White Paper

Minimizing Energy Consumption Through Valve Selection

Table of Contents

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Introduction

Valves play an important role in water systems by controlling flow and pressure, releasing air, and preventing backflow. One important characteristic of valves in water pumping systems that is often overlooked is the valve's ability to minimize energy consumption. Most engineers are familiar with valve headloss calculations and how they can predict pumping costs but few are aware that the published headloss characteristics of valves presume optimum valve operation (i.e. full-open), which can be affected by valve sizing and flow velocities. Further, studies have shown that the use of air valves can improve the flow efficiency of a water pipeline and thereby reduce energy consumption.

While it is important to judge valves on the basis of their headloss characteristics, it will be shown that other characteristics are equally as important. In other words, to minimize energy consumption, an engineer should not simply always select the valve that has the lowest headloss. This paper will discuss the flow and operating characteristics of various check valves and pipeline valves and how they impact system performance. Further, the concept of placing and selecting air valves to prevent air binding will be explored.

With an understanding of the effect of various valves on the energy consumption of a system, engineers can calculate the life cycle costs of valve alternatives and make the best decision for the water utility.

Headloss Calculations

The pump head is needed to overcome the combination of the static head and the friction head of the distribution system. The static head is the difference in elevation between the source and the highest point of water storage. The friction head is caused by roughness in the pipe and local flow disturbances in fittings and valves. Pumping and distribution system valves come in many varieties, but they all cause friction head in the same ways.

Body geometry dictates the general flow area through the valve. Some valves restrict the flow area to below 80% of the pipe area. Also, the internal contours of the body and seat should be smooth to avoid creating excessive turbulence. The valve body diameter and laying lengths are sometimes much greater than the pipe size to achieve a smooth flow pattern. If the port area is equal to the pipe size, then the closure member or disc needs to be somewhat larger to affect a seal. The body is contoured outward around the disc to achieve a full flow area through the valve. These types of bodies are called globe style (Figure 1). Other valves take advantage of an angled seat so that the pipe area can be maintained through the port without greatly increasing the size of the valve body (Figure 2).

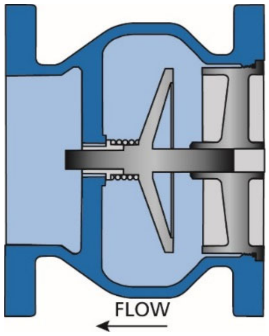

FIGURE 1. Silent Check Valve with Globe Style Body Provides 100% Flow Area

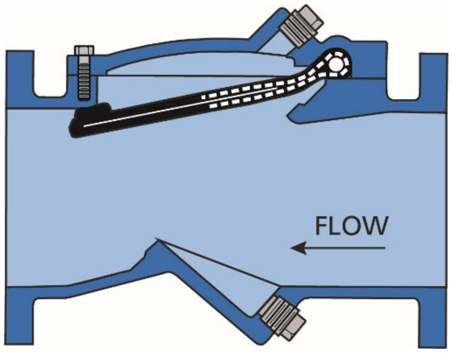

FIGURE 2. Resilient Hinge Check Valve with Angled Seat Provides 100% Flow Area

The design of the closure member or disc is important for two reasons. First, the lowest headloss will be achieved if the disc swings or rotates out of the flow path (Figure 2). Discs can also have special contours and shapes to fully open at low fluid velocities and create a smooth flow path through the valve. Second, disc geometry is often designed to provide a short stroke as shown in Figure 1. The disc in Figure 2 has only a 35 degree stroke. The short stroke allows the valve to close faster to prevent check valve slam.

It is normally considered a simple matter to compute the headloss produced by various types of valves. There are many types of flow coefficients and headloss formulas in general use today for rating of various valves on the basis of headloss. Probably the most ubiquitous flow coefficient for water valves is the Cv flow coefficient, which is defined as the amount of water in gallons per minute (gpm) that will pass through a valve with a 1 psi pressure drop. Hence, the more efficient the valve, the greater the valve Cv.

Unfortunately, Cv's are rather large numbers and vary widely (Figure 3), which make comparisons between alternate valves difficult. Further, Cv's are approximately proportional to the square of the valve diameter, so large valves (i.e. 72 inch) have Cv's as high as 250,000 or more. Cv should not be confused with the valve capacity. For example, the 12 inch ball valve has a Cv of 21,500 which far exceeds its capacity of 8,500 gpm or 35 ft/sec (AWWA C507, 1), thus, Cv should only be used for computing headloss, not determining the valve's flow capacity.

