



## **AUTHOR'S NOTE**

**Allistair Balutto – January 1996**

It is a common belief amongst engineers that the mere placement of air valves at peak points on a pipeline is sufficient to rid it of air. Research over the past 35 years however, have proven this method of approach to be inadequate for total air management. This is due to the unpredictable nature of air and inherent shortcomings in conventional air valve designs which does not solve the problems of air retention but can aggravate the phenomena related to its presence.

It was in cognizance of the need of an air valve that had the capability of releasing all air in a pipeline, regardless of flow velocities, without the inducement of water hammer and other destructive phenomena that spurred Vent-O-Mat into the design and the development, spanning more than a decade and has resulted in an operating concept that is revolutionising the water industry.

“Anti Shock” air valves have since their introduction in the market, solved a number of pipeline problems resulting in the product being described by a multitude of names such as: “the safety belt for pipelines”, “The air bag for pipelines”, “pipeline efficiency enhancer” and “air valve/ surge alleviation mechanism”. All these names describe but one or a few of the product’s functions as it is a very cost effective pipeline management device incorporating the functions of a double acting air valve and a surge alleviation mechanism.

The acronym CATT (Controlled Air Transfer Technology) is being used more often by engineers to describe the application of “Anti Shock” air valves to pipelines, especially existing pipelines where they are installed to solve problems such as inefficient flow and surge and water hammer etc.

It was in recognition of a need to introduce the advantages of CATT and to make available research that has been conducted into air valve designs and the destructive phenomena related to the presence of air in pipelines that the publishing of this document was undertaken.

The object of this document is to provide the engineer with a comprehensive source of reference on air valves. Included is a guide on the selection of pipeline components and computer software for surge analysis as well as important points to consider when sizing and positioning air valves. Data presented is based on years of research and practical experience. The financial and technical benefits of CATT is also outlined in this document under “An Effective Air Valve/Surge Alleviation Mechanism”

It is the author’s wish that the information provided will help towards more effective design and efficient operation of hydraulic pipelines.



## AIR VALVE TECHNOLOGY REVIEWED

(INTRODUCING CONTROLLED AIR TRANSFER TECHNOLOGY)

### INTRODUCTION

Double acting air valves are generally assumed to be simple mechanical devices but are in reality, due to the unpredictable nature of air, complex in operation. Inherent in all conventional air valves, is the creation of either surge or water hammer on closure of the large orifice. Manufacturers have over the years developed various auxiliaries to protect air valves and pipelines from the damaging effect of surge and water hammer, and other phenomena as a result of air release. This document describes the phenomena affecting efficient air valve operation by analysing various air valve designs, and introduces CATT (Controlled Air Transfer Technology) a revolutionary, well tested, concept in air valve design and surge/water hammer alleviation.

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# INTRODUCING CATT

Pipeline design and operation has entered a new era with the application of CATT (Controlled Air Transfer Technology). The obvious questions are: what is CATT and how is it of benefit? The above and other questions are answered below in a simple question and answer format.

## **What is CATT?**

CATT is the acronym for Controlled Air Transfer Technology and applies to a hydro mechanical pipeline flow enhancing mechanism incorporating the features of a double acting air valve and a surge/ water hammer alleviation mechanism to automatically prevent phenomena such as surge, water hammer, flow restrictions, pipe breaks and vacuum from occurring in water pipelines.

## **Is CATT technology relevant to water pipeline management?**

There is sufficient empirical proof that air, due to its unpredictable and destructive nature, is highly undesirable in water mains. Conventional air valves have inherent design shortcomings which limit their abilities to control the discharge or intake of air, without the inducement of secondary destructive phenomena. It is obvious therefore that the entry or discharge of air needs to be controlled if expensive pipe breaks, inefficient pipeline flows and high power consumption are to be avoided. This can only be done cost effectively and efficiently by applying CATT.

## **Is CATT a sales gimmick?**

It is estimated that the cost of repairing water main breaks in Canada alone, exceeds Can\$100 million annually. Whilst there is no data to indicate the cost of repairs in South Africa, the figure must be substantially high. It is often not pinpointed what the cause of these breaks are but, it can be safely said, based on research that a large majority stems from air and the use of conventional air valves, either as the primary cause or as a secondary contributing factor.

Inefficient air valve operation can reduce flow by 30% or more and also contributes to high energy consumption as pumps are forced to overcome the restrictions created by entrapped air. This is a major financial consideration to any water authority.

CATT has been used effectively on problem pipelines, and the financial and technical benefits are well documented (some case studies are briefly outlined in this document). It is therefore not a sales gimmick but a well researched and sound technology that is assisting engineers and water authorities in the design and running of cost effective and efficient water pipelines.

### **Are there any financial benefits in applying CATT?**

The answer is a resounding yes as CATT allows for:

- The elimination of conventional surge and water hammer equipment.
- Quicker draining and filling times.
- More efficient flows.
- The building of more cost effective pipelines as pipelines do not need to be over specified.
- A substantial reduction in maintenance costs.

### **Is CATT only applicable to a particular manufacturer's product?**

No, CATT applies to any manufacturer's product, complying to the description provided above and who can substantiate their performance claims through third party and field testing.

### **Is CATT the panacea to all pipeline problems?**

No, although CATT provides a solution to a vast majority of pipeline problems (mostly air related), a pipeline can only operate 100% efficiently and effectively and water hammer can only be totally avoided if other components such as isolators, check valves and level control valves are also taken into account.

### **Is CATT a new technology?**

No, CATT has evolved from years of research and development. A number of manufacturers have over the years done research in this important area and have manufactured a number of devices having some of the features required by CATT (refer to the section titled Air Valves/ Surge Alleviation Mechanisms). It is important to note however that CATT as is known today has evolved over the past decade through research conducted by Vent-O-Mat.

# **SURGE AND WATER HAMMER**

Is there a risk of surge, water hammer and other destructive phenomena occurring? This question is often posed by design engineers when the feasibility studies for any particular project have been completed and the functional design is in progress, the answer is a resounding yes. The occurrence of these phenomena is not only limited to pumping schemes as is often assumed by engineers but occur in gravity mains as well.

Surge and water hammer in a pipeline is inevitable if initial design precautions are not taken, as it may be initiated by the system operator, be imposed by an external event, be caused by a badly selected component or develop as a result of poor maintenance.

Good pipeline design practice dictates that a design engineer should in the design of a pipeline, conduct a thorough pressure surge and water hammer analysis. If the analysis is to be successful, it must be comprehensive in scope. This implies that a wide range of flow conditions and operating scenarios should be investigated. Of equal importance is the correct selection of pipeline equipment and the understanding of the limitations of the computer software surge analysis programme being used.

This section of the document takes a brief look at the surge and water hammer phenomena and points out to the design engineer possible problem areas and reasons to why surge pressures and pipeline damage occur despite "thorough" analysis.

## **SURGE AND WATER HAMMER ANALYSIS**

Some of the problem areas often overlooked in an analysis, which may have a great influence on the dynamics of the pipeline and the overall cost of building and maintaining the pipeline are the use of traditional surge protection mechanisms, the selection of pipeline components and the shortcomings of the computer software used. Each of these factors are briefly discussed below.

It is important to note that this document is dedicated to research done on air valves and therefore only highlights the shortcomings of other devices to lend emphasis to the fact that an analysis cannot be comprehensive if all pipeline components and flow conditions are not taken into account.

## **PIPELINE COMPONENTS**

The selection of pipeline components such as air valves, check valves and end line level control valves have a major effect on surge and water hammer, as preventive mechanisms in some designs, and as the primary source for the occurrence of these phenomena in others. This is often overlooked in an

analysis, resulting in a multitude of factors being blamed when these phenomena occur, not realising that either one or all of the above components could be the cause.

## Check Valves

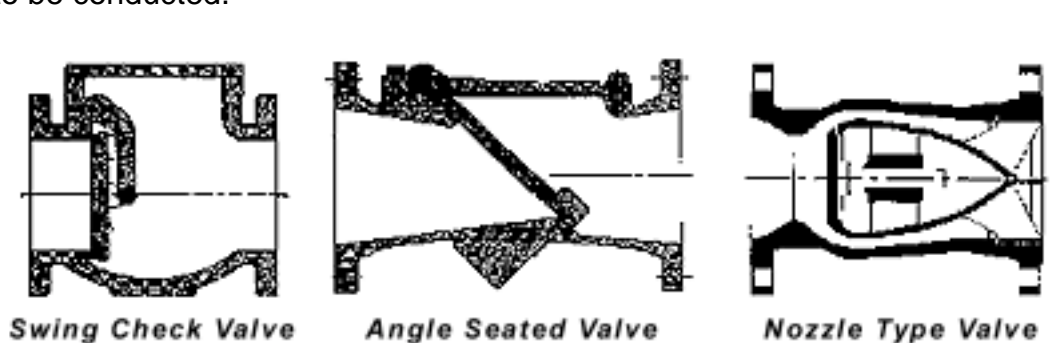
Check valves are often selected without proper thought to their response under pump trip conditions i.e., when a separated column commences to rejoin. The phenomenon of check valve slam occurs due to the fact that very many check valve designs require the reversal of flow to close it; this means that the column of water is already in motion and stops abruptly as the swing check valve closes, resulting in high transient pressures.

Pressures created in this manner are dependent on the valve design used, the initial pumping velocities and the design head of the system and can be calculated using Joukowski's equation.

In order to prevent or minimise this phenomenon, a quick acting, spring assisted design should be used that will react in a very low milli second time span and at low pressures to close, without slamming before reversal of flow has occurred.

There are instances such as low head and small scale systems where simple, swing check valves are quite acceptable, it is unwise however to regard them as the automatic choice. It is important when selecting check valves that they should be appropriate for the system of which they are an integral part. This can only occur if the design engineer is provided with dynamic performance for the check valve considered and if the computer software he uses, accommodates for the insertion of performance for various check valve (and other component) designs.

It is beyond the scope of this document to look in depth at various check valve designs. Reference can be made to the findings of Thorley (1989) et al on the phenomenon of check valve slam. Suffice to say that proper check valve selection is a factor that should not be ignored if a comprehensive surge analysis is to be conducted.



**Fig 1.** Three different check valve designs, with the Swing Check Valve being the cause of Check Valve Slam whilst the Angle Seated Valve reduces its occurrence slightly and the Nozzle Type check valve virtually prevents the occurrence of this phenomenon.

## **End Line Level Control Valves**

Water surface turbulence influence very many end line level control designs, as the control float bobs up and down on the waves in the tank or reservoir, causing unacceptable high surge pressures. This problem is compounded in the closing function as many mechanical and hydraulic valve's closing characteristics is such that it will induce damaging surges, if not fitted with sophisticated closing speed or relief controls.

The effect of the strain energy of the surges resulting from these phenomena will be cumulative and will result in damage to the valve and pipeline if measures are not taken to prevent their occurrence during the initial design stage.

There are available, a number of level control valve designs that have smooth closing characteristics, without the need for speed or relief controls, and that do not react to water surface turbulence, which can be used in place of conventional level control valves.

## **Air Release and Vacuum Break Valves**

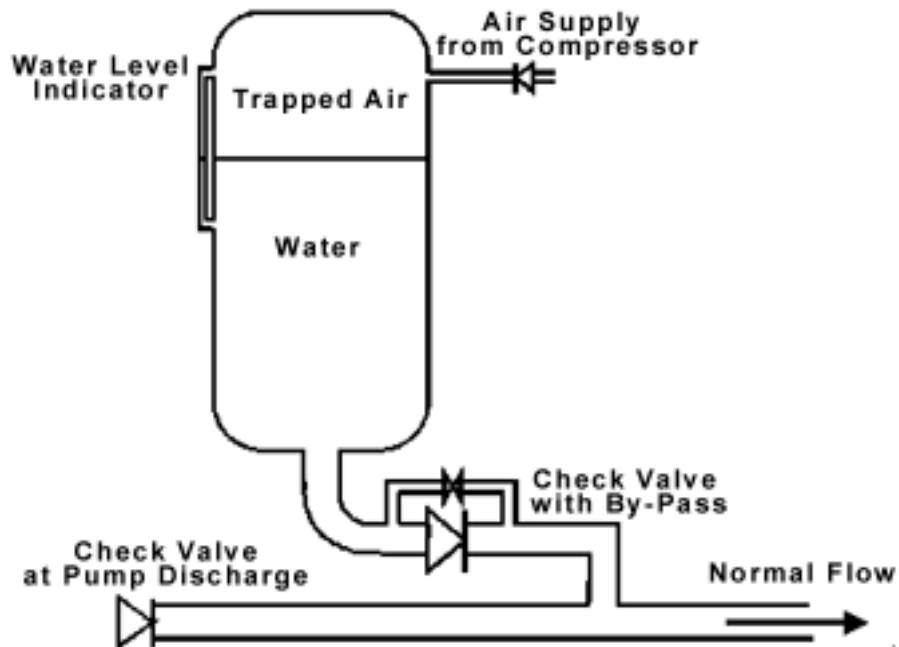
Conventional air valves are one of the prime sources of surge, water hammer and other destructive phenomena. There are alternative designs that function effectively, both as air valves and surge alleviation mechanisms, without the drawbacks of conventional designs. This entire document is dedicated to the research done into air valve designs and configurations and points out to the design engineer, what the effects of air, and the selection of air valves have on total pipeline dynamics.

Component selection has a major effect on surge and water hammer. The above are but three primary components which can and do result in these phenomena, but that are overlooked due to the lack of information on operating dynamic characteristics for the components considered. Valve manufacturers should therefore be encouraged to provide dynamic performance characteristics (just as pump manufacturers do). Product performance should be substantiated by third party and field testing.

