The data is defined by specifying the **Flow** coefficient $C_V$ as a function of $s$ (see previous section). The **Libraries** menu contains the **Valve types** menu, from which Flow coefficient $C_V$ should be selected. The completed dialog box is shown below.
Once again, this library is saved as refinery.vlb.



Description: HV-5002

Cv units are [m³/s/(Pa)1/2].

| s-value | Cv-value | dCv/ds |
|---|---|---|
| 0 | 0 | 4.058e-005 |
| 0.1 | 4.058e-006 | 0.0001314 |
| 0.2 | 2.62934e-0 | 0.0002912 |
| 0.3 | 6.23138e-0 | 0.0004156 |
| 0.4 | 0.0001094 | 0.0005357 |
| 0.5 | 0.0001694 | 0.0007181 |
| 0.7 | 0.0003366 | 0.0009992 |
| 1 | 0.0006854 | 0.0011626 |

Estimate gradients

Library Information
☑ Filed c:\tmapp\apps\app1\refinery.vlb

Figure 1-6 The Valve Type Dialog Box After Data Entry

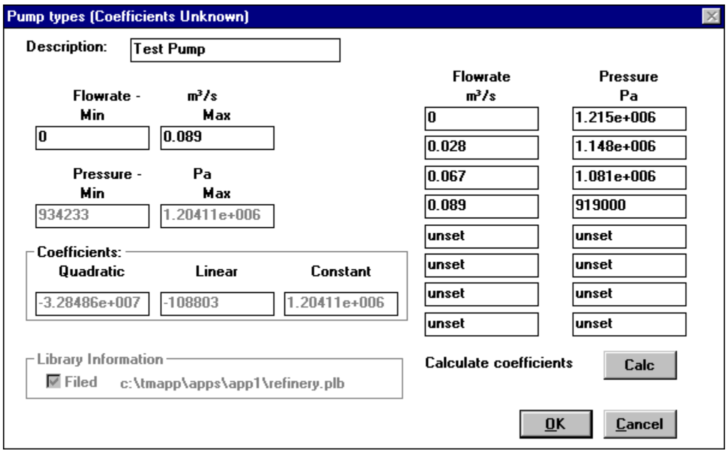
### 1.4.2.3 Pump Curve Data

The pump library is entered and saved in the same way as the pipe schedule. First **Pump types** is selected from the **Libraries** menu, which opens the **Pump types** menu bar.

The data for a simple pump will be used. If the coefficients which describe the pump performance curve were known, the **Simple (Coefficients Known)** option would be selected, which opens the **Pump types (Coefficients Known)** dialog box (see Figure 1- below). The coefficients can be entered in the

**Quadratic**, **Linear** and **Constant** boxes to define the pump. In this case, the user does not know suitable quadratic coefficients, so the pump must be defined by entering up to eight points on the pressure-flow curve of the pump by selecting **Simple (Coefficients Unknown)**, and PIPENET calculates the coefficients. Full details of how to do this are given in the User Manual.

When the data for the pump curve has been entered, the data is saved in a file named refinery.plb using the **File Save As** dialog box as before.



Description: Test Pump

Flowrate - m³/s Min: 0 Max: 0.089

Pressure - Pa Min: 934233 Max: 1.20411e+006

Coefficients:

| Quadratic | Linear | Constant |
|---|---|---|
| -3.28486e+007 | -108803 | 1.20411e+006 |

Library Information

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| Flowrate m³/s | Pressure Pa |
|---|---|
| 0 | 1.215e+006 |
| 0.028 | 1.148e+006 |
| 0.067 | 1.081e+006 |
| 0.089 | 919000 |
| unset | unset |
| unset | unset |
| unset | unset |
| unset | unset |

Figure 1-7 The Pump Type Dialog Box After Data Entry

In summary, the three supporting data files have been entered and saved. PIPENET now has all the necessary information about the three types of component, and can locate the supporting data files for each.

### 1.4.3 The View Menu

We shall write out the information that we need to specify for each of the components in the network.

- The Pipes

| Pipe Label | Input Node | Output Node | Diameter mm | Length m | Elevation m | Total k-factor |
|---|---|---|---|---|---|---|
| 3 | 3 | 4 | 250 | 5697.33 | 1.45 | none |
| 5 | 5 | 6 | 250 | 150 | 0 | none |

The pipes are defined in the **Pipe Types** dialog box, under **Init**. Note that no pipe linings are used in this example, and so that dialog box can be ignored, and that the diameters given in this table refer to the nominal diameters of the pipes. PIPENET will use the corresponding inner and outer diameters taken from the data given in the PDF.

**Pipes** is selected from the **View** menu. This opens the list of pipes in the network, which initially looks like Figure 1-8.

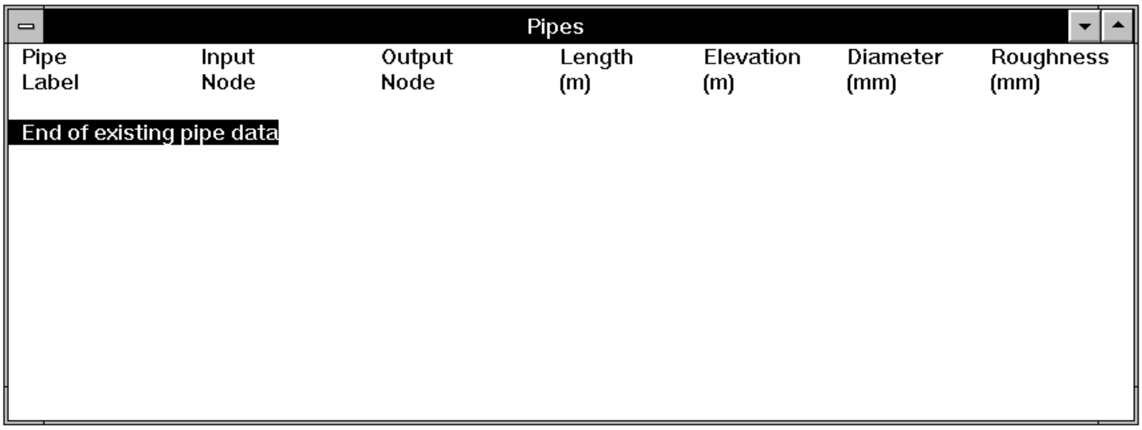
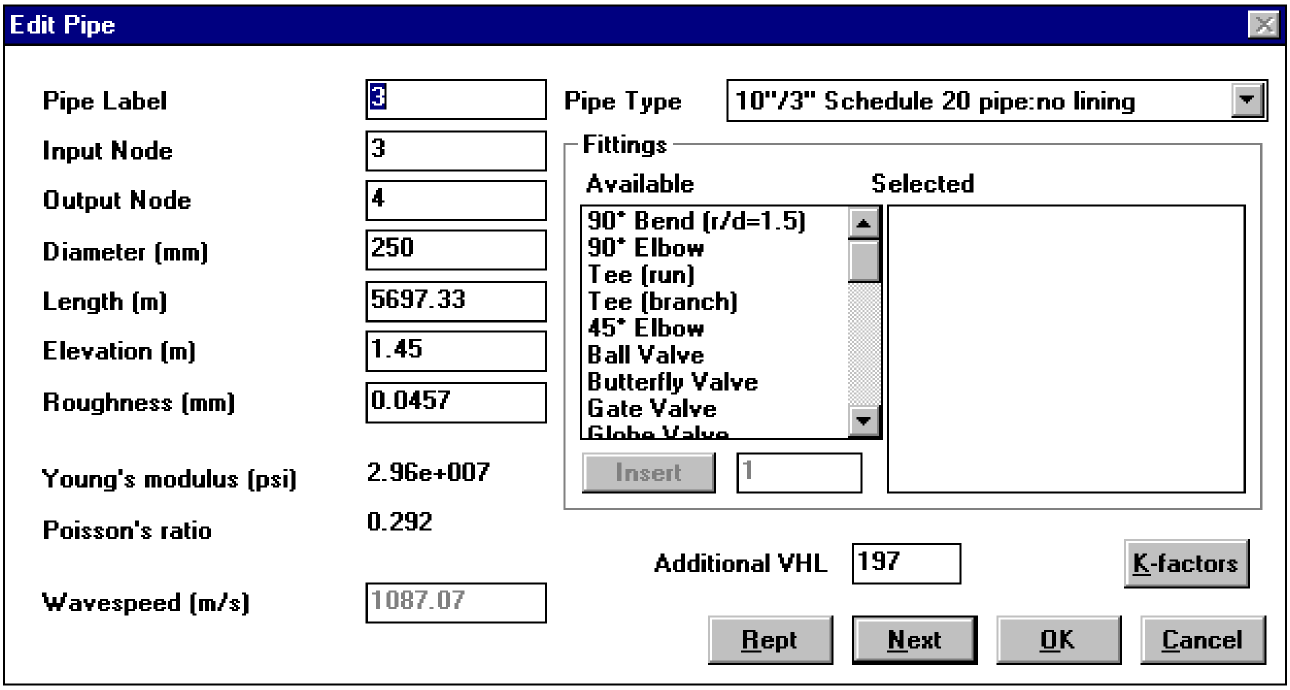


Figure 1-8 The Pipes List Before Data Entry

Pipes can be added to the network by double-clicking on **the End of existing pipe data** message in the list. PIPENET then displays the **Pipe** dialog. The information for the first pipe can be entered, so that the dialog box appears as shown below.



Pipe Label: 3
Input Node: 3
Output Node: 4
Diameter (mm): 250
Length (m): 5697.33
Elevation (m): 1.45
Roughness (mm): 0.0457
Young's modulus (psi): 2.96e+007
Poisson's ratio: 0.292
Wavespeed (m/s): 1087.07
Pipe Type: 10"/3" Schedule 20 pipe:no lining
Additional VHL: 197

Figure 1-9 The First Pipe Dialog Box After Data Entry

Clicking on the **Next** button has the same effect as clicking **OK,** except that a new dialog box is automatically opened ready for the next new pipe. After entering the data for the second pipe **OK** should be clicked. A summary of the two pipes is now added to the list of pipes. The **Pipes** list can be left open for reference while other components are being entered, or the window closed by double clicking on the system menu, to keep the desktop tidy.

- The Pump

The performance details for the pump are held in the Pump Library. The data for the pump is as follows:

| Pump Label | Input Node | Output Node | Information Node |
|---|---|---|---|
| 1 | 1 | 2 | I/1 |

The **Pumps**, **Simple** option on the **View** menu works in exactly the same way as the **Pipes** option. A list of simple pumps currently in the network appears and double-clicking on the **End of existing simple pump data** opens a dialog box into which the details of the pump listed above can be entered.

- The Non-return Valve

| NRTV Label | Input Node | Output Node |
|---|---|---|
| 2 | 2 | 3 |

The non-return valve in the network can be entered in a similar fashion to the pipes.

- The Valves

The characteristics of the valves are held in the Valve Library. The data for the valves are as follows:

| Valve Label | Input Node | Output Node | Information Node |
|---|---|---|---|
| 4 | 4 | 5 | I/2 |
| 8 | 6 | 9 | I/3 |

The information node of the valves, I/2 and I/3, represents their positions by a number between 0 and 1, where 1 is fully open. The valve position will be set later by an information specification on the information node. The valves in the network can be entered in the same manner as the pipes.

- The Accumulator

The data for the accumulator is as folows:

| Accumulator Label | Input Node | Diameter (mm) | Height (m) |
|---|---|---|---|
| 100 | 4 | 2500 | 8 |

- Specifications

The details for all of the components in the network have now been entered. The **View** menu is also used to define other details, such as specifications and output tables.

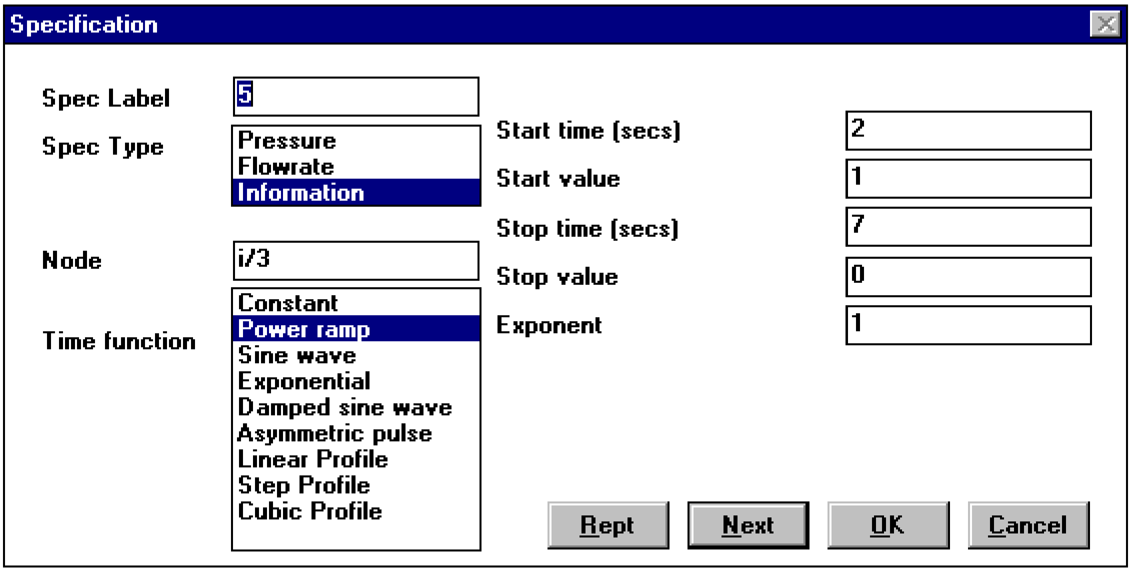
In any network there are nodes where fluid can enter or leave the system. These are called input and output flow nodes, or ionodes. PIPENET Transient Module uses the convention that flow entering the network is positive, and flow leaving the network is negative.

Before a simulation can take place, PIPENET requires information regarding the ionodes over the time period considered (i.e. the boundary conditions for the problem). The specifications may be constant, or vary with time (for example, oscillate as a damped sine wave or increase exponentially). Full details are given in the user manual. Note that PIPENET Transient Module requires there to be at least one node with a pressure specification.

In this example the input and output flow nodes are those labelled 1 and 9. Node 9 is open to the atmosphere, and so the pressure there is always 0 bar G. Node 1 is a point in the tanker into which the LNG is being pumped, and where the pressure is maintained at 3 bar G.

| Specification Label | Spec. Type | Ionode Label | Function | Value |
|---|---|---|---|---|
| input | Pressure | 1 | Constant | 0.0 bar G |
| output | Pressure | 9 | Constant | 1.71 bar G |

The four specifications are now entered; two flow specifications and two information specifications, that were described above. An example of the **Specification** dialog box is shown in figure 1-10.



Spec Label: 5
Spec Type: Information
Node: i/3
Time function: Power ramp
Start time (secs): 2
Start value: 1
Stop time (secs): 7
Stop value: 0
Exponent: 1

Figure 1-10 The Specification Dialog Box Showing The ERC Valve Setting

Note that the **Specification** dialog box automatically changes itself according to which type of specification is being set.

The final **View** menu option used is **Output tables**. PIPENET allows the user to define which variables he wishes to appear in each output table:

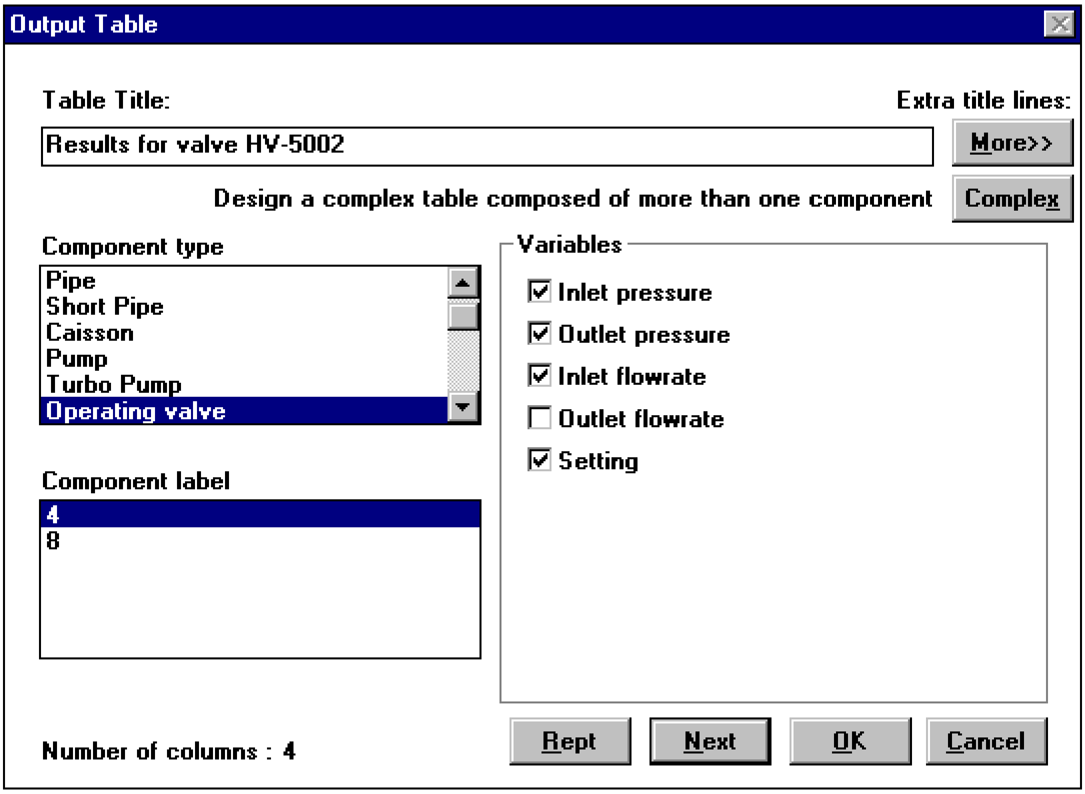
- Pressures at inlets and outlets of the non-return valve
- Pressures at inlets and outlets, and setting of the HV-5002 valve

- Pressures at inlets and outlets, and setting of the ERC valve

As each of these tables contains variables of a single component, each table can be defined inside a single **Simple** format dialog box. PIPENET can produce tables which compare variables from several components on one table. This is achieved using the **Complex** format which is described in the User Manual.

Double-clicking on the **End of existing output table data** line in the **Output tables** list opens a blank **Simple** format table. The table title 'Results for valve HV-5002' is entered in the **Table title** entry field, then **Valve** selected from the **Component type** list. The dialog box then automatically displays a list of pipes in the network and a list of variables associated with that component type. The desired outputs (in this case inlet pressure, outlet pressure and setting) can then be selected.

The **Next** button allows the remaining output tables to be entered in a similar fashion.



Output Table

Table Title: Results for valve HV-5002

Design a complex table composed of more than one component

Component type: Operating valve

Component label: 4

Variables
☑ Inlet pressure
☑ Outlet pressure
☑ Inlet flowrate
☐ Outlet flowrate
☑ Setting

Number of columns : 4

Figure 1-11 The Completed Output Table Dialog Box

## 1.4.4 The Check Menu

The check menu contains options to check how the network has been defined, such as checking that every component is connected to some other component. The User Manual lists all the checks that the check menu performs.

Selecting **All checks** allows PIPENET to examine the network. If no errors have been made during data entry, PIPENET displays a message saying that the network passed each of the tests successfully.

### 1.4.5 The Calculation Menu

The calculation menu allows the user to set up how the calculation is performed, and then to carry out the calculation itself. The first three options on this menu allow the user to fine-tune the calculation process. These options are rarely used and can normally be ignored.

The **Initial state** option allows the user to define the flows and pressures in the network at the start of the simulation. For example, the fluid in the system may be at rest before the simulation starts. Alternatively the system may initially be operating in a steady state, or a user-defined state can be used to start the simulation. For full details of these see the user manual. In this case it is assumed that before the valves start to close (i.e. at the start of the simulation) the system is operating in a steady state, and PIPENET will calculate this initial state for us automatically if we allow it a run-in time, starting from its own defaults. The final steady state of the system will also be calculated. In summary, PIPENET will start the simulation in the following way:

| Starting Point | Run-in Time (s) | Initial Steady State Calculation | Final Steady State Calculation |
|---|---|---|---|
| Defaults | 2.5 | Yes | Yes |

The **Output** option opens the **Calculation output** dialog box, which allows the user to define where the output files will be stored. For this simple problem only output tables are to be produced. The entry 'refinery.out' is a suitable output filename and **OK** should be clicked.

- Pump and Valve operation and information specifications

The other nodes which have specifications associated with them are the information nodes. These are the nodes at which information enters and leaves the system, and in this example they contain information which tells PIPENET how and when devices such as pumps and valves are to operate.

In these scenarios the effect of valves closing is being investigated, so we specify that in each case the pump is to work at full speed throughout, while the valve starts fully open and closes according to the closure pattern specified for the scenario. Thus for the pump we have:

| Spec. Label | Spec. Type | Info Node | Function Type | Value |
|---|---|---|---|---|
| pump | I | I/1 | Constant | 1.0 |

For the valves we have:

| Spec. Label | Spec Type | Info Node | Start Time | Initial Value | Final Value | Power |
|---|---|---|---|---|---|---|
| HV-5002 | 4 | I/2 | 0s | 1 | 0 | 1.0 |
| ERC Valve | 8 | I/3 | 0s | 1 | 0 | 1.0 |

The **Go** option starts the calculation. When it is selected, PIPENET initially displays the **Calculation Output** dialog again, to reaffirm the filenames for the results files. Selecting **OK** starts the simulation. After a brief pause, the **Calculator status** dialog box appears, which contains a status bar to show how much of the calculation has been completed.

When the simulation finishes, a message box appears on the screen to tell the user that the calculation was successful. This message box and the **Calculator status** dialog box can be dismissed.

### 1.4.6 The Output Menu

**Report** from the **Output** menu allows the user to 'browse' through the output file. He can examine the tables of results and check the maximum and minimum pressures observed during the simulation.

## 1.5 The Results

The focus in this application is on the pressure surges at the valves. Thus we plot results (in the Appendix) showing the pressure at the closing valve (either the HV-5002 or the ERC valve), and the pressure at the inlet and outlet of the non-return valve. As the non-return valve inherently only allows fluid to pass through in one direction, we should expect some interesting results at the point where the pressure wave returning from the closing valve raises the pressure on the outlet of the non-return valve above that at its inlet, resulting in the non-return valve shutting until the pressure wave reflects back.

Plotting the setting of the valve that closes superimposed on its inlet pressure should facilitate understanding of the effect of the different stages of valve closure on the pressure at that point.

## 1.6 Analysis of Results and Conclusions

In each case, where no accumulator is present, large amplitude oscillations occur (peak to peak about 5 bar G which slowly decrease in amplitude to a steady-state value of between 15 and 18 bar G Where an accumulator is present, these oscillations are eliminated, and a much smoother pressure rise is observed, with small damped oscillations occurring at the outlet of the non-return valve. The steady-state pressure in these cases is about 10.5 bar G

Thus the presence of the accumulator reduces the steady-state pressures and prevents large oscillations occuring in the network. In all cases, the maximum pressure observed is less than the design pressure of 19.2 bar G.

### 1.6.1 Planned Shutdown

#### 1.6.1.1 Two stage valve closure type 1 without accumulator

The graphs show that as valve HV-5002 closes the pressure at its inlet rapidly increases, but that where the setting reaches a plateau at s=0.2, a pressure wave is established, and continued when the valve closes fully, resulting in a damped periodic pressure wave with a peak of just over 16 bar G.

A similar effect occurs at the non-return valve outlet, which is delayed and out of phase from this first wave.. At the inlet to the non-return valve, however, the pressure remains constant once the valve has closed fully, at just above 12 bar G.

### 1.6.1.2 Two stage valve closure type 1 with accumulator

Here the inlet pressure inceases slowly up to just below 11 bar G, then remains there after approximately 550 seconds. The inlet and outlet pressures of the non-return valve rise from 8.6 bar G to about 10.5 bar G over the same time period, remaining at the latter value, except that small amplitude oscillations are initiated in the outlet pressure at that point, and slowly damped. The effect of the accumulator has been to eliminate large oscillations in the inlet pressure of the HV-5002 valve and the outlet pressure of the non-return valve, and to reduce the steady-state presures at those points.

### 1.6.1.3 Two stage valve closure type 2 without accumulator

In this scenario, oscillations are present again, with a larger amplitude than with the two stage valve closure type 1, but settle to the same value as before. Similarly, delayed oscillations are present in the outlet pressure of the non-return valve, but this time appear to be settling towards about 17 bar (higher than before.)

### 1.6.1.4 Two stage valve closure type 2 with accumulator

Here the accumulator has reduced the large amplitude oscillations again, and the steady state pressures reduced to nearly 11 bar G in both cases, but with small ripples occurring at around t=550 seconds.

### 1.6.1.5 Single stage valve closure without accumulator

Oscillations are again present in the inlet pressure of valve HV-5002 that are initiated when the valve shuts fully, and delayed in the outlet pressure of the non-return valve. The steady-state outlet pressures of these are about 17.5 bar G, and of the inlet of the non-return valve just over 12 bar G.

### 1.6.1.6 Single stage valve closure with accumulator

As we might expect, the large amplitude oscillations are once again damped, and the steady-state outlet pressures reduced.

## 1.6.2 Emergency Shutdown

### 1.6.2.1 Single stage closure of ERC valve without accumulator

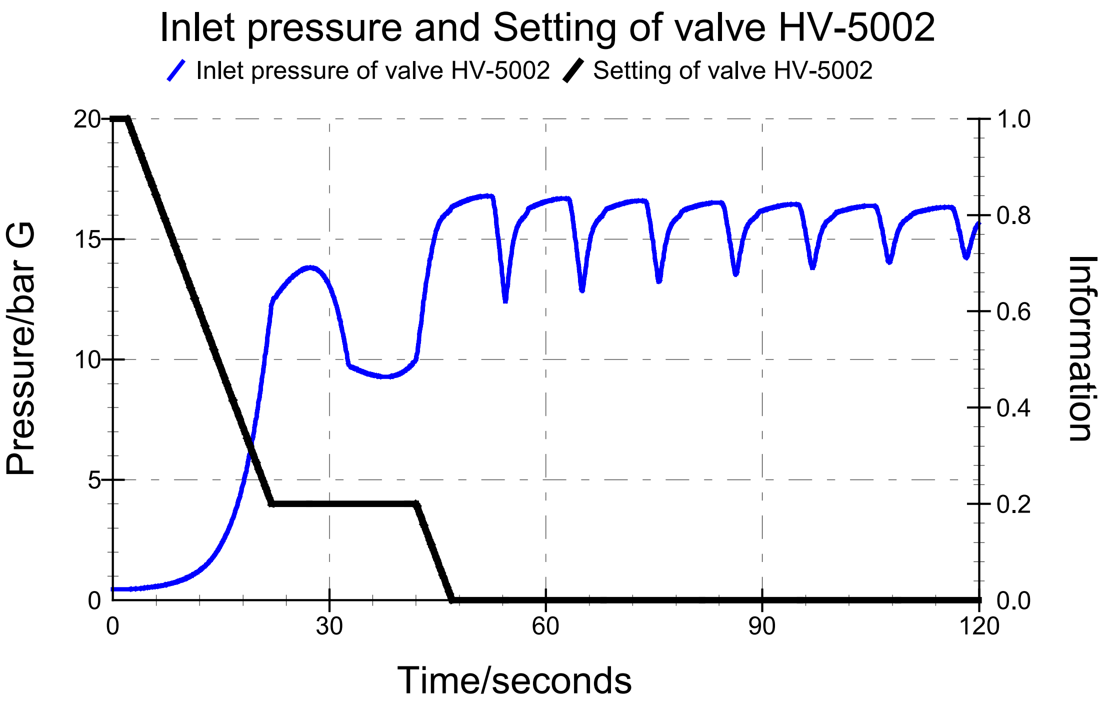
The largest pressures observed are once again at the peaks of the oscillations, and are about 17 bar G at the outlet of the non-return valve and the inlet of the ERC valve, induced when the valve partially shuts then closes fully.

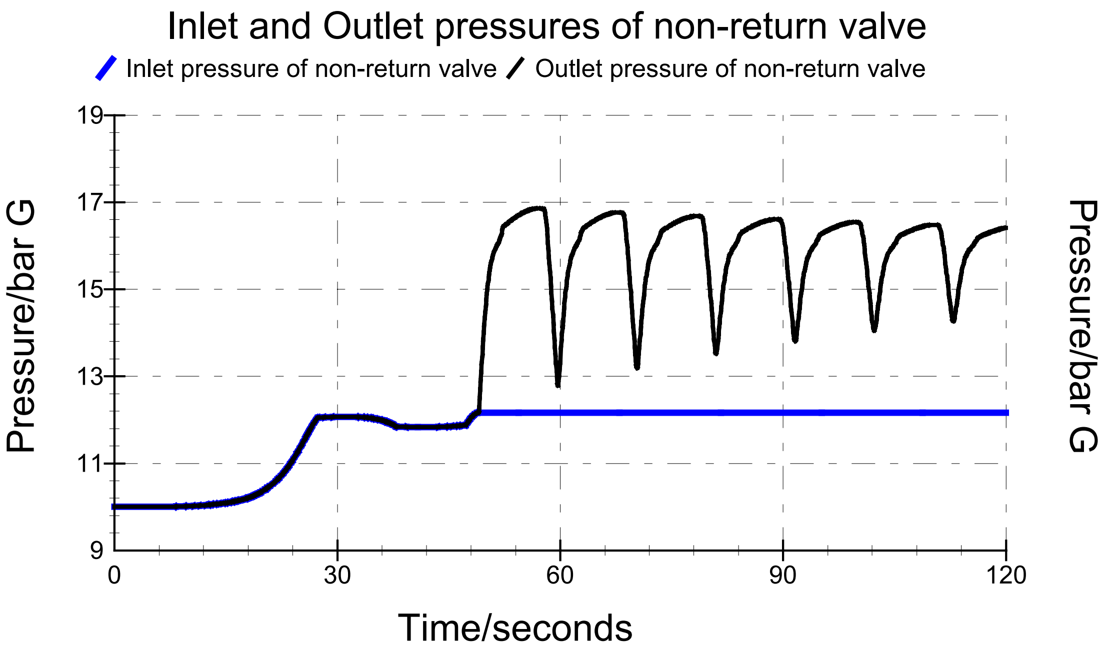
### 1.6.2.2 Single stage closure of ERC valve with accumulator

The same phenomenon as previously observed recurs here; the pressure rises at the valves, then levels out after about 550 seconds, with ripples present at the outlet of the non-return valve.

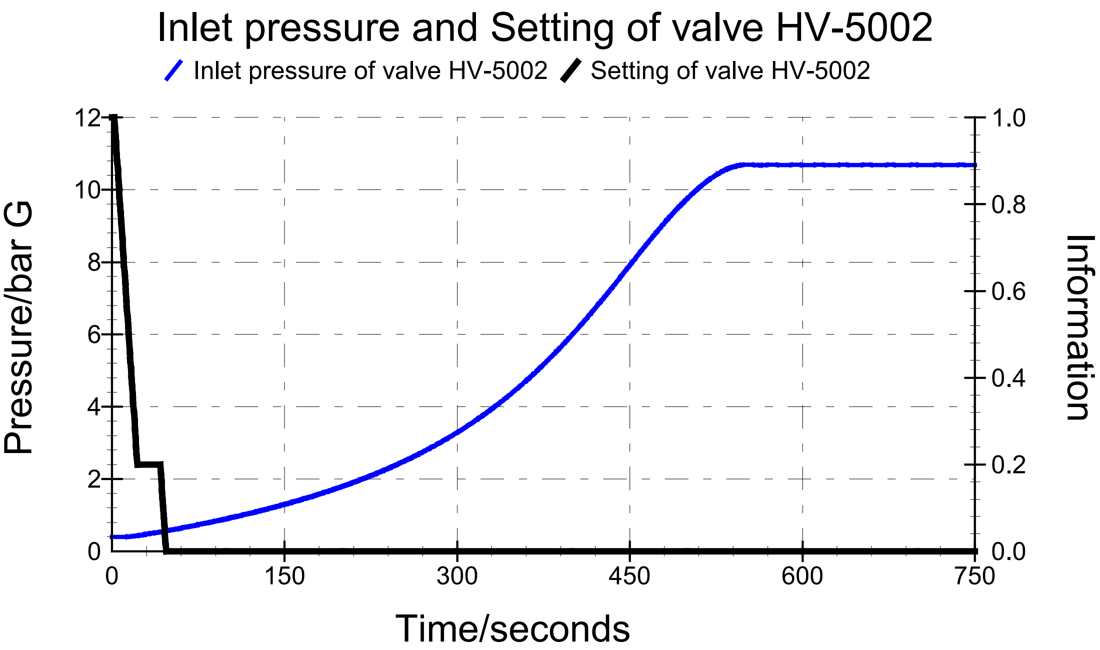
## 1.6.3 Planned Shutdown

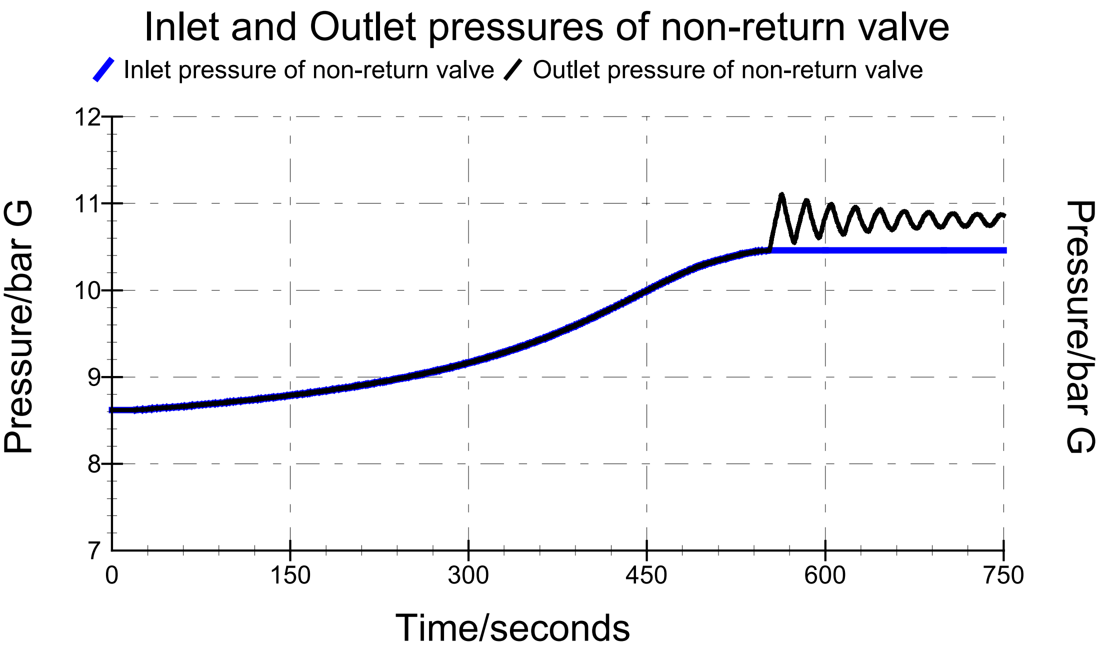
### 1.6.3.1 Two stage valve closure type 1 without accumulator



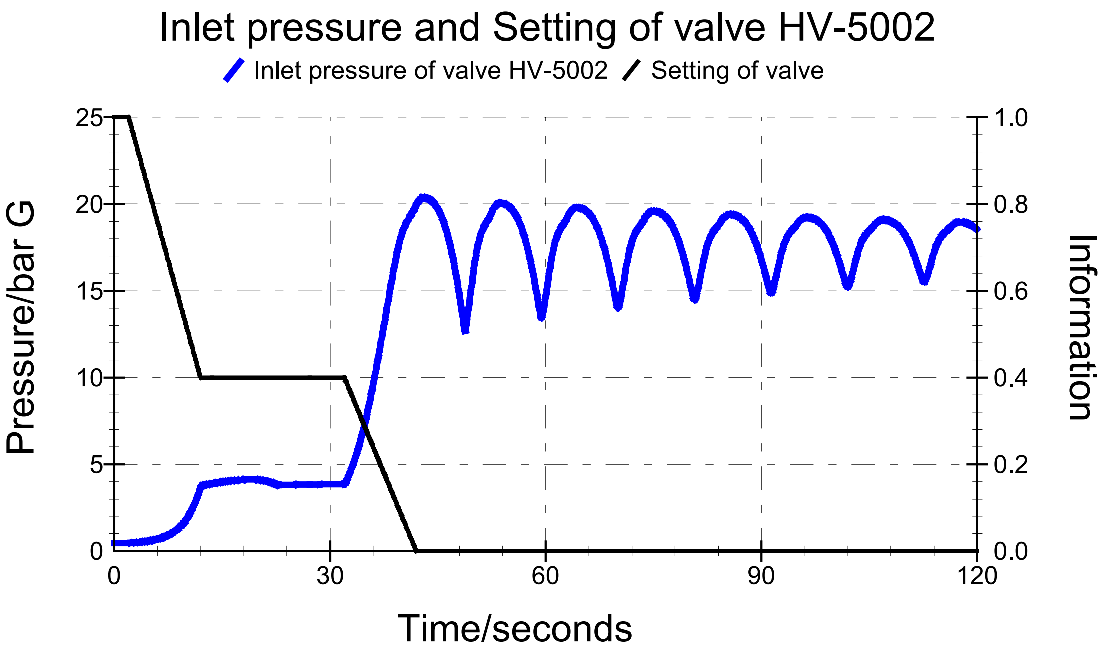


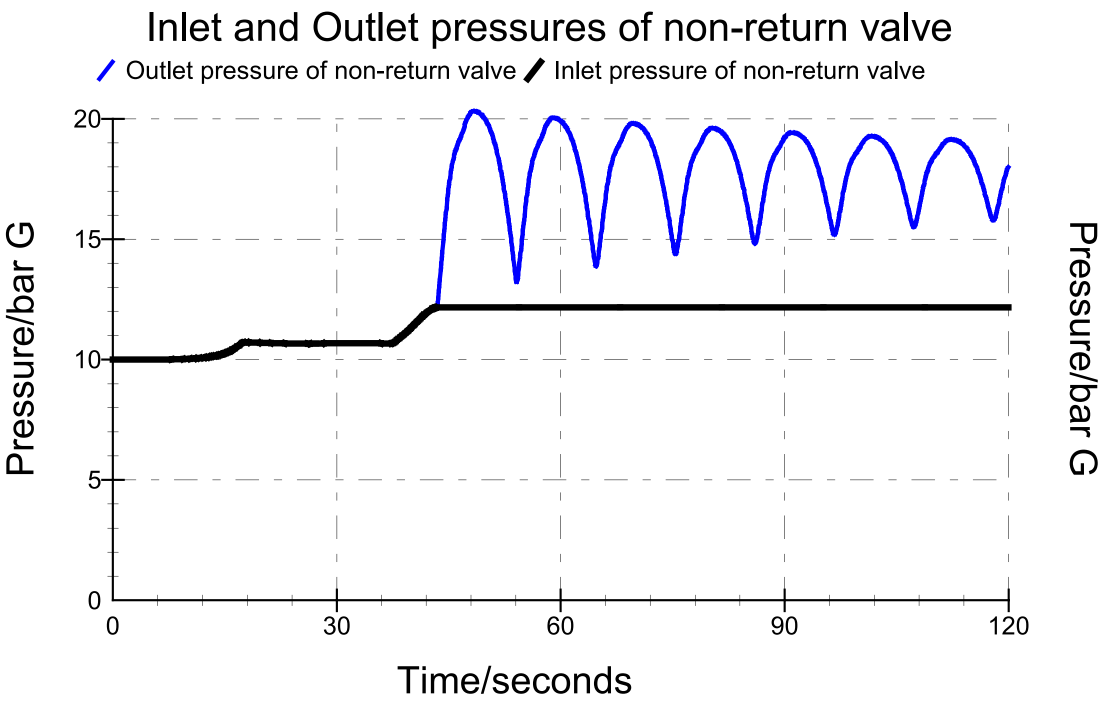
### 1.6.3.2 Two stage valve closure type 1 with accumulator



