# Calculating Most-Open-Valve Aeration Control

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*By Tom Jenkins, P.E., President of JenTech Inc.*

Most-Open-Valve (MOV) can be a cost-effective way to optimize aeration energy. It can also be a confusing and troublesome addition to a process automation project. In my experience MOV is the least understood aspect of aeration control. This article will shed light on MOV, the process and energy impacts and why it's worth the trouble.

## MOV Benefits

Many engineers and operators think MOV is part of the blower control system or part of the DO control logic. MOV integrates with blower and DO control, and they affect each other. However, MOV is a separate aspect of the control logic.

MOV is a method of minimizing the pressure of the air distribution system, thereby minimizing the discharge pressure of the blowers. Reducing pressure reduces aeration blower power. Reduced power results in lower energy cost to meet the process air demand.

Many parameters influence blower power:

$$P_{wa} = \frac{Q_s \cdot T_i}{\eta_{wa} \cdot 3131.6} \cdot \left[ \left( \frac{p_d}{p_i} \right)^{\frac{k-1}{k}} - 1 \right]$$

$$\frac{k-1}{k} \approx 0.283$$

Where:

$P_{wa}$ = wire-to-air power, kW

$Q_s$ = flow rate, SCFM

$T_i$ = inlet air temperature, °R

$\eta_{wa}$ = wire to air efficiency, decimal (includes blower, motor, and VFD)

$p_d$ and $p_i$ = discharge and inlet pressure, psia

k = ratio of heat capacity = Cp/Cv, dimensionless, ≈ 1.4 for air

Most factors determining wire-to-air power are beyond the control of the operator or the design engineer. Flow rate is determined by process demand, and DO control automatically alters flow rates as process load changes. Inlet air temperature and pressure are dictated by ambient conditions. Wire-to-air efficiency varies across the blower operating range and is established by equipment selection.

Discharge pressure is a function of air flow rate and the air distribution system's resistance to flow. The control system can manipulate discharge pressure – within limits.

System pressure includes two independent components. Their sum creates the system curve, i.e. the total pressure the blower must produce as a function of air flow rate.

$$p_{total} = d \cdot 0.433 + k_f \cdot Q_s^2$$

Where:

$p_{total}$ = total discharge pressure, psig

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$d$ = depth of water at top of diffuser, feet

$k_f$ = constant of proportionality for friction, psi/SCFM$^2$

$Q_s$ = flow rate, SCFM

The value of $d \cdot 0.433$ represents static pressure, typically 80% of total pressure in aeration systems. For conventional activated sludge, the static pressure is constant. For Sequencing Batch Reactors (SBRs), aerobic digesters and equalization basins the water depth and static pressure fluctuate.

The value of $k_f \cdot Q_s^2$ is the friction loss from air moving through pipes, diffusers and valves. For a given system, the pipe and diffuser losses are set by the design.

The remaining component of friction loss, pressure drop through valves, constantly varies as valve position and air flow change.

$$\Delta p_v = \left(\frac{Q_s}{22.66 \cdot C_v}\right)^2 \cdot \frac{SG \cdot T_u}{p_u}$$

Where:

$\Delta p_v$ = pressure drop across the valve, psi

$Q_s$ = air flow rate, SCFM

$C_v$ = valve flow coefficient from the manufacturer, dimensionless

SG = specific gravity, dimensionless, = 1.0 for air

$T_u$ = upstream absolute air temperature, °R

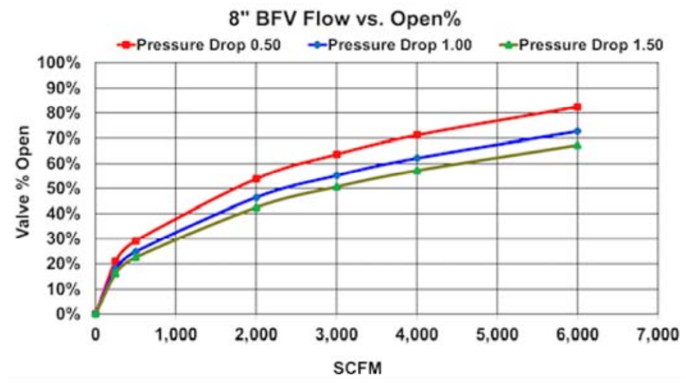
$p_u$ = upstream absolute air pressure, psia

