Pressure Surges and Air Valve Specification, Location, and Sizing

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Abstract

Air valves are an important tool for surge dampening and suppression. Accurate air valve specification, location and sizing are vitally essential for effective, efficient liquid flow and for sufficient pressure surge dampening and suppression. In this paper and presentation I will describe the air valves that were designed for surge protection, explain their operation, and list ways and tools to specify, to locate, and to size them for maximum flow efficiency and surge protection.

Introduction

Air plays a very important role in liquid flow in pipelines and in liquid conveyance and treatment systems in general. Surge suppression is one of the primary purposes for airflow control in liquid conveyance systems.

Air valves are universally recognized as the most effective airflow control tools for liquid conveyance systems. Their contribution to efficient liquid flow, to energy savings and to down-surge suppression and control is widely acknowledged, but their positive contribution to upsurge suppression and control is sometimes challenged.

Recognition and trust in air valves as surge controllers have improved with the development of specially designed non-slam, surge dampening and suppressing air valves, and with innovations in the design of user friendly, yet powerful tools for analysis and design of air valve airflow control systems.

Air and Liquid Conveyance

Pressurized two-phase flow in pipelines can be complicated, mostly due to their dissimilar properties. While the system operates in its normal, on-going manner, it is prudent to release air (and other gases) from the pipeline, thus, preventing or limiting two-phase flow.

However, there are situations in the liquid conveyance process, where air has to be taken in, primarily for efficient drainage, for vacuum protection, and/or for surge protection.

Some of the hindrances, problems, and dangers attributed to the presence of air in pressurized pipeline systems are listed below:

1. Interference with flow in pipelines –up to complete stoppage, at times.
2. Serious head losses - energy losses.
3. Water Hammer damages.
4. Inaccurate readings in meters and automatic metering valves.
5. Inadequate supply of water to areas in the system,
    a. Due to air obstruction to flow and accumulation of pressure losses.
    b. Due to faulty meter and automatic metering valve readings.
6. Serious damage to spinning internal parts of meters, metering valves.

7. Corrosion and cavitation.
8. Physical danger to operators from air-blown flying parts and from very strong streams of high velocity, escaping air.

However, there are, also, hindrances, problems, and dangers that require air intake for their prevention:

1. Vacuum enhanced problems and damages:
   a. Suction of mud and dirt through faulty connections, cracks in pipes an accessories, etc'.
   b. Suction of seals and gaskets, in–line fittings, and other internal accessories of pipes.
   c. Uncontrolled suction of injected chemicals into the system.
   d. Pipe or accessory collapse.
2. Pressure surges due to uncontrolled water column separation and return, resulting in vacuum enhanced down-surges and consequent up-surges.
3. In some cases, the absence of an air cushion can increase the damages of surge and slam phenomena.

Air Valves
Air valves are the most efficient and most cost effective tools for air control in pressurized liquid conveyance systems.

Air valves in general are often misnamed as "Air release valves" or, less frequently, as "Vacuum breakers". Actually, there are three basic types of air valves that function differently and serve different objectives.
- The Large Orifice Air Valve is usually called a "Kinetic Air Valve" in Europe and other parts of the world, and an "Air/Vacuum Valve" in the United States and North America. This type of air valve discharges large quantities of air from the pipeline at pipe filling and admits large quantities of air at pipe drainage (planned or due to rupture) or at water column separation. This air valve closes when the pipe fills up with liquid, and does not reopen until pressure within the air valve (pipeline) drops below atmospheric pressure.
- The Small Orifice Air Valve is usually called an "Automatic Air Valve" in Europe and other parts of the world, and an "Air Release Valve" in the United States and North America. This air valve continues to release small quantities of air when the system is pressurized and the Large Orifice Air Valves do not function.
- The Double Orifice or Combination Air Valve, includes two components, and performs the functions of the two types of air valves above.

Within the three categories of air valve types above, there are a variety of different models with a variety of additional accessories and attributes. One of the most important recent enhancements in air valve design is the non-slam, surge suppressing air valve.

Air Valve Location
Basically, air valves for exhausting air should be located at points on the pipeline to which air tends to be drawn, and/or where air tends to collect. Air valves for air intake should be located at points on the pipeline that are most susceptible to sub-atmospheric pressures. These points are often common for both functions.

This is a very simplified description of the air valve location methodology, while efficient and effective air valve location planning is often quite complicated, yet important. Proper location of air valves in a pressurized liquid conveyance systems can improve flow performance greatly, providing efficient, energy saving, dependable, and safe supply. Poor air valve location can cause problems, damage and hazards.

Manufacturers of air valves, in search for an easy to use rule-of-thumb, adopted sample pipeline profiles for location of air valves. Most of these sample pipeline profiles are quite similar, the main difference between them being valve specification (types of valves) for each type of location.

The AWWA – American Water Works Association, in their Manual of Water Supply Practices, M51 – "Air-Release, Air/Vacuum, & Combination Air Valves", adopted a sample pipeline profile similar to those of the American manufacturers.[2]
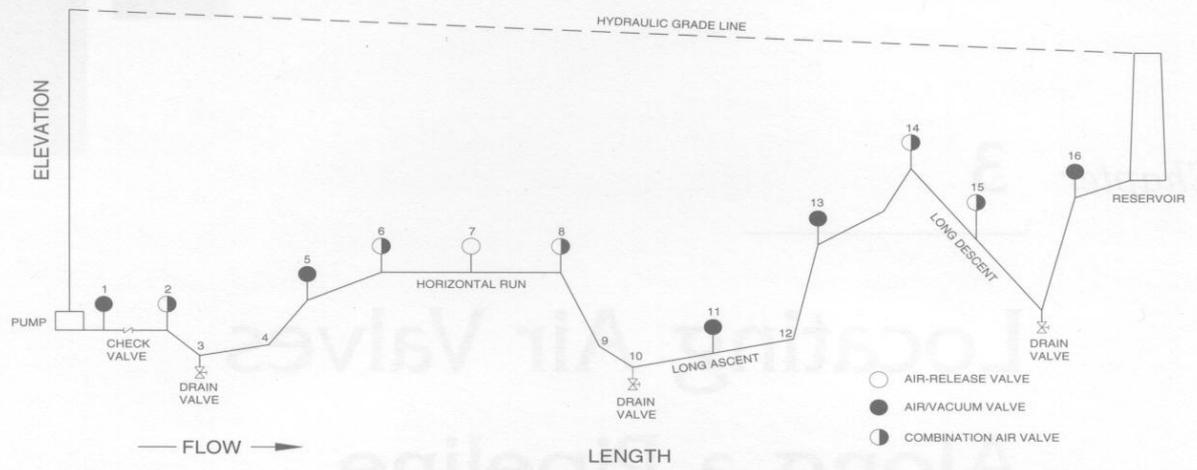

No.	Description	Recommended Types	No.	Description	Recommended Types
1	Pump Discharge	Air/Vac	9	Decr. Downslope	No Valve Required
2	Incr. Downslope	Combination	10	Low Point	No Valve Required
3	Low Point	No Valve Required	11	Long Ascent	Air/Vac or Combination
4	Incr. Upslope	No Valve Required	12	Incr. Upslope	No Valve Required
5	Decr. Upslope	Air/Vac or Combination	13	Decr. Upslope	Air/Vac or Combination
6	Beg. Horiz.	Combination	14	High Point	Combination
7	Horizontal	Air-Rel or Combination	15	Long Descent	Air-Rel or Combination
8	End Horiz.	Combination	16	Decr. Upslope	Air/Vac or Combination

AWWA sample profile for air valve location

These sample profiles are simplified rules-of-thumb and are not meant to be planning tools for complicated water supply systems. The AWWA manual, in addition to the locations pointed out in the sample profile above, does mention location of valves at in-line isolating valves, before Venturi water meters, and for siphons. But not enough emphasis is given in these sample profiles to location for surge protection.

