Air Management in Water Distribution Systems

A New Understanding of Air Transfer

In the late 1970's, a South African company began efforts to produce a pipeline air valve for market. Understandably, it wanted to introduce something that was competitive, and that, hopefully, would outperform those valves that already existed on the water and sewer scene.
The company sought and reviewed all performance data available worldwide from existing air valve manufacturers. To their surprise, and disappointment, the data was of little help.
Even when air valve design configurations were the same, the performance data supplied by the different manufacturers varied in the extreme.
The only safe conclusion to be reached was that all existing data was questionable, and that the performance claims of many conventional air valve manufacturers were, at best, unreliable.

With millions of air valves in service, and many on water systems more than a century old, it seemed incredible that so little scientific documentation existed to explain the phenomenon of air's interaction with a fluid in a pipeline.

Complicating things further, there was little technical data available describing the affects of air release on pressure surge and water hammer.
The phenomena of water hammer and pressure surge in pipelines was, to a very great extent, poorly approached, or just totally ignored by manufacturers of conventional air valves.

The company, subsequently, started from scratch to research and document the complete phenomenon of pipeline air management.
After years of laboratory and field-testing, they commissioned the prestigious Council for Scientific and Industrial Research (CSIR), of South Africa, to substantiate their findings, verify their test results, and confirm that they had solved many of the questions regarding the behaviour of air in fluid pipelines.

The air valve industry, finally, had data that could be considered reliable, and a new understanding of pipeline air transfer was a result. The company called this new scientific understanding 'Controlled Air Transfer Technology', or CATT.

Prior to this effort, the scarcity of reliable information on air release/vacuum break phenomena left design engineers at a decided disadvantage in their attempts to properly protect their pipelines.

Air: Where to find it, and how it gets there…

Pockets of air that accumulate at high points and bends create very real pipeline restrictions that lead to considerable loss of pipeline efficiency.

Water normally contains 3%, by volume, dissolved air that can come out of solution in a number of ways.

- ***Water that is constantly being subjected to changing temperature, flow velocity and pressure, will surrender a surprising amount of air.***
- ***Air is released during the turbulent passage of water through the coarse, tuberculated linings of older cast iron water mains.***
- ***Eddy effect turbulence at bends, valves and other pipeline fittings will release more air.***
- ***Pockets of air will form in the pipeline as a result of the vortex action of pumps.***

As well as being released from solution, air can be physically introduced to water piping.
Air can be draw in through pipeline leaks, at damaged joint seals, through leaking valve packing, and through any loose and leaking flange connection.
If there is any breach in the integrity of the pipeline and its fittings, air will enter there.
This usually happens when the system is subjected to poorly controlled, or unplanned negative pressure events.

The amount of air that can enter the system when the pipes are subjected to negative pressure is often underestimated.
Vacuum conditions occur far more frequently than many system operators anticipate, and the subsequent damage done at pipe joint seals by negative pressure will permit a significant volume of air to be draw inward.

Apart from ingress of air, water system operators should be equally concerned about contaminants that are drawn into the pipeline during vacuum events.
Studies by Dr. Mark W. LeChevallier, of the Centers for Disease Control and Prevention, Atlanta, Georgia, indicate that during the negative portion of a pressure wave, better than a gallon per minute of contaminated water can be pulled into pipelines through small leaks.
Given the myriad number of leaks that plague water systems, this threat to water quality cannot be overstated.

Air behaves very unpredictably in a pipeline, but even more so in a grid network of pipes. In the normal operation of a water pipeline system, maintenance activities and

fluctuating periods of consumption demand will cause air to release from solution and accumulate in the localized piping.
Very often, air pockets will form in sections of pipe that are not equipped with air valves, and will travel about the water grid, finding release only when drawn into a water service as someone opens a household tap.

The release of compressed air from within a pipeline can be explosive, if not managed effectively.
Tests by M.L. Albertson and J.S. Andrews ("Transients Caused by Air Release", Colorado State University, 1971) determined that, in a rapidly filling pipeline, peak pressures in a compressing pocket of air could exceed 15 times the pipeline operating pressure.
The sudden release of a highly pressurized air pocket can generate impressive transient surge waves. 'Impressive', perhaps, to the system analyst, but frightening to the pipeline operator.

Like any physical restriction, air pockets increase head loss, extend pumping cycles and increase energy consumption. The loss of pipeline efficiency due to trapped air can, at times, be greater than all frictional losses, and losses due to leaks combined.