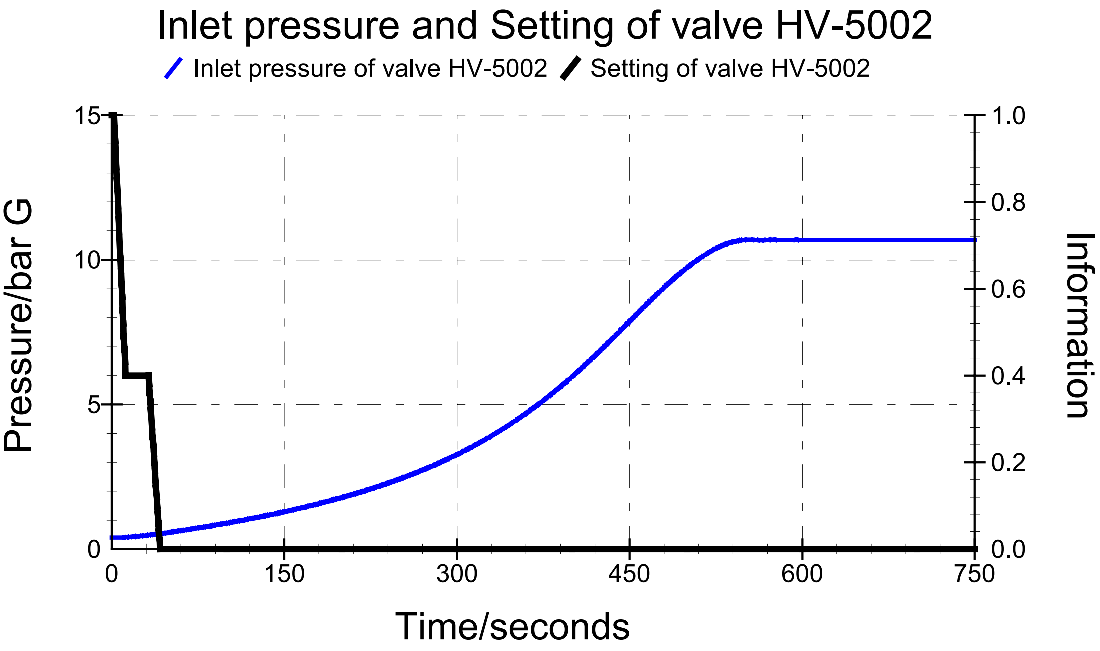


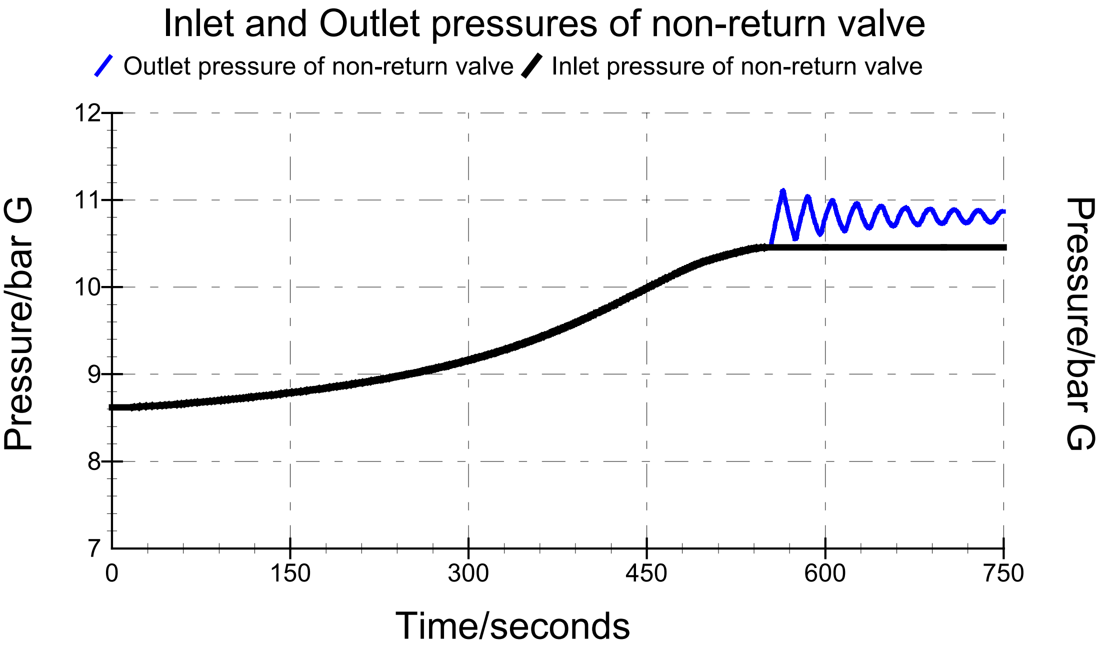
### 1.6.3.3 Two stage valve closure type 2 without accumulator



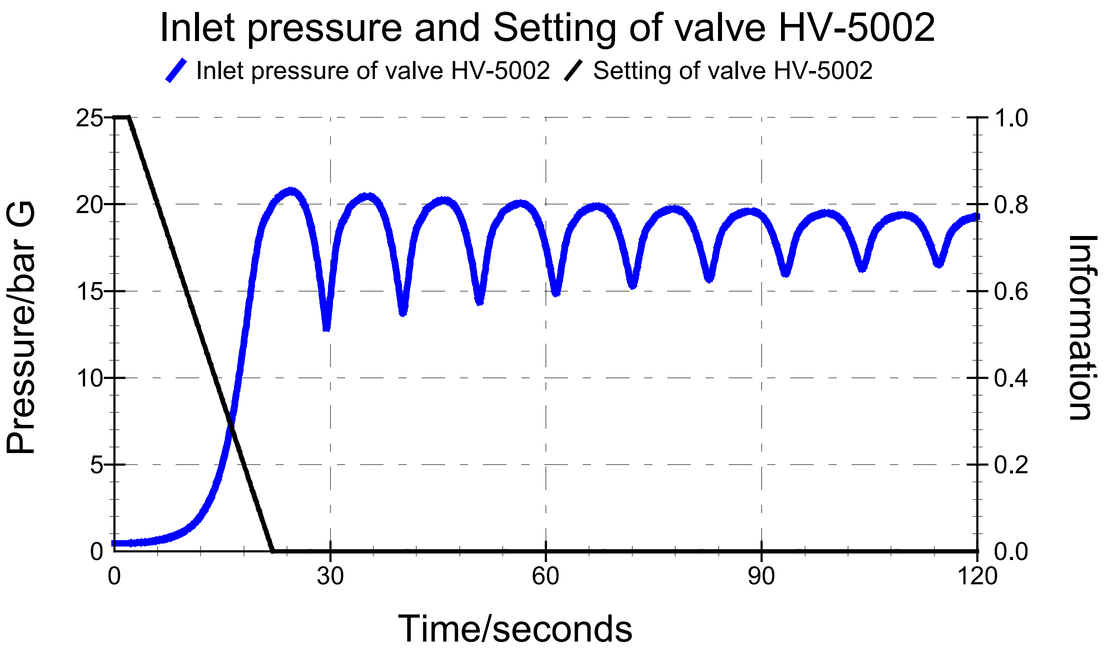


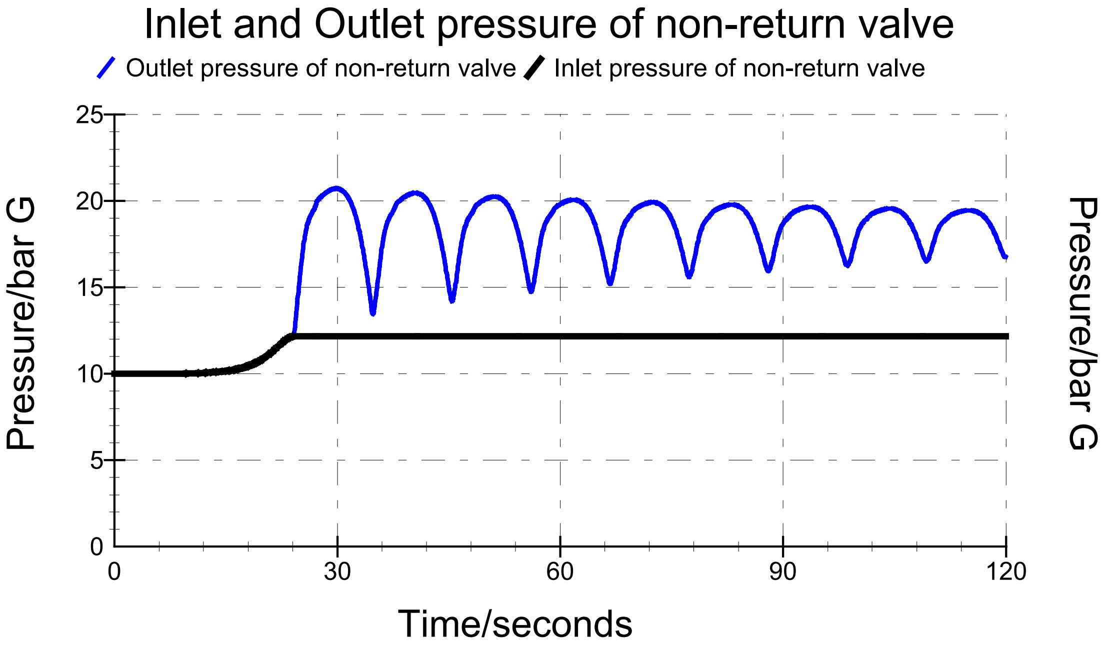
### 1.6.3.4 Two stage valve closure type 2 with accumulator



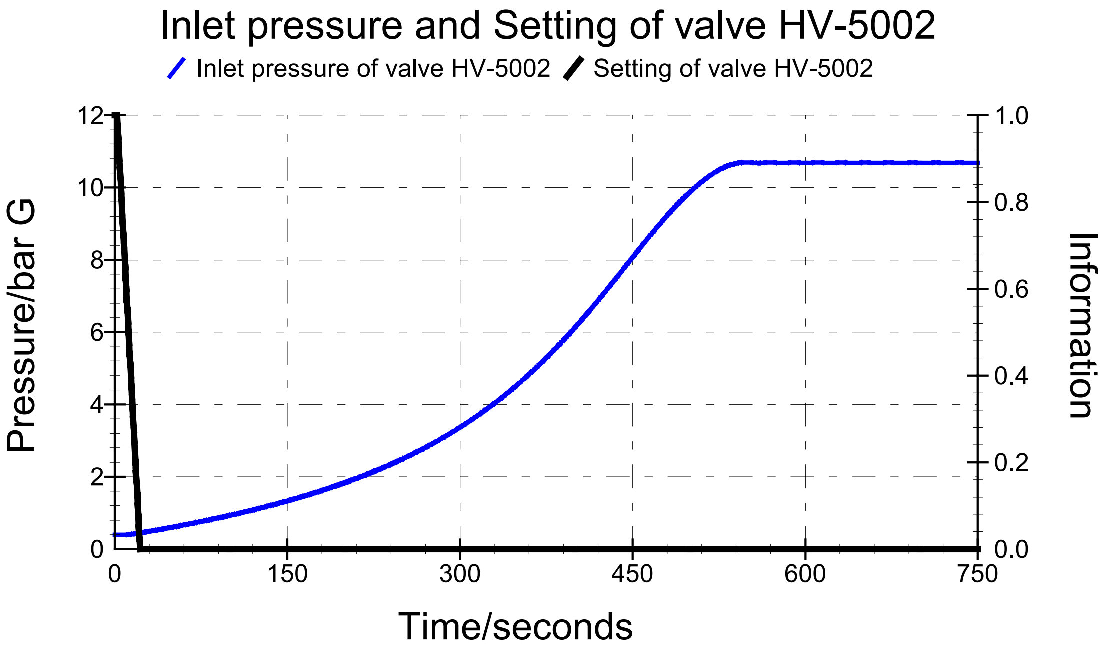


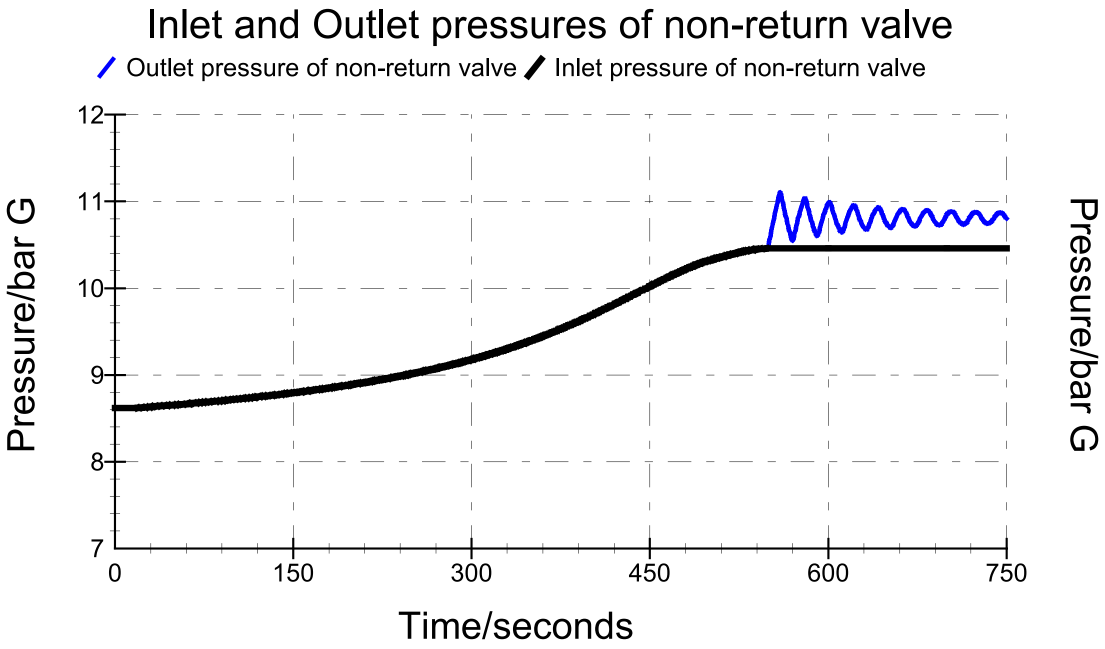
### 1.6.3.5 Single stage valve closure without accumulator





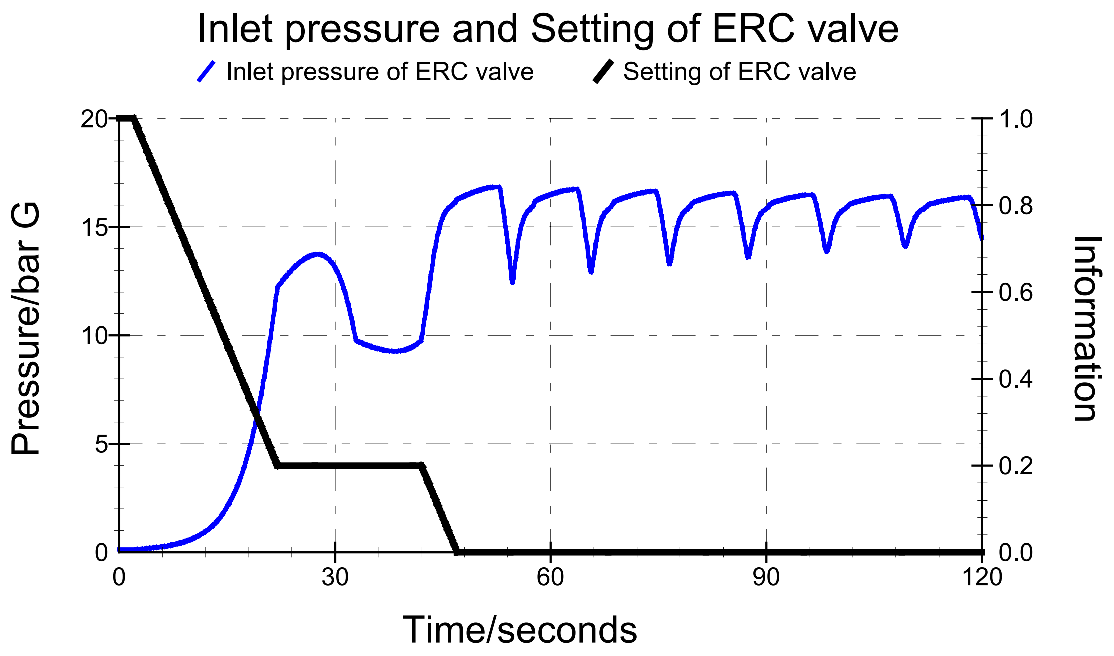
### 1.6.3.6 Single stage valve closure with accumulator

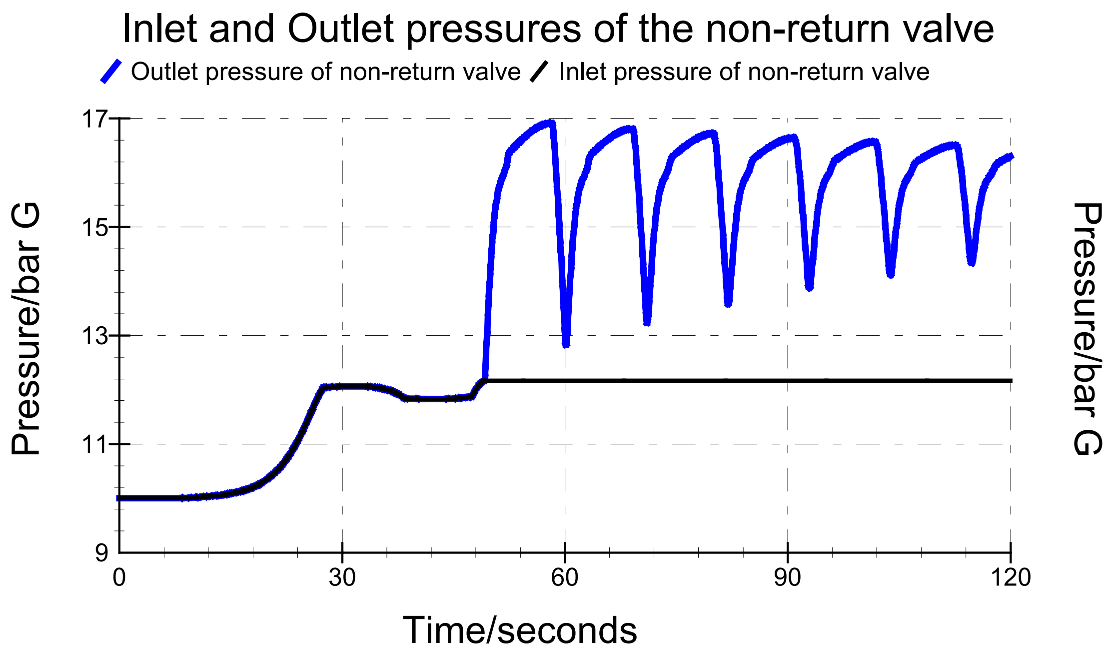




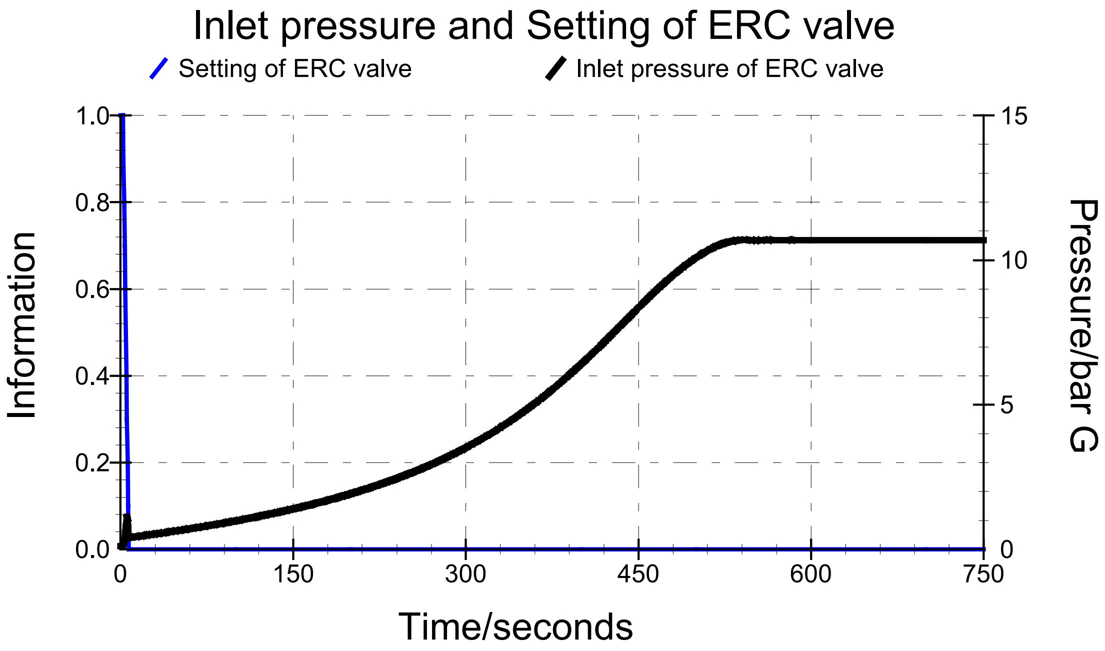
## 1.6.4 Emergency Shutdown

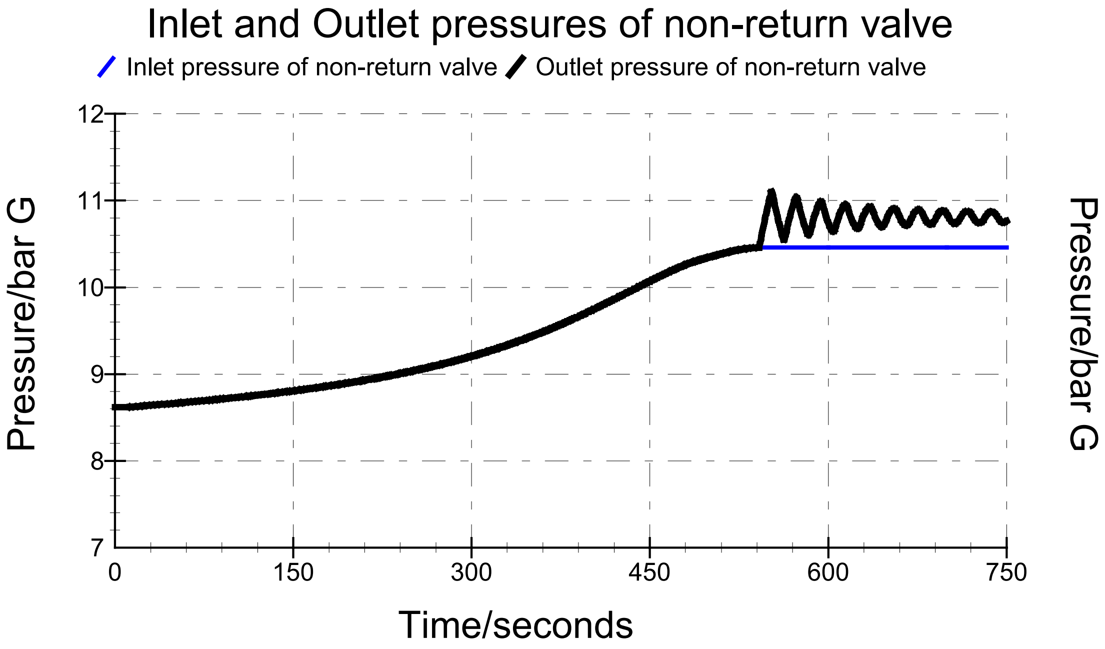
### 1.6.4.1 Single stage closure of ERC valve without accumulator





### 1.6.4.2 Single stage closure of ERC valve with accumulator





EXAMPLE 2

# THE USE OF PIPENET IN MODELLING PRESSURE SURGES AND LEAKS IN SUBSEA AND ONSHORE PIPELINES

**Eur. Ing. Dr. Waheed Al-Rafai, ZADCO, United Arab Emirates**

**Dr. Dev Sebastian, Sunrise Systems Ltd, United Kingdom**

In this paper we present results based on the pioneering work done by ZADCO in pipeline integrity risk management. We believe that this represents a major step achieved by ZADCO in developing techniques for optimising pipeline inspection & maintenance and sets a new worldwide standard. The project concerned with the integrity modelling of the arterial oil pipeline, which is a major asset of ZADCO.

ZADCO plan to derive greater value from its pipeline network which is one of its biggest asset covering hundreds of kilometres in the Arabian Gulf. The challenge is to achieve a high level of pipeline integrity, through risk-based approaches which have been gaining attention as a basis for making decisions on inspection & integrity maintenance. Considerable cost savings can be realised when utilising Risk Based Inspection (RBI). For example, RBI techniques generally yield longer inspection intervals compared to time-based inspections are effective in prioritising inspections and can provide the confidence to safely postpone subsea rehabilitation activities.

For example, the water content of ZADCO main oil line is expected to increase in the future. This brings with it the risk of significantly increased pressure surges due to increased water cut, even though the valve closure time may remain constant. The use of state-of-the-art techniques developed by ZADCO is invaluable in optimising and planning costly subsea rehabilitation activities, and in quantifying and justifying the benefit of installing a leak detection system in support of improved pipeline operation.

The total bill for deferred production and repair caused by subsea pipeline failure can be measured in hundred of millions of dollars. Given that the cost of pipeline failure is of such magnitude, then the use of dynamic modelling should be advocated as an enabling technique for achieving requisite performance. This paper gives an introduction to the role played by the PIPENET software in this application to enable better pipeline integrity and risk management.

## SUBSEA PIPELINE MODELLING:

A pipeline Maximum Allowable Operating Pressure (MAOP) may need to be modified from the original design pressure in some cases. If it is raised above the original design pressure, it will have significant implications on the pipeline integrity and risk which must be evaluated. When an operator increase the pressure, the risk of failure will also increase. Likewise, if it need to be lowered, this would also have a favourable impact on the risk of failure and the corresponding inspection frequency when utilising Risk Based Inspection.

PIPENET provide the means to quantify the MAOP requirement for lines that are placed in a service for which they were not originally designed. Pressure, flowrates, velocities, and the composition of the fluid transported change over time from the initial design, whilst corrosion and erosion reduce the pressure containment ability of a pipeline.

PIPENET also allow the investigation and limiting the consequences of an accident through designing an appropriate early warning system. Dynamic modelling of pipelines prevent an extreme scenario of risk to an operator who may be steadily increasing the pressure in the pipeline without introducing any mitigation measures.

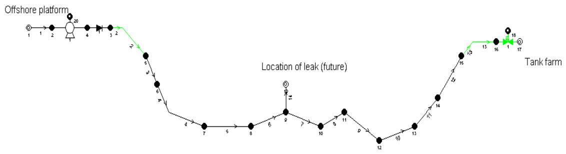
In this example we consider modelling a pipeline which carries oil from an offshore platform to onshore reception facilities.

- The effect of valve closure and closure time
- The effect of a pipe rupture

The objective in the first case is to determine the relationship between the valve closure time and the maximum pressure with the view of determining the optimum valve closure time. This calculation is particularly important where the integrity demand on the pipeline progressively increases due to weakening by corrosion, the need to transfer greater quantities of oil and an increase in the amount of produced water. By selecting an optimum valve closure time, which is inevitably a compromise between the emergency shutdown requirement and pipeline integrity constraints due to corrosion, the inspection frequency as calculated by Risk Based Inspection and the time to repair the line can also be optimised. The inspection due date for the pipeline is a function of the remnant life of the pipeline which is calculated as the date when the transient pressure containment ability (Maximum Allowable Surge Pressure) of the pipeline equal to the maximum pressure surge in the pipeline.

The objective in the second case is to minimise the environmental effect and the waste caused in the event of a subsea pipeline rupture. This is part of conducting a risk analysis in order to ensure that the risk in acceptable. During a leak every second counts and quick response by a leak detection system is critical for improved safety especially for lines handling $H_2S$-containing fluids. For the purpose of comparison, it was assumed that it would take 15 minutes to detect a leak manually and a further 1 minute to shutdown the pump. On the other hand, with a leak detection system installed, it would take 4 minutes to detect a leak and a further 1 minute to shutdown the pump. The estimated amount of oil which is drained into the sea is an important consideration for contingency planning and the development of an effective Emergency Pipeline Repair System EPRS.

For the valve closure surge analysis the network in the schematic form is shown below.



# EXAMPLE 2

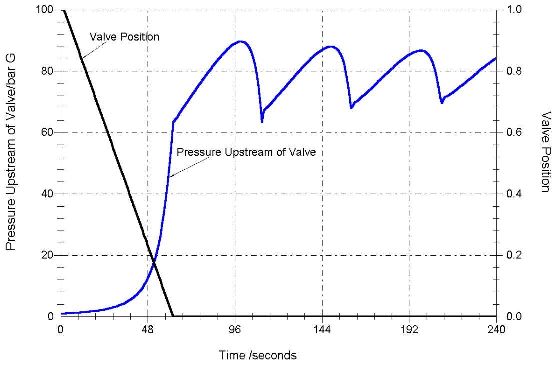
The pipeline is approximately 35 km of 200 mm pipe following the profile of the seabed. The lowest point of the pipeline is 80 m below the level of the platform. Oil is pumped by a booster/transfer pump and there is an isolation valve at the end of the pipeline.

Consider the following four valve closure cases.

60 sec
120 sec
240 sec
600 sec (quadratic valve closure)

In the first scenario, the valve is set to close in 60 sec. The wave speed is 1159 m/sec. The period for the pressure wave to return to the valve after traversing the length of the pipe is 60.4 sec. As this time, which is sometimes referred to as the critical time, is longer than the valve closure time, this scenario is likely to generate the maximum surge pressure.

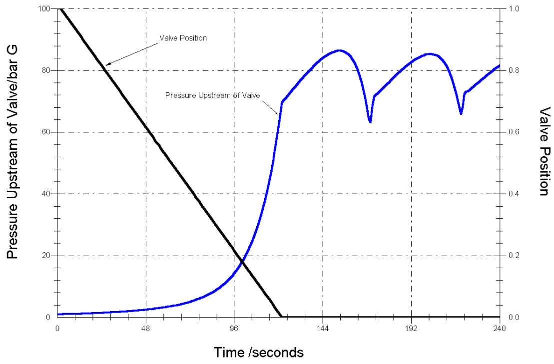
Graph 1.1. Offshore Oil Pipeline - Valve Closure in 60 sec



As expected the maximum pressure occurs at the lowest point in the system and reaches a value of 95.3 bar.

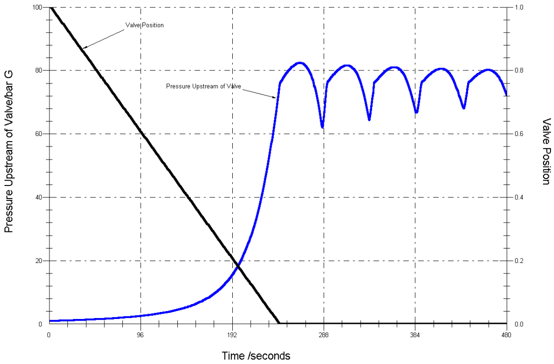
In the second scenario the valve closure time is increased to 120 sec. One would expect the pressure surge to decrease a little but not very significantly. This is because in a system of this type, the pressure surge can be expected to decrease significantly only after the valve closure time is many times the critical time. As described in the previous paragraph the critical time is the time it takes for the pressure wave emanating from the valve to travel the length of the system and return.

Graph 1.2. - Offshore Oil Pipeline - Valve Closure in 120 sec



The maximum pressure again occurs at lowest point in the system and reaches 92.5 bar. As expected this is a little less than the maximum pressure with 60 sec valve closure time but not greatly.

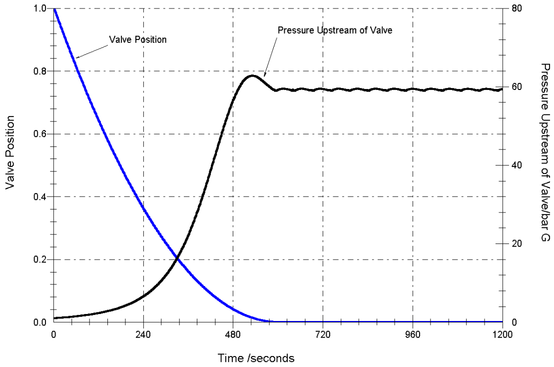
Graph 1.3. - Offshore Oil Pipeline - Valve Closure in 240 sec



The pressure peak occurs at the lowest point and has a value of 88.9 bar.

In the next case we consider a valve closure time of 600 sec with a quadratic pattern. The advantage of quadratic valve closure is the following. Generally, the pressure surge is created during the final stages of valve closure. With quadratic valve closure the valve closes quickly to begin with and slowly during the final moments. So, within a given valve closure time, the effective rate of closure during the critical period is slow.

Graph 1.4. - Offshore Oil Pipeline - 600 sec Quadratic Valve Closure



The maximum pressure at the lowest point of the system is 69.1 bar. It is difficult to reduce this significantly for the following reason. The closed head of the pump is 57 bar. The additional pressure due to static head is approximately 7 bar. The pressure at the lowest point would therefore be 64 bar even without any pressure surge.

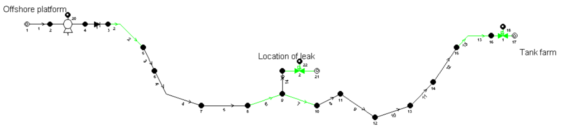
The next scenario we consider is the case in which a subsea pipeline ruptures on the seabed. This is potentially a serious hazard from two points of view. In an area like the Arabian Gulf leakage of oil into the sea could be a major disaster. Furthermore, the sheer waste is something an operator has to contend with.

One major issue in a matter like this is the analysis of the economics of the system. Is it cost effective to install a leak detection system? It would therefore be of interest to consider two cases.

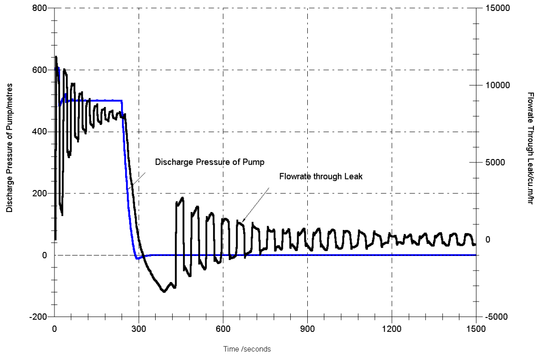
- The case in which a leak detection system has been installed.
- The case in which a leak detection system has not been installed.

In both cases we assume that the leak takes 30 sec to fully develop. The leak itself occurs approximately 15 km downstream of the pump.

In the first case the leak is detected 240 sec after it begins and a signal is sent to the pump to stop and the valve to close. After receiving the signal to stop, the pump takes 60 sec to wind down. The valve closes in 180 sec after receiving the signal to close. The system schematic and the graphical results are shown below.

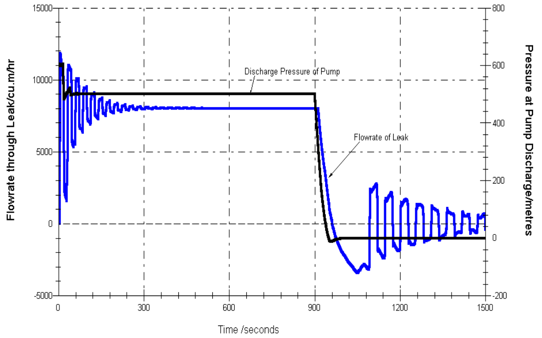


Graph 1.5. - Offshore Oil Pipeline - Pipe Rupture



In the second case we assume that the pump continues to operate and the valve remains open even after the leak starts. The operators manually detect that there has been a leak and the system is shutdown 15 minutes after the leak starts.

Graph 1.6 - Offshore Oil Pipeline - Pipe Rupture

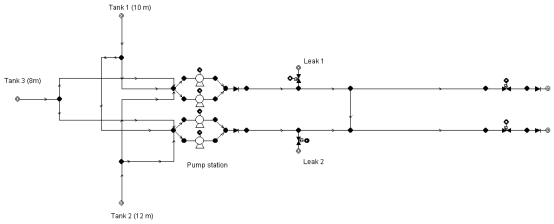


As expected, the case without the installation of the leak detection system results in a considerably greater environmental impact. In addition what PIPENET can do is to estimate the amount of oil which has leaked into the sea in the above cases. Furthermore, PIPENET can be used to assess the impact of parameters such as the response time of the leak detection system, the spindown time of the pump, the valve closure time and other parameters.

Amount of leakage with leak detection system - 600 m$^3$
Amount of leakage without a leak detection system- 2070 m$^3$

## ONSHORE PIPELINE MODELLING:

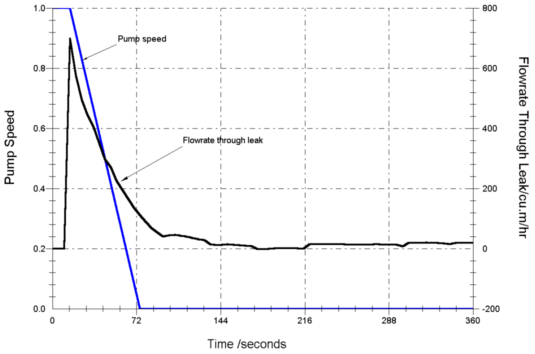
The second case we consider is an onshore cross-country pipeline system. The system imports oil from three tanks in a tank farm and delivers to two delivery points using two parallel pipelines. The oil is pumped by one pumping station consisting of four pumps, connected in the form of two parallel sets. The parallel pipes have an interconnecting pipe approximately half way along.



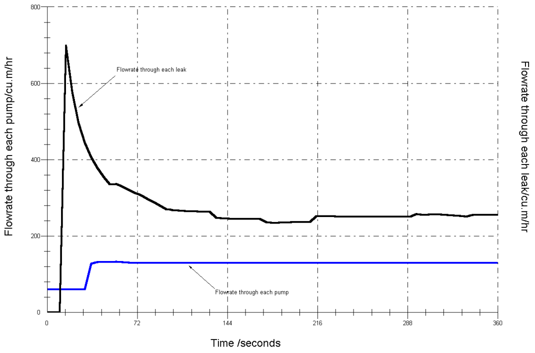
We model the case in which both pipelines rupture approximately in the same location. The leak fully develops in 10 secs. The following scenarios are considered.

