ONYX PINCH VALVE SIZING HAND BOOK

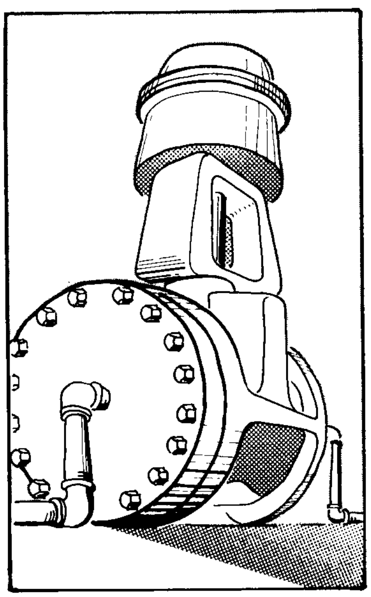
A Practical Guide to Sizing Pinch Valves for Accurate, Stable Control of Slurries and Hard to Handle Fluids

INTRODUCTION TO PINCH VALVE SIZING

Why size control valves?

Many people question whether valve sizing is necessary, as opposed to selecting a valve the same size as the pipe.

Obviously, a valve which is too small will not pass the required flow, prohibiting the process from achieving full capacity. Well then, if we make valves extra large to be on the "safe" side we will be able to handle any flow required, right?



Consider the effects of such an arbitrary choice, as opposed to selecting the *optimum* valve based on sound design principles.

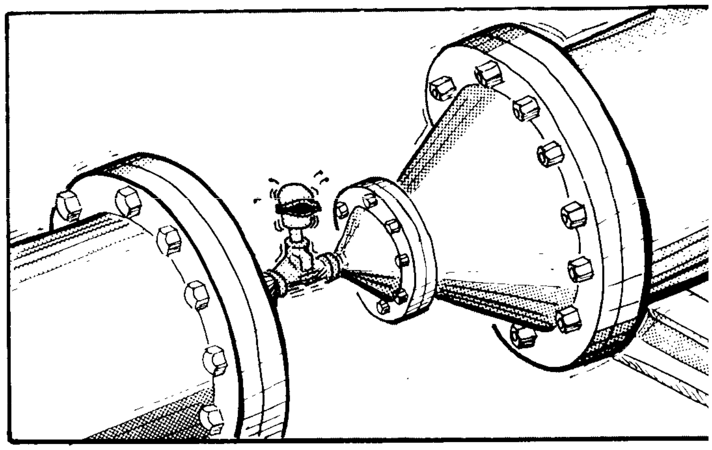
The first consideration is cost. Reducing a valve by even one size yields initial cost savings of 20% to 60% depending on line size. Multiply this by the total number of valves in a modern process plant and the savings are significant. Additional savings derive from reduced structural support and air consumption.

The second consideration is durability. Correctly sized valves operate fairly wide open. This eliminates sleeve erosion. **Correct sizing extends sleeve life.** Many applications utilizing properly sized valves are still in service with the original sleeve after 15 years of continuous operation.

The third consideration is performance. **Correct sizing enhances flow accuracy and rangeability.**

A properly sized pinch valve with its linear flow characteristic makes an excellent final control element. Coupling the valve to a modern digital solid state positioner further enhances the resolution obtainable with this type of valve.

Many users of this type of valve have a peculiar habit; they meticulously calculate required capacity and then multiply the results by an arbitrary "safety factor" of 2 to account for viscosity. This only degrades valve performance. This manual describes the proper method to account for density and viscosity.



Interestingly, while we see the ravages of over sizing every day in the form of eroded sleeves, we have yet to record a single case of a valve being undersized.

Sizing charts in this manual list the capacity of reduced port valves. They include the reduction in capacity caused by reducer fittings. Attaching reducers to high recovery valves like ball or pinch valves can reduce capacity more than 30%.

For example, a 4 inch valve in a 4 inch pipe has a C_V of 944. This same valve installed in a 10 inch pipe line undergoes a capacity reduction to 420! Our sizing charts take this reduction in capacity into account, eliminating the need to calculate the friction loss caused by reducer fittings. The flow capacity is the same through a 10 inch valve with a 4 inch port as it is through a 4 inch valve installed with reducers in a 10 inch pipe.

These capacity reductions have been determined by mathematical models and verified by extensive testing of valve and reducer combinations.

Onyx Valve Co is the recognized technical leader in the manufacture of pinch valves. Our president was first to actually measure the flow capacity of a pinch valve by actual test. He was also the first to publish a sizing method for pinch valves using the now widely accepted 2-formula method. He has also published numerous articles on valve applications and cavitation control. Onyx Valve Co manufactures pinch valves with pneumatic and electronic instruments to make them reliable final control elements in modern automated process plants.

About the Author

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President, Onyx Valve Co

Mr Gardellin is a licensed Professional Engineer, registered in New Jersey and Maryland. He received his BSME from Drexel University.

Former associations include Robertshaw Controls, WABCO Monorail, American Electronic Laboratories, Met-Lab Corporation, Met-Pro/Fybroc Pump, and Robbins & Myers/RKL Controls.

