Keep the Valve, Upgrade the Actuator

Resolution Delivers Precise Butterfly Valve Aeration Control

By Tom Jenkins, JenTech Inc.

Introduction

Accurate airflow control in secondary wastewater treatment is critical to maintaining process performance. The need for accuracy in activated sludge facilities is increasing, as more enhanced treatment processes, such as biological nutrient removal (BNR), and tighter effluent requirements are implemented. The ability of throttling valves to provide precise airflow rates to individual aeration zones is a major concern for designers and operators.

Problem Description

The conventional wisdom in wastewater treatment plant (WWTP) design says butterfly valves (BFVs) cannot provide accurate airflow control. According to conventional wisdom:

- Alternate valve technologies should be used to obtain good control, despite the higher cost of these devices.
- If a BFV must be used only the middle of the operating range, between approximately 20% and 70% open, is suitable for throttling.
- Electromechanical actuators are the best choice for aeration control.
- Actuators used for automatic control of BFVs need frequent calibration and are prone to failure.

Conventional wisdom was based on observed problems with control valves designed and specified using the standard practices of the past. These standard practices were, in turn, based on the available components of the time. Design practices were based on challenges unique to the wastewater treatment industry.

WWTPs designs must accommodate current loads as well as expected load increases twenty years into the future. Maximum airflow demand must match worst case pollutant concentrations. To this is added diurnal flow and organic load variations of 2:1 during dry weather. Hydraulic surges during rain events, producing several times the average daily flow, are part of the design. These factors combine to create a very wide range in airflow demand at each control zone.

Minimizing energy costs encourages designers to use large diameter piping to minimize frictional pressure losses. This results in oversized valves. The problem is compounded when process changes or diffuser upgrades significantly reduce air demand. Following the conventional wisdom, a reduction in valve size is needed to maintain control. This, in turn, necessitates expensive piping modifications.

Economics of first-cost dictated that the valve technology of choice for controlling airflow was the butterfly valve with an electromechanical actuator. The net result was that most BFVs were oversized. The actuators available were not able to provide accurate airflow control, and the valve was blamed for the problem.

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Causes of Control Inaccuracy

Valves control flow by throttling. This involves creating a restriction that results in a permanent pressure loss (Δp) from friction, created by the air flowing through the restriction. The restriction is calculated as C_v and defined as the gpm of water passing through the valve with a 1.0 psi pressure loss. The airflow rate will rise or fall until the available Δp is created. These three variables are related mathematically, and once two are fixed the third is determined. The equation for airflow through a valve is:

$$q_s = 22.66 \cdot C_v \cdot \sqrt{\frac{P_u \cdot \Delta p_v}{SG \cdot T_u}}$$

q_s = airflow rate, SCFM
C_v = valve flow coefficient, dimensionless
Δp_v = pressure drop across the valve, psi
P_u = upstream absolute air pressure, psia
SG = specific gravity, dimensionless (1.0 for air)
T_u = upstream absolute air temperature, °R

In an aeration system the pressures upstream and downstream of the throttling valve are determined by the submergence of the diffusers and the overall system configuration. The difference between pressure upstream and downstream of the valve, the Δp_v, varies with the frictional losses in the system.

When the airflow is throttled, there is only one value of C_v that will result in the desired flow rate for a given Δp_v. For controlling flow, it does not matter if the valve is a 10" BFV at 50% open, a 4" BFV at 90% open or an iris valve at 80% open. It is the ability of the actuator to adjust the opening of the valve and achieve the required C_v - its resolution - that determines the flow control precision. This is true for all control valve and actuator types.

