# Pneumatic Controllers in Upstream Oil and Gas

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## Summary

Process-control engineering is a fairly narrow field of study that has used inconsistent terminology among practitioners. Natural-gas-actuated pneumatic-control equipment has recently become a focus area for regulators trying to reduce the quantity of actual pollutants and greenhouse gases released to the atmosphere. The historical use of inconsistent key terms by experts has led to regulations that are at odds with the realities of existing equipment. The intention of this paper is to begin development of a rigorous set of terms and operational classifications that can help create a framework of knowledge consistent with how this equipment functions. Standardization of terminology has benefits for operators, manufacturers, and regulators alike.


## Introduction

Both state and federal regulators are finding *pneumatic controllers* to be a focus area for regulations to reduce air emissions (including methane and volatile organic compounds) from oil-and-gas-industry operations. Definitions and technical descriptions used in regulatory frameworks have sometimes produced misleading and contradictory concepts and have led to confusion regarding pneumatic controllers and their emissions. Pneumatic controllers should be addressed in standard and commonly understood language. The technical review presented in this paper is meant to be used to clarify and standardize the definitions and descriptions of pneumatic controllers and the operational basis for their emissions.

Recent data available through the Greenhouse Gas Reporting Program (GHGRP) (EPA 2013a) and data published in the US National Greenhouse Gas Inventory (EPA 2013b) indicate that natural-gas-operated pneumatic-process controllers appear to be a nontrivial source of methane emissions from upstream oil and gas operations. The GHGRP provides definitions with little guidance for device classification, which is needed to determine the type of regulatory requirements that must be followed. As a result, inconsistent and likely erroneous classification of the pneumatic controllers by operators, researchers, and others may result in inaccuracies and large uncertainties in emissions estimates. In addition, as this paper will show, the classifications used in many regulations in and of themselves have likely resulted in emission factors that are not aligned with the key physical and operational factors that determine actual emissions from pneumatic controllers.

This paper describes consistent and cost-effective methods to categorize and evaluate the magnitude of the emissions from various controllers and shows that the magnitude of exhaust gas of any controller, except continuous-high-bleed controllers, may be too small to provide value in trying to control their emissions.



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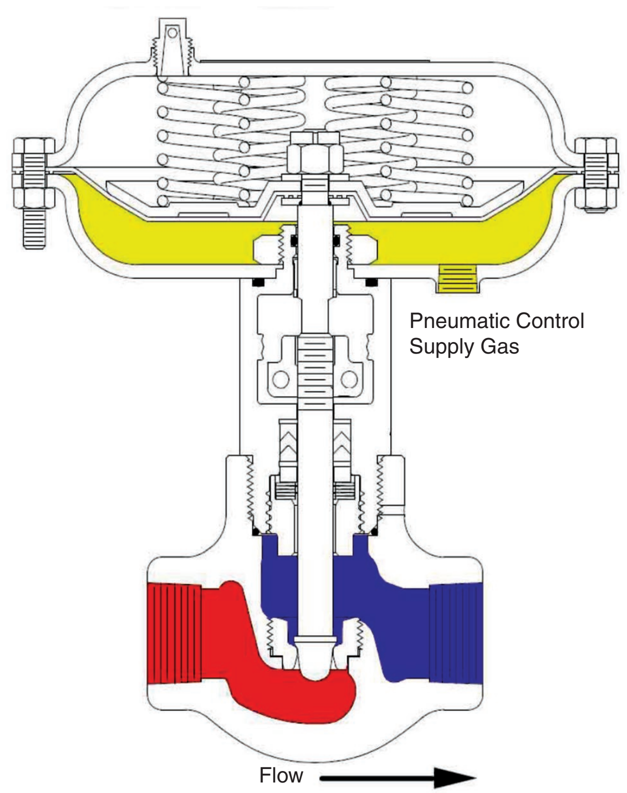


**Fig. 1—End device (Fisher 2011).**

## Process Control

The term process control is generally taken to mean "an engineering discipline that deals with architectures, mechanisms, and algorithms for maintaining the output of a specific process within a desired range" (Wikipedia 2014). A process-control system must have

- A way to sense the state of a process variable (the sensing device)
- A way to change the state of the sensed process variable (the end device, typically an actuated valve in upstream oil and gas)
- A way to translate the state of a process variable into an energy input to change the state of the sensed process variable (the controller)

Process variables can be nearly anything, and the variables most commonly controlled in upstream oil and gas are

- Fluid level (often found on separators, tanks, treaters)
- Pressure (includes pressure regulating, backpressure regulating, and overpressure limiting)
- Temperature (includes tank heaters, indirect-process heaters, direct-process heaters, and fan control)

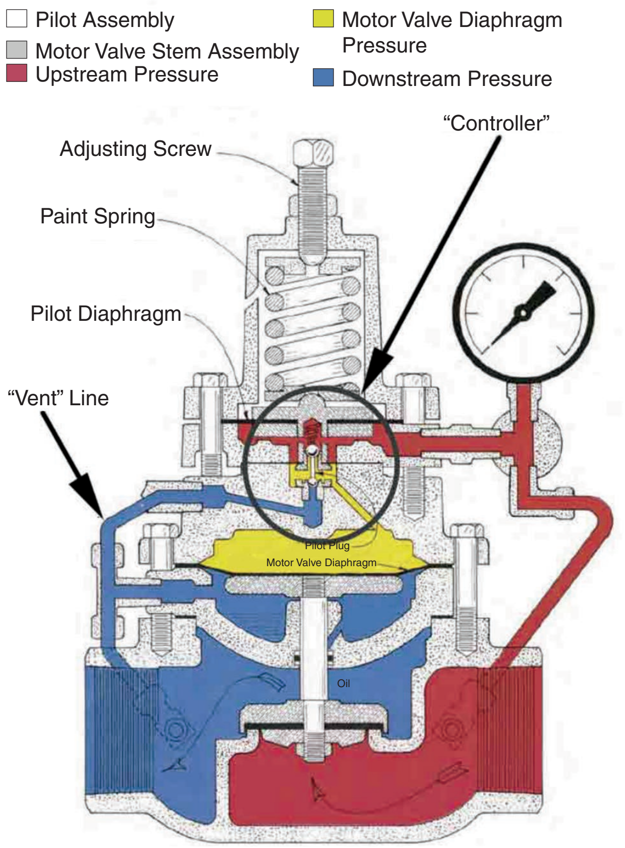


**Fig. 2—Integral controller (Kimray 2013b).**

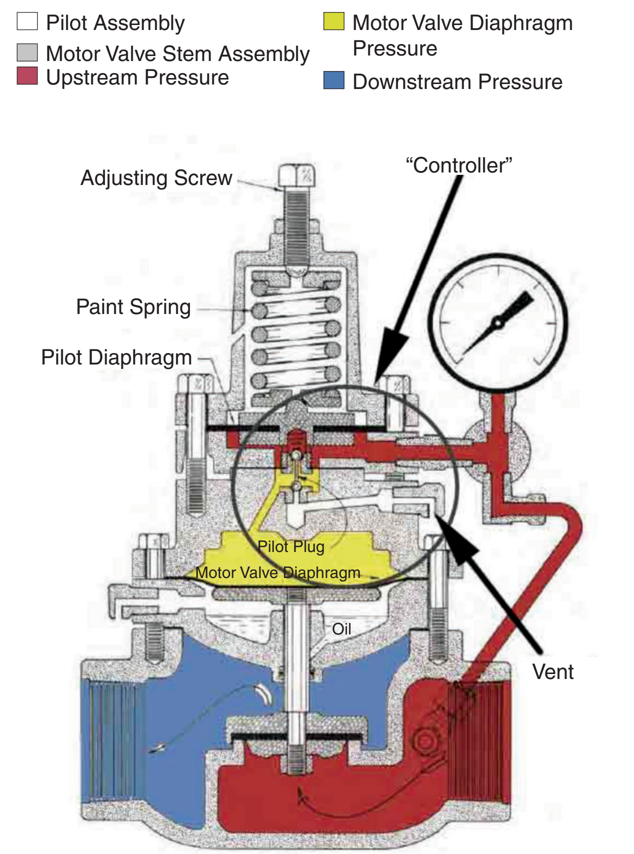


**Fig. 3—Local controller (Kimray 2013a).**

- Differential pressure (often used as a surrogate for flow and generally used for constant-flow processes)
- Position (includes devices that sense plunger arrival in a well and then signal end devices to allow afterflow and/or to shut off the flow to allow the plunger to drop)
- Safety (includes control of emergency-shutdown valves that shut when a manual button is tripped or an unsafe condition is sensed)

The state of a process variable is affected by changing the position of an *end device*. In this document, the term end device will refer to the combination of an "actuator" (i.e., a mechanical device that accepts an input signal and generates an output signal) and a "process valve" (i.e., a valve used for controlling processes that is positioned by an actuator). The end device accepts an electrical, hydraulic, or pneumatic signal to force valves to change position (e.g., from "shut" to "open" or from "heavily throttled" to "less heavily throttled"). In upstream oil and gas operations, the most common end devices are actuated valves that allow flow, stop flow, or throttle flow. In other industries, end devices can perform a wide variety of tasks such as positioning a tool or operating an access gate.

The end device in **Fig. 1** is a pressure-to-open control valve that is generally referred to as a "motor valve" because it uses pneumatic "motive force" to operate the valve. While the terminology motor valve is inconsistent with the general understanding of a "motor," it is the term used by control-valve manufacturers; therefore, to use a different term here would (overall) be more confusing than to use manufacturers' terminology.

The end device in Fig. 1 is closed or *at rest* in the drawing (the term at rest will be used to indicate that an end device is depressurized and is being held in position by actuator springs). When a controller (not shown) senses a need for the valve to move toward open, it increases the pressure under the actuator diaphragm (yellow section in Fig. 1), and the valve stem is forced to move upward against spring pressure to move the process valve (red and blue sections in Fig. 1) toward open. The end device in Fig. 1 can be in on/off service (e.g., it could be in "dump-valve" service connected to a level controller) or throttle service (e.g., a pressure-control valve trying to maintain downstream pressure at a constant value). Note that in Fig. 1 there is no exhaust connection. All decisions about increasing or decreasing pressure are made by the controller, and any gas that is exhausted will occur at the controller.

