Well Site Pneumatic Control

Course No: P03-007
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Abstract

Process control engineering is a fairly narrow field of study that has always used inconsistent terminology among practitioners. Since 2011, natural gas–actuated pneumatic controls equipment has been a focus for regulators trying to reduce the quantity of actual pollutants and so-called greenhouse gases (GHG) released. 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 course is to present a rigorous set of terms and operational classifications that can help create a framework of knowledge consistent with how this equipment functions.

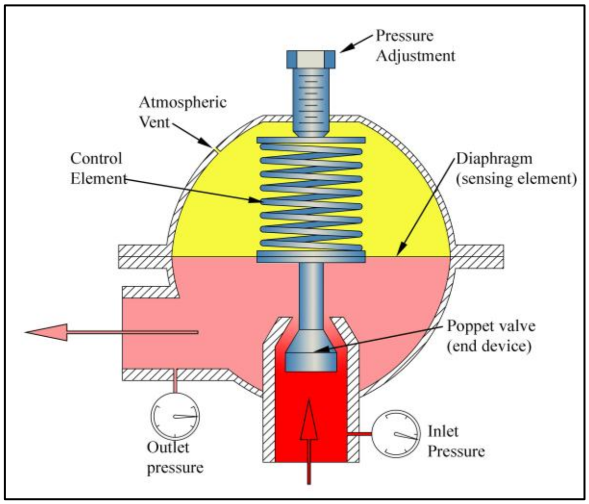

Figure 1: Pressure Regulator

While high-quality/low-power linear electronic actuators (such as the Fisher *easy -Drive* or the Kimray *Electric Actuator*) have evolved over the last few decades to being a very effective (and often the preferred) choice for many applications on well sites, there are still millions of pieces of pneumatic control equipment on well sites and gas-gathering systems. Understanding them is key to making informed decisions.

Introduction

Typical well site process control is pretty simple. Control gas comes from the well (although nitrogen bottles or air compressors are sometimes used). Separators need liquid-level controls. Separator heaters and many tanks require temperature control. Compressors often require suction-pressure control, discharge backpressure control, and/or recirculation control. All these processes can be independently controlled without requiring a Program Logic Controller (PLC). In fact, the outcome of the control process is often far superior if there is not a PLC to act as a gatekeeper.

Historically the well-site control philosophy was one-controller-one-end-device. This says that a level controller output goes to an end device called a "dump valve", a suction controller uses upstream gas to operate a pneumatic control valve, a temperature controller sends an on/off signal to a burner supply valve, etc. This is the "old way". The "new way" is to send all sensing element (see below) output into a PLC and expect the PLC to evaluate the data and reposition end devices as necessary. The vast computing power in today's PLC is just aching to be used. We must all do our best to avoid the trap of using it.

When helping a company troubleshoot a very expensive compressor skid that was not working properly it was found that they were using the on-skid PLC to control the suction control-valve, the discharge backpressure valve, the recirc valve, and even the control valves for the blow case. In addition to these control functions, the PLC had the assignment of gathering hourly performance parameters, connecting to the Internet, and sending the data to a database in the cloud. Unfortunately, it was a simple-minded PLC that could not start a step until the last step finished. Since everything in the entire system reported on the top of the hour, it could sometimes take 2-3 minutes to accomplish the reporting task. When the well would experience an increase in flowing bottom hole pressure at the top of the hour (maybe due to a dip in the liquid level downhole), suction pressure would increase, which should cause the suction controller to go towards shut and keep the increased mass flow rate from tripping the engine on low rpm, but the PLC was sending data that no one ever looks at to a database that no one can find, so the compressor dropped off line.