It has been estimated that 75% of the cost of operating a pipeline is the cost of pumping the transported product, be it water, or any other fluid.
Studies of a variety of water systems world-wide have revealed that entrapped air can reduce pipeline efficiency by as much as 30%, and that most water systems commonly work to overcome air pockets that rob system flow efficiencies by 15 to 20%.

Pockets of compressed air present formidable obstacles to any efforts to pump fluid. Air accumulation that increases head pressure by 20% will force pumps to work 20% harder, and thus draw 20% more electrical energy to overcome the restrictions.

In 1999, one large industrial city in Southern Ontario spent $1,600,000 on electricity to power its' water pumps. Assuming that this city's pumps had to work 20% harder to overcome the air blockages throughout their grid, the additional electrical demands cost this utility $320,000.
Nearly a third of a million dollars, spent in one year, to overcome a poorly vented system!

How much improved infrastructure will $320,000 buy?

The goal is to pump water, not air…

Air that gathers in a system will, primarily, accumulate at system apexes, or high points.

Air valves are placed at these points along the pipelines to intercept and vent the air, and to prevent accumulations from forming pockets that act as obstacles to water transmission.
If the air valves function poorly, or fail outright, pockets of air are certain to develop.

How can air become a physical obstacle?

One of the effects of air pocketing is that water velocity increases as the flow attempts to force its' way beyond a stationary bubble.
The air pocket is compressed by the water acting against it, and in this compressed state, acts as a physical restriction by pressing the water about it into a smaller pipeline channel.
Being forced to negotiate a smaller passageway in the pipe, the water increases velocity. This increased flow velocity across the span of the air pocket often shears away parts of, or the whole of the air pocket.
Once free in the system again, the air pocket will then travel downstream with unpredictable results.

The sudden and rapid change in fluid velocity when the air pocket dislodges creates a pressure 'spike', a sometimes severe transient pressure fluctuation, that can cause damage to the pipeline and its' fittings. Technically, this event is called Air Evacuation Induced Water Hammer.
When the traveling air pocket finds a home again at another bend, or high point of the pipeline, its' sudden arrest there creates another surge event.
Until an air pocket is finally vented from a pipeline, it will continue a nonsensical pattern of shear and release, travel and stoppage, with pressure surge always a result (E.R. Holley, 1969, "Surging in a laboratory pipeline with steady inflow").

Size Does Matter…

Proper pipeline venting can only take place, if the air valves employed are sized correctly, if they are placed appropriately throughout the system, and if, in fact, they can remain working in the face of transient pipeline pressure spikes.
Many air valves quietly fail, and disruptive air pockets are born.

A pipeline designer must be willing to look at his pipeline as sections of a whole. Depending upon grade and other physical factors, each section of pipeline will have different drainage and re-charge characteristics. The air valve sized and selected for pipe section #3 may not meet the requirements of pipe section #8, even though the pipe diameter is the same.
Pipeline designers must anticipate the worst-case scenarios of pipeline operation, and select the size, and type, of air valve that will succeed, and not collapse, under those large magnitude events.

A designer, who will not take the time to mate and properly coordinate all of the appurtenances along his pipeline, condemns his pipeline to a service life of poor delivery.

CONTROLLED VENTING OF PRESSURIZED AIR IS VITAL TO PIPELINE EFFICIENCY

The Consequence of Air Valve Failure

There are millions of conventional, non-kinetic and semi-kinetic air valves employed on water and fluid pipelines throughout the world.
And millions of those are made to conform to a design that has not changed substantially in over 100 years.

These 'conventional' air valves are designed to vent air that builds up and travels along the pipeline to their location, and to admit volumes of air when the pipeline is being de-watered (vacuum break).
A simple enough task to perform, it might seem.

The question that has to be asked, in light of new understanding of air transfer, is how well these millions of conventional air valves actually perform those two tasks.

Non-kinetic and semi-kinetic air valves suffer from a phenomenon called 'blow shut', or more technically, 'dynamic closure'.
These valves are characterized by their use of large, buoyant, usually hollow, spherical floats. These floats rise into place to seal the vent/vacuum orifice when air has escaped from the pipeline, and water has entered the valve body.

Unknown to early valve designers, as air is released from the pipeline, the accelerated discharge airflow tends to create a low- pressure zone above the large float. This low-pressure zone exerts an attractive force upon the large spherical float, and tends to draw the float toward the active orifice. The weight of the float will resist this motion, but not for long.
In some air valve configurations, floats may be drawn up to seal the valve fully by as little as 0.04 bar, or approximately 0.58 psi, of 'differential pressure'.
That's an exceedingly small difference in pressure to compromise an air valves' performance.