Some of the projects he has worked on:

- Electronic and pneumatic instruments to measure and control temperature, flow, and pressure.
- Non-metallic pumps for acid and other aggressive fluids. Size ranges 5 to 200 HP.
- Performed the first capacity tests of pinch valves. Published the first manual for sizing pinch valves using now widely accepted 2-formula method. Wrote and distributed the first computer program for sizing pinch valves.

Mr Gardellin is the author of numerous technical articles and editorials on valves and controls for various technical journals including 'Measurements & Control' and 'Chemical Engineering Progress'. His articles on valve cavitation have been incorporated into the Chemical Engineering Practical Encyclopedia, and he is co-author of the chapter on Pinch Valves for the Instrument Engineer's Handbook, published by the ISA.

He has lectured on numerous topics related to valves, controls, and instrumentation, including a lecture at the ISA National Convention. He has also created several technical courses for the ISA relating to valves, controls and electronics. He is also an active member of the American Society of Mechanical Engineers.

If you have any comments or questions on valve sizing, you can reach Mr Gardellin at Onyx Valve Co, Ph: (856) 829-2888 or Fax (856) 829-3080, or e-mail at david@onyxvalve.com

ONYX SIZING COEFFICIENTS

valve	port	CAR Cv
1/2	full	12
	0.37	9
	0.25	4
3/4	full	32
	0.50	14
	0.37	8
1	full	42
	0.75	31
	0.62	28
	0.50	18
	0.37	6
1.5	full	86
	1.00	35
	0.75	18
	0.62	12
	0.50	11
2	full	170
	1.50	79
	1.00	30
	0.75	17
	0.50	8
2.5	full	346
	2.00	156
	1.50	70
	1.00	29
	0.75	18
	0.50	10
3	full	576
	2.50	293
	2.00	148
	1.50	66
	1.00	29

		CAP Pre-Pinch	DAC Full Round
Valve	port	full	Cv
4	full	944	1133
	3.0	460	552
	2.5	186	303
	2.0	120	144
	1.5	51	61
5	full	1364	1637
	4.0	714	857
	3.0	287	344
	2.5	163	196
	2.0	94	113
6	full	1843	2212
	5.0	1180	1416
	4.0	567	680
	3.0	280	336
	2.5	152	182
	2.0	91	109
8	full	3040	3648
	6.0	1436	1723
	5.0	832	1000
	4.0	460	553
	3.0	233	280
	2.5	143	172
10	full	4520	5424
	8.0	2534	3040
	6.0	1149	1379
	5.0	800	960
	4.0	420	504
	3.0	208	250
12	full	6400	7680
	10	3936	4723
	8.0	2057	2468
	6.0	1003	1203
	4.0	402	482

		CAP Pre-Pinch	DAC Full Round
valve	port	Cv	Cv
14	full	8550	10260
	12	5764	6917
	10	3351	4021
	8	1837	2204
	6	943	1132
16	full	11200	13440
	14	7745	9294
	12	5004	6005
	10	3002	3602
	8	1711	2053
18	full	14300	17160
	16	10344	12413
	14	6710	8052
	12	4500	5400
	10	2790	3348
	8	1632	1958
20	full	17600	21120
	18	13400	16080
	16	9125	10950
	14	6000	7200
	12	4166	4999
	10	2650	3180
24	full	26100	31320
	20	15120	18144
	18	10830	12996
	16	7536	9043
	14	5167	6200
	12	3780	4536
	10	2475	2970
30	full	42500	51000
	24	21250	25500
	20	12000	14400
	18	8900	10680
	16	6461	7753

VALVE SELECTION

In order to select components for a process system, the nature of the system and its behavior should be fully understood. The first design decision is establishing maximum and minimum flow required to sustain the process. Flow requirements affect the selection of all the components in the system, especially pumps and valves which, taken together, determine the capacity and stability of the process. Once the flow through the system is determined, friction loss can be computed so a control valve and pump can be chosen. Notice that the control valve is selected *before* the pump. This is because pressure drop through the valve is part of the system loss which the pump must overcome. This pressure drop should be carefully considered for it bears directly on the stability of the system.

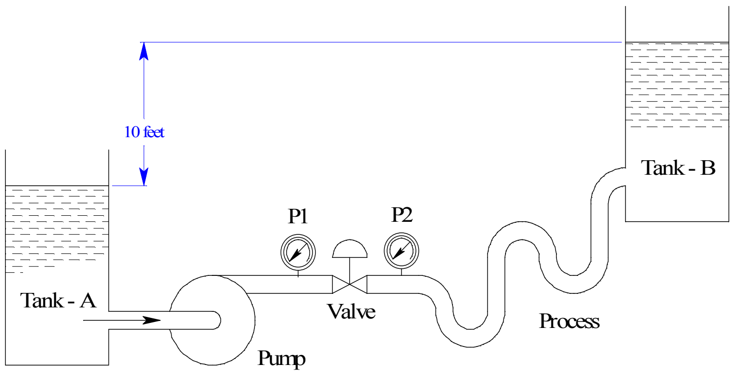


figure 1

The easiest way to explain the sizing procedure is to begin with a simplified model of a typical process. Figure 1 shows a schematic process with a pump and valve.