Another time, a slug of liquid hit the suction scrubber a few seconds after the top of the hour (while the PLC was gathering data), the blow case controls couldn't be told to empty the vessel, and the skid went down on the high scrubber-level kill (which luckily didn't go through the PLC). Still another time, a slug of liquid hit the scrubber a few seconds before the top of the hour, the dump opened and then the PLC was too busy to close it and for several minutes the skid blew a coherent stream of gas into the tank, unfortunately the end of the pipe was submerged so it blew the tank dry. There were 30 other scenarios that were interrupted by the data-gathering sub-routine. As a short term "fix" a second PLC which only had reporting assignments was installed which left the original PLC to actually do "Programmed Logic Control". Eventual solution was to replace all the PLC control with local control (see below) and to not allow the PLC to control any of the compressor processes except engine rpm and engine load-control. This was an extreme example and a particularly lame program, but it is by no means unique.

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 control system is made up of: (1) a sensing element; (2) a control element; and (3) an end-device. The sensing element can be something as simple as the float in a toilet tank. That system includes a flush handle (which is a “process event”, not part of the process control) which initiates the process to drain the tank when depressed. The “sensing element” is the tank float that sees a decreasing tank level and sends a signal to the control element that more water is needed. The control element is the linkage from the float to the water-supply valve that is direct-connected to the float arm. The end-device is the water-supply valve. It is easy to see that this system could have a radar level-sensor connected to a PLC that could open a solenoid on the water-supply line, but why in the world would you do that? It would only add complexity that does not add value.

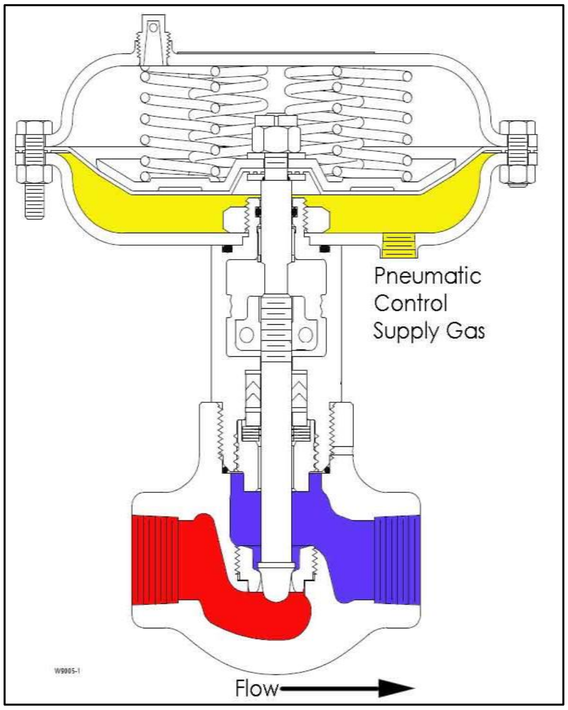

Figure 2 End Device [Fisher, 2011]

The sensing element is a device that can discriminate the condition of a process variable and can communicate that condition to a controller. Sensing elements can be mechanical (e.g., a bi-metallic temperature sensor has two metals with different coefficients of thermal expansion fused together, as temperature changes the two metals expand/contract differently which changes the curvature of the element), electrical (e.g., a “Radar Level Controller” senses fluid height by sending and receiving echoes from a sound wave), or hydraulic (e.g., a level float in a separator or tank).

The control element is anything that can cause an end-device to change state in response to the input of a sensing element. A PLC is the most obvious example of an electric control element; it can take the input of (multiple) sensing element(s) and evaluate that input and change the state of (multiple) end-device(s). At the other end of the spectrum is a temperature controller that can react to the curvature of a single bi-metallic element to turn gas on or off to an end-device controlling fuel-flow to a burner.

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, etc.)
- Pressure (includes pressure regulating, back pressure regulating, and overpressure limiting)
- Temperature (includes tank heaters, indirect process heaters, direct process heaters, and fan control)
- 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 after flow and/or to shut off the flow to allow the plunger to drop)
- Safety (includes control of emergency shutdown valves that go 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., mechanical device that accepts an input signal and generates an output signal) and "process valve" (i.e., valve used for controlling processes that is positioned by the "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 oil and gas upstream 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.