12 inch Valve Flow Data			
Type of Valve	**Port Size**	**Cv**	**Kv**
Control Valve	100%	1,800	5.70
Silent Check Valve	100%	2,500	2.95
Dual Disc® Check Valve	80%	4,000	1.15
Swing Check Valve	100%	4,200	1.05
Ball Check Valve	100%	4,700	0.83
Eccentric Plug Valve	80%	4,750	0.81
Flex Hinge Check Valve	100%	4,800	0.80
Tilted Disc® Check Valve	140%	5,400	0.63
Butterfly Valve	90%	6,550	0.43
Ball Valve	100%	21,500	0.04

FIGURE 3. Valve Types and Flow Coefficients

A better flow coefficient to use for making comparisons is the resistance coefficient Kv used in the general valve and fitting flow formula:

$$\Delta H = K_v v^2 / 2g$$

Where:

ΔH = headloss, feet of water column

K_v = resistance coefficient (valve), dimensionless

v = fluid velocity, ft/sec

g = gravity, 32.2 ft/sec^2

The flow factor K_v can also be related to the C_v by the formula:

$$K_v = 890\ d^4 / C_v^2$$

Where:

d = valve diameter, inch

Not only are the Kv factors for various valves similar in magnitude, but they are similar from size to size. For example, geometrically similar 12 inch valve and 72 inch valves may have nearly identical Kv's. Because of the similarity, Kv's are ideal for use in comparing valves and fittings. With the understanding that a run of 100 feet of steel pipe has a K of 1.5, an engineer can easily understand the relative impact a valve has on the total piping system pressure loss. For example, the silent check valve has a Kv of 2.9 which would be equivalent to the loss produced by about 200 feet of pipe.

Comparisons can also be made between various manufacturers for the same type of valve. For example, the published Kv's for 12 inch silent check valves from three prominent suppliers in the U.S. water industry are 2.9, 2.8, and 2.7. The magnitude of these differences are not significant when compared to the total K of a piping system which usually exceeds 50. The lesson here is that, while it is important to consider the headloss between types of valves, the headloss between various suppliers of a given valve type does not typically produce significant changes in system operation. This is why piping system computer simulations can accurately model system behavior based on generic valve characteristic data. Given that design differences between brands are small and testing methods can vary, slight differences in published flow data among manufacturers can usually be ignored.

Finally, the flow conditions of the system can affect the valve headloss. From the ΔH equation, it is clear that headloss is a function of fluid velocity squared. Hence, a doubling of the line velocity will increase the pipe, fitting, and valve headlosses four-fold. This is why pipeline velocities are typically held in the 4 to 8 ft/sec range even though the pump discharge velocities are often higher. Further, the velocity may affect the open position of the valve. Swing type check valves may require between 4 and 8 ft/sec of velocity to be forced fully open by the flow. If the valve is not full open, the headloss can be significantly higher than the published headloss, even double. Hence, a curve of flow coefficient versus fluid velocity should be employed when computing headloss for swing-type check valves.

Since valve coefficients and headloss are a function of velocity, the overall cost of energy consumption versus pipe costs must be evaluated. There is an optimum pipe size and velocity that provides the least present cost of installation costs plus annual operating costs. Many general guidelines and formulas are available for this analysis (Patton, 317).

Energy Calculations

It has been estimated that the water and wastewater plants in the United States consume 75 billion kW·h of energy annually. For water plants nearly 80% of that energy is consumed for high service pumping costs to overcome the static head and friction losses of distribution systems. Water utilities have the opportunity to employ various energy saving strategies that could result in a 20 to 50 percent reduction in energy consumption and likewise, operating costs (Oliver, 1). Energy costs typically have at least two main components, an energy charge and a demand charge. The energy charge represents the consumption of kilowatt hours of electricity with a typical cost of about $ 0.04 per kW·h. Surprisingly, the demand charge can be a higher charge and represents the cost of electrical generating capacity at a cost of about $10.00 per kW. The demand charge may also be affected by the time of the day with savings associated with pumping water during off-peak hours.

