VIETNAM - CASE STUDY

CAVITATION PROTECTION

Chu Se Water Treatment Plant in central Vietnam was built in early 2018 and receives raw water from a source 137meters above sea level and needs to have the pressure reduced to 10 meters before it is supplied to the plant.

The original valves supplied were extremely noisy and delivered very erratic control. Both issues are a result of the damaging cavitation that is present, a result of the high differential and relatively low delivery pressure both factors had not been considered in the original valve section.

CONTROL VALVE CAVITATION - *CAUSES & PREVENTION*

Cavitation prevention and protection is an important consideration in the design and operation of valves used in water distribution systems. One should be able to determine if cavitation exists, and if so its intensity and effects on the system. Cavitation in valves is a destructive condition that seriously affects the operation and service of the valve and occurs when fluid passing through the valve lowers to the vapor pressure of the fluid causing vapor cavities (bubbles) to form. When the fluid passes out of the low-pressure area into a higher-pressure area, the vapor cavity becomes unstable and collapses. This collapse is what can sometimes be heard or seen and is the reason we must be concerned about its presence in pipeline systems. The collapse can be violent and is accompanied by noise, vibrations, and possible erosion damage to the valve or surrounding pipeline.

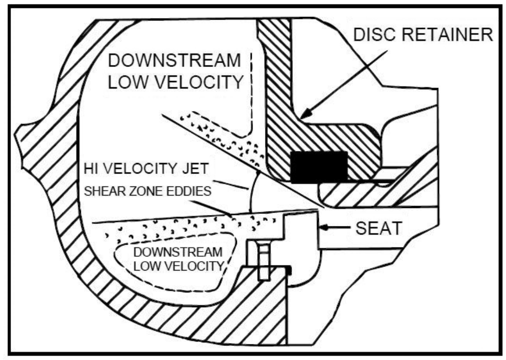
ORIGIN OF CAVITATION

There are three fundamental requirements for cavitation to occur. First, there must be gas bubbles (nuclei) or voids in the fluid that serves as a basis for vaporization to occur. Second, the internal pressure in the fluid must drop to or below vapor pressure. Third, the pressure surrounding the vapor bubble must be greater than the vapor pressure for it to collapse.

For cavitation to occur, there must be nuclei present. If the water was completely de-aerated and there were no contaminant's, voids or entrapped air, either in the water or in the boundary of the valve, the water could sustain tension and would not cavitate when the pressure dropped to the normal vapor pressure.

Therefore, nuclei are one of the primary requirements for cavitation to occur. The primary sources of nuclei are from free air bubbles and air bubbles trapped in crevasses of suspended material and crevasses in the valve body material (boundary).

SOURCES OF LOW PRESSURE



The mean pressure at the inlet to a valve is equal to the static head or pump pressure, minus the dynamic head. The local pressure in a valve is the sum of the mean pressure, which is uniform over a certain flow range and the dynamic pressure which depends on fluid motion which causes friction losses and local accelerations due to changes in the cross-sectional flow area and on the formation and dissipation of eddies and vortices in turbulent shear zones. Flow at the inlet to a valve for example, has a relatively low velocity and high pressure. As the flow approaches the partially open valve, the velocity must increase to maintain the same flowrate, and this causes the pressure to drop. When the high velocity jet enters the larger downstream area of the valve, a shear layer is created along the boundary of the high velocity jet and the lower velocity in the larger downstream area. The high velocity gradients created along this shear area creates eddies is considerably less than the already lower pressure of the high velocity jet. If nuclei are entrapped inside these eddies and the pressure drops to vapor pressure, it will begin to grow. If the pressure remains at vapor pressure long enough for the nuclei to reach a critical diameter, it then begins to grow rapidly through vaporization. As the size of the vapor pressure cavity increases, the strength of the eddy is rapidly destroyed, the rotational speed reduces, and the pressure is no longer vapor pressure.

Since surrounding pressure is above vapor pressure, the cavity becomes unstable and collapses inward. The time that a nucleus is subjected to low pressure inside the eddy is important. If the time is so short the bubble can- not reach its critical diameter, it will not become cavitation event.