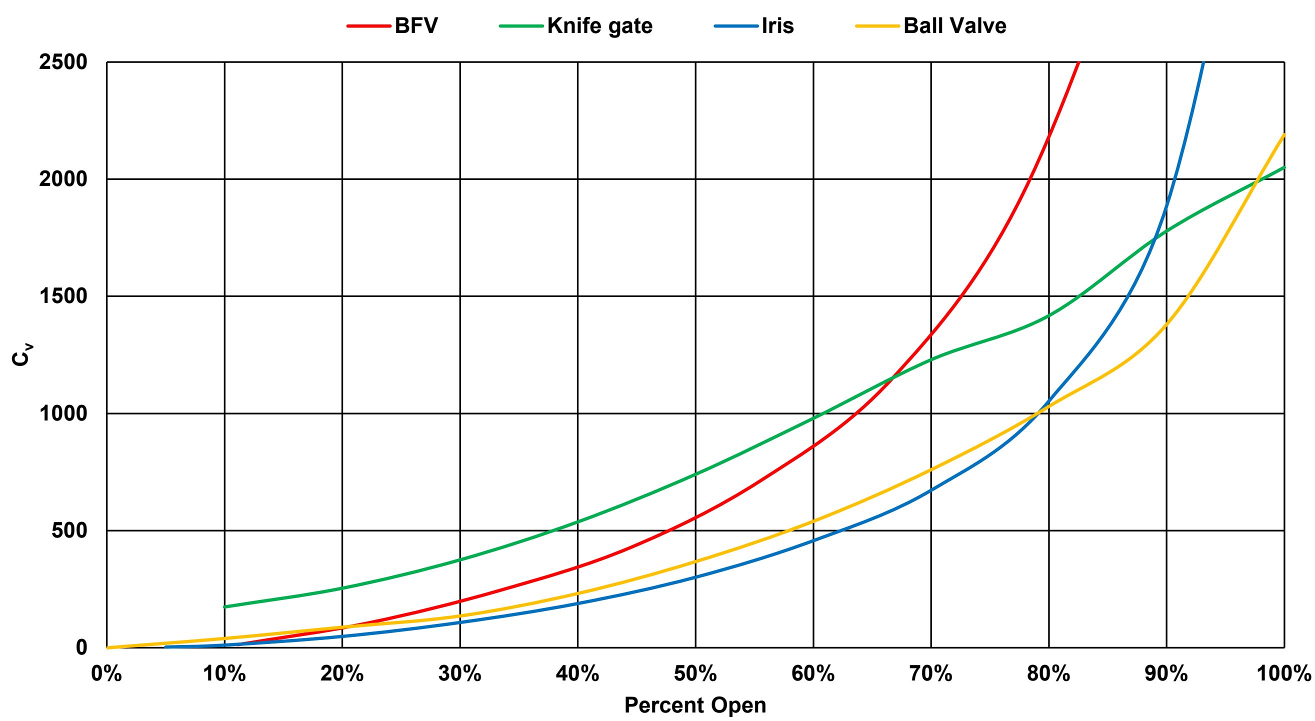

Figure 1: Comparison of Typical C_v Curves of Various 8" Valve Types

The variation of C_v with valve position is non-linear for all types of control valves in current use (See Figure 1). The degree of non-linearity varies from one technology to the next, but none have a linear relationship between flow or C_v to percent opening. This is most important at the extremes of travel. When the valves approach 100% open, a change in position results in negligible change in airflow.

The need for precise position control is particularly important when the valve is nearly closed. As a valve with conventional actuators approaches 0% open, air flow control becomes unstable. The large position increments of a typical electric actuator produce unacceptable changes in airflow. This phenomenon has been widely observed and reported. It is the basis for the conventional wisdom that BFVs provide poor throttling performance. In fact, the valve and its C_v aren't unstable. Rather, the combination of actuator deadband and hysteresis create undesirable jumps in the flow through the valve.

BFVs are classified as "equal percentage", and across most of their operating range each percent change in position results in approximately the same percentage change in flow (See Figure 2). At low flows, the relationship changes, and each position change represents an increasing percent of the previous flowrate. When actuator deadband creates large steps, the flow changes become more severe.