Differential Pressure can be described this way: 1 bar is equivalent to 14.7 psi, or the normal pressure of atmosphere, at sea level.
Differential pressure is a gauge measurement, focused on the center point of the air valve large orifice. As far as the gauge is concerned, atmospheric pressure registers as 0psi.

If the pressure within the pipeline were to build to 0.04 bar, that would indicate that the internal pressure of the pipeline being vented exceeds atmospheric pressure by 0.04 X 14.7, or 0.58 psi.
Therefore, the differential pressure at the orifice, or the difference between atmosphere and the pressure existing in the pipeline, is 0.58 psi.

Differential pressure can be a measure of both positive and negative pressure conditions within the pipeline being operated.
Careless de-watering of a pipeline can create negative pressure (vacuum) conditions that can exceed atmospheric pressure many times over.

It should be clear to the reader that it takes surprisingly little pressure change, while either releasing or vacuuming air, to create the conditions that invite premature closure of conventional air valve designs.
When you consider how difficult it is to limit pipeline pressures to below closure thresholds, then the real magnitude of the operational problem becomes crystal clear.
In practicality, whether draining or refilling a pipe, it is nearly impossible to manipulate a pipeline with such precision that conventional air valves can be nursed along, and kept in operation.

The unintended and abrupt closure of any air valve should be considered a performance failure.
A serious failure.

Everyday Maintenance, Everyday Pipeline Damage
...through the eyes of the Maintenance operator

A practiced water system operator will monitor air valves at certain points along a pipeline, when the pipe is being drained, and when it is being recharged.

Normal pipe drainage procedure:

During drainage, a drain valve is opened at the lowest point of the isolated section of pipeline. Usually, the maintenance operator will raise the gate only a couple turns out of the seat.
The operator must then travel to the air valve positioned at the pipe's highest point in the section being de-watered. Once there, he simply listens to confirm that air is being drawn through the air valve, into the main.

His hope is that the air intake matches the volume of water being discharged, but, apart from being able to mount a very sophisticated airflow measurement device on the air valve, there is no way that he can determine a correct dewatering rate. He sets the pace of drainage at what he 'feels' to be right.

Many times, satisfied that the air valve is operating, the maintenance man will return to the drain valve, and open it even further.
This seemingly innocent second action would cause an increase of vacuum pressure within the pipe, as the water column descends more rapidly, and would intensify the venturi effect attractive force upon the air valve's large float.
The new, and greater, differential pressure created may be enough to draw the float fully up, and close off the air valve completely, well before the pipeline is emptied.

With the air valve prematurely shut, the descending column of water will create an increasing vacuum pressure within the pipeline, between the closed air valve and the vacating water column.
The vacuum being created will affect the descent of the emptying column, to a point that the maintenance man may notice a cut- back, or an irregularity in the flow discharging from the drain valve. To compensate, he may then be inspired to open the drain valve even further.
In doing so, he will create a severe mismatch in discharge rate of water versus the rate of air intake within the pipeline.

The stage is now set for pipeline collapse.

If the pipe does not collapse outright under the extreme vacuum pressure, then it is highly likely that damage will be inflicted along the joints of the pipeline.
Joint seals may be drawn inward, openings could be created, and air and trench debris might be sucked into the interior of the water main.

The damage done by negative pressure may be serious enough to produce road upheaval and flooding as soon as the pipeline is put back into commission.
Many times, however, the damage inflicted by vacuum conditions is less noticeable. The water main may begin leaking from a collective number of partially compromised joint seals. These leaks may not surface immediately, and the water loss from the afflicted pipeline will become part of what many refer to as 'background losses'.

The veteran pipeline operator may never realize the damage being done by his 'time tested' maintenance procedure.
And he will repeat his procedure, over, and over.

Refilling a water main:

When filling a pipeline, it is intended to vent air ahead of the advancing column of water. The high-end air valve should be able to bleed the air well enough to prevent excessive pressure from building in the pipeline as the recharge is underway.

Let's visit the same practiced system operator, who, in this case, has been asked to refill a section of large water main.

He will close the drain valve that was used to drain the main, and select a small isolating gate valve near to the lowest point of the emptied pipeline.
After opening that gate valve just enough to get the valve 'singing', he will travel upgrade to the high-end air valve to confirm that air is discharging ahead of the water that he is introducing.

If the air valve is 'hissing', he may feel confident enough to open the recharge valve a few more turns out of the seat.

This second action may cripple the air valve.