PRESSURE RECOVERY

In the third phase of cavitation there must be a pressure in the cavitation zone greater than vapor pressure for the cavity to collapse. If the bubble collapses before reaching the boundary areas there will be no cavitation damage, only noise, vibrations and possible reduction of flow.

DAMAGE

If the vapor cavities are carried to the solid boundary of the valve before they collapse, erosion damage will occur. Prior research has indicated that the collapse must occur approximately one bubble diameter from the boundary to cause erosion damage. Since the bubbles are generally small, this indicates that only collapses near or on the surface of the boundary will cause erosion damage. High pressure shock waves are generated by the collapse of the vapor cavities and in severe cases have been estimated to be over 1,000,000 psi. No material can withstand this type of beating very long. Once a system reaches a point where erosion damage occurs, damage increases very rapidly as the velocity of the system is increased. Because of this it is important that when selecting conditions corresponding to the onset of erosion or cavitation damage, one should be conservative because a slight increase in velocity could cause a large increase in the damage rate.

EFFECTS OF CAVITATION

There are five basic problems associated with cavitation: noise, vibrations, pressure fluctuations, erosion damage and loss of flow capacity. The type and intensity of noise in a valve usually depends on the size of the valve. Cavitation in a small valve is usually identified as a hissing or a light crackling sound. In large valves, the noise may sound more like small explosions and can vary with the design of the valve. The shock waves generated by the collapsing vapor cavities can produce pressure fluctuations and system vibration. As the intensity of the cavitation increases, the magnitude of the vibration increases many times over and can cause serious damage to mounting bolts, pipe fitting and structural failure. If the vapor cavities collapse close to a boundary inside the valve, erosion damage can occur. In many cases cavitation damage has eroded holes through the side of valve bodies and in some cases has eroded holes in the bridge wall and valve seat areas. This is one of the most common types of failure.

During advanced stages of cavitation, large vapor cavities form, which can alter the flow characteristics of the valve and drastically reduce the efficiency. This is referred to as Choking cavitation and represents the condition at which the flow coefficient (Cv) is drastically reduced because of the large vapor cavities. Just prior to choking cavitation, erosion damage, noise and vibration are at their maxi- mum, then will start to drop off rapidly. Once the valve fully chokes, the vapor cavity will extend out beyond the dis- charge of the valve and into the down- stream piping where the collapsing vapor cavities can cause major damage to the downstream piping and fittings.

DESIGN PARAMETERS

If we understand cavitation, its causes and effects, we can probably think of several ways to prevent damage to the valve. One easy method would be to limit operation of the system to a level that would not produce enough energy to carry the vapor cavity to the boundary of the valve and there would be no cavitation damage.

Another method would be to change the internal geometry of the valve to remove the boundary out of the immediate damage cavitation zone. A number of years ago, Cla-Val took the data obtained from 25 years of studying cavitation and associated problems and changed the internal geometry of the valve. This allowed an increase in the operating differentials of the valve without causing cavitation damage.

DETERMINING CAVITATION LIMITS

Historically there was no analytical solution for determining the cavitation characteristics of a valve. Every valve design has its own "footprint" and for this reason the only way to properly evaluate the cavitation parameters is by laboratory experimentation. (This all changed with the advent of Computational Fluid Dynamics). Once these parameters are obtained for a specific valve geometry then it is possible to develop empirical relationships for predicting the various levels of cavitation. If the internal geometry is changed, then new experimental data must be obtained to develop new empirical relationships. For this reason, the empirical data developed for one company's products cannot be transferred to another manufacturer's products.

Most any laboratory instrument that can detect noise, pressure fluctuations, vibrations, pitting or loss of efficiency can be used to detect cavitation. An important factor in determining the cavitation parameters is to do the experimentation in a laboratory that is relatively free from other noises such as pumps, control valves and vibrations that could affect the data obtained. Probably the most common instrument used to detect cavitation is the accelerometer because it is easy to use and is sensitive to the lightest and heaviest levels of cavitation. To obtain the flow conditions for incipient damage, polished soft aluminum plates were installed flush with the inside surfaces of the valve, in the proper locations to record the pitting.