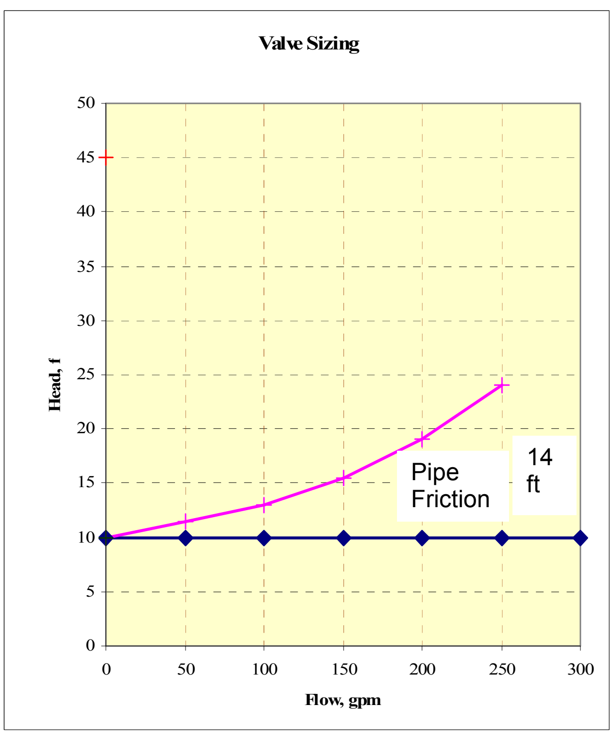


Figure 2

The process in figure 1 is shown graphically in figure 2.

The flow rate in GPM is the abscissa; the pressure drop in feet of head is the ordinate.

The horizontal line at 10 ft elevation on the graph shows the static pressure required to elevate the liquid from tank "A" to tank "B."

Friction drop through the pipe and process (not counting the valve) is calculated at 50 gpm intervals and plotted on the graph.

This curve shows what the pressure reading on gauge P2 (in figure 1) will be for any given flow rate.

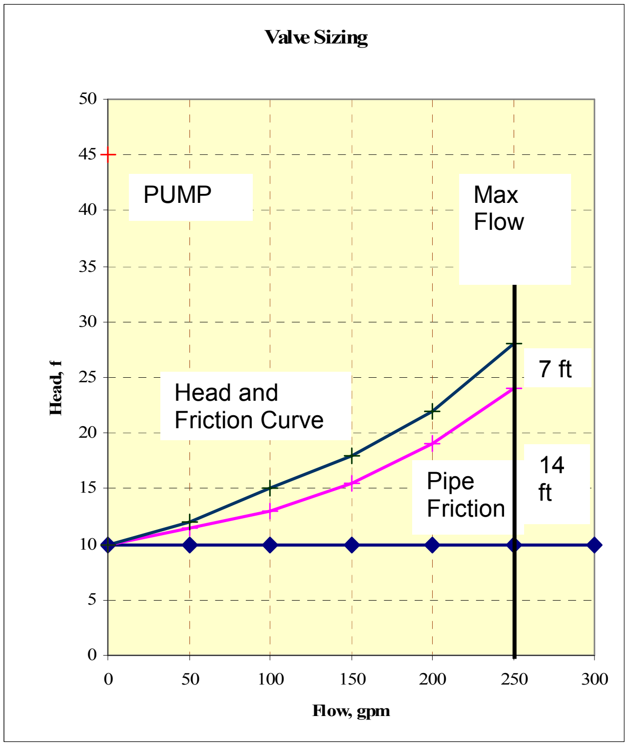


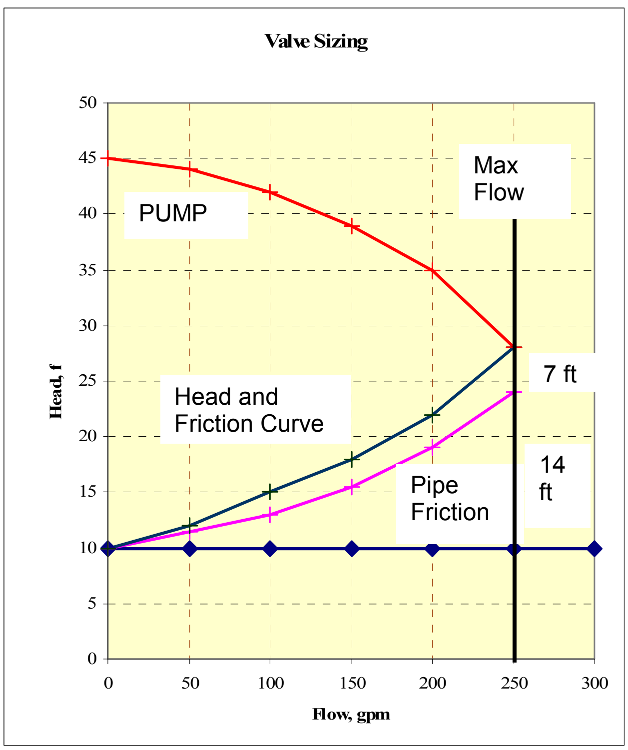
figure 3

Now some pressure drop has to be added to the system for the control valve.

How much ΔP is enough for accurate control? There is no set formula to determine this. You have to exercise your judgment to tailor the valve to your particular application.

Pressure drop through the valve is typically related to friction loss through the process at maximum flow.

The "Rule of Thumb" is to make the pressure drop through the valve (at maximum flow) equal to half the friction drop through the process.