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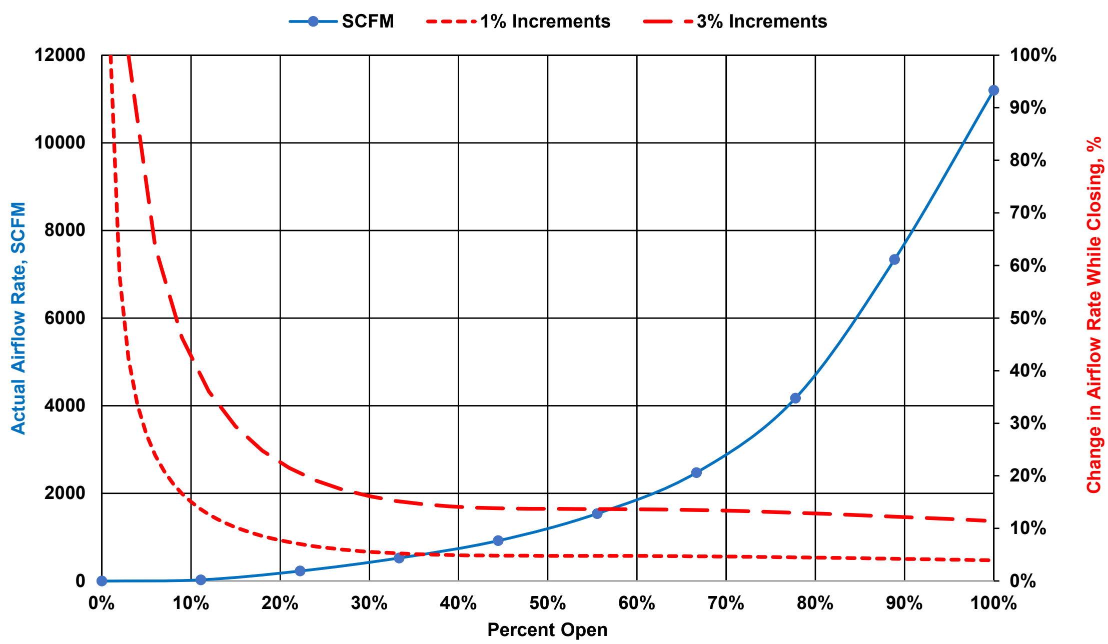

Figure 2: 8" BFV Air Flow Control Performance (0.25 psi Δp 560 ºR 23.2 psia)

Electro-Mechanical Actuators

Most electromechanical actuators have similar designs. A reversible motor is controlled by a contactor. Actuators use three-phase, single phase, or DC motors. Gear reducers are used to to multiply motor torque and reduce rotational speed. A potentiometer or optical encoder is used to provide position feedback. A comparator evaluates the feedback and position command signal. If the difference between the two exceeds the deadband, the contactor closes. The valve moves until the difference is within the deadband. For most electromechanical quarter-turn actuators the best available resolution is approximately ±1%.

There are several factors that establish the resolution of an actuator. The most important is the deadband of the positioning system. This is the change in the analog position command signal needed to force the actuator to initiate a change in position.

If the deadband is set too tight or too loose the actuator will hunt – oscillate continuously while trying to match the feedback to the command. This results in process instability and excessive wear on the actuator. If the deadband is too tight slight variations between command and feedback cause movement. If the deadband is too loose the valve does not respond to small command changes, causing the controller to increase the command. When the actuator finally moves, the result is overshoot. The control reverses the signal until the actuator moves and overshoots in the opposite direction. Hunting is aggravated by the overshoot in airflow rate, causing the controller command to hunt as well.

Hysteresis is a lag in travel that results from backlash in the actuator gearing. Hysteresis is the change in actuator signal needed to effect a change in the valve position and C_v when reversing travel direction. Overrun occurs in actuators without positive braking when the motor acts as a flywheel after the reversing contactor opens. This causes valve position to continue changing after the feedback and command match.

An often-neglected source of inaccuracy in flow control is the failure to specify modulating duty actuators, which may restrict the frequency of position adjustment. Many electric actuators, even those rated for modulating service, have a limited duty cycle. They limit the frequency of operation to reduce heat buildup and/or mechanical wear on the gear train.

When conventional wisdom was developed actuators generally had a resolution of ±3%. New electromechanical actuators are capable of ±1% resolution in their standard configuration. Alternate technology actuators with high resolution, such as REXA, can achieve ±0.2% or better.

Valves

The throttling device used in most aeration applications is the general purpose resilient-seated butterfly valve. They are low in cost, provide a bubble-tight shutoff and can be automated by a variety of actuators.

High performance butterfly valves are useful in high pressure and/or high temperature applications. However, they do little to improve the throttling characteristics of a basic BFV, and in most aeration applications, the additional cost is not justified by additional performance. Similarly, the AWWA butterfly valve has features designed to enhance performance in critical water distribution service, but these features are not beneficial in low pressure aeration applications found in wastewater treatment plants.

Current practice includes a number of alternates to the butterfly valve. These include several variations of the knife gate valve, which incorporate various port configurations such as a diamond or an ellipse. Another valve configuration uses an iris (like that in a camera) to provide a variable orifice. One proprietary design creates a variable annular venturi using the axial movement of a tapered core.