Any end device can be adapted to almost any control scheme; therefore, end devices are not an important factor in the understanding of emissions from process control.

**Controllers.** The state of the end device is changed by using "controllers." Controllers can be:

- Electric (sends an electric signal to an electric end device)
- Pneumatic (sends a gas-pressure signal to an end device, and pneumatic motive force can come from natural gas, on-site compressed air, or bottled compressed gas)
- Hydraulic (sends a liquid-pressure signal to an end device)
- Electrohydraulic (controller opens an electric valve to send liquid pressure to a hydraulic end device)
- Electropneumatic (controller opens an electric valve to send gas pressure to a pneumatic end device)

Understanding the relationship of a controller to an end device aids in identifying and subsequently classifying a particular controller:

- Integral—the controller is built into the end device. Supply gas comes from the process upstream of the valve. Integral controllers can only be used in a very small number of applications because of inherent limitations in the ability of a controller to

| | Power Media | Relationship to End Device | Service | Depressurization Method | Comment |
|---|---|---|---|---|---|
| LC1 and LC2 | Pneumatic | Remote | On/off | Intermittent vent | Blowcase high and low fluid levels |
| TC | Pneumatic | Remote | On/off | Intermittent vent | Temperature control |
| HL | Pneumatic | Remote | On/off | Bleeds only under abnormal conditions | High-low safety shutdown controller |
| LS | Electric | Remote | Alarm | n/a | Not a controller |
| PR | Pneumatic | Integral | Throttle | To process | No gas is vented |
| BPV | Pneumatic | Integral | Throttle | To process | No gas is vented |
| TCV | Pneumatic | n/a | n/a | n/a | End device |
| LCV | Pneumatic | n/a | n/a | n/a | End device |
| PGV | Pneumatic | n/a | n/a | n/a | End device |
| PSV | Pneumatic | Integral | Relief | n/a | No gas is vented until vessel overpressure |

Note: Grayed out rows represent devices that do not have an air-emissions impact.

Table 1—Process-control devices.

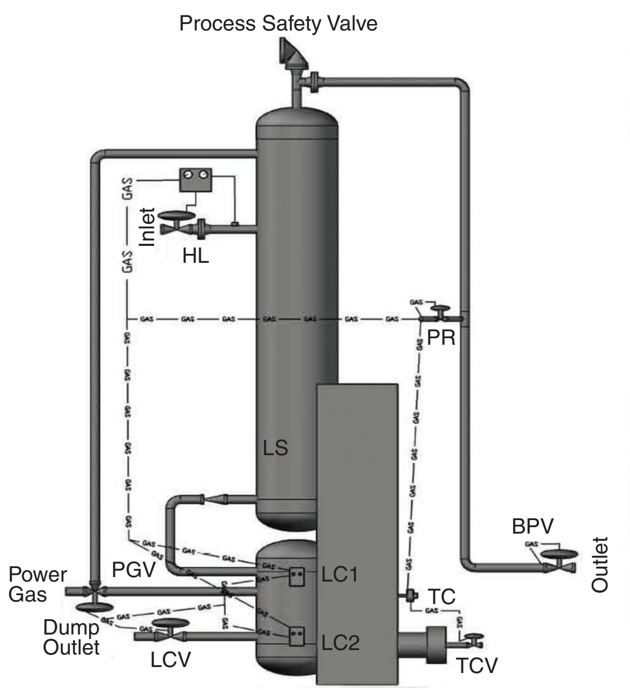


**Fig. 4—Wellsite vertical separator.**

exhaust into process pressure. Exhausted gas is returned to the process.

- Local—the controller is built into the end device, and supply gas comes from the process. Gas is exhausted to the atmosphere.
- Remote—the controller is physically separate from the end device. Gas is exhausted to the atmosphere.

The difference between integral and local is subtle but important. An *integral controller* (**Fig. 2**) is built into an end device and does not require an external source of gas, nor does it release *actuation gas* to the atmosphere (instead, it sends excess actuation gas into the process downstream). A *local controller* (**Fig. 3**) is also built into the end device, but it exhausts gas to the atmosphere to move the process valve toward closed.

The devices in Figs. 2 and 3 are intended to maintain the pressure upstream of the valve at a specific value (they are called backpressure-control valves). In both systems, the gas to operate the end device comes from the process gas upstream of the valve (the red section on both schematics). When the controller senses upstream pressure is at the set point, the controller repositions a *pilot plug* within the controller to shut off supply gas to the diaphragm (the yellow section on both schematics), which holds the actuation pressure constant. If the controller senses that the upstream pressure is too high, the supply opens against spring pressure to increase the process flow (lowering upstream pressure). If the controller senses that the upstream pressure is too low, the spring forces the exhaust side of the pilot plug to exhaust gas to move the process valve toward shut.

This is where the two devices diverge. In the local controller (Fig. 3), the exhaust side of the pilot plug connects to the atmosphere, venting gas from the process. In the integral controller (Fig. 2), the exhaust side of the pilot plug sends gas to the downstream on the process side (low-pressure side) of the end device, which allows it to function with zero gas exhausted to the atmosphere. Choosing one over the other is an operational decision—the local controller will always have the same exhaust pressure and will always go toward shut at the same speed. The integral-controller operating speed is a function of the uncontrolled downstream pressure, and valve operating speed can vary considerably from one actuation event to another. Sometimes actuation speed matters, and other times it does not.

Remote controllers make up everything else. They can be electric, hydraulic, electrohydraulic, electropneumatic, or pneumatic. Their defining characteristic is that they are not built into an end device. Remote controllers can be used in all applications of process control.

When discussing exhausted gas, it is clear that intrinsic, electric, and hydraulic remote controllers do not have the opportunity to exhaust gas, and these categories of controllers will not be discussed further.

**Upstream-Oil-and-Gas Controls Example.** The separator in **Fig. 4** has controls that cover the majority of the range of controllers that may be seen on wellsites (see **Table 1**). It has been rare historically for one vessel to have all of these controls, but as gas-line pressures decline, the need to install such things as blowcases and indirect heaters increases. This separator is purposely at the top end of the controls requirement, but it is not an impossible configuration.

In Fig. 4, liquids that are separated from the gas will drain into the blowcase. When enough liquids accumulate within the blowcase to change the state of the upper level controller (marked LC1), then the controller sends pressure to the dump valve (marked LCV) to open and to the power-gas three-way valve (marked PGV) to change from “equalize” to “power gas.” The end devices remain

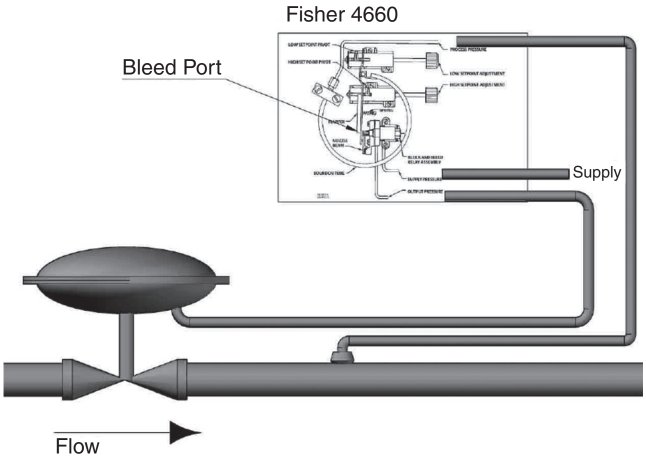


**Fig. 5—Pneumatic high/low controller.**

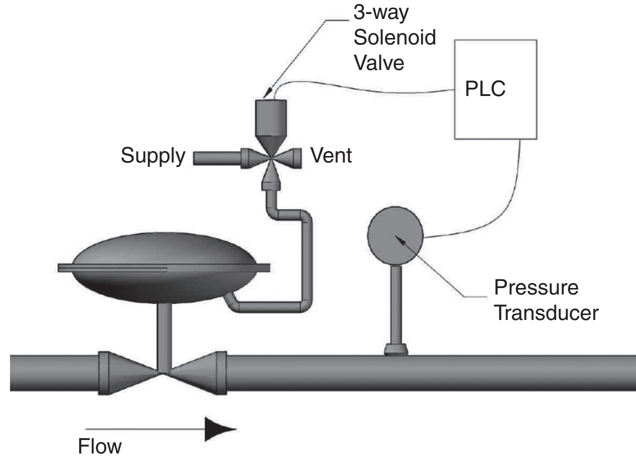


**Fig. 6—Electropneumatic high/low controller.**

in that position until the lower-level controller (marked LC2) changes state to remove the pressure from the two end devices. If the blowcase controls stop working or do not operate quickly enough, then enough liquid can accumulate to change the state of the level switch (marked LS) on the main vessel, which sends an alarm to initiate a site emergency shutdown. The pressure regulator (PR) does not use external gas, nor does it vent any gas to the atmosphere, so it is an integral device, as defined previously. The backpressure valve (marked BPV) is also an integral device that maintains the pressure on the separator at a specific value. The temperature controller (marked TC) is a remote device that determines when fuel gas needs to be sent to the burner (TCV) to maintain the process temperature. The high/low controller (HL) is discussed in a subsequent subsection.

**Control-System Example. Figs. 5 through 7** show remote controllers in "high/low" service. This service positions a control valve in response to pressure downstream of the control valve to protect the upstream piping in the event that downstream pressure builds up or to stop the flow when downstream pressure becomes low enough to indicate a possible line leak.

The configuration in Fig. 5 is pneumatic. The controller senses downstream pressure and allows gas to the end device or stops gas to the end device. Under normal conditions, the gas to the end device holds the valve open against spring pressure. In the event of a safety-shutdown scenario, gas is removed from the end device by venting, and the spring shuts the control valve.

The configuration in Fig. 6 is electropneumatic. Logic within the process logic controller (PLC) compares the pressure reading from the pressure transducer with the high and low set points. When the PLC determines that downstream pressure is outside of the operating range, it shuts off supply gas to the end device and vents the trapped gas, allowing the spring to shut the valve.