A.R.D. Thorley, in his "Fluid Transients in Pipeline Systems", introduces a similar typical rising main pipeline profile with air valve locations, but in his explanations, he suggests a number of possibilities at each location and he refers to possible local surges due to valve slamming at water column return and the possibility of damping this surge by the use of "a surge check or vented non-return valve".[3] But, this rule-of-thumb placement guide is also very simplified, and lacks some important air valve placement sites, such as at pump discharge, after pump check valve, before and/or after in-line isolating valves, before mechanical or Venturi water meters, after pressure reducers, etc'.
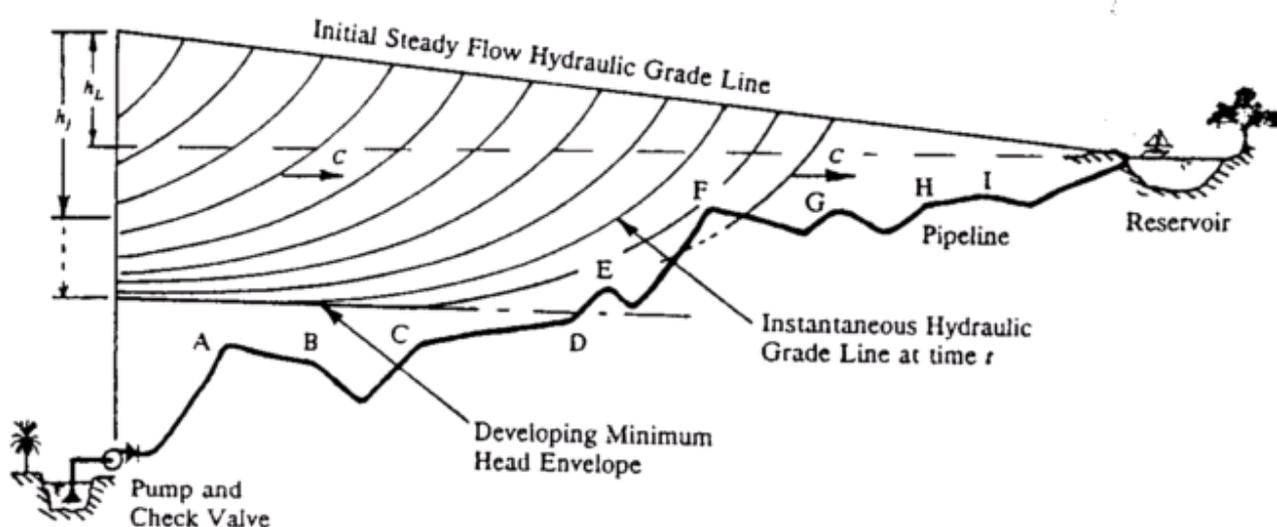
Thorley sample profile for air valve location

The explanations of Professor Thorley to the above air valve locations are, basically, as follows (abridged):

A   Rapid air admission for draining and rapid release. Consider surge
     check valve. Small Orifice will release entrained air coming out of solution.
B   If A and B are less than 100 m apart, Small Orifice will suffice.
     Otherwise, similar to A.
C   If there are Large Orifice air valves at D or E, one is not necessary
     here – only a Small Orifice. Otherwise, similar to A.
Between C and D   Small Orifice every 500-800 m.
E   Ventilation and Transient flow protection: Rapid air admission for draining,
     rapid air release at pipe filling, slow air release at pressurized flow.
     At transient flow, admitting air when pressure falls below atmospheric
     pressure, and controlled, non slamming, air release (surge check valve) at

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water column return.

F   Ventilation and Transient flow protection: "Perhaps the most critical point" for transient conditions. Dual orifice valve for the same functions and operations as in E, but more critical.

G, H, I   Because critical column separation will be at F, transient considerations are less critical here. Dual Orifice air valves.

The rule-of-thumb air valve location methods are partial, and, in addition to not covering some of the very important locations, as mentioned above, they do not put enough emphasis on the source of the air to the system. Pumps, for instance, are a major source of air to pipelines.

- Deep-well pumps usually have large columns of air that should be kept from reaching the piping system. Pumps pumping from wet wells, ditches, rivers, lakes, etc', suck in air through a vortex at the suction intakes. In addition to this atmospheric free air, dissolved air in the water is released from solution, due to pressure drops within the pump (turbulence), and due to temperature rises within the pump.

- When a warmer water source is connected to a transmission line, say, a surface water source connected to a groundwater source, dissolved air is released from solution.

- At points of pressure drop along the line, such as at pressure reducers, at pipe diameter reducers, at accessories that cause significant head losses, in areas of turbulence, etc', dissolved air is released from solution.

- At pipe and accessory connections that are not properly sealed, atmospheric air can infiltrate at pressure drop events.

These are some examples of air sources, and after each of these sources, it would be prudent to install automatic air release valves or combination air valves.

Air Valve Sizing

Proper sizing of air valves is essential for effective, efficient, and safe air control.

There is no standard accepted method to determine automatic air release flow requirements under pressure, since it is difficult to determine the amount of accumulated air in the system. Sometimes, a value of 2% of the operational water flow-rate is used, based on 2% solubility of air in water.[2]

Kinetic, large orifice air discharge requirements are usually based on the pipeline fill-rate, and are equal to the designed pipe filling flow-rate. Smaller large orifice air valves are sometimes used in sections along the pipeline, to throttle fill-rate, thus decreasing the danger of pressure surges at pipe filling. The use of throttled large orifice air valves will be discussed later.

Air intake requirements are usually considered the determining factor in air valve sizing. Most air valve manufacturers suggest the use of a pipe burst analysis using one of the common flow formulas, such as the Hazen-Williams Equation, the Darcy-Weisbach Equation, the Manning Equation, the Chezy Equation, or an equation derived from one of these. The analysis usually assumes a full diameter pipe burst resulting in a full diameter free water flow. In order to protect the pipe from collapse due to vacuum conditions, a large orifice air valve with an air intake capacity equal or greater than the above free water flow, is required.

For determining air intake requirement in valve sizing, the AWWA, in its M51 manual, suggests the use of an equation derived from the Chezy Equation:
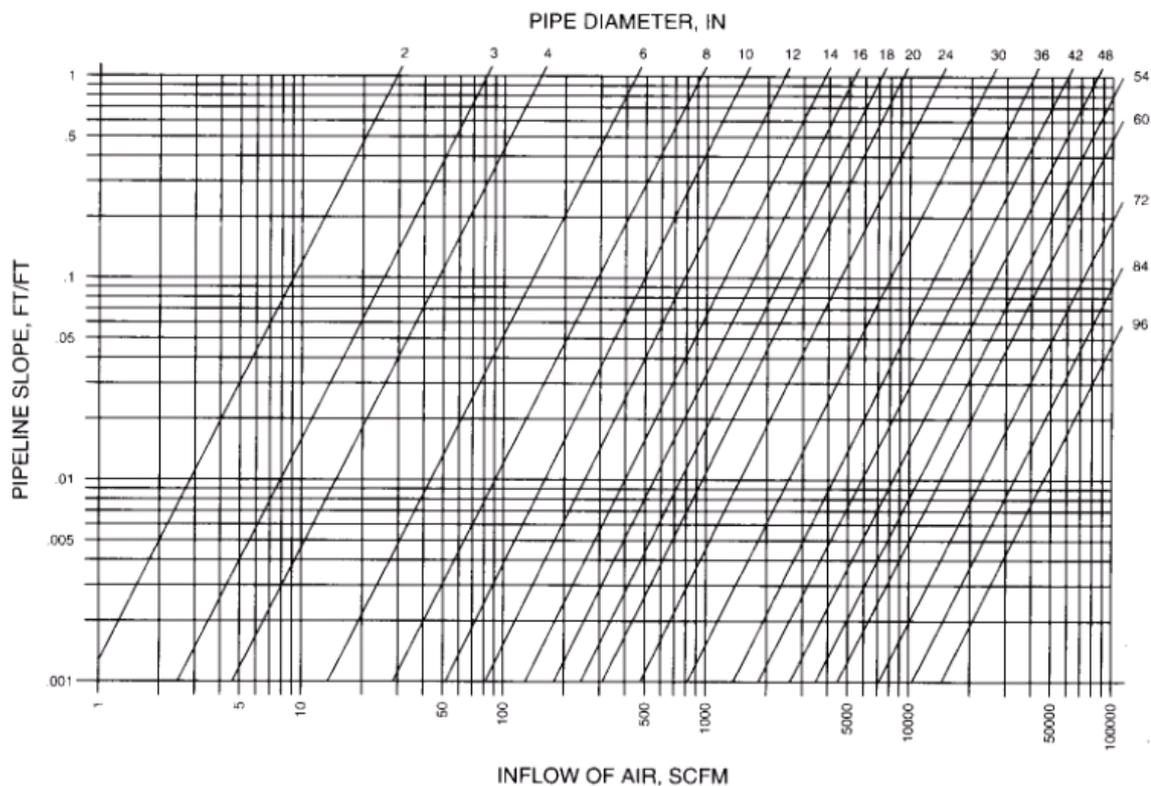
$$Q = 0.0472C\sqrt{SID^5}$$

Where:
Q = flow-rate in scfm
C = Chezy coefficient (110 for iron, 120 for concrete, 130 for steel, 190 for PVC)
S = pipeline slope in ft/ft
ID = pipeline inside diameter in in.[2]

Kinetic Large Orifice Air Intake Requirements According to AWWW Manual M51

As can be seen from the equation, air flow-rate requirements, in this analysis, are determined from the pipe inside diameter and slope. The other factors are constant for the particular pipe material. At very steep runs, no matter what the elevation differences (Δh), air intake requirements can be very high, and sometimes unrealistic. For small elevation changes, for instance, there may not be enough time for the air valve to open, or substantial sub-atmospheric pressures may not be reached.
Some air valve manufacturers suggest determining air valve capacity using a percentage of the water drainage flow-rate (sometimes called "estimated rupture"), often based on the pipe material.

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Water Column Separation and Pressure Surges

Pressure transient propagation through a pipeline affects a normally periodic pressure variation at any point along the pipeline[4], sometimes characterized by a down-surge and an up-surge, at certain critical points in the system.