Alternate technology suppliers claim throttling performance superior to BFVs. Many of them use multiturn actuators, potentially making them less sensitive to poor valve actuator resolution. However, as described above, it is the ability to accurately control travel and achieve the required C_v that establishes accurate control of airflow, regardless of valve design. The actuator resolution establishes control precision. Modifications to the valve design without addressing the actuator can have, at most, a modest impact on control performance.

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Testing

Theoretical analysis can provide insight into control issues. Field experience and testing are required to prove that performance capabilities match the expectations for high resolution actuators.

AERZEN USA, a leading manufacturer of blowers and aeration control systems, has experienced frequent problems with conventional actuators and BFVs. The most common dilemma occurs when oversized BFVs are used to throttle airflow and match process demand within the portion of the valve travel closest to the closed valve position, where the C_v curve of the valve flattens. Conventional electromechanical actuators do not provide the necessary position resolution to modulate in this portion of valve travel, which results in unsatisfactory control.

AERZEN tested a REXA Electraulic Actuator on a conventional BFV, looking to identify the precision of the resulting airflow control. Using their Test Lab, AERZEN arranged to create conditions typically encountered within an aeration system (See Figure 3).

A 10″ manual butterfly valve was set to create 8.5 psig pressure at the discharge of a constant speed positive displacement blower. The position of this valve was fixed throughout the testing. The blower capacity was 530 SCFM and the air was vented directly to atmosphere

A parallel pipe was equipped with a 12″ BFV controlled by a high-resolution actuator. The actuator deadband was set to ±0.1%. The initial position was set to 0% open, with all airflow passing through the 10″ blowoff valve. The parallel 12″ valve was then opened in 0.13% increments, until it reached 15% open. At that point, all airflow was passing through the 12″ BFV, and the test was terminated. Flow, pressure, temperature, and valve position were continuously logged by a PC based data acquisition system during the test.

AERZEN Test Setup

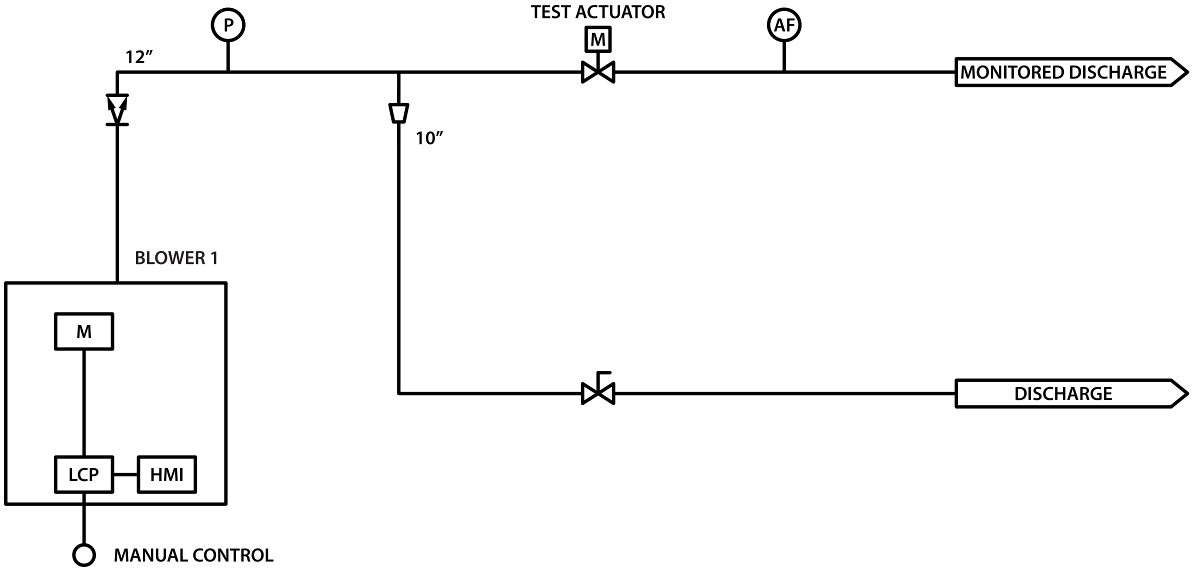

Figure 3: AERZEN Test Setup

The collected data was plotted to show the variation in airflow compared to the valve position at approximately 0.13% increments, when moved from fully closed to 15% open. The same data was plotted with valve position changes in 1% and 3% position increments, simulating typical electro-mechanical actuator performance.