As valve opening increases at constant flow, $C_v$ increases and $\Delta p_v$ decreases. The objective of MOV is to minimize power by minimizing blower discharge pressure. This is accomplished by keeping the basin valves as close to maximum position as possible. The valve at maximum position is referred to as the “Most-Open-Valve,” giving rise to the name of the technique.

## Air Flow Control Basics

The $C_v$ for a valve is defined as the gpm of water the valve will pass at 1.0 psi pressure differential. It is determined by valve geometry, size and opening. [See Figure 1.] The most common valve type for aeration air flow control is the butterfly valve (BFV). This is largely dictated by economics. Butterfly valves are generally lower cost than other types of valves, like specialized knife gate valves, that have better flow control characteristics.

**Figure 1: Typical Flow Response for Butterfly Valves**



Air flow control with a BFV is non-linear. As the valve disk closes and approaches the seat, small changes in position create large changes in flow at constant Δp. Conversely, when the valve is nearly open, large changes in

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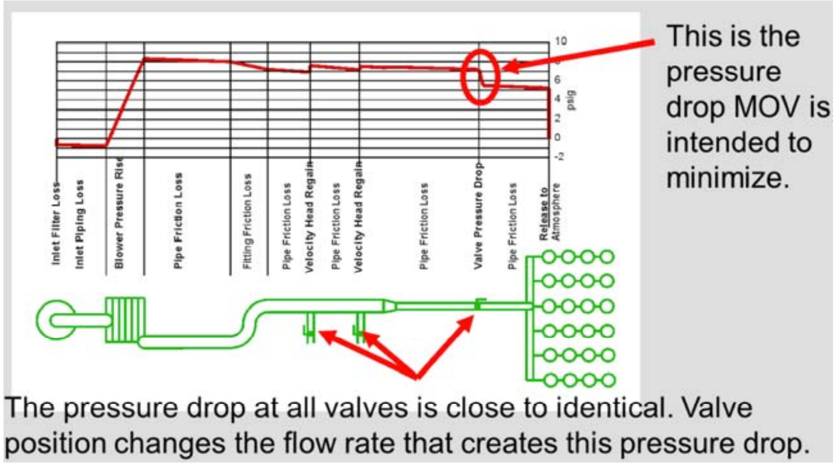
position result in minimal changes in flow. To maintain effective control, the travel range for a BFV is commonly kept between 20% to 70% open.

It is apparent in any given position a valve may pass a wide range of air flows, depending on pressure differential. At 50% open, for example, the flow rate changes from 1,700 scfm to 3,000 scfm with a 1.0 psi change in Δp. This magnitude of pressure variation is common in aeration. Similarly, with a changing Δp the BFV can maintain 3,000 scfm by moving from 50% to 64% open.

Air pressure constantly changes along the length of aeration piping. [See Figure 2.] The pressure rises through the blower, and gradually dissipates from friction through the system. At the point of release from the diffuser into the wastewater, pressure exactly equals static pressure. As the bubbles rise, the pressure returns to atmospheric.

