Limiting air release from air valves on pipelines

The reasons and motivations why VENTOMAT limit the amount of discharge from their air release valves

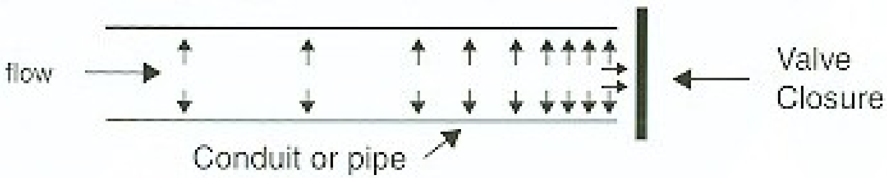
Preamble

This is one of the most misunderstood areas of air release valve application. Traditionally manufacturers have sold their particular air valves based on the capability of venting as much air as possible, hence the performance of one manufacturer of a given size to vent more th the competitor was seen as a benefit. Logically then a large number of specifications fr consultants and authorities were based on the fact that air valves should be capable of meeting some requirement for air release. A typical specification would go as follows: - "Double orifice air valves must be capable of venting air up to 100kPa (1 bar) without closing kinetically or in the presence of air".

It is important to understand the historical steps which led to some of these specifications . The original ball valve type air release valve design is almost a hundred years old and would inevitably "blow closed" at roughly 5kPa differential, which left large amounts of air in the pipeline and resulted in surges and reduced flows etc (in hindsight we now believe the air, although reducing performance, assisted in reducing pipe burst). This led manufacturers to start producing kinetic air release valves that were capable venting air at higher differential pressures. Although this resolved the problem of getting the air out, it brought with it a whole host of other problems related to higher discharge velocities. Typically the manufacturer would bolt on the air valve to some air source and demonstrate the valve venting air up to say 100kPa differential without closing by air alone - the valve was then specified and placed on the pipeline, but unlike the test rig venting air on the pipeline it meant that as soon as the air was vented out of the pipeline there was water behind it, and it was travelling at the same velocity as the air being vented. The air valve is designed to close as soon as possible with the presence of water and it does so. This leads to the unraveling of the puzzle as to why the pipelines started to burst and leak.

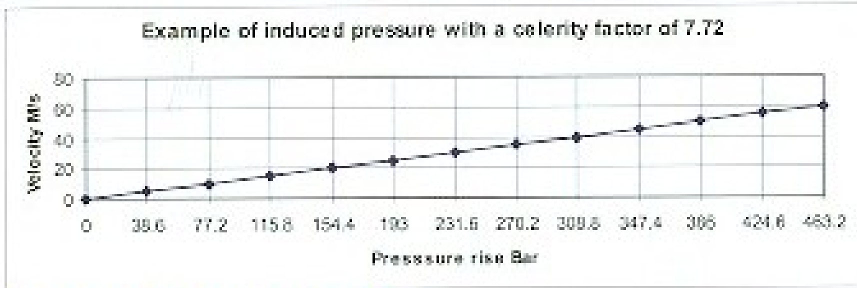
Joukowski

Joukowski and formally Allevi discovered that if a fluid was confined to a closed conduit such as a pipeline, and allowed to discharge at a certain rate, and the flow was suddenly closed off (as in an air valve closure on the arrival of water), the pressure internally would rise. The results are well documented and understood. Simplified Joukowski's equation goes like this: $P = K \times V$ ⇨(P = resultant pressure in bar, K = Celerity Factor or stiffness of the conduit or pipe and ⇨ V = velocity in M/s of the fluid being discharged) The less flexible the conduit or pipe (or the more stiff) the higher the celerity factor, and the higher the induced pressure.



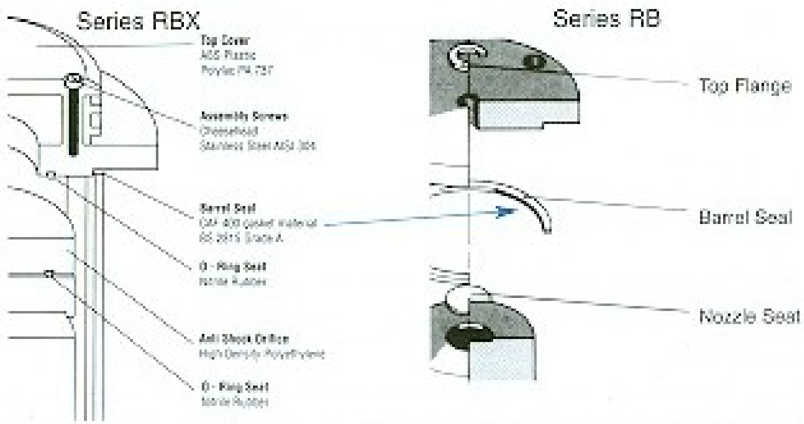
What does this mean to the pipeline designer ?