The Impact of Resolution

The airflow control performance data that resulted from the testing demonstrates the significance of resolution. Take for example the data collected when incrementally opening the valve from a position of 8.94% open. At this valve position, the flow through the 12" valve was 430 SCFM, and the flow through the 10" valve was 100 SCFM. The temperature was 109°F, and the Δp across the valves was 2.25 psi. The initial air velocity through the 12" line was 500 ft/minute. These values are all within the normal range for aeration systems, verifying that the test results are representative of those found in practice.

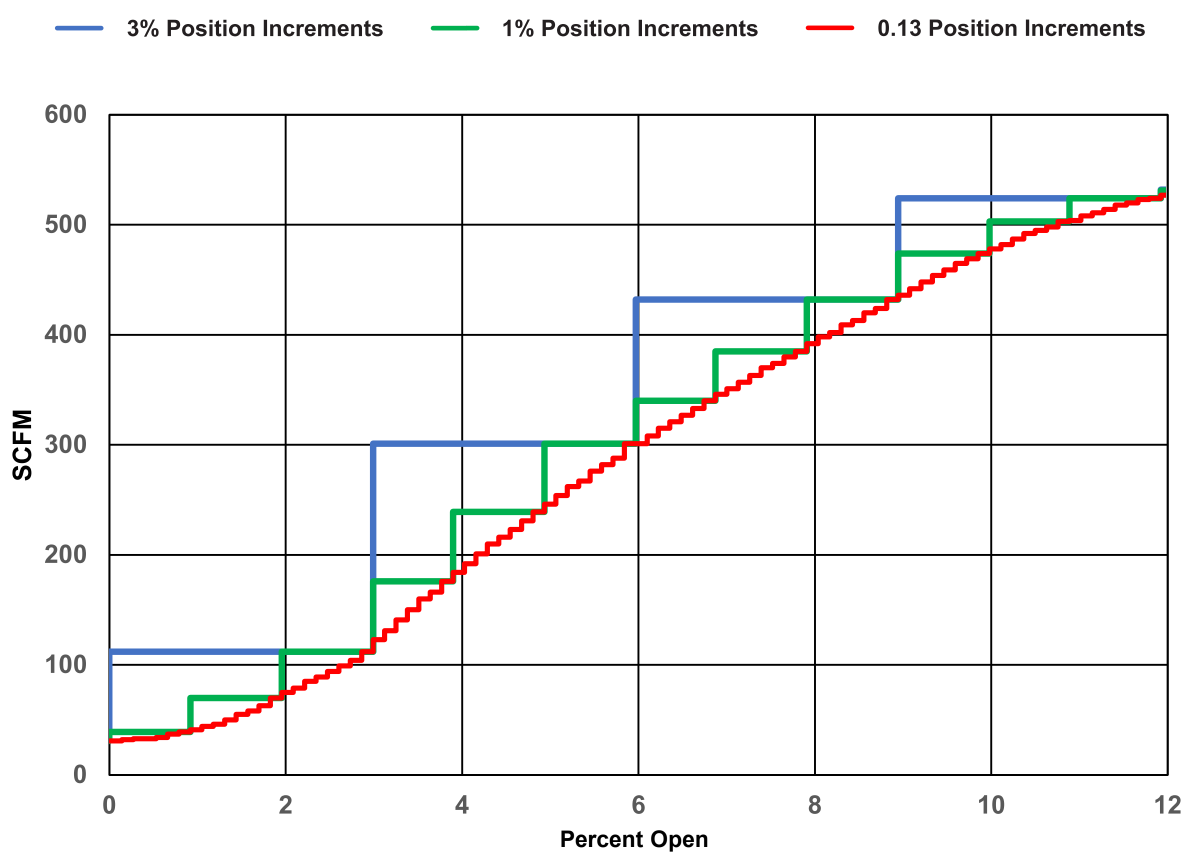

Figure 4: Effects of Increased Resolution on BFV Control

When the position was increased by 0.13% to 9.07% open, the airflow rate changed by 4 SCFM – less than a 1% change. This is well within the precision requirements for aeration system control.

A position change of 1.04%, approximating the resolution of state-of-the-art electromechanical actuators, changed airflow through the 12" valve by 42 SCFM, or 10% of the total flow passing through the valve (and 10x greater airflow than achieved at 0.13% position increments). This is at best marginal control precision. For many aeration systems, this step change in airflow rate would not be acceptable.

