TECHNICAL NOTES

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AIR VENTS, VACUUM RELIEF VALVES, AND PRESSURE RELIEF VALVES IN PRESSURIZED PIPELINES

SUMMARY
Air vents, vacuum relief valves, and pressure relief valves are needed to release potentially damaging air when filling, operating, or draining pressurized pipelines. Such use reduces the effect of pressure surges and protects pipes from bursting and/or collapsing. This technical note and the corresponding spreadsheet, **Air-Vent**, provide information and calculations needed to determine the number and size of valves that are required for pressurized pipelines.

Generally, it is better to add an extra valve than to end up with a pipeline that has inadequate venting. If more than one valve is required, the riser pipe can be sized for multiple valves.

BACKGROUND

All pipelines that convey water must be vented in order to prevent air from being entrapped in the line. Air comes in at the entrance, either through open channel flow, or entrapped air bubbles in the water. Automatic valves are used to allow air to be vented in or out and to reduce stress on the pipes.

Water is not very compressible, since the density of water varies only slightly as pressure increases. However, air is different. Air will compress under pressure and it acts like a spring when compressed. That spring-like compression/expansion action can be quite harmful to pipelines. Therefore it is very important to get it out, and to keep it out, of a pipeline.

Locations

Air vents and/or vacuum relief valves are installed at these critical points:

- the inlet to the pipeline
- high points in the pipe
- ¼ mile spacing
- the end of the pipeline

AIR VENTS

Air vents are positioned to allow air to escape from the pipeline as it is filling and while it is operating. These are the three different types of air vents:

- Open – a vented T in the line only used at the *inlet* of gravity lines.
- Float type – a ball is positioned in the valve and rests on a grate to allow air to escape. As water fills the line, the ball floats up to seal and close the valve. This only works during the filling process, because once the ball closes the valve, no more air, or water, will escape.
- Continuous Acting – this has a float ball, similar to the float type listed above, but there is also a secondary vent in the valve that allows small quantities of air to continue escaping after the line is at pressure and the float has been pushed up and has closed the valve.

Different procedures require different vents. The proper selection of air vents is associated with various operational procedures on the pipeline. When the pipeline begins filling, the empty pipe is full of air which must be replaced by water. Water fills the low points first and the air is forced to the high points of the pipe. Since trapped air is displacing water, that increases the velocity of the water under the trapped air in the pipeline. That increased water velocity can result in more friction loss and also greater potential for damaging water surges in the pipeline.

Without adequate venting, the air will remain trapped, and the damaging spring-like compression/expansion action can occur. Therefore it is important to have the correct type of vents, the proper size of vents, and the best location for the vents, depending on the operation. The location of the air vents allows air to flow out of, or into, the pipe during the different stages of operation in a pressurized line. There are three basic operation procedures: filling the pipeline, operating the line, and draining the line.

➢ Filling the Pipe

During filling, the pipe is full of air and water is taking its place. The following describes various locations where air vents will be needed to exhaust air from the line as it is filling with water:

- The *inlet vent* allows the air to flow in and out as the pipeline fills. That prevents pressure from building before the pipe is full of water.
- *High point vents* release air trapped in the pipelines.
- *End of the line* vents allow for air to escape as the water fills the pipeline.
- *Spaced air vents* (every 1,320 ft) remove air throughout the line.
- Vents at any point where the *grade increases by 10%* or more. That amount of grade will leave an empty space in the pipe and air vents are needed to allow air into that empty space or the pipe could collapse.