- In the first scenario we assume that a leak detection system has been installed which sends a signal to shut down the pumps, within 5 sec of the leak beginning to develop. The pumps themselves take 60 sec to spin down. (Graph 2.1.)
- In the second scenario we consider the case where a leak detection system has not been installed. The pumps continue to operate normally even after the leak occurs. (graph 2.2.)

Graph 2.1 - Onshore Oil Pipeline - Pipe Rupture



Graph 2.2. - Onshore Oil Pipeline - Pipe Rupture



In both the scenarios there is a rush of oil when the leak occurs. However, in the case where a leak detection system has been installed, the flow rapidly goes down to almost zero. There is a small remaining flowrate because of the static head caused by the oil level in the tanks. In the scenario without the leak detection system, the flowrate through the leak continues at a substantial level.

PIPENET can be used to estimate important factors such as the volume of leakage and the impact of parameters which are under the control of the pipeline integrity engineer.

## CONCLUSION:

ZADCO has achieved pioneering leadership in the field of developing pipeline integrity risk management techniques. In this paper we have shown how to achieve practical benefits by illustrating the application of this technology in support of pipeline integrity risk management initiatives. This is an important issue in the Arabian Gulf.

The dynamic nature of pipeline operations makes the risk picture a complex one. Many lines are placed in a service for which they were not originally designed. Pressure, flowrates, velocities, and the composition of the fluid transported change over time from the initial design. Inspection, maintenance and repair are weather dependent as well and require boats, special equipment and expensive personnel, adding to the costs.

Dynamic modelling using PIPENET can allow more informed decisions to be made in order to better manage pipeline assets including reduce wasted efforts in inspection and maintenance. The result of this work is an increase in safety and reliability of operating pipelines at the lowest possible cost.

## THE AUTHORS:

Dr Waheed Al-Rafai obtained his PhD in Fluid Mechanics in 1990 from LJM University. He worked for Brown & Root Energy Services in the Arabian Gulf, USA and the UK. He now works for ZADCO in the UAE, with responsibility for developing a Pipeline Integrity Risk Management System for an extensive subsea pipeline network. He is a Fellow of the Institution of Mechanical Engineers in London and has a Master of Business Administration degree from Surrey University. He is the author of a number of papers on pipelines and related technologies.

Dr Dev Sebastian obtained his PhD in mathematics from Imperial College, London. He also has an MSc in Chemical Engineering. After working for BOC and CADCentre, he is now the Marketing Manager at Sunrise Systems in Cambridge, United Kingdom. He is the author of a number of papers on numerical methods.

The authors would like to thank ZADCO for giving permission to present this paper.

REPORT SUBMITTED TO

…………………..

BY

SUNRISE SYSTEMS LTD
Flint Bridge Business Centre
Ely Road
Cambridge CB5 9QZ

………………………………….

# FIREWATER SYSTEM DYNAMIC ANALYSIS

Project Number: ………………………
Project Reference: ……………………
Date: June 2000

# MANAGEMENT SUMMARY

This study is concerned with the ................. ................. ................. Project. The firewater system on the new platform ………… of the ................. ................. installation is supplied by the fire pumps on the existing platform …………….. This analysis considers the complete firewater system which extends through both platforms.

Data for the new ……………….. systems were derived from design documentation. Data for the existing …………………….. systems was obtained from documentation held by ……. and from site representatives. Some of the data for the existing systems was incomplete and assumptions have been incorporated in the analysis where necessary. The primary assumption is that the existing system operates satisfactorily.

The objective of the project was to consider the possibility of pressure surges occurring during the following cases, and where necessary recommend methods for reducing such pressures:

Pump Start Up and Priming

Start Up of the Worst Case Scenario on ……………….. platform

Shut Down of the Worst Case Scenario on …………………….. platform

Based on the results of the simulations the following recommendations are made:

- The overboard dump valve is closed over a period of 5 secs after the system has primed.
- The deluge valve is made to open in no less than 5 secs
- A vacuum breaker (50 mm vacuum breaker, 10 mm air release) valve is fitted to the highest point in the system.
- The deluge valves and other valves should have a closure time based on the usual rules for valve closure times, subject to a minimum of 5 secs.

## 1. INTRODUCTION:

This part of the report is concerned with the results of the simulations performed on the firewater ringmain system. It considers three scenarios.

Pump Start Up and Priming

Start Up of the Worst Case Scenario

Shut Down of the Worst Case Scenario

Several simulations were performed in each of the above scenarios. Many of the simulations were aimed at studying the effect of varying the relevant parameter, with the view of selecting an optimum value. For example, one of the objectives was to investigate the need for an overboard dump valve. The simulations were not only performed with the view of establishing the need for such a dump valve, but also its optimum size.

The report also outlines the observations which were made as a result of the simulations and describes the possible solutions to any surge problems which were discovered.

## 2. PUMP START UP AND PRIMING:

The models which were used to perform this simulation were a pipe which represents the depth of water to the caisson inlet, the fire pump, a caisson which is used to model the riser pipe and the firewater ringmain itself. The caisson model takes the LAT as its initial water level and determines the time it takes to fully prime the riser pipe. The data used for the fire pumps and the caisson are shown below:

Pump data:

Pump curves for Firewater Lift and Booster pumps.

| Flow rate, m3/hr | Pressure, m (Pump No P-7002A as tested on 01/10/98) | Pressure, m ( Pump No P-7002B as tested on 01/10/98) |
|---|---|---|
| 0 | 202 | 199 |
| 50 | 184 | 178 |
| 70 | 172 | 166 |
| 100 | 138 | 126 |

Pump connectivity for the Firewater pump

| | |
|---|---|
| Pump label | 1 |
| Inlet node | 24 |
| Outlet node | 22 |
| Information node | 25 |
| Pump Type | P – 7002B |

Pump P – 7002B was used in a majority of simulations. Pump P – 7002A was used for the purpose of spot checks.

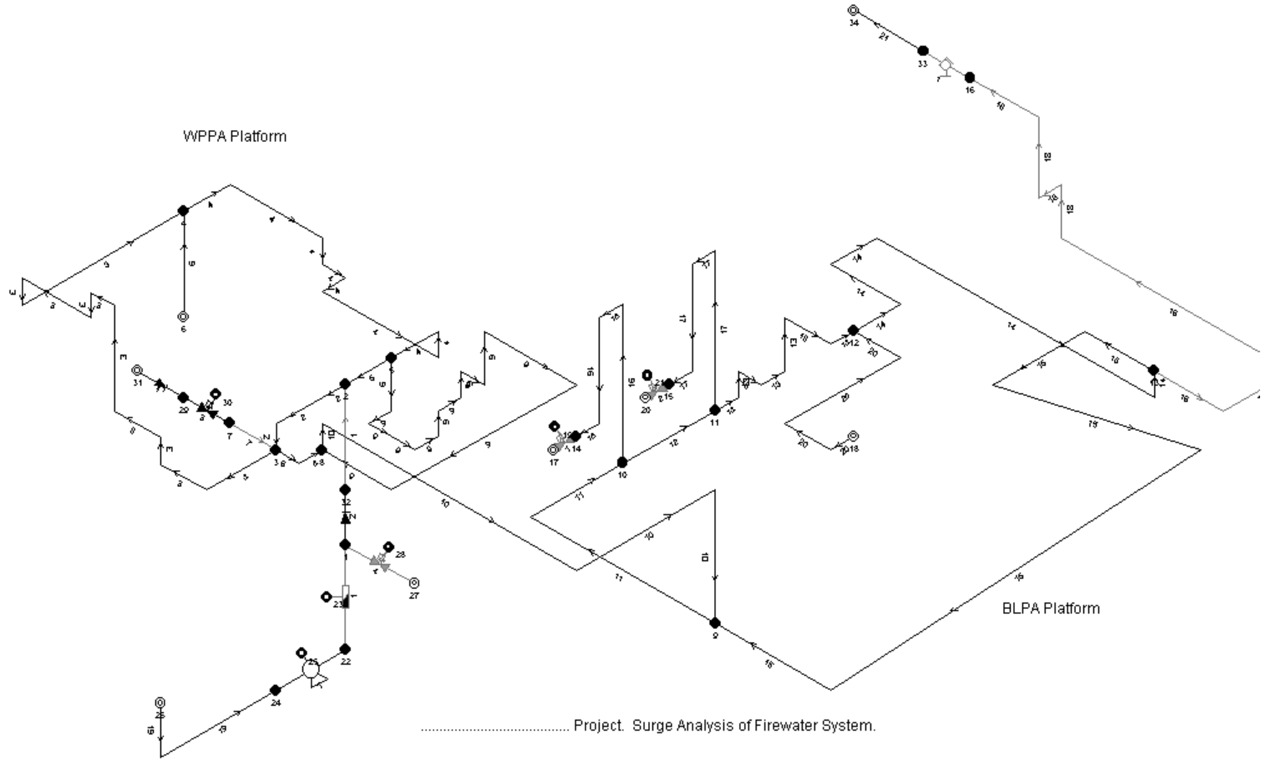
Caisson data:

| | |
|---|---|
| Caisson label | 1 |
| Inlet flow node | 22 |
| Valve information node | 1 |
| Caisson length, m | 35.995 |
| Caisson diameter. Mm | 200 |
| Caisson elevation, m | 35.995 |
| Initial fluid depth, m | 11.995 |
| Critical fluid depth, m | 35.995 |
| Valve diameter, mm | 50 |
| Valve discharge coefficient | 1 |

In principle there are three specifications :-

- The inlet pressure to the system is 0 bar(g)
- The fire pump starts at 1 sec and achieves full speed at 15 secs
- The air release valve on the caisson starts to open at 1 sec and completes opening at 2 sec

A sketch of the system is shown on the next page.:



Fire pump priming is known to be a potential cause of unacceptable levels of pressure surge in fire water systems. Fire pumps are typically started under two circumstances.

If there is a fire and, as a result, the firewater ringmain depressurises.

During routine tests of the firewater pumps, which are generally carried out once a week.

Under both these circumstances, water which rises rapidly in the dry riser pipe could be brought to rest instantaneously on completion of priming. This is likely to cause a substantial pressure surge, unless an escape route is found by the water. This is typically provided by an overboard dump valve, which is closed after priming in a manner which will reduce the level of pressure surge to an acceptable value.

The traditional method of reducing the pressure surge at the end of pump priming is by using an overboard dump valve. At this point in time the overboard dump valve size is not known. It is known that the ……………….. platform does not exhibit surge problems. So, it was decided to find a suitable size and closure time for the overboard dump valve, which would then be used in the ringmain simulation calculations.

In selecting the optimum valve size, two conflicting factors have to be balanced. If the valve is too small, when the rising water reaches it, there could be significant deceleration which would result in a high pressure surge. While this surge would not be as high as the case where there is no overboard dump valve, it could still be unacceptably high. If the valve is too big another problem might be encountered. If the valve closure time is the same, and the flow rate is the same, a larger valve could potentially increase the pressure surge. This is because the flow rate would tend to be decelerated more quickly during the final moments of valve closure. A larger valve would offer a smaller resistance, given the same flow rate and the flow rate would decrease more slowly during the initial stages of valve closure.

The overboard dump valve is assumed to close from 15 to 20 seconds in all simulations.

| Case | Valve $C_v$ (lit/min, bar) | Peak Pressure, bar | Graphs |
|---|---|---|---|
| Scenario 1 | None (with Vacuum breaker) | 101.9 | 1.1. – 1.4. |
| Scenario 2 | None (no Vacuum breaker) | 101.9 | 2.1. – 2.4. |
| Scenario 3 | 2000 | 18.99 | 3.1. – 3.4. |
| Scenario 4 | 1000 | 33.52 | 4.1. – 4.4. |
| Scenario 5 | 3000 | 19.43 | 5.1. – 5.4. |
| Scenario 6 | 2500 | 19.21 | 6.1. – 6.4. |

As expected there is a clear optimum size for the valve represented by its $C_v$ factor. The optimum valve would correspond to a $C_v$ value of 2000 (lit/min, bar). The value of $C_v$ for the actual valve is unknown. For this reason, the above value is used for all the subsequent simulations.

The above values for $C_v$ expressed in US units are shown below:

| $C_v$ (lit/min, bar) | $C_v$ (USgpm, psi) |
|---|---|
| 1000 | 69.36 |
| 2000 | 138.71 |
| 2500 | 173.39 |
| 3000 | 208.07 |

## 3. START UP OF THE WORST CASE SCENARIO:

The start up and shut down of the largest system is a potential source of pressure surge.

During start up the firewater ringmain could be depressurised, because the fire pumps have not primed the riser pipe and begun delivering water. As a result of this the higher parts of the system could experience cavity separation. When the fire pumps re-pressurise the system the cavity would collapse, creating a high pressure due to the implosion effect.

The restriction orifice plate in the interconnecting line is modelled by specifying its $C_v$ factor. In the simulations it is assumed that the flow is controlled by a restriction orifice plate in the interconnecting line, and so the $C_v$ is assumed to be a constant value. There is also a check valve in the interconnecting line between the sea water system and the fire water system. The purpose of this line is to keep the firewater ring main system pressurised when the fire pumps are not working.

The $C_v$ of the orifice plate itself is calculated as follows. The flow rate through the orifice plate was assumed to be 433 lit/min when the pressure loss is 2 bar. The corresponding $C_v$ was calculated as follows:

$C_v$ = 433/sqrt(2) = 306.2 (lit/min,bar) = 21.24 (USgpm,psi)

This value is assumed to be constant.

The two deluge systems which form the worst case scenario are also modelled using the corresponding $C_v$'s. The deluge systems have the following system demands and the corresponding $C_v$'s are also shown below:

$C_v$ = 2958/sqrt(8.437) = 1018.4 (lit/min, bar) = 70.63 (USgpm,psi)

$C_v$ = 2257/sqrt(8.542) = 772.2 (lit/min, bar) = 53.56 (USgpm,psi)

For the sake of simplicity it is assumed that the deluge systems can be modelled as linear valves with the above characteristic flow coefficients.

The pipework data is shown in the following table:

| Pipe label | Input node | Output node | Diameter, mm | Length, m | Elevation, m |
|---|---|---|---|---|---|
| 1 | 32 | 2 | 150 | 15.922 | 5.253 |
| 2 | 2 | 3 | 150 | 4.059 | 0.13 |
| 3 | 3 | 4 | 200 | 2.761 | 0 |
| 4 | 4 | 5 | 150 | 98.34 | 0 |
| 5 | 5 | 2 | 150 | 1.423 | 0 |
| 6 | 6 | 4 | 150 | 17.481 | 5.27 |
| 7 | 7 | 3 | 80 | 15 | 0 |
| 8 | 3 | 8 | 250 | 0.968 | 0 |
| 9 | 5 | 8 | 150 | 13.111 | 0.13 |
| 10 | 8 | 9 | 250 | 130.429 | -5.349 |
| 11 | 9 | 10 | 250 | 8.75 | 0 |
| 12 | 10 | 11 | 250 | 4.6 | 0 |
| 13 | 11 | 12 | 250 | 19.89 | 5.8 |
| 14 | 12 | 13 | 150 | 37.25 | 0.55 |
| 15 | 13 | 9 | 150 | 70.11 | -6.35 |
| 16 | 10 | 14 | 150 | 6.405 | -0.611 |
| 17 | 11 | 15 | 150 | 6.405 | -0.611 |
| 18 | 13 | 16 | 100 | 48.79 | 9.27 |
| 19 | 26 | 24 | 800 | 11.995 | -11.995 |
| 20 | 18 | 12 | 250 | 11.7 | 6.15 |

|  |  |  |  |  |  |
|---|---|---|---|---|---|
| 21 | 33 | 34 | 80 | 10 | 0 |
|  |  |  |  |  |  |

The valves used in the simulations are described below:

Valve 4 represents the overboard dump valve. In cases where there is an overboard dump valve, it closes at the prescribed closure time for the overboard dump valve.

Valves 3 represents the orifice plates in the interconnecting line between the sea water system and the firewater system. It has a $C_v$ of 306.2 (lit/min, bar) as calculated above.

Valves 1 and 2 represent the operation of the deluge systems. Their $C_v$ values are 1018.4 and 772.2 (lit/min, bar) as calculated above

The pump curves were the same as those used in pump priming simulation.

The results are summarised in the following table:

| Case | Vacuum breaker size | Peak Pressure, bar | Deluge Valve Opening time,sec | Graphs |
|---|---|---|---|---|
| Scenario 7 | None | 68.88 | 1 | 7.1. – 7.4. |
| Scenario 8 | 50 mm x 12.5 mm | 39.49 | 1 | 8.1. – 8.4. |
| Scenario 9 | 50 mm x 10 mm | 22.80 | 1 | 9.1. – 9.4. |
| Scenario 10 | 50 mm x 6.25 mm | 11.71 | 1 | 10.1. – 10.4. |
| Scenario 11 | 50 mm x 10 mm | 19.61 | 5 | 11.1. – 11.4. |

Based on the above results, the following recommendations are made:

The deluge valve is made to open in no less than 5 secs

A vacuum breaker (50 mm vacuum breaker, 10 mm air release) valve is fitted to the highest point in the system.

## 4. SHUT DOWN OF THE WORST CASE SCENARIO:

System shut down is also a potential case for pressure surge.

| Case | Deluge valve closure time, sec | Peak Pressure, bar | Graphs |
|---|---|---|---|
| Scenario 12 | 5 | 19.68 | 12.1. – 12.4. |
| Scenario 13 | 10 | 19.12 | 13.1. – 13.4. |
| Scenario 14 | 1 | 27.94 | 14.1. – 14.4. |

It is recommended therefore that the deluge valve closure time is no less than 5 sec

## 5. RECOMMENDATIONS:

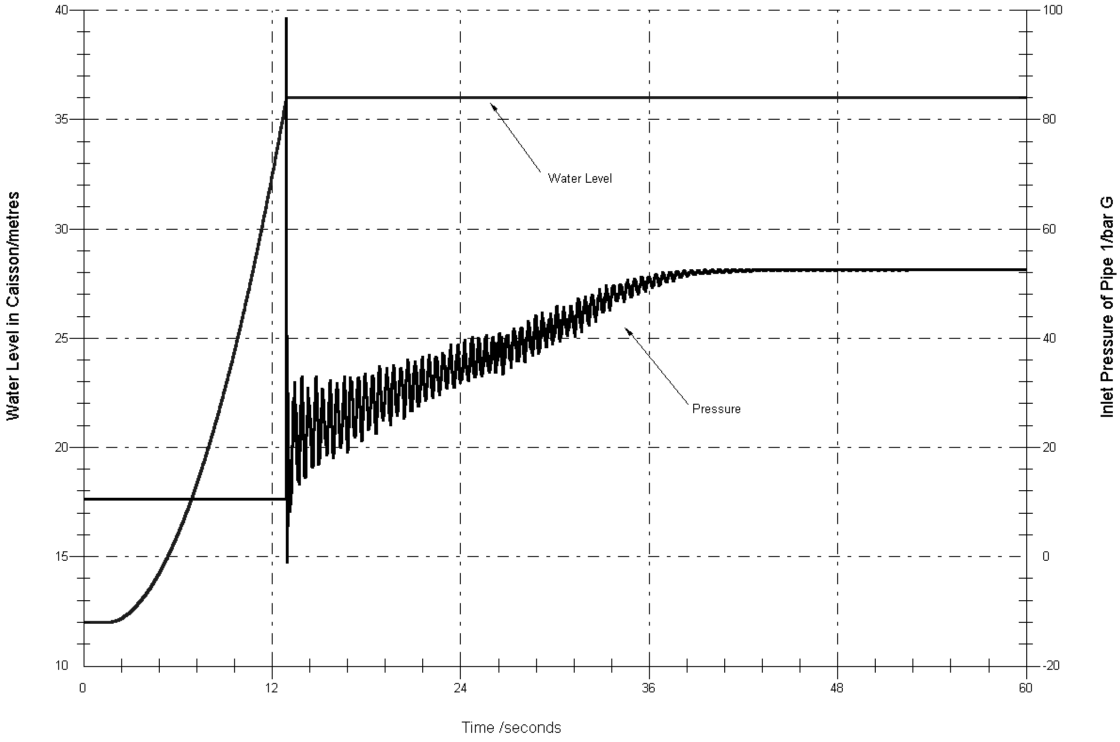
Based on the results of the simulations the following recommendations are made:

- The overboard dump valve is closed over a period of 5 secs after the system has primed.
- The deluge valve is made to open in no less than 5 secs
- A vacuum breaker (50 mm vacuum breaker, 10 mm air release) valve is fitted to the highest point in the system.
- The deluge valves and other valves should have a closure time based on the usual rules for valve closure times, subject to a minimum of 5 secs.

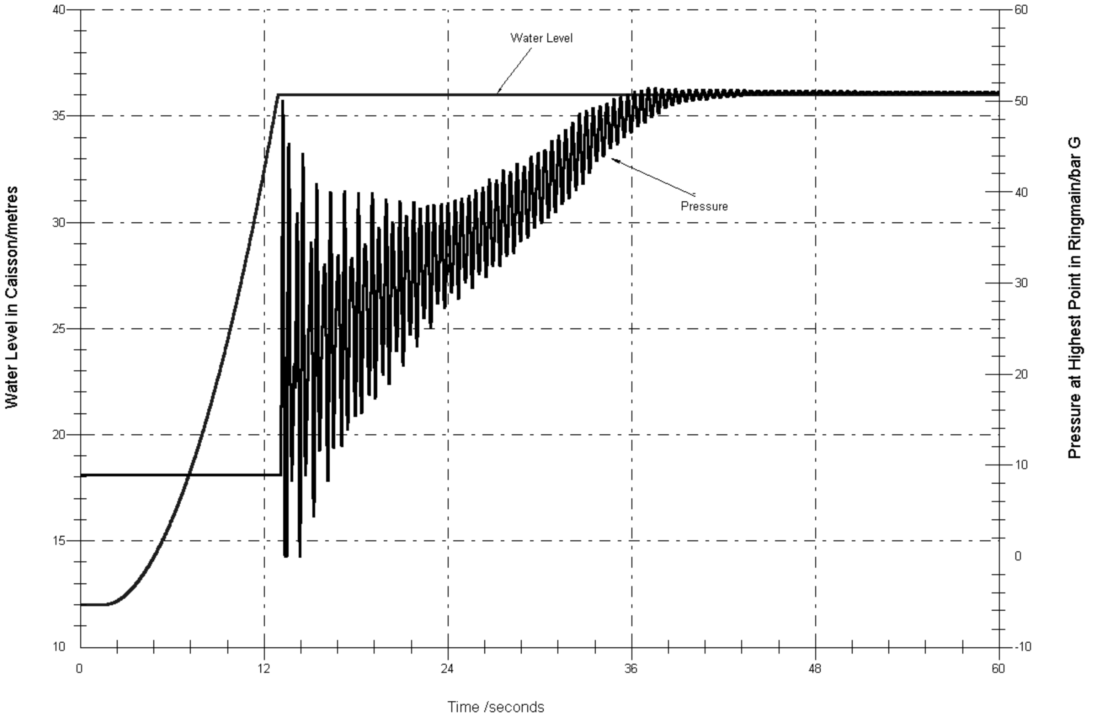
Note: It has been assume throughout that the existing priming arrangements operate satisfactorily. In particular it has been assumed that an overboard dump valve of an appropriate size has been installed.

# GRAPHICAL RESULTS

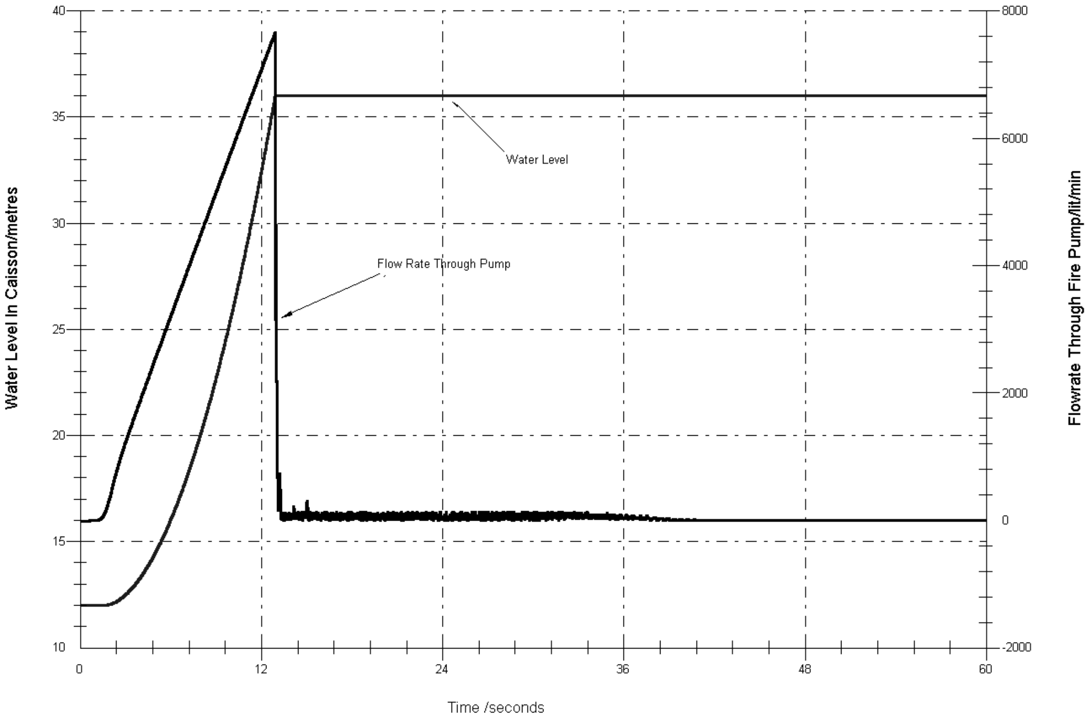
Graph 1.1. - Pump Priming with No Overboard Dump Valve



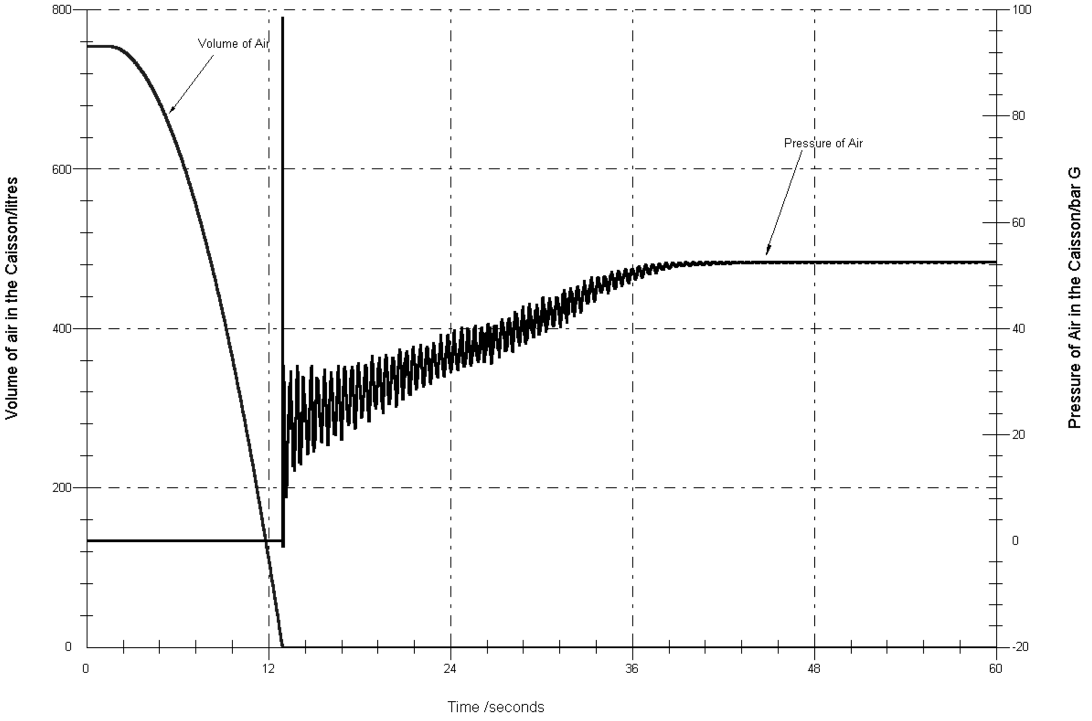
Graph 1.2. - Pump Priming with No Overboard Dump Valve



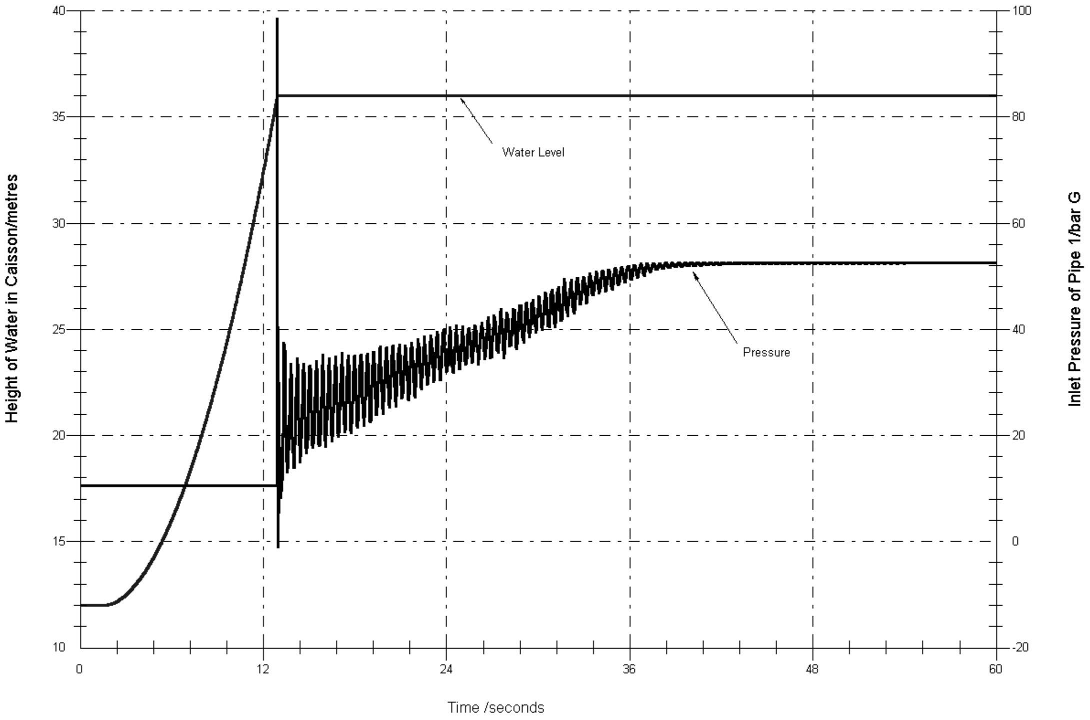
Graph 1.3. - Pump Priming with No Overboard Dump Valve



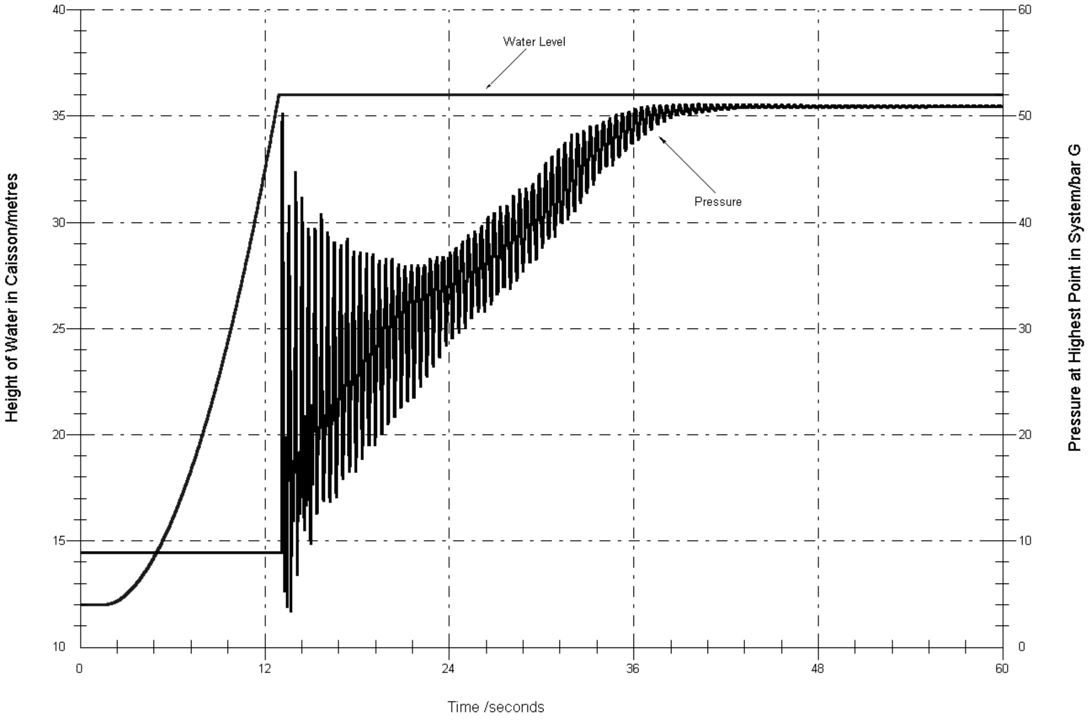
Graph 1.4. - Pump Priming with No Overboard Dump Valve



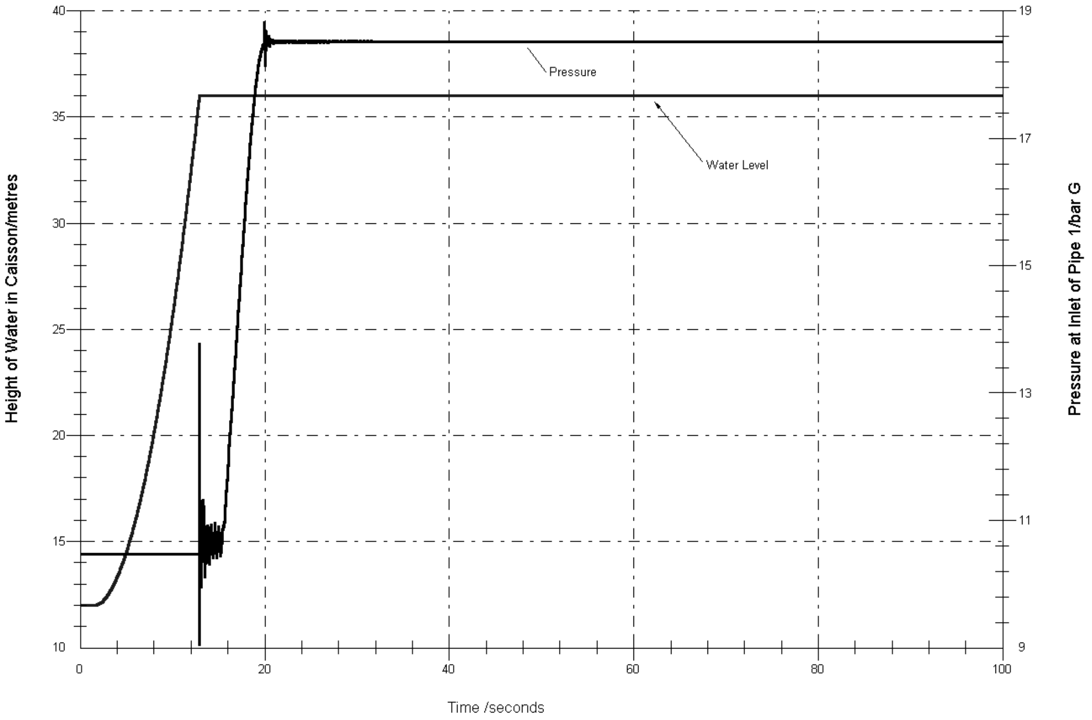
Graph 2.1. - Pump Priming with No Overboard Dump Valve, with Vac Breaker



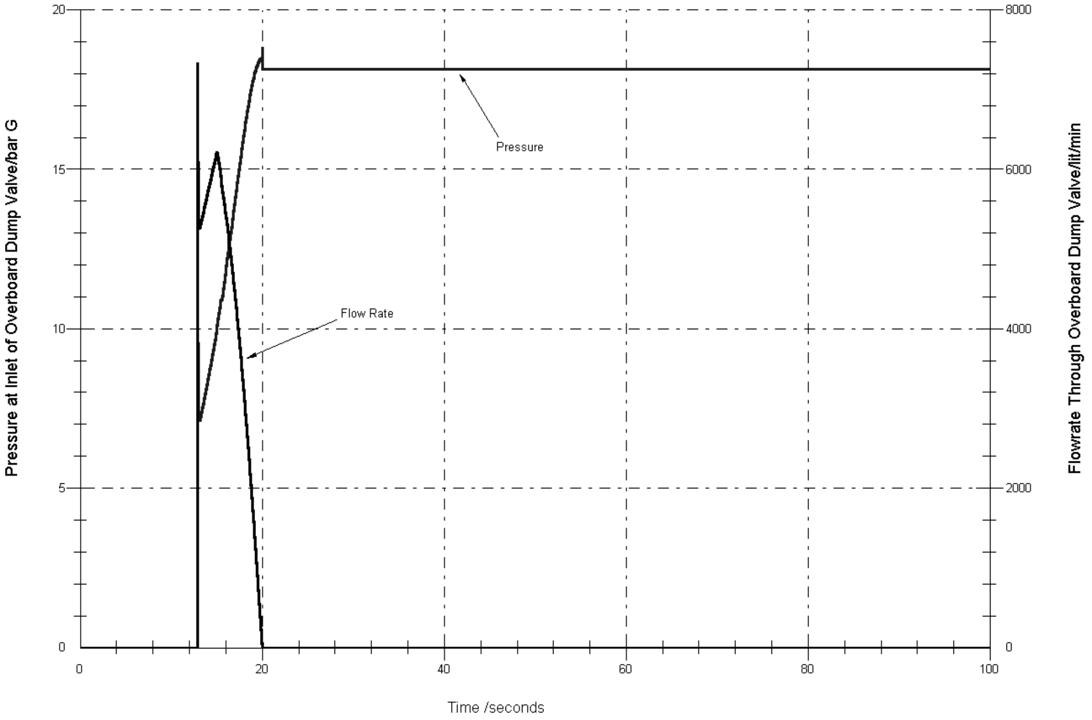
Graph 2.2. - Pump Priming with No Overboard Dump Valve, with Vac Breaker