The data clearly demonstrates that accurate control of position (less than 0.5% resolution) is required to create precise airflow control with a standard BFV - even at nearly closed valve positions.

With a position change of 2.98% and a new position of 11.92% open, the problem with poor resolution was dramatically illustrated. The airflow rate changed by 92 SCFM. This is a step change in airflow rate of over 20% of the total air flow and clearly indicates why control attempts with BFVs operating near their closed position are unsuccessful. Furthermore, it illustrates why the conventional wisdom recommends a BFV be operated in the range of approximately 20-70% open and demonstrates why control precision was inadequate with older actuators.

Results Moving From 8.94% Open			
Resolution	2.98%	1.04%	0.13%
New Position	11.92%	9.98%	9.07%
Flow Change	92 SCFM	42 SCFM	4 SCFM
SCFM % Change	>20%	10%	<1%

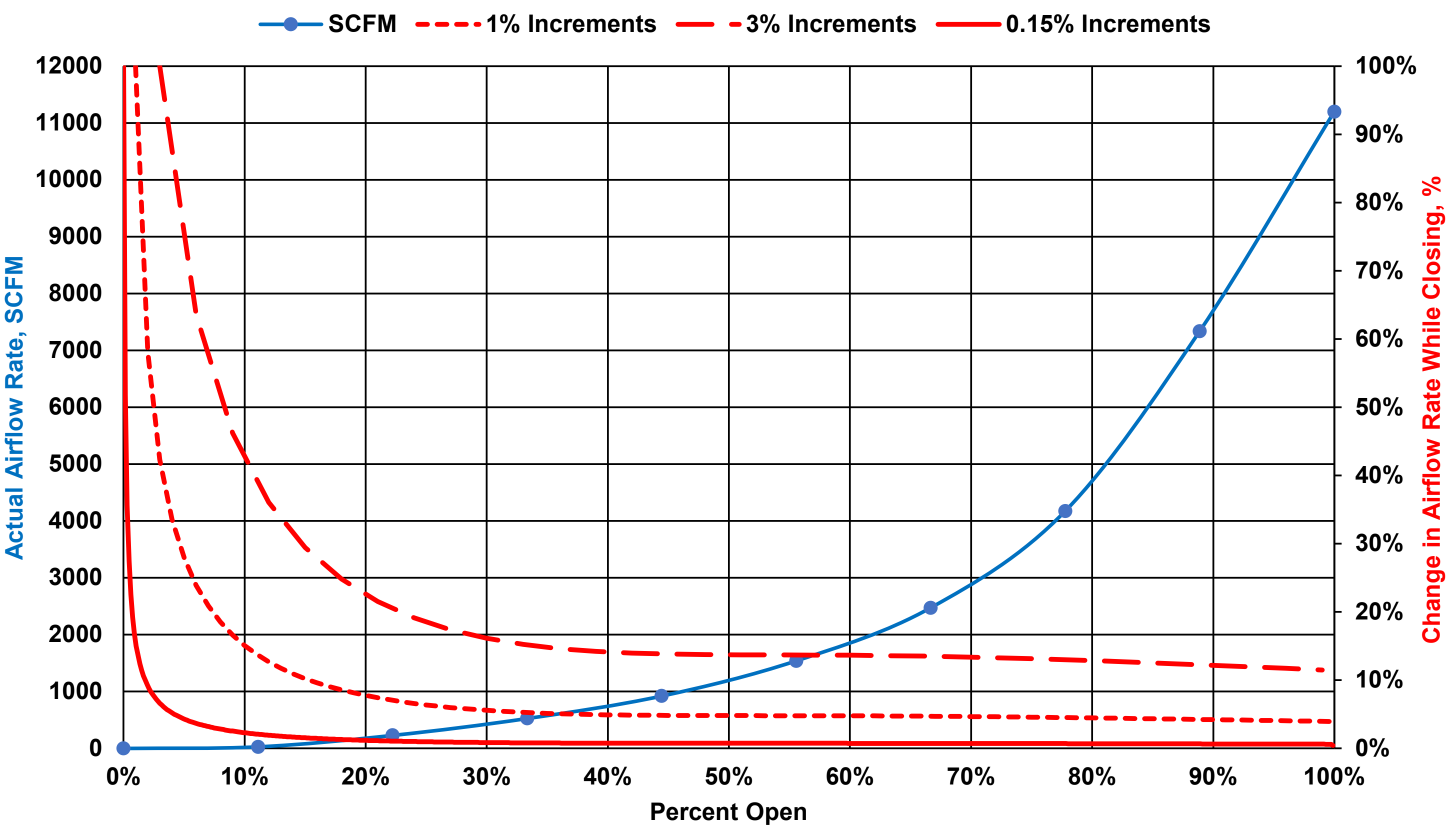

Figure 5: 8" BFV Air Flow Control Performance (with 0.15% increments)