➢ Operating the Pipe under pressure

With proper venting during filling, trapped air should have escaped as the pipeline filled with water. However, air can still enter into the pipe at the inlet, at the pump, or at any leaks. That air can be absorbed into the water and can cause damage before it reaches a vent. To prevent such problems, continuous acting air vents are spaced along the line. (See Figure 1)

Figure 1

Waterman Continuous Acting Air Vent & Vacuum Relief Valve

➢ Draining the Pipe

While draining the pipeline, air must be allowed into the line at high points and inlets to prevent damage and collapse from vacuums. The devise used to accomplish this is a vacuum relief valve. (See Figure 2)

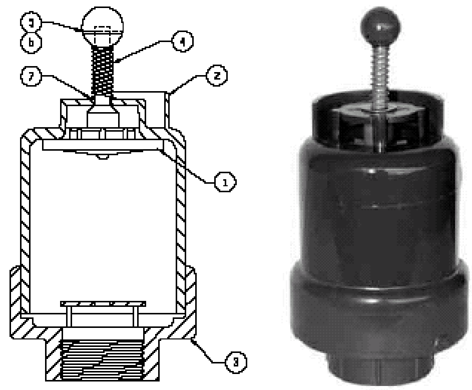
VACUUM RELIEF VALVE

Whenever a pipeline is drained, either on purpose, or by accident, a vacuum could occur if water is moving out of the system faster then air is coming into the system. If a full vacuum (14.7 psi) occurs, the pipe could collapse. The vacuum pressure required to collapse a pipe varies based on the pipe material, wall thickness, and length of time the suction is on the material. For safety purposes, the maximum vacuum allowed on pipes is 5 psi, since pipelines can collapse at pressures much lower than a full vacuum pressure (14.7 psi).

Generally vacuum relief is provided by the combination of air vent valves and vacuum relief valves on irrigation systems. Vacuum relief valves can be used as a stand alone item, or in combination with the air release valve. It is usually easier to use a combination air and vacuum relief valve. These valves need to be located at all high points along the line.

Figure 2

PARTS LIST	
No.	Name
1	Poppet
2	Body
3	Base
4	Spring
5	Knob
6	Spring Pin
7	Washer



Waterman VRP 110 Vacuum Relief Valve

PRESSURE RELIEF VALVE

The pressure relief valve is designed to release water whenever the pressure gets above the valve's preset level. Generally it is more economical to use a lower pressure rated pipe and install a pressure relief valve than to use a higher pressure rated pipe without the relief valve.

Figure 3

Waterman AA6 Pressure Relief Valve

Pressure surges occur as a result of changes in velocity in the pipeline. This can be caused by: a valve opening or closing; the pump shutting down; or any time the flow changes in the line. The surge pressure adds to the operating pressure, making for a potentially very high total pressure.

The location of the pressure relief valve is generally at the point of highest surge pressure in the line. The highest pressure in the line depends on the slope and friction loss in the line. During operation, the lowest elevation point in the line may, or may not be, the highest pressure.

The minimum size of the pressure relief valve is ¼" per inch of pipe size and is set to open at no more than 5 psi above the pressure rating of the pipe. For example an 8" pipe needs a 2" pressure relief valve. Manufacturers provide performance charts for each valve with flow rates at varying pressures. (See Figure 4) The valve should be able to release the entire line flow rate before the pressure reaches 1.5 times the pressure rating of the pipe. As an example, with a 600 gpm flow in an 80 psi pipe, the pressure relief valve would need to open enough so that the entire 600 gpm could be released before the pressure reaches 120 psi (1.5 x 80 psi).

DESIGN CRITERIA

➢ Air Vents

Air vent sizes are determined by the velocity of the water filling the pipeline. The size of the air vent opening is usually estimated at 25% of the pipe size. So, a 12" pipe would require a 3" vent. The vents come in a number of sizes including, 1½", 2", 3" and 4" diameter, depending on the manufacturer. Generally the 2" valve is the most commonly used size for systems NRCS designs, therefore one 2" vent would be adequate for an 8" pipe. The **Air-Vent** spreadsheet calculates the air vent size necessary based on a fill rate in a pipe using the orifice equation. (See pg 6)

➢ Vacuum Relief Valve

Vacuum relief valves are sized at the same proportion as air vents, with the vent opening at 25% of the pipe diameter. This is adequate for letting air back into the line. This can be met using one or more valves. To calculate the buckling pressure from a vacuum that a pipe can withstand, the following equation can be used:

Unconstrained Critical Buckling Pressure Formula, psi

$$P_{uc} = \frac{2E}{(1-\mu^2)}\left(\frac{1}{DR-1}\right)^3 \frac{Fo}{N}$$

Where:
P_{uc} = Unconstrained critical buckling pressure, psi
E = Elastic modulus at the average expected service temperature
μ = Poisson's Ratio
DR = Dimension Ratio
Fo = Ovality compensation factor, 0.62 for 5% ovality
N = Factor of safety, normally 2.0

Example of Unconstrained Critical Buckling Pressure
Determine the short term buckling pressure for HDPE pipe, with a DR of 17.
Using the above equation, the elastic modulus (E) for the short term with HDPE is 110,000 psi. Assuming a 5% deflection (ovality) the buckling pressure would be:

$$P_{uc} = \frac{2(110000)}{\left(1-0.35^2\right)}\left(\frac{1}{17-1}\right)^3 \frac{0.62}{2.0}$$

P_{uc} = 14.7 psi–this is the maximum vacuum allowable.

In this case the pipe can handle a total vacuum (14.7 psi). This is not a good condition to maintain with any material for any length of time, since a collapsed pipe is still a potential.

Vacuum Relief Example

As the pipe drains, the line fills with air from an opening, such as a vacuum relief valve. The rate the valve lets air in determines the amount of vacuum that develops in the line. If the valve is absent, or too small, a vacuum will develop. If there are adequate points for air to enter the line, the pressure inside the line will be closer to the same pressure as outside the line which prevents a vacuum from forming. Since water is 50+ times thicker than air, water flows more slowly than air. In order to determine how large of a vent is required the general guide is to limit vacuum pressure to 5 psi. The attached **Air-Vent** spread sheet has the following equation for calculating what size vacuum relief valve is necessary while maintaining the vacuum pressure at a certain level.

The following orifice formula is used to calculate the opening size required for venting:

Vent Area Orifice Size Formula, sq ft

$$A_{ov-sqft} = \frac{Q_{r-cfs}}{K_{vr} * \sqrt{64.4 * P_{cd-psf} / \gamma_{air}}}$$

Where:

$A_{ov-sqft}$ = Area of the opening for the vacuum relief vent, sq ft

Q_{r-cfs} = Flow rate out of the pipeline, cfs

K_{vr} = Outlet constant for the vent (typically 0.6)

P_{cd-psf} = Pressure limit in the pipe, psi

γ_{air} = Density of air, 0.08 psf

- **Pressure Relief Valve**

A change in flow velocity will cause a pressure surge in the line. This surge pressure is added to the operating pressure to determine the total pressure in the pipeline. If the total pressure is greater than the pressure rating of the pipe, a pressure relief valve is needed. In order to determine the surge pressure there are a few calculations that should be made.

First, determine the velocity of the surge wave in the pipe using the velocity of the shock wave formula. After the shock wave velocity has been determined, the surge pressure can be calculated using the next equation.

Velocity of the Shock Wave Formula, ft/sec

$$a = \frac{4720}{\left(1 + \frac{Kl}{E} * \frac{Di}{t}\right)^{1/2}}$$

Where:
a = Velocity of the pressure wave, ft/sec
Kl = Bulk modulus of liquid, lb/in2 (water – 300,000 psi)
E = Modulus of elasticity of pipe material, lb/in2
Di = Pipe inside diameter, in
t = Pipe wall thickness, in