## **CONVENTIONAL SURGE ALLEVIATION MECHANISMS**

### **Air Vessels**

One of the most common devices used in the water industry for the suppression of water hammer, particularly in the instances of pump trip, is the air vessel, see fig.2.



**Fig.2** A typical arrangement for an Air Vessel.

The ability of an air vessel to react to the phenomenon of vacuum is dependent on the type of check valves used. Vacuum occurs instantaneously in a very low milli second time span, which may be too quick for the check valve to react, and for the water to fill the cavity sufficiently. Hence damage, such as the sucking in of seals occurs, due to a partial vacuum existing in the pipeline.

Sometimes a check valve is not installed in the configuration indicated above. The purpose of an air vessel without a check valve, is in effect, to attempt to convert a rapid fluid transient (water hammer) event into a controlled mass liquid oscillation (surge). This is in reality converting one destructive phenomenon into another, as the oscillation can be just as damaging to the system over a time period, due the effect of the strain energy of this phenomenon being accumulative, which will be a contributing factor to pipe failure.

Another drawback of this device is failure due to lack of maintenance or total loss of power, especially when used on pipelines in developing countries where these factors are a reality.

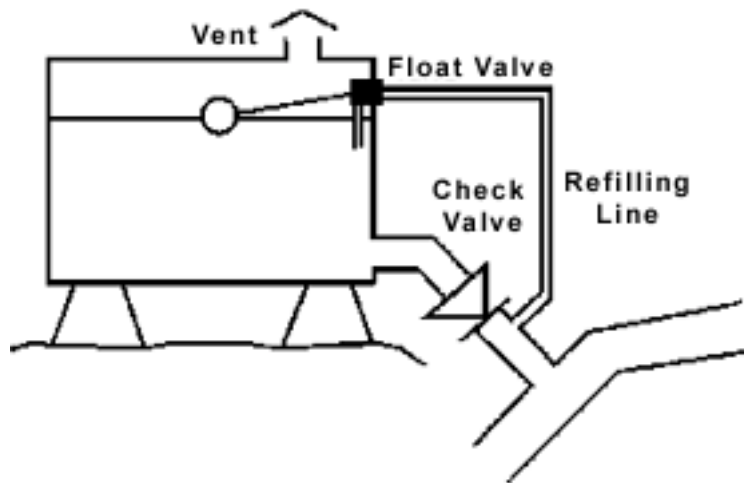
Pipe, downstream of the air vessels are normally overspecified to accommodate for the short comings of the air vessels. This is a costly option if the over specified pipe and cost of the air vessel is considered. Surge, water hammer and vacuum conditions can be managed much more cost effectively by the use of air valve/ surge alleviation mechanism as discussed further on in this document.



## One Way Surge Vessels

Surge tanks are normally positioned at reductions in an upward slope, or peaks of a pipeline to prevent severe sub-atmospheric pressures from occurring a result of pump trip.

These devices have the same drawback as air vessels in that their response under vacuum conditions is dependent on the type of check valve used. An air valve/ surge alleviation mechanism offers a much better solution as air reacts 28 times faster than water and is not restricted by a check valve in response to cavity formation, therefore having the ability to fill a cavity much more rapidly.



**Fig.3** One Way Surge Tank

It is important to note that despite their popularity, air vessels and surge tanks are not the panacea for surge and water hammer, especially if other pipeline components are not taken into account. More importantly is the fact that cost effective alternatives are available which do not have the space, operational limitations or, power requirements of traditional surge alleviation devices.

## COMPUTER SURGE ANALYSIS SOFTWARE

Much development has taken place in the design of computer software, with a number of software programmes available that can analyse a wide range of flow conditions. Lacking in very many of these programmes however is a comprehensive range of boundary conditions (pumps, valves, junctions, surge control devices etc.), and the comprehensive modelling of behaviour of components that are causing, or may prevent surge and water hammer, such as valves etc.

Surge analysis is not easy as equations resulting in flow are of the non linear, partially differential variety, component performance data is difficult to obtain (due to lack of research by many manufacturers) and the pipeline systems themselves

are subjected to a host of operating conditions and requirements. This is compounded by the effects of air in pipelines (due to its unpredictable nature), and the transmission of pressure transients which is frequently difficult to visualise or interpret even for the design engineer accustomed to the surge and water hammer phenomena.

The complexity of these phenomena has resulted in very many designers adopting simplified design procedures as the basis for computer codes in their analysis software, leading to either one, or a combination of three common problems, these are:

1. Pipelines being designed very conservatively, resulting in costly pipelines, components and maintenance requirements which may not be justified for the particular application.
2. Pipelines that are under protected from surge and other destructive phenomena which present major operating problems and result in costly pipe breaks and pipe and pipeline component damage.
3. Pipelines not operating to their designed capacities due to badly selected components. This is especially true for air valves, where the incorrect selection can result in a major loss in pipeline capacity (up to 30%).

An analysis should be performed on a realistic representation of the physical system without making unwarranted and possibly incorrect assumptions about component requirements and their effects on the pipeline system dynamics. This can only be achieved if the analysis software programme used, allows for the insertion of dynamic component performance data and outlines to the user the short comings of various component designs and configurations. Which inevitably means that designers of surge analysis software should work closely with pipeline component manufacturers and that manufacturers should supply technical data based on actual field applications.

The following are factors to look for in a well developed surge analysis software programme:

- The behaviour of components that are causing, or may reduce surge and water hammer phenomena, such as pumps tripping, valves operating etc., are comprehensively modelled.
- A full range of boundary conditions (pumps, valves, junctions, surge control devices, etc.) should be available
- A suitable strategy for incorporating line friction is included.
- The phenomena of sub atmospheric pressures and vapour cavities should be comprehensively modelled. This is also true for the control mechanisms used to limit these phenomena from occurring.
- The techniques used to yield numerical solutions does not distort the fluctuations in pressures and flows being predicted in the system.

- The programme must be validated, as far as possible against experimental data or other recognised criteria.
- Comprehensive results are produced in a suitable format.

The information contained above is sufficient for the design engineer to see that factors often overlooked may have a major effect on the total pipeline dynamics and ultimately the cost of building and maintaining a pipeline.

## **CONVENTIONAL AIR VALVE DESIGNS**

Conventional double acting air valves are available in a confusion of designs and configurations but ultimately fall in one of two categories namely:

1. Non Kinetic Air Valves - these are usually air valves with hollow spherical floats, which have a tendency of closing prematurely and often retain large pockets of air in the pipeline, this phenomenon is known as "Dynamic Closure".
2. Kinetic Air valves - these are valves which have the ability to discharge air at extremely high velocities and differential pressures and will only close once water has entered the valve chamber to buoy the operating float.

Although other air valve functions such as low pressure sealing and pressurised discharge can be tested fairly easily with the use of simple apparatus, the investigation into many designs determined that they did not operate within the parameters claimed, or created severe damage to pipelines due to inherent features. It can only be assumed that this was as a result of a total disregard to basic operating principles and design considerations, and that relevant testing methods which would pin point aspects of short comings are not specified or applied, indicating a gross lack of research.

The intention of this section of the document is to familiarise the specifier or user with the basic operating principles and design considerations which govern the functional limits of conventional air valve designs

### **AIR VALVE PERFORMANCE CAPABILITIES**

It has for decades been a generally accepted standard to specify an air valve in terms of the nominal inlet diameter only. This is a peculiar practice considering that the discharge and intake performance of any particular air valve is dependent on design and internal configuration, the size of the large orifice in relation to the nominal size of the valve, the shape and mass of the large orifice control float and the maximum allowable differential pressure across the large orifice. Performance may, dependent on the above, vary dramatically between different makes with the same nominal inlet diameter.

Following, is a comprehensive guide of the limitations of conventional air valves. The data presented, is based on years of research into air valve design and provides the designer with empirical proof that features inherent in specific air valves can and does cause substantial damage to pipelines, or prevent pipelines from operating efficiently.

## **NON KINETIC AIR VALVES**

Non Kinetic double acting air valves are characterised by hollow ball control floats, and the basic valve design has remained the same since its introduction more than a hundred years ago. This is most probably the most common air valve design with virtually millions installed on water pipelines around the world. The employment of the ball to seal off the large orifice, presents serious operating problems some of which are:

### **Poor Sealing and Working Pressures**

A ball must be perfectly spherical in order to effect a leak tight seal against a resilient seat located around the circumference of an orifice.

It is not possible in practice, to mass produce perfectly spherical balls and generally a working pressure of at least 1 bar is required for a ball float to deform its resilient seat sufficiently and achieve an acceptable seal.

To compensate for the non - uniform ball float seating surfaces very soft seals are often used, these become adhered to the float material and prevent operation of the large orifice function.

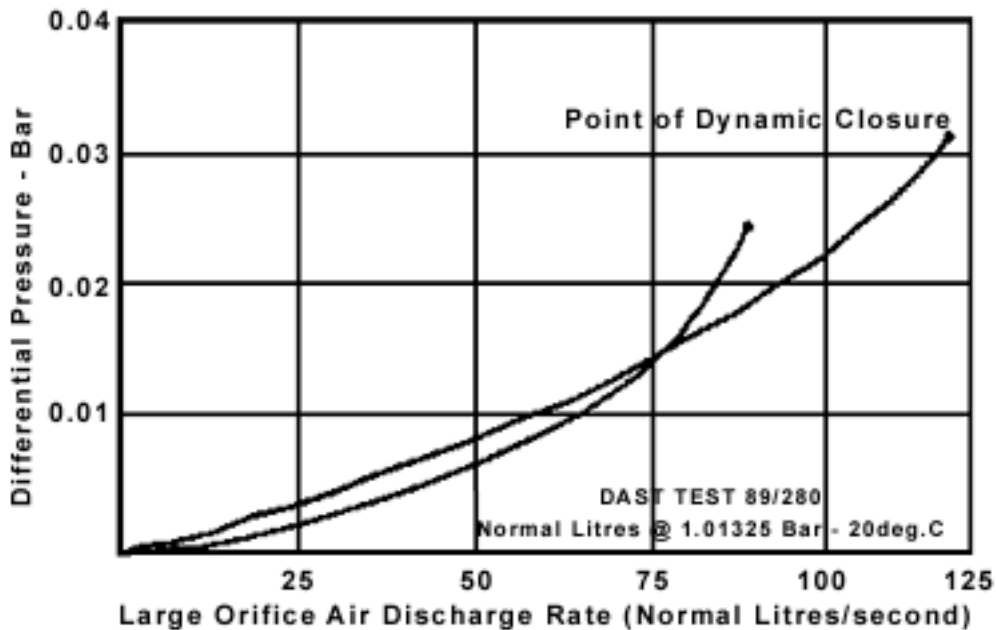
### **Deformation and Jamming**

The hollow construction of ball type floats make them susceptible to distortion and permanent deformation when subjected to high pressures and shock loads. A ball float sealing a 150mm outlet orifice at 25 bar differential pressure must resist 4.5 tonne total force and considerably more if water hammer or surge (liquid oscillation) occurs.

In practice it has been found that floats elongate and wedge into the large orifice. Obviously if the ball float is jammed into the orifice it will not perform either air intake or discharge functions.

### **Premature Closure**

Tests conducted by the Council for Scientific and Industrial Research - South Africa in 1989, indicates that ball type air valve designs have a tendency for the large orifice to be closed by the control float at very low differential pressures (0.02 - 0.05 bar) without any further discharge, see fig. 4. This results in the entrapment of large pockets of air in the pipeline. The term "Dynamic Closure" is used to describe this phenomenon.



**Fig.4** Tests conducted by Council for Scientific and Industrial Research - South Africa, indicating the dynamic closure point of two different DN80 Non Kinetic Air Valve designs.

Air retention results in surge (liquid oscillation) as the water compresses the retained air to a point, whence it acts as a spring, violently oscillating the liquid.

The magnitude of the surge generated is dependent on the water flow velocity (either during initial filling or when separated water columns commences to rejoin) and the size of the entrapped air pocket on closure.

Effect of the strain energy of the surges will be cumulative and concentrated at points of weakness such as reductions in pipe class, fittings which may be of a lower standard than the surrounding pipes, near line valves or tapers and in branches with closed ends.

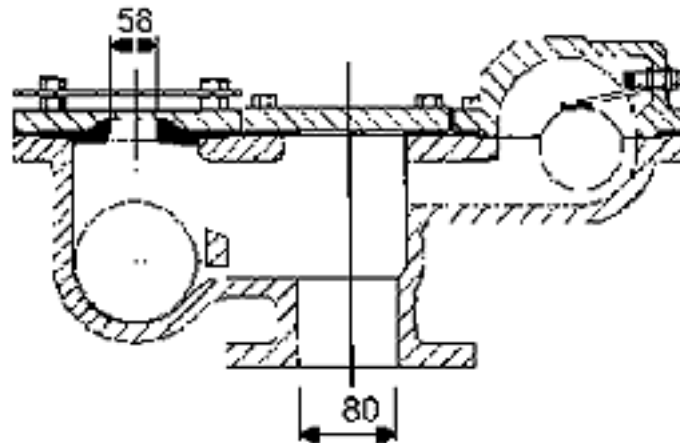
Pipes may also fail structurally due to the combined effect of the surge pressures which crack protective pipe linings and the retained air pockets which promotes corrosion.

Retained air causes restrictions which lead to inefficient pipeline operation and increased electrical consumption in pumping schemes as pumps are forced to work at higher heads in order to overcome the restrictions.

### **Limitation of Orifice Size and It's Effect on Performance**

The diameter of a ball float should not be less than 3 times the large orifice diameter otherwise it will wedge into the orifice.