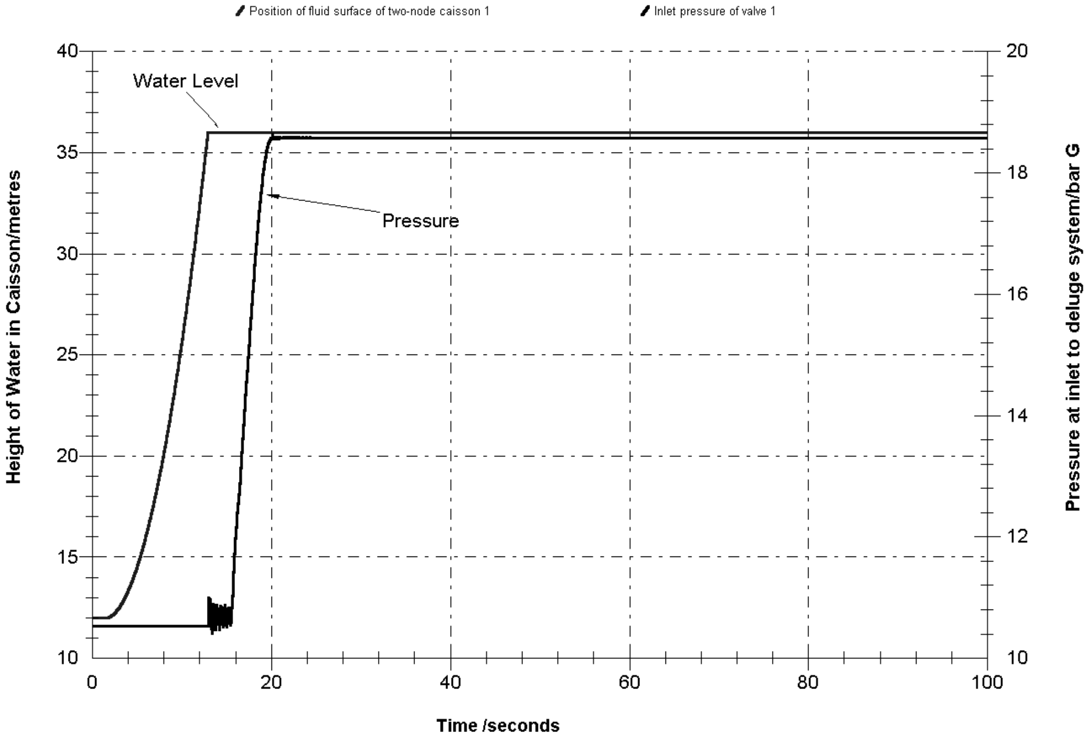
Graph 3.1. - Pump Priming with Overboard Dump Valve (Cv=2000,15 - 20 sec Close)



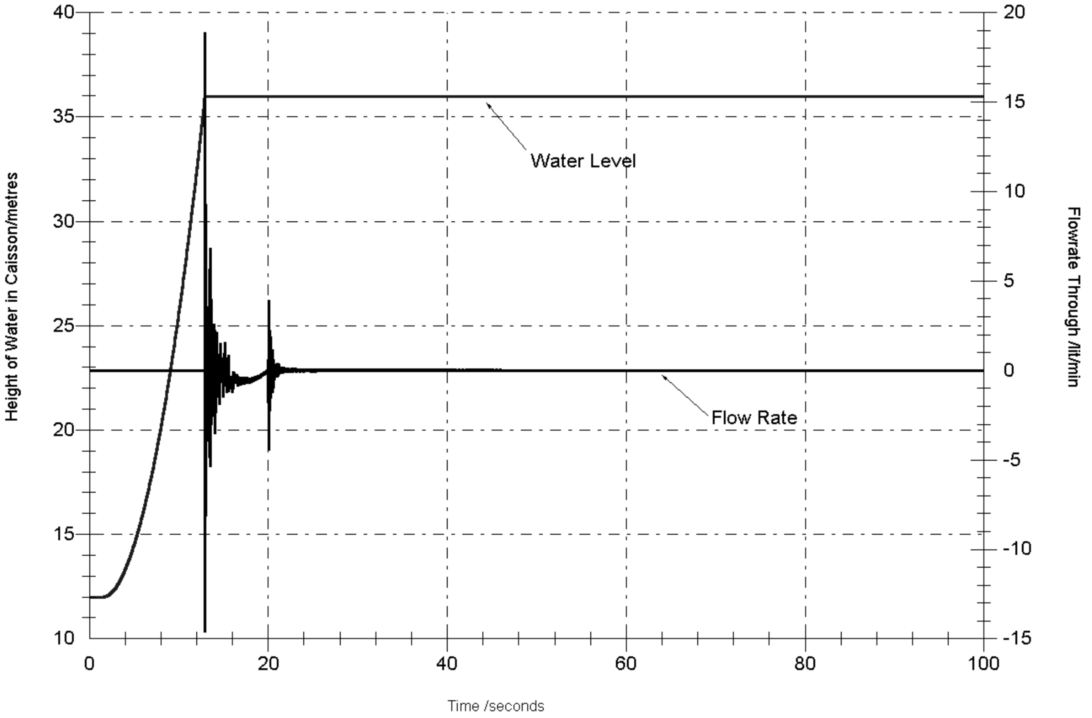
Graph 3.2. - Pump Priming with Overboard Dump Valve (Cv=2000,15-20 sec Closure)



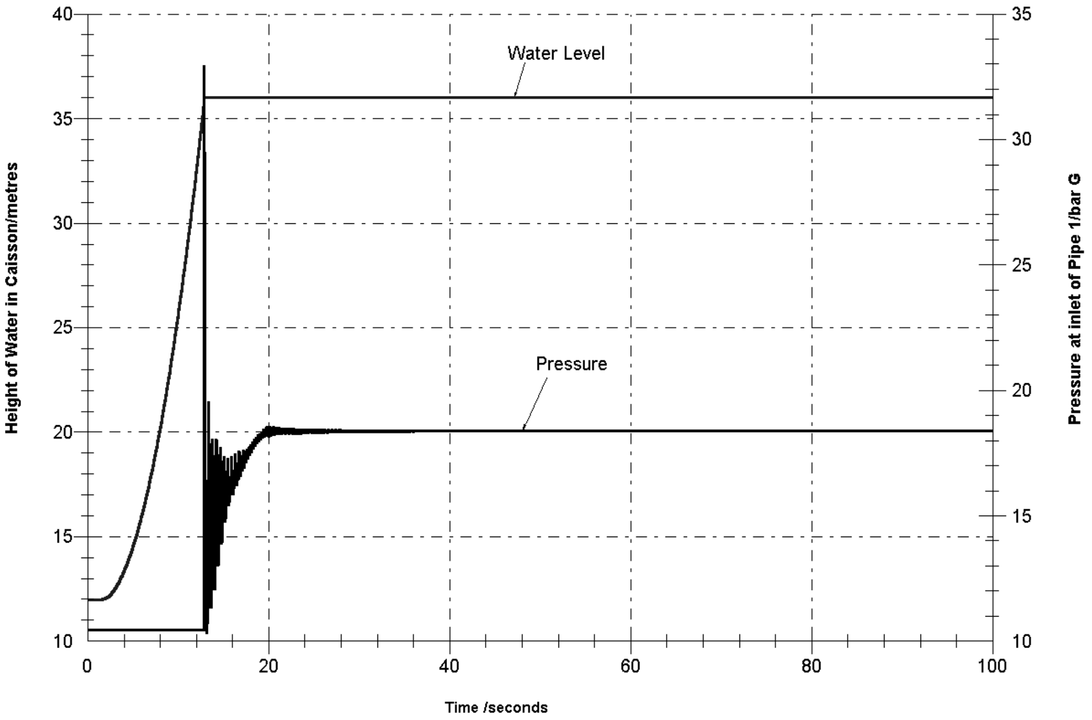
Pump Priming with Overboard Dump Valve (Cv=2000,15-20 sec close)



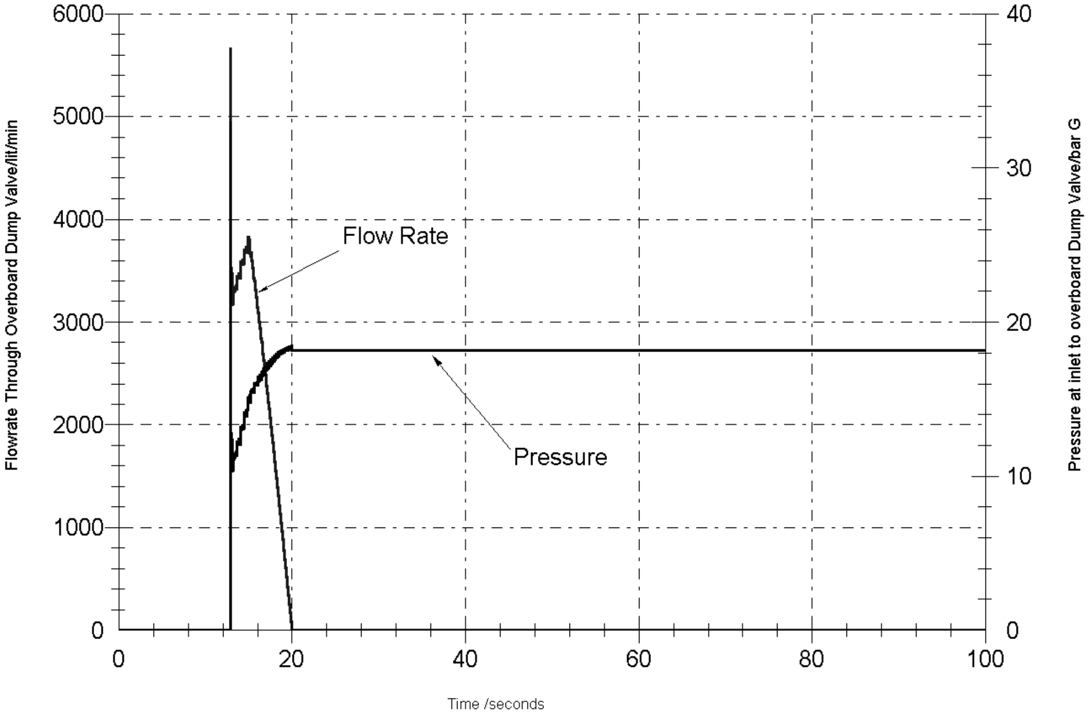
Graph 3.4. - Pump Priming with Overboard Dump Valve (Cv=2000,15-20 sec Close)



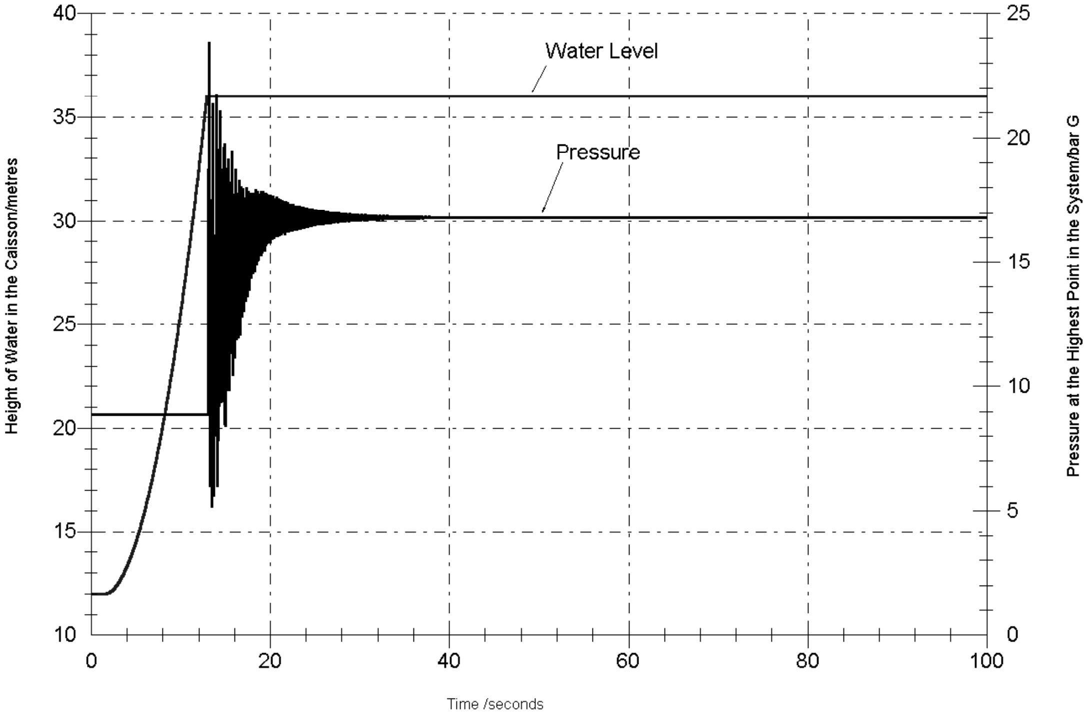
Graph 4.1. - Pump Priming with Overboard Dump Valve (Cv=1000,15 to 20 sec Close)



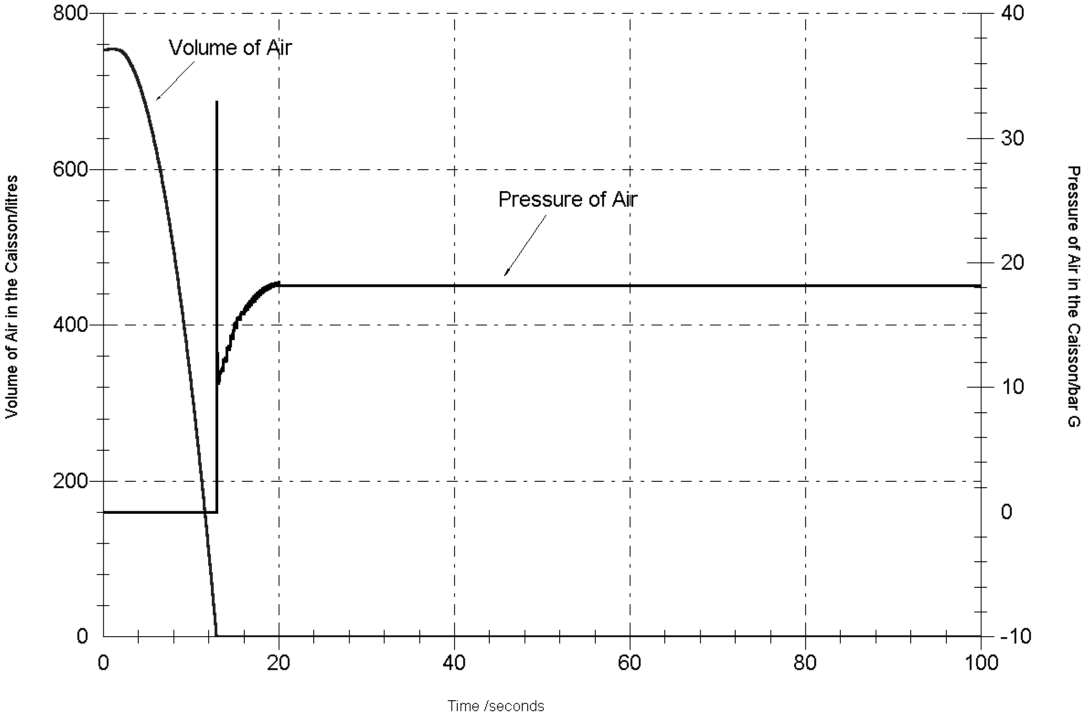
Graph 4.2. - Pump Priming with Overboard Dump Valve



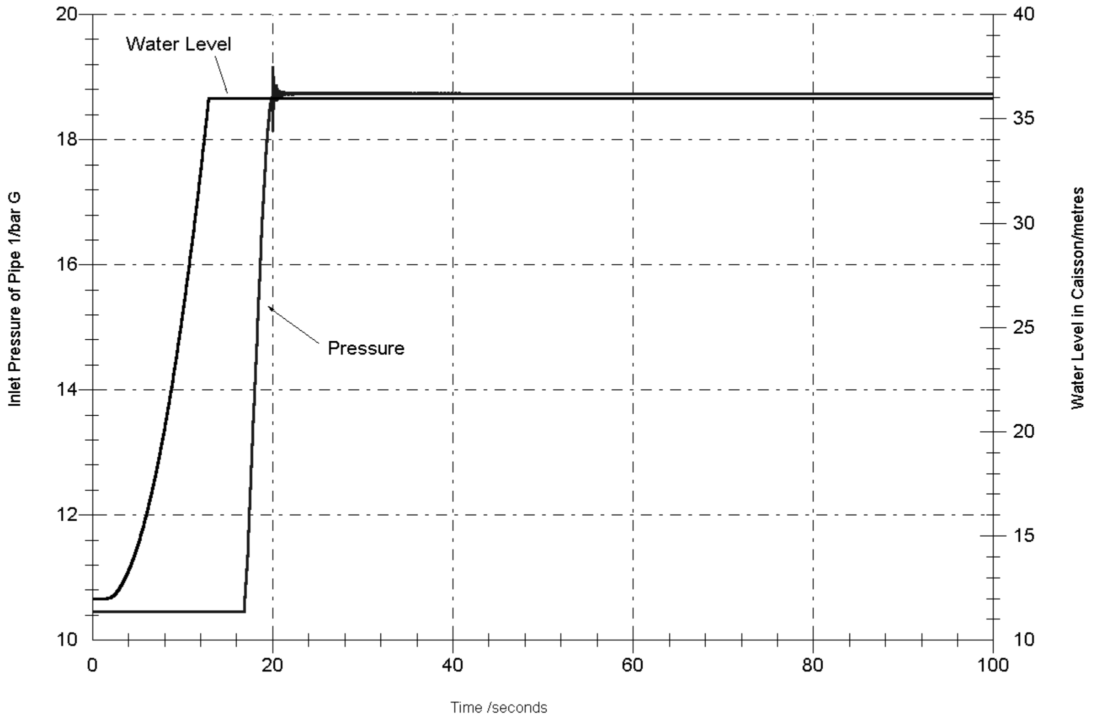
Graph 4.3. - Pump Priming with Overboard Dump Valve



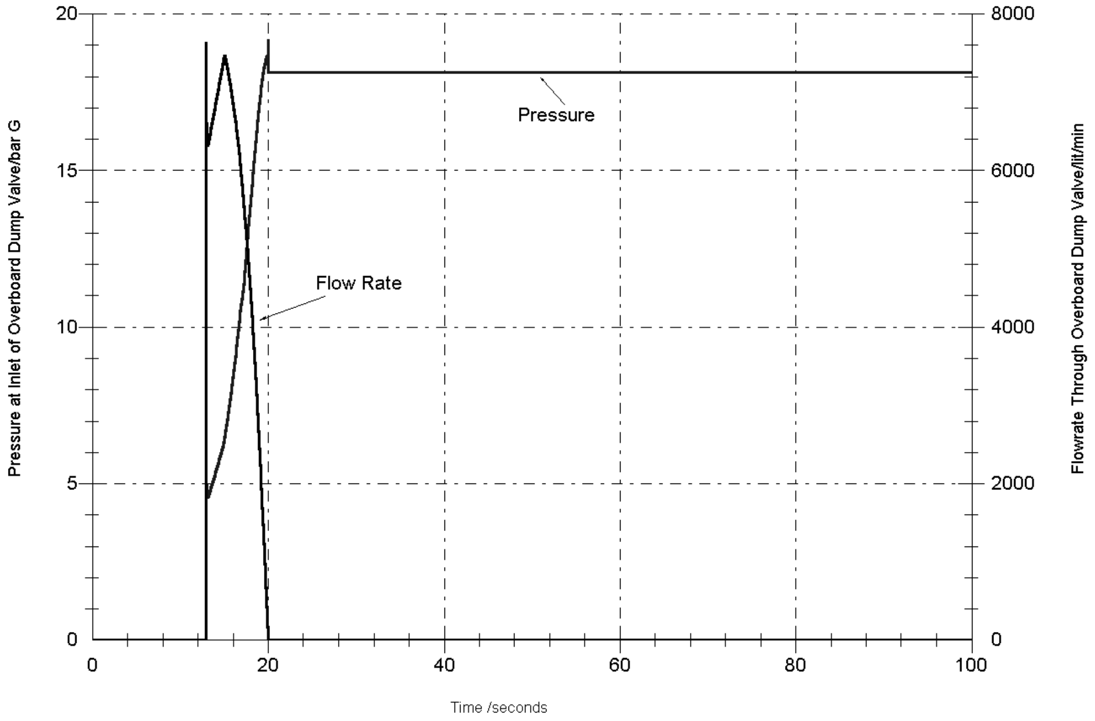
Graph 4.4. - Pump Priming with Overboard Dump Valve



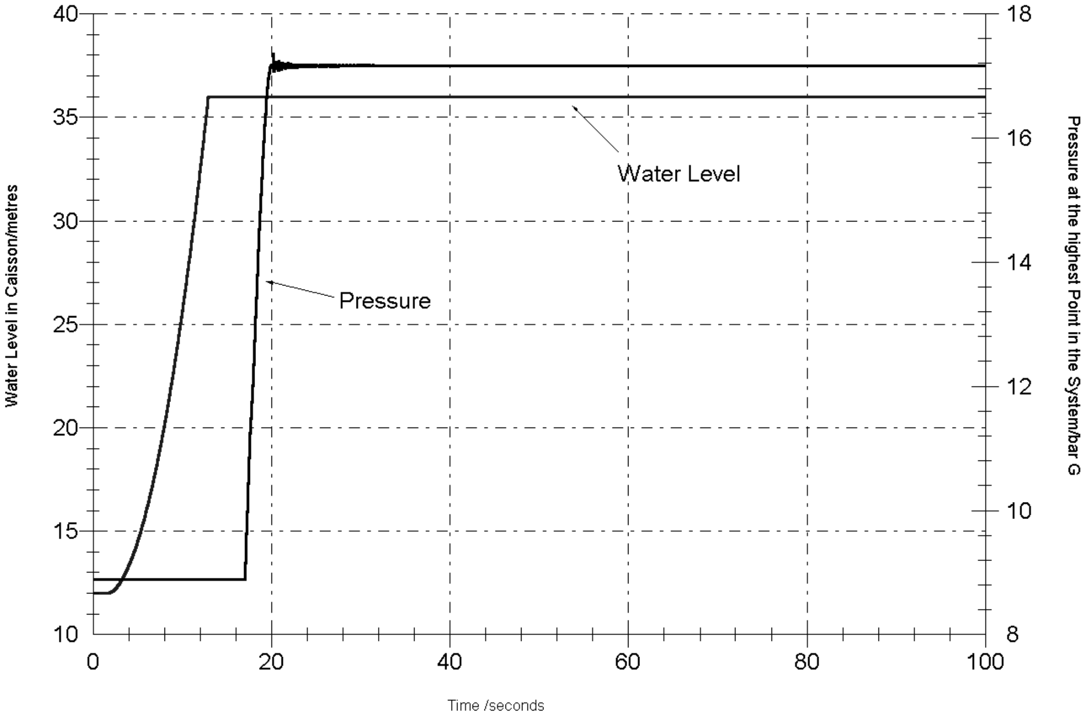
Graph 5.1. - Pump Priming with Overboard Dump Valve(Cv=3000, 15-20 sec Closure)



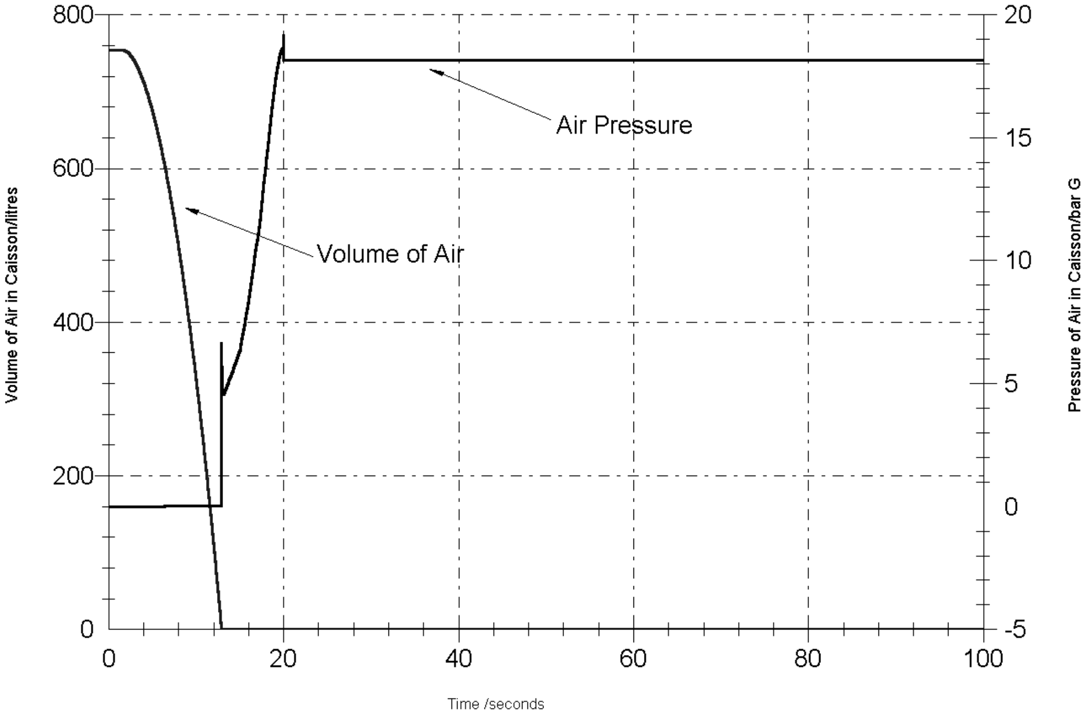
Graph 5.2. - Pump Priming with Overboard Dump Valve(Cv=3000, 15-20 sec Closure)



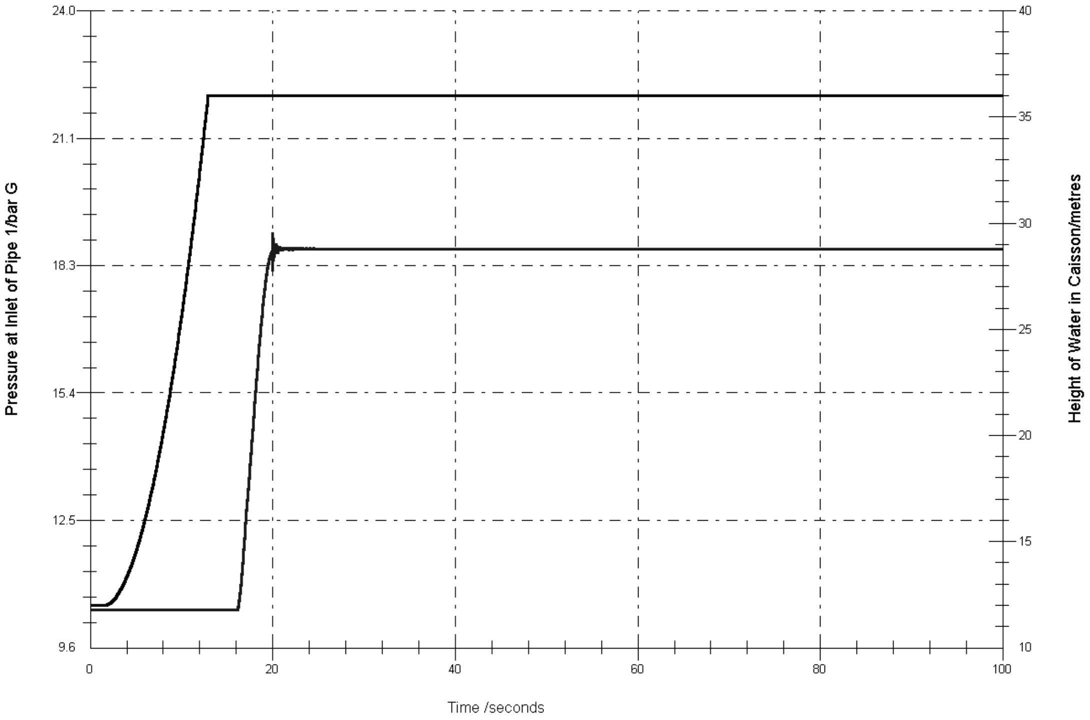
Graph 5.3. - Pump Priming with Overboard Dump Valve



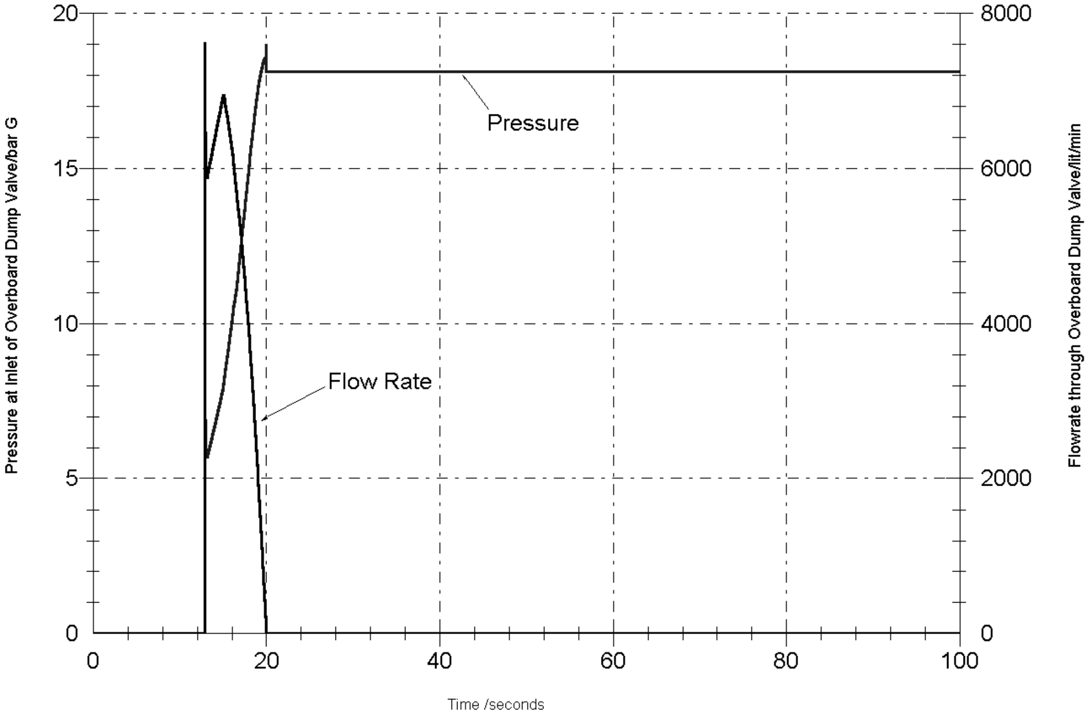
Graph 5.4. - Pump Priming with Overboard Dump Valve(Cv=3000,15-20sec Closure)



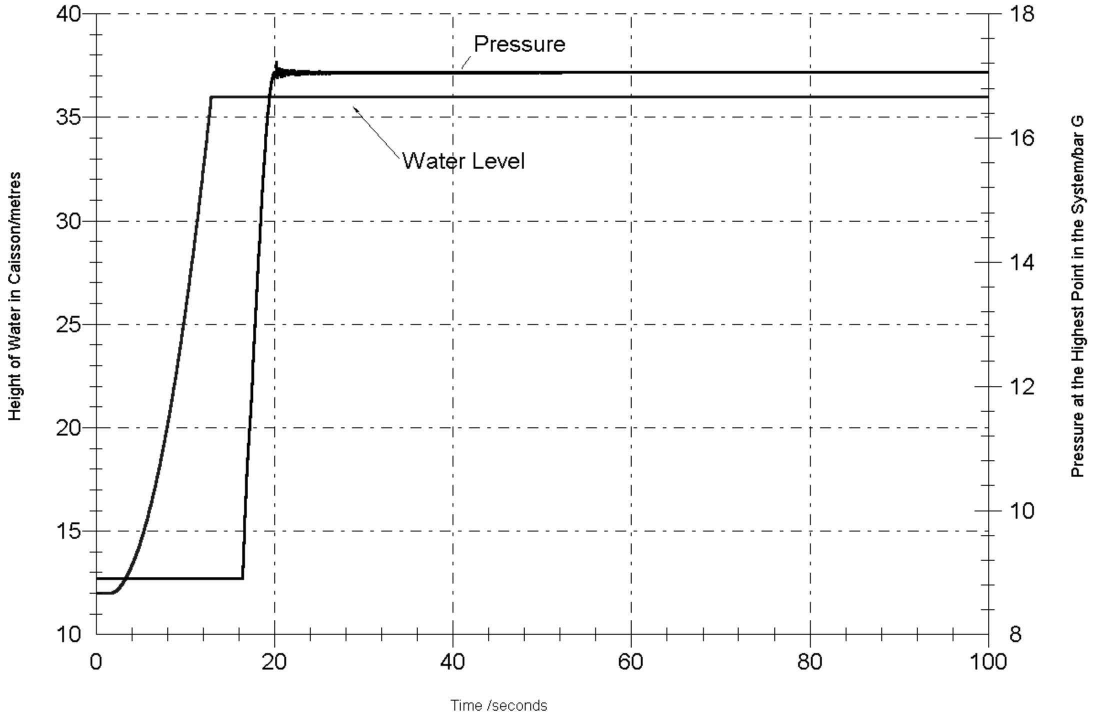
Graph 6.1.-Pump Priming with Overboard Dump Valve(Cv=2500,15-20sec Closure)



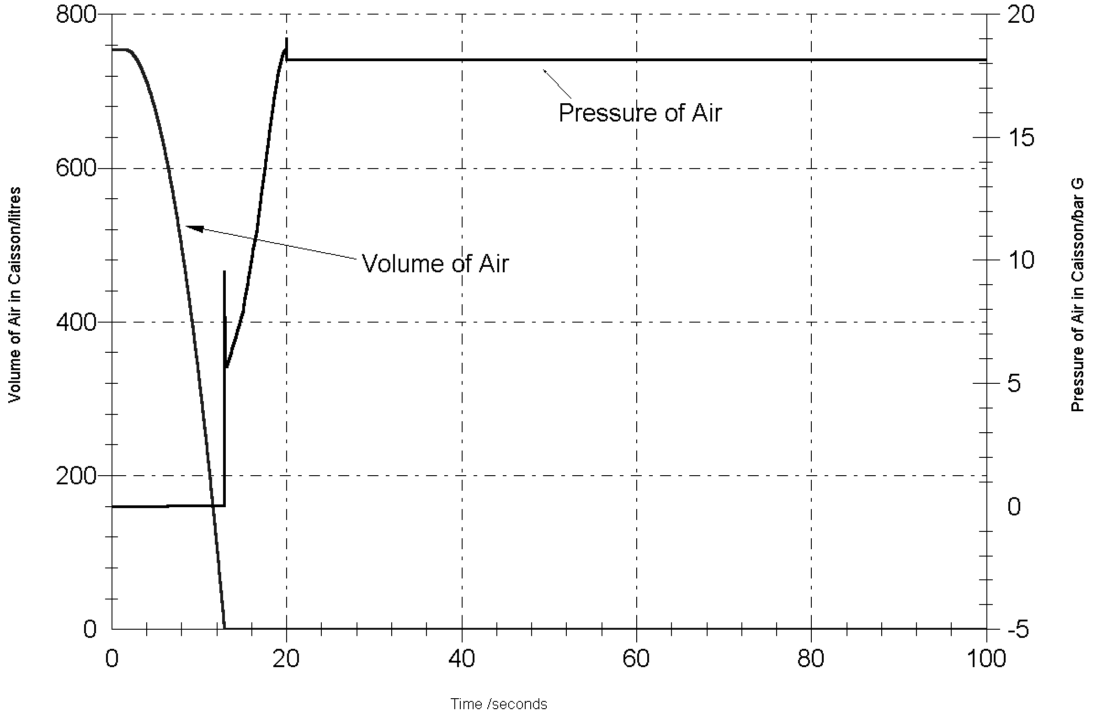
Graph 6.2.-Pump Priming with Overboard Dump Valve(Cv=2500,15-20 sec Closure)



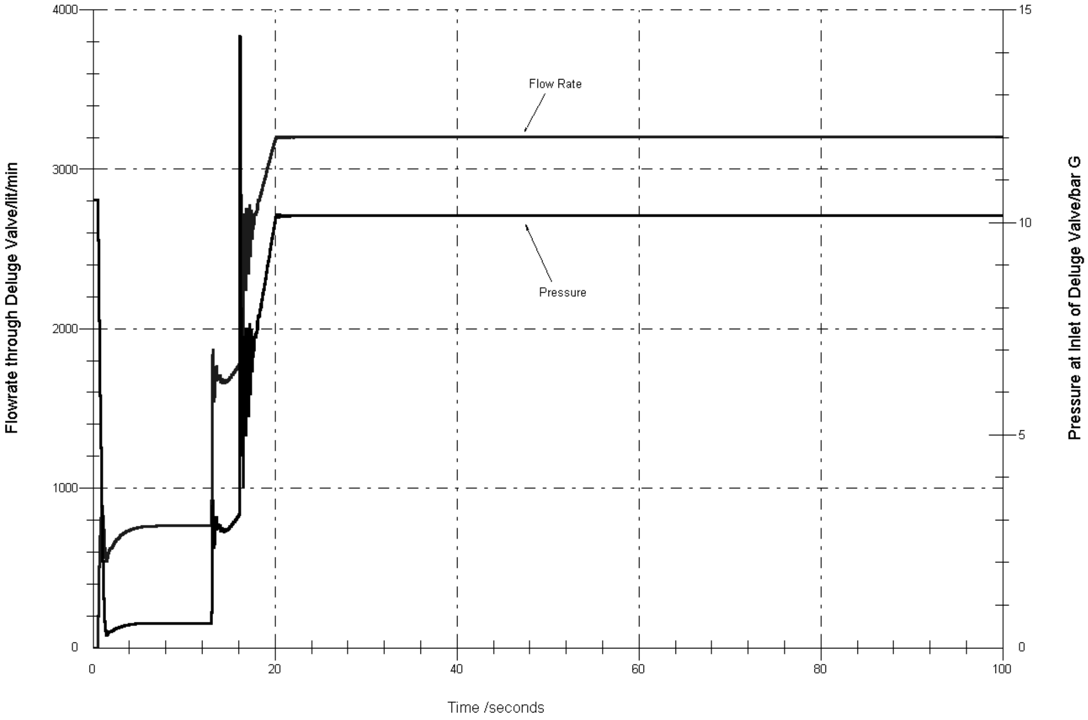
Graph 6.3.-Pump Priming with Overboard Dump Valve(Cv=2500,15-20sec Closure)



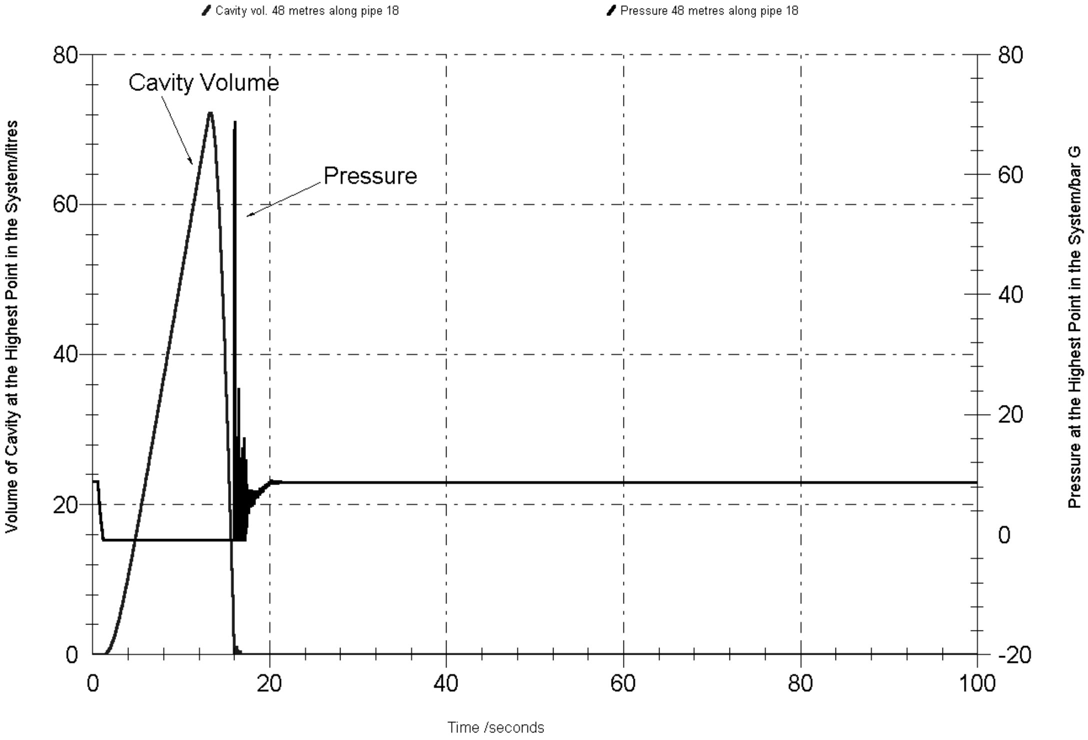
Graph 6.4.-Pump Priming with Overboard Dump Valve(Cv=2500,15-20 sec Closure)