By opening the recharge valve further, he will cause the advancing column of water to accelerate toward the discharging air valve.
The water column will compress the air ahead of it, creating even higher air pressure within the pipe, and within the body of the air valve.
The higher differential pressure, between the outside atmosphere and the pipe's interior, will set the stage for 'dynamic closure'.
If the air valve that he's relying upon is a conventional design, the denser discharging air, nearing sonic velocity, will cause the air valves' large float to draw close to the vent orifice.
The force of the outflowing air may be enough to draw the float fully against the orifice seat, shutting the valve against any further air release.
The air valve will fall silent.

It's not likely that the good operator will visit the air valve a second time, while the pipe is being filled. Why should he? He has already confirmed that the air is being bled. Instead, he will 'judge' the time that it might take to fill his section of pipeline, and may return to listen to the air valve, perhaps, hours later.

Unknown to him, his air valve may have fallen silent soon after he increased the rate of re-charge. What he 'judged' to be a good fill rate may have over-powered the air valve, and, as a consequence, he may have trapped a huge amount of air at the high end of his pipeline.

Another worrisome phenomenon will occur when an air valve closes prematurely.
The passage of air may have stopped, but the column of water pushing it is still on the move.
The mass and momentum of the advancing column will continue to compress the air trapped ahead of it. The air pocket will compress until it reaches a critical point, at which it will act as a physical barrier to the columns' further advance.
The trapped air will cushion and decelerate the advance of the water column somewhat, but at the moment of zero progress, the columns' remaining kinetic energy will release in the form of a series of transient high pressure waves that reflect back along the pipeline, through the water column.
If the velocity of the advancing water column was excessive, the resultant pressure 'spikes' may be severe enough to cause the pipe to burst adjacent to the air pocket.

More often, the stalled water column generates transient oscillating surge waves that are transmitted the length of the pipeline, traveling faster than the speed of sound, looking to deplete their energy against the pipeline, it's fittings, or any attached structures.

This phenomenon is known as 'water hammer', or simply, surge.
The energy released during a water hammer event may cause extensive damage to both the air valve and the pipeline.
The measure of damage will be a factor of the mass, velocity and contained energy of the water column, and the ability of the pipeline and its' fittings to withstand the resultant shock.

Significant damage can happen with absolutely no warning.

On the street surface above, the operator will likely continue on with his task, blissfully unaware of the forces at work beneath his feet.
It is almost certain that he will work under the assumption that, when the air valve falls silent, the pipeline is completely refilled.

Hearing nothing but silence at the air valve, his next steps are obvious enough to him.

He will open the recharge valve fully, and then reopen every other valve that was used to isolate the line.
He will place the water main back into service, with no knowledge that the pipeline may have been ravaged by vacuum pressures, and hammered by pressure spikes.
He will have no knowledge that a newly created large pocket of air has been introduced into the open system, with freedom to travel about, and lodge, further along the pipeline, and throughout the system.

Could he have proceeded differently?

Certainly.

He would, without a doubt, have altered his maintenance routine, if:

- *he was aware of conventional air valve vulnerability to premature closure.*
- *he knew something about differential pressure.*
- *he had a way of measuring differential pressure at the air valve on his section of pipeline.*
- *he knew what the premature closure bar thresholds were for every conventional air valve model, and could adjust his procedures so as not to exceed them.*
- *he had a supervisor that knew all of this too.*

In practicality, if most design engineers are not well versed in the physical laws that govern air valve performance, then it is a given that the average man assigned to operate the pipeline will know nothing of air valve limitations.

Our good maintenance man is truly between a rock and a hard place.

Without having sophisticated airflow measurement instruments in place to gauge differential pressure at the air valve's large orifice, there is no way to judge how many opening turns of the drain valve is correct for de-watering a section of pipeline. Similarly, how is our maintenance man to know how many opening turns of the recharge valve will establish a fill rate that will not over-power the existing air valves?

What a delicate act to attempt!
What a triumph if it can be accomplished!

Consider, as well, that the dynamic closure 'threshold' differs for almost every conventional air valve.
This closure threshold is fickle.
It's value can change markedly, affected by the air valves' size, it's age and condition, its' internal configuration and air flow aerodynamics, and the mass/ dimensions and condition of the large orifice spherical float.

Quite obviously, both venturi-effect closure during de-watering, and dynamic closure at recharge, are conventional air valve phenomena that, in the everyday operation of a water system, are almost impossible to remedy.

If no solution is found for premature air valve closure, pipelines will continue to suffer the injury inflicted by high internal vacuum pressures, and will have to endure the flow restrictions and surge pressures that come, hand-in-hand, with pockets of air that are created and allowed to exist in the system.