The configuration in Fig. 7 is electric. It has the same control logic in the PLC as the electropneumatic device. Instead of sending the shut signal to a solenoid on a control-gas system, it sends the signal directly to an electric-motor-operated valve. In some versions, the PLC removes power from the valve and either a spring or a capacitor forces the valve shut. In other versions, the PLC sends a shut signal to the control valve. The end result is the same; the difference between the two schemes is the reliability of the shutdown in various failure modes.

Controllers in high/low safety/shutdown service operate in an on/off mode and do not bleed or vent gas in normal operations. They only vent gas when a high- or low-pressure condition is detected, which is not common. The most common usage of these types of controllers in the oil- and gas-production sector is upstream of separators, where they control whether a well (or group of wells) flow to the separator or are shut-in. Because they do not vent or bleed gas in normal operation and function as a safety shutdown device rather than for a process-variable control, they do not have significant emissions (except in upset conditions) and should be inventoried separately, if at all, and excluded from consideration in regulatory/policy actions.

## Pneumatic-Controller Technical Discussion

*Process controllers* are devices that sense a physical state (*process variable*) and direct an end device to take an action to modify that physical state. The choice of end device is largely immaterial to the amount of motive-force media that is released or where it is released. As discussed previously, this discussion is limited to local and *remote pneumatic* and *electropneumatic controllers*. There are many ways to classify pneumatic and electropneumatic controllers, but they can be completely defined with two parameters:

- Service: Is it used for on/off control, or does it throttle the process?
- Depressurization method (**Table 2**): Does it bleed supply gas continuously (continuous bleed), or does it vent actuation gas at the end of the on cycle (intermittent vent)?

*On/off controllers* are often described as either *snap action* or *proportional action*, which describes the type of action a controller in on/off service may take and does not have a great impact on emissions.

- A snap-acting controller will never send a partial pressure. It will wait until the signal has reached a maximum value and then snap open and stay in that fully open position until the

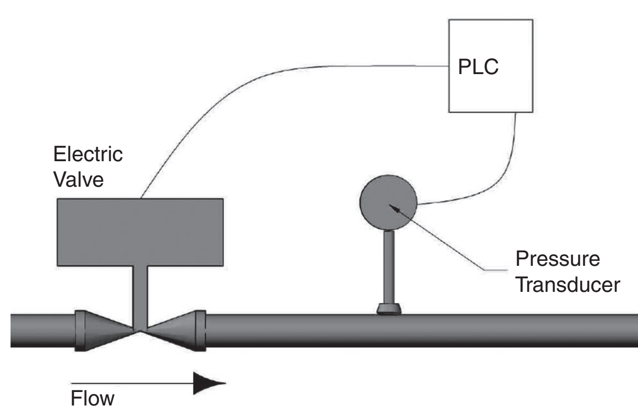


**Fig. 7—Electric high/low controller.**

| | On/Off | Throttle |
|---|---|---|
| Intermittent Vent | Vents to zero at the end of the cycle. | Partially vents when the valve needs to move toward closed. |
| Continuous Bleed | Bleeds continuously. Bleed rate slows while process is on, but accelerates at the end of the cycle. Total bleed is consistent with time. | Bleeds continuously. Bleed rate slows while process is on, but accelerates at the end of the cycle. Total bleed is consistent with time. |

Table 2—Depressurization method.

input parameter reaches a minimum value, and then it will snap shut and an exhaust port will snap open. This could be considered analogous to a simple on/off light switch.
- A proportional controller will send a partial signal as soon as the input parameter increases to greater than a minimum value, and as the input continues to increase, the rate at which the controller sends gas to the end device will increase. Proportional intermittent-vent devices in on/off service will only allow supply gas to enter the process until the differential pressure across the controller pilot plug is zero (i.e., actuation pressure equals supply pressure). If the process variable is satisfied before reaching zero differential pressure, then the controller will shut off supply gas and open the vent without ever fully opening the end device, and it will exhaust slightly less gas than with a snap-action controller. In the light-switch analogy, this could be considered comparable to a dimmer switch that is not allowed to pause at an intermediate position (i.e., it gradually moves toward on until the condition has been satisfied, and then gradually moves toward off, but it cannot be left in an intermediate position).

Snap-action controllers tend to reposition end devices open and shut very quickly, which can cause serious process problems in some situations. Proportional controllers tend to ease into a change of state with fewer problems such as slugging and surging. The choice depends on the process being controlled.

Both continuous-bleed and intermittent-vent controllers can be either snap action or proportional. This descriptor is not a defining function of a controller for the purposes of determining emissions. It is necessary to understand how each type of controller (intermittent vent or continuous bleed) operates in each service (on/off or throttling) to understand the potential and actual emissions from the controller.

If these two basic parameters are used for every pneumatic and electropneumatic controller, then one can develop a clear and unambiguous way to refer to controllers, both within the industry and between regulators and industry.

**Service (On/Off vs. Throttle).** ***On/Off Controllers***. These units are often used to control mechanisms such as open/close "dump valves" in level-control service or "burner control" in temperature-control service. When these controllers sense a change in the process variable, they send supply gas to fully pressurize the control valve, causing the valve to open fully. When the controller senses that the process variable has returned to normal, the pressure is removed from the control valve by exhausting the actuation gas, causing the valve to shut.

The defining characteristic of an on/off controller is that the controller is not required to hold an end device in an intermediate position (i.e., at the end of a control cycle, the pressure to the end device goes to zero).

***Throttling Controllers.*** *Throttling controllers* are used for processes such as pressure control, in which the operator attempts to keep the pressure on one side of an end device in a predefined range when faced with changing conditions. They are also used for interface control in processes that rely on gravity separation of two liquids (such as a three-phase vertical separator).

The defining characteristic of a throttling controller is that the controller is required to control an end device in an intermediate position (i.e., the control gas pressure to the end device is maintained at a pressure between atmospheric and supply pressure). Throttling controllers could be considered analogous to an automobile cruise-control system.

**Depressurization Method (Continuous Bleed vs. Intermittent Vent).** ***Continuous-Bleed Controllers.*** These devices can be used for on/off or throttling service. They use a combination of a *restriction orifice* and a *bleed port* (**Fig. 8**). Gas can always pass through the restriction orifice (there is no mechanical barrier between the supply-gas source and the end device), and the magnitude of the input signal determines how much gas the *block* will allow to exit the bleed port. When the input signal determines that more pressure is needed to the end device, the block will move to partially shut the bleed port. When less pressure is needed to the end device, the block will move farther off the bleed port to allow more gas to vent and lower the pressure to the end device.

The bleed port is larger than the restriction orifice so that, when the block is fully off the bleed port, all of the gas that moves through the restriction orifice exits through the bleed port and the pressure to the end device is approximately zero. Because the block/bleed-port connection is not intended to seal bubble tight, there is always some amount of gas exhausted from these controllers.

It is common to think of continuous-bleed controllers as throttling devices, and they perform this function very well, but they are also used extensively in on/off service.

***Intermittent-Vent Controllers.*** These controllers (**Fig. 9**) have mechanical barriers between the supply gas, the end device, and the vent port. Frequently, these barriers consist of a pair of ball seats connected by a rod (often called a "pilot plug"), as shown in Fig. 9, but that is not the only way that this is accomplished. When the

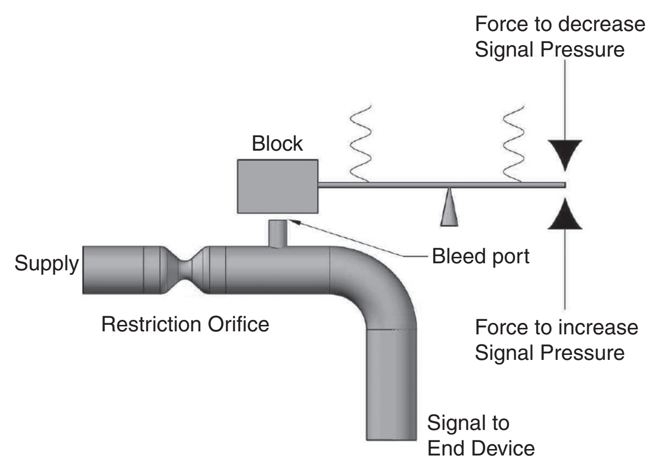


**Fig. 8—Continuous-bleed controller.**

input signal calls for more pressure to the end device, a pilot valve (e.g., the bottom ball on the pilot plug in Fig. 9) between the supply gas and the end device will open (while the vent remains closed). When the input signal calls for reducing pressure to the end device, a pilot valve (e.g., the top ball on the pilot plug in Fig. 9) between the end device and the atmosphere will open (while the supply remains shut).

It is common to think of intermittent-vent devices as limited to on/off service, and their design facilitates that service very well, but they are also quite common in throttle service. The device shown in Fig. 9 is an intermittent-vent controller for throttle service. During steady operation, both balls on the pilot plug are tight on their seat. If less pressure is required for the end device, then the push rod will move upward, pulling the seat away from the top ball and venting gas. When the condition is satisfied, the push rod pushes the seat back against the ball and venting stops. When more pressure is required to the end device, the push rod pushes the bottom ball off the seat against the spring pressure (while holding the vent closed tightly) and allows supply-gas pressure to the end device to increase.

***Defining Characteristic.*** The distinction between venting and bleeding is subtle, but a clear line can be drawn—if there is a mechanical barrier between the supply gas and the end device, then it is a vent. If the pressure is maintained by bleeding off gas with the supply open, then it is a bleed. The distinction between "high-bleed" and "low-bleed" continuous-bleed controllers is an arbitrary limit of 6 scf/hr set by regulations. This limit was described in the Environmental Protection Agency's (EPA's) Natural Gas Star program and was recently included in the EPA's revision to the New Source Performance Standard (NSPS) Subpart OOOO regulation (*40 CFR 60, Subpart OOOO* 2012). Low bleed is not an inherent property of a controller, and the actual bleed rate is a function of both the size of the restriction orifice and the supply-gas pressure.

***Exhaust Rate.*** All controllers exhaust some amount of gas when the end device is at rest between actuation cycles. For intermittent controllers with metal-to-metal sealing between the pilot ball and the seat, this is limited to very small rates that seep/leak past the pilot ball and seat. For continuous-bleed controllers, this rate is defined by the amount of gas that can pass through the restriction orifice. This at-rest volume or "minimum exhaust rate" can accurately be said to represent an "emissions rate" (i.e., a volume per unit time).