Air valve large orifice diameters are restricted for economical reasons this can be demonstrated as follows: The actual diameter of the large orifice of a conventional DN80 double acting Non Kinetic air valve is 58mm and the diameter of the control float is 150mm. If the orifice diameter had to be increased to 80mm the control float will have to increase to 240mm. The overall weight and size would increase proportionally, which in this example, is an increase of 60% (in size and weight).



**Fig.5** A typical DN80 Double Acting Conventional Air Valve design with a restricted large orifice.

Discharge is adversely affected as can be seen from tests conducted by the Council for Scientific and Industrial Research - South Africa, demonstrating the flow capabilities of four different DN80 valve designs with different large orifice diameters, at equivalent differential pressures see fig. 6 (note the country of manufacture has been used to identify the different air valve designs).

Country of Manufacture	British	Israeli	Turkish	South African
Valve Nominal Size	DN80	DN80	DN80	DN80
Diameter of Large Orifice	65mm	32mm	65mm	80mm
Max Discharge at 0.05 Bar $\Delta p$	83 nl/sec	36 nl/sec	81 nl/sec	156 nl/sec

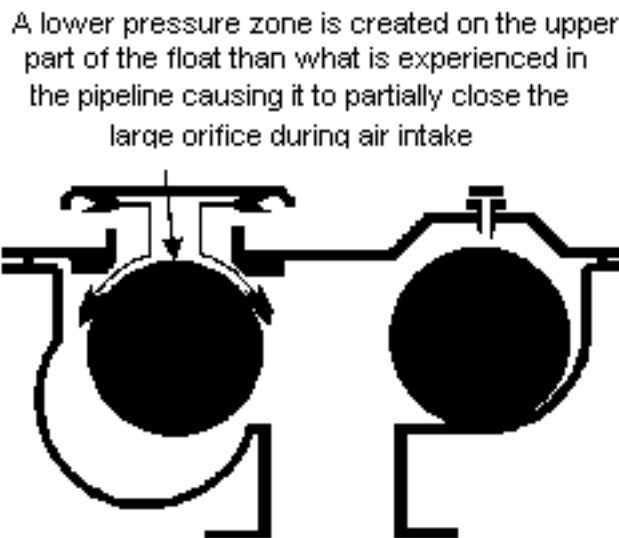
**Fig.6** An indication of the effect of the large orifice diameter on an air valve's performance capabilities.

Restriction of the large orifice does lead to pipe collapse if not accommodated for during air intake (vacuum conditions).

### **Venturi Effect**

Inherent in all air valve designs with spherical floats is the tendency for the large orifice control float to partially close the large orifice during air intake. This is due

to the creation of a lower pressure zone on the upper part of the float than what is experienced in the pipeline (Venturi Effect), see fig 7.



**Fig.7** An air valve with spherical control floats, under vacuum conditions.

This phenomenon occurs at low differential pressures of 0.15 to 0.20 bar, which greatly restricts the valve's performance and has been the cause of pipe collapse.

Many technicians are aware of this phenomenon, and insert wedges in the large orifice, prior to scouring, to prevent it from occurring. This however is not a practical and cost effective solution on large pipelines.

## **Maintenance**

It is recommended, due to the problems described above, that conventional air valves be maintained regularly.

## **KINETIC AIR VALVES**

Kinetic air valves were developed primarily to overcome the premature closure phenomenon that plagues conventional Non Kinetic Designs. This is achieved by altering the internal configuration of the valve and therefore it's aerodynamic characteristic such that, during air discharge the large orifice float is biased towards the inlet orifice thereby preventing premature "Dynamic Closure" of the outlet orifice.

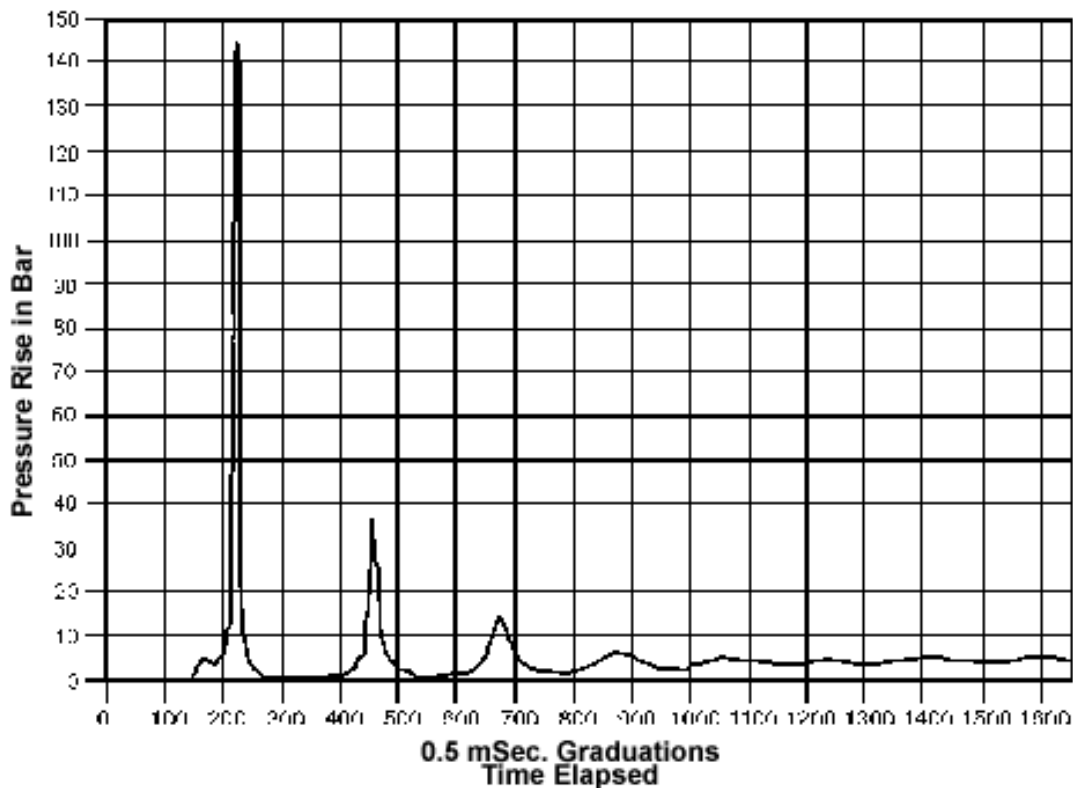
Being able to discharge air at high velocities has created serious pipeline operating problems some of which are:



## Water Hammer

An air valve discharging air at high differential pressures and velocities, will on closure induce high, damaging transient pressures. This is due to the water flow entering the valve suddenly being arrested by the large orifice control float sealing on the large orifice. The effect on the pipeline dynamics is equivalent to the rapid closure of an isolating valve.

The magnitude of the transient pressures induced often exceed the test pressures of the valves and pipeline as is evident from tests conducted by the Council for Scientific and Industrial Research - South Africa in 1994. This can be clearly demonstrated by the graph in fig.8 which indicates the magnitude of induced pressure rise in a conventional DN80 Kinetic Valve on closure of the large orifice whilst discharging at a differential of only 0.17 bar.



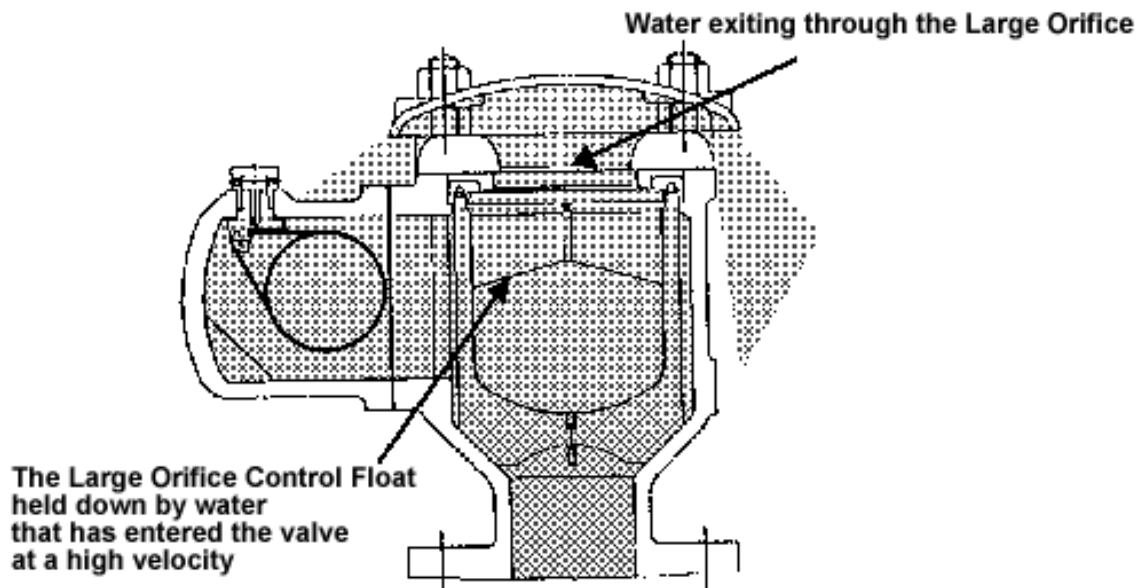
**Fig.8** Diagram indicating the magnitude of pressure transients induced by a conventional DN80 kinetic type air valve on closure of the large orifice at a differential pressure of 0.17 bar - Results of tests conducted by The Council for Scientific and Industrial Research - South Africa (AERO TEST 94/140) .

The magnitude of transient pressure rise created by kinetic air valves on closure, is dependent on the valve size, length of pipe, differential pressure across the large orifice on closure, bulk modulus of the water etc. and can be calculated using Joukowski's relation.

Research conclusively proves that the damage created by these valves, discharging at high velocities, is a factor that cannot be ignored in pipeline design. It is recommended, from research conducted by numerous authorities and manufacturers, to limit the discharge differential across the large orifice of Kinetic Air Valves to 0.05 bar differential pressure, in order to prevent damaging high pressure transients from occurring.

## Water Spillage

It happens often in practice where the large orifice control float fails to react when high velocity water enters the valve chamber. This results in the water covering the control float, effectively holding the float down, whilst exiting through the large orifice, see fig.9



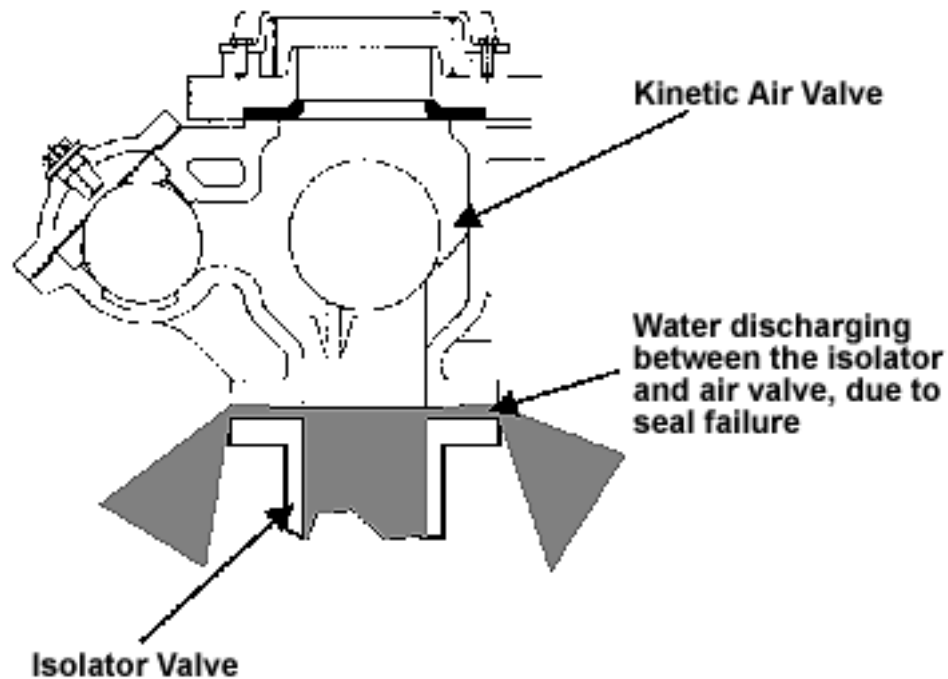
**Fig.9** High velocity water exiting through the Large Orifice of a Kinetic Valve, whilst holding the Large Orifice Control Float down, effectively preventing valve closure.

The amount of water spilled in this manner is substantial and results in flooded valve chambers. Cost of repairing the damage due to this and the cost of the actual water being spilled, could far outstrip the cost of the valve.

Actual spillage of the water induces a pressure surge because water has a much higher density than air, causing the flow rate to drop as it reaches the large orifice opening, which will have a similar effect to the sudden closure of a valve at the end of a pipeline discharging water. The magnitude of the surge induced in this manner will be dependent on the velocity of the water entering, the valve chamber, the length and diameter of the pipe etc, but can be substantially high.

## Seal Failure

Another phenomenon peculiar to Kinetic Air valves is the failure of the seal between the valve and isolator on closure of the large orifice which results in water spillage, see fig.10. This is as a result of the transient pressures created on closure.