At power failure, at pump tripping, or at sudden in-line isolating valve closure, water column separation can occur at the pump's discharge or down stream from the valve, depending on the hydraulic gradient. A down-surge results, where pressure falls below the vapor pressure of water, often to sub-atmospheric levels. A vapor cavity develops and expands behind the advancing water column. When the water column returns, pressure rises, bursting the vapor cavity, releasing great amounts of energy. The water column slams against the closed valve or pump check valve. The vapor cavity burst and the water column slam create an up-surge. As the water column bounces off the pump check valve or closed valve and returns, in the direction of the original flow, a vacuum cavity develops again, and the process repeats itself over and over again, until friction dissipates the kinetic energy. This phenomenon also occurs at peaks close to the hydraulic gradient, at sudden flow stoppage.

In the above examples, pressure oscillation begins with a down-surge and is followed by a consequent upsurge.

A reverse process occurs at a dead end or at a closed valve, when a pipeline is filled at high velocity (above 0.5 m/s), and up-stream of a suddenly closing in-line isolating valve. An up-surge occurs as the water column slams at the dead end or at the closed valve. When the water column bounces back, accelerating in the opposite direction, column separation occurs, resulting in a down-surge. Here also, as pressure falls below the vapor pressure of water, often to sub-atmospheric levels, a vapor cavity develops and expands to fill the vacuum left by the parting water column. When the water column returns, pressure rises, bursting the vapor cavity, releasing great amounts of energy. The returning water column slams against the closed valve or dead end. As in the previous examples, the process repeats itself over and over again, and the periodic oscillation continues until friction dissipates the kinetic energy.

In this, second set of examples, pressure oscillation begins with an up-surge and is followed by a down-surge.

The above locations, prone to water column separation, are very important locations for air valve placement.

Air Valves and Pressure Surges

Down-surges can cause damages to pipe fittings and accessories or can generate suction of gaskets, of seals, of dirt, of chemicals, of pollutants, etc', into the pipeline. When the pipeline is uniformly weak round its circumference, severe down-surges can result in pipe implosion and collapse. When certain areas around the circumference of the pipe are weaker than others, such as the pipe's crown, recurring incidents of cyclic down-surges and up-surges can result in pipe ruptures and bursts.
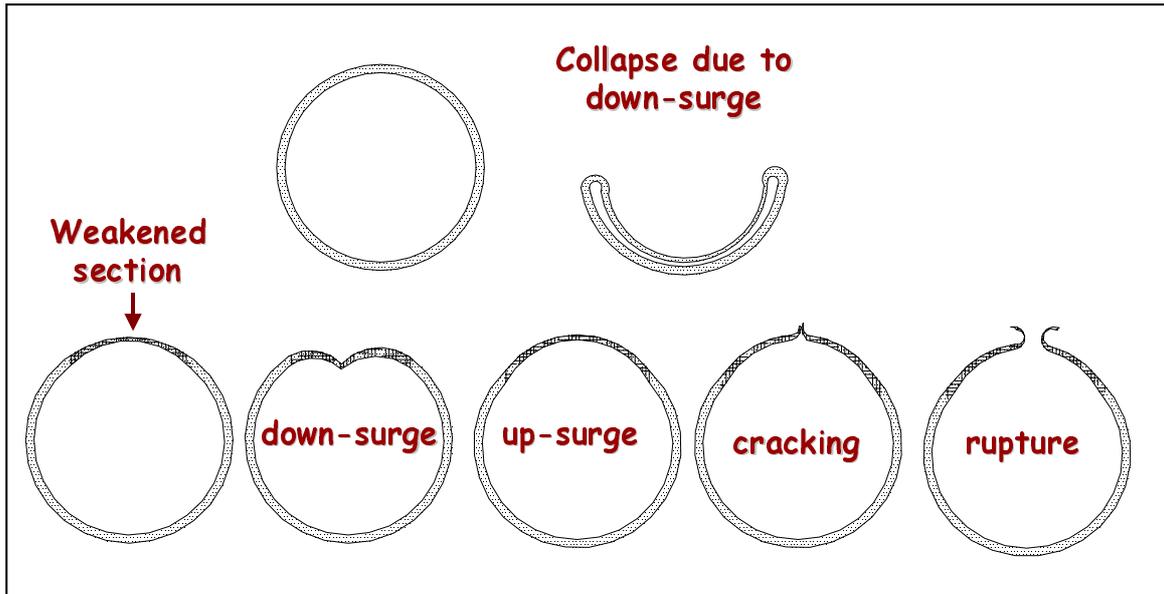
Pipe damage do to down-surges and up-surges

**Pipe Collapse in India**   **Pipe rupture in New York City[5]**

The use of air valves as vacuum breakers for the prevention of vacuum
conditions and consequent pipe collapse is well known and recognized world-
wide. Their potential contribution to the control of cyclic pressure surges,
brought on by the water column separation process, is less known, and
sometimes challenged.

In his presentation at the Fourth International Meeting on Water Column
Separation in Cagliari, Italy, on September 11-13, 1979, C. Samuel Martin, from
the School of Civil Engineering of the Georgia Institute of Technology in Atlanta,
concluded that: "Column-separation induced waterhammer can be eliminated
by vacuum breakers of adequate size".[1]

Since pressure surges, brought on by water column separation are cyclic, control
of one extreme of the pressure wave, say the down-surge, has a definite effect on
the opposite extreme, in this case, the up-surge. The advantages of air valves, in

restraining up-surges by controlling down-surges, is becoming more and more recognized. Advances in digital computation and better understanding of transient flow and surge processes, brought to the development of mathematical and digital models that are able to analyze and predict transient processes, while testing possible solutions.

Hydraulic transients caused by power cuts to pumps on a huge pipeline system in a desalination plant, caused damages, resulting in lengthy shut-downs of the system. Marko V. Ivetić, a Leverhulme trust Fellow, in the University of Exeter, UK, on leave from the Faculty of Civil Engineering, in the University of Belgrade, analyzed a number of possible solutions to the problem by running computer simulations of transient events. Dr. Ivetić, in his report: "Hydraulic/Forensic Transient Analyses of two Pipeline Failures", discusses two sets of simulations for the desalination project.[6]
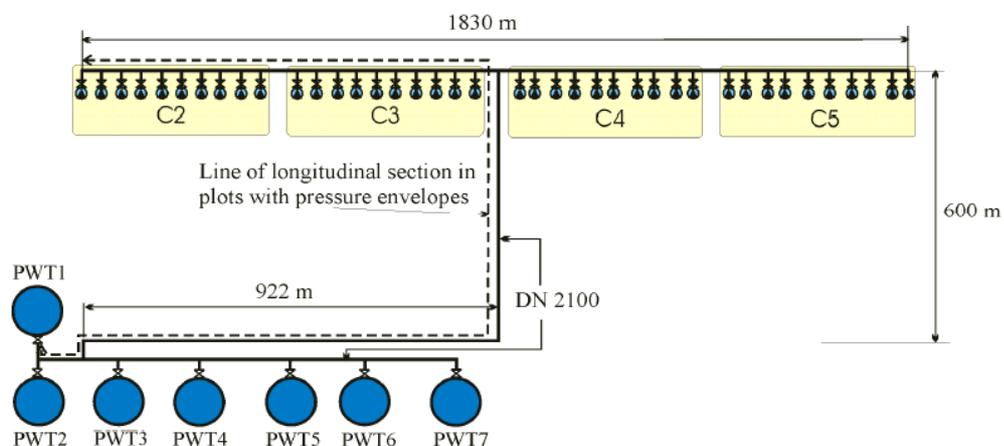

Layout of the desalination plant piping system and presentation in the model according to Marko V. Ivetić

The desalination plant piping system includes 40 pumps, arranged in four production blocks (PB), C2-C5, with 10 pumps each. Pipes with diameters of 350mm-2100mm collect the water from the 40 pumps and lead from the pumps to seven Production Water Tanks, PWT1 to PWT7. The system operating pressure is very low, between 2 and 3bars, but the high system velocities, in excess of 3 m/s, probably contributed to the transient problems.

