Valve Sizing and Selection

Sizing flow valves is a science with many rules of thumb that few people agree on. In this article I'll try to define a more standard procedure for sizing a valve as well as helping to select the appropriate type of valve. **Please note that the correlation within this article is for turbulent flow

STEP #1: **Define the system**

The system is pumping water from one tank to another through a piping system with a total pressure drop of 150 psi. The fluid is water at 70 ^{0}F. Design (maximum) flowrate of 150 gpm, operating flow rate of 110 gpm, and a minimum flowrate of 25 gpm. The pipe diameter is 3 inches. At 70 ^{0}F, water has a specific gravity of 1.0.

Key Variables: Total pressure drop, design flow, operating flow, minimum flow, pipe diameter, specific gravity

STEP #2: Define a maximum allowable pressure drop for the valve

When defining the allowable pressure drop across the valve, you should first investigate the pump. What is its maximum available head? Remember that the system pressure drop is limited by the pump. Essentially the Net Positive Suction Head Available (NPSHA) minus the Net Positive Suction Head Required (NPSHR) is the maximum available pressure drop for the valve to use and this must not be exceeded or another pump will be needed. It's important to remember the trade off, larger pressure drops increase the pumping cost (operating) and smaller pressure drops increase the valve cost because a larger valve is required (capital cost). The usual rule of thumb is that a valve should be designed to use 10-15% of the total pressure drop or 10 psi, whichever is greater. For our system, 10% of the total pressure drop is 15 psi which is what we'll use as our allowable pressure drop when the valve is wide open (the pump is our system is easily capable of the additional pressure drop).

STEP #3: Calculate the valve characteristic

$$C_v = Q\sqrt{\frac{G}{\Delta P}}$$

where:

$Q = \text{design flowrate (gpm)}$

$G = \text{specific gravity relative to water}$

$\Delta P = \text{allowable pressure drop across wide open valve}$

For our system,

$$C_v = 150\sqrt{\frac{1}{15}} = 38.7 \cong 39$$

At this point, some people would be tempted to go to the valve charts or characteristic curves and select a valve. Don't make this mistake, instead, proceed to Step #4!

STEP #4: Preliminary valve selection

Don't make the mistake of trying to match a valve with your calculated Cv value.   The Cv value should be used as a guide in the valve selection, not a hard and fast rule. Some other considerations are:

a. Never use a valve that is less than half the pipe size

b. Avoid using the lower 10% and upper 20% of the valve stroke. The valve is much easier to control in the 10-80% stroke range.

Before a valve can be selected, you have to decide what type of valve will be used (**See the list of valve types later in this article**). For our case, we'll assume we're using an equal percentage, globe valve (equal percentage will be explained later). The valve chart for this type of valve is shown below.   This is a typical chart that will be supplied by the manufacturer (as a matter of fact, it was!)

FLOW CHARAC-TERISTIC	VALVE SIZE		MAXI-MUM TRAVEL	PORT DIA.	DESIGNS ED AND ET (FLOW DOWN)					DESIGN ES (FLOW UP)				
					Valve Opening, Percent of Total Travel									
					10	30	70	100	100	10	30	70	100	100
	DIN	Inches	mm	mm	C_v				F_L	C_v				F_L
Equal Percentage	DN 25	1, 1-1/4	19	33.3	.783	2.20	7.83	17.2	.88	.783	1.86	9.54	17.4	.95
	DN 40	1-1/2	19	47.6	1.52	3.87	17.4	35.8	.84	1.54	3.57	17.2	33.4	.94
	DN 50	2	29	58.7	1.66	4.66	25.4	59.7	.85	1.74	4.72	25.0	56.2	.92
	DN 65	2-1/2	38	73.0	3.43	10.8	49.2	99.4	.84	4.05	10.6	45.5	82.7	.93
	DN 80	3	38	87.3	4.32	10.9	66.0	136	.82	4.05	10.0	59.0	121	.89
	DN 100	4	51	111.1	5.85	18.3	125	224	.82	6.56	17.3	103	203	.91
	DN 150	6	51	177.8	12.9	43.3	239	394	.85	13.2	41.1	223	357	.86
	DN 200	8	76	203.2	27.0	105	605	818	.96	25.9	97.8	618	808	.85
					X_T				- - -	X_T				- - -
	DN 25	1, 1-1/4	19	33.3	.766	.587	.743	.667	- - -	.754	.763	.630	.721	- - -
	DN 40	1-1/2	19	47.6	.780	.716	.690	.679	- - -	.674	.694	.698	.793	- - -
	DN 50	2	29	58.7	.827	.774	.702	.687	- - -	.863	.849	.792	.848	- - -
	DN 65	2-1/2	38	73.0	.778	.678	.661	.660	- - -	.747	.745	.783	.878	- - -
	DN 80	3	38	87.3	.774	.682	.663	.675	- - -	.768	.761	.754	.757	- - -
	DN 100	4	51	111.1	.731	.643	.672	.716	- - -	.722	.739	.718	.822	- - -
	DN 150	6	51	177.8	.688	.682	.736	.778	- - -	.723	.767	.808	.816	- - -
	DN 200	8	76	203.2	.644	.636	.725	.807	- - -	.825	.681	.735	.827	