The "actuation volume" is the gas that is exhausted when the controller changes the end device state from *not at rest* toward *at rest*. This value may or may not be appropriately tied to a volume-per-unit-time framework, depending on the controller depressurization method. As will be discussed subsequently, the emission rate of a continuous-bleed controller is effectively immune to actuation frequency, and it is appropriate to tie emissions from continuous-bleed controllers to a calendar schedule.

On the other hand, intermittent-vent-controller emissions from actuation events are a function of the frequency of the actuation events. That frequency is dependent on the process being controlled. Two identical intermittent-vent controllers in similar service on different process streams could have vastly different emissions quantities. For example, if there is a well with a plunger, all of the liquid will come up the tubing, and the separator level-control process will operate with every plunger arrival. If the plunger is replaced with a downhole pump (a common progression in gas-well-deliquefication operations) and the pump is directed to a water tank instead of the separator (with the gas flow up the tubing/casing annulus and into the existing separator), the level-control function in the separator will operate far less frequently [in many cases, it will never dump again (Simpson 2012)]. It should be obvious that a pneumatic controller that does not exhaust significant quantities between actuation events will exhaust less gas if the frequency of the actuation events changes from hourly to annually. While one can determine the flow per actuation with reasonable reliability,

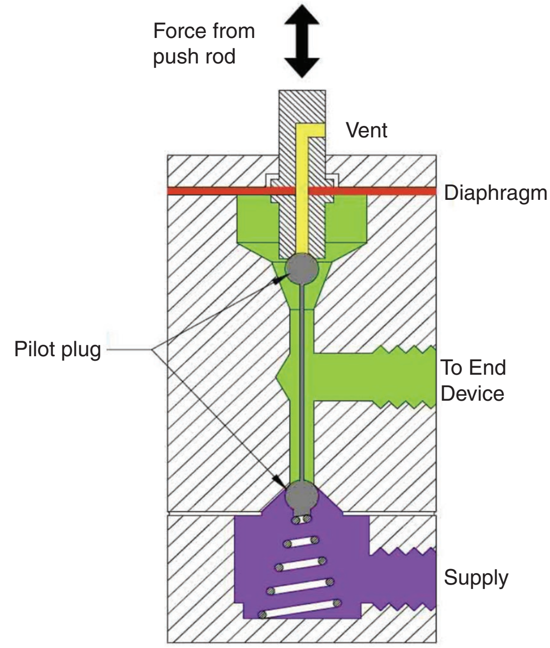


**Fig. 9—Intermittent-vent controller.**

total emission over a period of time (such as a month or a year) is totally dependent on the number of times that controller is actuated during the period. This "actuation count" is a function of the process being controlled, and it varies widely from system to system, function to function, and day to day. It is generally not possible to develop an emissions-per-unit-time value for any class of event-based devices because every one of these controllers is installed on a specific system with its own actuation frequency.

***Determining Exhaust Volume.*** A report submitted to the Western Climate Initiative (Simpson 2010) showed that the issues associated with measuring controller exhaust volume are significant. First, fluid flow is not measured directly, but it is inferred from other measured parameters. Fluid-flow determinations in the oil and natural-gas industry are conducted with flowmeters, which incorporate electronic devices that can assess physical parameters (e.g., pressure, temperature, differential temperature, angular velocity of a wheel, Doppler shift in sound waves) and other characteristics of the fluids being measured. For example, one can use an orifice meter that combines measured pressure, temperature, and differential pressure across a known orifice and processed-input fluid properties to infer a bulk velocity (and therefore a volume flow rate) by using empirical equations developed from the Bernoulli equation.

Inference is a critical concept in any attempt to measure exhaust volume from a pneumatic controller. For example, in a turbine meter, the device infers flow rate by counting revolutions of a spinning wheel. The wheel is rotating because force is applied to the wheel by the fluid. A key input to the force calculation is mass ($F = m \times a$). If fluid density changes (as it will with changes in temperature, pressure, or fluid composition), the ability of the gas to impart the needed force changes dramatically. Therefore, with an intermittent-vent controller, the pressure in the *actuation space* may be 30 psig when the vent opens. That pressure (and therefore the density and the mass-flow rate) begins dropping immediately and rapidly, which has a profound effect on the rate at which the wheel spins. The meter sees a rapidly changing flow rate when it is actually seeing a constant velocity with a declining mass-flow rate, while the assumptions made by the software are that the density is constant and the velocity is changing.

Another key concept is *latency.* Because surrogate parameters are being measured for flow, one must wait until conditions match

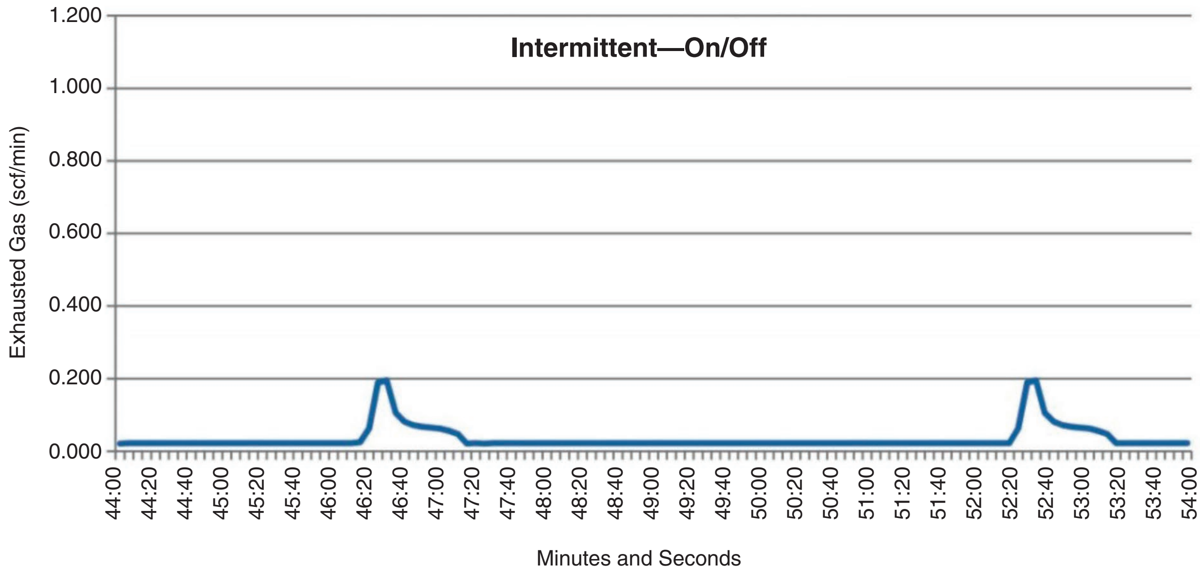


**Fig. 10—Intermittent-vent theoretical exhaust rate.**

the assumed conditions before the numbers from a meter begin to relate to a flow rate. It is easiest to picture this by looking at a turbine meter. A wheel at rest has considerable inertia. The flowing gas must exert more force to overcome this inertia than is required to change the speed of a spinning wheel. During the time that the wheel is coming up to speed (which can be well over 1 second), there is no correlation between the angular velocity of the wheel and the volume flow rate of the fluid. If a turbine meter has latency of 1 second and the flow event lasts 0.5 seconds, then the numbers from the meter are meaningless. Even square-edged-orifice meters have significant latency. The underlying assumptions behind converting pressure, differential pressure, and temperature to a flow rate are that the maximum velocity is in the center of the pipe and the velocity will be nonspinning and symmetrical about the maximum velocity. While a meter is shut down, the trapped gas exhibits disorganized random movement within the trapped space. Turning on gas flow will have to organize that volume before the instrument readings relate to a flow rate. This organizing action takes time. Often, several seconds will elapse before reliable flow can be recorded. Latency is not the same as "response time" or "sensitivity." Response time refers to the time required for an operating meter to respond to a flow transient. Response time will often be much shorter than the latency because the starting point of the transient involves an operating meter, not an idle meter. Sensitivity is a measure of the smallest transient that the meter can detect. Sensitivity only has meaning after the end of the latency period, when the flow matches the assumed conditions. Every meter has some amount of latency, so short-duration events are exceedingly difficult to measure.

Finally, one must consider the *turndown ratio*. This parameter is a measure of the span of flow that the measurement device can detect with acceptable uncertainty without modifying the equipment. If one has an intermittent-vent controller that has a minimum seepage of 0.017 scf/hr and a vent volume after actuation of 0.186 scf and it completes the vent event in 0.3 seconds (2,232-scf/hr equivalent rate), then the device must have a turndown ratio of 1:32,000. The very best meters on the market today have a turndown ratio closer to 1:10. No meter ever envisioned would be able to measure both the seepage and the actuation.

Most emissions studies are performed with variations on the HI FLOW® Sampler from Bacharach. This device pulls in a large volume of available gases and then analyzes the flow stream to eliminate the air from the "known" flow rate of total gases. This device infers a flow rate from the differential pressure across an orifice and then measures the hydrocarbons in the gas sucked into the device. Unless background samples are taken, it includes any other source of emissions in the area as device emissions. The gas-mixture measurement will provide a mixture with some degree of certainty; however, applying that gas mixture to an implied flow rate can be unreliable because of uncertainties in the total flow rate. The manufacturer (Bacharach 2014) claims a total system uncertainty of ±10% of reading and a turndown ratio of 1:20. However, they do not define their methodology for arriving at the uncertainty, nor do they represent any independent flow-measurement testing in their technical literature. Although HI FLOW Samplers are useful tools, researchers that use them must understand the emission characteristics of the controllers they intend to evaluate and design the sampling methodology and time to accurately represent these characteristics. There is no point in the control process at which an instantaneous or short-term sample will yield representative data for an entire process cycle.