In the initial run of the first set of simulations, a hydraulic analysis of a transient event caused by a power cut to pumps in PB C2, is performed.
From the pressure envelope snapshots of the simulation, below, an initial down-surge, resulting in sub-atmospheric pressure, when vaporous cavitation develops, can be observed at the C2 and C3 collection manifold, followed by an extreme up-surge at cavity collapse.
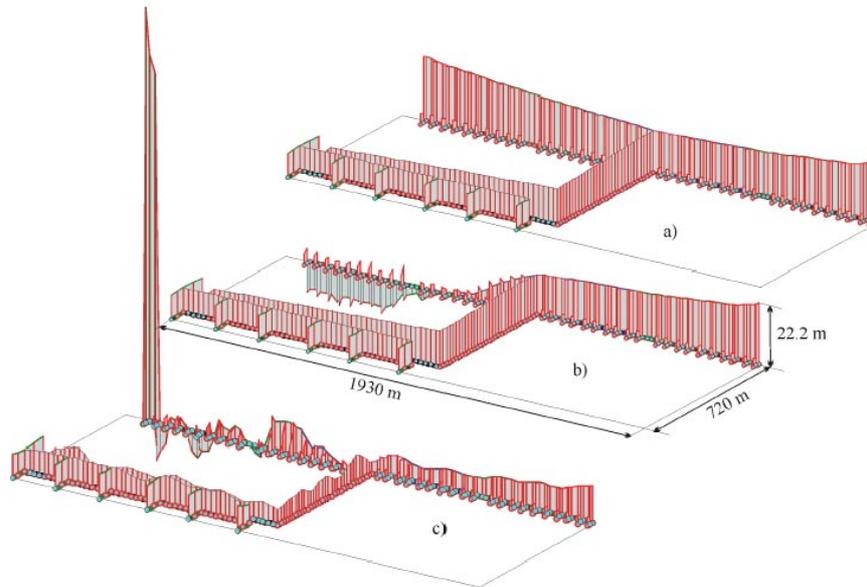
Ivetić's pressure envelope snapshots of the first simulation: a) Steady State, b) Minimum pressure with vaporous cavitation, and c) maximum pressure at cavity collapse

Ivetić's graphs, below, show simulated behaviour at the largest cavity, showing pressure, flow-rate, and cavity formation and collapse against time. Here, at a peak in the pipeline, the sub-atmospheric down-surge, at water column separation (negative flow-rate), can be observed, together with the relatively slow build-up of the vapour cavity. This is followed by an abrupt cavity collapse and up-surge of over 15 bars (compared to 2-3 bars operating pressure), as separated water columns return, slamming at each other.
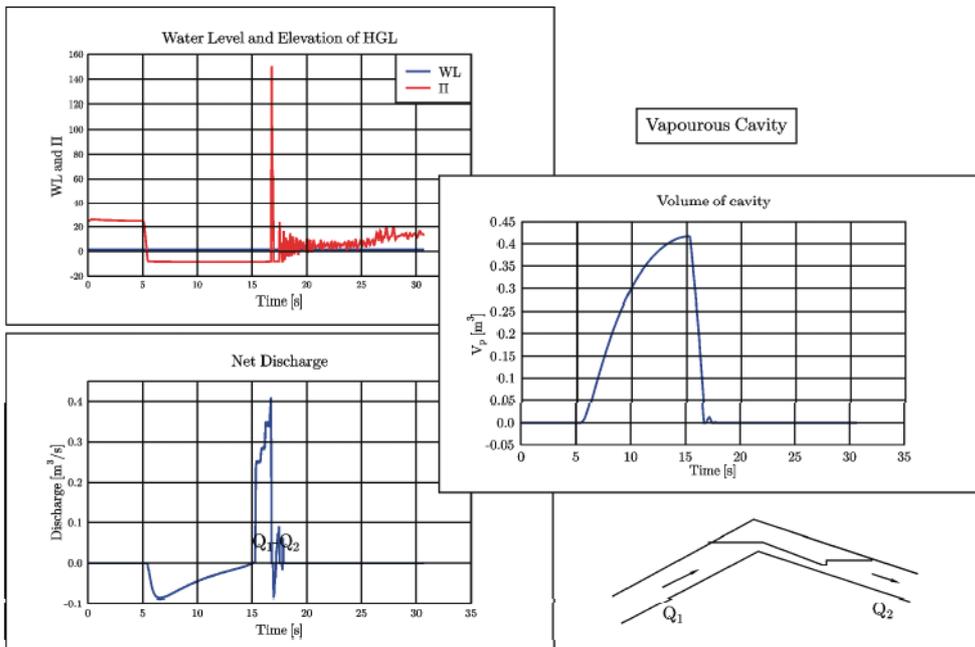
System behavior at the most upstream cavity, after power cut to pumps in PB C2

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The first test for reducing the danger of pressure surges was the partial placement of vacuum breakers. These were installed at every second pump connection, though, according to Ivetić, it was suggested to install at every pump connection. Ivetić states that with vacuum breakers at every second pump connection, approximately 10 kg of air, occupying approximately 9 m^3 are taken in by the vacuum breakers. Had valves been installed at every pump connection, the amount of air intake would have been much higher. Ivetić also points out the important fact that: "These valves have much smaller outflow capacity, and cannot evacuate that air efficiently". He further points out that as a result, special caution should be practiced at pump restart.

Despite the shortcomings listed above, the simulated analysis of power shut-off to pumps at PB C2 with alternate installation of vacuum breakers, results in a significant improvement, compared to power shut-off without vacuum protection. This can be seen in the following pressure envelope snapshots.
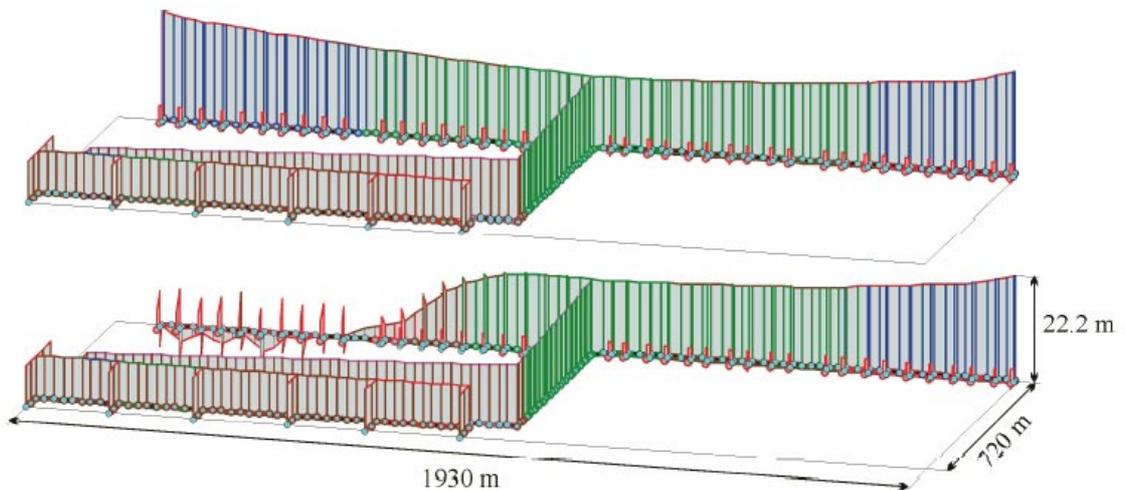
Pressure envelope snapshots of simulation of power cut to pumps at PB C2 with vacuum breakers at every second pump connection. Steady state, above, and minimum pressures, at bottom

Notice the significant reduction of down-surge, compared to the pressure envelope snapshots without vacuum breakers.

Next, simulations were run with a more extreme event – a sudden, simultaneous power cut to both, PB C2 and PB C3. Without the protection of air valves, the down-surge extended way beyond Power Blocks C2 and C3, to PB C4 and the 1522 m of the DN 2100 main header pipe, as seen in the pressure envelope snapshots below.
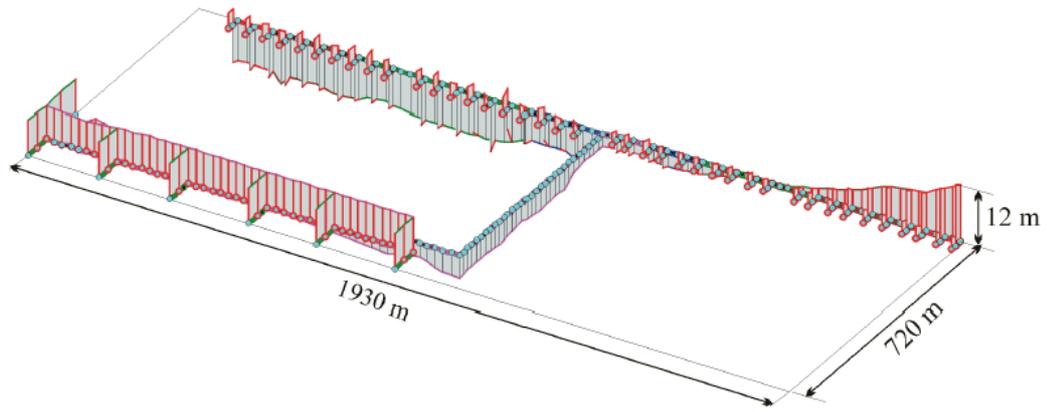
Pressure envelope snapshot from simulation of power cut to pumps at PB C2 and PB C3, at minimum pressures with vaporous cavitation

Not seen in the above snapshot, is the fact that up-surge, at water column return and cavity burst, may rise to above 20 bars! According to Ivetić, in this simulation, the size of the largest vaporous cavity reaches approximately 1.4 m³.