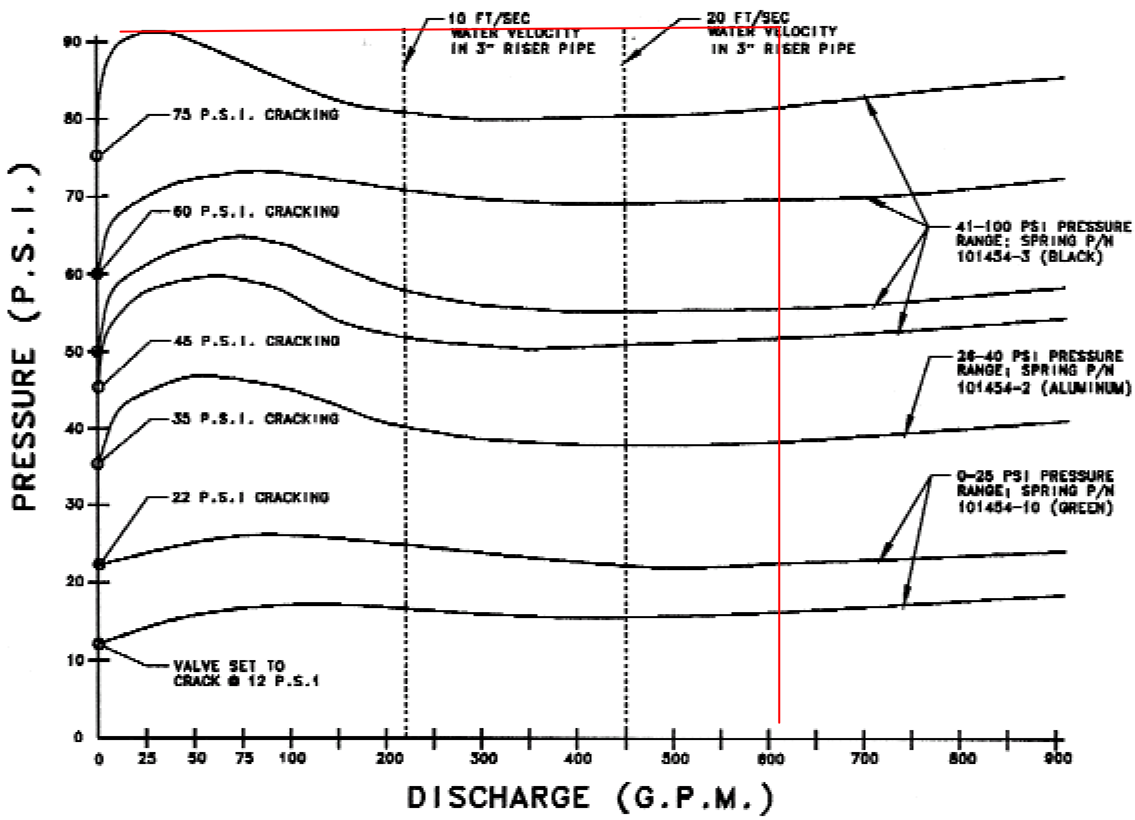
Surge Pressure Formula, psi

$$P_{surge} = \left(\frac{a * \Delta V}{g * 2.31}\right)$$

Where:
P_{surge} = Surge of pressure, psi
a = Velocity of the pressure wave, ft/sec
ΔV = Change in velocity, ft/sec
g = Acceleration due to gravity, 32.2 ft/sec^2

Using the above equations the surge pressure can be determined. Add this to the operating pressure to get the total pressure. If this is *greater* than the pipe pressure rating, as stated by the manufacturer, a pressure relief valve is required. If the total pressure is *less* than the pipe pressure rating, a pressure relief valve is not required, but highly recommended.

Figure 4



Waterman 3" AA-96 Pressure Relief Valve Discharge vs. Pressure Chart
(See www.watermanusa.com)

Field Example

- A pivot irrigation system is installed on a crop field with a slope from the pump, which is the high point in the line, to the pivot pad (at center of the field)
- Pipeline to the pivot will have a maximum design flow rate of 610 gpm
- Pipe is 1000 ft long and 8" diameter 80 psi PVC pipe
- Water supply pump operating pressure of 55 psi
- Ground elevation at pump 100 ft; Ground elevation is 90 ft at the pivot point
- There is a gate valve at both the pump and at the pivot

What vents and protection does this pipeline need?