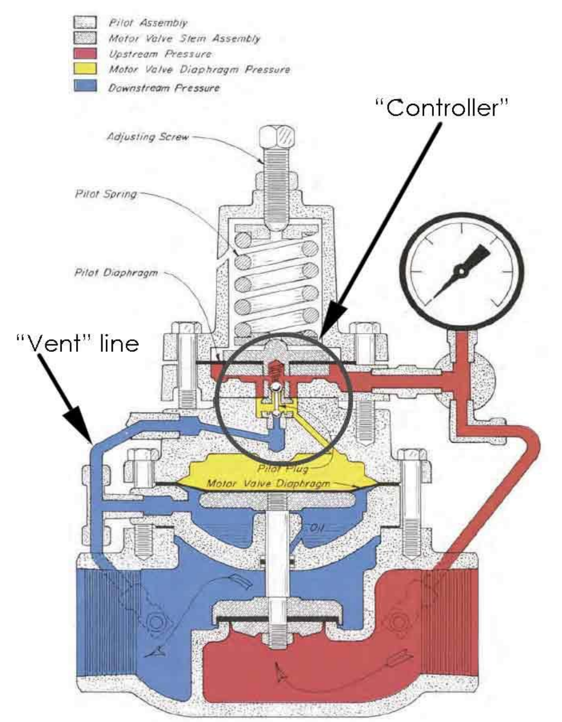

Figure 3: Integral Controller [Kimray, 08/2013]

The end device in Figure 2 is a pressure-to-open control valve that is generally referred to as a "motor 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, using a different term here would overall be more confusing than using manufacturers' terminology.

The end device in Figure 2 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 Figure 2), and the valve stem is forced to move upward against spring pressure to move the process valve (red and blue sections in Figure 2) toward "open." The end device in Figure 2 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 Figure 2 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, not the end device.

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 actuator)
- Pneumatic (sends a gas pressure signal to pneumatic actuator; pneumatic motive force can come from natural gas, on-site compressed air, or bottled compressed gas)
- Hydraulic (sends a liquid pressure signal to a hydraulic actuator)
- Electro-hydraulic (controller opens an electric valve to send liquid pressure to a hydraulic actuator)
- Electro-pneumatic (controller opens an electric valve to send gas pressure to a pneumatic actuator)

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

- Integral—the controller is built into the end device (Figure 3). Supply gas comes from the process upstream of the valve, and the excess gas is "vented" to the process downstream. Integral controllers can only be used in a very small number of applications because of inherent limitations in the ability of a controller to exhaust into process pressure. The part marked "Controller" in Figure 3 is functionally identical to the Intermittent Vent Controller in Figure 9. Many backpressure and pressure regulators (Figure 1) are integral controllers (the exception is those regulators and/or back pressure regulators that are controlled by a PLC). The pressure regulator in Figure 1 "exhausts" excess pressure into the downstream piping by the process using more gas than the poppet will pass. The "atmospheric vent" in Figure 1 is always open, if it ever gets clogged then pressure above the diaphragm will change the set point of the device because the diaphragm moving up will compress the air in the space (adding that pressure to spring force), and the diaphragm moving down creates a low-pressure area (subtracting from the spring force).
- Local—the controller is built into the end device, and supply gas comes from the process. The controller in Figure 3 would become a Local Controller if the vent line were opened to the atmosphere. Gas that is exhausted by a local controller, is exhausted to the atmosphere
- Remote—the controller is physically separate from the end device. Remote controllers are used in applications like tank-level control, separator dump valves, or temperature controllers. Gas is exhausted to the atmosphere.

The difference between "integral" and "local" is subtle but important. An integral controller (Figure 3) 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 is also built into the end device, but if it exhausts gas, it exhausts it to the atmosphere to move the process valve toward "closed."

"Remote" controllers include everything else. They can be electric, hydraulic, electro-hydraulic, electro-pneumatic, 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 remote hydraulic-controllers do not have the opportunity to exhaust gas, and these categories of controllers will not be discussed further.