When "double action vacuum breakers", as called by Dr. Ivetić, are installed at every second pump connection, about 35 m³ of air, weighing about 45 kg, enter the system at power cut to pumps at PB's C2 and C3. This air intake is sufficient to very significantly reduce the down-surge and consequent up-surge, as seen below.
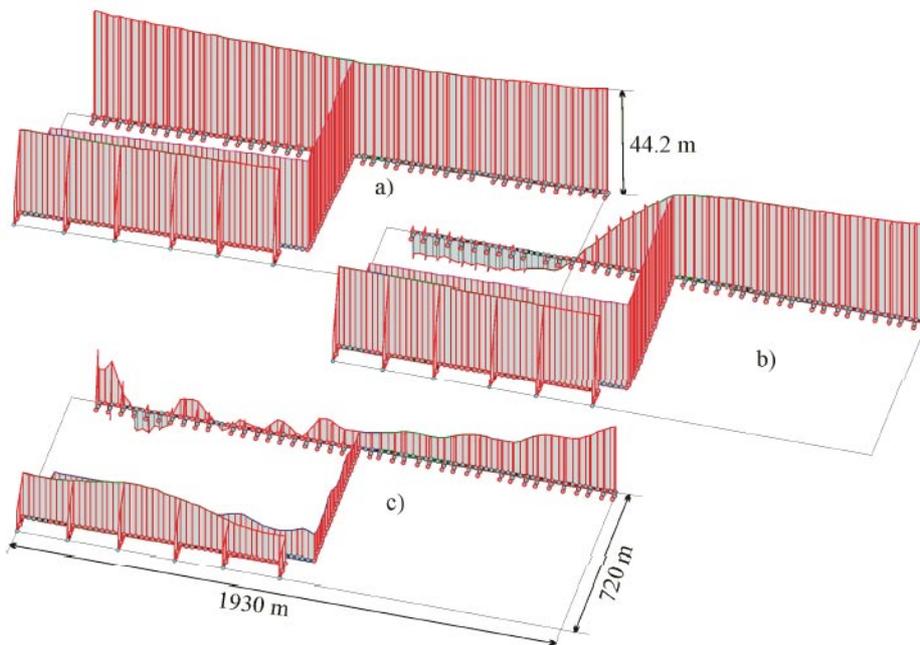
Pressure envelope snapshots of simulation of power cut to pumps at C2 and C3, with vacuum breakers every second pump connection: a) Steady state, b) minimum pressure after power cut, and c) moments after collapse of the vaporous cavity.

Though this inexpensive solution provides a very significant reduction in down-surges and a complete elimination of the up-surge, because of the limiting of the number of air valves (vacuum breakers) and the capacity of air intake, some down-surge is experienced in the PB C2 and C3 areas. A sub-atmospheric

pressure of about –0.5 bar was allowed between the vacuum breakers because pipe collapse was considered unlikely because of the smaller pipe diameter in this region, and the risk of infiltration of pollutants by backflow was considered minimal because the pipe runs above ground.[6]

Non-Slam Air Valves and Pressure Surges

The main reason for Dr. Ivetić's acceptance of the –0.5 bar down-surge, and for not increasing air intake capacity by increasing the number and the size of air valves, is, probably, the fear of up-surges. When a regular large orifice air valve is sized for maximum air intake, in order to eliminate down-surge, air discharge through the same orifice may cause problems. Air discharge flow-rates through an air valve are usually higher than intake flow-rates through the same orifice. As air discharges at a very high velocity, the water column follows at a similar velocity. As the high velocity water flow reaches the air valve float and slams it shut, a very high local up-surge may evolve, reflecting and propagating into the pipe. This phenomenon is the reason some engineers are sceptical about the use of air valves where pressure transients are expected to develop.

To overcome the problem of air valve slamming and the consequent pressure surges, the firm of A.R.I. Flow Control Accessories developed a revolutionary non-slam air valve, the K-060 HF NS kinetic air/vacuum valve and its combination version, D-060 HF NS combination air valve, both of which provide excellent down-surge protection and subsequent up-surge protection, without the danger of slam-induced local surges.

The K-060 HF NS is a three-stage kinetic air/vacuum valve constituting a regular K-060 HF high flow kinetic air/vacuum valve and a non-slam addition comprising of a special, aero-dynamically designed, Aero-Flow throttling orifice disc in a special chamber.
The three stages of operation of the K-060 HF NS are:
1. At pipe drainage or water column separation, large volumes of air, at high flow-rates, enter the air valve through the large orifice.
2. At pipe filling or at initial stages of water column return, large volumes of air, at high flow-rates, are discharged through the large orifice.
3. When discharging air raises the differential pressure across the air valve to a predetermined level (0.009-0.03 bar), called the switching point, the Aero-Flow throttling orifice disc rises to its throttling position, and throttles the air flow through its small kinetic orifice. Air continues to discharge until water reaches the kinetic float, buoying it up to its sealing position.
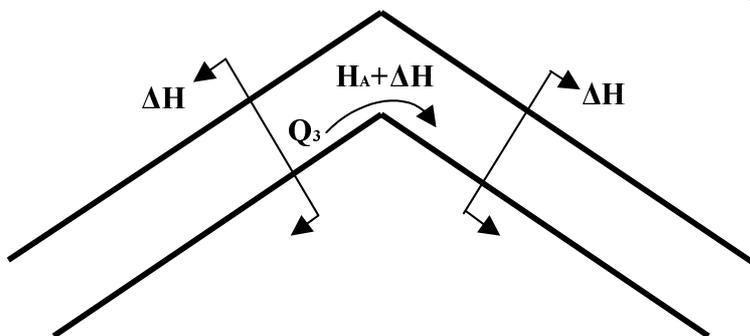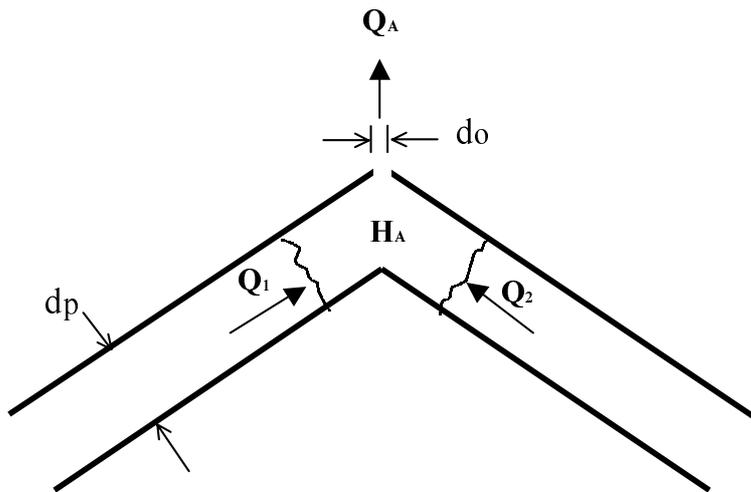
These three stages do not have to operate in the above order. Stages 2 and 3 can precede Stage 1 (at a dead end at pipe filling or upstream of a suddenly shut in-line isolating valve, for instance).

In the D-060 HF NS, in addition to the three kinetic stages of operation mentioned above, the automatic air release valve will continue to release entrapped and accumulated air when the system is and in operation under pressure.
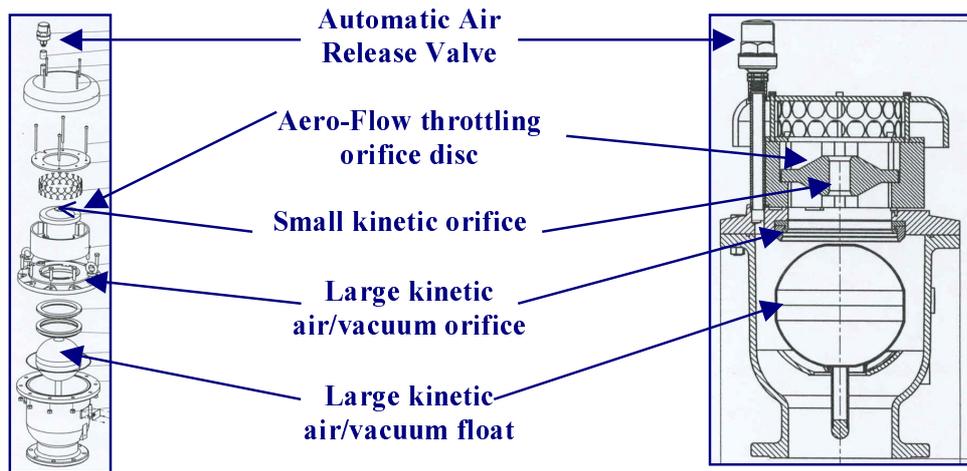
A.R.I. D-060 HF NS high- flow, non-slam, combination air valve

Dr. Srinivasa Lingireddy and Dr. Don Wood, of the Department of Civil Engineering, the University of Kentucky, studied the interaction between air valves and pressure surges, including examination of the A.R.I. non-slam, 3 stage air valve, D-060 HF NS. The study included laboratory tests as well as computer surge analysis. Results of this study are included in a paper that was submitted to the AWWA, and is presently under review for publication, "Pressure Surges Due to Air Release".[7]


H_A = Air pressure
Q_A = Volumetric air flow
d_o = diameter orifice
d_p = diameter pipe
Q_1, Q_2 = Initial Volumetric Flows in pipes 1 and 2
Q_3 = Final Volumetric Flows
ΔH = pressure surge magnitude
C = wave speed in pipes
A = cross-sectional area pipes

Conditions before and after "Air Slam"

In the study, and subsequent report, Dr. Lingireddy and Dr. Wood investigated the phenomenon they call "Air Slam". Separated water columns return to a peak on a pipeline, where an air valve was installed, and force accumulated air out of the air valve orifice, until the air valve slams shut, as water buoys the air valve float, sealing the orifice.