A little 'Air Valve 101'

Conventional true kinetic and semi-kinetic air valves have no way of limiting the velocity of approaching water while venting air. The operation of conventional air valves is such that they will close instantaneously upon the arrival of water into the valve body.

This abrupt closure is called 'air valve slam', and it creates transient pressure spikes (water hammer) approximately equal in magnitude to the quick closing of an isolating valve.

Many modern semi-kinetic models trumpet that they are able to exhaust great volumes of air at high velocities. In doing so, they encourage rapid water column advance. Far from a selling feature, this attribute can only serve to intensify water hammer and subsequent liquid oscillation when the float is eventually driven home forcefully by high velocity water.

The Council for Scientific and Industrial Research (South Africa) conducted tests to determine the swiftness and measure of destructive force of the pressure wave created by air valve slam. Using Joukowski's Equation, they were able to estimate the magnitude of pressure rise (water hammer) under a variety of flow velocities.

Joukowski's relation implies that the greater the approach velocity of a column of water, in meters/second, the greater the pressure rise in the pipeline when a valve closes.
This equation is used extensively to calculate the magnitude of surge pressures caused by rapid changes in velocities.

This same relationship between pressure surge and velocity applies throughout the pipeline system, when pockets of air cause water columns to adjust their velocity. The pressure surge is measurable, and sometimes destructive, when the kinetic energy of an advancing column of water is released at a point of restriction, such as at a stationary pocket of compressed air.

Most conventional air valves have a restricted large orifice, relevant to the nominal size of the valve.
This is of particular importance to design engineers, as the size of the large orifice will dictate how well their pipeline will manage vacuum conditions.
Pipeline designers customarily order the installation of air valves based upon function requirement, and inlet size.
They should be just as concerned about the actual size of the 'performance orifice', the vent/vacuum orifice of the air valve.
If this orifice is smaller than the inlet diameter, then it's clear that their design expectations will never be met, and the pipeline will be at risk from the moment of its' commissioning.

A general rule of thumb when sizing air valves is that the air vacuum capacity should be twice that of the venting rate.
It should be understood that, when a pipeline is draining, air enters an air valve under the force of atmospheric pressure only.
Once sonic velocity is achieved (and that velocity is usually achieved at remarkably low differential pressure), the air valve has reached its' capacity to ingest air.
For this reason, it is vital that an air valve be sized properly, and has substantial vacuum break capacity, to handle aggressive pipe drainage.

Any air valve design that reduces the size of the large orifice can impose serious operational difficulties, and can place the pipeline at risk of collapse.

WATER HAMMER AS A DESTRUCTIVE FORCE

Pascal's Law states that pressure exerted on a confined fluid is transmitted equally in all directions.

Since force=pressure X area, any small pressure rise in the air valve will be multiplied in terms of force within the pipeline, as the main pipeline is substantially greater in area than that of the valve.

In understanding water hammer, it should be remembered that water hammer can lead to immediate rupture of the pipeline, or its' damaging effects can be less dramatic, more cumulative, across time.
Water hammer pressures may slowly batter and weaken pipelines and components until larger break events become unavoidable.

Of the conventional designs, it has been determined that non-kinetic air valves will induce higher transient pressures on closure, than semi-kinetic models, and that the pressure waves they generate will be more intense, and radiate farther along the pipeline. Semi-kinetic air valves only partially alleviate this problem.

A Likely Answer to an Old Problem

It has finally been proven that both kinetic and non-kinetic air valves cause water hammer on closure, pressures that propagate throughout the pipeline.
Independent testing has determined that the inadequate functioning of conventional air valve designs may induce pressure spikes that can measure 5 times the rated working pressure of the valve.
Both valve and pipeline suffer from this oft-repeated battering.

For decades, system operators tried to locate the cause of seemingly inexplicable pipeline damage, often attributing the damage to 'combined forces'.
'Combined forces' is engineering lexicon for "we just don't know."

In light of tests and research, it has been determined that air valve failure, or weak performance, may have been the root cause of nearly 60% of the pipeline failures that challenged explanation.

Conventional air valve manufacturers acknowledge, and have tried to address, some of the failings of their valves.
Some have created 'slow-closing air valves' by attaching a spring-loaded throttling plug to the underside of a typical kinetic valve.
The mechanism is effective in cushioning the seating action of the large float upon the arrival of water into the body of the air valve, but the closure of the throttling plate still induces water hammer that could damage the pipeline.
These bolt-on adaptations do reduce the effects of float slam, but serve mainly to protect only the valve itself from the forces of water hammer and pressure surge.