Air vents and/or vacuum relief valves are installed at these critical points:

- the inlet to the pipeline
- high points in the pipe
- ¼ mile spacing

- the end of the pipeline

Using the **Air-Vent** spread sheet with the above data entered, the results would be as follows:

Starting at the pump, the pipeline is 8”, so 25% of the pipe’s diameter would be 2”, therefore install a 2” continuous acting air vacuum relief valve at the *high point* in the pumping plant area. Next, the gate valve at the pump would be the *beginning of the pipeline*, and a 2” air vent is required there, just downstream of the gate valve. From the pipe to the pivot, since it is less than ¼ mile, the next place where an air vent is needed is at the *end of the line,* just upstream of the pivot gate valve.

Place a 2” air vent just upstream from the pivot gate valve to let air out while filling. If a gate valve was not installed at the pivot point, the sprinklers on the pivot could be the vent. Any *high points* along the line would need to have a continuous acting air and vacuum relief valve to let air out during filling, and let air in during draining. Again since the line is 8” diameter all of these valves are 2” diameter.

The surge pressure calculations from **Air-Vent** result in a total pressure potential of 96 psi. This is higher than the pipe pressure rating (80 psi) therefore a surge valve is needed and should be set at a maximum of 85 psi (pipe pressure of 80 psi + 5 psi). Since there isn’t a 2” diameter pressure relief valve that meets NRCS specifications, choose a 3” diameter. The 3” Waterman AA-96 valve is selected. The chart for this valve is shown on Figure 4. Because there isn’t an 85 psi line shown for this valve in Figure 4, one option is to interpolate between pressure curves shown on the graphs and estimate the pressure versus flow for the valve. A better option would be to lower the pressure setting which opens the surge valve. The pipeline is operating at 55 psi and if the surge valve opened at 75 psi, the pipe would be protected even from a surge.

In order to determine if the pressure relief valve will release the full pipe flow at less than the 150% of the pipe pressure rating, draw a line vertically up from the flow rate until you intercept the correct cracking pressure line on Figure 4. Then move to the left horizontally to the pressure axis and read the highest pressure. These are shown as red lines in Figure 4. Normally the peak pressure through the valve is at the maximum flow. With this example the surge valve peak is right after opening, and the highest pressure would be 92 psi. This valve will release (610 gpm) with an increased pressure of 17 psi (75 to 92 psi). This is less than the 150% of the pipe allowable pressure of 120 psi (80 psi x 1.5). It would also release all of the design water flow from the pipeline.

The location of the pressure relief valve is generally at the lowest point on the line (highest pressure), which in this case, is at the pivot point. Place it upstream from the gate valve at the pivot. Both the air vacuum relief valve and the pressure relief valve could be on the same riser. Since the air vacuum relief valve is 2” and the pressure relief valve is 3” diameter the riser pipe must be minimum of 3”. With the pressure relief valve flowing at 610 gpm, the velocity is greater that 20 ft/sec in the riser pipe (See Figure 4). This velocity is greater than the 5 ft/sec allowed for plastic pipe, so the riser should either be made from steel pipe or use larger pipe to reduce the velocity.

Any brand names used in this note are a reference and not a recommendation to a particular manufacturer.

REFERENCES, LITERATURE

THE PLASTIC PIPE INSTITUTE, HANDBOOK OF POLYETHYLENE PIPE; First Edition, 2006; Washington DC

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Jim Dunlap, WNTC, NRCS – Spread sheet on air vent and vacuum relief opening sizing, modified by Steve Durgin, Spokane, WA NRCS

USDA NRCS - Part 636, Structural Engineering National Engineering Handbook, Chapter 52, Structural Design of Flexible Conduits

Waterman USA, for Figures and PR Charts, at www.watermanusa.com