If there were measurement equipment with adequate latency, appropriate inference, and acceptable turndown ratios for measuring the flow streams from pneumatic controllers, one would still have to consider the extent of the potential population of devices. With 500,000 gas wells (more or less) in the United States, each with 0 to 20 pneumatic controllers, the population of flow streams that must be evaluated is certainly in the millions and represents a very diverse population of emission characteristics and rates. Designing a measurement program to replicate this diverse population, and then sampling a large enough population to represent such a diverse population, is very difficult and expensive.

As discussed previously, installing permanent-flow measurement at each individual natural-gas-powered pneumatic controller would be prohibitively expensive, and the potential for significant flow-measurement errors would be too large to be ignored. High-quality evaluation-scale measurement is possible on a few dozen or a few hundred controllers, but extrapolating this subset to a broader population is beyond the current knowledge/data of this study. There is simply no way to predict the emissions from an event-based device without current knowledge of the actuation frequency for that particular controller in that particular stream at any particular time. Thus, engineering calculations are used to estimate the flow from each actuation event, and local knowledge of actuation frequency is used to convert those data into an emissions volume for the previous period. Fortunately, these calculations are quite robust and have been used for decades by engineers to design pneumatic-control systems at oil- and gas-production sites (GPSA 2004).

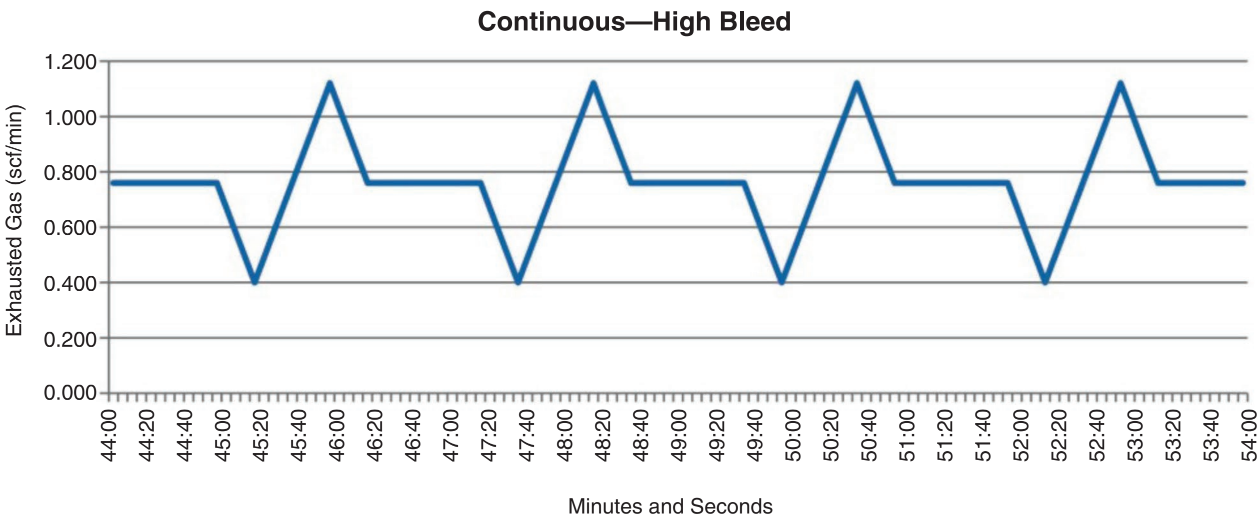


**Fig. 11—Continuous-bleed theoretical exhaust rate.**

***Minimum Exhaust Rate.*** For intermittent-vent controllers (**Fig. 10**), the at-rest volume is determined by the need for the device to operate quickly with little overshoot and minimal hysteresis (i.e., the amount that the previous state impacts a future state). If the internal pilot plug on an intermittent-vent controller were bubble tight (e.g., if it had stronger springs and resilient valve seats), then it would take more actuation force to take the valve off the seat than it would take to change the position of the valve after flow begins. This varying force is very difficult to provide reliably. One manufacturer (Kimray 2012) has tabulated the at-rest seepage for their current generation of intermittent-vent controllers (by use of 30-psig gas) as 0.407 scf/D (0.017 scf/hr) in snap-action mode and 0.610 scf/D (0.025 scf/hr) in proportional mode. These numbers are presented as maximums for a valve in good operating condition, and 0.610 scf/D of natural gas equates to 4.9 kg/a.

For continuous-bleed controllers, the minimum exhaust rate is a function of the size of the restriction orifice, the makeup of the gas (i.e., its specific gravity), and the supply-gas pressure. In **Fig. 11**, one can see that (in on/off service), when the controller calls for more pressure to the end device, it closes the block down on the bleed port, which temporarily reduces the bleed rate and sends more gas to the end device. At the end of the cycle, this actuation volume that was not exhausted during the end-device pressurization begins to return to the bleed port and will eventually be added to the at-rest volume to spike the bleed rate. Over time the total exhausted gas in continuous-bleed controllers is essentially equal to the flow rate through the restriction orifice.

One control-valve manufacturer (Fisher 2013) lists the "steady-state air consumption" of their digital-valve positioner with a standard-bleed orifice at 14 scf/hr at 20 psig and 49 scf/hr at 80 psig. Their low-bleed version of the same valve is 2.1 scf/hr at 20 psig and 6.9 scf/hr at 80 psig. Wellmark lists their Cemco 6900 level controller as having 19.7-scf/hr minimum bleed rate (without specifying either the makeup of the gas or the supply-gas pressure).

***Actuation Rate.*** With the categorization in the preceding, as shown in Table 2, all controllers can be placed into one of four groups: (1) intermittent-vent controller in on/off service, (2) intermittent-vent controller in throttle service, (3) continuous-bleed controller in on/off service, and (4) continuous-bleed controller in throttle service. Methods for calculating the emissions are different for each group.

*Intermittent-Vent Controller in On/Off Service.* Supply gas is sent to the end device when an on condition is called for. The pressure on the end device quickly reaches supply-gas pressure and remains there until it receives the signal to shift to the off condition. At that time, the controller shuts off pressure to the end device and opens a vent to allow the trapped gas (actuation volume) to exit to the atmosphere. Every time the device shifts from on to off, the same volume of gas is vented. This volume can be calculated by Eq. 1:

$$Vol_{system} = Vol_{pipe} + \Delta Vol_{bonnet} = \frac{\pi}{4} ID_{pipe}^2 \times L_{pipe} + \Delta Vol_{bonnet}. \qquad (1)$$

This volume is only useful with regard to standard conditions that allow gas volumes at different pressures and temperatures to be aggregated. Because supply gas is at relatively low pressure, the conversion to standard conditions in this case can generally disregard changes in temperature and compressibility, so the standard volume becomes

$$Vol_{scf} = \left(\frac{\pi}{4} ID_{pipe}^2 \times L_{pipe} + \Delta Vol_{bonnet}\right)\left(\frac{P_{control} + P_{atm}}{P_{std}}\right). \qquad (2)$$

For example, if a supply-gas system is operating at 25 psig at sea level ($P_{atm}$ equal to 14.7 psia), with ⅜-in.-outside-diameter tubing (inside diameter is 0.026 ft) that is 10 ft long to operate an end device with a 110-in.$^3$ (0.064-ft$^3$) $\Delta Vol_{bonnet}$, then the volume per cycle is 0.186 scf, which would be the actuation volume of this piping configuration at 25 psig at sea level.

It is useful to generalize the system volume and to convert the per cycle volume into a standard pressure to obtain a generalized exhaust scf/cycle, but it is not reasonable to convert that into a typical vented volume per unit time because exhausted volume is a function of the number of times the device operates.

This is a major source of confusion in regulatory language because the tables included in Subpart W are all time based, not actuation based, which is inappropriate for intermittent-vent controllers. The basis for the very high actuation volumes in that table is not clear from the available documentation. None of the technical-support documents for Subpart W or Subpart OOOO provide adequate details to determine the exact technique used or the data set relied upon. The magnitude of the value in Subpart W for intermittent-vent controllers could have come from someone actuating a controller, measuring the exhausted volume (call it 0.186 scf), calculating the time from the start of exhaust flow to the end of exhaust flow (call it 0.8 seconds), and dividing the (very short) time into the (fairly large) flow and resulting in more than 72 cycles/hr (0.233 scf/sec or 13.5 scf/hr from their table, assuming 25-psig actuation pressure and the largest bonnet readily available). This value is significantly higher than the regulatory definition of low-bleed continuous-bleed controller. The end result of this calcula-

| Supply-Gas Pressure (psig) | Exhaust Volume (scf/cycle) | Emissions | |
|---|---|---|---|
| | | 1.3 gal/cycle (32.3 cycles/bbl) Exhaust Volume (scf/bbl) | 3.9 gal/cycle (10.8 cycles/bbl) Exhaust Volume (scf/bbl) |
| 10 | 0.116 | 3.75 | 1.25 |
| 15 | 0.130 | 4.20 | 1.40 |
| 20 | 0.162 | 5.23 | 1.75 |
| 25 | 0.186 | 6.01 | 2.01 |
| 30 | 0.209 | 6.75 | 2.26 |
| 35 | 0.233 | 7.53 | 2.52 |
| 40 | 0.256 | 8.27 | 2.76 |
| 45 | 0.280 | 9.04 | 3.02 |

Table 3—Intermittent-vent, on/off level-controller example emissions.

tion is an overstatement of the Greenhouse Gas Reporting Program (2012) data by at least two orders of magnitude for intermittent-vent pneumatic controllers.

Far-more-useful results would be realized by estimating the effect of each cycle on the total result. For example, if the controller is in level-control service, then it is often possible to determine how much volume is removed in each dump cycle by counting dumps and measuring the accumulated volume. Combining this calculation with Eq. 2 yields Eq. 3:

$$Vol_{\text{scf/unit time}}\left(\frac{\pi}{4}ID^2_{\text{pipe}}\times L_{\text{pipe}}+\Delta Vol_{\text{bonnet}}\right)\times\left(\frac{P_{\text{control}}+P_{\text{atm}}}{P_{\text{std}}}\right)\left(\frac{Event\ Count}{Output\ per\ Event}\right)\left(\frac{Output\ per\ Unit\ Time}{Unit\ Time}\right)\ .\ \ldots\ldots (3)$$

The Output per Event is in process units. It might be the magnitude of a temperature change (e.g., 10°F/burner cycle), an amount of liquid dumped from a separator (e.g., 3.9 gal/dump), or a magnitude of pressure change (e.g., 5 psig/actuation). The Output per Unit Time is the aggregate of the process units. It might be a cumulative temperature change (e.g., the sum of the temperature increases is 1,700°F in a month) or an amount of liquid accumulated (e.g., 10 B/D).