On systems with low turndown this figure may be lower, but 25% is usually the minimum.

In our example, the pressure drop through the process is 14 ft of friction at maximum flow, so we will specify 7 feet of drop through the control valve.

This may sound excessive (and inefficient) on first examination but valves cannot contribute to the flow in a system. A valve regulates flow by absorbing or giving up pressure drop to the system. As the proportion of system drop available to the valve is reduced, its ability to regulate flow rapidly disappears.

Now a pump can be chosen which to match the system. (See fig. 4)

figure 4

Figure 4 includes a typical pump curve. We select a pump with sufficient total dynamic head to overcome the difference in liquid elevation, the friction in the process piping, and the pressure drop through the valve. The difference between the pump curve and the pipe friction curve at any flow rate represents the pressure drop across the control valve.

This pump curve represents the pressure reading on gauge P1 (in figure 1) at any given flow rate.

VALVE SIZING FOR LIQUID SERVICE- The 2 Formula Method

The First Formula:

Control valves in the modern sense appeared around the mid 1800's. They have been continually refined and applied to more sophisticated throttling applications through the years. At some point it became necessary to develop a mathematical model to predict, in advance of installation, flow at a given pressure drop.

To derive such a model, engineers started with Bernoulli's Theorem describing the conservation of energy. By assuming constant elevation through the valve the potential energy term can be neglected. If we further assume turbulent flow to insure Reynolds numbers in excess of 2000 then inertial forces predominate over viscous forces and the relationship of pressure drop to flow is a square root function:

$$Q = K\,A\sqrt{\frac{\Delta P}{G_f}}$$

where:
Q = Flow in gpm
A = Cross sectional Area, in^2
ΔP = Pressure drop across the valve, psi
G_f = Specific gravity

K is a constant which represents area ratios, measurement units, and correction factors.
If we replace K and A with the term Cv, then the resulting formula reads:

$$Q = C_V * \sqrt{\frac{\Delta P}{G_f}}$$

Each particular size and style valve has a constant value C_V associated with it. We can rearrange the terms in this equation to read:

Important Concept →

$$C_V = Q * \sqrt{\frac{G_f}{\Delta P}}$$

Formula #1

This C_V represents flow capacity or fluid "conductivity" of the valve. It is, by definition, the number of US. gallons per minute of water at 60°F that pass through the valve with a 1 PSI pressure differential between inlet and outlet. It is determined experimentally by testing specimen valves under controlled conditions in accordance with established industry standards.

By inserting the required flow, specific gravity, and pressure drop across the valve into the above formula, you can determine the C_V required and you can compare this to the C_V available of various valves until you find one whose capacity equals or exceeds that required for the process at design flow.

The above formula was applied to Globe style valves for years with good results. As new types of high recovery valves such as ball, butterfly and pinch valves became more popular, the formula began to drift. Measured flow and predicted flows began to diverge. This time thermodynamic engineers came to the rescue.

The Second Formula:

Valves have three mechanisms to dissipate energy:

1. **Turbulence.** Changing fluid direction increases shear rate. This extracts energy from the liquid, converting it into non-recoverable heat and noise that radiate to the surrounding space. The classic globe valve, due to its "tortuous path", makes extensive use of this mechanism to reduce energy in the flow stream.

2. **Energy exchange.** A pump imparts energy to the flow stream. This energy has a kinetic component in the form of foreword momentum, and a potential component, which is pressure.

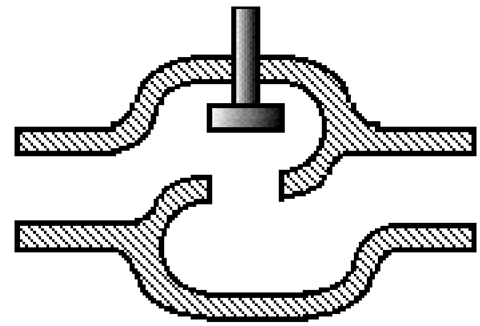


fig 5. ***Tortuous path develops high turbulence.***

After liquid leaves the pump, exchanges between potential and kinetic energy occur, but total energy can not increase. Flowing liquid draws from its store of potential energy to overcome friction.

Liquid squeezing into a restriction accelerates to maintain constant volumetric flow. This increases kinetic energy at the expense of potential energy: Pressure falls as the liquid accelerates.

These energy exchanges are not perfectly adiabatic and a portion of energy is irreversibly lost to entropy.

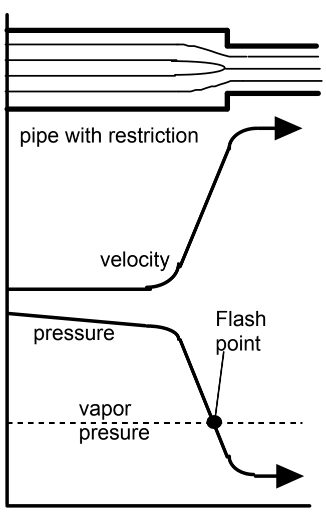


fig 6.

3. **Change of state.** Conditions inside piping are not subject to the same limitations we experience in the outside world.

In our frame of reference the lowest pressure we experience is atmospheric, around 14.7 psi absolute. Pressure inside pipe and valves is not subject to this limitation and can drop into the vacuum range.