**Figure 2: Pressure Changes in an Air Distribution System**

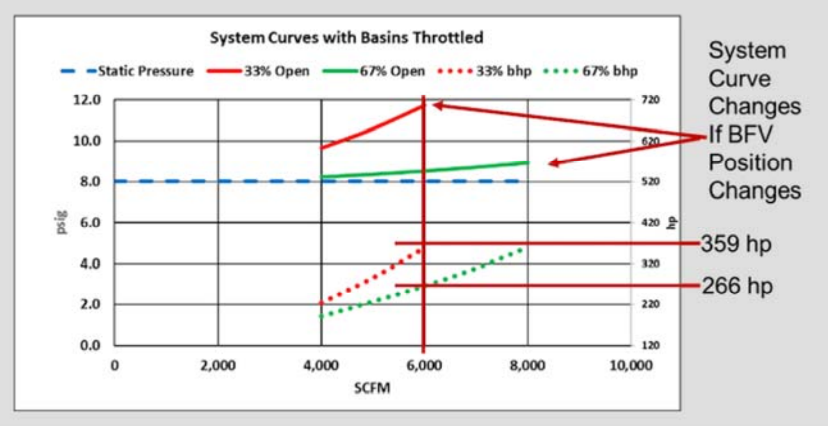


This is the pressure drop MOV is intended to minimize.

The pressure drop at all valves is close to identical. Valve position changes the flow rate that creates this pressure drop.

Two important aspects of the air distribution system are illustrated by Figure 2. First, MOV logic only controls one of many pressure drops in a system. Second, the Δp across all basin flow control valves is essentially identical. For a given set of operating conditions, changing BFV position merely changes the air flow rate required to create that Δp. This effectively changes the system curve and power demand. [See Figure 3.] If the total air flow rate remains constant, then changing one valve's position will shift the air flow from that basin to the others. This changes the proportion of total flow going to each basin. [See Figure 4]

**Figure 3: Changes in BFV Position and System Curves**

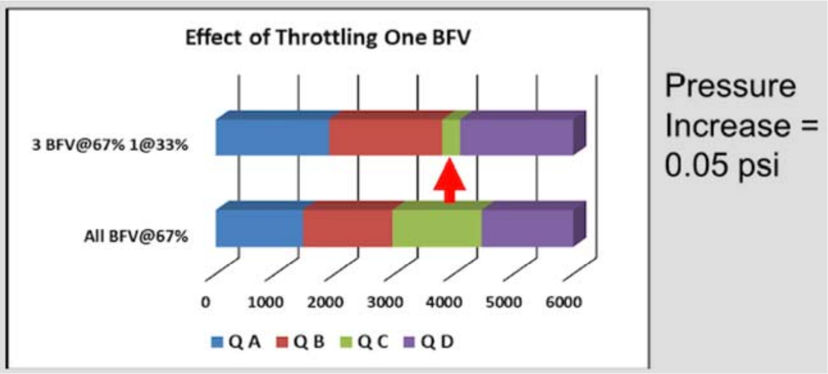


System Curve Changes If BFV Position Changes

359 hp

266 hp

**Figure 4: Changing Flow Proportions**



These relationships are integral to understanding MOV control logic. At any time, there will be one BFV representing the "worst case." That is, one control location will have a combination of flow rate and valve restriction ($C_v$), dictating the minimum pressure required to provide the air flow needed to meet process demand. The objective of MOV is to have this valve be at the maximum open position and minimize Δp. This in turn minimizes the blower power demand. The valve at maximum position is the system's "most-open-valve."

### Pressure Based Systems

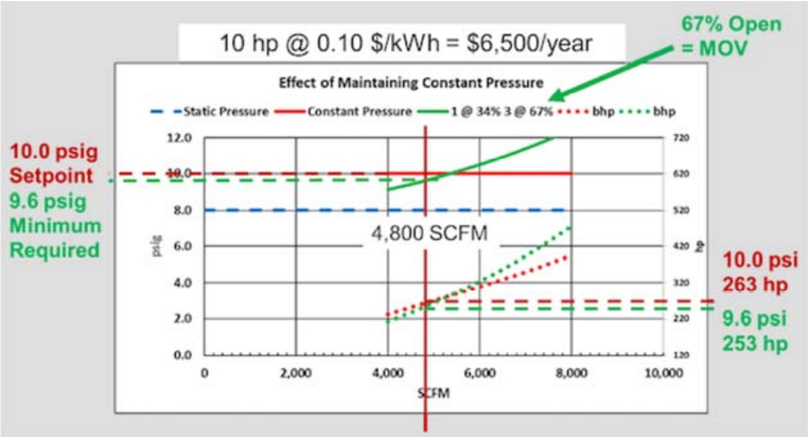
Blower control can operate in one of two ways. It can maintain a set flow rate and let the pressure vary as required by the system restriction. Conversely, it can maintain constant pressure and vary the flow to generate that pressure.