The "Air Slam" Phenomenon is described graphically in the sketch, above, which is included in the report.

Two transient flow models were set up, to determine "Air Slam" invoked pressure surges for different sized outlet orifices of air valves.
For the first, simple model, below, the head on the left of the valve was lowered from 100 ft. to 10 ft. in 10 seconds then raised back up to 100 ft. in the next 10 seconds. An air valve with a 4 inch (100 mm) inlet orifice and an outlet orifice varying from 4 inches (100 mm) down to 0.5 inches (12.5 mm) was analyzed. The air valve opens to emit air when the head is lowered and then expels the air when the head increases.

Air Valve
elevation = 50 ft.

Reservoir A
initial head = 100 ft.

Reservoir B
head = 20 ft.
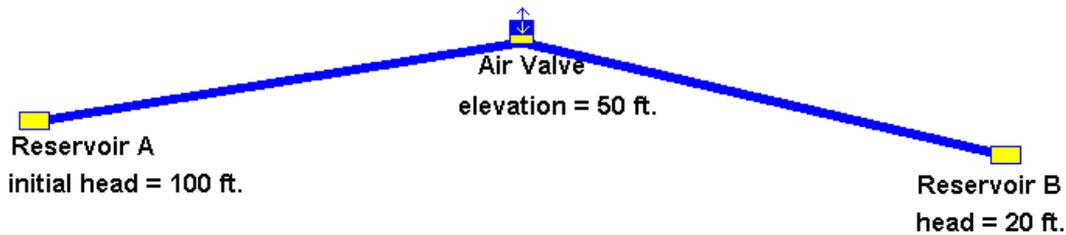
Simple transient flow model to calculate "Air Slam"

The results of the first model analyses are shown in the graph and table below.

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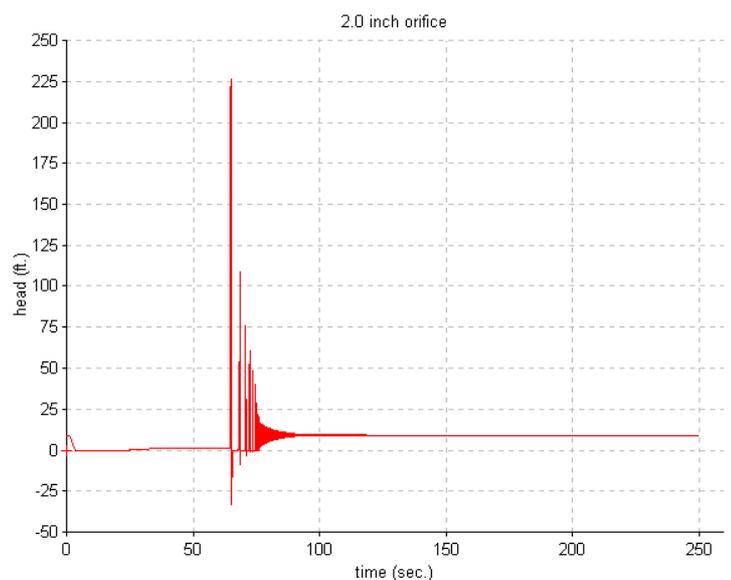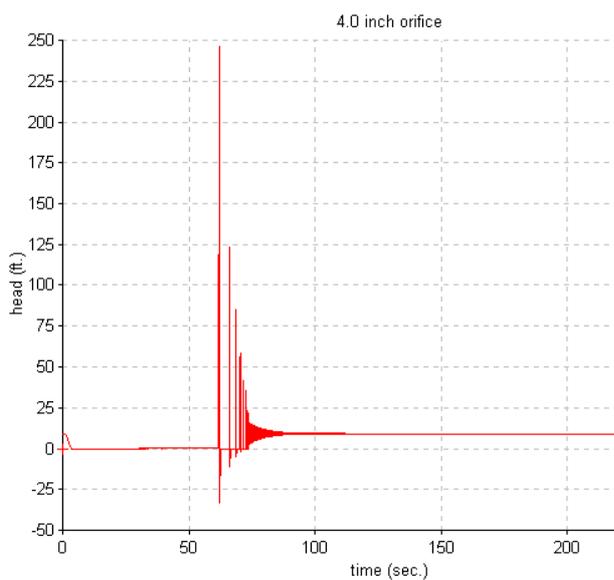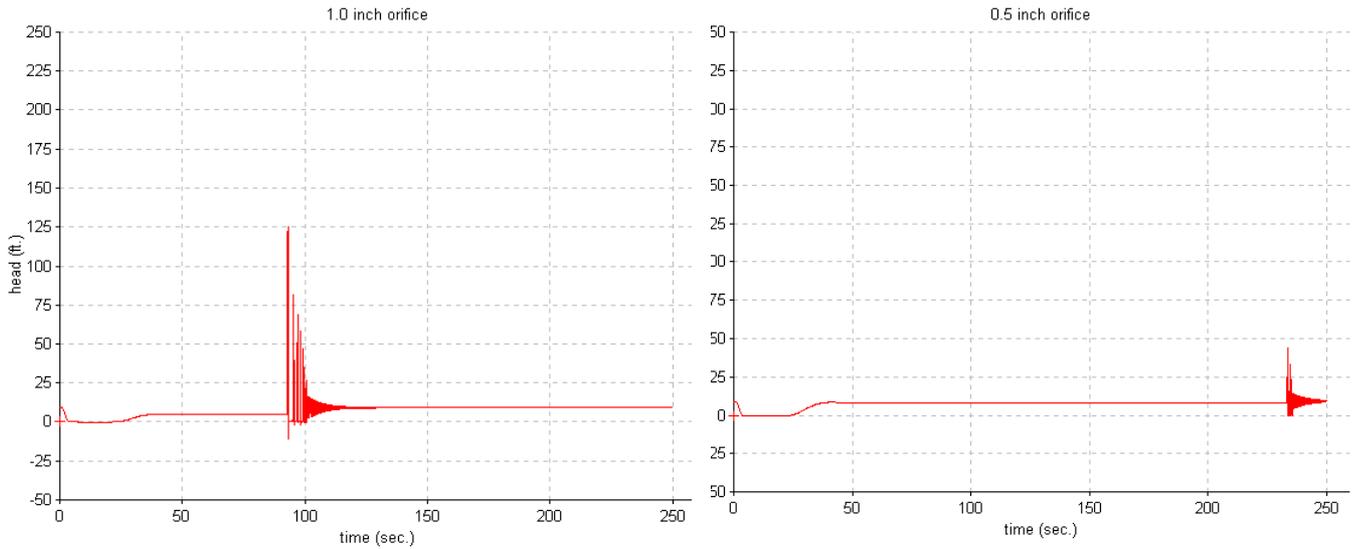
Surge analysis results for 4", 2", 1", and 0.5" orifices on a 4" air valve

| Orifice Size (inch)	Head in air valve (H_A) (ft)	ΔH (Eq.10)(ft)	ΔH (Surge Analysis) (ft)
4.0	0.059	240.0	240
2.0	0.825	220.0	224
1.0	4.700	115.5	120
0.5	7.800	34.6	35

Summary of pressure increases through different size orifices following expulsion of air