The headloss from valves can be converted into an energy cost related to the pumping electrical power needed to overcome the additional headloss from the valve with the equation (AWWA, 25):

$$A = (1.65\ Q\ \Delta H\ S_g\ C\ U) / E$$

Where:

A = annual energy cost, dollars per year

Q = flow rate, gpm

ΔH = head loss, ft. of water

S_g = specific gravity, dimensionless (water = 1.0)

C = cost of electricity, \$/kW·h

U = usage, percent x 100 (1.0 equals 24 hr per day)

E = efficiency of pump and motor set (0.80 typical)

Alternatively, the energy consumption difference between two valve selections can be calculated by using the headloss difference between the two valves for the variable ΔH in the equation above. For example, the difference in headloss between a 12 inch silent check valve and a tilted disc check valve in a 4,500 gpm system operating 50% of the time can be calculated as follows:

$$\begin{aligned}\Delta H &= (2.95 - 0.63)\,(12.7)^2 / 2\cdot 32.2 \\ &= 2.50 \text{ ft. wc}\end{aligned}$$

$$\begin{aligned}A &= (1.65 \times 4500 \times 2.50 \times 1.0 \times 0.04 \times 0.5) / (0.8) \\ &= \$464\end{aligned}$$

The calculation shows that the use of a 12 inch tilted disc check valve in the place of a 12 inch silent check valve can save $464 per year in energy costs. If the pump station had four such valves operating for forty years, the total savings will be $74,240 over the life of the plant. Similar savings may also be achieved due to the reduced demand charges. Therefore, it is clear that valve selection can play an important role is energy savings.

Valve Characteristics

While important, headloss characteristics of valves cannot be the sole reason for making a valve selection. Headloss is only a contributing factor to the total cost of the valve. Other cost considerations are the purchase, installation, and maintenance costs. Also, various types of valves can have laying length dimensions that vary widely requiring an increase in the size of the pumping pit or valve vault. Many swing type-check valves require five straight pipe diameters upstream to prevent damaging vibration to the valve (MSS, 3). Maintenance costs can be high with some valves especially when

VALVE LIFE CYCLE COSTS

- Purchase Cost
- Installation Cost
- Maintenance Cost
- Energy Cost

the cost of system downtime is considered. These other costs need to be estimated and combined to provide the valve life cycle costs.

A second characteristic of valves that is important is the inherent flow characteristic of the valve. Some valves will linearly reduce the flow rate in proportion to the movement of the closure member while some valves may only affect flow rate during their last 30% of closure. If the valve is merely an isolation valve, the flow characteristic is not important, but if the valve is used to control flow or pressure, then the flow characteristic will be of paramount importance.

Further, check valves can sometimes produce valve slam and water hammer, which can wreak havoc on a pumping system. In general, to avoid these problems, a check valve must close either extremely fast or extremely slow. Various types of check valves are available to provide either function and many are equipped with auxiliary equipment such as dashpots, power actuators, and springs to provide special functions. If the pump is not capable of withstanding backspin or the pump station is equipped with a hydro-pneumatic surge tank, then a slow closing check valve may not be appropriate. An automatic fast-closing check valve should be selected carefully, given proper consideration to its dynamic closing characteristic (Val-Matic).

Finally, valves may be differentiated by their capability of handling various fluids. Valves with spokes such as the silent check valve, dual disc check valve or valves with rotating discs such as the tilted disc check valve and the butterfly valve are not recommended for wastewater containing suspended solids. Valves have either metal-to-metal or resilient seats. Metal-seated valves can provide a long-reliable life but if zero leakage is required, then valves equipped with resilient seats should be used.

Valve selection is a complex process that involves detailed analysis of system operation and valve performance characteristics. Check valves and pipeline valves should be chosen with full consideration to the valve life cycle costs including energy costs, inherent flow characteristics, slamming characteristics, and seating characteristics.

Air Binding

Another family of valves that is important for energy conservation is the air valve. It often surprises a pipeline designer that the cause of a pumping system's inefficiency or even stoppage is a result of trapped air in the pipeline. One common misconception is that it is easier to pump against air instead of water. However, when a pipeline contains highpoints followed by descending runs, air can be trapped in pressurized pockets downstream of the highpoint due to the buoyancy of the air. As shown in Figure 4, trapped air forms a long pocket along the pipe descent with a constant depth "d". Since the air is at the same pressure along the air pocket, it can be shown that the headloss is equal to the vertical height of the pocket or dimension "H" (Edmunds, 272).