Unfortunately, these 'new solution' air valves are also more expensive, are more complex and cumbersome, and, from a maintenance viewpoint, simply employ more moving parts to inspect, and remedy when they fail.

Slow-closing hardware still does nothing to address the phenomena of venturi effect and dynamic closure that can incapacitate a conventional air valve, with no warning of impending failure.

Air Valve role in Surge Suppression

Water column separation, the most extreme example of liquid oscillation, can generate some of the most destructive energies imposed upon pipelines.
Sudden power loss, or pump trip, can cause a moving column of water to separate from the normal supply volume.
The water column, placed into motion by the action of the pumps, will obey its' own inertia and continue in motion, even when the pumps cease. The withdrawing column of water will create an air gap between the pump and the upstream end of the column.

If large volumes of air, or water, are not permitted to quickly fill the void created by the vacating column, serious pipeline vacuum pressures will develop.

Most often, pipelines are equipped with surge suppression towers, or custom-sized pressurized cylinders, to quickly fill the void created by a separating column, by flooding the space with either air or water.
In a dual role, the same structures must then manage, and try to diffuse, the potential energy of the water column as it gains momentum on a return track to the water plant.

Surge suppression structures are usually placed immediately downstream of pumping stations. These structures protect the station piping and fixtures against damaging surge, and will, to some degree, also protect the local piping system downstream of the surge structure.

Unfortunately, the protective influence of surge structures is limited.

Recent advances in air valve technology are changing the way pipeline designers employ standard surge structures.

The same South African company mentioned at the beginning of this article has produced a high-performance air release/vacuum break air valve that has had great success in mimicking the performance of formal, specialized surge devices.

Properly sized for the pipeline, and sometimes employed in sequence, these revolutionary air valves ingest air into the vacated void, without allowing dangerous vacuum pressures to develop.

Once the water column begins its' return motion to interface, these air valves feature an anti-surge mechanism that identifies high velocity water column approach.
The pocket of air that is being compressed ahead of the water column is bled off in a controlled manner through a special anti-shock orifice, and the columns' advance is slowly decelerated using the diminishing air pocket itself as a cushion.

This controlled water column deceleration is precisely what large surge structures are supposed to accomplish.
Today, however, many costly surge structures can be replaced, and surge protection modified, by the proper utilization of high performance air valves that also specialize in surge relief.

This new air valve technology can also protect the far reaches of a water system from surge events.
Severe water main breaks, heavy intermittent industrial demands, firefighting draw-downs, and system operator errors can create damaging fluid oscillation, and even column separation, far out into the system, and well beyond the protective influence of surge towers and structures.

It is at these more distant points that something more has to be added to pipelines to provide umbrella surge protection.
Fortunately, Controlled Air Transfer Technology has emerged into the pipeline marketplace, and blanket surge protection is possible.

As air accumulation is exacerbated by changes of pressure and flow velocity, it is in the direct interest of system operators to explore all methods and available devices designed to bring stability to water systems.

Companies that specialize in Pressure Management are available to provide specific system analysis, and can detect strengths and weaknesses of any water system.
These companies make sound recommendations in the use of equipment, and the design of operational procedures, aimed at reducing the destructive energies that are far too common to pipeline systems.

Testimonials to a New Scientific Understanding of Pipeline Air Transfer

Hamilton, Ontario, Canada

Population: 490,000
System: 22 pressure districts.
Complicated, Class 4, water-rich distribution system, dating from 1859

Autumn, 1999

C.A.T.T (Controlled Air Transfer Technology) was first employed in Hamiltons' water system to remedy chronic noise and vibration plaguing the plumbing of residents at the high end of Ravenscliffe Ave. This looped water main was vulnerable to the peak demand pressure surges of Hamilton's closed District 3 system.

Initially, maintenance staff placed a standard semi-kinetic air valve at the high point of the main, fairly close to the mainstops of the affected residents. As no air valve existed there before, all were confident that this move would alleviate the offending conditions.

After weeks of trial, and confirmation that the air valve was working, noise and vibration on the main were still frequent and loud enough to rattle services and irritate homeowners.

At this point, arrangements were made to acquire a properly sized CATT air valve from a company called 'Vent-o-mat'.
Hamilton staff installed this high-tech valve in place of the conventional semi-kinetic model.

Result : The CATT technology air valve immediately acted to stabilize the surge and water hammer that were once common to the streets' water main and water services. Not a single complaint has been heard from the residents of that street since the CATT air valve was installed.

Summer, 2001

Location: The Upper James Street 16" water main, key supply to the village of Mount Hope, Hamilton International Airport, and main revenue supply line to the former Region of Haldimand-Norfolk.