Determining how to quantify the magnitude of the specific quantities changed by an actuation cycle is very difficult for most controlled parameters. The easiest is liquid volume produced from a level-control process because one has obligations to measure liquid volume independent of emissions-reporting requirements.

If a facility accumulates 1 bbl (42 gal) and observations show that the dump valve cycled 11 times, then the average Output per Event is 3.82 gal (0.091 bbl). If the liquid accumulation in an average month was 320 bbl, then in the 25-psig supply-gas-pressure example in the preceding, the exhaust volume is 933 scf/yr (1.06 scf/hr) for the 110-in.$^3$ bonnet and 10 ft of ⅜-in. tubing.

With this information, one can look at a specific separator and determine the volume of liquid dumped per cycle (assuming zero inflow during the control cycle). Two particular vessels were evaluated, and it was found that one unit produced 1.3 gal/control cycle and the other separator had a longer float travel and produced 3.9 gal/control cycle. For a fixed-volume flow rate, these two separators had significantly different emissions for the same liquid volume (**Table 3**).

Table W-1A of Subpart W (*40 CFR 98, Subpart W* 2013) specifies 13.5 scf/hr for intermittent-vent controllers regardless of supply-gas pressure, volume of piping and actuator, or actuation frequency. At 1-bbl/hr (24-B/D) liquid throughput, the emission calculations in the preceding would say that at a 25-psig supply pressure for the small-span separator, the Subpart W factor would overstate emissions by 123%, and for the long span, it would overstate emissions by 569%. If the liquid throughput was 2 B/D, then the Table W-1A factor would overstate emissions by 2,600 and 8,000%, respectively. If the well produces 100 B/D, then the Table W-1A factor would understate the emissions for the small separator by 46%, and for the large separator, it would overstate emissions by 61%.

In addition, the volume of the valve actuator must be taken into account when evaluating emissions from an intermittent controller. In the preceding level-control example, the volume assumed (110 in.$^3$) is for a large actuator capable of operating a 2-in. valve through the full range of its motion in fairly high process-differential-pressure conditions. In contrast, an actuator on the fuel-supply valve to a small field heater (temperature control), which is small in diameter and low in pressure service, has a volume in the 1.1-in.$^3$ range (1-in. valve), which would yield emissions some 100 times smaller than the 110-in.$^3$ actuator per cycle. To reach hourly emissions of 6 scf would require approximately 378 cycles, or 1 cycle every 9.5 seconds. These control valves are not designed to operate that frequently and would fail in short order.

This disparity between the emission factors listed in Table W-1A in Subpart W and an event-based approach is a clear indication that intermittent-vent controllers simply cannot be forced into a time-based framework with any expectation of reliable or repeatable data regardless of the size of the data set accumulated.

*Intermittent-Vent Controller in Throttle Service.* These devices vent so little gas, and so irregularly, that it is nearly impossible to either measure or estimate the vented volume. For example, this type of controller can be used to control the flow on a secondary cooling loop on an oil-flooded screw compressor to maintain the discharge temperature of the compressor. In this service, the controller will often vent a tiny fraction of an scf of gas two to three times per day. Trying to estimate this volume as other than zero will create a great burden on users of the device, which will tend to drive users away from this truly environmentally responsible technology in favor of one that exhausts more gas but is easier to comply with reporting requirements.

*Continuous-Bleed Controller in On/Off Service.* When the device in Fig. 8 is in the at-rest position (i.e., the block is clear of the bleed port), then the flow rate out of the bleed port can be calculated with a standard orifice calculation, as shown in Eq. 4 (note that the equation was modified from the source to bring two adjustment terms directly into the equation instead of calculating them outside and to convert from flow rate at actual conditions to flow rate at standard conditions) (GPSA 2004):

$$Vol_{\text{scf/D}}=16,330\left[1+\left(\frac{d}{D}\right)^4\right]d^2\times\left[\left(H_{\text{cntl}}\right)\left(29.32+0.3H_{\text{cntl}}\right)\left(\frac{T_{\text{std}}}{T_{\text{cntl}}}\right)\left(\frac{SG_{\text{ref}}}{SG_{\text{cntl}}}\right)\right]^{0.5}\left(\frac{H_{\text{cntl}}+H_{\text{atm}}}{H_{\text{std}}}\right)\ .\ \ldots(4)$$

Note that Eq. 4 is an empirical equation that should be solved in the units provided in the Nomenclature section. The use of other units will not result in correct answers unless the constants are converted properly and that conversion is obscure. Eq. 4 will yield higher results than reported by some manufacturers because of the use of the tubing diameter ($D$) rather than the internal flow channels within the controller. If available, the manufacturer's data should be used instead of Eq. 4.

In the example for a an intermittent-vent controller in on/off service,

$d = 0.030$ in.
$ID = 0.313$ in.
$H_{cntl} = 25$ psig$=50.9$ in. Hg
$H_{std} = 29.99$ in. Hg
$H_{atm} = 29.93$ in. Hg (sea level, 14.7 psia)
$T_{cntl} = 80°F + 460° = 540°$
$T_{std} = 60°F + 460° = 520°$
$SG_{ref} = 0.6$
$SG_{cntl} = 0.6$

Eq. 4 works out to 1,807 scf/D (75 scf/hr) for 25-psig supply gas at sea level for this example data. Introduction of supply gas into the process and exhaust gas to the atmosphere is very close to continuous. If the controller is calling for no supply gas to the end device, then the bleed rate is equal to the flow rate through the orifice. When the controller calls for supply gas to the end device, it either partially plugs the vent with the block (proportional) or fully blocks the vent (snap action), allowing pressure to build up in the end-device bonnet. At the end of the transient, the block clears the vent and the activation volume is exhausted along with the continued inflow through the restriction orifice. Fig. 11 shows a theoretical bleed cycle. The end result of the bleed cycle in Fig. 11 is that the exhaust rate over time is approximately equal to the at-rest flow rate of the restriction orifice regardless of the size of the end-device-bonnet size or the length and inside diameter of the tubing. The only factors that matter are the pressure of the supply gas, the gas composition, and the size of the restriction orifice.

The preceding example uses a restriction-orifice size of 0.030 in., which is the largest size in common use. Controllers with restriction-orifice sizes of 0.020 in. are also common, and controllers with restriction-orifice sizes of 0.010 in. and smaller are in use. Changing the orifice sizes to these smaller values would lower the calculated volumes significantly, but increase the risk of plugging the orifice.

This information also lends itself to developing **Table 4**. This table shows that even a low-bleed controller (i.e., exhaust rate less than 6 scf/hr) can be turned into a high-bleed controller (i.e., exhaust rate greater than 6 scf/hr) through the choice of supply-gas pressure. The 0.010 orifice is specifically intended to be low bleed, and with a supply-gas pressure less than 19.3 psig at sea level, it is successful. If that device is moved to a site near Denver (atmospheric pressure 13.0 psia instead of 14.7 psia), it is low bleed, with a supply-gas pressure of less than 20.1 psig.

*Continuous-Bleed Controller in Throttle Service.* In throttle service, the bleed rate is difficult to determine. There are several characteristics that can be expected to slightly lower the exhaust rate, but the benefit will be very slight and, Eq. 4 is still appropriate for most situations.

Estimating exhaust volumes from a continuous-bleed controller in throttle service requires capturing actuation pressure. Because this volume will always be lower than that of an on/off device, it might be reasonable to select an arbitrary multiplier (say 0.75) times the on/off numbers.

*After-Market Retrofit Kit.* Several manufacturers have retrofit kits that convert a continuous-bleed on/off controller into an intermittent-vent on/off controller. One example is the MIZER® from WellMark Company LLC. This device uses the mechanical movement of the block in Fig. 8 to operate an "actuation poppet" on an on/off controller (called a pilot plug elsewhere in this document). A continuous-bleed on/off controller with this sort of kit installed becomes an intermittent-vent on/off controller, and the emissions should be calculated on the basis of the revised category.

| Supply-Gas Pressure (psig) | 0.030 in. Orifice (scf/hr) | 0.010 in. Orifice (scf/hr) |
|---|---|---|
| 10 | 26.4 | 2.9 |
| 15 | 40.5 | 4.5 |
| 20 | 56.8 | 6.3 |
| 25 | 75.3 | 8.4 |
| 30 | 96.0 | 10.7 |
| 35 | 118.9 | 13.2 |
| 40 | 144.1 | 16.0 |
| 45 | 171.4 | 19.0 |

Note: This table was developed for $SG_{gas}$ of 0.63. Other gas specific gravities result in different values that must be calculated with Eq. 4.

Table 4—Continuous-bleed, on/off level controller example emission factors.

Many continuous-bleed controllers in on/off service try to take advantage of the fact that most on/off services spend significantly more time at rest than actuated. To capitalize on this observation, operators sometimes turn the controller upside down (so that at rest, the block is hard on the vent and, in the actuated position, the block is off the vent) and actuate the end device by means of an intermittent-vent external pilot. The external pilot is set up to send an actuation signal on loss of pressure. This adaptation does not change the emissions factors of a continuous-bleed controller significantly, but it provides the feeling that the operator has taken a proactive step.

## Controller-Selection Considerations

Each of the four categories of controller has a place at which it represents the lowest emissions (**Table 5**). This can be demonstrated with a level-control example. The separator in Fig. 4 has a high-level controller (LC1) that begins the dump cycle and a high-level switch (LS) that actuates the site emergency shutdown electronically. The volume between these two devices is 24 gal. This LC1 is operating two end devices and has fairly complex connections between it and the other level controller (LC2); the actuation space is 0.143 ft$^3$.

Both the dump valve and the power-gas three-way valve require approximately 5 psig to begin movement. In every case, the piping downstream of the dump valve is assumed to have 4-gal/sec flow capacity (8,200 B/D) so that in any flow regime in this example, when the dump valve opens, the level drops to the low set point very quickly and the size of the exhaust port in the controller allows the dump valve to shut without the vessel blowing dry. **Fig. 12** shows the comparative emissions.