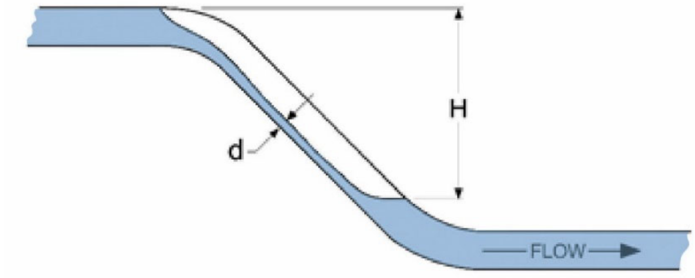

FIGURE 4. Headloss Due to Air Pocket

When there are several highpoints in a pipeline, the headlosses are additive. During initial pump startup, the line can appear to be blocked because the pump cannot overcome the sum of the headlosses in all of the highpoints, even at the pump shutoff pressure.

The length of the pocket, and hence, the magnitude of the headloss is a function of how much air accumulates. The source of the air can be from the system inlet, changes in water pressure, or intentional air entry through air valves. The air can be removed by entrainment of bubbles at the downstream end, sweeping the pocket downstream by the velocity, or by an automatic air valve located at the top of the pocket.

The entrainment process is a slow and inefficient process and often does not keep up with the supply of air from pumping and other sources. Better is the possibility of sweeping the air pocket downstream with velocity. As can be expected, the velocity necessary to move the pocket is related to the slope of the descending line. For a 24 inch diameter pipe, the velocities needed to sweep the air pocket are shown in Figure 5.

Required Velocities to Sweep Air from 24 inch Diameter Pipe Slopes			
0%	**5%**	**25%**	**100%**
6.6 ft/sec	7.1 ft/sec	7.6 ft/sec	8.3 ft/sec

FIGURE 5. 24 inch Pipeline Velocities (Sanks, p. 904)

Studies also show that as the size of the pipe diameter grows, the required velocities to sweep air pockets increases dramatically. Typically the required velocity is proportional to the pipe diameter. For a 48 inch pipeline, the velocities in Figure 6 would need to be doubled. The simplest solution around this problem includes the careful design of the pipe grade to avoid downslopes. Additional excavation in some areas can eliminate a highpoint and subsequent downgrade. Also, increased velocities can be used to help expel air from the high points. Alternatively, the use of automatic air valves can be used to eliminate the air and restore the pumping efficiency of the pipeline without the potentially high costs of extra excavation or flow velocities (recall that doubling the flow velocity quadruples the system energy costs).

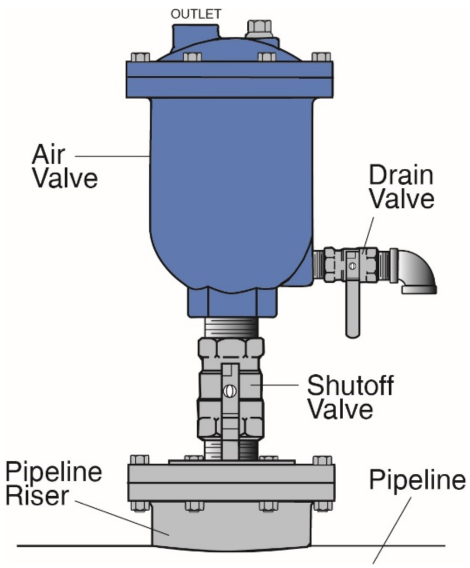

FIGURE 6. Air Valve Directly Mounted on Pipeline

Air valves can be directly mounted to the top of the pipeline and serve several functions. An air/vacuum valve has a large orifice equal to about one-quarter the diameter of the pipeline and is used to vent large quantities of air during pipeline filling. The valve also allows the rapid entry of air to prevent a vacuum from forming in the pipeline during draining or after a power failure. Once pressurized and closed, an air/vacuum valve will no longer vent pressurized air. An air release valve is needed for that purpose. An air release valve has a small orifice (i.e. 0.125 in. diameter) and vents air while the pipeline is in operation and under pressure. The third type of air valve is the combination air valve, which performs all of the functions of the air/vacuum and air release valves. Combination air valves are usually installed at all high points and major changes in grade to automatically vent air and prevent the formation of vacuum conditions. The location and sizing of air valves are presented in the AWWA Manual M51.

The importance of air valves cannot be overlooked. They not only maintain the flow efficiency of a pipeline by venting accumulated air, but also perform many other functions including surge control and vacuum protection.

Conclusion

Valves play an important role in the operation of the piping system. Care in their selection and placement can greatly enhance the energy efficiency of the system. While it is important to calculate the headloss and energy costs associated with valves, many other valve characteristics must be considered to guarantee the best selection of valve type for a given application.

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