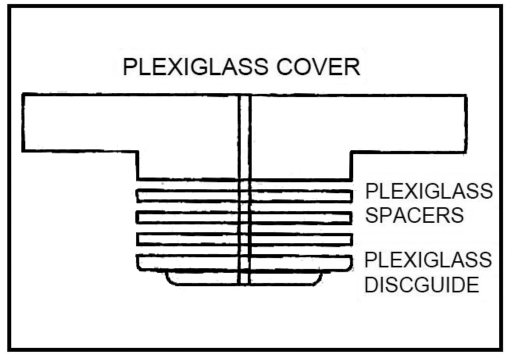
Nearly all the experimental data taken in the laboratory is taken at reduced pressures and flows from actual applications and for this reason just scaling the experimental data up to actual conditions in the field will not give true cavitation data. Therefore, pressure scale effects for a given valve geometry must be determined in the laboratory.

CAVITATION DAMAGE STUDIES

Testing of valves in conjunction with reputable flow laboratories have been undertaken by certain manufacturers to determine the maximum operating limits without incurring cavitation damage. Tests were conducted to determine the flow conditions where cavitation noise first begins (Critical Cavitation), the pressure scale effects on critical cavitation, the flow conditions where cavitation damage begins, (Incipient Damage) and the flow conditions where choking cavitation begin to occur.

A dimensionless cavitation parameter sigma was used to quantify the intensity of cavitation at different flow conditions. The most common formula for determining sigma is (= (Pd - Pvg)/Pu - Pd) where Pd is the down-stream pressure, Pvg is the gage vapor pressure and Pu is the valve inlet pressure. Data were collected at every 10 percent of opening to provide a valve opening versus Cv curve. The intensity of cavitation at critical level consists of steady light popping sounds. This level of cavitation does not cause erosion damage or reduce the service life of the valve and for most applications is recommended for what could be termed "cavitation free operation". The critical cavitation levels were determined by ear during these tests.

To determine the sigma value at incipient damage, it was first necessary to determine the location inside the valve where actual cavitation was occurring. This was done by making a valve cover and valve disc from Lucite with spacers for each 10 percent of valve opening. When installed, one could observe where inside the valve, cavitation occurred when operated at various percentages of opening. Polished soft aluminum plugs were then inserted through the walls of the valve body and positioned flush with the inside wall in the locations where cavitation was observed. Plates were also fastened flush with the bridge wall boundary inside the valve.



The internals were then re-installed in the valves and the valves operated at each 10 percent opening at various differentials and flow rates until pitting was observed on the soft aluminum plates.

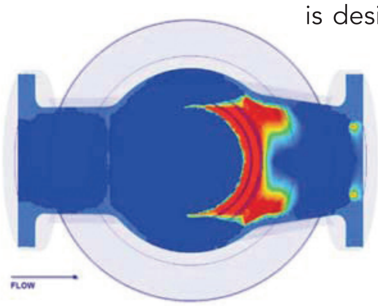
This was a very time-consuming test because the valve had to be operated at a known condition for 10 to 20 minutes, then disassembled and the plates examined to see if there were any pits in the soft aluminum plates. If there were no pits the valve was re-assembled, and the process repeated at a lower sigma value until the proper number of pits were obtained. Incipient damage for these tests was taken as one pit per square inch per minute on the soft aluminum plates. This procedure was then repeated at each 10 percent of valve opening.

At the end of the cavitation damage studies, the cavitation program was modified to include the condition of incipient damage and it was found that certain body designs would tolerate a much higher degree of cavitation than others before the onset of cavitation damage.

Over the years, different series of valves have been developed and much of the information obtained from the cavitation studies has been incorporated into the design. When designing a valve with a reduced seat diameter to eliminate the need for reducing flanges that are required in many installations, it gave the opportunity to design a valve that had improved cavitation characteristics.

The results of these reduced seat valves in testing were far better than expected and this series of valves will operate at much greater velocities without experiencing cavitation damage.

Valves that operate intermittently such as some relief applications may be able to operate at a higher degree of cavitation. In this type of service, erosion damage may not be the deciding factor. If the system is designed to withstand the vibration and noise the valve may be able to operate at choke flows. The intensity of cavitation, noise, vibration and erosion damage is usually at their maximum just before the valve chokes and the flow may be very unstable. The cavitation program shows the occurrence of choking cavitation.