For our case, it appears the 2 inch valve will work well for our Cv value at about 80-85% of the stroke range. Notice that we're not trying to squeeze our Cv into the 1 1/2 valve which would need to be at 100% stroke to handle our maximum flow.   If this valve were used, two consequences would be experienced: the pressure drop would be a little higher than 15 psi at our design (max) flow and the valve would be difficult to control at maximum flow. Also, there would be no room for error with this valve, but the valve we've chosen will allow for flow surges beyond the 150 gpm range with severe headaches!

So we've selected a valve...but are we ready to order? Not yet, there are still some characteristics to consider.

STEP #5: Check the Cv and stroke percentage at the minimum flow

If the stroke percentage falls below 10% at our minimum flow, a smaller valve may have to be used in some cases. Judgements plays role in many cases. For example, is your system more likely to operate closer to the maximum flowrates more often than the minimum flowrates? Or is it more likely to operate near the minimum flowrate for extended periods of time. It's difficult to find the perfect valve, but you should find one that operates well most of the time. Let's check the valve we've selected for our system:

$$C_v = 25\sqrt{\frac{1}{15}} = 6.5$$

Referring back to our valve chart, we see that a Cv of 6.5 would correspond to a stroke percentage of around 35-40% which is certainly acceptable. Notice that we used the maximum pressure drop of 15 psi once again in our calculation. Although the pressure drop across the valve will be lower at smaller flowrates, using the maximum value gives us a "worst case" scenario. If our Cv at the minimum flow would have been around 1.5, there would not really be a problem because the valve has a Cv of 1.66 at 10% stroke and since we use the maximum pressure drop, our estimate is conservative. Essentially, at lower pressure drops, Cv would only increase which in this case would be advantageous.

STEP #6: Check the gain across applicable flowrates

Gain is defined as:

$$\text{Gain} = \frac{\Delta\,\text{Flow}}{\Delta\,\text{Stroke or Travel}}$$

Now, at our three flowrates:
Qmin = 25 gpm
Qop = 110 gpm
Qdes = 150 gpm
we have corresponding Cv values of 6.5, 28, and 39. The corresponding stroke percentages are 35%, 73%, and 85% respectively. Now we construct the following table:

Flow (gpm)	Stroke (%)	Change in flow (gpm)	Change in Stroke (%)
25	35	110-25 = 85	73-35 = 38
110	73		
150	85	150-110 = 40	85-73 = 12

Gain #1 = 85/38 = 2.2
Gain #2 = 40/12 = 3.3

The difference between these values should be less than 50% of the higher value.
0.5 (3.3) = 1.65
and 3.3 - 2.2 = 1.10. Since 1.10 is less than 1.65, there should be no problem in controlling the valve. Also note that the gain should never be less than 0.50. So for our case, I believe our selected valve will do nicely!

OTHER NOTES:
Another valve characteristic that can be examined is called the choked flow. The relation uses the F_L value found on the valve chart. I recommend checking the choked flow for vastly different maximum and minimum flowrates. For example if the difference

between the maximum and minimum flows is above 90% of the maximum flow, you may want to check the choked flow. Usually, the rule of thumb for determining the maximum pressure drop across the valve also helps to avoid choking flow.

SELECTING A VALVE TYPE

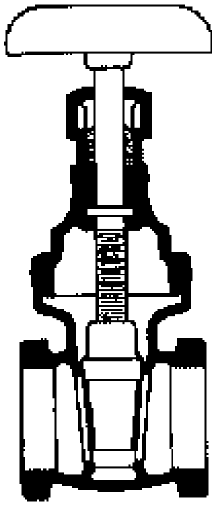
When speaking of valves, it's easy to get lost in the terminology. Valve types are used to describe the mechanical characteristics and geometry (Ex/ gate, ball, globe valves). We'll use valve control to refer to how the valve travel or stroke (openness) relates to the flow:
1. *Equal Percentage*: equal increments of valve travel produce an equal percentage in flow change
2. *Linear*: valve travel is directly proportional to the valve stoke
3. *Quick opening*: large increase in flow with a small change in valve stroke

So how do you decide which valve control to use? Here are some rules of thumb for each one:
1. *Equal Percentage (most commonly used valve control)*
a. Used in processes where large changes in pressure drop are expected
b. Used in processes where a small percentage of the total pressure drop is permitted by the valve
c. Used in temperature and pressure control loops

2. *Linear*
a. Used in liquid level or flow loops
b. Used in systems where the pressure drop across the valve is expected to remain fairly constant (ie. steady state systems)

3. *Quick Opening*
a. Used for frequent on-off service
b. Used for processes where "instantly" large flow is needed (ie. safety systems or cooling water systems)

Now that we've covered the various types of valve control, we'll take a look at the most common valve types.