The boiling point, the temperature at which liquid changes to gas, is a function of pressure. As pressure drops the boiling point also drops. If pressure falls low enough the boiling point will be depressed below room temperature.

Inside a valve the "vena contracta" is the locus of minimum cross sectional area of the flow stream. This is where the flow stream achieves its highest velocity so this is where pressure falls to its lowest value.

If pressure at the vena contracta falls below the vapor pressure the liquid changes to a gas forming pockets or cavities in the flow stream.

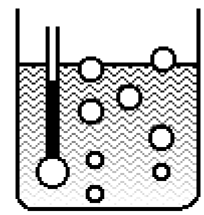


fig 7. ***Liquid boils when pressure in the jar falls below vapor pressure.***

If fluid pressure remains below the vapor pressure, a fraction of the fluid remains in the gaseous state and a froth of bubbles and liquid continues down stream.

This is flashing.

When fluid emerges from a restriction, the process reverses itself; the fluid decelerates and pressure recovers.

Since this is not perfectly adiabatic, pressure does not recover to its original magnitude.

If pressure recovers beyond the vapor pressure, the cavities re-liquefy and collapse.

This is cavitation.

These gas pockets collapse violently.

Cavitation is more destructive than flashing.

Flashing and cavitation consume energy to effect the change of state by which these phenomena operate.

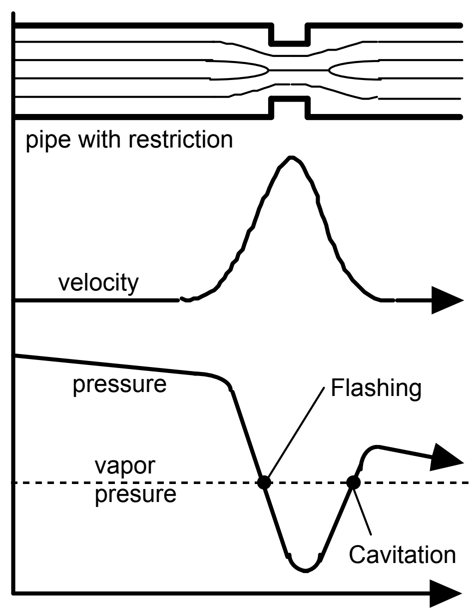


fig 8.
Cavitation occurs when pressure recovers past the vapor pressure.

When sizing valves, this energy must be accounted for. Also, the cavities crowd the vena contracta, blocking increased liquid flow despite increases in ΔP.

The physical effects of cavitation vary widely with the type of valve involved. Metal valves deteriorate rapidly in the presence of cavitation or flashing, so these phenomena should be avoided when using metal valves.

Pinch valves withstand considerable levels of cavitation. This is because the rubber lining absorbs and dissipates the shock waves generated by the collapsing cavities. It is best to operate the valve at more than 30% open under these conditions so turbulence and back flow are avoided, which cause more collisions of cavities with the sleeve walls.

The tendency of any valve to recover pressure is determined experimentally in a fluid laboratory, and is assigned a unitless number, called F_L. The higher the F_L number, the less pressure the valve recovers. Thus, to properly predict the behavior of any valve, two coefficients are required, C_V and F_L.

Other factors that affect cavitation are: inlet pressure (P1), vapor pressure (Pv), and the ratio of critical pressure to vapor pressure of the liquid (r_C). "r_C" is theoretically a function of vapor pressure and critical pressure of the liquid in question. For liquids within the temperature and pressure range of pinch valves, r_C can be considered to be a constant.

$$r_C = 0.93$$

These factors are combined in the second formula of the "2-Formula" method to give:

$$\Delta P_S = F_L^{\,2}\left[(P1 + 14.7) - 0.93 * P_V\right]$$

Formula #2

ΔP_S is the ceiling value for the ΔP term in the first formula:

Important Concept → $C_V = Q\sqrt{\dfrac{G_f}{\Delta P \leftarrow}}$ must not exceed ΔP_S

The value of F_L varies slightly with different sizes of valve and different combinations of port size and body size, but for pinch valve sizing a constant value of $F_L = 0.68$ will yield sufficiently accurate results.

In real life situations it *is* entirely possible to have a pressure drop greater than ΔP_S. Furthermore, the valve will handle this ΔP and throttle properly. It is just that you cannot use this ΔP in Formula #1 to predict flow.

Quite simply: if ΔP is greater than ΔP_S then your process is in choked flow cavitation. A pressure in excess of ΔPs does nothing but create and collapse bubbles! That's why ΔP_S is the ceiling value for ΔP in equation 1.

If ΔP in equation 1 is higher than ΔP_S, go back to equation 1, throw out the original ΔP, substitute ΔP_S, recalculate C_V, and if necessary, select a larger valve.