In the past ten years, Computational Fluid Dynamics (CFD), has significantly evolved using numerical methods and algorithms to analyze complex fluid flow problems. Utilizing this process allows an analysis to be seen on valve designs, clearly indicating areas of cavitation.

VALVE APPLICATION

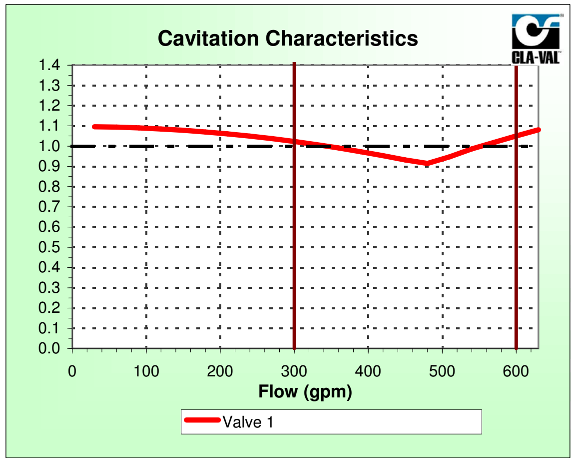
When specifying a valve, a manufacturer supplied calculator can be used to determine the cavitation characteristics of the valve for the specific application. As in example 1, let's say we have a 4 inch main valve, located at the end of a long pipeline flowing from 300 to 600 gpm. The long supply pipeline has a pressure loss of 20 psi at 600 gpm. The static inlet pressure is 100 psi, the outlet pressure is 20 psi and the valve is at 800 feet elevation. The cavitation program shows cavitation damage starting at 300 gpm and again at 550 gpm.

Valve 1		
Valve size	4" 100-01	
Maximum flow rate	600	gpm
Minimum flow rate	300	gpm
Static inlet pressure	100	psi
Static outlet pressure	20	psi
Elevation above S.L.	800	ft
Water temperature	60	deg F
Dynam. inlet pressure	80.0	psi
Dynam outlet pressure	20.0	psi
Backpressure orifice	None	
Orifice backpressure	0	
Orifice discharge to	Downstream piping	

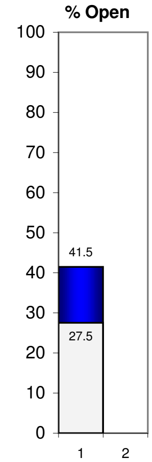
Valve operation

Continuous (>50%)

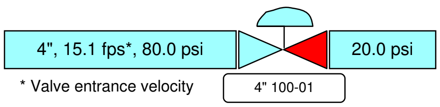
Avoid operation near (within 10 %) cavitation damage level of 1.0.



If the lines go above 1.0 there will be cavitation damage.



No damage
Caution - near damage
Damaging cavitation



* Valve entrance velocity

Valve 1	Flow Rate GPM	Inlet (psi)	Outlet (psi)	% Open	Pipe Vel. (ft/s)	Cav Damage
	30	100.0	20.0	5.5	0.8	Yes
	150	98.8	20.0	20.1	3.8	Yes
	300	95.0	20.0	27.5	7.6	Yes
	450	88.8	20.0	34.2	11.3	Near
	600	80.0	20.0	41.5	15.1	Yes

Now that we know there will be cavitation damage, what can we do about it? One method of combating cavitation damage is to add back pressure to the valve.

This is done in the cavitation program by entering a value for the back pressure, which must be greater than the normal outlet pressure. As the flow rate increases, the pressure at the outlet of the valve increases causing the valve to open further which reduces the velocity of the jet through the partially open valve and increases the outlet pressure which may raise the internal pressure above vapor pressure.