Unfortunately this is one area where the designer does not have a lot of control. If the old type ball air valves are used the air would normally be trapped inside the pipeline. On the other hand if the kinetic type air valves are used there is no control on how much air is released and subsequent increased velocities and induced pressures. From the following graph it is clear that the higher the air / water discharge velocity in the valve throat or riser, the higher the induced pressure. The graph shows the possible induced pressures from air valve closure. Data obtained from CSIR testing 1994.



How are we sure this phenomena exists ?

The Ventomat series RBX is an evolution of the original Ventomat RB series, the X denoting the addition of the anti - shock orifice. The RB series valve has always had a secondary safety system in the form of two gaskets at the top and bottom of the barrel which forms the seal. Factory testing verifies that these seals will fail at approx 90 bar or 900 meters.



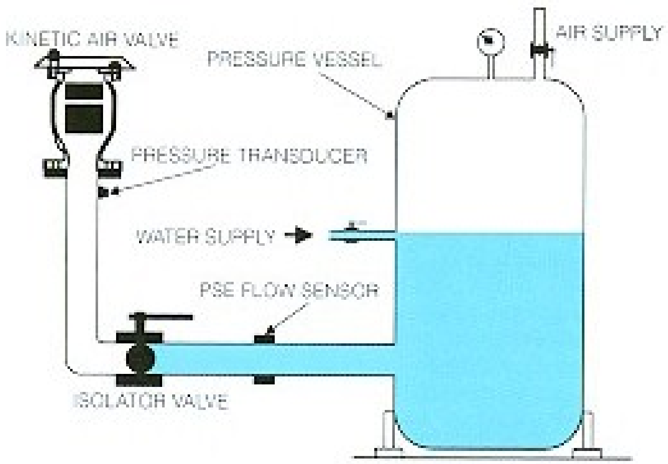
In one particular example we had a customer with a gravity pipeline of about 30 meters head. The pipeline was fitted with Ventomat series RB valves and the customer reported that during the initial operation the seals on the Air valves had failed. We demonstrated on our test rig that 900 meters was required to make them fail and that the pipeline had been subjected to more than 900 meters. The customer was adamant that this was impossible as he only had a head of 30 meters. Some tests were conducted using various commercial hand held devices all of which showed a maximum of 30 - 40 meters when the isolation valve was closed. This led us to a more in depth look at measuring devices.

What sort of measuring devices can be used to get an effective pressure / time graph ?

We conducted various further induced pressure testing and found: -

a. Bourbon tube type gauges are simply too slow.
b. Hand held devices with pressure transducers ranged in a scan every 1.0 sec - 0.5 secs and could simply not see the pressure rise - too slow.
c. High speed scanning devices were the obvious way but unless they were coupled with a transducer which had a similar scanning frequency the results were useless.

Ultimately we came up with an electronic scanning device with a suitable transducer (very difficult to get hold of) that had the capability of scanning and recording 2000 times a sec or 2 scans per ms. This opened a whole new world for us, allowing us to "see" the range and shape of the induced pressures. In subsequent tests on our test rig we could repeatedly produce 140 bar with 30 meters head by simply allowing an air valve to discharge and close when water entered it. (copies of those CSIR tests available on request)

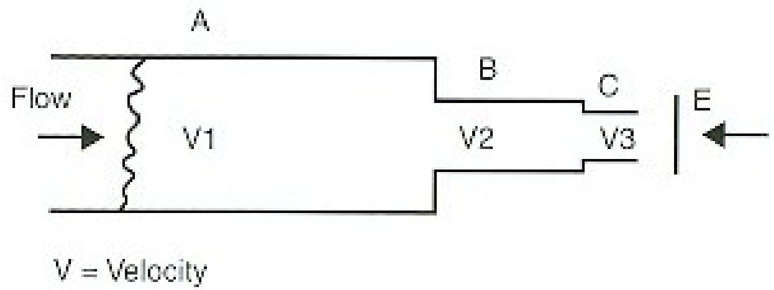


Layout of Test Rig Required to Conduct Induced Pressure Tests

We found the pressure spike to be only 20ms wide and without this specialised equipment simply impossible to see!