Valve Characteristics

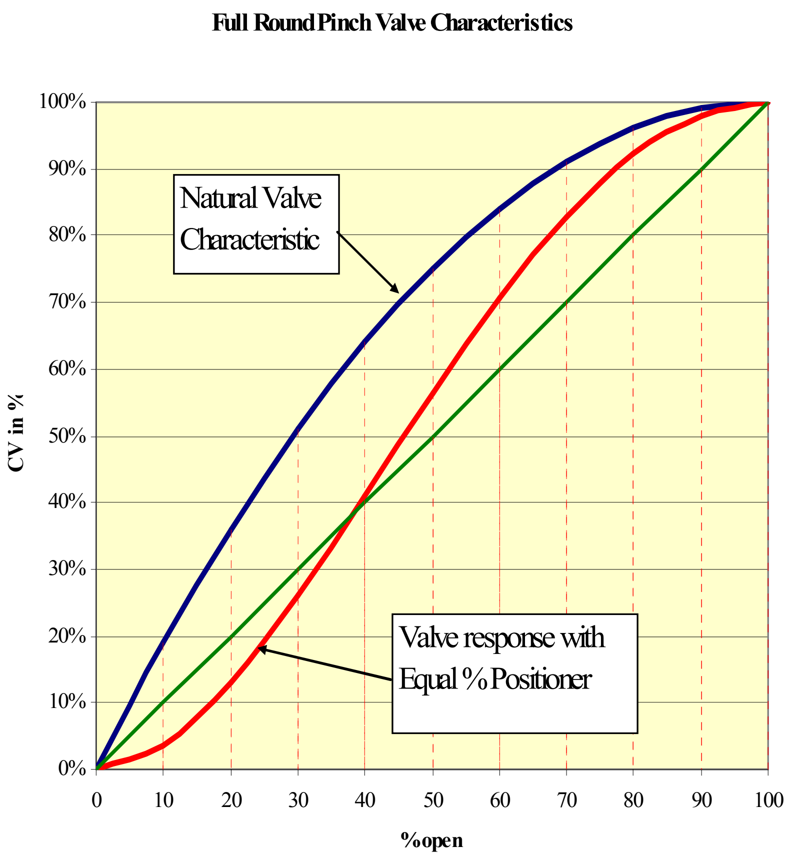
A correctly sized pinch valve makes excellent throttling valve.

Onyx Valve makes two different types of pinch valve, each with slightly different throttling characteristics:

1. Round opening type. This has a circular opening and includes the model CHR, CAR, CER, DHC, DAC, DEC, DHO, and DAO.

2. Pre-pinched type. This type has "D-shaped" opening, and includes the CHP, CAP, and CEP.

Both valves do an excellent job controlling flow.



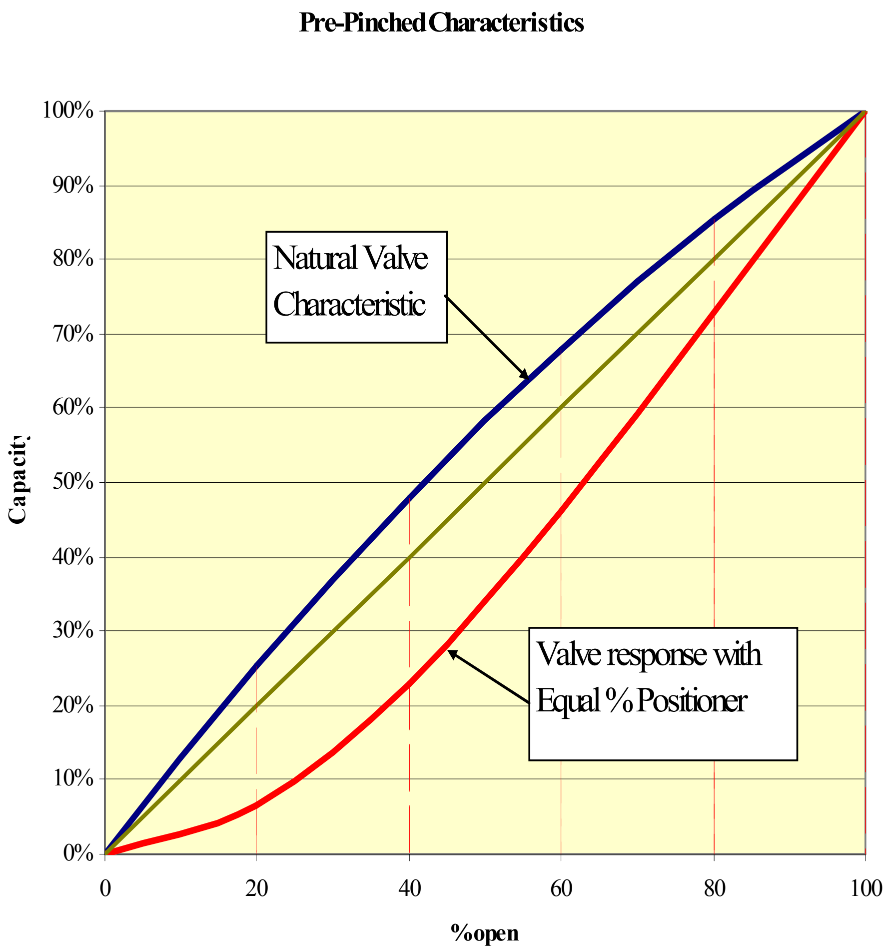
The Round Opening characteristic is illustrated at the left.

This series of valves has a slightly non-linear inherent characteristic, represented by the blue line in the graph.

All Onyx pinch valves are available with a digital, characterizable positioner. When the positioner is configured for "Equal Percent" response, the valve characteristic is modified to a more linear shape shown by the red line in the graph. This forces the valve into a response that stays within 10% of linear throughout its entire range, provides accurate, stable flow control.