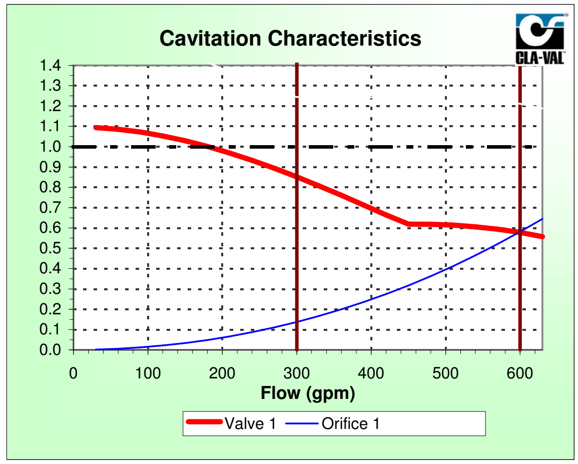
In example 2, a back pressure of 37.8 psi was added and the cavitation damage was completely eliminated. Adding back pressure to a valve can be accomplished by adding an orifice plate downstream of the valve. In a pressure reducing valve application, the pressure regulating pilot must sense the pressure downstream of the orifice plate. If there is considerable resistance in the discharge line of the valve, then the back pressure on the valve will automatically increase as the flow increases and this must be taken into consideration when entering the data. If the discharge line is long and the valve is anything but a pressure reducing valve, then the dis- charge pipe Cv must be entered which will automatically raise the outlet pressure as the flow increases. This should be done before entering back pressure to eliminate damage cavitation. Still another method of reducing cavitation damage in a valve installation is to use two or more valves in series. Using the cavitation program, one can determine the maximum pressure conditions for each valve that will permit them to operate free of cavitation damage.

Valve 1		
Valve size	4" 100-01	
Maximum flow rate	600	gpm
Minimum flow rate	300	gpm
Static inlet pressure	100	psi
Static outlet pressure	20	psi
Elevation above S.L.	800	ft
Water temperature	60	deg F
Dynam. inlet pressure	80.0	psi
Dynam outlet pressure	20.0	psi
Backpressure orifice	Single	
Orifice backpressure	37.8	psi
Orifice discharge to	Downstream piping	

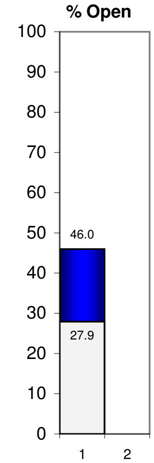
Valve operation

Continuous (>50%)

Avoid operation near (within 10 %) cavitation damage level of 1.0.

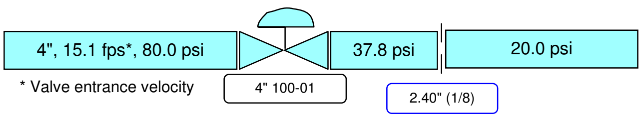


If the lines go above 1.0 there will be cavitation damage.



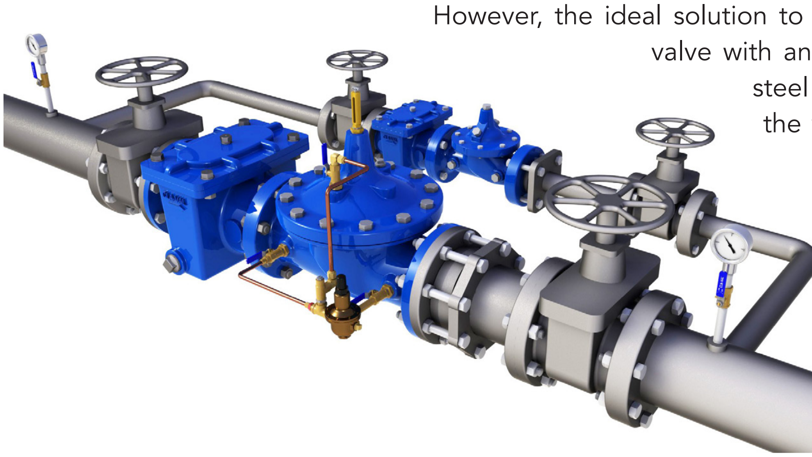
No damage
Caution - near damage
Damaging cavitation

Valve damage occurs <15 psi.



Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	% Open	Pipe Vel. (ft/s)	Cav Damage
30	100.0	20.0	5.5	0.8	Yes
150	98.8	21.1	20.2	3.8	Yes
300	95.0	24.5	27.9	7.6	No
450	88.8	30.0	35.7	11.3	No
600	80.0	37.8	46.0	15.1	No

Orifice plate thickness shown in parentheses



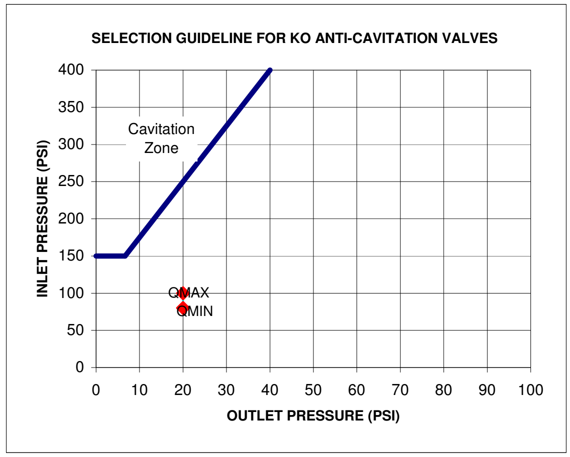
However, the ideal solution to cavitation occurrences is to install a control valve with anti-cavitation trim. This involves two stainless steel cages, the inner cage being free to move with the valve stroke. The cages are either slotted or drilled, and control where cavitation occurs in the valve. Essentially the cage openings create enough back pressure to keep the cavitation inside the center of the cages where no damage can occur. This solution guarantees that cavitation damage will not migrate downstream and cause pipework damage, whilst also ensuring the control valve gives years of damage free operation.

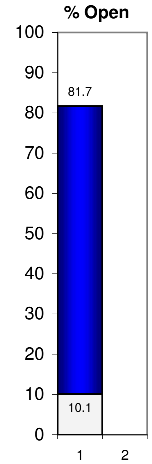
Valve 1		
Valve size	4" 100-01	
Maximum flow rate	600	gpm
Minimum flow rate	50	gpm
Static inlet pressure	100	psi
Static outlet pressure	20	psi
Elevation above S.L.	800	ft
Water temperature	60	deg F
Dynam. inlet pressure	80.0	psi
Dynam outlet pressure	20.0	psi
Backpressure orifice	None	
Orifice backpressure	0	
Orifice discharge to	Downstream piping	

Valve operation

Continuous (>50%)

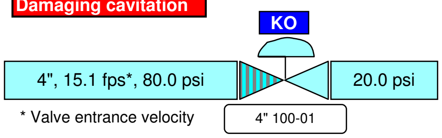
Avoid operation above 18 ft/sec.





Published Cavitation Chart.

No damage
Caution - near damage
Damaging cavitation



* Valve entrance velocity

Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	est. % Open	Pipe Vel. (ft/s)	Cav Damage
30	100.0	20.0	7.4	0.8	No
150	98.8	20.0	19.9	3.8	No
300	95.0	20.0	36.8	7.6	No
450	88.8	20.0	56.5	11.3	No
600	80.0	20.0	81.7	15.1	No

CONCLUSION

When dealing with cavitation it is always important to select the correct valve for the application and having computer programs to assist in this process certainly is beneficial. It is prudent to request copies of these computer reports, ensuring that the reports are specific to the valve manufacturer you are evaluating, rather than a generic program to ensure a correct analysis is performed.

CHU SE WATER TREATMENT PLANT

CVP were approached via Breen International our Vietnam agent to assist with a solution. Use of our unique "CLA-CAV" sizing programme allowed us to select the correct valve size for the required high-low flows plus identify the cavitation issue and selection of the required KO anti-cavitation trim.

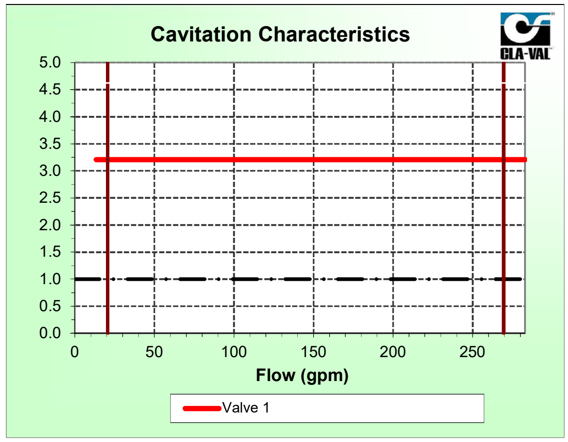
CLA-CAV NO KO

Valve 1		
Valve size	6" 100-01	
Maximum flow rate	269.5	gpm
Minimum flow rate	20.6	gpm
Static inlet pressure	198.7	psi
Static outlet pressure	14.5	psi
Elevation above S.L.	500	ft
Water temperature	60	deg F
Dynam. inlet pressure	198.7	psi
Dynam outlet pressure	14.5	psi
Backpressure orifice	None	
Orifice backpressure	0	
Orifice discharge to	Downstream piping	