Figure 5 adds a third data set to the air flow control performance graph of Figure 2, showing the impact of 0.15% increments on control capabilities. This curve flattens significantly in the <20% open range compared to the others. It demonstrates that the higher resolution of the actuator can split valve travel into smaller increments, causing the percent change in flow to effectively linearize.

There are no standards for establishing acceptable control precision. Requirements are site-specific, but most operators expect ±3% to 5% deviation in flow for adequate process control. Tight control is always desirable. The data clearly demonstrates that accurate control of position (less than 0.5% resolution) is required to create precise airflow control with a standard BFV - even at nearly closed valve positions. This data contrasts the expectations commonly held for precision standards in aeration control. It shows tighter control comes from tighter resolution, rather than an alternate valve solution.

Conclusions

The ability to accurately control valve C_v is key to accurate airflow control. The flow characteristics of all types of throttling valves in current use are non-linear. Design practices often result in oversized valves, particularly in upgrade projects, which aggravates control issues. The difference between successful operation and erratic airflow control is the resolution of the actuator.

As often happens, the conventional wisdom has been overturned by advances in technology. High-resolution actuators, like REXA Electraulic Actuators, can provide accurate airflow control throughout the operating range of conventional butterfly valves. They represent a fundamental enhancement in valve actuation. These actuators offer substantial improvement in controlling aeration air flow, overturning conventional wisdom.

The AERZEN testing demonstrates that when a standard butterfly valve is paired with a high-resolution actuator:

- Expensive retrofits of alternate valve technologies are not required to achieve accurate air flow control.
- The full C_v range of a traditional BFV can be utilized, even on an oversized BFV that is being operated near the closed limit.
- Airflow control can be significantly improved by utilizing actuators that are specifically designed to provide precision control.
- Aeration process efficiency and stability is attainable by combining standard butterfly valves with precision actuators.

The technological advantages resulting from accurate position control represent a major advancement in aeration control performance. It is time to reconsider the conventional wisdom and take a new approach to throttling applications in aeration systems, one that considers actuator resolution as the key to achieving accurate air flow control.

Aeration Control With High-Resolution Actuator

About the author:

Tom Jenkins is a successful entrepreneur and an innovative engineer. He co-founded Energy Strategies Corporation (ESCOR) in 1984 and is widely recognized for successfully introducing many original techniques to the wastewater industry. As the President of JenTech, Inc., Tom provides consulting services that include design and analysis of control systems, aeration systems, energy conservation measures and blower systems. Tom is an Adjunct Professor (Professor of Practice) at the University of Wisconsin-Madison and teaches water and wastewater treatment for the Department of Engineering Professional Development. He is a member of the ASME committee that developed PTC 13, "Wire-To-Air Performance Test Code for Blower Systems." ***www.jentechinc.com***

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About AERZEN USA:

AERZEN is an international manufacturer of energy-efficient Positive Displacement Blowers, Hybrid Blowers, Screw Compressors, and Turbo Blowers. AERZEN also provides state-of-the-art aeration and blower control systems to the water and wastewater treatment industries. ***www.aerzen.com***

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About REXA, Inc:

REXA, Inc. is a leading manufacturer of custom engineered products fully manufactured outside of Boston, MA. They supply Electraulic™ Actuators, a hybrid technology that delivers hydraulic based actuation that does not require oil maintenance in a package that looks and operates similar to conventional, gear-type electric actuators. The result is a product that offers superior actuator performance and unmatched modulating position control accuracy from an actuator that delivers the greatest level of reliability available in the market. Specific to wastewater treatment operations, REXA provides actuators for critical valve and gate applications where equipment failures cannot be tolerated and modulating control is of critical importance, with average maintenance free operation of 10 years or more. ***www.rexa.com***

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