The Pre-pinched characteristic is shown in the second graph.

The Pre-pinched valve has a more linear natural response, but its D-shaped opening can be susceptible to plugging than the round opening style of valve.



As with the round opening valve, the positioner can again be configured for "Equal Percentage" response. This produces very accurate flow control at the bottom end of valve stroke. At the top end the stem travels further in response to a given change in control signal. This yields fast response to process upsets in the higher flow region.

This characteristic allows higher turn down and increased stability over what would otherwise be possible. As a result, the valve is forgiving in applications where it may be slightly oversized or where other instruments in the control loop may not have sufficient stability or resolution to function as required.

VISCOSITY

When sizing valves for liquid considerably different in viscosity then water, this difference must be taken into account. In such cases, find the C_V required in the conventional manner, and then multiply by a viscosity correction factor. The viscosity correction factor is a function of Reynolds number, which in turn is a function of viscosity and flow rate.

1) Establish kinematic viscosity in centistokes. If viscosity is given as absolute viscosity, convert:

$$\upsilon_{kinematic}(centistokes) = \frac{\upsilon_{absolute}(centipoise)}{G_f}$$

2) Calculate Reynolds number:

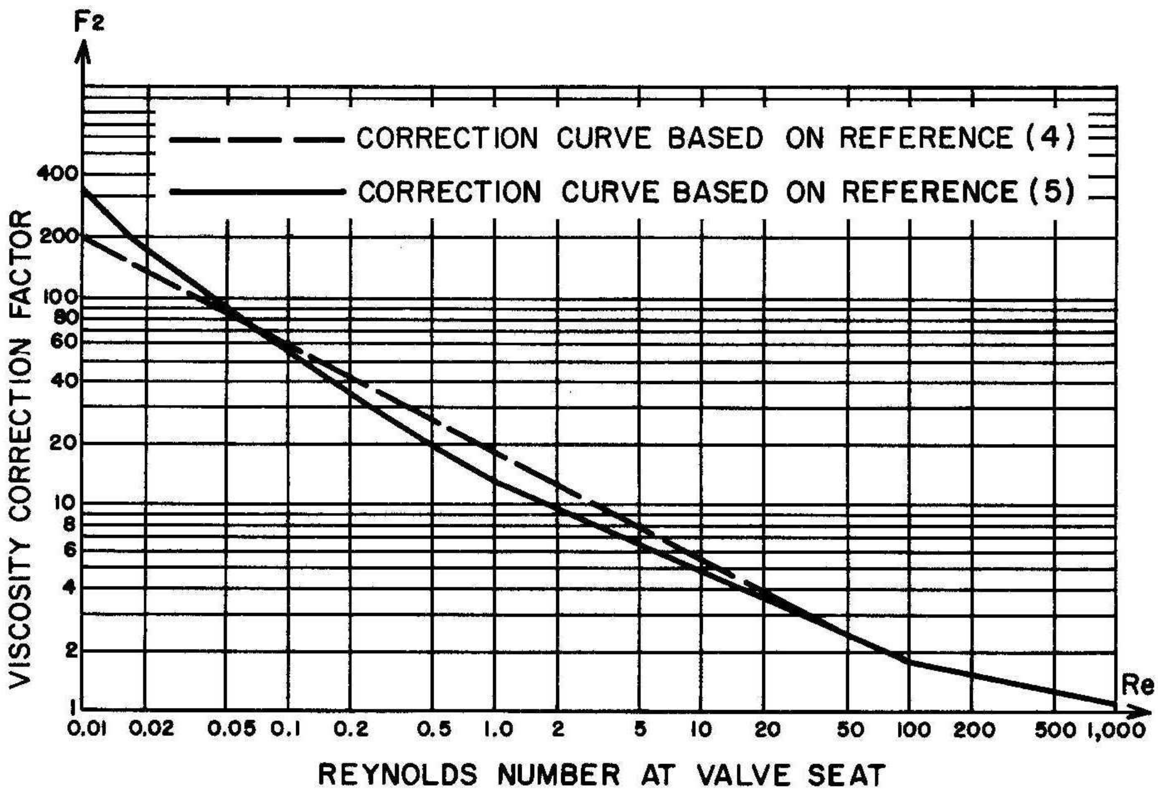
$$R_e = \frac{15{,}500\ Q}{\upsilon\sqrt{C_V}}$$

Where C_V is the capacity required as originally calculated if liquid was turbulent.

3) Refer to the viscosity correction graph for a correction factor "F".