The second model was a bit more complex. This pipeline comprised over 8000ft of 12 inch line with a 165Hp pump pumping from a ground level storage facility to an elevated storage tank. There was a 3inch air valve at the most elevation point (50ft higher than the ground storage facility) along the pipeline profile. Transient condition for this pipeline was generated by a 5-second controlled shutdown (linear variation in pump speed) of the pump at time t=5seconds followed by a 5-second pump startup. There was a 30second lag between the pump shutdown and subsequent pump startup.
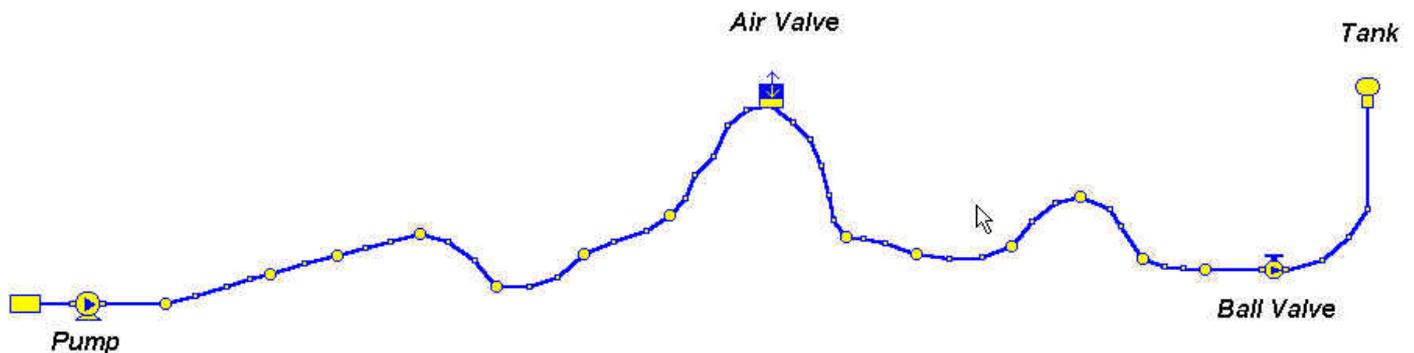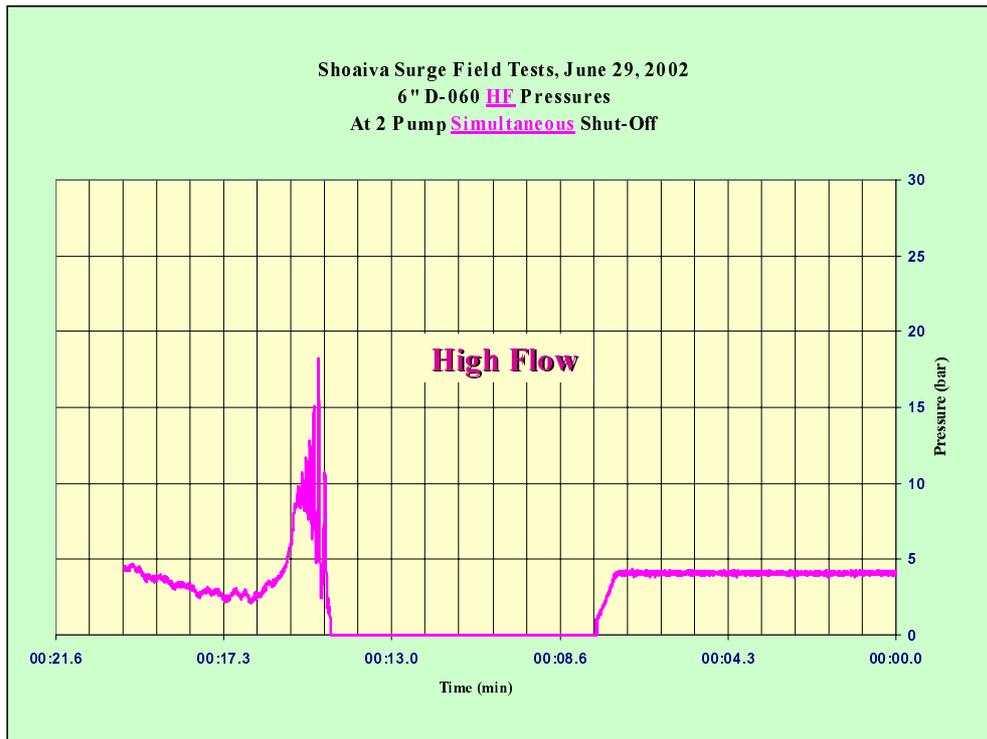

More complex pipeline model schematic

Here, also, the difference in the pressure surges due to "Air Slam" are very significant, as can be seen in the graphs below.
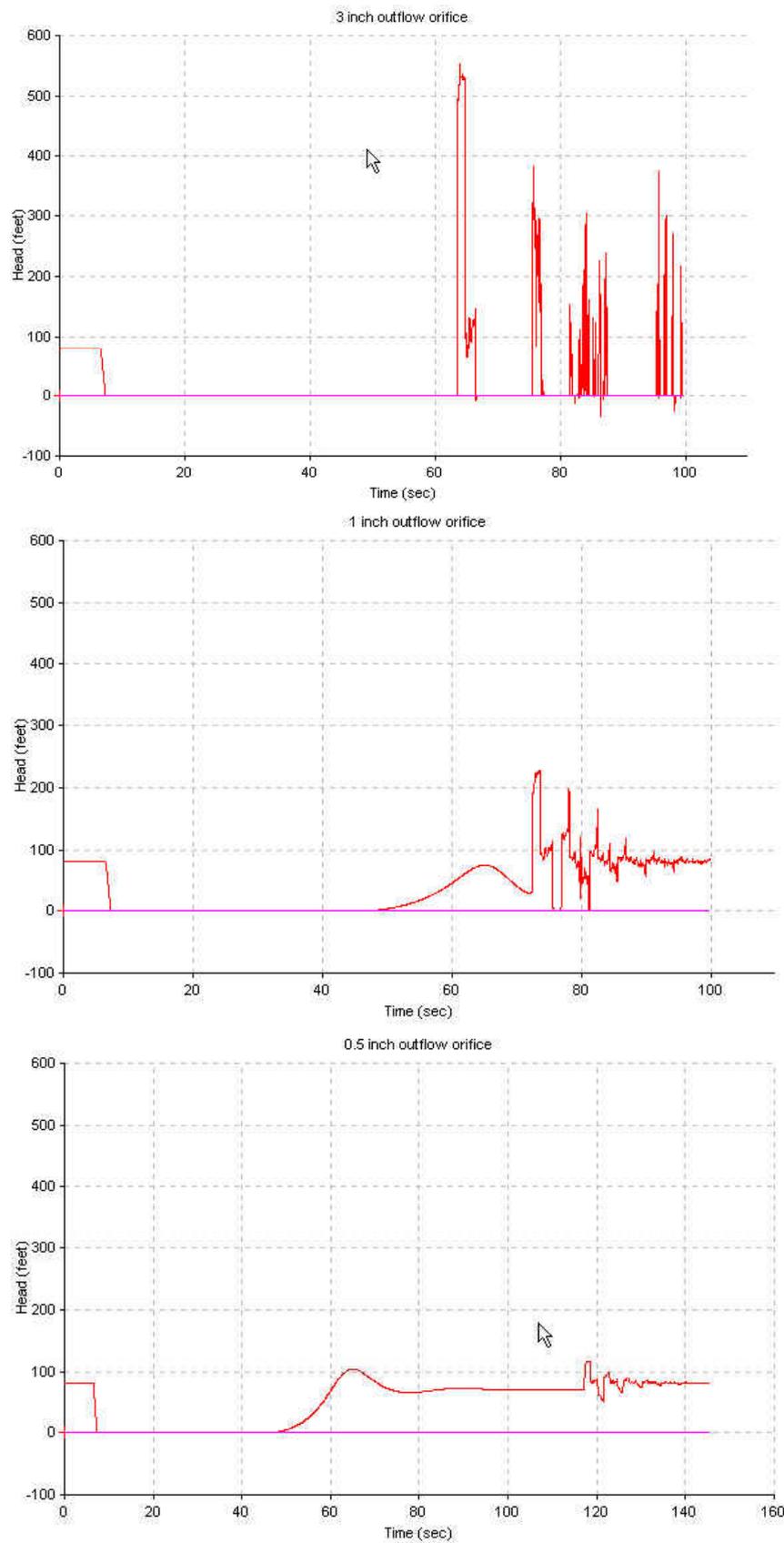

Surges due to "Air Slam", in a 3" air valve, with 3", 1", and 0.5" orifices

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"Mekorot", Israel's national water company, conducted field tests on the Fourth Water Supply Line to Jerusalem, a 42 km pressure main with four major pumping stations and four major balancing reservoirs, 5,500 m^3 each, supplying about 50 million m^3 of water annually to the mountain city. These tests were made to determine the surge suppression capabilities of the A.R.I. D-060 HF NS, high flow, non-slam, combination air valve. One of the tests compared pressure surges when two pumps were shut-off simultaneously at a 6" D-060 HF, with and without the non-slam addition. Though pressures were not very high, the difference in the intensity of the surge pressures were very significant, as can be seen on the graphs below.

Shoaiva Surge Field Tests, June 29, 2002
6" D-060 HF Pressures
At 2 Pump Simultaneous Shut-Off

High Flow

Shoaiva Surge Field Tests, June 29, 2002
6" D-060 HF NS Pressures
At 2 Pump Simultaneous Shut-Off

Non Slam
(Simultaneous Shut-Off)

Pressure surges with a regular and with a non-slam air valve at two-pump simultaneous shut-off. Maximum pressure for the high-flow air valve was 18.24bar and the maximum pressure for the high-flow, non-slam air valve was 9.81bar. Duration of the water column separation for the high-flow was 6.9sec. and for the non-slam 6.1sec.