Gate Valve

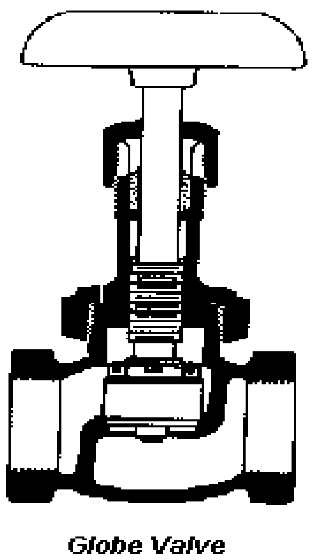
Gate Valves
Best Suited Control: Quick Opening

Recommended Uses:
1. Fully open/closed, non-throttling
2. Infrequent operation
3. Minimal fluid trapping in line

Applications: Oil, gas, air, slurries, heavy liquids, steam, noncondensing gases, and corrosive liquids

Advantages:
1. High capacity
2. Tight shutoff
3. Low cost
4. Little resistance to flow

Disadvantages:
1. Poor control
2. Cavitate at low pressure drops
3. Cannot be used for throttling



Globe Valves

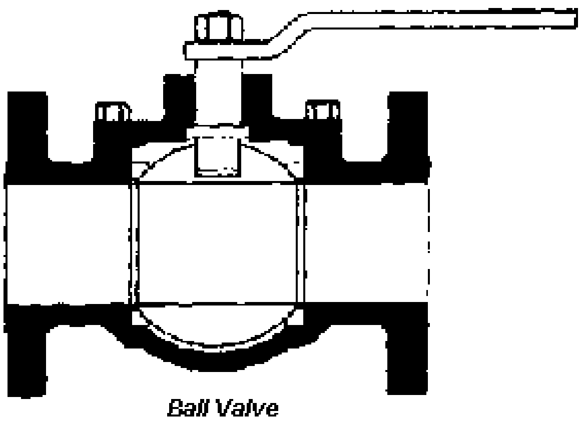
Best Suited Control: Linear and Equal percentage

Recommended Uses:
1. Throttling service/flow regulation
2. Frequent operation

Applications: Liquids, vapors, gases, corrosive substances, slurries

Advantages:
1. Efficient throttling
2. Accurate flow control
3. Available in multiple ports

Disadvantages:
1. High pressure drop
2. More expensive than other valves



Ball Valves

Best Suited Control: Quick opening, linear

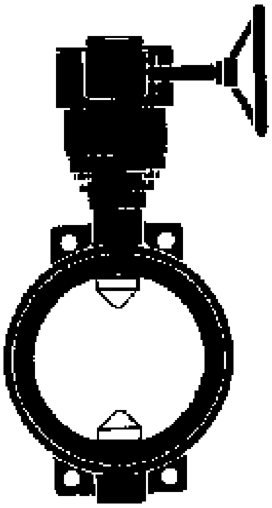
Recommended Uses:
1. Fully open/closed, limited-throttling
2. Higher temperature fluids

Applications: Most liquids, high temperatures, slurries

Advantages:
1. Low cost
2. High capacity
3. Low leakage and maint.
4. Tight sealing with low torque

Disadvantages:
1. Poor throttling characteristics
2. Prone to cavitation

Butterfly Valves



Butterfly Valve

Best Suited Control: Linear, Equal percentage

Recommended Uses:
1. Fully open/closed or throttling services
2. Frequent operation
3. Minimal fluid trapping in line

Applications: Liquids, gases, slurries, liquids with suspended solids

Advantages:
1. Low cost and maint.
2. High capacity
3. Good flow control
4. Low pressure drop

Disadvantages:
1. High torque required for control
2. Prone to cavitation at lower flows

Other Valves

Another type of valve commonly used in conjunction with other valves is called a check valve. Check valves are designed to restrict the flow to one direction. If the flow reverses direction, the check valve closes. Relief valves are used to regulate the operating pressure of incompressible flow. Safety valves are used to release excess pressure in gases or compressible fluids.

References:

Rosaler, Robert C., Standard Handbook of Plant Engineering, McGraw-Hill, New York, 1995, pages 10-110 through 10-122
Purcell, Michael K., "Easily Select and Size Control Valves", Chemical Engineering Progress, March 1999, pages 45-50