Airport plumbing inspectors had complained to Hamiltons' water distribution staff that water supply was erratic, and pressures were very inconsistent.
Upon investigation, staff confirmed that there was an unacceptable quantity of air in the single supply main, affecting the smooth delivery of water to that area.
The water main was systematically flushed, and pockets of high-pressure air were released at several hydrants along the pipeline.
The solution was short-lived however, as air pockets reformed shortly afterward.

Because of the difficulty in venting the air from the line, and recognizing that water supply was erratic, a special fire-fighting protocol had to be developed for the Mount Hope/Airport area until a solution could be reached.

The subject pipeline is a long, dead end water main. The main feeds an area that has seen a recent leap in water demand, with the offshoot construction of a 20" supply line to Haldimand-Norfolk, and growing activity at the busy airport.
These changing conditions probably served to generate new flow velocities in the main, which may have encouraged greater dissolution of air from the water being carried by the older pipeline.
The new demand on the pipeline was also highlighting the inability of the existing air valves to remedy the air pockets that were developing.

Regardless of the end-cause, small hydrant-mounted air valves were installed at intervals to apply a temporary half-measure remedy to the formation of air pockets.

An order was placed for several CATT air valves to be installed in place of the existing semi-kinetic air valves that were installed with the original pipeline.

Result : The CATT air valves soon brought a level of stability to the system that enabled water distribution management to cancel the temporary fire fighting protocol. The system rebounded to its' normal condition of sustained mid-level pressure and abundant water supply.
Plans are being made to examine greater use of CATT air valves along this key supply main, and along other key trunk water mains across Hamilton's pipeline network.

Could have used CATT Here

April 1988

Event : 6" Non-kinetic air valve malfunction, 48" main, Delena Ave, Hamilton.

In the early morning, a valve crew was called to respond to serious flooding reported on Delena Avenue, north of Main Street.
Upon arrival, the crew witnessed several inches of water across the street, charging upward from an air valve chamber on a key 48" supply main to large District One.

Just as they were trying to position their valve key on the isolator of the air valve, the large float of the air valve slammed home against its' closure seat.
Water stopped immediately, but the force of the impact of the float slamming home caused the men to jump from the shock transmitted through the pavement.
They held their breath, just waiting for the 48" to rupture where they stood, or along the pipeline nearby.

The flooding could have been caused by a number of things : high velocity water, returning to interface after a pump station-induced column separation, could have submerged the float and held it away from the orifice seat; internal corrosion and/or

debris could have caused the large float to 'hang up', and not move smoothly to close the port with the arrival of water into the body of the air valve.

A lot of water was lost, and many streets were flooded by the time the men arrived on site. The crews' frantic attempts to place a heavy valve key on the isolation valve may have triggered the release of the debris, permitting the float to release and seat, or the velocity of the returning water column may have dissipated enough to release the float from its' grip.

Maintenance staff and pumping station personnel were placed on notice for better than a week, to watch for any leaks or main breaks that might develop along or near to the 48" as a result of this event.

All present that morning had witnessed the kind of severe vibration that is known to rupture mains, and cause smaller leaks radiating far outward from the point origin of the water hammer.

A force triggered by an air valve!

THE REAL COST OF SURGE AND HAMMER

One thing that system operators should be aware of is the nature of water main breaks brought on by pressure events resulting from water hammer.

Pressure event breaks are usually severe, resulting in large splits or holes (sometimes in combination) in the water piping.
The intense boil and flooding from these breaks soon tears apart the roadbase as it floods nearby streets and properties, and can often cause sewers to separate at joints or develop 'slumps', as their trench bedding is softened or washed away.

A pressure event split pipe can easily develop into a $50,000 to $100,000 repair.

- ***Factor in the additional manpower and equipment that needs to be assembled for breaks of this magnitude.***
- ***These are not quick repairs; prepare for overtime wage costs.***
- ***The size of the excavation often requires that specialized shoring be brought on site, properly installed, and inspected.***
- ***Devastating water main breaks will attract broad attention. Expect frequent visits by inspectors from the Ministry of Labour, and possibly those from the Environment Ministry. Don't be surprised if your worksite is captured by local news cameras.***
- ***Repair site preparation is essential, and elaborate traffic diversion plans will have to be put in place.***

- ***Consider, also, the costs of repairing collateral damage to private property and other nearby utility runs.***
- ***Don't forget the greater costs of repair parts, and greater quantities of new roadbase aggregate you'll have trucked to the site.***
- ***Add in the later road, curb and sidewalk final cut restoration costs.***
- ***And also include the considerable costs to camera inspect, clean and/or repair sewers that may have been affected by the scouring floodwater.***

Pressure event pipeline breaks can also cause spectacular roadway and private property flooding that can:

- ***endanger the public.***
- ***disrupt traffic before, and during the eventual repair.***
- ***result in multiple damage claims being filed against the system operator by citizens whose properties and homes were hit by floodwaters and water-born debris.***
- ***Result in financial reclamation lawsuits from businesses affected by water outage, and commercial traffic disruption.***

The system operator may often be called upon, in court or before municipal council, to establish that all steps had been taken to safeguard and ensure the satisfactory operation of the water system that just erupted.