**Intermittent-Vent Controller in Throttle Service.** In level control, this controller introduces gas or vents gas only when the inflow rate to the separator changes. From the standpoint of emissions being caused by pneumatic control, this is by far the best choice for flows that are reasonably constant. From a process-control standpoint, it is frequently not desirable to maintain a level in a vessel (e.g., if the inflow was approximately the same as the potential evaporation rate, the controller can end up with fluid levels below the set point and throttling-control valves do not seal as well as on/off-control valves; gas leakage into the water system is common in this service, which can result in significantly higher emissions than from controller actuation). In Fig. 12, the emissions are indistinguishable from the manufacturer's estimates of seepage.

**Intermittent-Vent Controller in On/Off Service.** Emissions from this device are event based, so depending on the liquid inflow rate,

| | On/Off | Throttle |
|---|---|---|
| Intermittent Vent | Lowest emissions for systems with low to moderate actuation frequency or small actuation space. Lowest emissions for systems with high actuation frequency that do not have adequate reserve capacity to allow low-bleed-continuous controllers to function. | Lowest emissions for reasonably steady flows in which the process tolerates maintaining the process variable permanently in an intermediate position. |
| Low Continuous Bleed | Lowest emissions for systems with high actuation rate and the highest actuation space that do have adequate reserve capacity to wait for slow actuation rate to pressurize. | Lowest emissions for inherently unstable systems that require changing the position of the end device many times per second. |
| High Continuous Bleed | Lowest emissions in very high flows | No scenario in which this has the lowest emissions. |

Table 5—Controller-selection considerations on the basis of lowest emissions.

intermittent-vent controllers in on/off service can often be the best emissions-control choice. In Fig. 12, the line of the intermittent-vent controller in on/off service crosses the low-continuous-bleed on/off line at 369 B/D. Below this number, the intermittent-vent device has lower emissions. This is important because, in 2003, the average water/gas ratio (WGR) in the United States was 0.436 Mscf/bbl (Welch and Rychel 2004). Well counts and gross dry production from the Energy Information Administration for 2003 and this WGR indicate that an average onshore gas well would make less than 60 B/D. The actual distribution is highly skewed toward a small percentage of the wells producing the bulk of the water. Excluding the high-water-rate wells from the average results in water rates closer to 10 B/D/well. These small water rates result in a distinct preference for intermittent-vent controllers in this service.

**Low-Continuous-Bleed Controller in On/Off Service.** Low-bleed controllers move gas through the restriction orifice slowly. For this configuration, it requires 105 sec to reach the minimum pressure to overcome control-valve hysteresis. During this time, liquid continues to flow into the vessel. If the flow rate is greater than the reserve capacity (24 gal) divided by the charge time (105 seconds), then the liquid will reach the level switch and trip the site emergency shutdown on the high-high separator level. This flow rate converts to 470 B/D. This is the maximum inflow that this controller can tolerate in this vessel. The result is that in this exact service, the low-continuous-bleed controller is the best choice between 369 and 470 B/D of inflow. However, this advantage is too narrow an operating range to recommend over intermittent-vent controllers because of the frequent variability of daily production rates in real-world application.

**High-Continuous-Bleed Controller in On/Off Service.** High-bleed devices exhaust a considerable amount of gas. There are few applications in which they are the best choice, but there are some. For the vessel in this example, the high-bleed controller can pressurize the actuation space in 4 seconds. This leads to a maximum capacity of 12,000 B/D and lower emissions than an intermittent-vent device greater than 4,600 B/D.

**Common Malfunctions.** Malfunctioning controllers result in emissions that are inconsistent with the manufacturer's published emissions data. Some percentage of the population of any mechanical device will be malfunctioning at any given time. The data-gathering studies that are currently ongoing or that have been completed recently seem to be dominated by a small number of malfunctioning devices. This is likely a result of the small number of devices sampled and/or the short time interval allotted to each controller evaluation. Participants in the (published and soon-to-be-published) studies have reported that up to 90% of the emissions identified from any given make/model of controller come from fewer than 10% of the units sampled (some say 80:20 instead of 90:10, but either number leads to the same conclusion). This observation has been reported too often to be an anomaly from any one study. Once an activation signature of a properly functioning controller has been defined, it is quite reasonable for operators to use that signature to look for malfunctioning controllers, but including the malfunctioning devices in the emissions-factors evaluations has a serious risk of overstating emissions significantly.

There is a group of malfunctions specific to the supply-gas system, but not necessarily to a controller. Malfunctions such as (but not limited to) tubing leaks, failed end-device actuator diaphragms, and supply-gas-pressure drift are not included in controller emissions because they are quite unusual and should be captured in an "equipment-leaks" category.

Many of the malfunctions that are specific to controllers include the accumulation of debris. Wellsites are a rich source of foreign material. One finds geologic material from the reservoir, stimulation material from the completions, pipe scale, corrosion products, and phase-change scale inside of control systems. Some are too small to be reliably captured by installed filters, and some are created by a change of fluid state. Regardless of the source, the industry has been unable to keep all occurrences of this material out of control systems.

The malfunctions that are common to pneumatic controllers are specific both to the service and to the depressurization method.

***Intermittent-Vent Controllers in On/Off Service.***

1. Debris on the vent pilot plug: Debris on the vent pilot can allow the controller to exhaust gas during the activation cycle. Because of port sizes, this exhaust volume is limited to a small proportion of the controller's normal activation volume.
2. Debris on the supply pilot plug: Debris on the supply pilot can cause the introduction of gas while the vent is open. Again, the port sizes limit this exhaust volume to a small proportion of the controller's normal activation volume.
3. Broken spring (if equipped): The spring holds the supply pilot plug on its seat, and without this spring, the controller has emissions similar to those of a continuous-bleed controller (with the d term in Eq. 4 equal to the flow area of the vent pilot). This particular malfunction generally calls attention to itself quickly because the end device being actuated never operates.
4. Broken diaphragm (where installed): Many intermittent-vent controllers in on/off service have diaphragms for various reasons. A detailed analysis of a particular device would be required to determine the effects of the failure on the exhausted gas.

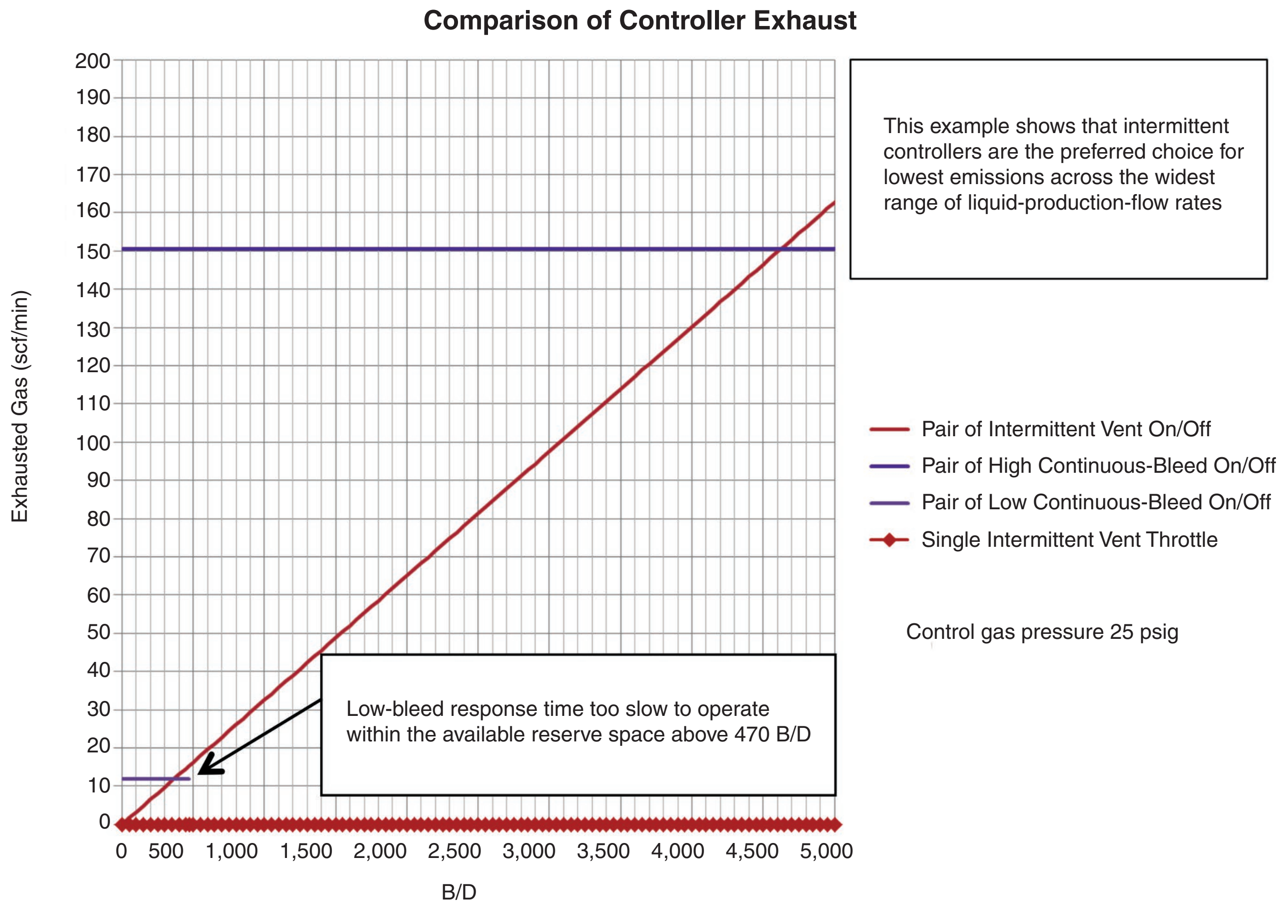


**Fig. 12—Exhaust-gas comparison for a separator with two controllers.**

***Intermittent-Vent Controllers in Throttle Service.***

1. Debris on the vent pilot plug: Debris on the vent pilot can allow the controller to exhaust gas continuously (with supply being added to make up the lost gas). This leakage turns the intermittent vent into a continuous bleed, with the *d* factor in Eq. 4 estimated by the amount of the vent pilot plug that is open.
2. Debris on the supply pilot plug: Debris on the supply pilot can cause the introduction of gas to the end device, which requires the vent to be opened frequently to keep the end device in the proper position. This leakage turns the intermittent vent into a continuous bleed, with the *d* factor in Eq. 4 estimated by the amount of the supply pilot plug that is open.
3. Broken spring: The spring holds the supply plug on its seat, and without this spring, the controller has emissions similar to those of a continuous-bleed controller (with the *d* term in Eq. 4 equal to the flow area of the vent pilot). This particular malfunction generally calls attention to itself quickly because the end device being actuated is left in an indeterminate position.
4. Broken diaphragm (where installed): Most intermittent-vent controllers in throttle service have diaphragms for various reasons. A detailed analysis of a particular device would be required to determine the effects of the failure on the exhausted gas.