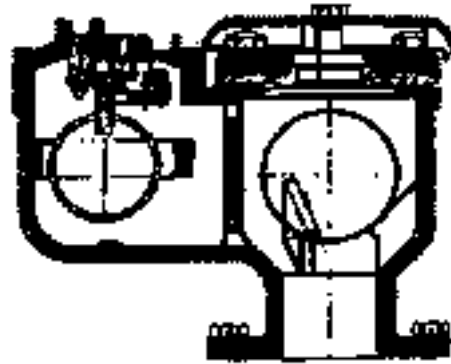


**Fig.10** Seal Failure between the air valve and isolator, due to transients created by Kinetic Air Valves on closure.

Repetitive tests, indicates that this phenomenon occurs at 80 - 85 bar, which implies that the transients created by Kinetic valves, discharging at high differential pressures are in excess of 85 bar. This corroborates findings by the Council for Scientific and Industrial Research - South Africa and manufacturers such as Apco and Vent-O-Mat.

## Limitations of the Large Orifice

Very many Kinetic air valve designs are mere modifications of Non Kinetic, ball type designs, using hollow spherical floats to seal off the large orifice. They are therefore, because of financial considerations, limited to the same design constraints as Non Kinetic air valve manufacturers (see Limitations of Orifice Size).



**Fig.11** A typical Kinetic type air valve with ball control floats

Discharge, the same as for Non Kinetic Valves, is adversely affected, due to the restricted large orifice diameter.

### **Under Sizing**

Kinetic Air valves are more susceptible to being undersized than other air valve designs. This is due to engineers concentrating on their discharge requirements, selecting valves to discharge at high differential pressures, and thereby ignoring their vacuum requirements.

Valve selection based totally on discharge requirements is detrimental to the pipeline under vacuum conditions, as the valve may not fully protect the pipeline under these conditions. This is especially true for plastic pipes, and pipeline seals which cannot withstand very high differential negative pressures.

### **Venturi Phenomenon**

The Venturi phenomenon described under Non Kinetic Valves is also applicable to Kinetic Designs, even more so, on undersized valves.

### **AIR VALVE MISCONCEPTIONS**

Much traditional "wisdom" has evolved over time to explain air valve design and its effects on pipeline efficiency. Many of the assumptions are so misleading and frequently false that they should not be regarded as rational design rules but more as outdated and discredited air valve folklore. Some of these misconceptions are addressed below.

**Misconception:** Air valve size should be specified by the nominal inlet diameter.

**Fact:** It is the large orifice area and the valve's dynamic characteristics which determine performance. It cannot be taken for granted that different air valve

designs of the same nominal size will perform equally, this can be seen in fig.6 . Accurate selection can only be achieved by reference to substantiated performance data for a particular design, and by taking into account the limitations of conventional air valves and standard orifices.

**Misconception:** Conventional air valves can be sized to discharge in excess of 0.3 bar differential pressure across the large orifice with no effect to the valve and pipeline.

**Fact:** This is most probably the biggest misconception about air valves. The differential pressure across the large orifice on closure of an air valve, has a major effect on transient pressures and surge in the pipeline.

A Kinetic air valve if properly sized for vacuum will seldomly, and only in instances of excessive filling velocities or where column separation has occurred, exceed 0.2 bar differential across the large orifice. The magnitude of the transient pressures created on air valve closure at any differential pressure in excess of 0.1 bar will however exceed the maximum pipeline design pressure and cause severe damage to the pipeline.

Non Kinetic Air valve will close at extremely low differential pressures of between 0.03 and 0.05 bar (contrary to manufacturers published data), retaining air in the pipeline which leads to a number of destructive phenomena.

It is recommended from tests conducted by air valve manufacturers and research by independent third party test authorities as well as engineers such as Wisner et al, that the differential pressure across the large orifice of conventional air valves be restricted to 0.05 - 0.07 bar (30 - 35 m/sec. velocity up the air valve riser). This is to prevent "Dynamic Closure" in Non Kinetic valves and the water hammer phenomenon in Kinetic Designs.

**Misconception:** Air valves can on intake (vacuum conditions) be sized to withstand 0.5 bar negative differential pressure across the large orifice.

**Fact:** This misconception stems from air valve manufacturers who publish intake performance curves based on theoretical calculations which have no foundation in actual air valve vacuum tests.

Actual vacuum tests indicate that choked air valve orifice conditions begin to occur at 0.35 bar differential and that there is virtually no increase in air inflow between this point and 0.5 bar differential (when air reaches sonic velocities on intake).

The recommended safe average across the large orifice, without the risk of pipe wall collapse or the sucking in of joint seals or other possible damage due to negative internal pressures will vary according to the pipeline material used. It is

advisable to consult the relevant manufacturer in order to determine the collapsing pressure of a particular pipe material. Obviously this advice is also applicable to any joint seal systems or other components which may be vulnerable to damage when a system is subjected to negative internal pressures.

It is important to note that an air valve's capabilities is limited to 0.35 bar negative differential pressure regardless of whether the pipeline can withstand a greater vacuum. The partial vacuum within the pipeline may draw in debris behind the seal joints resulting in leakage when the pipeline is filled with water again.

**Misconception:** If a pipeline is built according to recommendations obtained from Surge Analysis software, then the pipeline will be safe from these destructive phenomena.

**Fact:** This is only true if a programme takes the effects of air and the operational limitations of air valves and other components into account.

Very many computer programmes assume that pipelines are hydraulically full when surge occurs. This is a fundamental error as there are often large pockets of air trapped in the pipeline by air valves closing prematurely, which can aggravate or reduce the impact of this phenomenon.

The transient pressures created by kinetic air valves do exceed the test pressure of the pipeline and can cause pipeline damage despite the use of conventional surge alleviation equipment.

Computer modelling can therefore only be effective, if the programme used, takes the short comings of conventional air valves, and the effects of air into account.

**Misconception:** All manufacturers' published data can always be accepted as being correct.

**Fact:** All air valve manufacturers are obliged to publish performance data pertaining to the high volume air discharge and intake capabilities of their valves. This data is relied upon by pipeline designers to provide the basis for selection of valve size for any particular application requirement.

Strikingly absent in manufacturers' data however, are how their air valve designs influence factors such as surge and water hammer, vacuum, corrosion and effective pipeline operation. This is due to either lack of research, or, partial research in one area of air valve operation, whilst totally neglecting other factors. Some typical examples are shown below.

## **High Discharge Performance**

This is most probably the only feature that a conventional valve is marketed on. It is therefore not uncommon for virtually every manufacturer to claim that their valve can discharge up to, and including sonic velocities (0.9 bar differential). Whilst this is possible under controlled conditions, it is totally impossible in reality as an air valve will seldom exceed 0.2 bar differential across the large orifice (as discussed above). The surge pressures induced at high velocity discharge is a factor that cannot be ignored.

**It should be a prerequisite of kinetic valve manufacturers to publish the magnitude of pressures induced by their valves, on closure of the large orifice as an indication to the pipeline design engineer of the possible damage to his pipeline.**

Tests have proved that although some manufacturers claim their valves to be of kinetic design, that these valves actually close prematurely.

Some manufacturers claim extremely high volume discharge and intake capabilities, that have no relation to actual air valve performance. The Council for Scientific and Industrial Research - South Africa conducted tests in 1989 on orifice plates with nominal sizes equivalent to air valves, so as to provide a quick check reference as to the validity of claimed performance data. Obviously an air release valve will have a lower discharge rate compared to an equivalent size orifice plate at any specific differential pressure yet, manufacturers' publish data indicating their valves exceeding the capabilities of orifice plates, which is misleading and can create pipeline problems due to undersizing. A copy of orifice plate performance data, obtained from the tests conducted in 1989 is enclosed.

## **Air Intake Performance Data**

Air intake performance is the most expensive air valve function to test as it does require extremely large vacuum pumps to duplicate what happens in reality. It is because of the cost factor involved in performing these tests that many manufacturers either publish data based on theoretical calculations, or blow air through the large orifice i.e., the air discharge test is performed in reverse.

Both these methods have proven to be grossly inaccurate as it does not reflect what happens in reality. Realistically, the air is forced through the large orifice by atmospheric at the rate of which the water is drawn from the pipeline. The air in flow is therefore substantially lower than the air discharge for any valve at a specific differential pressure (as atmospheric is the only motive force and cannot be increased - unlike discharge where the upstream pressure can be increased).

The Venturi phenomenon is strikingly absent in the published data of ball type air valve manufacturers which is further proof that published data can be very misleading.

A very important consideration which is often ignored by manufacturers is the fact that choked orifice velocities for air intake commence at about 0.35 bar and there is no substantial air increase between this point and where air reaches sonic velocity at 0.5 bar. The graphs shown are the maximum intake capabilities of orifice plates and provides a quick check reference as to the validity of claimed performance data (obviously an air valve of equivalent diameter will have a lower intake capacity than an orifice plate, at the same differential pressure).

Data that cannot be substantiated by third party testing should therefore be treated as questionable. It is important that the method of testing is also questioned.

## **SYNOPSIS**

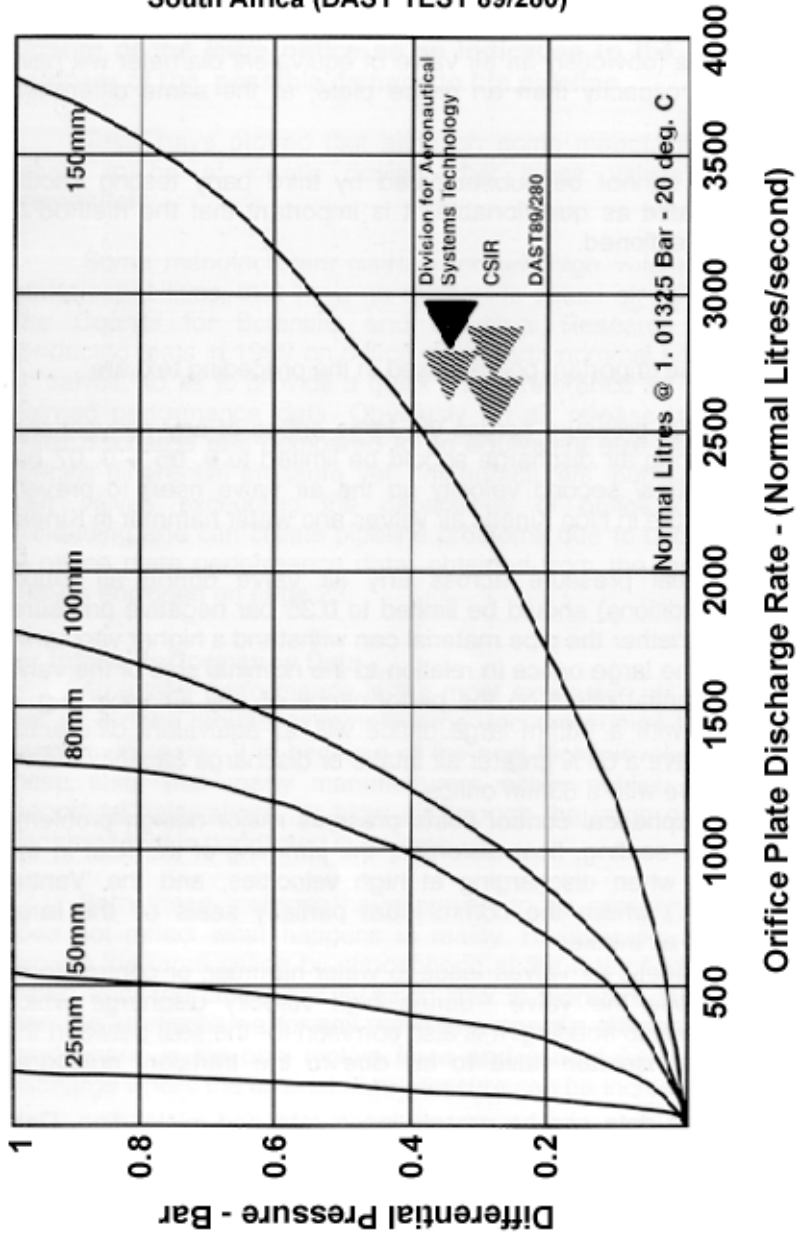
Some of the important points raised in the preceding text are:

1. The differential pressure across the large orifice of any conventional air valve, during air discharge should be limited to 0.05 - 0.07 bar (30 - 35 metres/second velocity up the air valve riser) to prevent dynamic closure in Non Kinetic air valves and water hammer in Kinetic designs.
2. The differential pressure across any air valve during air intake (vacuum conditions) should be limited to 0.35 bar negative pressure, regardless whether the pipe material can withstand a higher vacuum.
3. The size of the large orifice in relation to the nominal size of the valve has a substantial effect on the performance of any air valve e.g. a DN80 valve with a 80mm large orifice will, at equivalent differential pressures, have a 61% greater air intake or discharge capacity than a DN80 air valve with a 63mm orifice.
4. The use of spherical control floats presents major design problems such as poor sealing, float distortion, the jamming of the float in the large orifice when discharging at high velocities, and the 'Venturi Phenomenon', where the control float partially seals off the large orifice during air intake.
5. The use of Kinetic air valves leads to water hammer, or control floats failing to close the valve during high velocity discharge which inevitably leads to flooding. It is also common for the seal between the air valve and isolator valve to fail due to the transient pressures induced.
6. Manufacturers data can be grossly inaccurate and misleading. Data should therefore not be accepted, unless it is substantiated by third party testing, or conforms to certain known values, i.e., orifice plate performances.