In light of such possible scrutiny, system managers need to be able to establish that:

- ***they have, in place, modern monitoring and maintenance practices.***
- ***they can demonstrate competency, and understanding of their system.***
- ***they take advantage of latest innovations to protect the system placed into their trust.***

Tough Roads Ahead

In 2002, system managers face more challenges than ever before in their efforts to maintain and upgrade their distribution systems, as well as guaranteeing the delivery of safe, clear and appealing drinking water.

Falling under the larger umbrella of the new Safe Drinking Water Act, the Sustained Sewer and Water Systems Act calls for municipalities to conduct a condition rating inventory of their sewer and water facilities infrastructure, and to estimate what financing would be required to upgrade and maintain their systems to recognized standards.
This system 'report card' would be the base point used to determine what sustained level of funding would be required to systematically renew stations and piping over the next 100 years. Those engineering reports were to have been submitted to the province by July 2002, and the province, in turn, would then expect system operators to

accelerate water rates, or to enter into private/public partnerships, or to begin to issue municipal bonds to raise the monies to accomplish those 100 year sustainability plans.

Accelerating water rates is not popular, and is generally regarded by the ratepayer as simply another form of municipal taxation.
Accelerated rates also comes as a great shock to many Ontario residents who have, for many decades, enjoyed some of the lowest flat rate and metered water rates in North America.
This action is recognized as necessary, but is still politically unpalatable.

Partnerships are difficult to arrange and enter into, as there are few companies that can envision a profit margin in bankrolling the restoration of aged infrastructure.
Creating a win-win situation between municipalities and private investors might entail the sale of, or surrender of, the whole, or parts, of the system to private interests, with some manner of negotiated user fee applied back to the municipality.

Currently, there are few successful partnership models to act as a template, and municipal councils are understandably nervous about surrendering the control of water quality and water delivery to the private sector.

Issuing municipal bonds is a new option introduced by the Eve's government in 2002.
The province indicated that it would be agreeable to permit cities to issue tax-free municipal bonds that would encourage the raising of additional revenue for infrastructure works.
These 'munibonds' are not a popular option, as they still require municipalities to go further into debt to honour the interest on the issued bonds.
This is just another indication that, when it comes to infrastructure upgrading, the province is directing municipalities to go it on their own.
It's also the latest, and strongest, indicator that the province is quickly getting out of the infrastructure aid business.

A lack of infrastructure funding is all the more reason to consider innovative measures to preserve the existing system, and to reduce the number of costly repairs.

And all the more reason to manage AIR in water pipelines as intelligently as possible.

It will take years to set up the necessary financing to support 100year sustainability programs, and the traditional financial assistance from the province seems certain to dry up.

Managers will need to guard every dollar, and employ every reasonable mechanism, to minimize the costs of operating their utility.

Controlled air management technologies are emerging from a late-understood science. Born of that science are new, cost-effective tools to help stabilize aging systems, and to regain lost pipeline efficiencies.

Every water system manager should be aggressively exploring these new offerings and considering what may work well with his system.

Summary

In light of recent research, it has become clear that system operators, and pipeline designers, have lived with a poor understanding of the true science of pipeline air transfer.

For many decades, system designers have been so uncomfortable with issues of air in pipelines, that they have, more often than not, over-engineered their pipeline designs to build in additional strength, to handle 'rogue and inexplicable pipeline dynamics'.

Air has been uncovered as one of the true villains in the operation of a water distribution system, robbing pipelines of transmission efficiency.

Although air valves constitute far less than half of one percent of a pipelines' average installation cost, poorly performing conventional models can soon become responsible for an estimated 60% of pipeline deficiencies.

Water system operators are now being introduced to Controlled Air Transfer Technology (CATT), and the latest findings in the science of pipeline air management.
It is hoped that, with this new understanding, municipalities might be able to design better, more cost-effective pipelines, and that they might also be able to extend the service life, and regain efficiencies, of existing water pipes.

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