***Continuous-Bleed Controllers in Any Service.***

1. Debris in the restriction orifice: Debris in the restriction orifice will reduce the exhaust rate, but it is difficult to quantify the reduction.
2. Debris in the vent line: Debris in the vent line allows pressure to build up to the end device and will operate it. In dump service, this failure may cause the dump valve to go to open, blowing the vessel dry and sending a significant gas stream into the water tank or water-gathering system. Volumes are far too large to rely on rules of thumb to calculate them.
3. Scarred block: The block on the vent is cut frequently by the seating surface. This increases the bleed rate for any given target pressure to the end device and can make the end device operate sluggishly. This malfunction does not automatically change vented-gas volumes unless a sluggish end device allows afterflow (i.e., flow of the process fluid after the controller sent an "end-evolution" signal).

## Recommendations and Conclusions

The preceding analysis demonstrates the way in which the actual emissions from pneumatic controllers change with design classification and supply-gas pressure. If each controller was placed in one of the categories defined in the preceding analysis, then it is possible to use a matrix to determine the emissions factors that are applicable for specific situations and that reflect the dependence on operating conditions, as summarized in **Table 6**.

As shown by the previous discussion, exhausted volumes from a continuous-bleed controller will generally be significantly higher than those of an intermittent-vent controller in similar service. This is because of the continuous bleed of gas to the atmosphere between actuation cycles for a continuous-bleed controller, which does not occur with an intermittent-vent controller, although both types do exhaust the actuation volume at the end of the actuation cycle.

Many regulations—including the US mandatory greenhouse-gas (GHG) reporting requirements in *40 CFR 98, Subpart W* (2013)—specify the use of emission factors for intermittent-vent controllers that result in seemingly high exhaust rates for this category of controller. Such emission factors seem to have been derived by attempting to represent event-based exhaust venting, such as for intermittent-vent controllers, by an unrepresentative average

| | On/Off | Throttle |
|---|---|---|
| Intermittent Vent | Event based. Must consider supply-gas pressure, size of actuator, and length and inside diameter of tubing to determine emissions per cycle. Relating event count per unit time to some process variable per event is crucial. | Event based. Must consider supply-gas intermediate actuation pressure (i.e., the pressure that holds the end device in the required position), size of actuator, and length and inside diameter of tubing to determine emissions per cycle. Relating event count per unit time to some process variable per event is crucial. |
| Continuous Bleed | Emissions based on time schedule are appropriate as long as orifice size, operating pressure, and gas composition are factored in. | Emissions based on time schedule are appropriate as long as orifice size, operating pressure, and gas composition are factored in. |

Table 6—Determination of emissions factors.

exhaust flow over a distinct period of time, leading to very high emission estimates. These high average emission factors used for GHG emissions inventorying and reporting programs are inconsistent with the findings of carefully executed field studies or with the recommendations that are based on the engineering-calculation methods presented in this paper.

## Nomenclature

- $d$ = inside diameter of the restriction orifice, in.
- $D$ = inside diameter of the piping, in.
- *Event Count* = number of actuation events that took place within a given time period, count
- $H_{atm}$ = local atmospheric pressure, in. Hg (absolute)
- $H_{std}$ = pressure designated by proper authority to represent the standard pressure to be used for aggregating volumes, in Hg (absolute)
- *Output per Event* = the amount that a process variable changes each time the actuator is opened, units depend on the variable being measured
- $ID_{pipe}$ = inside diameter of the piping, ft [m]
- $L_{pipe}$ = length of all piping in the system, ft [m]
- $P_{atm}$ = local atmospheric pressure, psia [kPaa]
- $P_{control}$ = pressure of the supply-gas system, psig [kPag]
- $P_{std}$ = pressure designated by proper authority to represent the standard pressure to be used for aggregating volumes, psia [kPaa]
- $SG_{cntl}$ = supply-gas specific gravity (relative to air=1.0), fraction
- $SG_{ref}$ = reference specific gravity (relative to air=1.0), 0.6
- $T_{cntl}$ = supply-gas temperature, °R
- $T_{std}$ = temperature designated by proper authority to represent the standard temperature to be used for aggregating volumes, °R
- $Vol_{pipe}$ = the physical volume of the piping connecting components, $ft^3$ [$m^3$]
- $Vol_{scf/D}$ = the amount of gas released per day converted to standard temperature and pressure, scf/D
- $Vol_{system}$ = the physical volume of a system of pipes and actuators, $ft^3$ [$m^3$]
- $\Delta Vol_{bonnet}$ = the physical volume of a system of pipes and actuators, $ft^3$ [$m^3$]


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## Appendix A: Glossary

*Actuation:* The act of transitioning an end device from at rest to not at rest.

*Actuation space:* The piping and equipment downstream of the restriction orifice (continuous-bleed controllers) or downstream of the controller's source barrier (intermittent-vent controller).

*At rest:* In this context, an end device is at rest when actuation pressure is removed and the valve is forced to the position that is determined by spring pressure.

*Bleed port:* On a continuous-bleed controller, the port that allows gas to exhaust from the actuation space. The bleed port is used in combination with the block to control bleed rate. The bleed port is always larger than the restriction orifice so that when the block is off the port, all the gas that passes through the restriction orifice will exhaust without increasing the pressure in the actuation space.

*Block:* On a continuous-bleed controller, the block rides on the bleed port to throttle (or stop) the flow of gas to the atmosphere to increase the pressure in the actuation space. Also called a "flap" or "flapper."

*Continuous-bleed pneumatic controller:* A pneumatic controller that does not have a mechanical barrier between supply gas and the end device. These units rely on a bleed port that is covered by a block or flapper to increase the amount of pressure sent to the end device (close the bleed port) or decrease the amount of pressure sent to the end device (open the bleedport).

*Electropneumatic controller:* A process controller that responds to an electronic signal representing a process variable by sending an electrical signal to an electrically actuated valve that varies a gas-pressure signal to an end device.

*End device:* A piece of equipment that is acted upon by a controller to impact the state of a process variable.

*Integral controller:* A pneumatic controller that is physically built into an end device, receives its supply gas untreated from the process being controlled, and exhausts excess supply gas back into the process stream without any gas exhausting to the atmosphere.

*Intermittent-vent pneumatic controller:* A pneumatic controller that has a mechanical barrier between the supply gas and the end device. These units do not allow supply gas and a vent port to be both open at the same time.

*Latency:* A measure of the elapsed time between initiating flow and the onset of reliable flow measurement.

*Local controller:* An integral controller that exhausts gas to the atmosphere instead of back into the process stream.

*No-bleed pneumatic controller:* A marketing term with no discernible meaning (some regulators have defined no bleed as any controller that uses compressed air or compressed nitrogen instead of a methane mixture, but this practice has proved to be very confusing and should not be encouraged). Intermittent-vent controllers (which do not emit between deactuation cycles) are often mistakenly referred to as no-bleed controllers.

*Not at rest:* The state of an end device at which actuation pressure is greater than atmospheric pressure and the process valve is out of its at-rest position.

*On/off controller:* A controller that does not have the ability to sustain an end device in an intermediate position. It can only actuate an end device toward fully open or toward fully shut.

*Pilot plug:* A device within many intermittent-vent controllers that contains the part of the pilot that supplies a mechanical barrier between the supply gas and the actuation space and supplies a mechanical barrier between the actuation space and the exhaust sink. Also called a "peanut valve."

*Pneumatic controller:* A process controller that responds to a process variable by altering a gas-pressure signal to an end device.

*Process controller:* A device that senses a physical state and directs an end device to take an action to modify that physical state.

*Process variable:* A parameter that is sensed by a controller and is managed by an end device.

*Proportional action:* When an on/off controller begins to send a partial open signal as soon as the sensing device reaches greater than some minimum value and increases the strength of the signal—as long as the sensing device is above the minimum, its action is considered proportional. At some point in the increasing sensor value, the actuation space will be fully pressurized and the end device will be fully open—at that point, further controller movement toward open causes no further change in end-device position. Proportional action can be thought of as "soft operate" because its action is less abrupt than a snap action.

*Remote pneumatic controller:* A pneumatic controller that is not physically built into an end device.

*Restriction orifice:* The reduced-diameter section of a continuous-bleed controller that limits the rate at which supply gas is supplied to the actuation volume.

*Snap action:* When an on/off controller does not send an open signal until the sensing device moves to the maximum extent of travel, its action is considered snap action. When the sensing element reaches its minimum value, the controller rapidly depressurizes the actuation space. Snap action can be thought of as "hard operate" because its action is quite abrupt.

*Throttling controller:* A controller that is designed to hold an end device in an intermediate position and move it from any position to more (or less) open without a requirement to go to fully open or fully shut at every actuation cycle.

*Turndown ratio:* The ratio of a minimum to a maximum. Often used in gas measurement and flow-control equipment. In gas measurement, it is calculated by determining the maximum reliable flow rate (i.e., the flow rate with maximum differential pressure that the instruments can measure without the static pressure going out of range) and dividing that number by the minimum reliable flow rate (usually taken as zero differential pressure plus the uncertainty of the differential-pressure instrument), and it is expressed as an ordered pair (e.g., if the turndown ratio is 10, then it would be written as 10:1).

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