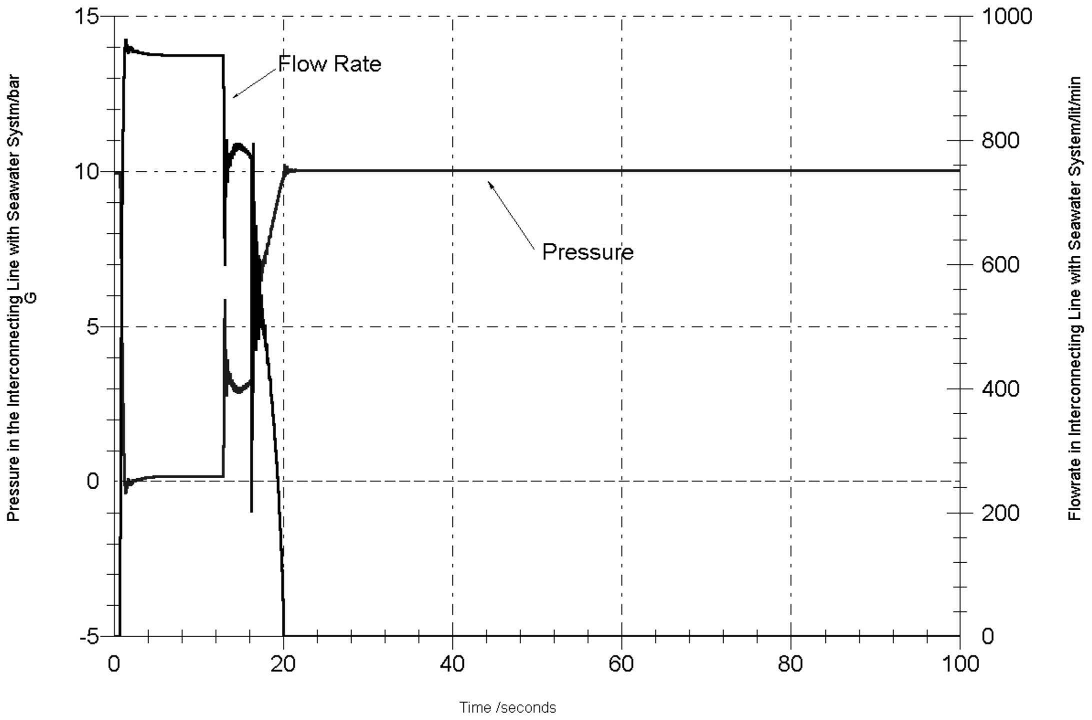
Graph 7.1.- Deluge System Operating



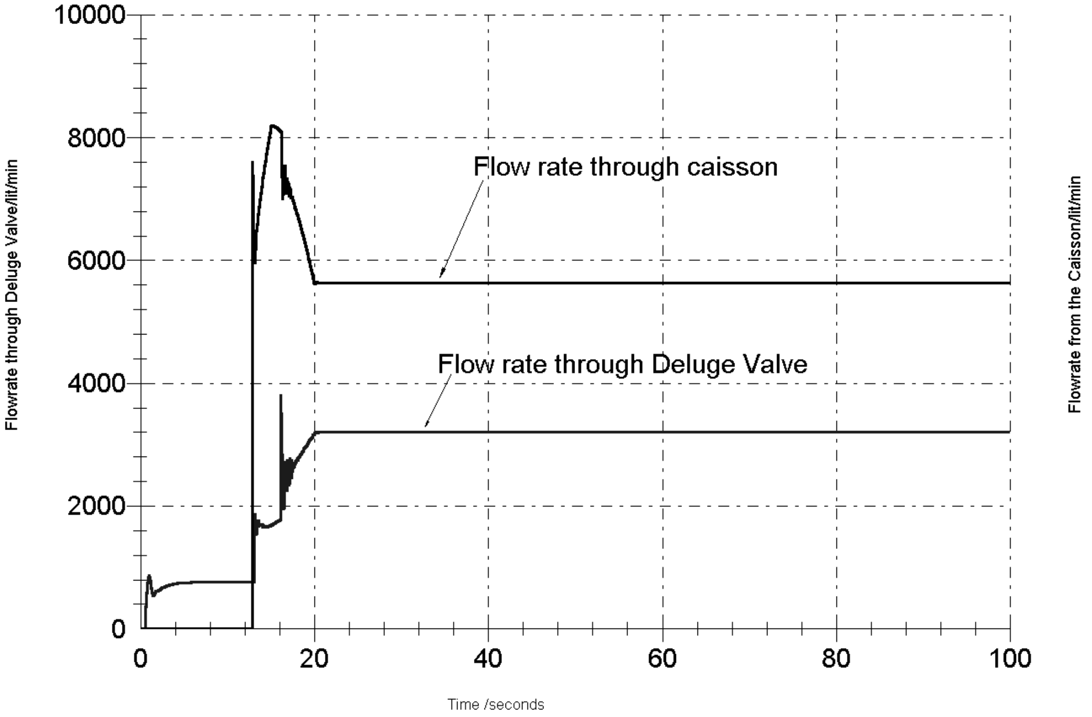
Graph 7.2. - Deluge System Operating



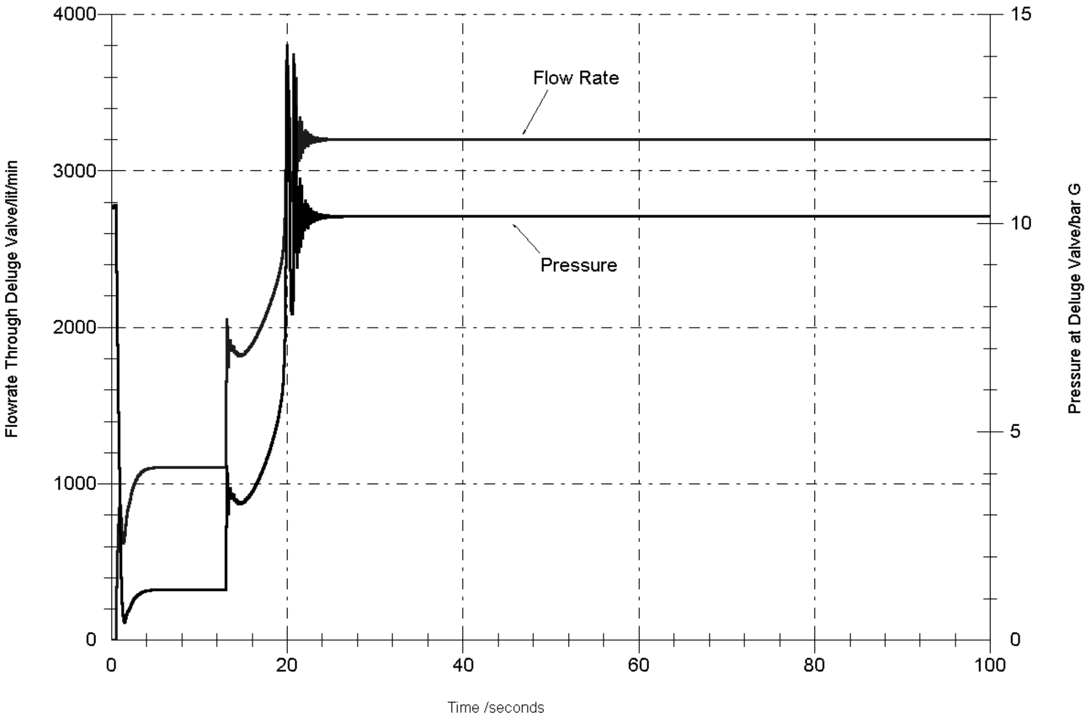
Graph 7.3.- Deluge System Operating



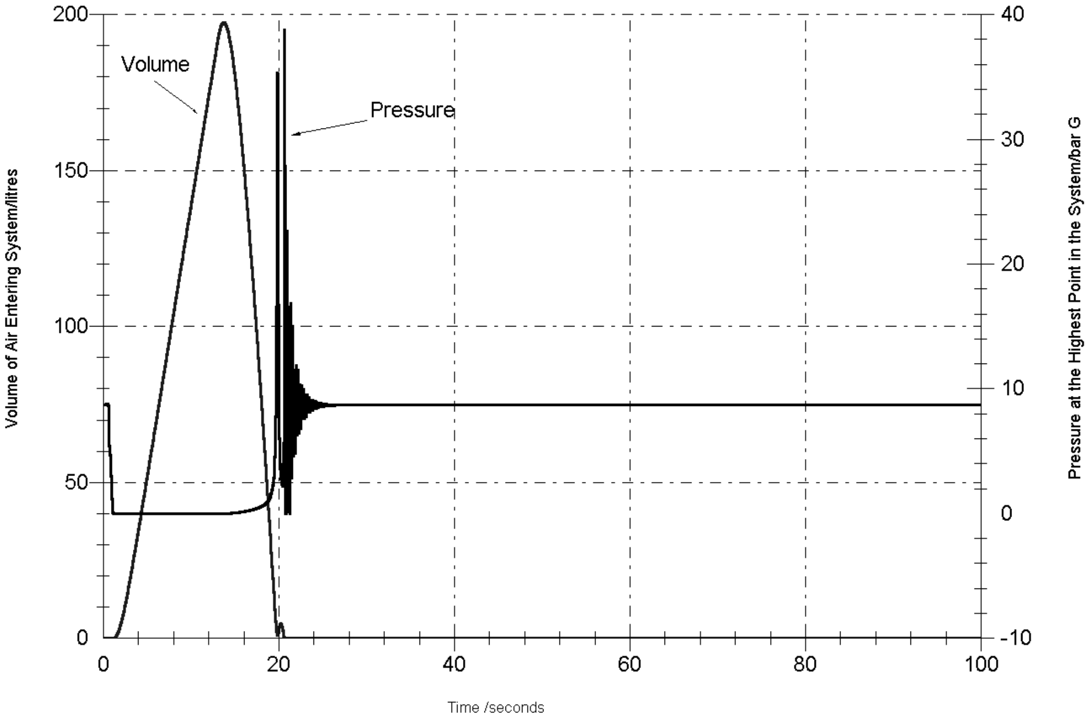
Graph 7.4.- Deluge System Operating



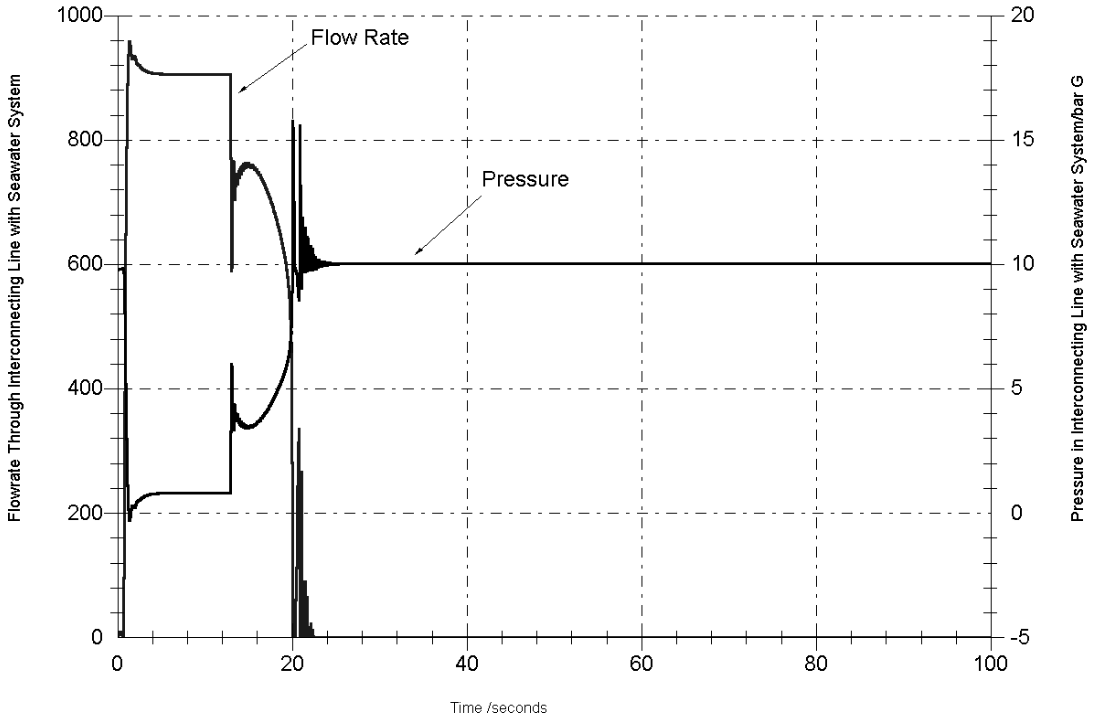
Graph 8.1. - Deluge System Operating - vac breaker(50x12.5)



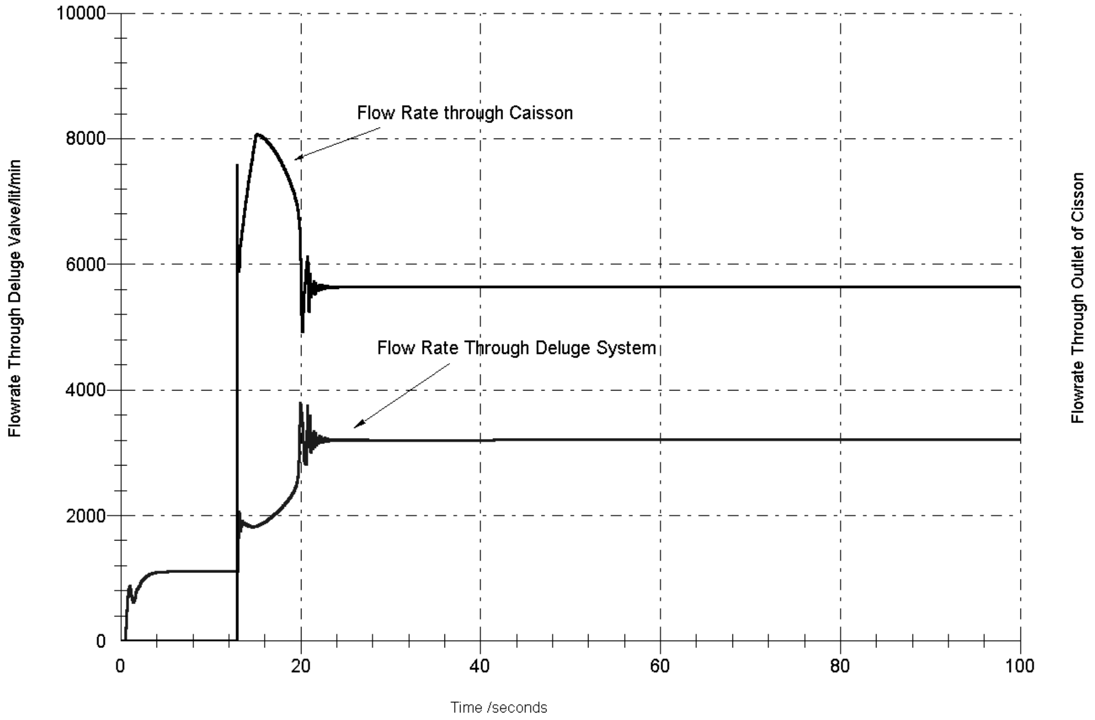
Graph 8.2. - Deluge System Operates - Vac Breaker(50x12.5)



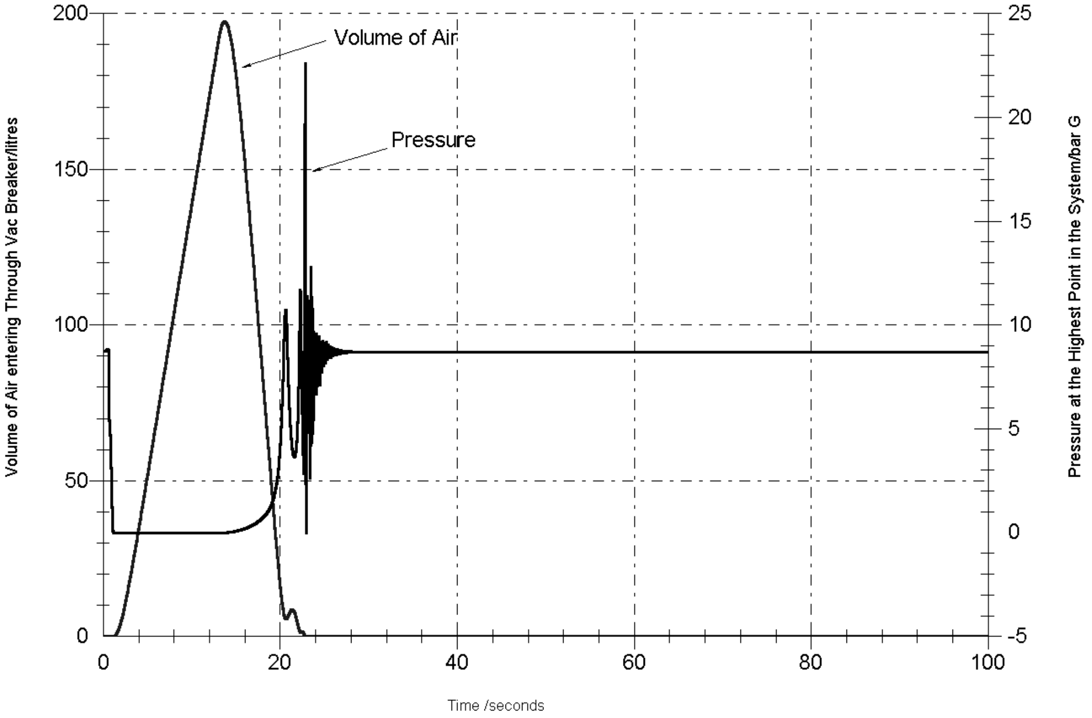
Graph 8.3. - Deluge System Operating - Vac Breaker (50x12.5)



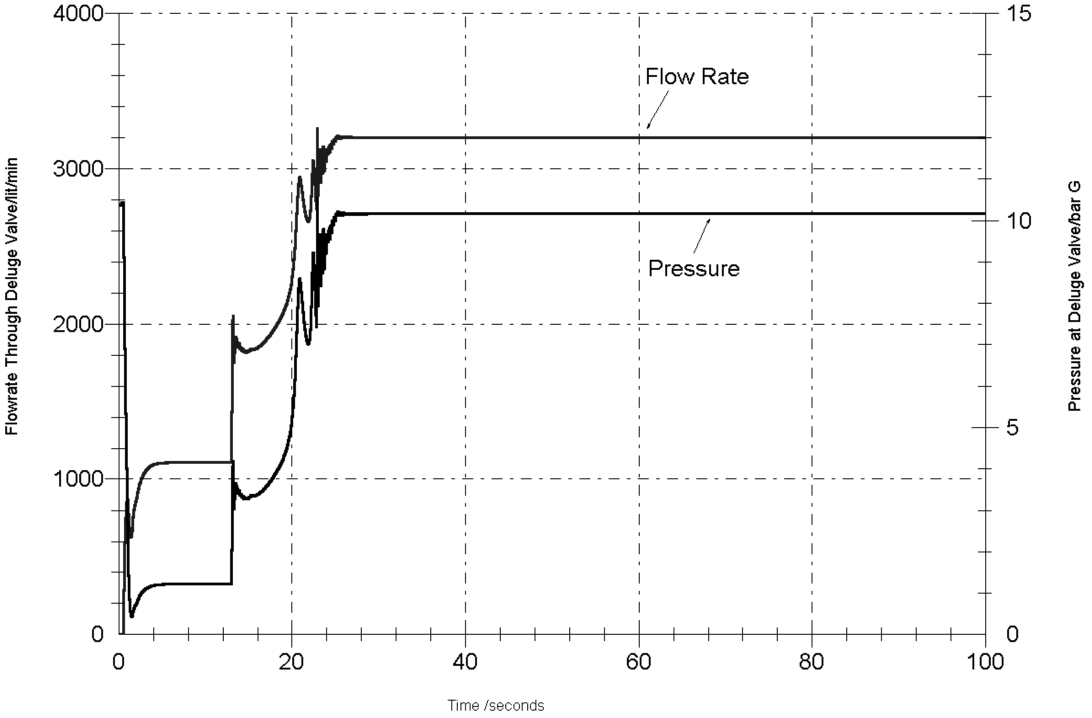
Graph 8.4. - Deluge System Operates - Vac breaker (50x12.5)



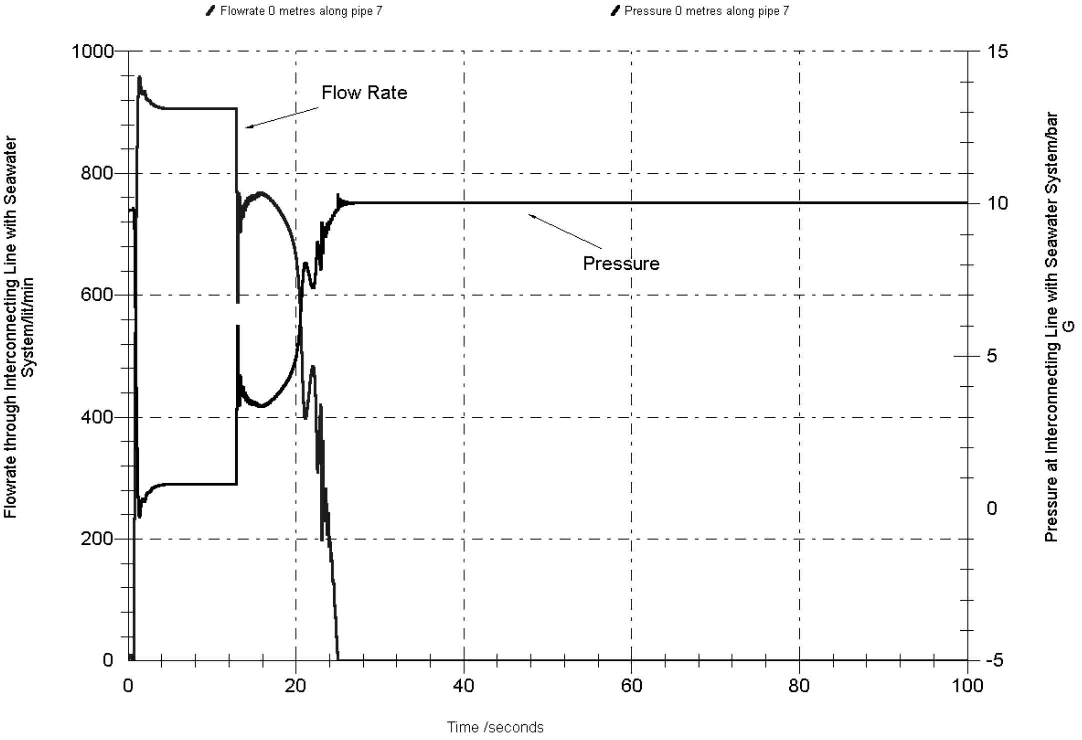
Graph 9.1. - Deluge System Operating - Vac Breaker(50X25)



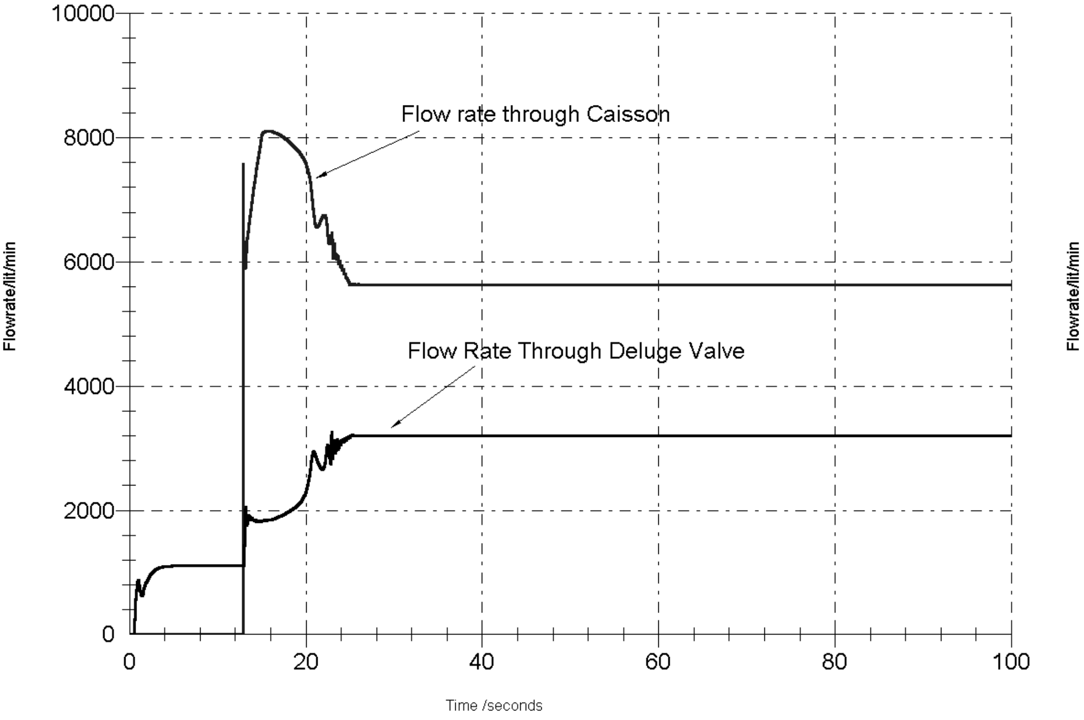
Graph 9.2. - Deluge System Operating - Vac Breaker (50x25)



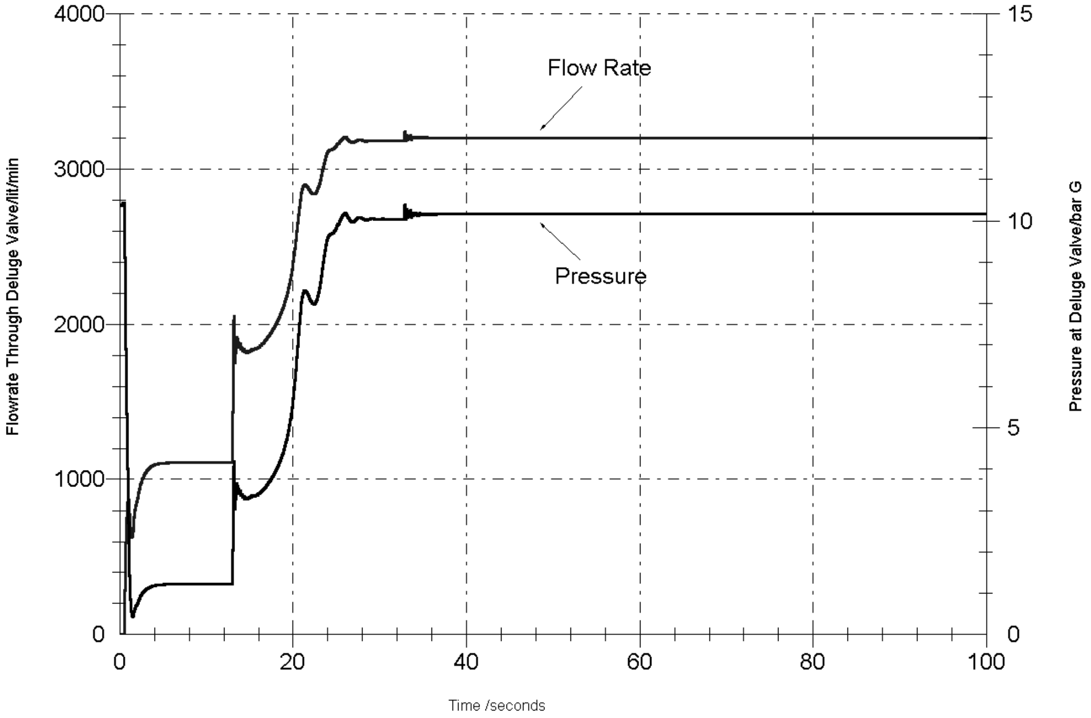
Graph 9.3. - Deluge System Operates - Vac Breaker (50x25)



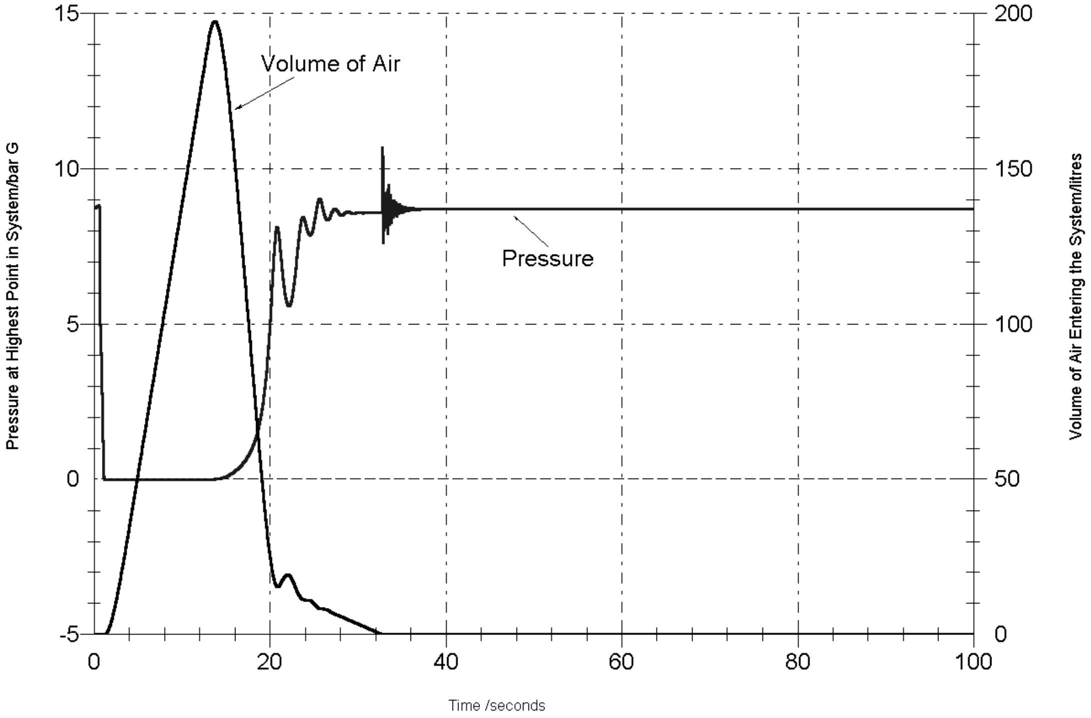
Graph 9.4. - Deluge System Operates - Vac Breaker (50x25)



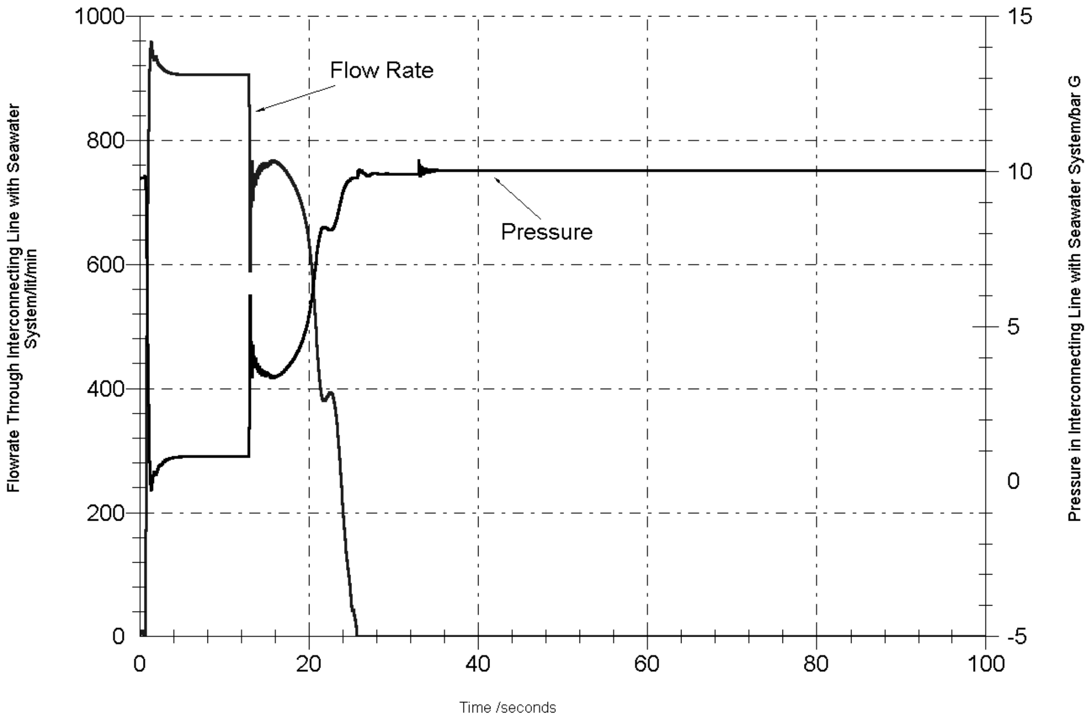
Graph 10.1 - Deluge System Operates - Vac Breaker (50x 6.25)



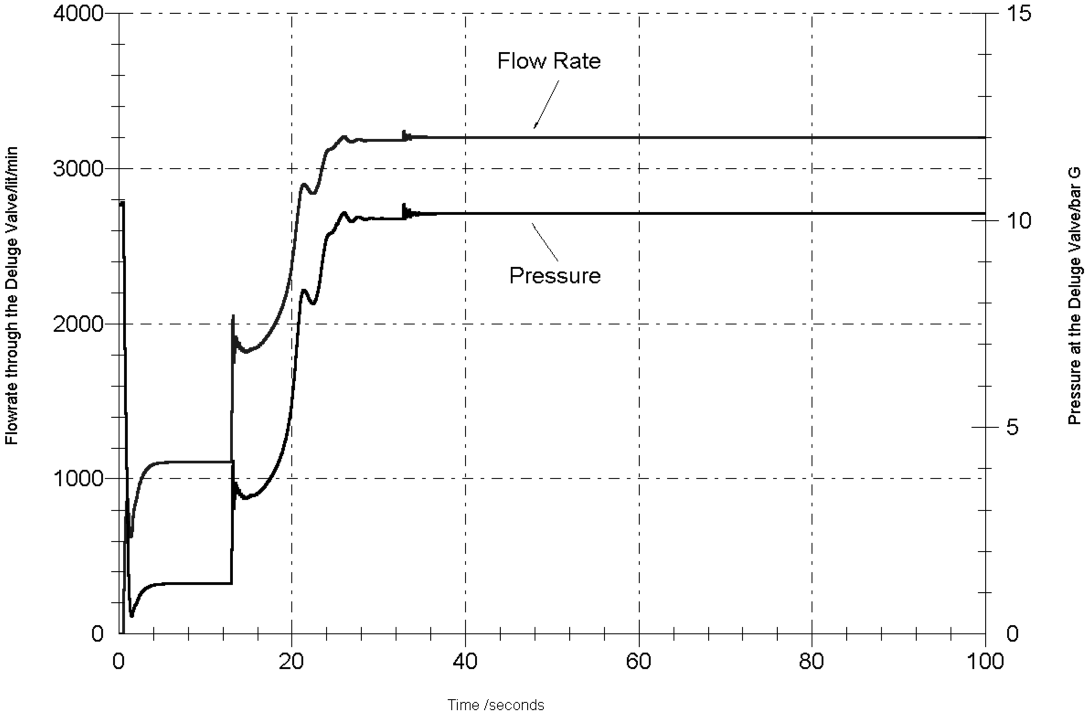
Graph 10.2 - Deluge System Operates - Vac Breaker (50x6.25)



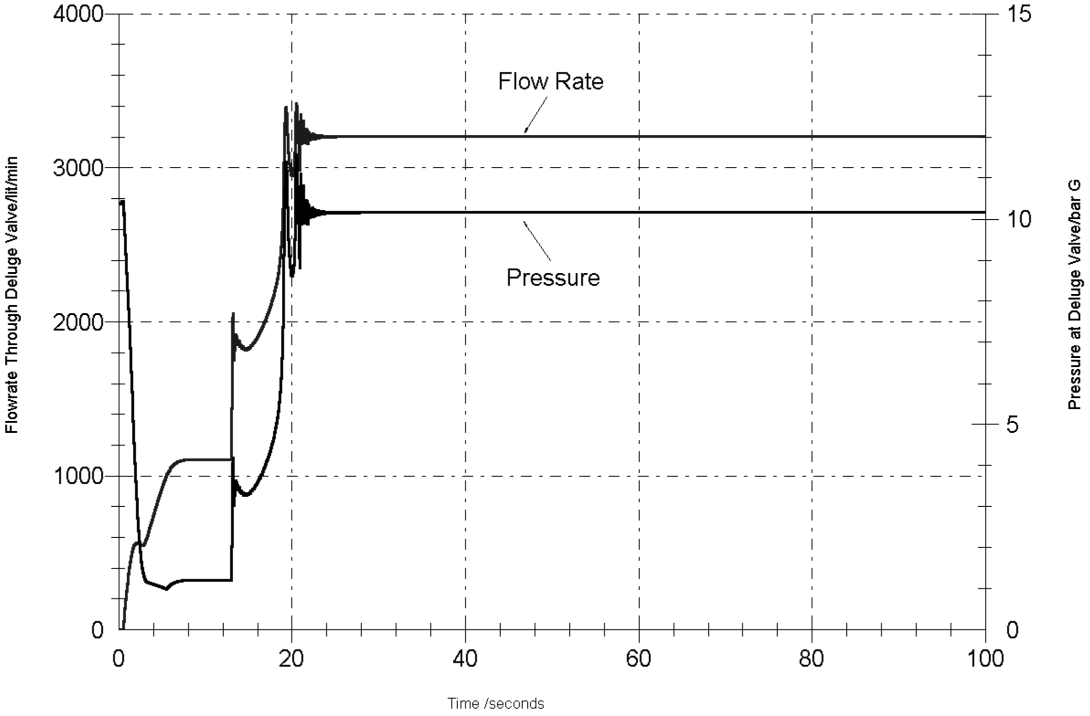
Graph 10.3. - Deluge System Operates - Vac Breaker (50x6.25)