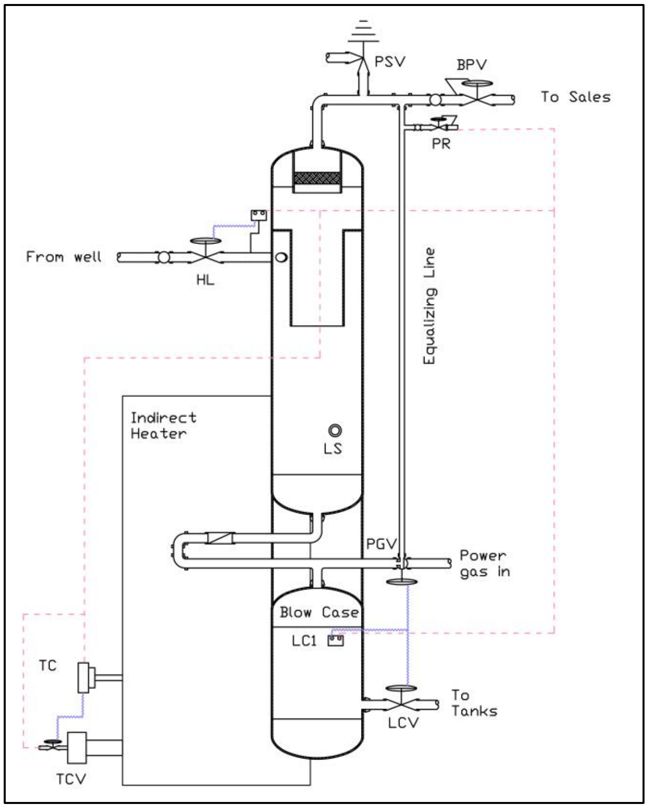

Figure 4: Wellsite Vertical Separator

Upstream Oil and Gas Controls Example. The separator in Figure 4 has controls that cover most of the functions of controllers that may be seen on well sites (see Table 1). It has historically been rare for one vessel to have all these controls, but as gas line pressures decline, the need to install such things as blow cases and indirect heaters increases. This separator is purposely at the top end of the control's requirement, but it is not an impossible configuration.

In Figure 4, liquids that are separated from the gas will drain into the blow case through a check valve. When enough liquids accumulate within the blow case to change the state of the level-controller (marked "LC1"), then the controller sends pressure to the dump valve (marked "LCV") to "open" and sends pressure to the power-gas three-way valve (marked "PGV") to change from "equalize" to "power gas" (of course this scenario requires a source of power gas at a higher pressure than the separator backpressure valve set point so that it can seal the check valve between the vessel and the blow case).

Table 1: Process Control Devices in Figure 4

	Power Media	**Relationship to End Device**	**Service**	**Depressurization Method**	**Comment**
LC1	Pneumatic	Remote	On/Off	Intermittent vent	Manage blow case fluid level
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

Greyed out rows represent devices that do not have an air emissions impact

The end devices remain in that position until the controller changes state to remove the pressure from the two end devices allowing the pressure to equalize and the check valve to reopen.

If the blow case 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 above. 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 through the temperature control valve ("TCV") to maintain the process temperature. The high-low controller (HL) is discussed below.

High/Low Pressure Control. Figures 5 to 7 show remote controllers in "high-low" service. This service positions a control valve in response to downstream pressure to protect the upstream piping if downstream pressure builds or to stop the flow when downstream pressure gets low enough to indicate a possible line leak.