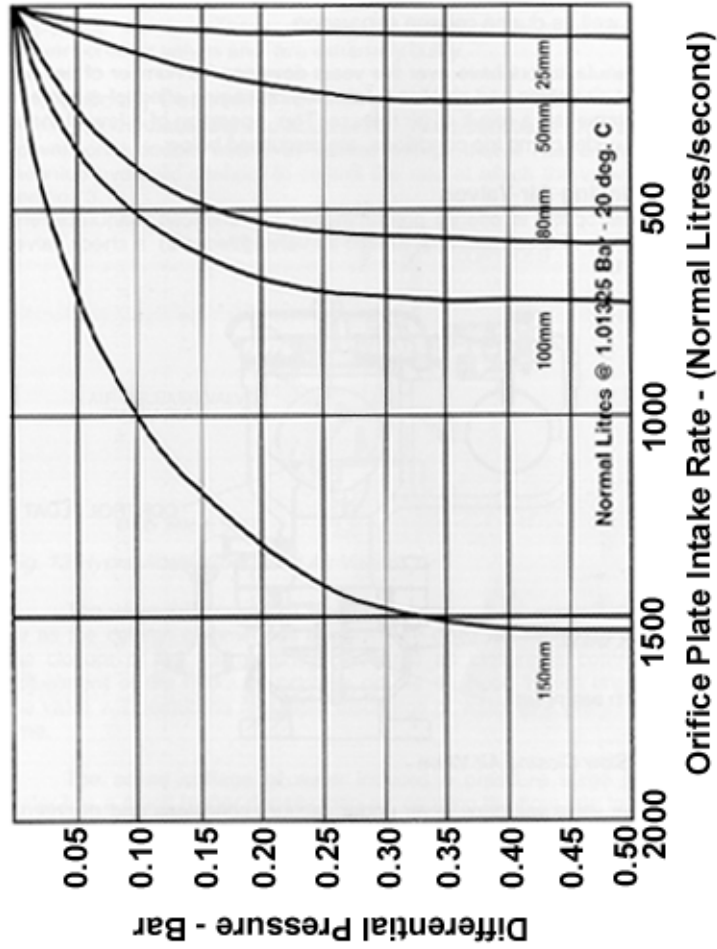
# ORIFICE PLATES - DISCHARGE PERFORMANCE

From tests conducted by the Council for  
Scientific and Industrial Research -  
South Africa (DAST TEST 89/280)



# ORIFICE PLATES - INTAKE PERFORMANCE

Extrapolated from tests conducted in 1994 -  
using Nash Vacuum Pumps.



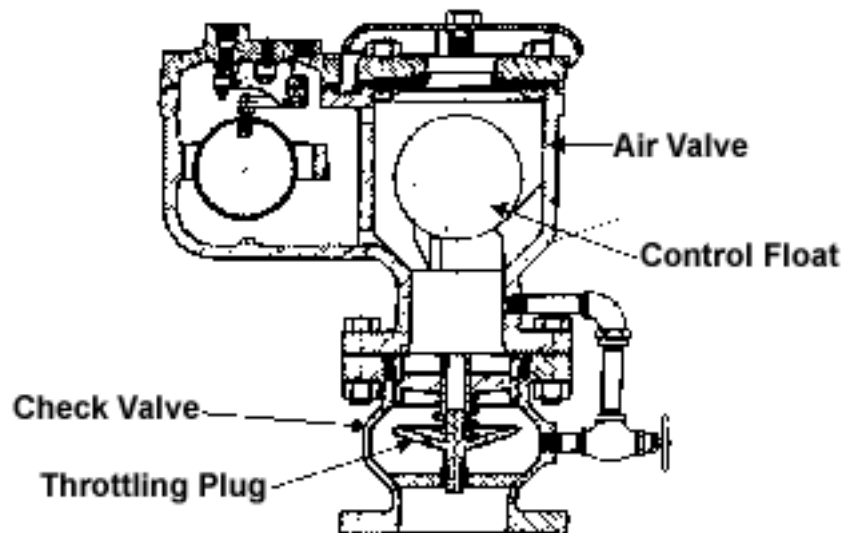
## AIR VALVES/SURGE ALLEVIATION MECHANISMS

Inherent in all conventional air valves, is the creation of surge or water hammer on closure of the large orifice. This is regardless of whether the system on which the valves are employed is as a gravity fed main or pumping system as these phenomena occur during initial filling as well as during column separation.

Manufacturers have over the years developed a number of devices to protect air valves and pipelines from the damaging effect of surge and water hammer as a result of air release. The operation of a few of these designs, under pump trip conditions, are discussed below.

### SLOW CLOSING AIR VALVES

This option is offered predominantly by American manufacturers' and consists of a conventional Kinetic air valve fitted with a check valve, see Fig. 12.



*Fig. 12 Slow Closing Air Valve*

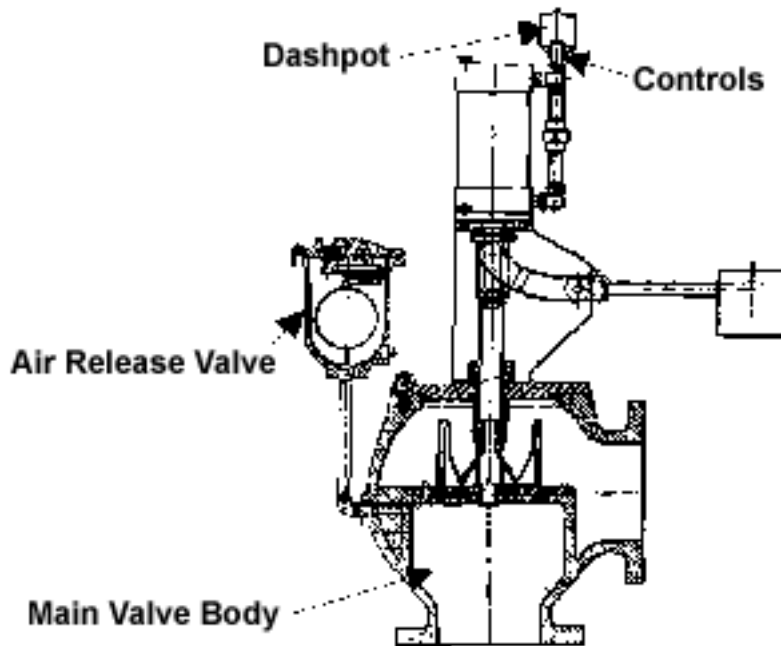
The valve will draw in air under vacuum conditions and discharge air as the water columns commences to rejoin. Air will pass unrestricted through the valve but when water, because of its greater density, enters the check valve, the throttling plug will move to a closed position. The passage of water through the throttling plug will then be throttled through small ports within the plug. The operating float is then moved to a closed position by the water which enters the valve at a greatly reduced rate.

It is important to note that this device only offers protection to the air valve as the throttling plug is slammed in the closed position by the water entering the valve which creates water hammer and inevitably leads to pipeline damage. These

devices are substantially more costly than conventional air valves and are extremely bulky.

## HYDRAULICALLY CONTROLLED AIR VALVES

The Hydraulically Controlled Air Valve functions the same as conventional double acting air valves except that it has an externally mounted hydraulic dashpot to control the rate at which the valve closes, see fig.13.



**Fig. 13** *Hydraulically Controlled Air Valve*

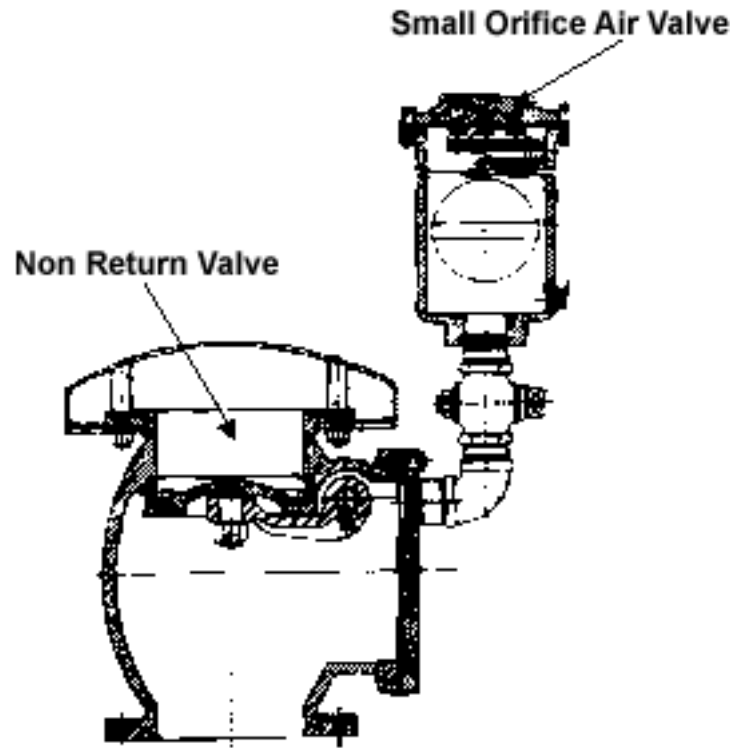
The valve will draw in air when pump trip occurs, and will discharge air as the column commences to rejoin. Air does not have any effect on the closure of the valve during discharge as closure is controlled by adjustment of the hydraulic controls on the dashpot. Which implies that the valve will permit the regulated discharge of water at a pre set closing time.

The actual spillage of water induces a pressure surge because water has a much higher density than air, causing the flow rate to drop as it reaches the opening, which will have a similar effect to the sudden closure of a valve at the end of a pipeline discharging water. Experimental work conducted by Slawminski and van Vuuren indicates that the most important variables influencing the magnitude of a pressure rise for air released in this manner are; internal pressure, volume of compressed air pocket, size of opening through which the air escapes and the elasticity of the system.

The valve in addition to the above is extremely bulky and very costly and requires a factory engineer on site to adjust the hydraulic controls.

## **NON RETURN AIR VALVES**

These are usually conventional non return valves fitted with a small orifice air release valve, see fig. 14. The operation of these valves are similar in function to "Vented Non Return" Air Valve designs offered by British and European manufacturers.



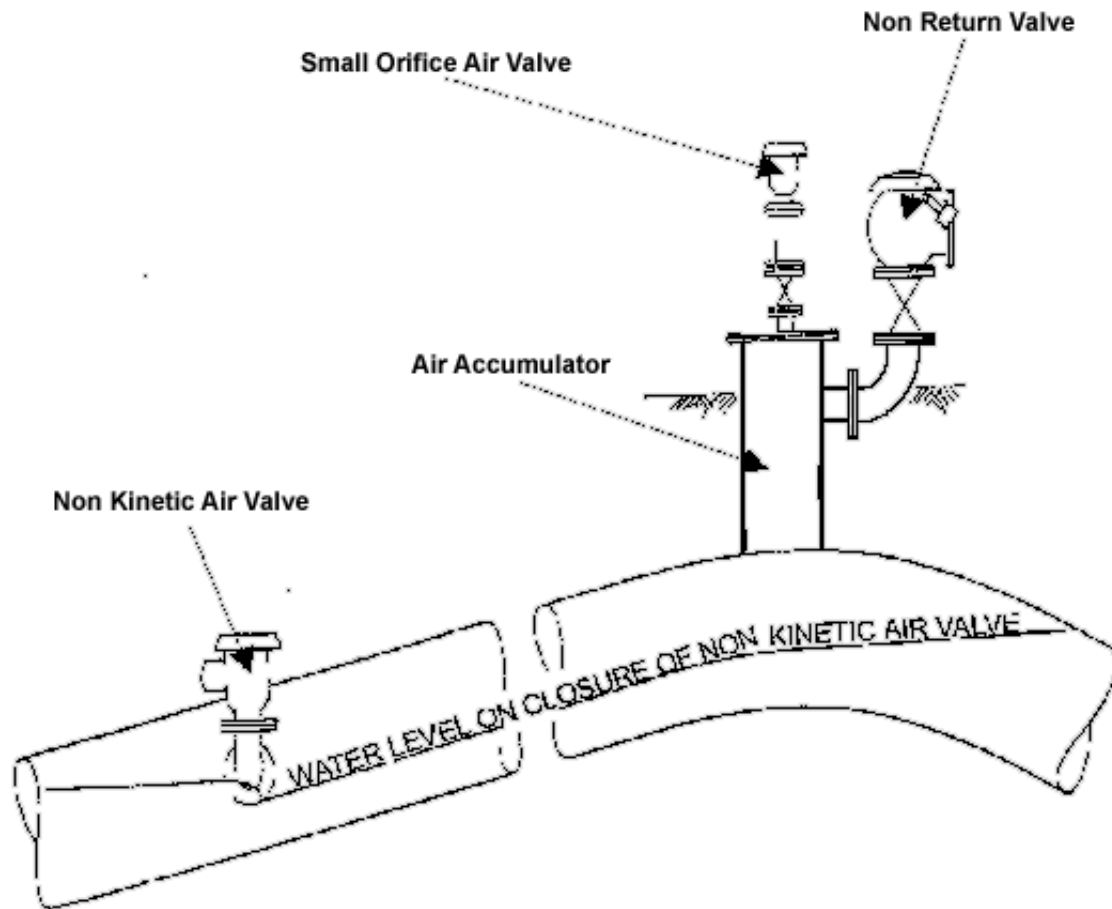
**Fig. 14** *Non Return Air Valve*

These valves allow unrestricted air intake during column separation but controls the air discharge as the column commences to rejoin, thereby effectively eliminating the possibilities of water hammer from occurring.

The fact that air is only released through the small orifice can lead to liquid oscillation (surge pressures) as the rejoining water column tends to compress the large volume of air very rapidly, faster than the small orifice can release the air, whence the air will act as a spring, causing the liquid to oscillate in the system.