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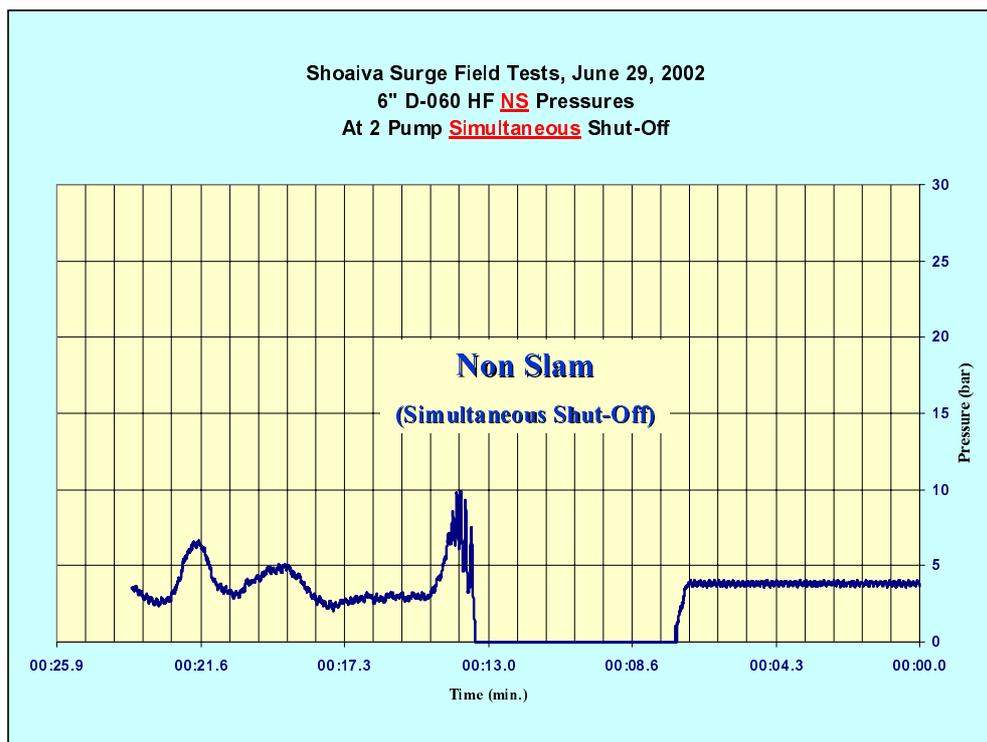
Advanced Air Valve Sizing and Location

As can be concluded from the information above, air valves, which are often, collectively, miss-named, as "Air Release Valves", are much more than merely air release valves and vacuum breakers. Even their vacuum breaking function is often a means, and a step, in pressure surge suppression. Realizing this, it is obvious that placement and sizing of air valves for air release at pipe filling or air intake at pipeline drainage is not enough, and can be damaging, at times. When deciding on placement and sizing of air valves, the water system designer must consider all the functions required from the particular air valve, and decide accordingly. The capability of having a different intake and discharge capacity in the same air valve makes this task much, much easier.

The most common calculations for air valve sizing were discussed in the "Air Valve Sizing" section, above. The calculation of air intake requirements for all air valves on very long lines or systems, can be very difficult and time consuming. For this reason, some of the air valve manufacturers developed computer programs to aid in the sizing, and, sometimes, both, sizing and placement of air valves. In most of these, the same, most common calculations for air valve sizing that were discussed in the "Air Valve Sizing" section, were performed by the computer.

Since burst analysis, based on the Hazen-Williams equation, for instance, relates only to pipe slope, and not to elevation difference, for slight elevation differences over a very sight distance, computer programs utilizing only Hazen-Williams based burst analysis, may come up with very extreme and unrealistic results.

Ariplan

A.R.I. developed a user friendly, yet comprehensive computer program, the **Ariplan Sizing and Location Program**, designed to aid in the design of air control systems, in the way of air valves, for water and wastewater pressurized systems. This program offers the designers three different types of analyses for the location and sizing of air valves. The designer can use one, or any combination of two or three of the analyses to design his air valve system. A virtual analysis can also be performed, when actual values result in solutions with low feasibility for implementation.

Fill-Rate Analysis

For systems of very low probability for pipe collapse or damaging vacuum conditions, where the topography is fairly flat, with no significant slope changes, especially where budgets are limited, a designer may rely on Fill-Rate Analysis. Here, air valve size is determined according to the air discharge capacity required at pipe filling at a given filling velocity. The air discharge requirement is equal to the pipe-filling rate, as determined by the maximum filling velocity established by the designer. The equation used by the program for Fill-Rate Analysis is:

$$Q_F = V_F \frac{\pi D^2}{4}$$

Where:

Q_F = Kinetic (large orifice) air discharge requirement for pipe filling (m³/s)

V_F = Pipe filling velocity (m/s)

D = Pipe internal diameter (m)

Fill-rate Analysis places air valves at peaks on the pipeline, at pump stations and reservoirs, and at in-line isolating valves.

Burst Analysis
As mentioned before, this is the analysis most commonly recommended by air valve manufacturers. Burst Analysis is one of the three main analyses offered by Ariplan, based on the Hazen-Williams equation. This analysis assumes a full flow-cross-section pipe burst, resulting in full diameter, free-flow drainage, at the pipe bust. The actual equation used by Ariplan, in this analysis, is:

$$Q_B = {}^{1.852}\sqrt{\frac{SD^{4.87}C^{1.852}}{10.69}}$$

Where:

Q_B = Air intake flow-rate requirement for vacuum protection at pipe burst (m³/s)
S = Slope of the pipe (m/m)
C = Hazen –Williams Coefficient

Burst Analysis places air valves at peaks on the pipeline, at pump stations and reservoirs, and at in-line isolating valves. At points of slope decrease on ascending lines and at points of slope increase on descending lines, where the difference in velocity head between the two pipe sectors is 1.5m and higher, an air valve is located at the point of change of slope. If $\frac{V_B^2}{2g} - \frac{V_A^2}{2g} < 1.5$, no air valve is placed by Ariplan. The air intake requirement at a slope transition point where an air valve is required, is the calculated Q_B at this point minus the calculated Q_B at the peak directly above it.

Burst Analysis individually analyzes pairs of pipe segments, at their meeting points, without consideration of what happens up-stream or down-stream.

Drainage Analysis
The third choice of analysis offered by Ariplan is Drainage Analysis. This analysis assumes free-flow drainage through a drainage valve whose size was determined by the user. Here, the air intake requirement for vacuum protection is equal to the calculated discharge through the drain valve. Flow-rate is calculated using the Orifice Equation, which considers elevation difference between the given air valve location and the drainage valve, without considering slope or head losses. The equation used is:

$$Q_D = C_d \sqrt{(2g\Delta h)}\pi\left(\frac{D_D}{2}\right)^2$$

Where:
Q_D = Required air intake flow-rate for vacuum protection at drainage (m³/s)
C_d = Discharge Coefficient (0.6)
g = Gravitational acceleration (9.81 m/s)
Δh = Elevation difference between the air valve and the drain valve (m)
D_D = Diameter of drain valve

Drainage Analysis can be used to represent a rupture analysis, where a virtual drainage valve (which, in the equation, is merely an orifice) is used to simulate a rupture of a given size. In this way, the program user can determine the level of pipe protection according to the size of the rupture it covers. This analysis gives a more coherent solution than simply a percentage of burst analysis, as suggested by some manufacturers.

Drainage Analysis, places air valves at peaks that flow to drain valves (no higher peaks between them and the drainage valves), at pump stations and reservoirs, and at in-line isolating valves that flow to drain valves (again, no higher peaks between them and the drainage valves). When there are more than one peak flowing to the same drainage valve, the highest peak requires full air intake, as determined by the Orifice Equation. All other air valves on the way to the same drain valve require only half the air intake capacity that was calculated by the Orifice Equation.

Drainage Analysis is the most complicated analysis, which analyses the whole pipeline, considering each location against all applicable drain valves (since some locations can be drained to a number of different drain valves), and taking into account the effect of one air valve on another. All that was said about drain valves is also true for virtual drain valves.

In addition to the air valve locations listed above, all three analyses locate small orifice, automatic air release valves, on horizontal runs or on sections of constant slope, at intervals chosen by the program user. The default interval is 500m, and the recommended distance is 500m-800m. If these pipe sections are longer than 2000m, **Ariplan** replaces an automatic air release valve with a combination air valve, every 2000m.

Ariplan was developed before the D-060 HF NS air valves were introduced to the market. For this reason, the three-stage, non-slam air valves are not included in the **Ariplan** database. In any case, **Ariplan** is not meant to, and, does not perform surge analysis.

Ariplan can work very effectively, together with a surge program. Firstly, run **Ariplan**, using available data on the pipeline, choosing "High Flow" for "Valve Characteristics" in the "Selection Criteria". Secondly, enter the resulting air valve data in your surge analysis program, entering three-stage, non-slam air valve data in places where you think water column separation and return could occur. Run the surge analysis. In air valve locations where up-surges appear, replace regular high flow air valves with three-stage, non-slam air valve. This should greatly improve, if not eliminate most pressure surges.

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