Due to technological limitations, early aeration and blower control systems used independent, single loop, feedback controllers. When a basin control valve was modulated to a more open position, the system's total restriction would decrease and the system curve would become flatter. A larger proportion of the total flow would go to the modulated basin, and a smaller proportion to the other basins. If the system had a manually controlled centrifugal blower, the pressure decrease would increase the total system air flow as well.

The designers' response to these interactions was to maintain constant pressure. If the system restriction decreased, the pressure controller would increase the blower flow. If the other basin valves held position, the Δp would stay the same and so would the air flow through those valves. Theoretically, the increase in total air flow would match the desired increase in the modulated basin, and all other basins would be unaffected.

The problem with this system was if the pressure was set too high it wasted energy. This was particularly true during periods of low process air demand. [See Figure 5.]

**Figure 5: Blower Power with Pressure Control**



MOV logic was developed to minimize wasted power. In pressure based systems, MOV functions by changing the pressure setpoint. In the above example if the most-open-valve position was below a certain threshold, say 50%, the pressure setpoint would decrease by a fixed increment. This would force a decrease in blower and total system air flow to drop the pressure. This in turn would cause all basin valves to open to increase their air flow rate. The restriction decrease would drop system pressure, forcing the pressure control loop to increase blower air flow again. After a few iterations the system would in theory, stabilize with the desired air flow to all basins, reduce system pressure and have a greater opening at the most-open-valve.

## Flow Based Systems

Pressure based systems, with or without MOV, were likely to experience problems. Tuning the controllers was intimidating for many operators. If tuning and response times were not compatible, both blower and aeration basin controls began hunting. Adding the complex interactions of MOV increased the tendency to hunt. The deadband between maximum and minimum valve position meant the discharge pressure was not always optimized.

Early controllers limited the interface between devices to a single electrical or pneumatic signal. Modern control technology includes communications links, networked controllers and consolidation of multiple control functions into one controller. Coordination of related process control functions is possible. The programming task may be more complicated, but stability and performance are improved.

Newer direct flow based DO controls take advantage of the data exchange capability to blend the various functions of blower and aeration basin control. Multiple process air flow demands are combined. The total demand is matched with the air flow supplied by multiple blowers. This eliminates the need for pressure control. The iterations of the control logic needed to achieve equilibrium are reduced.

A flow based master controller can access the position of every valve in a system. If none of the BFVs are in the maximum position, it can make required adjustments. Most importantly, it provides control based on actual process equipment functions. It uses the blower controls to match total air flow to process demand. It uses basin flow control valves to divide the total air flow to the basins in proportion to their individual demands.

Flow based systems inhibit movement of the most-open-valve, until another valve reaches maximum position. Air is divided in proportion to process demand. If the zone with the most-open-valve has excess flow, then another zone will have insufficient flow. The BFV in the zone with insufficient flow will open, and at some point, it will reach maximum position. The original valve is then allowed to close. One valve will always be at maximum position.

## Effects of Blower and Blower Control Type

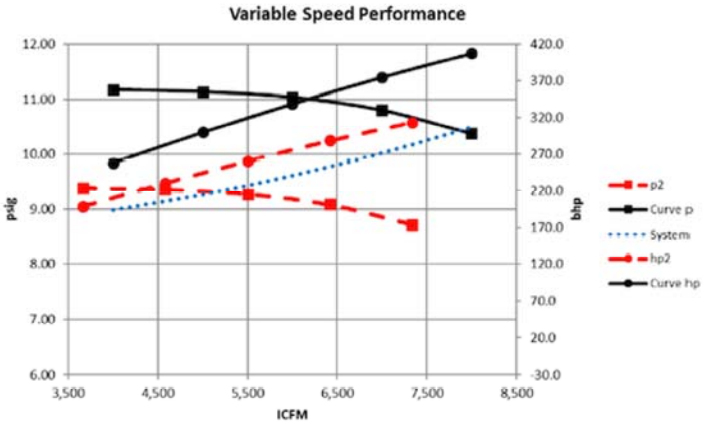
The improvement in energy consumption from MOV depends on the type of blower and the type of blower control. MOV can minimize pressure, but not all blower systems benefit equally from the reduction.