Initial filling operating procedures are also lengthened by using these valve types. Experimental work conducted by Campbell in Saudi Arabia, indicates that these valves do act very effectively as water hammer/ surge alleviation mechanisms, if used in conjunction with conventional Non Kinetic air valves, see fig. 15. The

conventional Non Kinetic valve, which is placed a little upstream of the Non Return Air Valve, will discharge a large volume of air prior to closure and the surge created by the closure will be absorbed by the remaining air in the system. The air retained will be released in a controlled manner by the Non Return Air Valve thereby absorbing the energy of any potential surge or water hammer, which will be dissipated through the small orifice.



**Fig. 15** Non Kinetic Air Valve & Non Return Air Valve Arrangement

It is obvious that these valves are effective in eliminating surge and water hammer but are very costly as they need to be installed together with a conventional Non Kinetic air valves to work efficiently, which is a major cost consideration to design engineers and end users.

## **CATT - AN EFFECTIVE AIR VALVE/SURGE ALLEVIATION MECHANISM**

The previous section are but a few of a number of various pipeline devices, which have been developed over the years to protect pipelines from surge as a result of air release. Investigations into these devices has indicated that they are not superior from all points of view and instead offer either protection to the air valves only or, pipeline protection at the expense of one or other air valve function or, create further hydraulic problems by compounding the surge and water hammer phenomena instead of alleviating or eliminating these phenomena. These devices are usually substantially more costly than conventional air valves and are therefore only used at specific points on a pipeline e.g. at the peak of steep slopes and subsequent to check valves. They therefore provide limited protection as surge or water hammer will, depending on the valve used and the discharge velocity within the pipeline, be induced at every air valve location.

It follows therefore that there is a great demand for an air valve that does not have the drawbacks of conventional air valves as described above, as it must effectively draw in air under vacuum conditions, effectively release air during initial filling and under operating pressures and, eliminate surge and water hammer as an automatic and integral function, during column separation and initial filling. This seemingly "tall order" for a mechanical device such as an air valve has been achieved by Vent-O-Mat, in their Series RBX range of "Anti - Shock" air valves.

### **Product Background**

The advanced and unique Vent-O-Mat air valve design was introduced in 1982. Obviously commitment to research and development was needed to gain credibility amongst pipeline engineers for the actual operating concept. As a result, the company embarked on an intensive research and development programme.

All performance data available from air valve manufacturers world wide was reviewed. It was found that even where designs and configurations were virtually the same, the published data varied in the extreme. Surge and water hammer as a result of air release and a number of other conventional air valve short comings were not included in many manufacturers' published data. This was despite of research that has been done by some manufacturers and a number of well known and respected authorities on surge and water hammer over the past 30 years, pin pointing problems associated with conventional air valves. The only logical conclusion is that that most available data should at the very least be considered questionable, unless substantiated by third party testing.

The use of Vent-O-Mat in the field indicated that it solved a number of major pipeline problems. Some of these problems and how they were solved, are described in the section titled "Incidents and Solutions".

Of interest to the design engineer and end user was the fact that for the first time, an effective and efficient air valve existed that, in addition to its air valve functions effectively eliminated surge and water hammer as a standard and automatic function. The abilities of the valve was not based solely on the manufacturer's claim but was substantiated by the Council for Scientific and Industrial Research and other testing, and was corroborated by findings of others in the field.

This has in essence revolutionised the manner in which air valves and surge protection equipment are viewed during pipeline design as the Vent-O-Mat valve design presents the consulting engineer with a more cost effective and efficient alternative to the building of pipelines and the management of destructive phenomena such as surge, water hammer and vacuum.

In addition efficiency on existing pipelines can be enhanced by up to 30% and surge and water hammer can be substantially reduced by the mere replacement of conventional air valves with the Vent-O-Mat design. This takes a great load off authorities who are constantly pressed to increase supply but do not have the finance to do so immediately, as it allows them to increase flow through existing infrastructure at the mere cost of replacing the air valves. Which ultimately allows for the proper study and the gathering of finances to build new pipelines.

The Vent-O-Mat design has transcended the line of being a mere air valve or surge alleviation mechanism as it represents more than just the combination of these two functions (although it is described as an air valve/ surge alleviation mechanism in this document). It will become obvious to the user that the descriptions: "an air bag for water pipelines" or "the safety belt for water pipelines" or "pipeline efficiency enhancing device" all describe but a mere function of the valve as it performs all these functions and more. In fact it is best described as a cost effective pipeline management mechanism incorporating the features of a double acting air valve and surge alleviation device. The acronym CATT (Controlled Air Transfer Technology) is being used more often by engineers to describe its application to pipeline design.

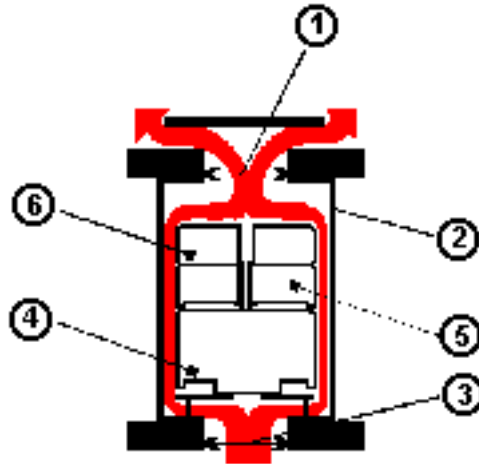
### **Vent-O-Mat Operation**

The Vent-O-Mat Series RBX valve, under normal conditions, operates as a standard air valve with the exception that it does not have the drawbacks such as: restricted large orifice diameters, is not affected by phenomena such as the "Venturi Effect" or "Dynamic Closure" and does not induce surge and water hammer on closure of the large orifice.



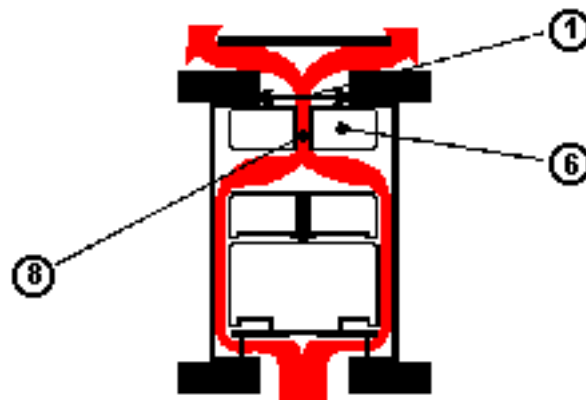
The valve reacts, in instances of rapid filling or column separation as an effective surge alleviation mechanism, in that it automatically controls the rate of air discharge, thereby effectively dissipating the energy of the surge whilst decelerating the approaching water column. The operation of the valve under these conditions can be compared to a safety air bag in a motor vehicle.

### Venting of a Filling Pipeline (Sub Critical Water Approach Velocity)



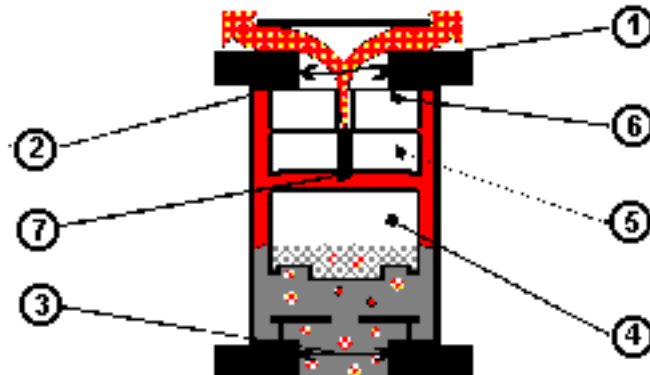
Air enters Orifice (3), travels through the annular space between the cylindrical floats (4), (5) and (6) and the Valve Chamber Barrel (2) and discharges from the Large Orifice (1) into atmosphere.

### Venting of a Filling Pipeline (Excessive Water Approach Velocity)



In reaction to the increased air flow, Float (6) closes the Large Orifice (1) and air is forced through the "Anti-Shock" Orifice (8) resulting in the deceleration of the approaching water due to the resistance of the rising air pressure in the valve.

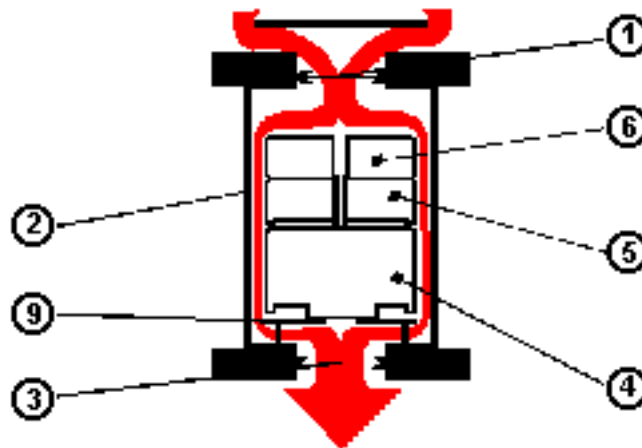
## Pressurised Air Release from a Full Pipeline



Subsequent to the filling of a pipeline, liquid enters the valve Barrel Chamber (2) and the Float (4), (5) and (6) are buoyed so that the Large orifice (1) is closed by Float (6), the valve will then become internally pressurised. A minimal working pressure of  $< 0.5$  bar acting on a relatively large area of the Orifice (1) will lock Floats (5) and (6) into a closed position across the Large Orifice (1).

Disentrained air rises through the liquid and accumulates in the valve chamber, when the volume of air is sufficient to displace the liquid, Float (4) will no longer be buoyant and will gravitate downwards thereby opening the Small Orifice (7) and allowing accumulated air to be discharged into atmosphere, as air is discharged the liquid raises Float (4) and reseals the Small Orifice (7) and prevents the escape of liquid.

## Vacuum Relief (Air Intake) of a Draining Pipeline



Simultaneous drainage of liquid from Valve Chamber (2) causes Floats (4), (5) and (6) to gravitate downwards onto the Baffle Plate (9), thereby allowing atmospheric air through the valve to rapidly displace draining liquid in the pipeline and prevent potentially damaging internal negative pressure.

## **Technical Features and Financial Benefits**

The criteria for assessing the merits of any form of pipeline equipment would be capital costs, operating and maintenance requirements. It is likely if all the below are taken into account, Vent-O-Mat valves will be seen as a cost effective, reliable and efficient form of pipeline protection.

### **Vacuum Protection**

All Vent-O-Mat valves have large orifice diameters equal to the nominal size of the valve i.e., a DN200 valve has a 200mm orifice. This ensures the least possible resistance to the intake of air and consequently the least possible negative pressure within a draining pipeline.

Conventional air valves have restricted large orifice diameters in relation to the nominal size of the valve i.e., a DN100 conventional air valve has a large orifice of 73mm. A DN80 Vent-O-Mat can therefore be cost effectively used in place of a DN100 conventional air valve, whilst providing 20% greater vacuum protection at equivalent differential pressures.

### **Discharge Performance**

The Vent-O-Mat design is not limited by the velocity within the pipeline and the differential across the large orifice as conventional air valves are, and will effectively remove all air from a filling pipeline, whilst eliminating all possibilities of surge or water hammer on closure of the large orifice.

### **Serviceability**

The Vent -O- Mat design is virtually maintenance free, but facilitates extreme ease of service and maintenance in the rare instances when required. Components are in corrosion free materials to allow problem free disassembly and reassemble even after years of operation. All maintenance spares are replaceable without special tools or skills.

### **Performance**

Vent -O-Mat RBX has been designed and developed to provide the optimum usable and safe performance relative to all functions. Selection data has been substantiated through the Council for Scientific and Industrial Research - South Africa and other testing and can therefore be confidently referenced.

### **Surge and Water Hammer**

Surge and water hammer as a result of air release and the shortcomings of air valve are factors that are very often overlooked by design engineers. It is

therefore not uncommon for pipelines to experience these phenomena despite careful computer modeling.

Vent-O-Mat offers a cost effective and efficient solution to these phenomena as all valves are supplied as standard, with an integral "Anti - Shock" surge alleviation mechanism which only operates in instances such as rapid filling or column separation to effectively and efficiently eliminate surge and water hammer (very much like an air bag in a motor vehicle in that it only operates in emergencies).

The "Anti-Shock" mechanism together with other features of the Vent-O-Mat design provides a number of financial benefits some of which are:

- The elimination of surge vessels and other traditional surge protection devices as the valve acts both as an effective double acting air valve and as a cost effective surge alleviation mechanism. This renders total protection to a pipeline at a fraction of the cost of any other conventional method.
- The shortening of operational procedures without the risk of pipeline collapse, premature closure or water hammer. This allows for major time saving.
- The cost saving on over specified pipe. Very many design engineers over specify on pipe thickness to prevent unforeseen pipeline damage. This is unnecessary when using Vent-O-Mat air valves as it efficiently and cost effectively manages air within the pipeline, therefore greatly minimizing the possibility of unforeseen accidents.
- Increase of flow through existing infrastructure. Many pipelines operate very inefficiently because of the restrictions created by air that is not released effectively by conventional air valves. Vent-O-Mat valves are designed to discharge all air in a pipeline regardless of flow velocities, without the inducement of water hammer and other destructive phenomena associated with kinetic valves. This feature allows for the increase of flow, of up to 30%, through existing infrastructure, by the mere replacement of conventional air valves with the Vent-O-Mat design.

## **INCIDENTS AND SOLUTIONS**

Conventional air valves as mentioned previously often cause damage to pipelines, or present major operating problems that lead to inefficient pipeline operation. This is especially evident in pipelines built in the last 30 years, due to the introduction of kinetic air valves, the demand for larger and more complex pipeline systems, and the necessity to build more cost effective systems. Some of conventional air valves problems and how they were solved, are discussed below.