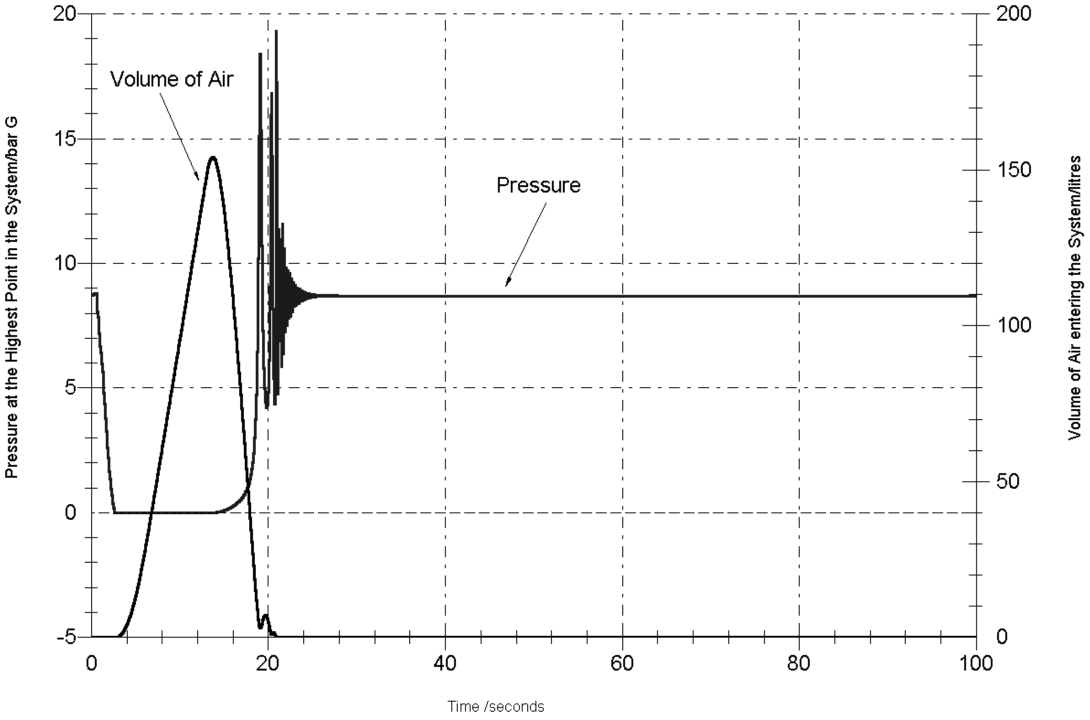
Graph 10.4. - Deluge System Operates - Vac Breaker (50x6.25)



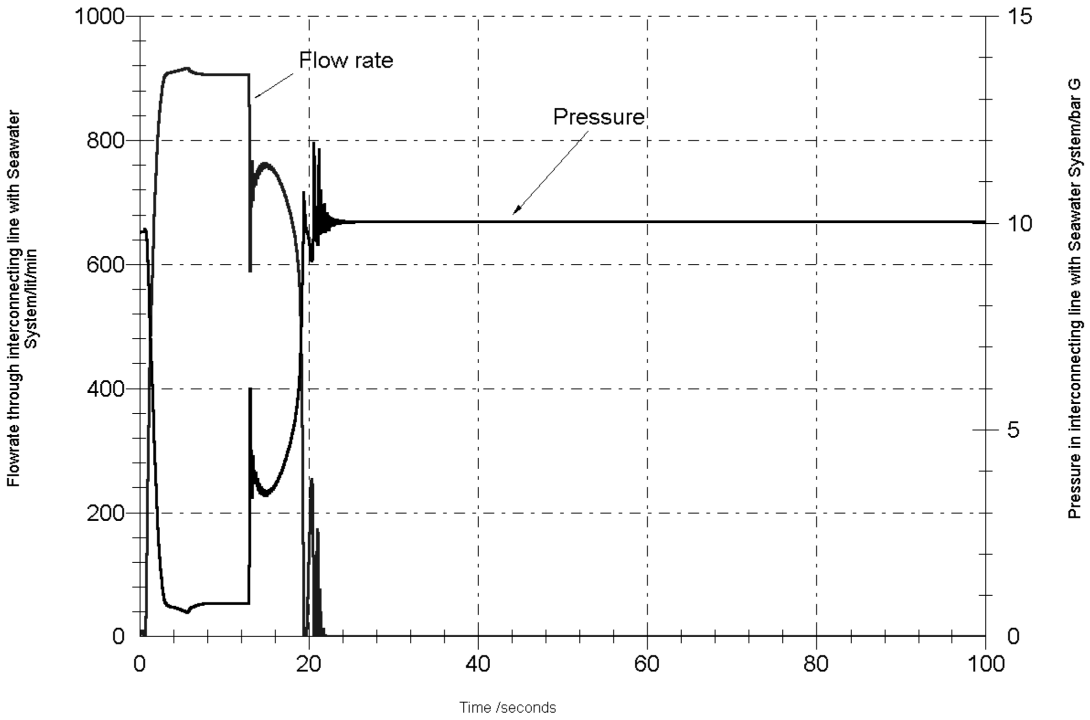
## Graph 11.1. - Deluge System Operates - Vac Breaker (50x10)



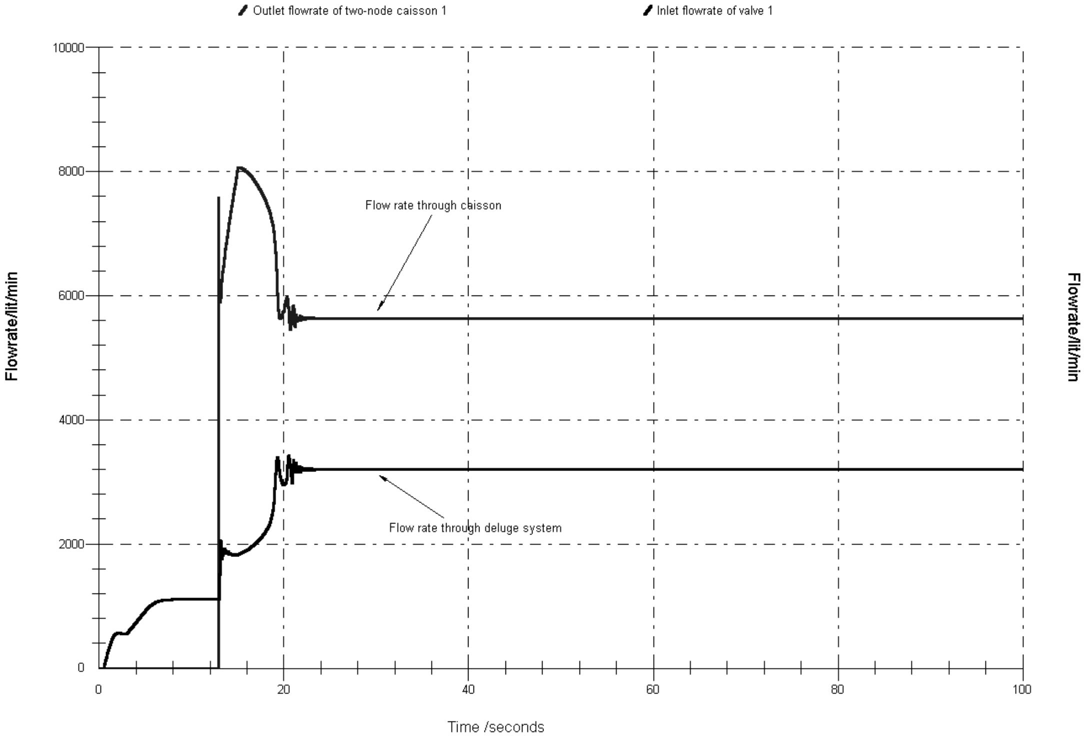
## Graph 11.2. - Deluge System Operates - Vac Breaker (50x10)



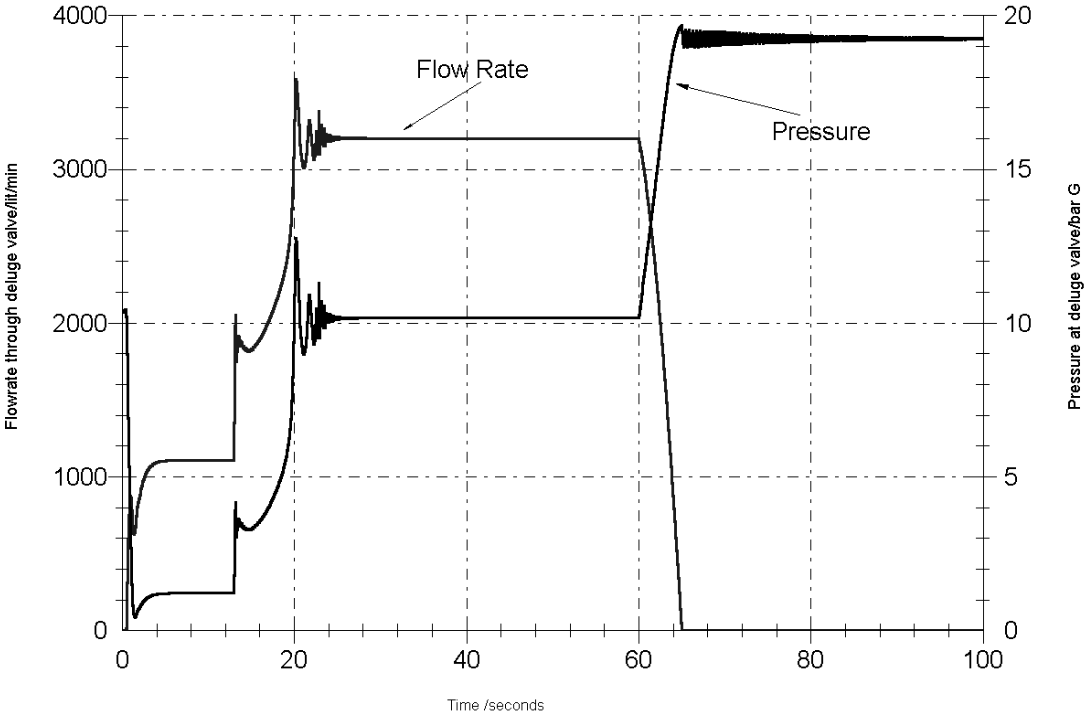
Graph 11.3. - Deluge System Operates - Vac Breaker (50x10)



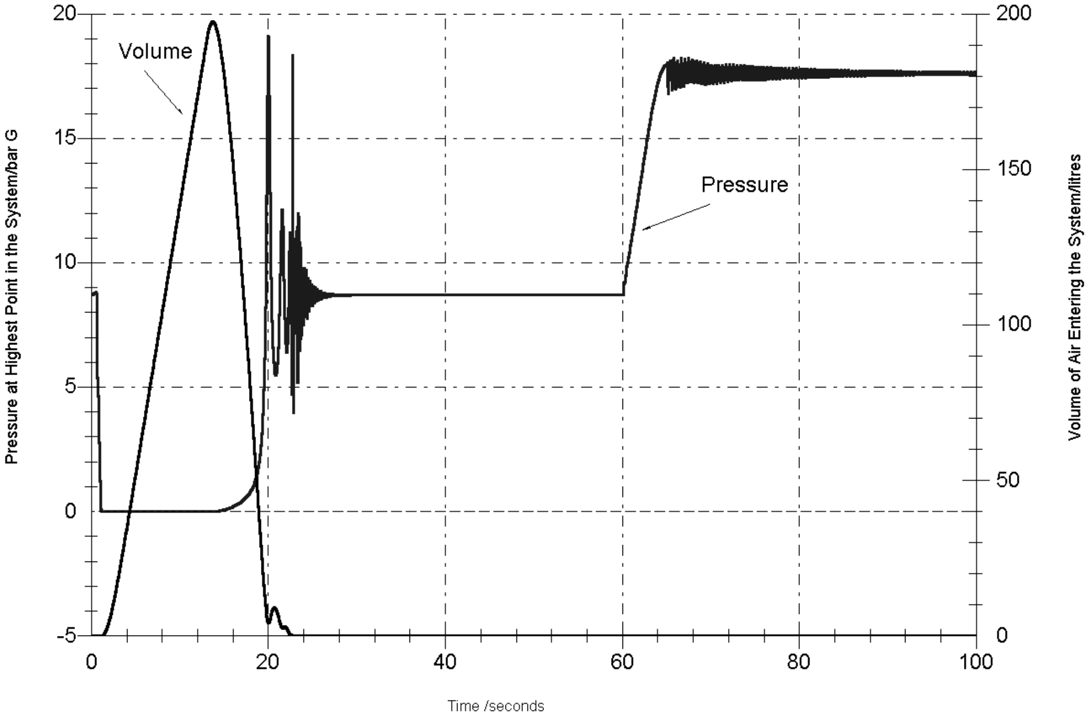
Graph 11.4. - Deluge System Operates - Vac Breaker (50x10)



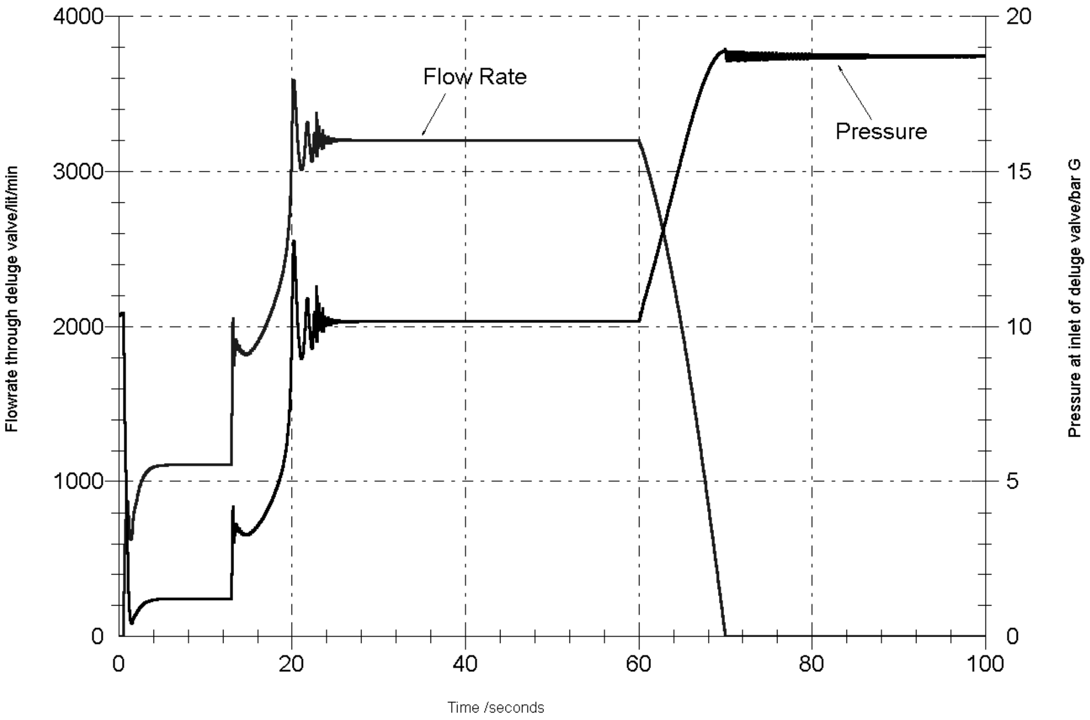
Graph 12.1. - Deluge Valve Closes 60 -65 sec



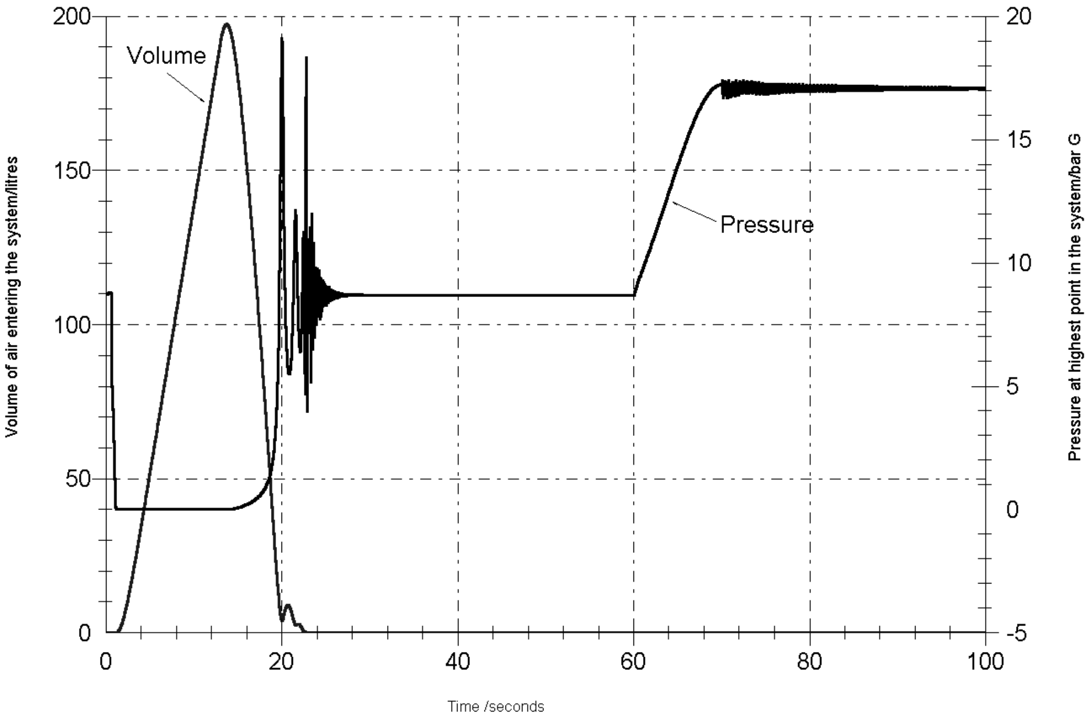
Graph 12.2. - Deluge Valve Closes 60 - 65 secs



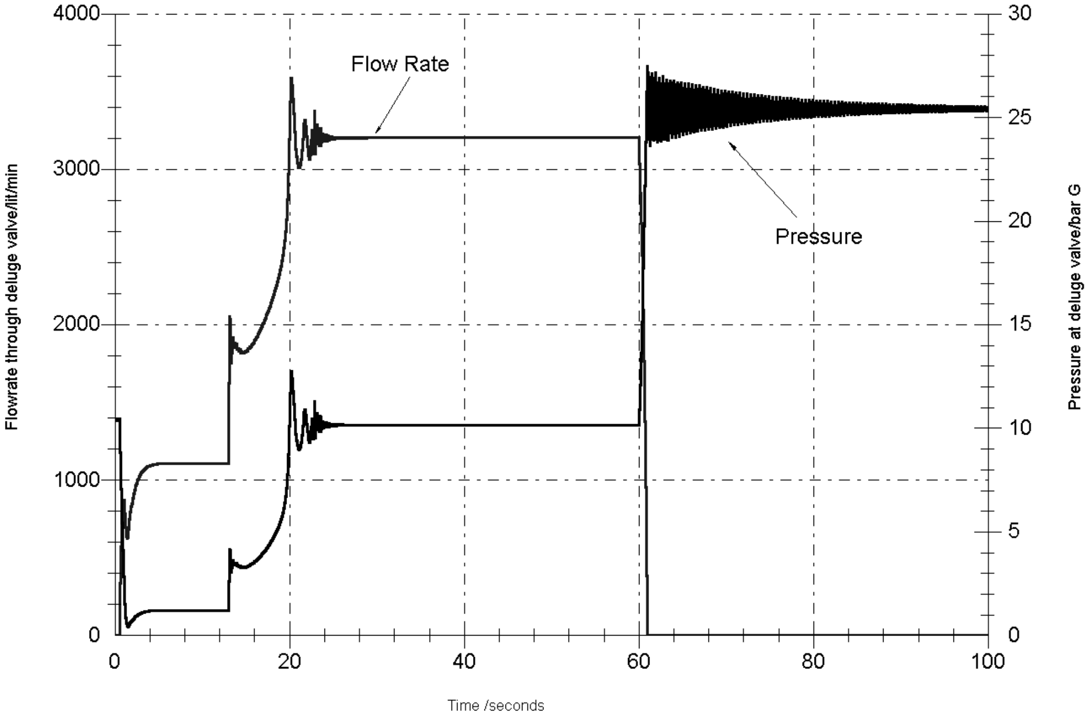
## Graph 13.1. - Deluge Valve Closes 60 - 70 sec



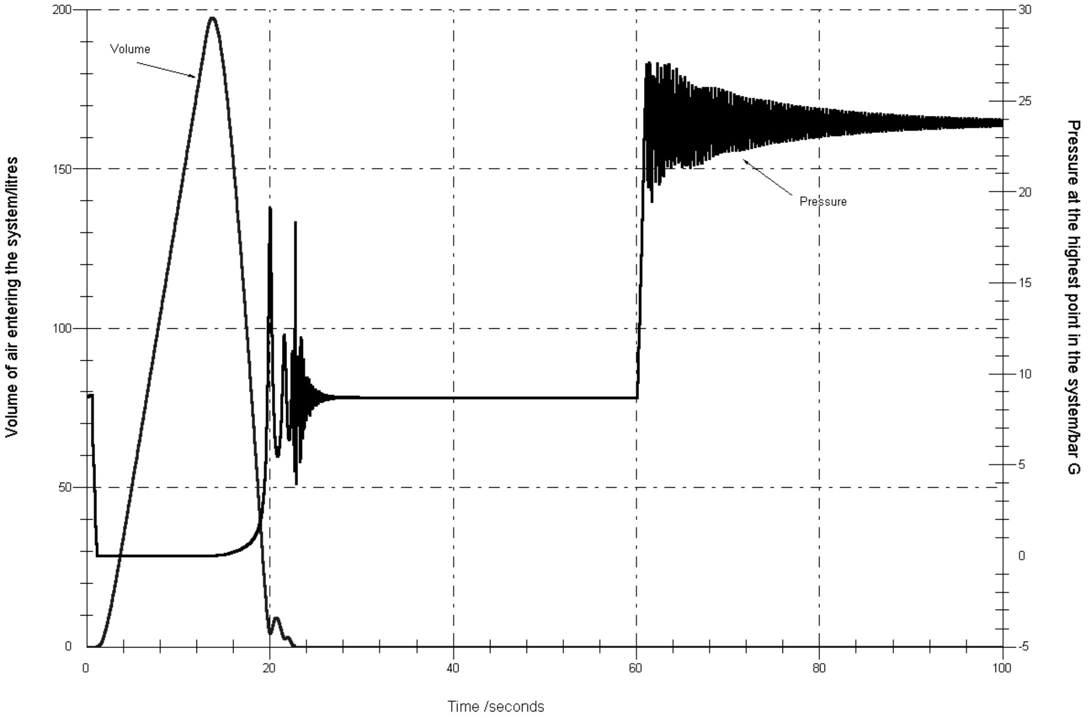
## Graph 13.2. - Deluge Valve Closes 60 - 70 secs



Graph 14.1. - Deluge Valve Closes 60 - 61 sec



Graph 14.2. - Deluge Valve Closes 60 - 61 secs



# Waterhammer Effects Caused by Pump Shutdown

## Introduction

Pumps are usually protected against flow reversal by some type of check valve. In the event of a pump shutdown, the valve attached to the pump closes when the flow starts reversing. The closing of the check valve can be very fast, thus causing pressure surges in the pipe network.

The aim of this study is to determine the effect of the valve parameters on the pressure surges. To this end the valve is represented by PIPENET's Inertial Check Valve, which can be adjusted to model a real valve by a number of user-defined parameters. A number of different scenarios are looked at in order to determine in which circumstance the worst waterhammer occurs.

This example is motivated by an engine cooling system on a barge. Its main components are 8 pumps in parallel that feed into a common header pipe. This pipe feeds 7 heat exchanger assemblies, again in parallel. Each of these consists of one high temperature cooler and one low temperature cooler.

The outlet of the heat exchangers is feed into a common discharge main and from there the water is released into the sea via a discharge pipe.

### *Scenarios*

In normal operation 7 pumps are running while one is on stand-by. Three scenarios are investigated:

- 8 pumps are running and one is shut down.
- 7 pumps are running and one is shut down.

Both of these scenarios are examined in **Case 1**. At the start of this simulation all 8 pumps are running, then one is shut down and the system is allowed to settle. At this point the normal state of operation is reached and now another pump is shut down. The shutdown of the second pump represents a situation in which one pump fails during normal operation.

There are a number of parameters affecting the magnitude of the pressure surge. Some of these have been investigated:

- Mass of the valve door **(Simulations 1A and 1B)**
- Damping of the valve door **(Simulations 1A, 1C and 1D)**
- Pump shutdown time (not shown)

- $C_V$ value of the valve (not shown)

The shutdown of the complete system is also of interest. This is considered in **Case 2**:

- 8 pumps are running and all are shut down simultaneously

An overview of the system as it is represented in PIPENET is shown in Figure 1. The 7 heat exchanger groups are modelled using Pipes 30 to 36. The pressure drop across the heat exchangers is represented by an additional K-Factor that has been determined by PIPENET to match the pressure drop/flowrate specification of the heat exchanger.

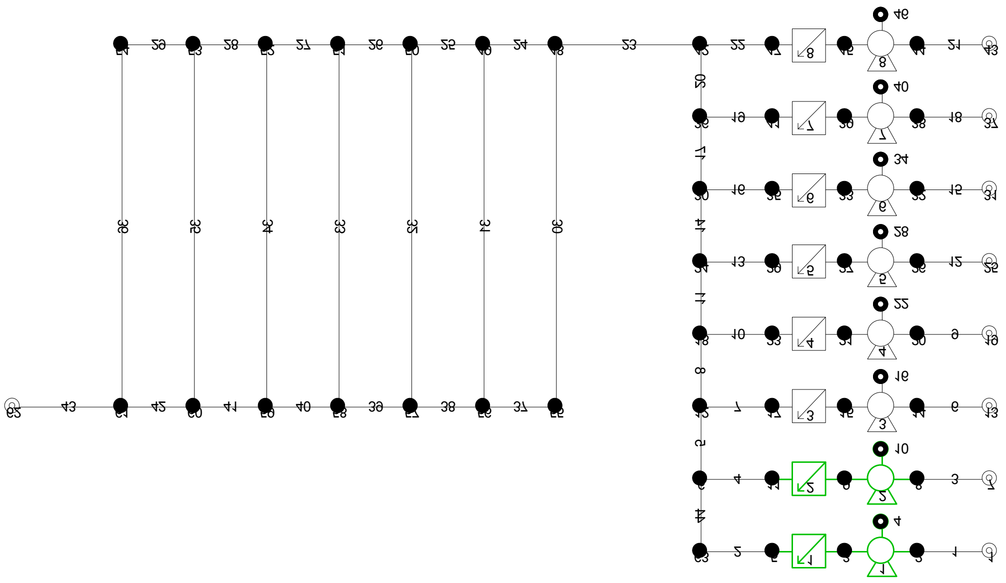


**Figure 1: PIPENET Schematic Representation of the Cooling System**

## Management Summary

This study uses PIPENET Transient Module simulations to assess the magnitude of pressure surges caused by the shutdown of one or more pumps. The pumps are protected against flow reversal by check valves, which close in the event of pump shutdown. The way in which these check valves close determines the magnitude of the pressure surge and whether or not there is any risk of pipe breakage.

There are a number of parameters both of the valves and of the overall system that determine the pressure surge. To highlight the benefits of using PIPENET for analysing the dynamic phenomenon of waterhammer two of these parameters have been chosen in Case 1:

- The mass of the valve door. It is shown that increasing the weight of the valve door reduces the peak pressure.
- The damping of the valve door. A small amount of damping turns out to be worse than none at all, whereas a large amount of damping reduces the pressure peak at the price of increasing the reverse flow through the valve.

In Case 2, the analysis of the simultaneous shutdown of all pumps shows that this situation does not pose any risk of pipe breakage.

## Case 1: Shutdown of Pump 1 and Pump 2

In this example all 8 pumps are operating to start with. Then Pump 1 is shut down, which leaves the system in its normal state of operation with 7 pumps running at the same time. At this point Pump 2 shuts down, a situation which might occur in the event of a pump failure.

### *Parameters of Simulation 1A*

The parameters of the first set of simulations are

- Pump shutdown within 2 seconds, represented by a linear change of the pump setting.
- Mass of the valve door: 20 kg
- $C_v$ value of the valve: 3000 $m^3/h/bar^{½}$
- No damping of the valve door.

### *List of Figures*

The following variables are shown:

INPUT DATA

Figure 2: Setting of Pump 1 and Pump 2

RESULTS COMPUTED BY PIPENET

- Figure 3: Valve Door Angle of Valve 1 and Valve 2
- Figure 4: Flowrate of Valve 1 and Valve 2
- Figure 5: Outlet Pressure of Valve 1
- Figure 6: Outlet Pressure of Valve 2
- Figure 7: Inlet Pressure of the Discharge Pipe (Pipe 43)
- Figure 8: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## *Summary of the Results*

The shutdown of Pump 1 leads to the closure of Valve 1. This causes a pressure peak at the outlet of Valve 1 due to the sudden stopping of the reverse flow across this valve. The pressure peak is almost 5 bar G. In principle the same happens at the shutdown of Pump 2, but the pressure peak is lower at just over 4 bar G in this case.

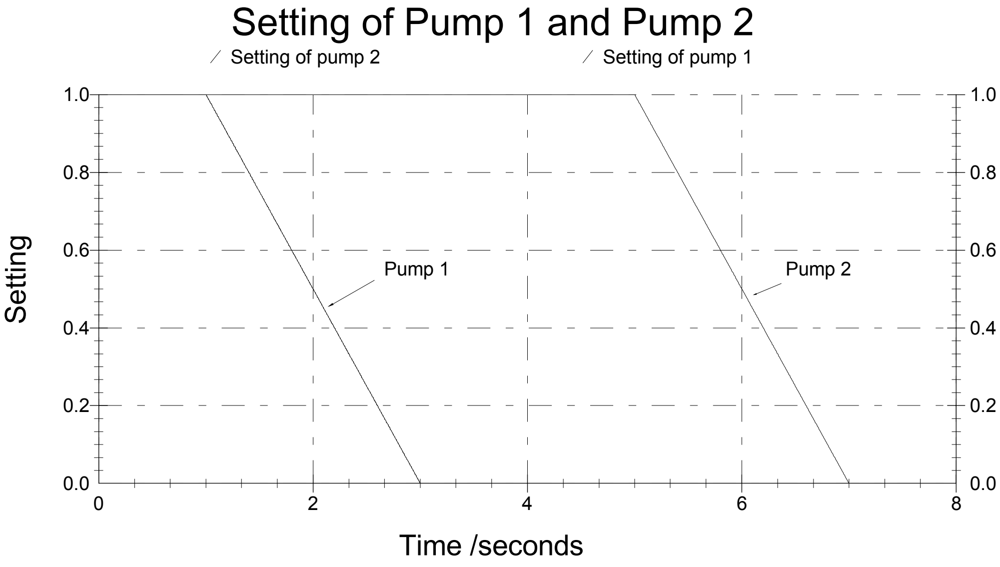


**Figure 2: Setting of Pump 1 and Pump 2**

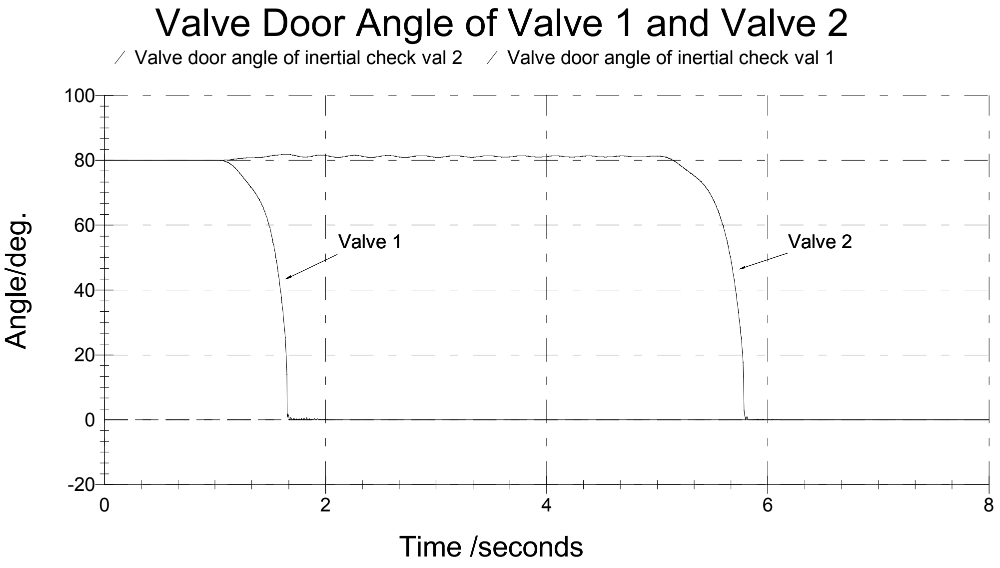


**Figure 3: Valve Door Angle of Valve 1 and Valve 2**

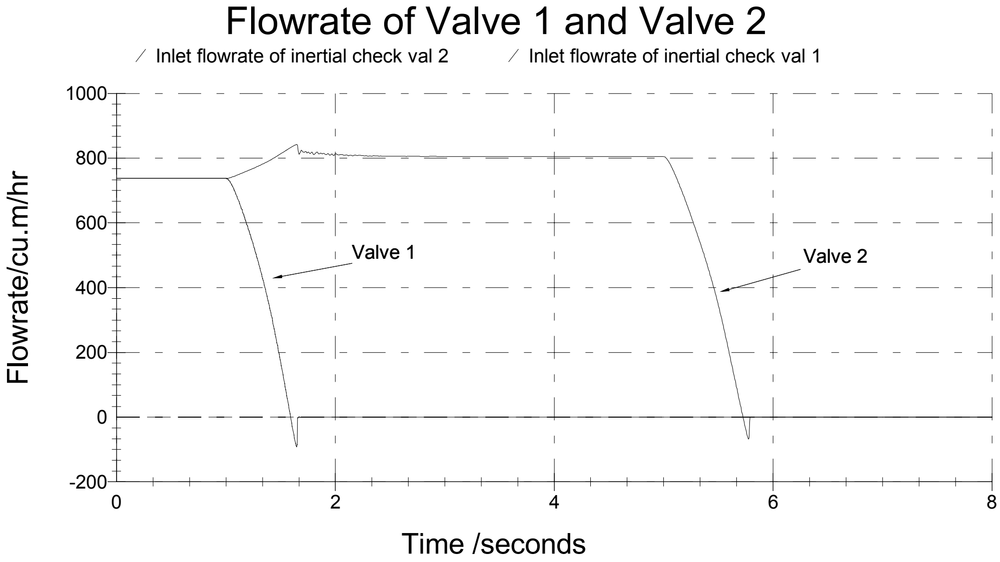


Figure 4: Flowrate of Valve 1 and Valve 2

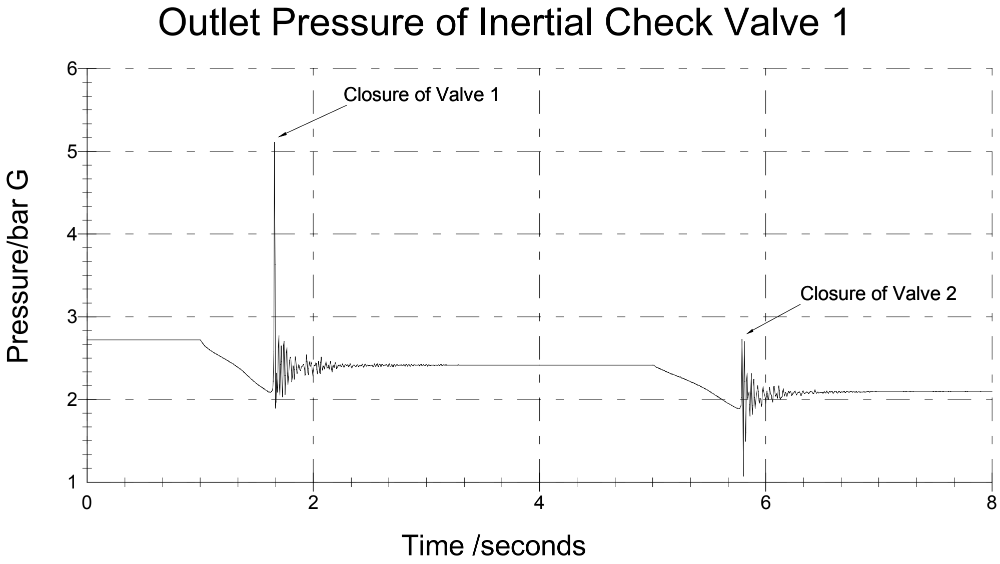


Figure 5: Outlet Pressure of Valve 1

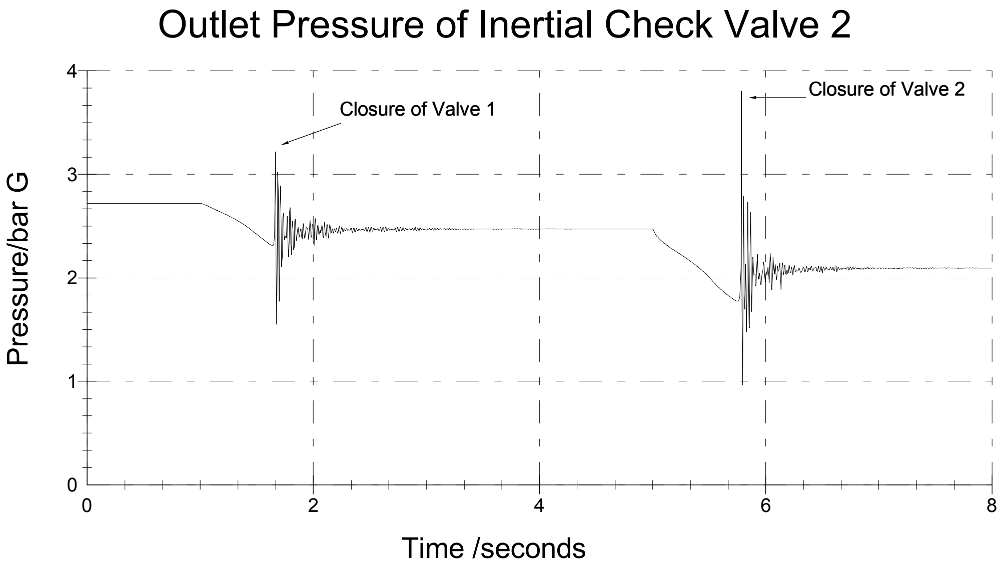


**Figure 6: Outlet Pressure of Valve 2**

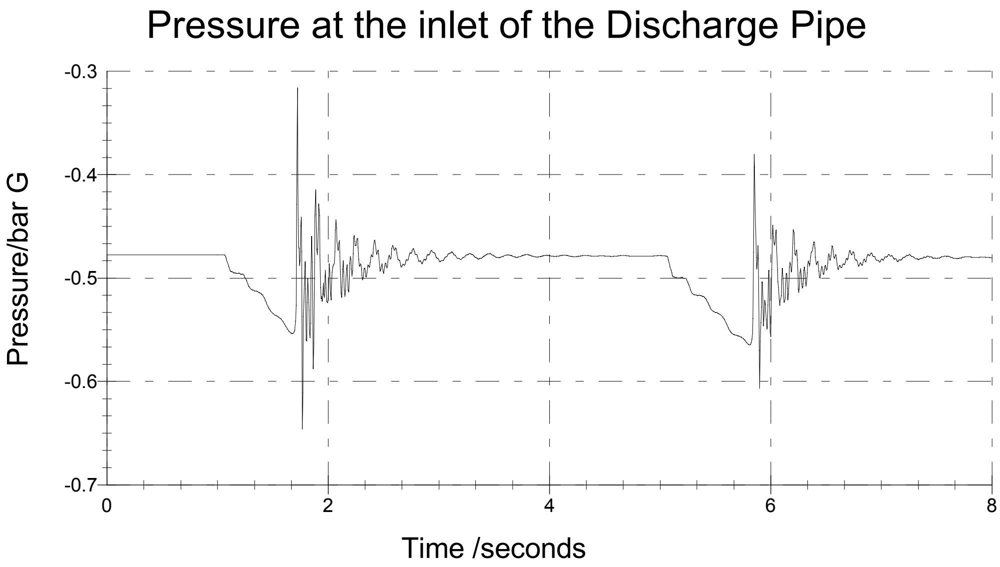


**Figure 7: Pressure at the Inlet of the Discharge Pipe**

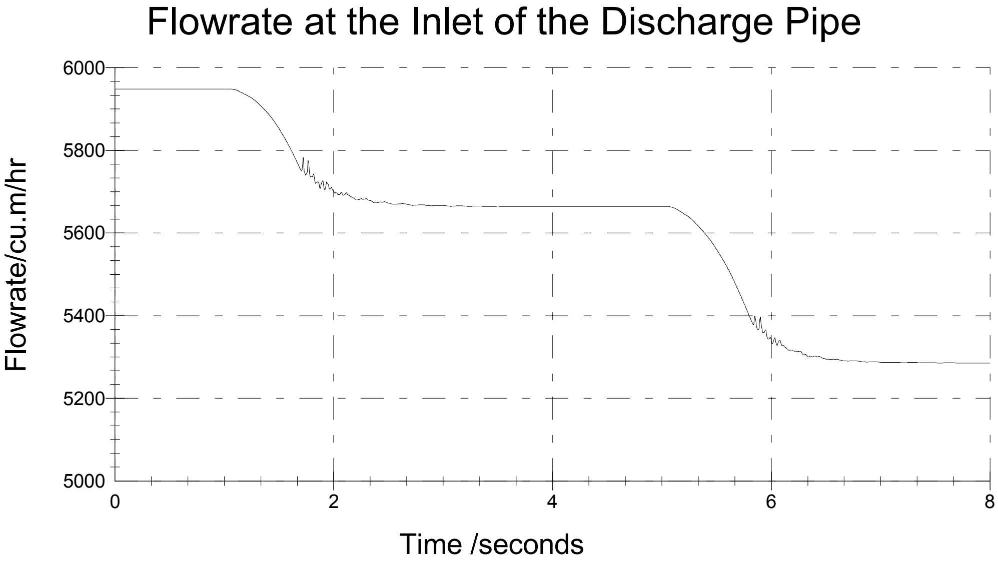


**Figure 8: Flowrate at the Inlet of the Discharge Pipe**

## *Parameters of Simulation 1B*

The only parameter that has been changed is the weight of the valve door. It is now set to 100kg

- Pump shutdown within 2 seconds, represented by a linear change of the pump setting.
- Mass of the valve door: 100 kg
- $C_v$ value of the valve: 3000 $m^3/h/bar^{1/2}$
- No damping of the valve door.