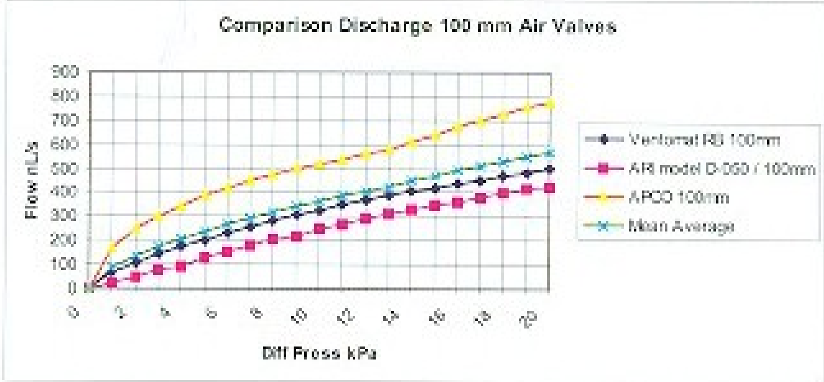
Developed Model

This model serves to simplify the relationship between water / air flow in the main pipeline, riser and air valve: -



In the model **A** = the main pipeline and has an internal diameter of 356.82 mm = 100 L/meter. **B** (riser) = 112.83 mm = 10 L/meter. **C** = air valve which has an outlet of 100mm Dia.

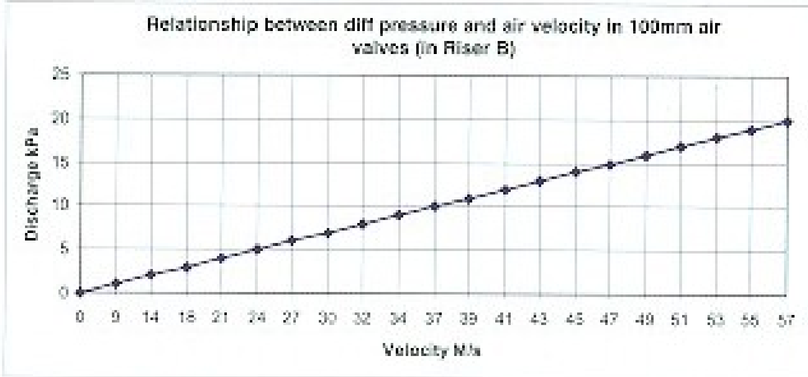
In order to get some real world figures we have taken the flow rates from three air valve manufacturers of 100mm dia valves. They were averaged to get a mean average which is as follows : -



Note: The methods used by each manufacturer to get to the given data needs to be questioned, but for now the graph gives an indication of the given range of data

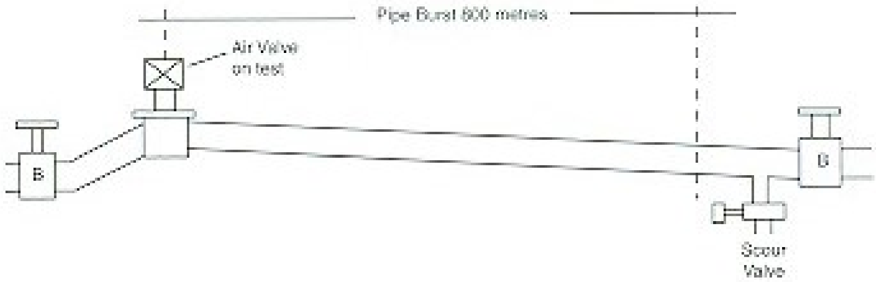
Now we can tabulate and compare flow rates to velocities:-

B Velocity in Riser m/s	0	14	21	27	32	37	41	45	49	53	57
A Velocity in Main Pipeline m/s	0.0	1.4	2.1	2.7	3.2	3.7	4.1	4.5	4.9	5.3	5.7
Mean Average Discharge nL/s	0	139	207	272	322	367	410	453	495	535	570
Differential Press Kpa	0	2	4	6	8	10	12	14	16	18	20



One thing is painfully clear - by specifying that the valve must be capable of discharge of say 20 kPa air pressure will equate water velocities of up to 57 meters/sec in the valve throat (the associated pressure/velocity changes as the water enters the riser is quite complex - suffice here to simplify it to 10 x the main pipeline velocity). Couple that with the range of induced pressure as per Joukowski's equation and the result can be extreme. Contrary to popular belief many instances of damage have been found although it is difficult to clearly indicate cause and effect because of the ability to record data and indeed to see inside the pipeline!