### **Faster Filling Times**

One of the water authorities in the Free State province of South Africa, which supplies water to the goldfields and surrounding rural communities, has been using conventional air valves and were aware that their air valves were giving them major operational problems.

It was decided to replace the air valves on an existing 56km line with Vent-O-Mat valves in order to assess their benefits.

The benefits of this decision was immediate and enormous as: surge in the line was virtually eliminated, a substantial increase in flow was experienced, and the line could be filled in a 6th of the time it took when conventional valves were employed.

This pleased the authorities to such a degree that they have decided to use Vent-O-Mat valves on all new pipelines and to replace existing conventional valves with the Vent-O-Mat design as and when their budget allowed. An enormous task considering that they supply up to 216 mega litres a day, have a bulk water supply pipe network of 700km and supply an area of 8000km<sup>2</sup>.

### **Increase in Flow and Reduction of Surge in a Gravity Main**

Pietermaritzburg is the second largest city and the provincial capital of the Kwa Zulu/Natal province. The municipality, who is responsible for the city's water supply, were experiencing surge problems on a fairly old - gravity fed pipeline on which conventional air valves were employed.

It was assumed that the surge was related to the use of an end line level control valve. Vent-O-Mat however suspected that the surge was related to the Non Kinetic air valves employed and recommended that these be replaced with the Vent-O-Mat design.

Only half of the pipeline was initially fitted with Vent-O-Mat valves to assess any changes in the magnitude of surge pressures, and flow. It was found that the surge pressures had been reduced substantially and that the flow through the

pipeline had increased substantially, representing a major saving to the water authority. Arrangements were made, at the time of printing this document, to fit the rest of the pipeline with Vent-O-Mat valves. It is hoped that this will further increase flow through the pipeline and therefore increase savings to the municipality.

### **Surge Problems Solved**

Transvaal Suiker Beperk, one of the largest sugar estates in South Africa, with a daily pumping capacity of 900 mega litres, was experiencing pipe breaks on their fibre cement pipelines. This occurred usually when the pipelines were drained and refilled which happened quite often.

The estate could not find the reason for this phenomena occurring, as it persisted despite a consulting engineering firm's recommendations. Vent-O-Mat knew that the reason for these phenomena occurring was directly related to the use of Kinetic air valves which induced pressure transients of great magnitude on closure of the large orifice and resulted in pipe breaks. It was therefore recommended that the existing air valves be replaced with valves of the Vent-O-Mat design. This resulted in an immediate end to the pipe breaks and the pipelines have been operating - problem free ever since then.

### **Kinetic Valves and Flooded Valve Chambers**

Although very many manufacturers claim that their air valve are of kinetic design, research has proven this to be seldomly true. True Kinetic air valves present major pipeline problems, it is therefore not of marketing benefit to make this claim anyhow. This can be seen from the following pipeline incident.

A prominent consulting engineer had specified a particular kinetic air valve design for use on a fairly large pipeline. Design of the pipeline was carried out on the basis of the valve's high velocity discharge capabilities, totally ignoring a number of possible problems.

These problems only became evident when the pipeline was commissioned and the air valves failed to close, due the phenomenon described earlier on in this document. This resulted in the air valves flooding the valve chambers and washing away the embankment on which the pipeline was built.

The end result was a great loss of money by the manufacturer as the client demanded the damages to be repaired, an extremely angry client, and the consulting engineer filing a law suit against the manufacturer.

## **Kinetic Air Valves and Seal Failure**

Botswana experiences extremely cold winter mornings and extremely hot midday summer temperatures. The country is arid and water pipelines are laid over long distances to supply water to towns and villages.

A consulting engineer had specified a particular Kinetic air valve design for use on a recently built pipeline. It was observed that the seal between the isolator and air valve failed every time the pipeline was filled. The failure was laid down to the extreme variation in temperature. This was however very peculiar as the use of similar seals on other pipelines in the vicinity, where a variety of air valves designs were used for decades, did not render the same phenomenon.

Subsequent research proved that this phenomenon occurs at high differential pressures of 80 - 85 bar. The pressure transients that the Kinetic air valves induced on closure had therefore to exceed a pressure of 85 bar for this phenomenon to occur.

The above are but a few of a number of phenomena that occur as a result of air valves. Of importance to the reader is the fact that these problems can be solved cost effectively by using the Vent-O-Mat design. The author was, at the time of publishing this document, gathering all the technical and financial details on the above and other similar cases to publish in a later document which will give a fair indication to the engineer and end user of the financial savings in using the Vent-O-Mat design and of the financial and efficiency losses in instances where other air valve designs were used.

# SELECTION AND POSITIONING OF DOUBLE ACTING VALVES

The presence of air in a water main in service or in the process of being filled is well known to be the cause of serious problems such as delay in filling, throttling and reduction in discharge capacities, risk of surge and water hammer, and corrosion.

The indiscriminate selection and positioning of double acting air valves, without thorough evaluation of the systems characteristics and dynamics and inherent short comings in the air valve design selected, will not solve the problem of air in the main but can and will lead to the aggravation of phenomena associated with it's presence as well as introduce other destructive phenomena.

Air valve selection and positioning is a complex exercise because of the unpredictable nature of air as it is influenced by many factors such as pressure, temperature, pipeline velocities etc., and it in turn influences the pipeline dynamics dramatically. The problem is compounded in that air is an invisible culprit, making it difficult to quantify.

This section of the document provides the design engineer with a guideline of where to position double acting air valves and points to consider when selecting an air valve design.

## INTRODUCTORY NOTES

1. It is standard practice for very many designers to specify an air valve based on it's nominal diameter only. This is a peculiar practice when it is considered that it is the large orifice area and the dynamic characteristics which determines an air valve's performance. It cannot therefore be taken for granted that different valve designs of the same nominal diameter will perform equally. Accurate selection of a double acting air valve can only be achieved by reference to substantiated performance data for a particular design.
2. An air valve's intake performance, regardless of it's design, is limited to 0.35 bar differential across the large orifice. Pipeline materials such as fibre cement pipe can withstand lower negative pressures than -0.35 bar but it is of no benefit to size beyond this point as a partial vacuum will exist which will result in the sucking in of seal systems or damage to other components which are vulnerable to negative pressures.

It is beyond the scope of this document to consider the mechanical strength characteristics of the wide variety of piping materials in general use. The relevant manufacturer should be contacted to determine the collapsing pressure for the material under consideration. It is recommended from



practical experience that a differential of 0.35 bar be used for fairly rigid materials such as fibre cement and steel pipe. A differential pressure of 0.15 bar is recommended for plastic pipes and thin walled, large diameter steel pipes.

3. Conventional air valves should be limited on discharge, to 0.05 bar differential across the large orifice, regardless of whether the valve under consideration is of a Kinetic or Non Kinetic design. This is due to the fact that non Kinetic air valves close prematurely at a higher differential causing corrosion, pipeline restriction and surge. Kinetic valves on the other hand induce damaging water hammer on closure (depending on the differential pressure on closure and pipe material strength) which can lead to pipe failure or an array of other destructive phenomena as described under "Conventional Air Valve Designs".
4. Conventional air valves do not provide surge and water hammer protection, they have therefore to be used in conjunction with conventional surge devices.

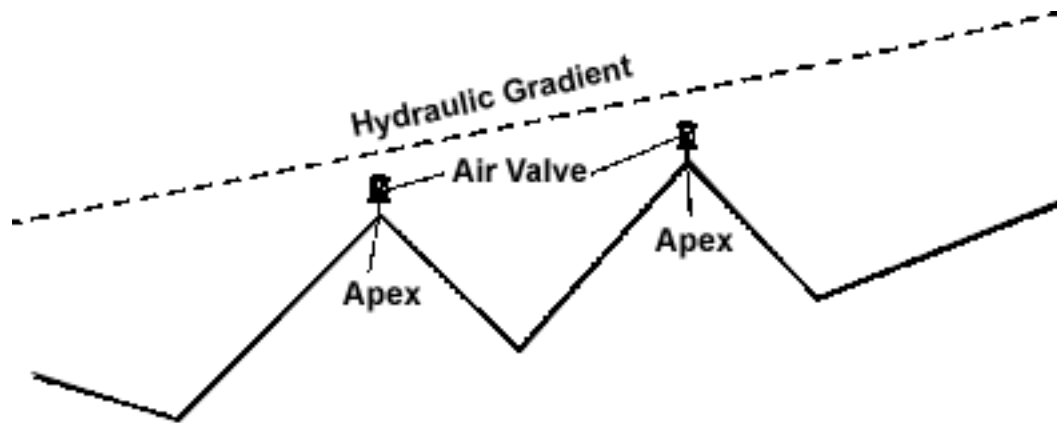
Vent-O-Mat air valves in addition to acting as efficient air valves, prevent surge and water hammer as an automatic function. The use of Vent-O-Mat air valves therefore obviate the need for surge and water hammer equipment, which relates to a major saving to the end user in initial cost and maintenance requirements.

## **LOCATION OF AIR VALVES FOR AIR INTAKE THROUGH LARGE ORIFICE.**

Air valves are first and foremost sized for vacuum conditions which may result from scouring of the pipeline, pipeline rupture or instantaneous pump stoppage causing column separation. The following provides a guide of where to position air valves for vacuum conditions and how to determine air valves sizes. Note the calculations are to determine large orifice performance capacities. It is important not to exceed a differential pressure of 0.35 bar as described in point 2 of the introductory notes.

### **1. Apex Points**

From the pipeline under consideration, identify the apex points which fall below the hydraulic gradient.



**Fig.16** Indicating apex points below the hydraulic gradient.

Calculate necessary valves independently for each apex.

Consider the most severe of the two gradients adjacent to each high point.

Determine the maximum rate of flow that can occur in this gradient as a result of pipe rupture at the lowest elevation or, flow due to scouring. Generally valves are sized on scouring velocities or partial rupture to economise on the valve size selected.

The following equation can be used to determine maximum flow rate (based on full rupture). The required rate of air intake will be equivalent to that of the liquid drainage rate.

$$\text{Rate of Flow in } \ell/\text{sec.} = 0.26 \text{ SD}$$

**Where:**

**S = Pipe slope (expressed as a decimal)**

**D = Internal pipe diameter in centimetres**

**To convert l/sec. to m/sec., the following equation can be used:**

$$\text{Flow in m/sec} = \left( \frac{\text{Rate of Flow in } \ell/\text{sec.}}{\text{Area of Pipeline in cm}^2} \right) \times 10$$

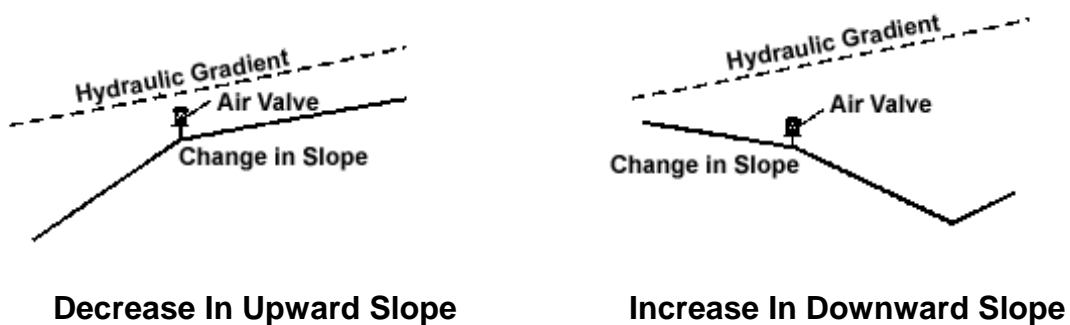
It is important to note that the valve selected should not exceed a differential of 0.35 bar while drawing in air across the large orifice (or lower, depending on pipe material). Restrictions in large orifice diameters and phenomena such as the "Venturi Effect" should be taken into account when selecting an air valve design.

Sometimes a single rupture of a pipeline can result in drainage of both gradients adjacent to an apex point. Unless this is impossible, due to the pipeline characteristics or preventative mechanisms, it is advisable to select the number and size air valves accordingly.

An important consideration in a pumping main is the possibility of pump trip and the rejoining of separated water columns, which could lead to damaging surge and water hammer. Conventional air valves have no way of limiting the discharge of air under such conditions and will therefore compound the water hammer phenomenon on closure of the large orifice. Vent-O-Mat air valves automatically limit the occurrence of this phenomenon by controlling the air discharge rate through the "Anti Shock" orifice, therefore providing total pipeline protection.

## 2. Negative Breaks

A negative break is defined as an increase in a downward slope or a decrease in an upward slope.



**Fig.17** Indicating negative breaks

From the pipeline under consideration identify all negative breaks.

Assume a pipe rupture at the bottom of the most severe slope, or complete pump stoppage.

A cavity will form at the point of change in slope that is equal the difference in flow in the two gradients. The rate of air flow into the pipeline should therefore equal the cavity developing rate.