For ease of comparison, the same variables as in Simulation 1A are shown:

## *List of Figures*

INPUT DATA

Figure 2: Setting of Pump 1 and Pump 2

RESULTS COMPUTED BY PIPENET

- Figure 9: Valve Door Angle of Valve 1 and Valve 2
- Figure 10: Flowrate of Valve 1 and Valve 2
- Figure 11: Outlet Pressure of Valve 1
- Figure 12: Outlet Pressure of Valve 2
- Figure 13: Inlet Pressure of the Discharge Pipe (Pipe 43)
- Figure 14: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## *Summary of the Results*

The heavier valve doors of the Inertial Check Valves in this example result in a reduced pressure surge as compared to Simulation 1A. The reason for this is the initially faster closing of the valve but a lower angular velocity of the door as the valve shuts. There is also a slightly reduced reverse flow before the closure of the valve.

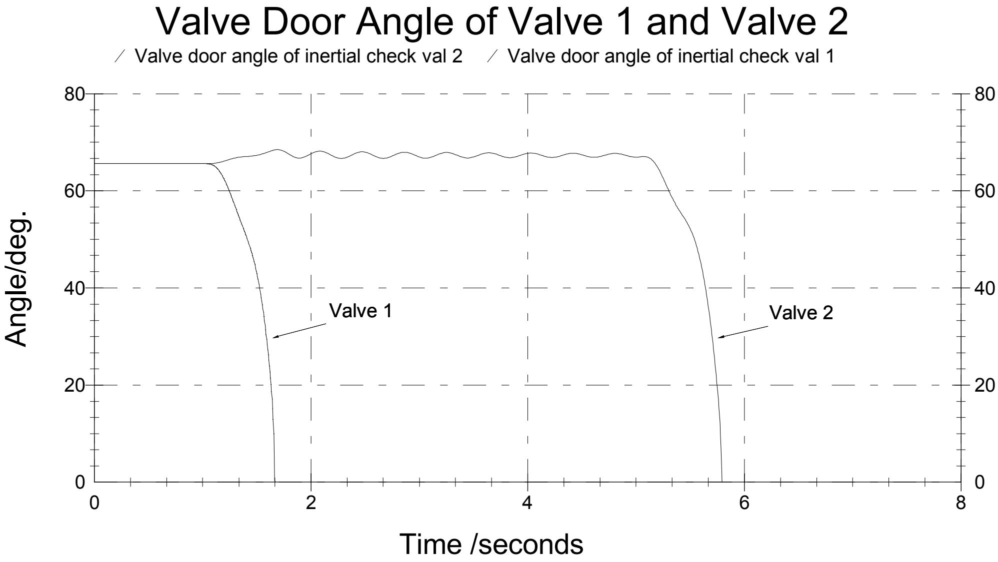


**Figure 9: Valve Door Angle of Valve 1 and Valve 2**

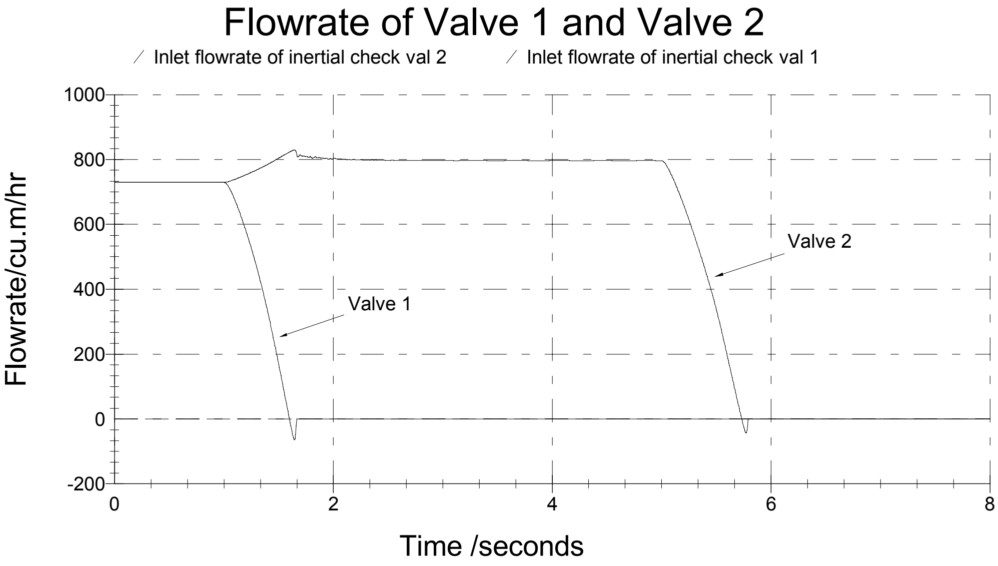


**Figure 10: Flowrate of Valve 1 and Valve 2**

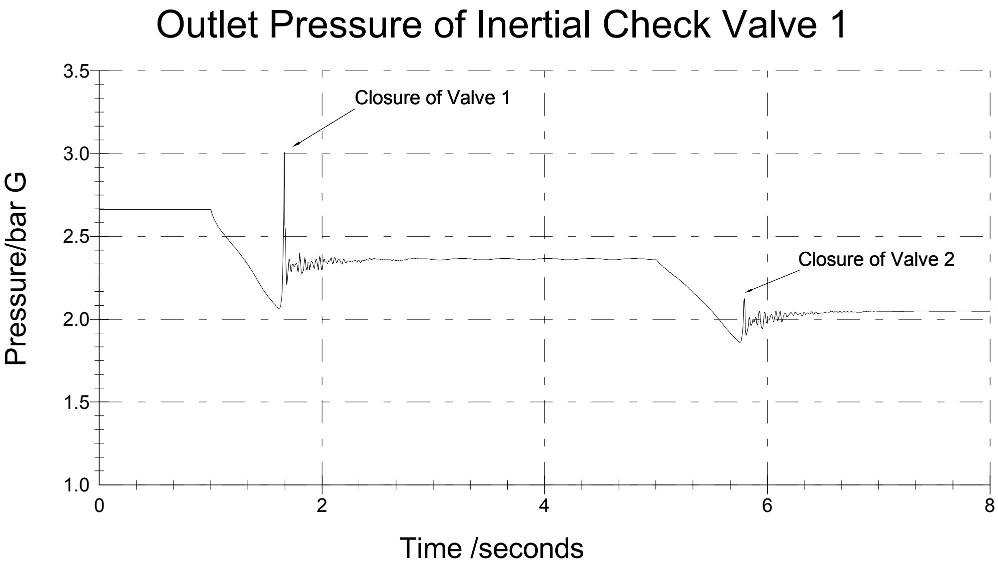


**Figure 11: Outlet Pressure of Valve 1**

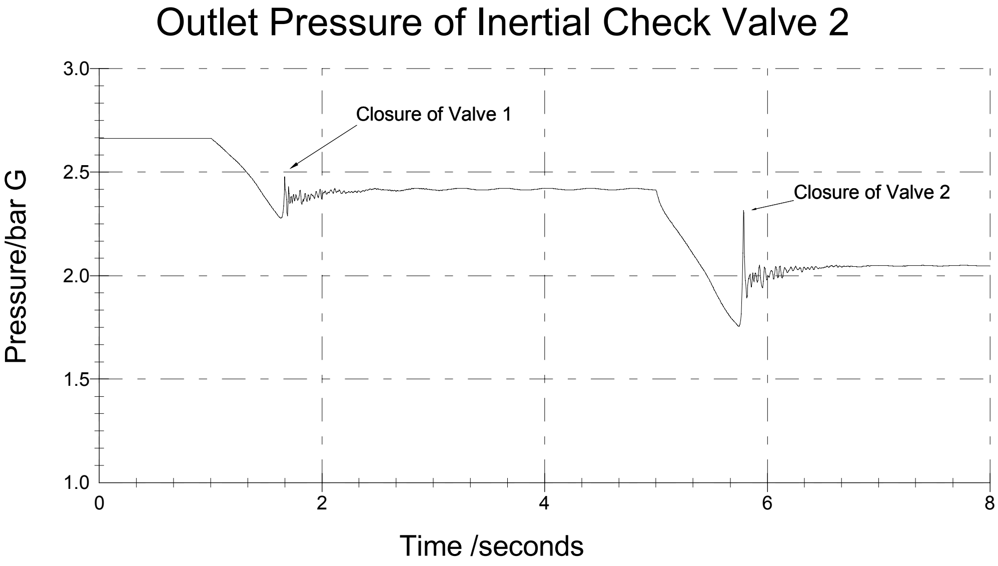


**Figure 12: Outlet Pressure of Valve 2**

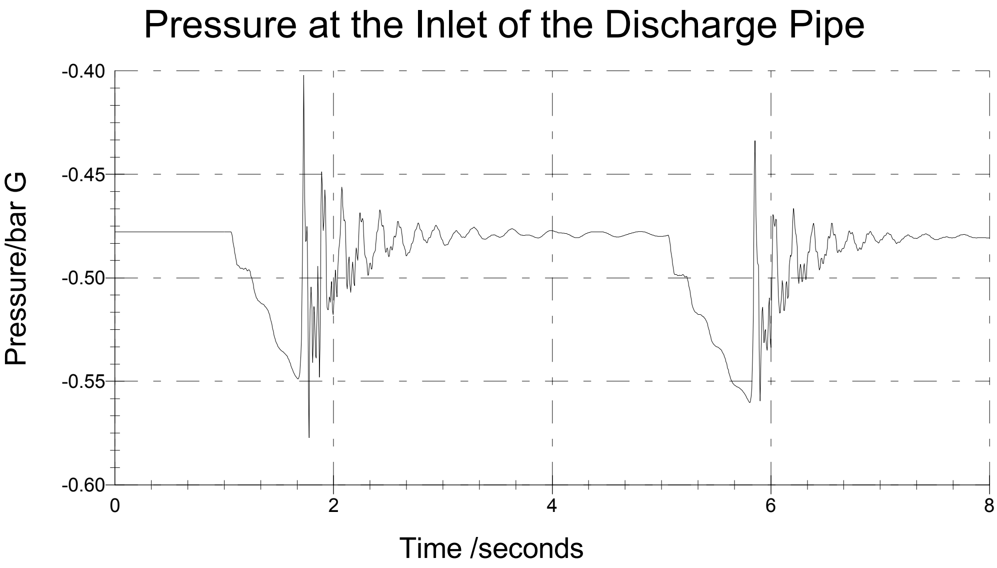


Figure 13: Pressure at the Inlet of the Discharge Pipe (Pipe 43)

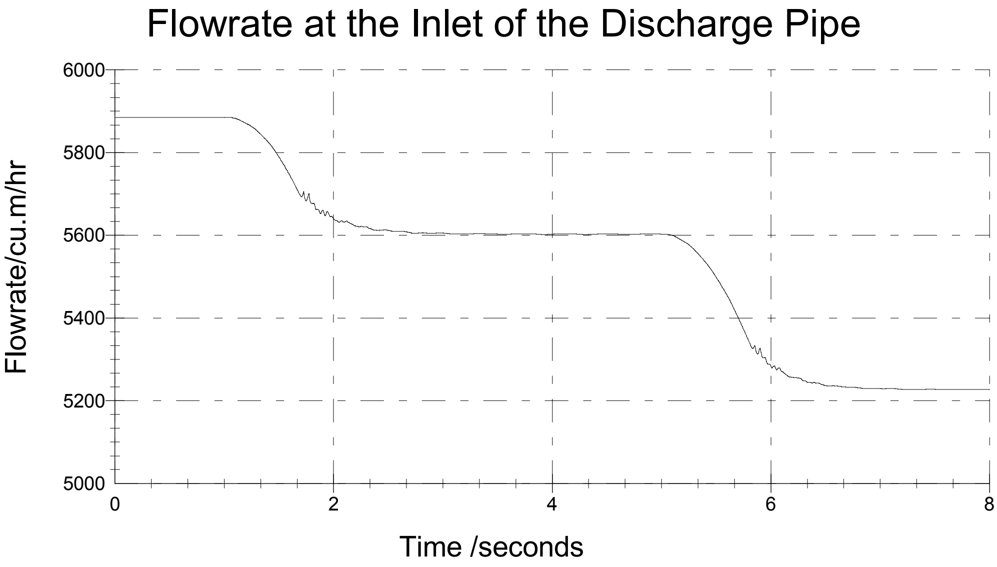


Figure 14: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

### *Parameters of Simulation 1C*

In this simulation the mass of the valve doors has been changed back to 20 kg and damping of the valve door has been introduced.

- Pump shutdown within 2 seconds, represented by a linear change of the pump setting.
- Mass of the valve door: 20 kg
- $C_v$ value of the valve: 3000 $m^3/h/bar^{½}$
- Damping of the valve door: 200 Nm/(rad/s)

For easy comparison, the same variables as in Simulation 1A are shown:

## *List of Figures*

INPUT DATA

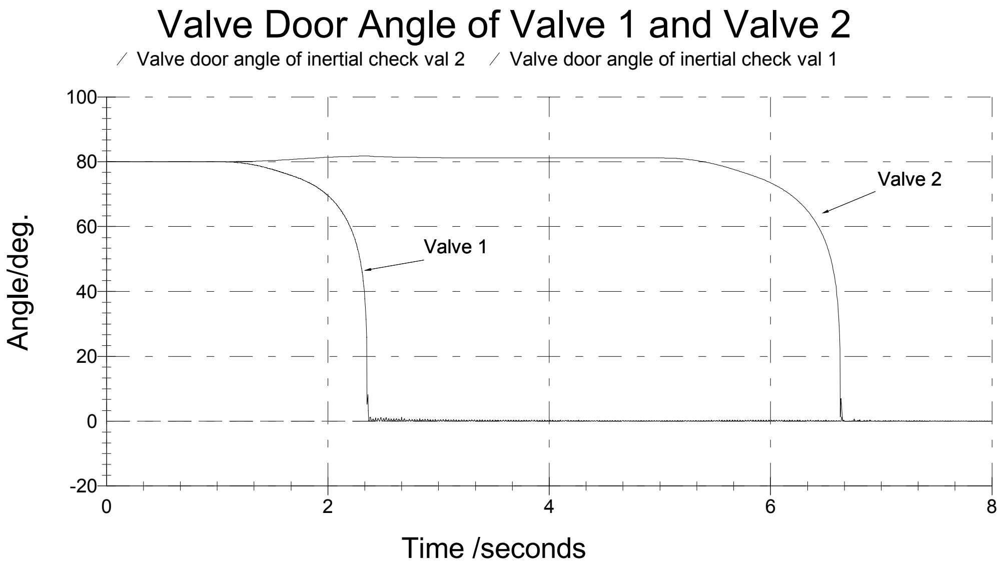
Figure 2: Setting of Pump 1 and Pump 2

RESULTS COMPUTED BY PIPENET

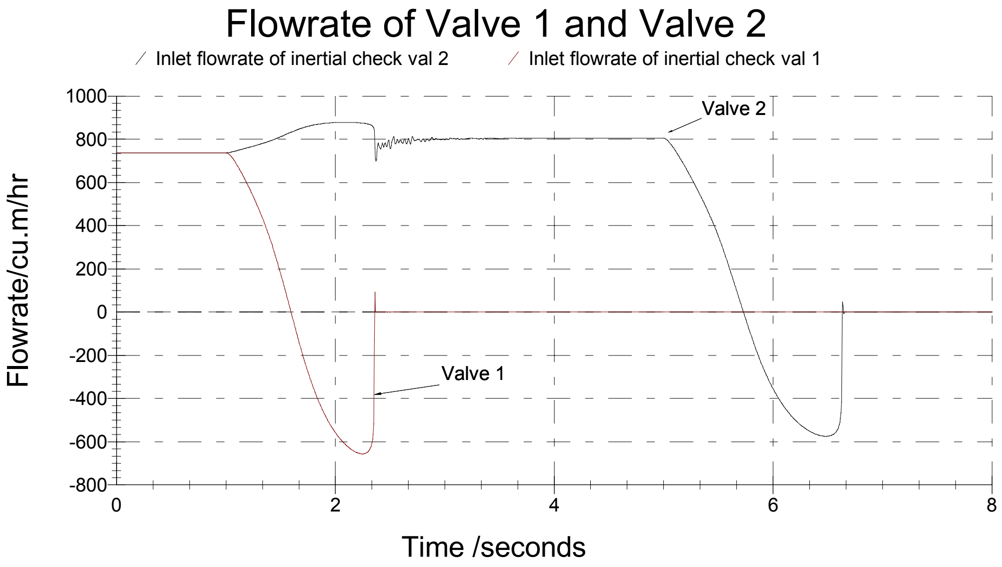
- Figure 15: Valve Door Angle of Valve 1 and Valve 2
- Figure 16: Flowrate of Valve 1 and Valve 2
- Figure 17: Outlet Pressure of Valve 1
- Figure 18: Outlet Pressure of Valve 2
- Figure 19: Inlet Pressure of the Discharge Pipe (Pipe 43)
- Figure 20: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## *Summary of the Results*

Introducing damping of the valve door results in a much increased pressure surge as compared to Simulation 1A. The reason for this is the slower response of the valve, which allows a substantial reverse flow before it actually closes. However, some damping might be required to prevent damage to the valve.



## Figure 15: Valve Door Angle of Valve 1 and Valve 2



## Figure 16: Flowrate of Valve 1 and Valve 2

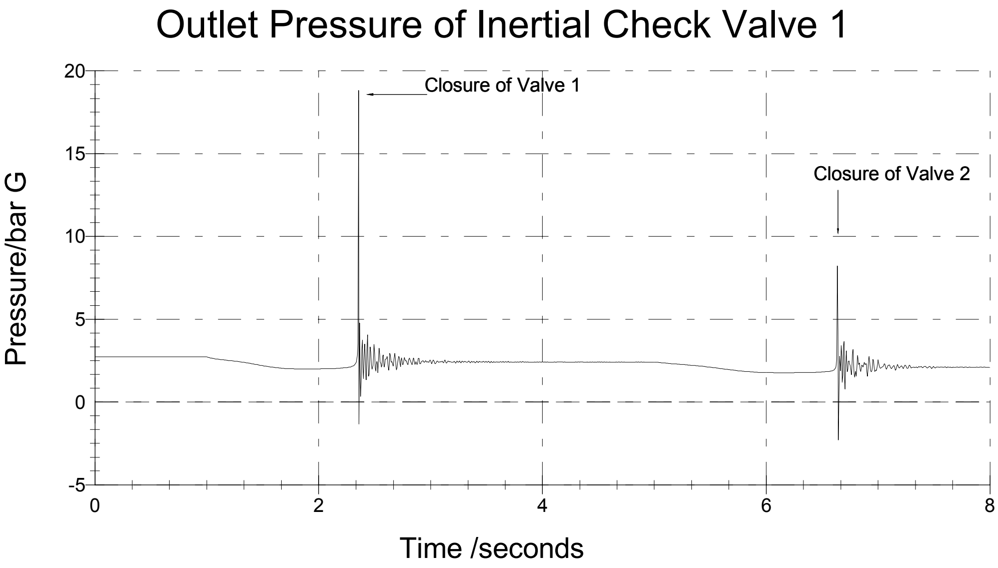


Figure 17: Outlet Pressure of Valve 1

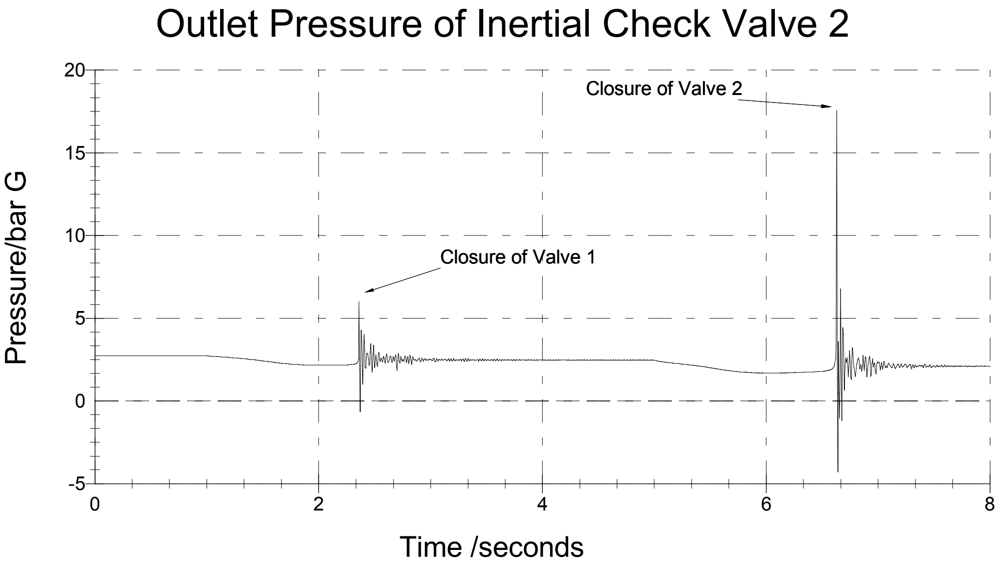


Figure 18: Outlet Pressure of Valve 2

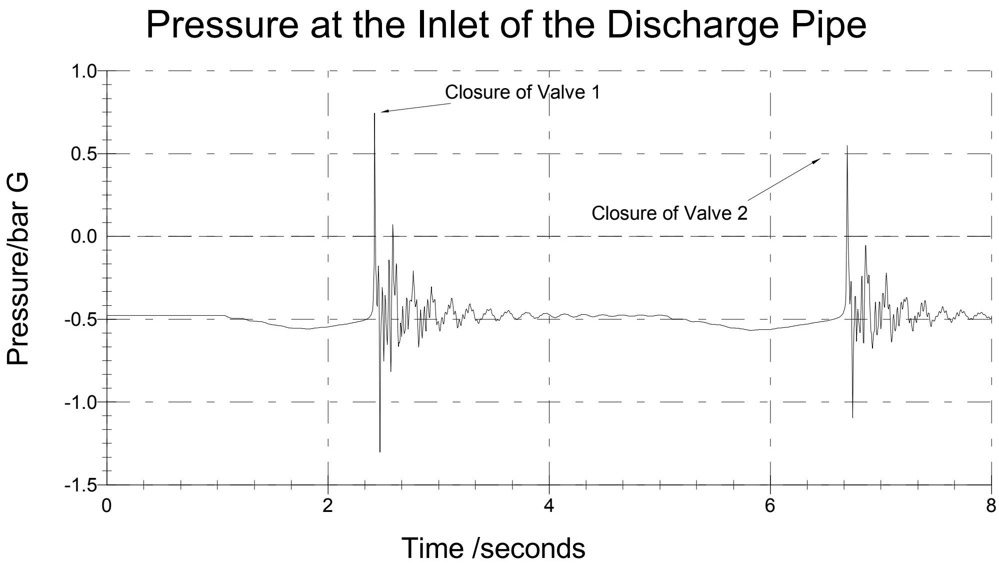


Figure 19: Pressure at the Inlet of the Discharge Pipe (Pipe 43)

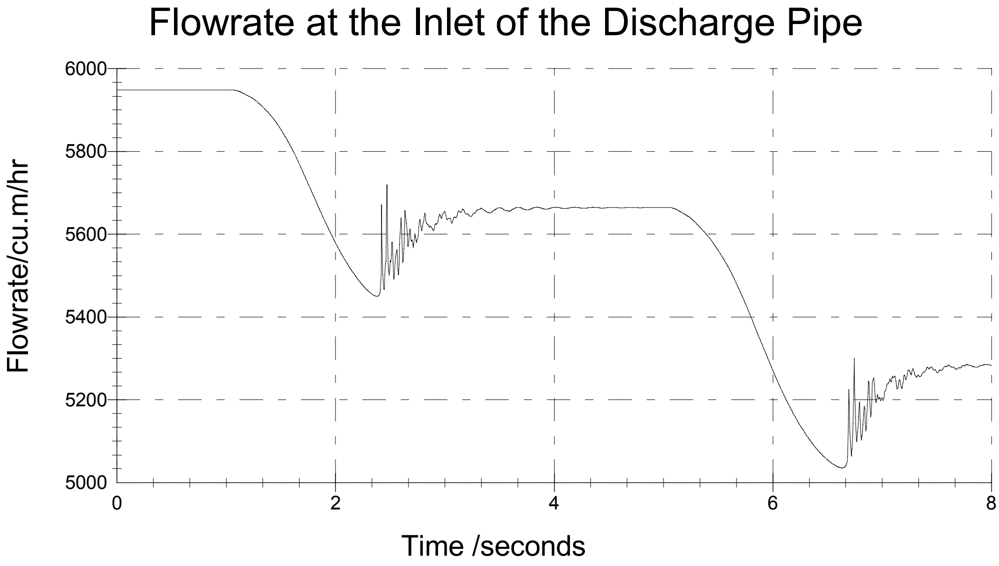


Figure 20: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## Parameters of Simulation 1D

In this simulation the damping of the valve door has been increased drastically.

- Pump shutdown within 2 seconds, represented by a linear change of the pump setting.
- Mass of the valve door: 20 kg
- $C_V$ value of the valve: 3000 $m^3/h/bar^{½}$
- Damping of the valve door: 1000 Nm/(rad/s)

For easy comparison, the same variables as in Simulation 1A are shown, except for the outlet pressure of Valve 2, as this valve does not close within the simulation interval.

## List of Figures

INPUT DATA

Figure 2: Setting of Pump 1 and Pump 2

RESULTS COMPUTED BY PIPENET

- Figure 21: Valve Door Angle of Valve 1 and Valve 2
- Figure 22: Flowrate of Valve 1 and Valve 2
- Figure 23: Outlet Pressure of Valve 1
- Figure 24: Inlet Pressure of the Discharge Pipe (Pipe 43)
- Figure 25: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## Summary of the Results

Increasing the amount of damping as compared to Simulation 1C reduces the pressure surge to level below that of even Simulation 1A. This comes at the prize of substantial reverse flow for about 3 seconds. The pressure surge due to the closure of Valve 2 is outside the simulation interval in this example.

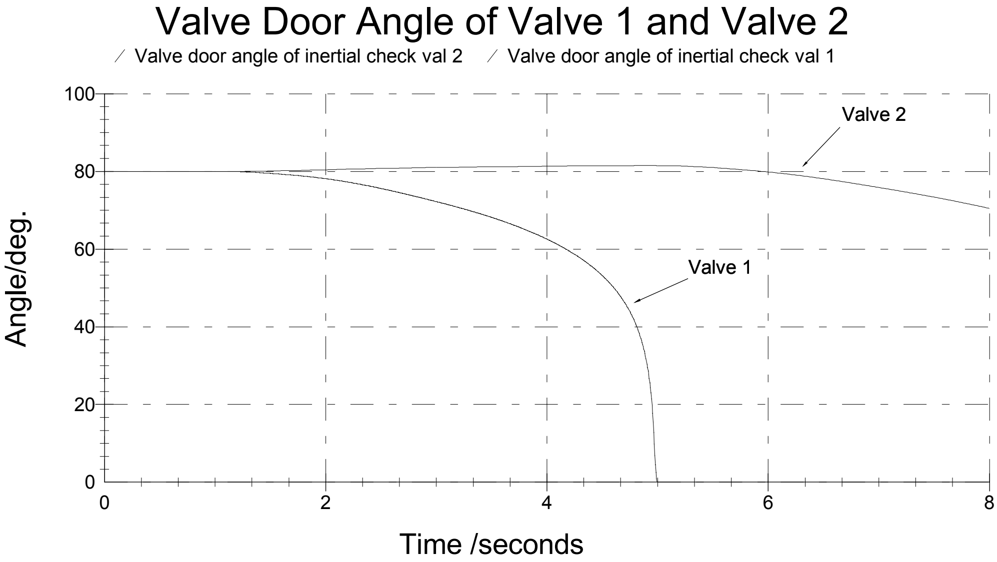


**Figure 21: Valve Door Angle of Valve 1 and Valve 2**

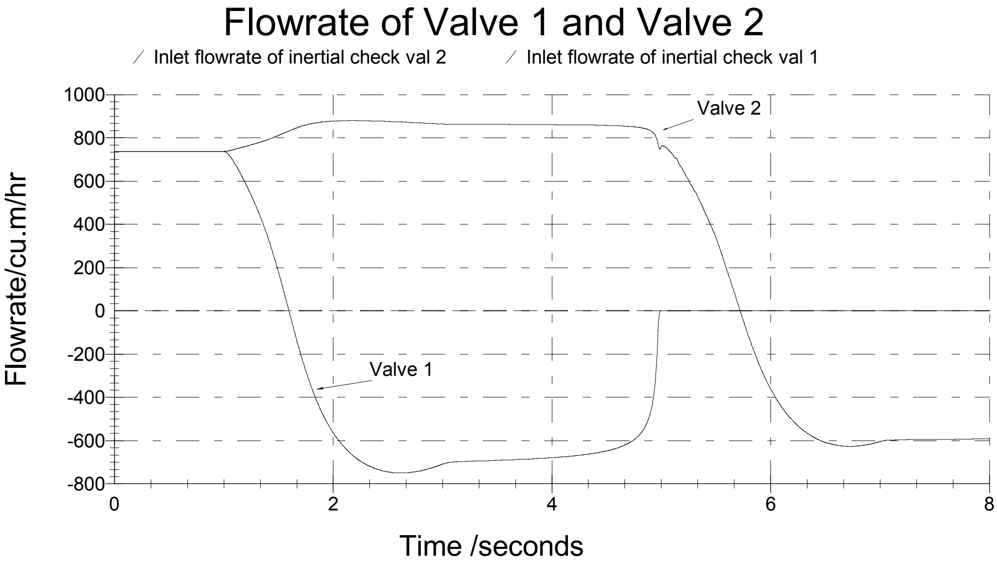


**Figure 22: Flowrate of Valve 1 and Valve 2**

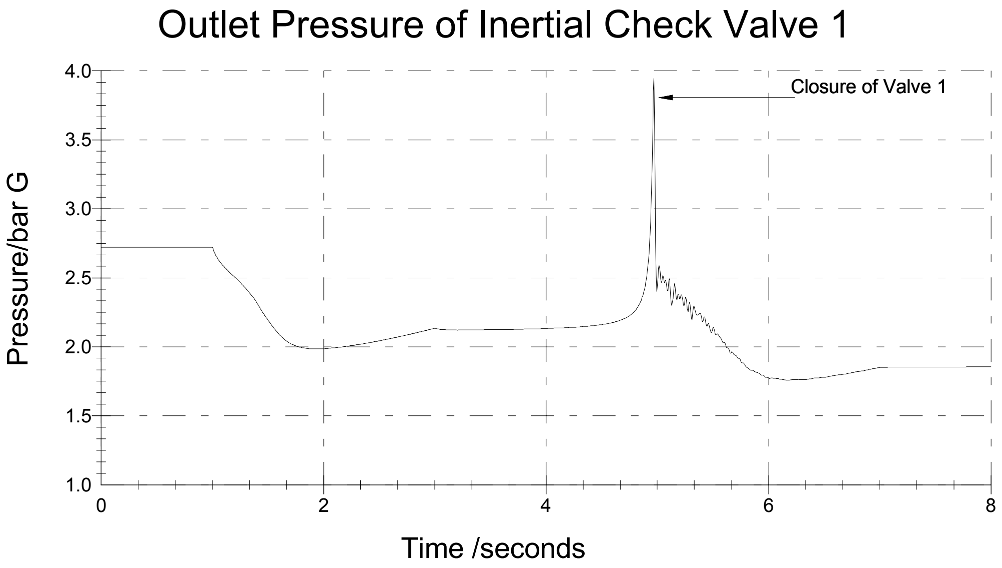


Figure 23: Outlet Pressure of Valve 1

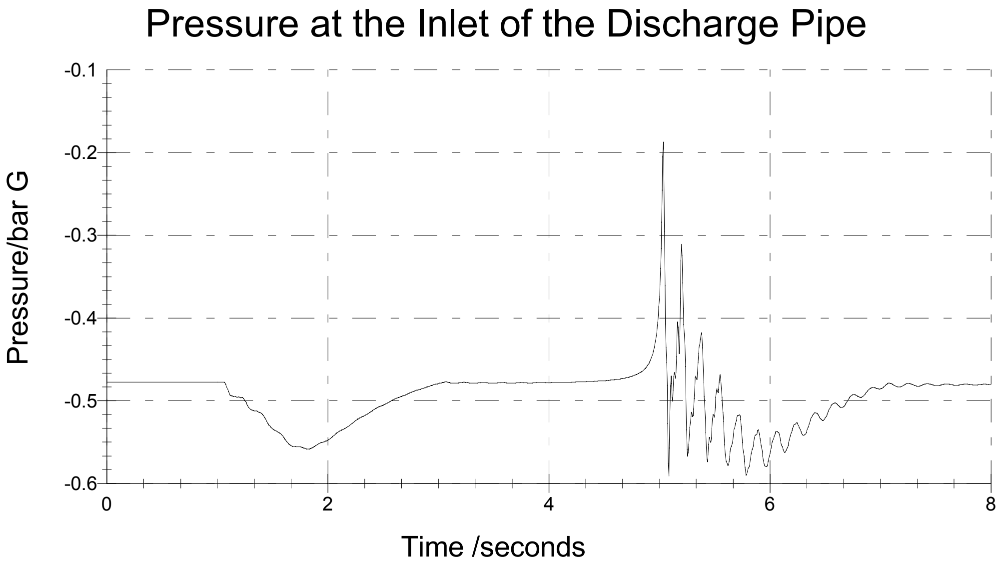


Figure 24: Pressure at the Inlet of the Discharge Pipe (Pipe 43)

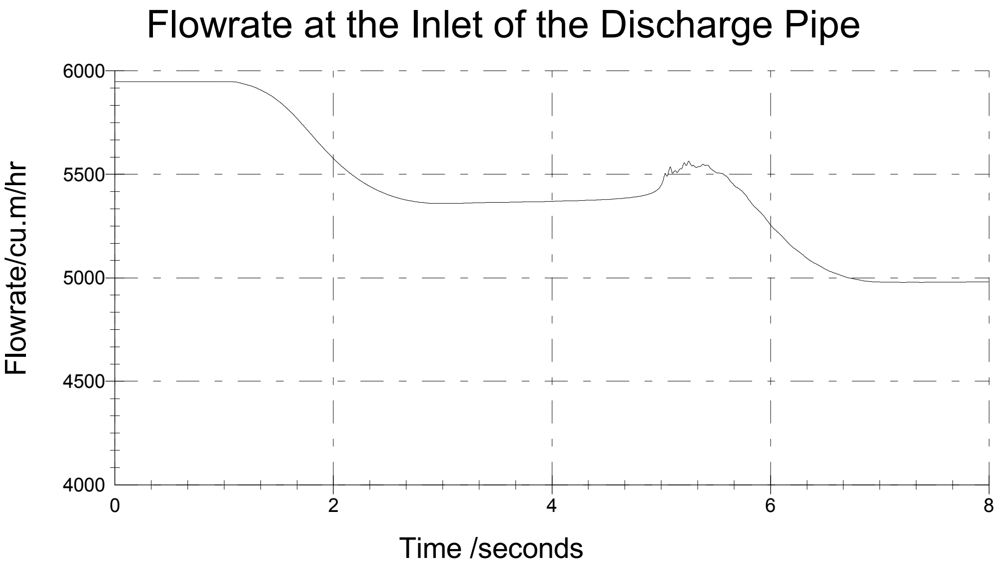


**Figure 25: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)**

# Case 2: Shutdown of All Pumps Simultaneously

In this example all 8 pumps are operating to start with. Then all of them are shutdown in exactly the same way as Pump 2 was shut down in Case 1.

## *Parameters of Simulation 2*

The parameters of this set of simulations are

- Pump shutdown within 2 seconds, represented by a linear change of the pump setting.
- Mass of the valve door: 20 kg
- $C_V$ value of the valve: 3000 $m^3/h/bar^{½}$
- No damping of the valve door.