The induced pressure is not confined to the air valve but is transmitted back into the system!



In an actual test on a gravity pipeline, the pipeline burst 800m away from the air valve on test, proving that the induced pressure, although attenuated by the pipeline structure was sufficient to damage the pipeline 800m away from the source of the pressure rise.

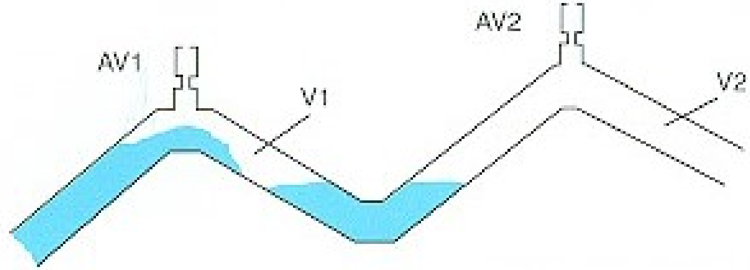
(a copy of a test conducted by a prominent Water authority where damaged occurred almost 1 km from the air valve tested - available on request)

Boyles Law

In the race for higher discharge rates from air valves some of the basic principles are forgotten. Lets take a look at the actual mechanics of an example. The specification calls for an air valve capable of venting up to 100kPa diff pressure air - where are we going to get this air to meet the specification? Our pipeline is say 50kms long. The only way we can get 100kPa of air in the pipeline (Boyle's law - halve the volume to double the pressure) is to seal it off completely ie no air valves open and the end is closed - then to fill it with water until half the pipeline is filled with water - 25 kms! Only then could the air valve be opened and only then would the pipeline have enough air to meet the specification !

Under normal operating circumstances the pipeline would be fitted with a number of air valves, and the outlet would probably be open making it very difficult to get very high internal air pressures during initial filling - so where does the higher pressure air come from during initial filling?

It all comes down to the ability to halve the volume of the air as the pipeline fills. In the following sketch the water goes up the first section and then down the second section, filling the lower part of the second section. This creates a "U" tube and the water at the bottom of the second section effectively seals off the pipeline.



The filling rate is the same as in the first pipeline example, but the volume (V1) is now reduced dramatically. This means the volume can be halved much more rapidly than the whole pipeline and hence the pressure of the air can be raised much higher than 20 kPa. This is where the problem begins, as all the air is discharged from the Air Valve (AV 1) the water moving behind it is travelling at the same velocity as the air and the result is a sudden rise in pressure, probably higher than the design test pressure. While it is true the pipeline is not blocked off, the mass of the water in the "U - tube" in the second section will simply not move that fast and instantaneously looks like a solid. In this example its important to control the air flow out of the air valve when the velocity gets too high.

This is where the Ventomat "anti - shock" is designed to change the outlet of the air valve and build up the air pressure as the pocket of air is being compressed by the water filling the pipeline. As the internal pressure reaches approx 5 kPa, the "Anti - shock" orifice is lifted up reducing the outlet size. The opposing back pressure of the air slows down the approaching water and the process is ever increasing - ie halving the volume doubles the back pressure, so the reduction of the approaching water velocity is considerable. The air however is always escaping ensuring that by the time the water gets there, most of the air and energy is lost and the result is little or no surge.

Filling Rates

Its important here to put in perspective the relationship between filling and draining rates. In most pipelines with the exception of fairly flat ones the filling or pumping rate is generally slower than the drainage rates. If the air release valves have been sized in order to protect the pipeline from negative pressures either from scouring or pump trip, it means they will be sized correctly for filling.

Conclusion

It is absolutely vital that in any form of specification, that performance is based on the ability of the air valve to allow the atmospheric pressure back into the pipeline when it goes below the atmospheric. It is also equally important that the air valve is capable of controlling the air flow from the pipeline into atmosphere when the pipeline vents, and thereby controlling the induced pressure as the air valve is closed by the approaching water.

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