Positive displacement (PD) blowers maximize the power reduction. The air flow rate delivered by PD blowers is controlled by seed variation. Discharge pressure inherently rises and falls to match the system requirement, and blower power is linear with discharge pressure. If discharge pressure drops, the power draw drops.

Centrifugal (dynamic) blowers exhibit a performance curve identifying the pressure capability and power draw at specific flow rates and inlet conditions. The intersection of system curve and blower curve establishes the operating flow rate. This, in turn, defines the blower’s power demand. Centrifugal blowers are controlled by devices modifying the performance curve.

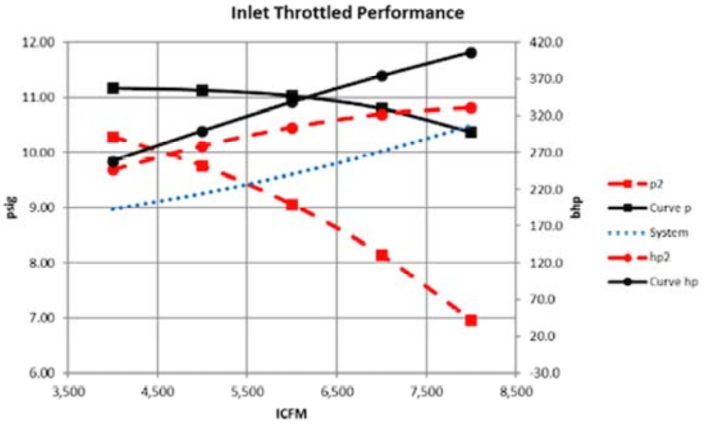
Reducing the speed of a centrifugal blower shifts the performance curve down and to the left. [See Figure 6.] At reduced speed the pressure ratio is reduced, and therefore the pressure increase from inlet to discharge is also reduced. The intersection of the performance curve with the system curve shifts to a lower flow. This is the most efficient way to control centrifugal blowers, since both flow and pressure ratio are reduced. The benefit of MOV logic is maximized with this control method.

**Figure 6: Centrifugal Blower with Variable Speed Control**



Throttling a constant speed blower does not change the pressure ratio. Instead it moves some of the total pressure increase through the blower from discharge to inlet. [See figure 7.] This decreases the discharge pressure. The intersection of blower and system curves move left, reducing flow and power. However, the benefit of MOV is minimal, since the blower pressure ratio is unchanged.

**Figure 7: Centrifugal Blower with Inlet Throttling**



Large centrifugal blowers are often controlled by inlet and/or discharge guide vanes. Guide vanes function by shifting the blower curve. Guide vanes also obstruct and throttle the air flow into the blower. As a result, the reduction of blower power from MOV control is good, but not maximized.

## Conclusion

MOV is a concept causing confusion for designers, programmers and operators. Despite the confusion and potential complexity, MOV control can decrease power by minimizing the pressure drop through basin air flow control valves. A variety of MOV techniques have been developed. They can be adapted to aeration control maintaining blower discharge pressure or air flow rate.

Coordination between multiple components and control loops is necessary for successful MOV implementation. MOV control, DO control and blower control affect each other and should be considered as parts of a system. It is particularly important to select a blower control strategy maximizing the benefits from MOV control.

For more information contact Tom Jenkins, P.E., President of JenTech Inc. at email: info@jentechinc.com or visit www.jentechinc.com. Mr. Jenkins has texts now available in hardcopy and electronic versions titled Aeration Control and Facility Design at www.e-wef.org/store.

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