The following equation can be used to determine the cavity developing rate and hence the air valve size required.

$$\text{Cavity Developing Rate} = V_2 - V_1$$

Where:

$V_2$  = Rate of flow in  $l/sec$ . in the most severe slope

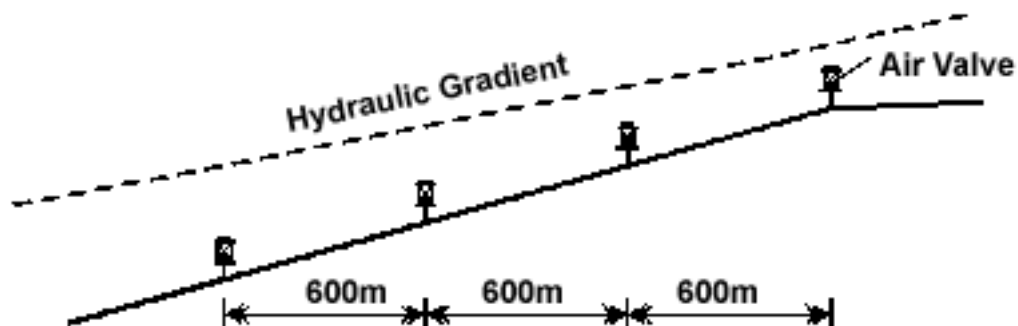
$V_1$  = Rate of flow in  $l/sec$  in the least severe of the two slopes

The formula under "Apex Points" can be used to convert  $l/sec$  to  $m/sec$

It is important to note that the valve selected should not exceed a differential of 0.35 bar across the large orifice (or lower, depending on pipe material). Restrictions in large orifice diameters and phenomena such as the "Venturi Effect" should be taken into account when selecting an air valve design.

### 3. Long Ascending Sections

From what has already been established, there will be a double acting air valve positioned at the top end of every ascending section. If the length of the ascending section is considerable, additional air valves will be required, to ensure adequate discharge when filling the pipeline and ample ventilation when it is being drained. It is recommended that these valves be positioned at intervals of 600m maximum to ensure both functions are performed effectively.



**Fig.18** Long Ascending Sections

To size the air valves for these positions, firstly calculate for air intake requirements, based on rupture, pump stoppage, or scouring velocities.

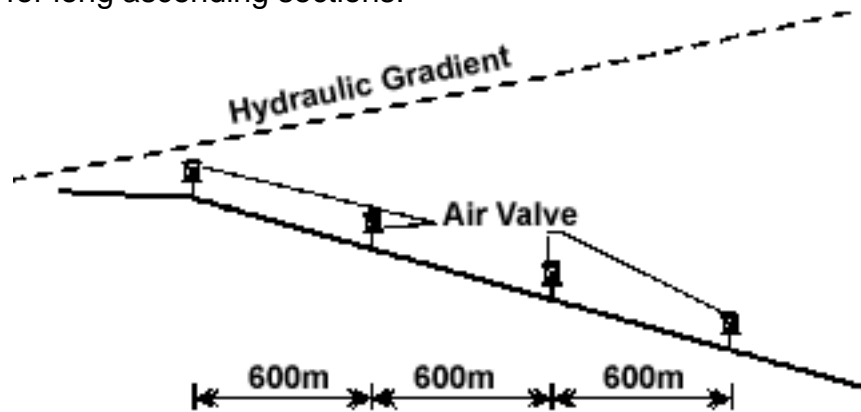
Before determining the valve size, compare the intake requirements with the filling rate. If the filling rate is greater than the intake rate, then the valves should be sized according to the filling rate.

Of utmost importance, is not to exceed a differential of 0.05 bar across the large orifice when sizing, based on filling rates, for conventional valves. A greater differential will lead to either premature closure of the large orifice and inefficient air release (Non Kinetic Air Valve designs) or, water hammer (Kinetic Air Valve designs).

Vent-O-Mat air valves are not affected by dynamic closure, neither will the valve induce water hammer on closure of the large orifice. The valve is designed to discharge all air in a pipeline, regardless of filling velocities. Valve size selection is therefore based on vacuum requirements only.

#### 4. Long Descending Sections

The sizing and positioning of double acting air valves for these are exactly the same as for long ascending sections.



*Fig.19 Long Descending Sections.*

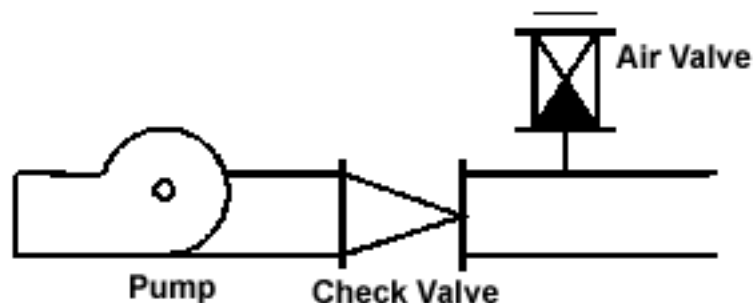
#### 5. Long Horizontal Sections

Long horizontal sections should wherever possible be avoided. Ideally a pipeline should have a minimum slope of 3 to 6 millimetres per metre to facilitate effective air removal as air will tend to gravitate to the highest point, allowing for removal along the pipeline and at peaks. If long horizontal sections are unavoidable then air valves should be positioned at 600m intervals.

The sizing of air valves at these positions should be based on the filling rate.

Of utmost importance, is not to exceed a differential of 0.05 bar across the large orifice when sizing, based on filling rates, for conventional valves.

#### 6. Pump Discharge - Subsequent to a Check Valve



*Fig.20 Air Valve subsequent to a check valve on a pumping main.*

Assume total pump stoppage.

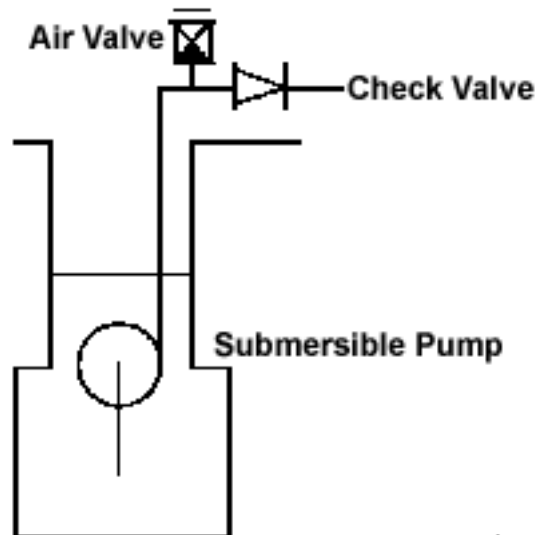
The air valve size required will be based on an air inflow rate equivalent to the pump flow rate.

Important, when sizing for conventional air valves, do not exceed 0.05 bar differential across the large orifice on filling.

Of utmost importance is that conventional air valves positioned at this point, have no way of controlling the discharge of air when pump trip occurs, and a separated column commences to rejoin. This will ultimately result in high surge pressures and pipeline damage.

Air vessels are normally positioned at this point to prevent the phenomena of surge and water hammer. This function can however be performed much more cost effectively and efficiently by the installation of a Vent-O-Mat air valve.

## 7. Prior to a Check Valve on Deep Well Pump Installations



**Fig.21** Air valve placed subsequent to a pump but prior to a check valve on a DeepWell application.

An air valve is essential at this point to prevent large volumes of air entering the pipeline each time the pump is started and to prevent a vacuum when the pump stops.

A conventional air valve is not suitable for this application as it will either induce water hammer on closure of the large orifice or, not close at all due to the high water velocity, or close prematurely trapping large pockets of air which leads to operating problems.

It is recommended that a Vent-O-Mat or similar air valve design be used for this application, that will control the discharge of air to eliminate water hammer problems as well as adequately protect against vacuum conditions.

The air valve selected, should be sized on pump discharge velocities.

## **8. Blank Ends**

This is usually where a pipeline is terminated by a blank flange or a valve. A valve selected for this positioned should be sized on pipe filling rate, whilst not exceeding 0.05 bar differential across the large orifice, if conventional air valves are considered.

### **LOCATION OF AIR VALVES FOR DISCHARGE THROUGH LARGE ORIFICE.**

Generally, the location of air valves for air intake will suffice for air discharge. The sizes selected however (if conventional air valves are considered) may not be large enough to discharge air efficiently and effectively or may induce a number of destructive phenomena if discharging at too high a differential.

It is strongly recommended, based on research over the past 35 years, that the differential across the large orifice of any conventional air valve design does not exceed 0.05 bar on discharge. This is to prevent premature closure and subsequent air related problems in Non Kinetic Air valves, and water hammer in Kinetic designs.

If conventional air valves are considered, then every air valve selected for air intake, should be assessed separately for discharge. This is done by comparing the discharge requirements (not exceeding 0.05 bar differential across the large orifice) with that for intake and selecting the larger valve size i.e., if the air discharge requirement is 300 l/sec. (air discharge is equal to water filling rate) and the air intake requirement is only 150 l/sec., then an air valve should be selected to discharge 300 l/sec, whilst not exceeding 0.05 bar across the large orifice.

The same is not true for Vent-O-Mat air valves as the valves selected for air intake will efficiently and effectively discharge air, whilst protecting the pipeline from surge, water hammer and vacuum.

### **SMALL ORIFICE FUNCTION**

Effective discharge by any double acting valve of pressurised air depends on the existence of a "Critical Relationship" between the area of the small orifice and the mass of the control float, i.e., the mass of the float must be greater than the force created by the working pressure acting on the orifice area. If the float is relatively

too light or the orifice area relatively too great, the float will be held against the orifice, even when not buoyed, and air discharge will not take place.

Air valves of hollow float design often do not have the correct "Critical Relationship" between the control float and the discharge nozzle, resulting in valves not discharging pressurised air, which inevitably leads to air related problems such as surge, restrictions in flow and corrosion as air accumulates under the air valve.

## **THE PIPELINE AS A WHOLE**

When air valve provisions have been made for all situations mentioned, it is desirable to check the water main as a whole to ensure that the air valve design and other components selected will perform their intended function adequately without the creation of surge and water hammer or other destructive phenomena.

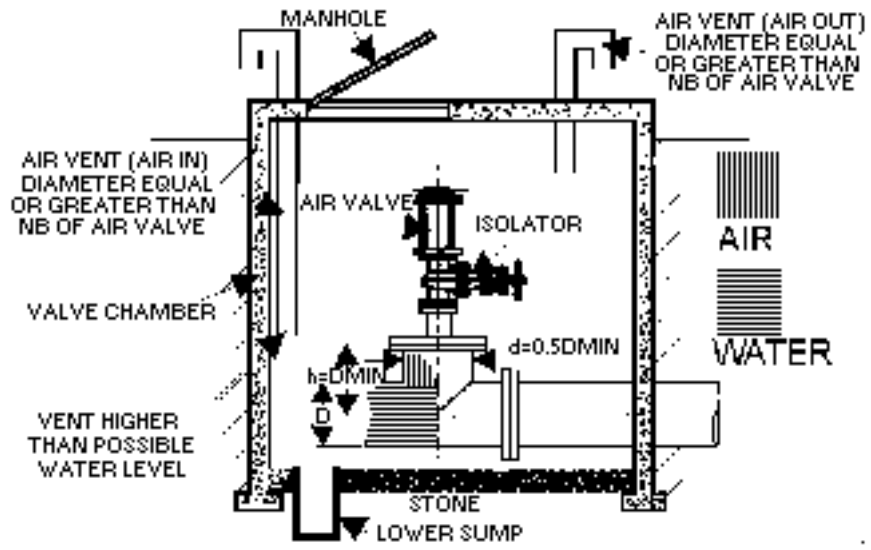
It will be obvious to the prudent engineer that Vent-O-Mat air valves provide a very cost effective and efficient solution to a number of pipeline problems, as the valves do not have the maintenance requirements or operational draw backs of conventional air valve designs. The valve, whilst sized and positioned as a conventional air valve, provides effective surge, water hammer and vacuum protection, obviating the need for conventional surge protection devices on a pipeline.

## **RECOMMENDED INSTALLATION AND AIR VALVE CHAMBER DESIGN**

It is common practice amongst many design engineers to place an air valve on a riser welded directly onto the main pipeline. This method however leads to inefficient air valve operation and restrictions in the main pipeline as the air that is taken in the pipeline during vacuum conditions collect away from the air valve, and will be swept away when the pumps are restarted. Vent-O-Mat recommends, from years of practical experience, that an accumulator should be provided for every air valve in order to facilitate efficient air valve operation.

A well designed air valve chamber is of importance and should be designed with easy access to the valve for installation and subsequent maintenance. Good support is required in the event of the chamber settling. It is recommended that a layer of stone be placed under the pipe for drainage purposes. Two vents should be installed in the manner indicated in fig 22.





*Fig.22 Typical air valve chamber*

# DEFINITIONS

## **Air Valves**

Valves that allow the automatic entry and/or release of air.

## **Double Acting Air Valves (Air Release and Vacuum Break Valves)**

Valves that allow the automatic release and intake of air as well as the release of air under pressure.

## **Large Orifice**

The opening through which air discharge to and from atmosphere occurs.

## **Small Orifice**

The opening through which the discharge of pressurised air occurs.

## **Non Kinetic Air Valve**

Air valves that have the tendency to close at very low differential air pressures, often trapping large pockets of air in the pipeline.

## **Kinetic Air Valves**

Valves that resist dynamic closure by air and only close in the presence of water, generating high transient pressures as the water is suddenly arrested by the operating float sealing off the large orifice.

## **Surge Pressures**

A sudden rise in pressure and subsequent liquid oscillation on closure of a Non Kinetic Air Valve.

## **Water Hammer**

High pressure transients as a result of the sudden closure of a Kinetic Air Valve, control, non return or isolating valve.

## **Air Valve/ Surge Alleviation Mechanism**

Any device that in addition to operating as an Air Valve, reduces or eliminates surge and/ or water hammer.

## **Anti-Shock Mechanism**

A proprietary surge alleviation mechanism, that is designed to act automatically in instances where the pipeline is at risk to damage by either surge or water hammer.

## **CATT**

CATT is the acronym for Controlled Air Transfer Technology and is applied to a pipeline flow enhancing device, incorporating the features of a very efficient double acting air valve and surge alleviation mechanism.

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