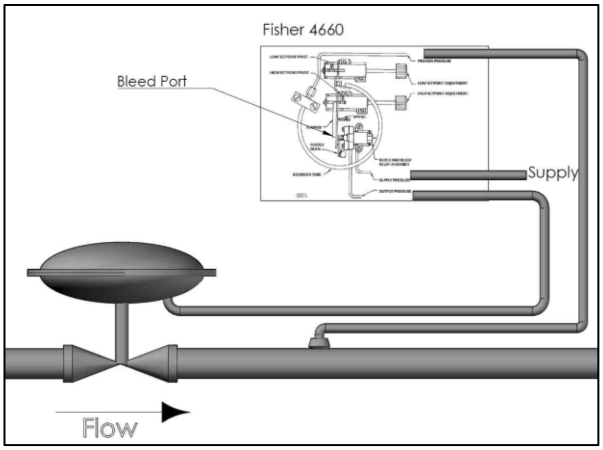

Figure 6: Pneumatic High-Low Controller

The configuration in Figure 5 is pneumatic. The controller senses downstream pressure and allows gas to the end device or stops gas to the end device and vents the line. 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.

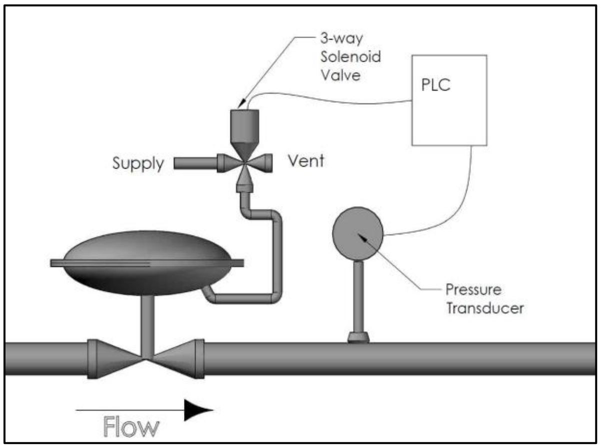

Figure 6: Electro-pneumatic High-Low Controller

The configuration in Figure 6 is electro-pneumatic. Logic within the PLC compares the pressure reading from the pressure transducer to 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 Figure 7 is electric. It has the same control logic in the PLC as the electro-pneumatic 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 result is the same; the difference between the two schemes is the reliability of the shutdown in various failure modes.

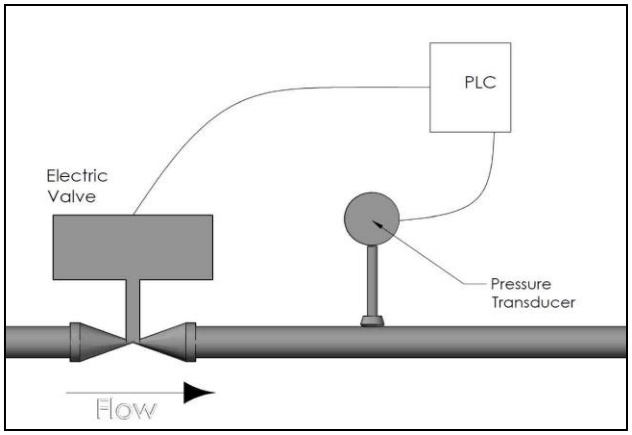

Figure 7: Electric High-Low Controller

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 Exhaust Gases

Process controllers are devices that sense a physical state (process variable) and direct an end device to take 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 above, this discussion is limited to local and remote pneumatic and electro-pneumatic controllers. There are many ways to classify pneumatic and electro-pneumatic 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: Does it *bleed* supply gas continuously (continuous bleed), or does it *vent* actuation gas at the end of the "on" cycle (intermittent vent)?

Table 2: Pneumatic Controller Classification

	On/Off	**Throttle**
Intermittent Vent	Vents to zero actuation pressure at the end of the cycle.	Partially vents when 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.

On/off controllers are often described as either “snap acting” or “proportional,” which describes the type of action a controller in on/off service may take and does not have a significant 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 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 above a minimum value, and as the input continues to increase, the rate that the controller sends gas to the end device increases. 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 prior to 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-acting 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-acting 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 (while operating much slower). The choice depends on the process being controlled.