## *List of Figures*

The following variables are shown:

INPUT DATA

Figure 26: Setting of All Pumps

RESULTS COMPUTED BY PIPENET

- Figure 27: Valve Door Angle of Valve 1
- Figure 28: Flowrate of Valve 1
- Figure 29: Outlet Pressure of Valve 1
- Figure 30: Inlet Pressure of the Discharge Pipe (Pipe 43)
- Figure 31: Flowrate at the Inlet of the Discharge Pipe (Pipe 43)

## *Summary of the Results*

The shutdown of all valves does not cause any significant water hammer. The flow stops gently allowing the valves to close relatively slowly. Some oscillations occur after the closure of all valves due pressure waves being reflected at the inlets and outlets of the system.

The pump shutdown time of all the pumps in this simulation is the same as that of Pump 1 in Simulations 1A – 1D. The simulation time is reduced to 6 seconds as there is no other event is this case.

In this simulation only the pressure and flowrate of Valve 1 is shown. This is representative of all valves as they close simultaneously.

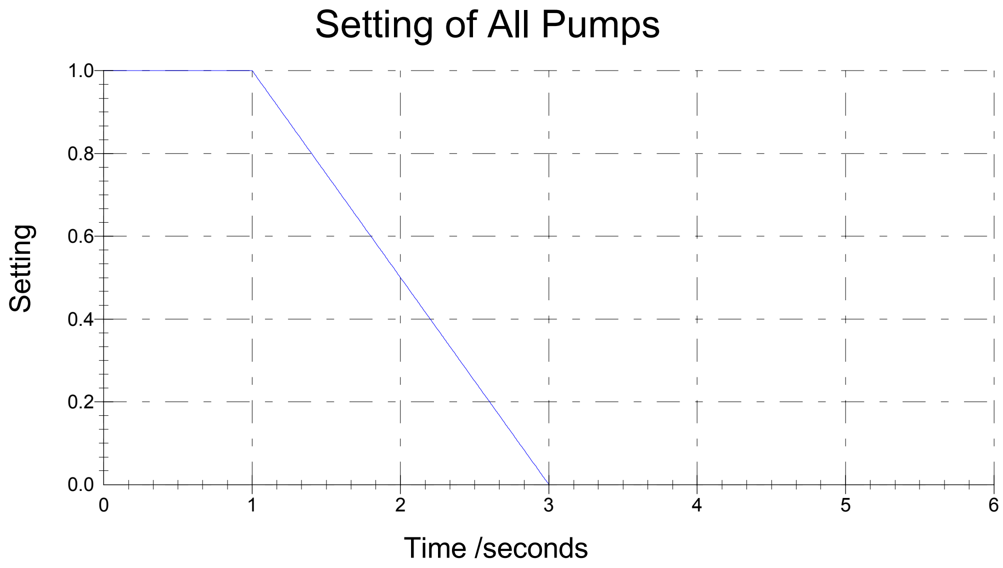


**Figure 26: Setting of All Pumps (1-8)**

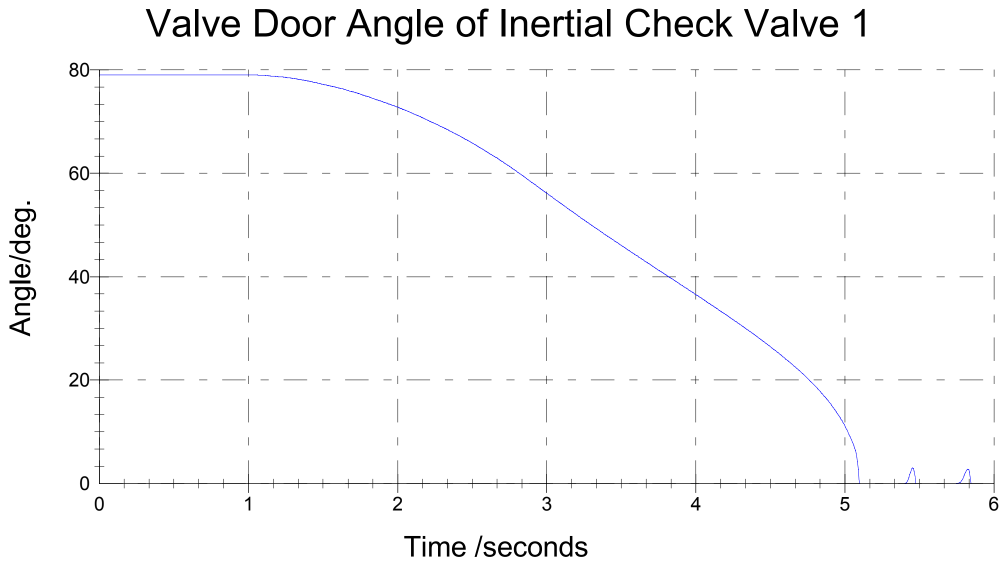


**Figure 27: Valve Door Angle**

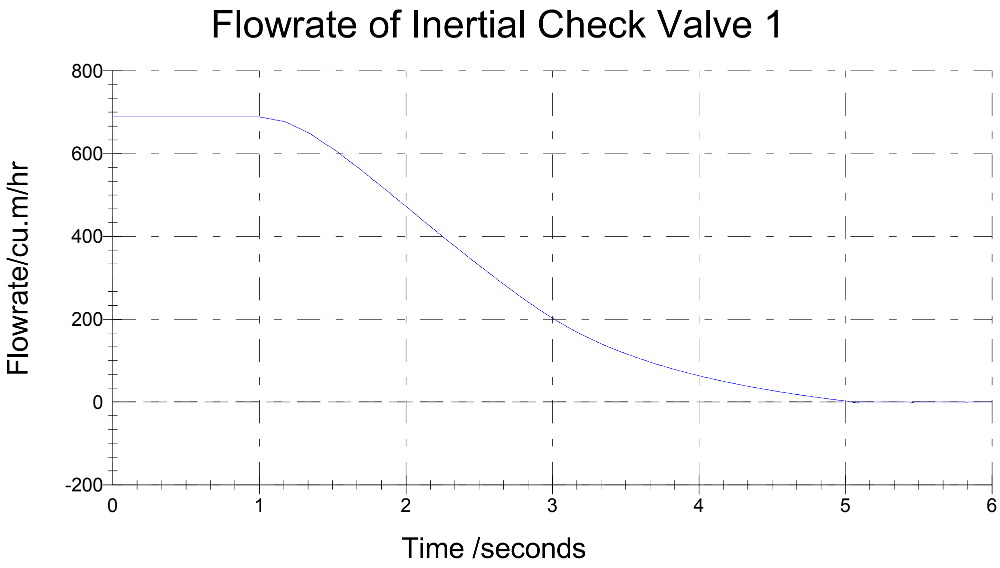


**Figure 28: Flowrate of Valve 1**

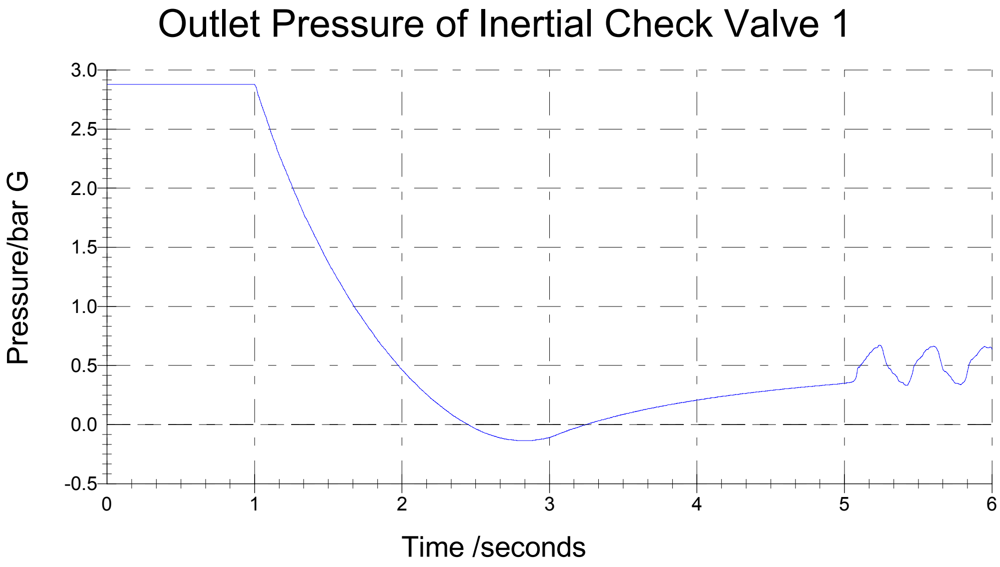


**Figure 29: Outlet Pressure of Valve 1**

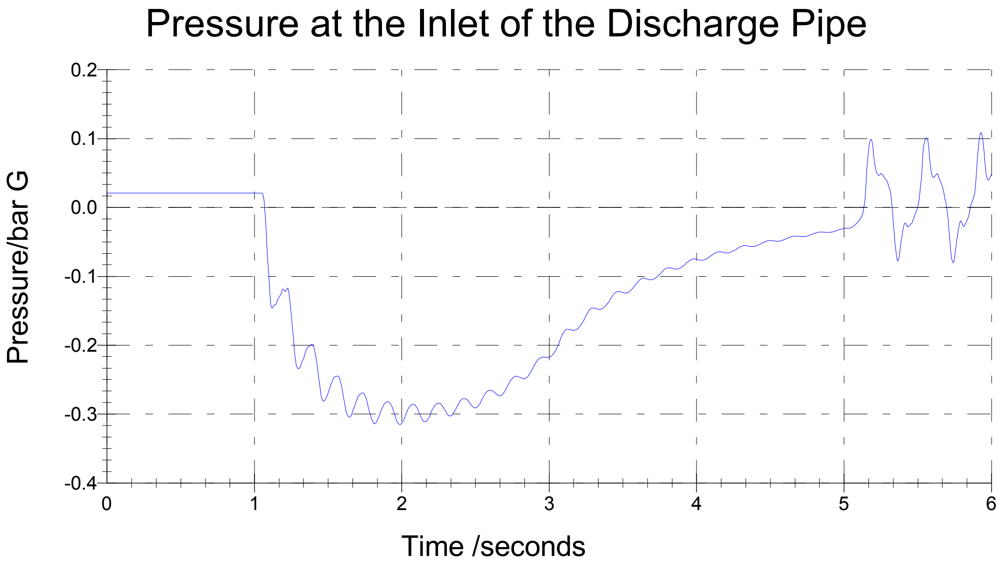


**Figure 30: Pressure at the Inlet of the Discharge Pipe**

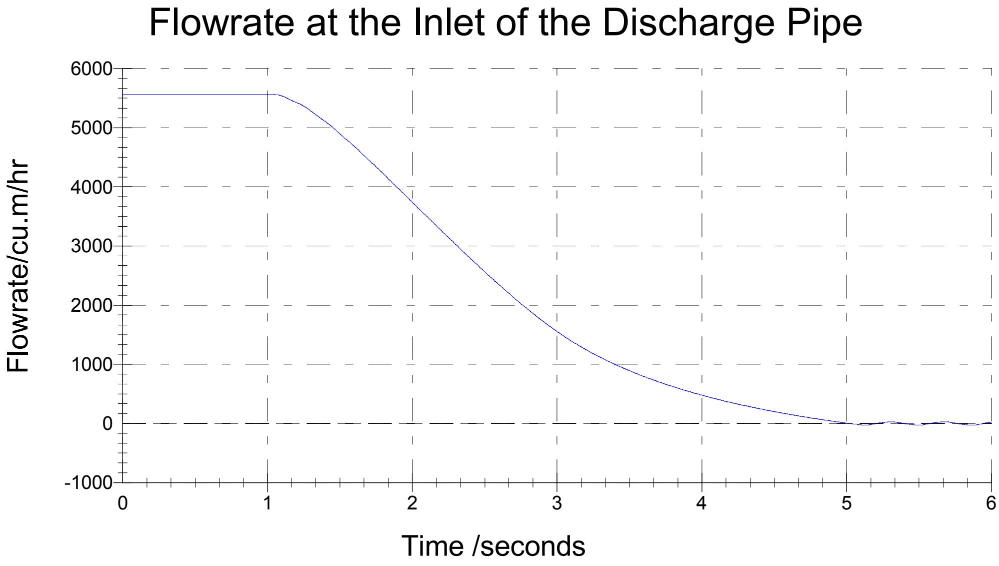


**Figure 31: Flowrate at the Inlet of the Discharge Pipe**

# Conclusion

The simulations presented show that PIPENET is a useful tool for designing and analysing pipe networks. The effect of parameter changes can be assessed quickly and easily and dangerous designs can be avoided. Furthermore, it is possible to tune system parameters for optimal performance.

The results of this brief study are:

- It was shown that an increase of valve door mass leads to a reduction in the magnitude of the pressure surge caused by the shutdown of a single pump. (Comparison of Simulation 1A with Simulation 1B)
- A small amount of damping of the valve door can cause dangerously high pressure surges. (Comparison of Simulation 1A with Simulation 1C)
- Conversely, a heavily damped valve door reduces the magnitude of the pressure surge, albeit at the price of substantial reverse flow. This leads to the conclusion that there is an optimal amount of damping for the best performance. (Comparison of Simulation 1C with Simulation 1D)
- In this problem the shutdown of all pumps simultaneously does not pose any risk of waterhammer as the flow subsides gently in this case. There are no pumps left operating to generate the pressure that is needed for the rapid closure of the Inertial Check Valves. (Comparison of Simulation 1A with Simulation 2)

# Case Study

## Brown & Root successfully model water injection system using PIPENET$^{TM}$ Transient Module

**12 September 1998**

Brown & Root Energy Services are well advanced with the development of the detailed design of the South Anne oil and gas production platform for the client Amerada Hess A/S. This platform will produce 55,000 bpd of crude oil and 70 MMscfd of gas from the Danish sector of the North Sea. To support oil production, it will be necessary to inject deaerated seawater to the oil reservoir at very high pressure (345 barg) and at rates up to 795 m3/h. Economical design dictates that this system operates close to its design pressure limit and so it was recognised that there was a need to check that various operating modes (start-up, shutdown, valve failures) would not lead to generation of excessively high, transient pressures within the system.

**PIPENET Transient Module** software from Sunrise Systems was selected as the means to carry out hydraulic surge analysis. This software has been validated by Brown & Root and is considered appropriate for hydraulic surge analysis. A typical engineering workstation PC (Pentium processor, 32MB RAM) was used to run the software within the Windows$^{TM}$ 95 environment. This provided the engineer with the benefits of multitasking computer use whilst working with the PIPENET$^{TM}$ program.

A nodal model of the water injection system was first sketched out on paper using piping isometrics as a basis and system components were identified for entry into the PIPENET$^{TM}$ program input. The components included pumps in series, piping pipe fittings and valves.

Pump curve data was entered which was then processed by the software through a curve fitting routine to characterise the curve as a quadratic equation. The pump data is entered into a library file, which can contain numerous pump curves, which may then be referenced by the main program as required. This allowed entry of data representing different configurations of pumps, which was used in the various scenarios simulated. Similarly, pipe diameter and wall thickness data was entered into a pipe library file from which the main program retrieved data as necessary. The software also has its own library of pipe fittings data. All data input is via user friendly windows.

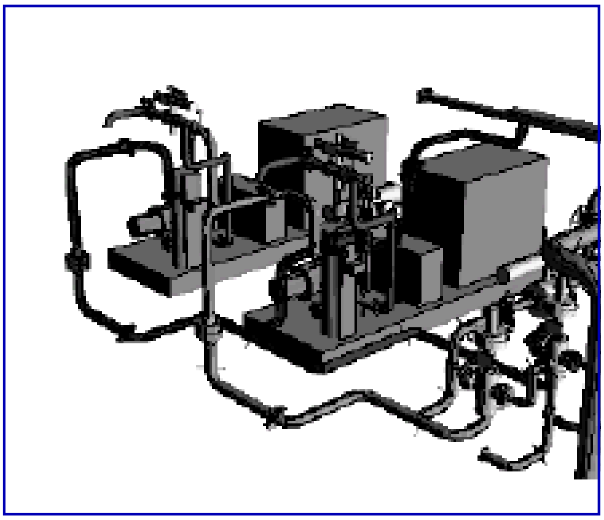
The software model required input of basic data such as pipe lengths, elevation changes, fittings, valve cv's, characteristics and closure time together with boundary conditions of pressure at system inlet (pump suction) and outlet (wellhead). The software can be used to check for input errors before running the program. Once the model was completed, various runs were performed to examine the pressure surges that are generated by scenarios such a simultaneous closure of all wellhead wing valves and during pump start-up. The findings pointed to a need to adjust certain valve closure times to bring peak pressures within the system design maximum allowable.

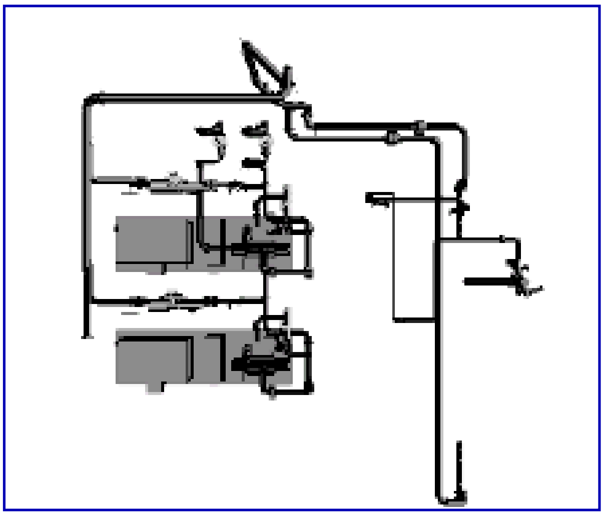
Sunrise Systems provided support during development of the model and program operation enabling a process engineer unfamiliar with the software package to gain useful results quickly. When a problem could not be solved

(continued)

immediately by telephone, the input files were emailed to Sunrise Systems and suggestions for solutions were made in a timely manner.

The diagrams below show two views of the Water Injection System.





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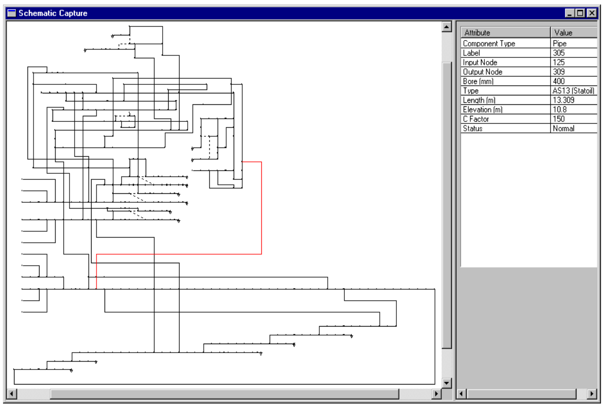
# Case Study

**Aker Maritime (AOGT) successfully develop the Gullfaks C fire fighting system models for steady state and transient analysis using PIPENET™ Spray Sprinkler Module.**

Aker Maritime are undertaking the GCM Modifications for Gullfaks C as part of the GFSAT Satellite Phase II development project. The tie-in of GFSAT phase 2 incorporates a well stream transfer from GFS, Brent subsea template to GFC through a total of three new pipelines, (two production and one test line). These pipelines are pulled through existing J-tubes on GFC.

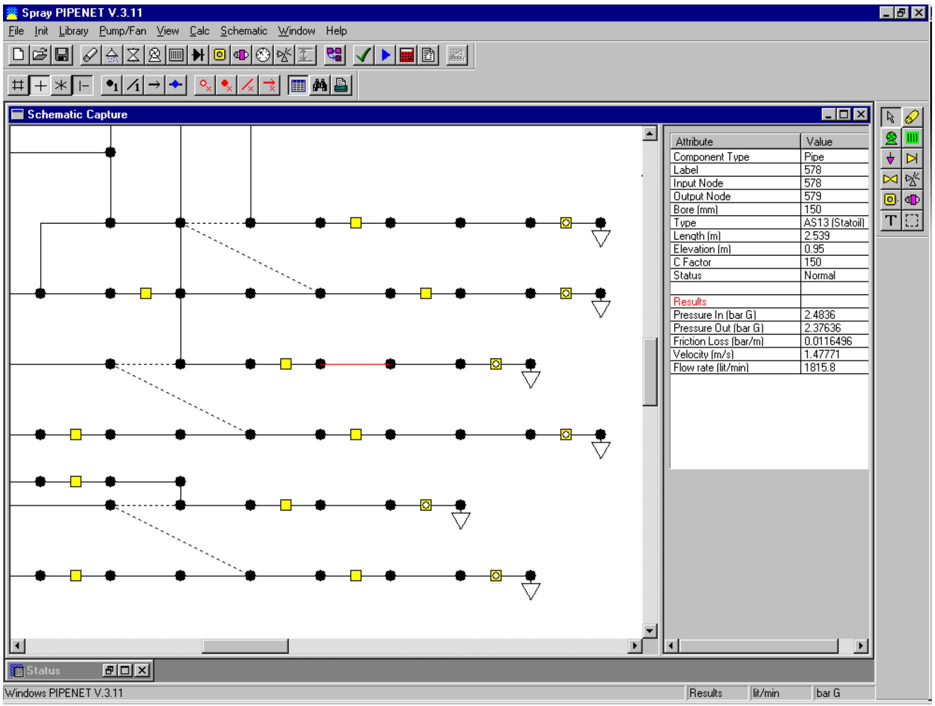
The two new subsea templates on GFS, Brent – L and M will produce two new 14” pipelines. The incoming 14” pipelines will be routed to the new Production Wellhead Module M19, installed adjacent to the existing south wellbay module M17. The test and production lines are tied into production manifolds. A new production line will then feed an inlet separator in the new Process Separation Module M10, installed adjacent to the Gas Treatment Module M14. From the inlet Separator the hydrocarbon fluids are processed within the existing process trains. Gas processing, Compression and Export facilities will be modified and upgraded to process sales gas into the Statpipe system to a capacity of 16.1MSm$^3$/d.

In adding the new modules on to Gullfaks C the Design Accident Dimensioning Load (DADL) will be increased. The existing worst case scenario will increase with the addition of the new Module M19.



| Attribute | Value |
|---|---|
| Component Type | Pipe |
| Label | 305 |
| Input Node | 125 |
| Output Node | 309 |
| Bore (mm) | 400 |
| Type | AS13 (Statoil) |
| Length (m) | 13.309 |
| Elevation (m) | 10.8 |
| C Factor | 150 |
| Status | Normal |

Aker Oil and Gas Technology UK plc (AOGT), who are undertaking the topsides design and engineering, had at first to develop a model of the firewater ringmain and each of the deluge systems. This was undertaken by firstly converting the existing analysis reports to PIPENET™ format. The converted files were then verified and confirmed against as built information.



| Attribute | Value |
|---|---|
| Component Type | Pipe |
| Label | 578 |
| Input Node | 578 |
| Output Node | 579 |
| Bore (mm) | 150 |
| Type | AS13 (Statoil) |
| Length (m) | 2.539 |
| Elevation (m) | 0.95 |
| C Factor | 150 |
| Status | Normal |
| | |
| Results | |
| Pressure In (bar G) | 2.4836 |
| Pressure Out (bar G) | 2.37636 |
| Friction Loss (bar/m) | 0.0116496 |
| Velocity (m/s) | 1.47771 |
| Flow rate (lit/min) | 1815.8 |

From the analysis that was undertaken using PIPENET™, AOGT were able to set the duty point for the new DADL. This was determined as being 2800m³/hr at 19.1 bar at the discharge flange. The existing firepumps are being refurbished and upgraded to meet this new demand.

By using PIPENET™, AOGT have been able to identify areas within existing deluge systems where the hydraulic gradient is being constrained by undersized piping. We are undertaking to rectify these piping anomalies with a resultant saving in firewater demand of over 20%.

The PIPENET™ Spray Sprinkler Module by Sunrise Systems has played a major part in enabling AOGT's Fire Protection Engineer to complete this work in a very short timescale. The program is running on a desktop PC using Windows 95™ which allows the responsible engineer to benefit from working in a multi-tasking environment.

The complete library of data and output files will be presented to Statoil for their future use.

AOGT are now undertaking a review of the transient conditions within the ringmain post modification. This will allow AOGT to determine the best solution required to reduce surge overpressures to an acceptable level.

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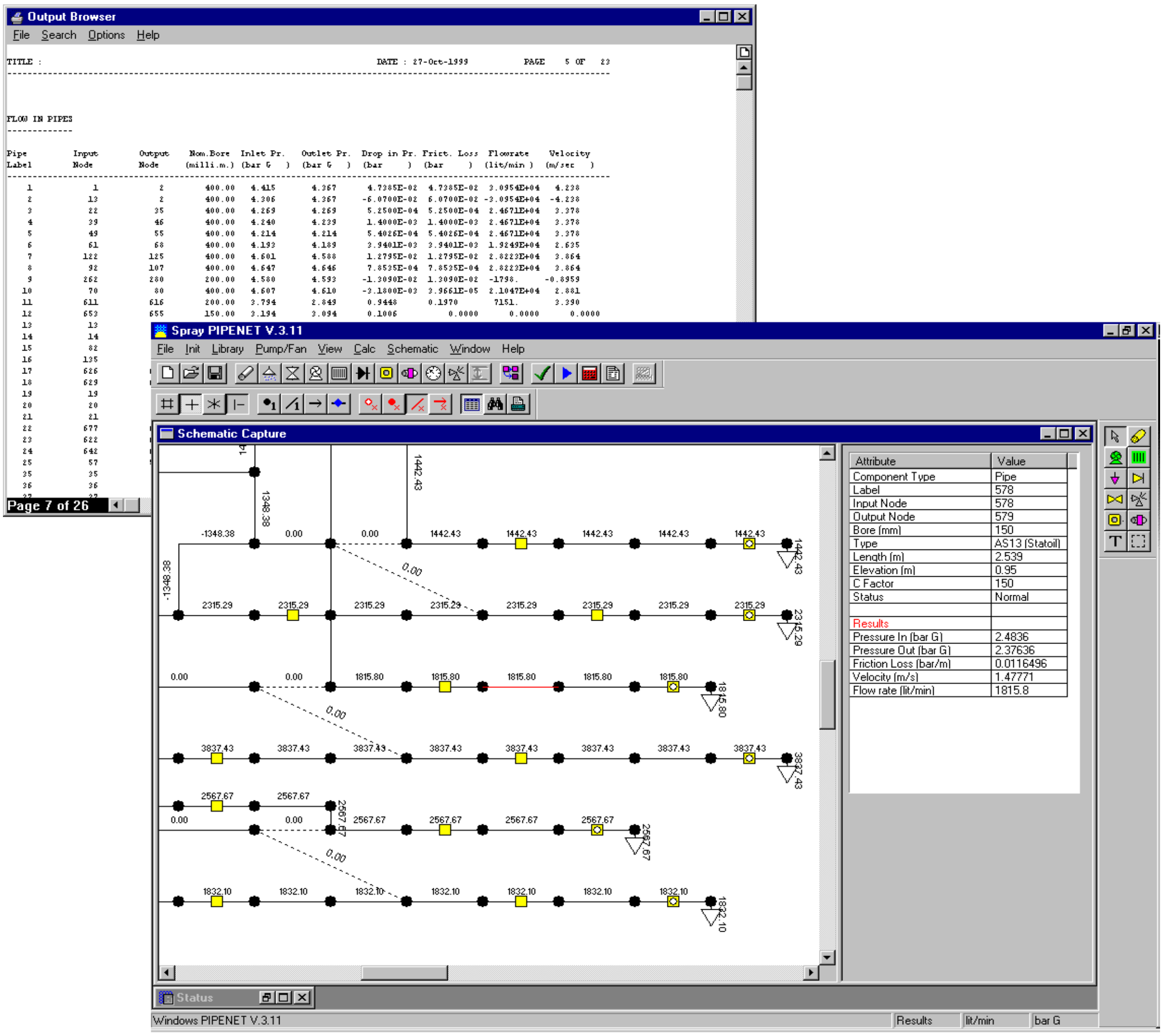

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TITLE :                                            DATE : 27-Oct-1999        PAGE    5 OF   23
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FLOW IN PIPES
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Pipe         Input        Output     Nom.Bore  Inlet Pr.   Outlet Pr.  Drop in Pr. Frict. Loss  Flowrate   Velocity
Label        Node         Node      (milli.m.) (bar G   )  (bar G   )  (bar      )  (bar      ) (lit/min )  (m/sec    )
-----------------------------------------------------------------------------------------------
    1            1            2       400.00     4.415       4.367      4.7385E-02  4.7385E-02  3.0954E+04   4.238
    2           13            2       400.00     4.306       4.367     -6.0700E-02  6.0700E-02 -3.0954E+04  -4.238
    3           22           35       400.00     4.269       4.269      5.2500E-04  5.2500E-04  2.4671E+04   3.378
    4           39           46       400.00     4.240       4.239      1.4000E-03  1.4000E-03  2.4671E+04   3.378
    5           49           55       400.00     4.214       4.214      5.4026E-04  5.4026E-04  2.4671E+04   3.378
    6           61           68       400.00     4.193       4.189      3.9401E-03  3.9401E-03  1.9249E+04   2.635
    7          122          125       400.00     4.601       4.588      1.2795E-02  1.2795E-02  2.8223E+04   3.864
    8           92          107       400.00     4.647       4.646      7.8535E-04  7.8535E-04  2.8223E+04   3.864
    9          262          280       200.00     4.580       4.593     -1.3090E-02  1.3090E-02 -1798.       -0.8959
   10           70           80       400.00     4.607       4.610     -3.1800E-03  3.9661E-05  2.1047E+04   2.881
   11          611          616       200.00     3.794       2.849      0.9448      0.1970      7151.        3.390
   12          653          655       150.00     3.194       3.094      0.1006          0.0000      0.0000      0.0000
   13           13
   14           14
   15           82
   16          135
   17          626
   18          629
   19           19
   20           20
   21           21
   22          677
   23          622
   24          642
   25           57
   35           35
   36           36
```

| Attribute | Value |
|---|---|
| Component Type | Pipe |
| Label | 578 |
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| Output Node | 579 |
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| Velocity (m/s) | 1.47771 |
| Flow rate (lit/min) | 1815.8 |

# Case Study

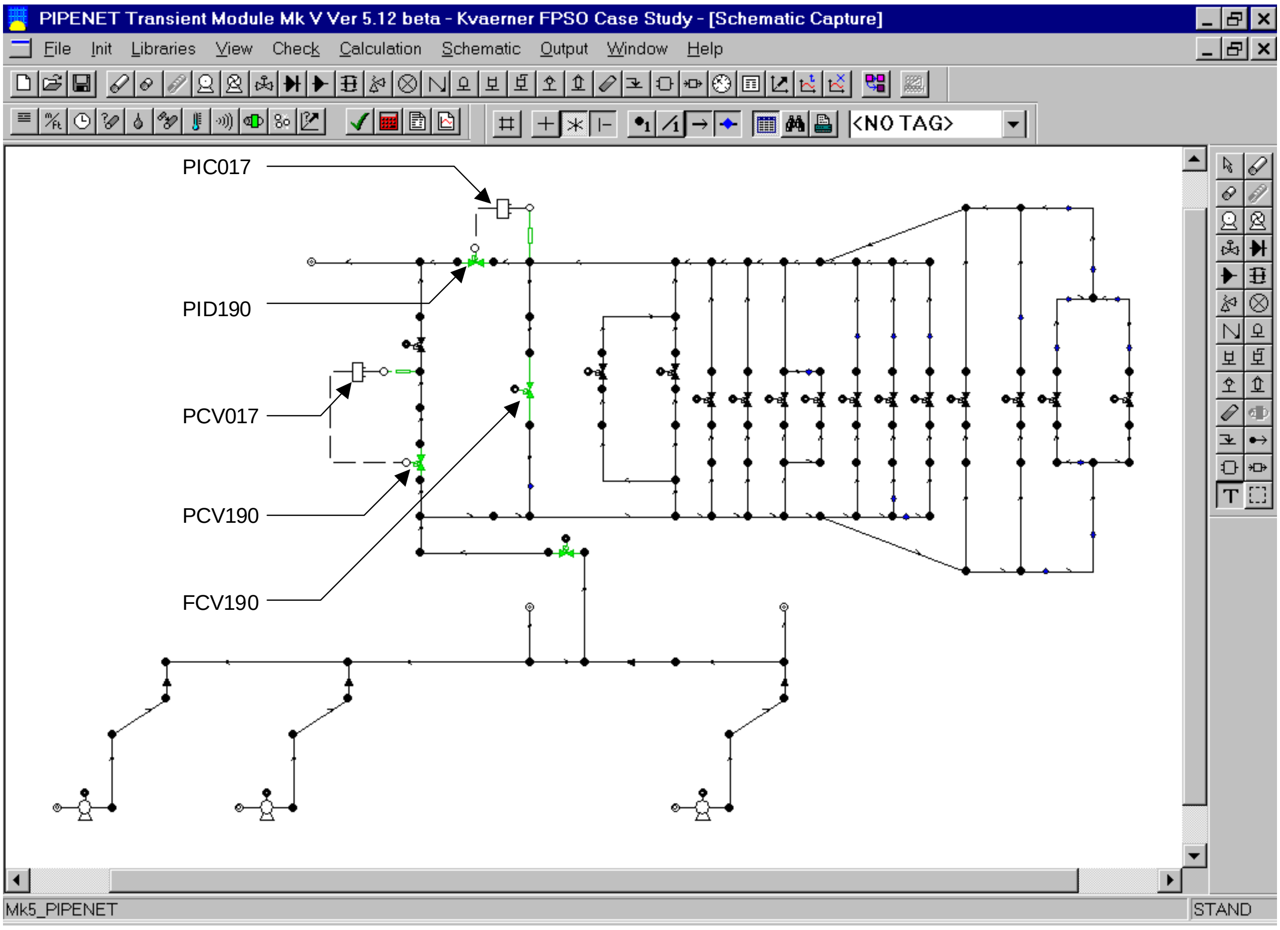
## Surge analysis of a floating platform storage offshore seawater system using PIPENET™ Transient Module

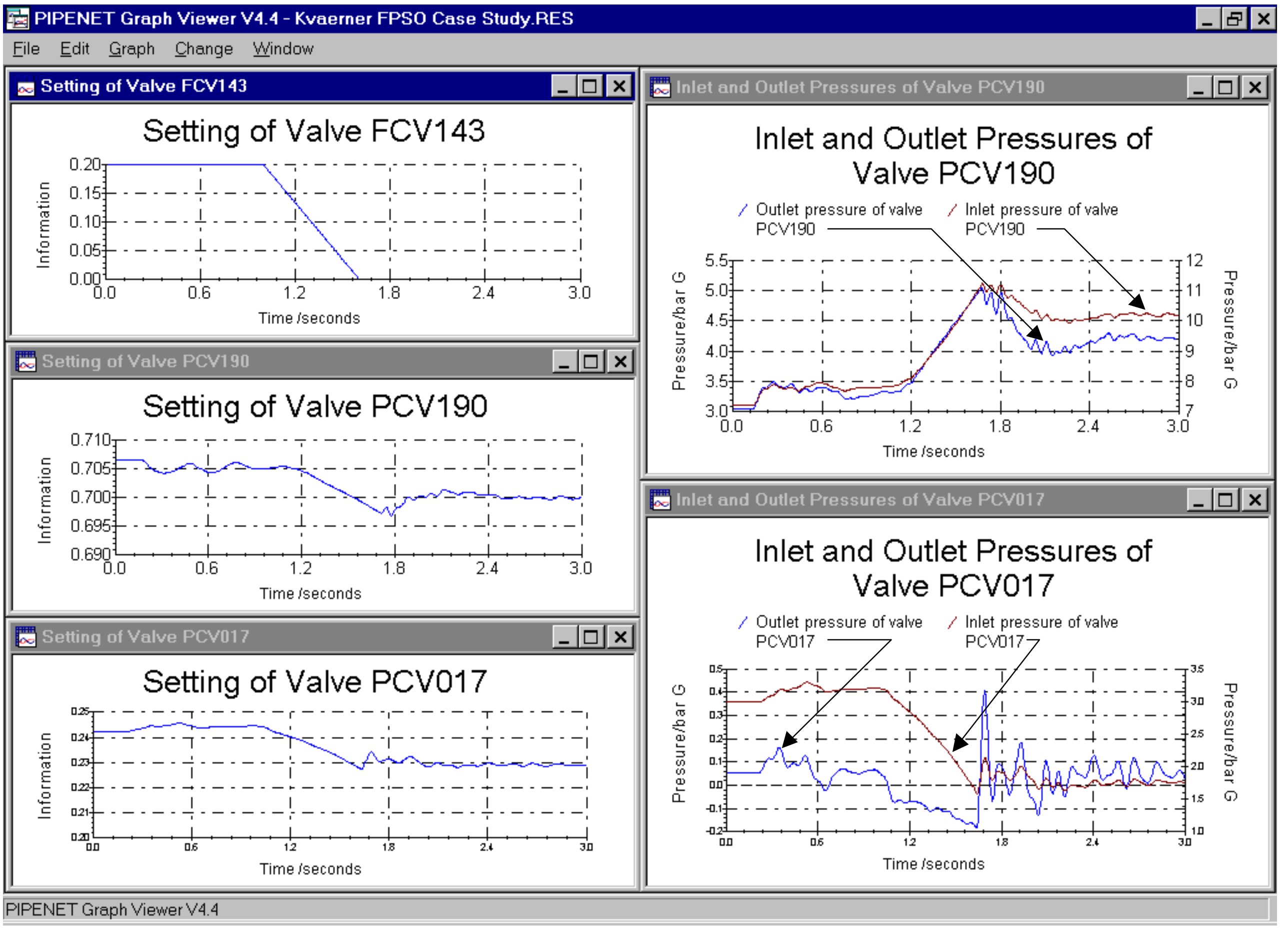
Kvaerner E&C (Australia) was commissioned by a client to investigate operational difficulties that have been experienced on the seawater system of a floating platform storage offshore (FPSO). These difficulties included: water hammer when the system was returned to normal operation after tripping to firewater mode; water hammer when the standby seawater lift pump was started; and water hammer when the minimum flow control valve closed quickly on instrument air failure.

The study utilised Pipenet Transient Module to model the events that caused water hammer and then to investigate methods to mitigate the forces generated.

The major problem identified when the seawater system was returned to normal operation was that the slow tuning required of the seawater return back-pressure controller resulted in the valve remaining open for some time after the SW/FW isolation valve had closed. This allowed the seawater system to drain partially, causing vapour pockets to form at high points. When the system was re-started, these vapour pockets collapsed with the consequence that shock waves were generated. Any air entrained within the system would cause severe slugging as it was brought back online. The modifications comprised a software change to close the back-pressure control valve on trip to firewater mode, and a procedure to utilise the drain valves around the main isolation valve to prime the system before re-opening the main isolation valve.

The changes to the standby seawater lift pump system comprised modifications to the discharge check valves. There were three check valves in the discharge line: one immediately downstream of the pump; and two further along the discharge





line. Due to leakage past the pump discharge check valve it was possible to draw a vacuum between the check valves when the pump was idle. It was therefore proposed to remove one of the latter valves and to drill a small hole into the remaining second check valve. The simulations showed that this ensured that the discharge line would remain primed between standby pump operations.

Instrument air failure was simulated to investigate the maximum closure rate for the minimum flow control valve that would not cause waterhammer.

Key findings of the study were:

- the offline seawater system must be fully primed before opening the main isolation valve;
- the standby pump discharge must be fully primed at all times to prevent starting into a dry riser;
- all main control valves must have relatively slow closure times defined by their actuator, so that they cannot cause waterhammer on instrument air failure.

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