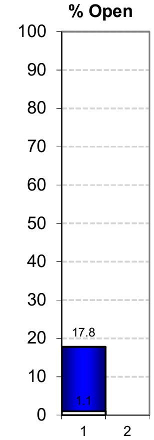
Valve operation

Continuous (>50%)

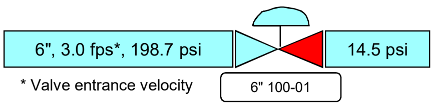
Avoid operation near (within 10 %) cavitation



If the lines go above 1.0 there will be cavitation damage.



No damage
Caution - near damage
Damaging cavitation



* Valve entrance velocity

Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	% Open	Pipe Vel. (ft/s)	Cav Damage
13	198.7	14.5	0.7	0.1	Yes
67	198.7	14.5	8.9	0.7	Yes
135	198.7	14.5	12.6	1.5	Yes
202	198.7	14.5	15.8	2.2	Yes
270	198.7	14.5	17.8	3.0	Yes

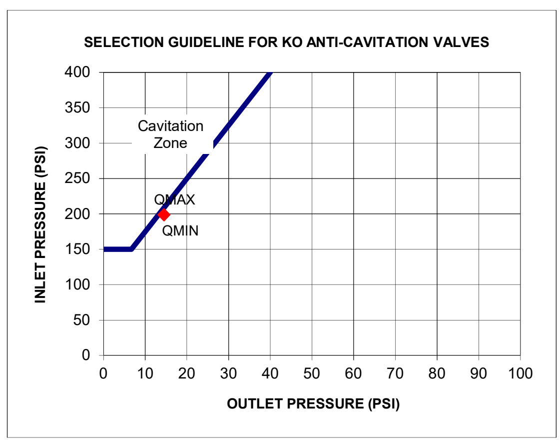
CLA CAV

Valve 1		
Valve size	3" 100-01	
Maximum flow rate	269.5	gpm
Minimum flow rate	20.6	gpm
Static inlet pressure	198.7	psi
Static outlet pressure	14.5	psi
Elevation above S.L.	500	ft
Water temperature	60	deg F
Dynam. inlet pressure	198.7	psi
Dynam outlet pressure	14.5	psi
Backpressure orifice	None	
Orifice backpressure	0	
Orifice discharge to	Downstream piping	

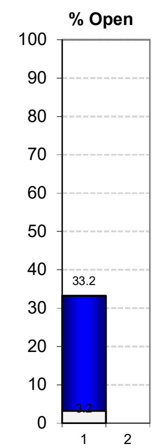
Valve operation

Continuous (>50%)

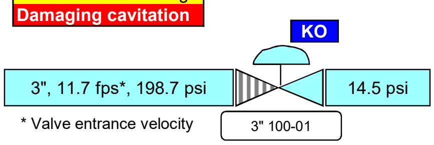
Avoid operation above 18 ft/sec.



Published Cavitation Chart.



No damage
Caution - near damage
Damaging cavitation



* Valve entrance velocity

Valve 1 Flow Rate GPM	Inlet (psi)	Outlet (psi)	est. % Open	Pipe Vel. (ft/s)	Cav Damage
13	198.7	14.5	2.1	0.6	No
67	198.7	14.5	8.6	2.9	No
135	198.7	14.5	16.4	5.8	No
202	198.7	14.5	24.8	8.8	No
270	198.7	14.5	33.2	11.7	No

Valves were selected, supplied and installed with 100% success they are very stable, quiet and we have a very happy client.

Cla-Val has since been selected to replace other defective valves at the same site and proving again the value of well qualified and motived local partners with access to world class technology