4) Recalculate C_V:

$$C_V = F_{viscosity}\ Q\sqrt{\frac{G_f}{\Delta P}}$$



Summary

Valve sizing Data required:

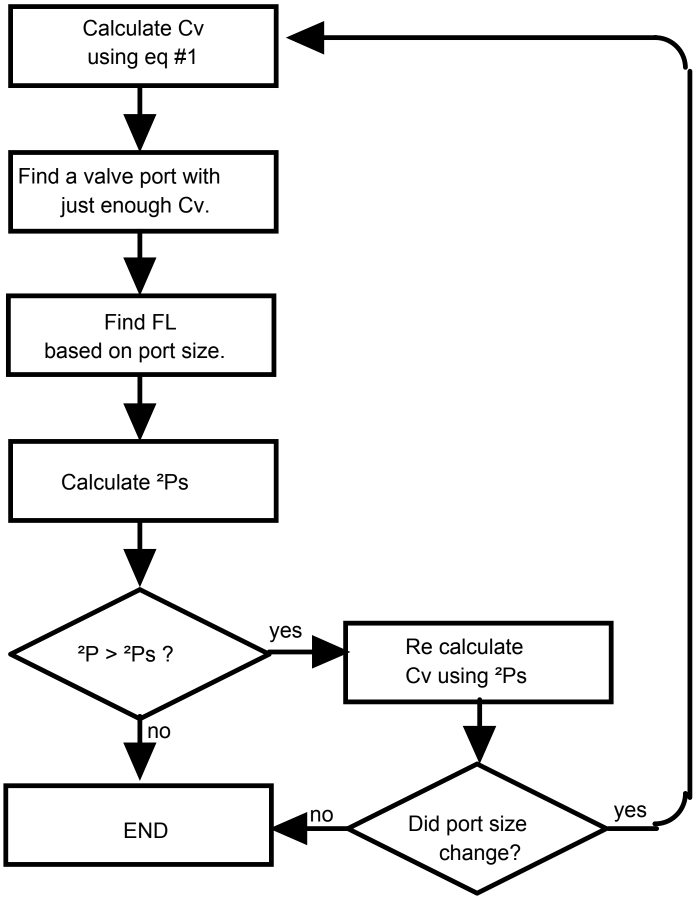
- Pipe size
- Q max. = maximum flow, US GPM
- Q norm = design flow, US GPM
- Q min. = minimum flow, US GPM
- P1 = inlet pressure, psi (at maximum, norm, and minimum flow)
- ΔP = pressure drop through the valve, psi (at maximum, norm, and minimum flow)
- Gf = specific gravity
- Pv = vapor pressure, PSIA

Notes:

a) The valve sizing data is valid for any combination of valve size and port size. For example, the C_V of a 3 x 1 is 29, so:
   - The capacity of a 3" valve with a 1" diameter port is 29.
   - The capacity of a 1" valve installed in a 3" pipe with reducers on the inlet and outlet is still 29.
   - In an installation with 3" pipe, 3 x 2 reducers, a 2" valve and a 1" port, the capacity is still 29. The only thing that matters is the pipe size and port size. How you get there is irrelevant.

Vapor Pressure Table

T ° F	P_V psia	T ° F	P_V psia	T ° F	P_V psia	T ° F	P_V psia
32	0.089	70	0.363	115	1.484	160	4.741
35	0.099	75	0.430	120	1.693	170	5.992
40	0.121	80	0.507	125	1.958	180	7.511
45	0.147	85	0.596	130	2.223	190	9.340
50	0.178	90	0.698	135	2.556	200	11.52
55	0.214	100	0.949	140	2.889	210	14.12
60	0.256	105	1.112	145	3.304	220	17.19
65	0.306	110	1.275	150	3.718	240	24.97



Nomenclature:		**Units**
C_V:	Liquid sizing coefficient...	US gpm
F_L:	Recovery constant.	unitless
G_f:	Specific gravity.	
	Ratio of density of liquid compared to water at 60°F.	
P_V:	Vapor pressure...	psia
P1:	Pressure at inlet to valve...	psig
P2:	Pressure at outlet of valve.	psig
ΔP:	Pressure drop across valve.	psi
	$\Delta P = P1 - P2$	
Q:	Flow..	US gpm
r_c:	Function of critical pressure and vapor pressure.......	unitless
	For pinch valves, this is 0.93	
Re:	Reynolds number...	unitless
v:	Viscosity	Centistokes

Pipe size: 3" Maximum flow: 650 gpm Inlet pressure: 35 psig Outlet pressure: 5 psig Specific gravity: 1.30 Temperature: 80° F	**step 1:** $\Delta P = P1 - P2$ $= 35 - 5$ $= 30$ psi
step 2: $C_V = Q\sqrt{\frac{G_f}{\Delta P}}$ $= 650\sqrt{\frac{1.3}{30}}$ $= 135$	**step 3:** Refer to capacity table. A 3 x 2 valve has C_V of 148, use $F_L = 0.68$
step 4: $\Delta P_S = F_L^2\left[(P1 + 14.7) - 0.93\ P_V\right]$ Refer to the vapor pressure table. Pv at 80° F is 0.507, so: $\Delta P_S = 0.68^2\left[(35 + 14.7) - 0.93 * 0.507\right]$ $= 22.7\ psi$ $\Delta P \geq \Delta P_S$	**step 5:** Since ?P is greater than ?P_S, we have to re-calculate C_V: $C_V = Q\sqrt{\frac{G_f}{\Delta P_S}}$ $= 650\sqrt{\frac{1.3}{22.7}}$ $= 156$

But 156 is greater than the capacity of a 3 x 2 valve, so we have to increase the port size to a 3 x 2.5 valve.

The 3 x 2.5 valve has a capacity of 293, and the C_V required is 156, so:

$$\frac{156}{293} = 0.58 \therefore\ valve\ is\ 53\%\ open.$$

Your options are to use a 3 inch valve with a 2.50 inch port, or you can use a 2.5 inch valve and 3 x 2.5 reducers on the inlet and outlet.