Both continuous bleed and intermittent vent controllers can be either snap acting 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 electro-pneumatic 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 things like 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 fully open. When the controller senses that the process variable has returned to normal, they remove the pressure from the control valve by exhausting the actuation gas, causing the valve to shut via spring pressure.

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. These devices are used for things like pressure control, where the operator attempts to keep the pressure on one side of an end device in a predefined range when faced with changing conditions on the uncontrolled side and changes in demand on the controlled side. 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" (Figure 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.

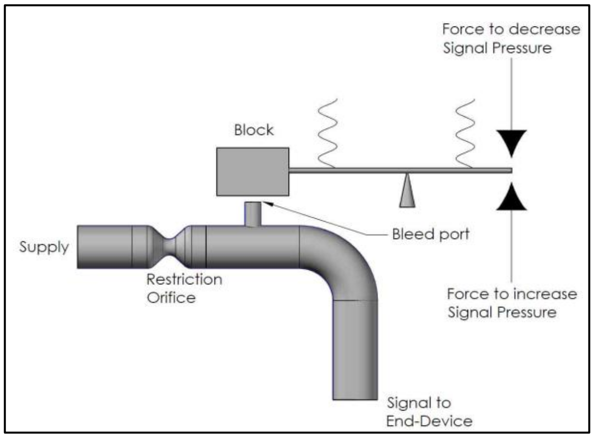

Figure 8: Continuous Bleed Controller

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 gets through the restriction orifice exits through the bleed port and the pressure to the end device is approximately zero. Since 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 (Figure 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" or a "peanut valve") as shown in Figure 9. When the input signal calls for more pressure to the end device, a pilot valve (e.g., the bottom ball on the pilot plug in Figure 9) between the supply gas and the end device will open (while the vent remains closed because the combination of the spring at the bottom and the down force from the push rod hold the vent ball on the seat, i.e., the vent ball moves with the valve seat). 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 Figure 9) between the end device and the atmosphere will open (while the supply remains shut).

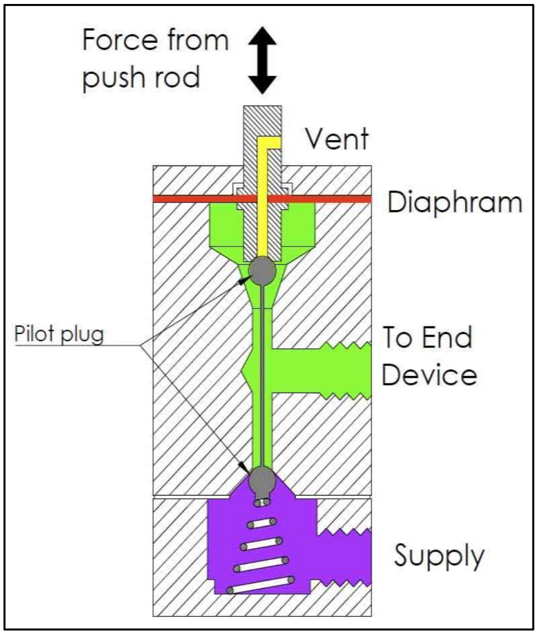

Figure 9: Intermittent Vent Controller

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 Figure 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 spring pressure (while holding the vent tightly closed) 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 SCFH set by regulations. This limit was described in the EPA "Natural Gas Star" program and has been included in EPA's revision to the New Source Performance Standard (NSPS) Subpart OOOO regulation. "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 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 below, continuous bleed controller emission rate is effectively immune from 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 deliquification 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, 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 since 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 petroleum and natural gas industry are conducted using 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, etc.) and other characteristics of the fluids being measured. For example, an orifice meter 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 Bernoulli’s 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 that 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 that the software makes are that the density is constant and the velocity is changing.

Another key concept is "latency." Since surrogate parameters are being measured for flow, one must wait until conditions match 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 sec and the flow event lasts 0.5 sec, 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 non-spinning 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 sec (2232 SCF/hr equivalent rate), then the device must have a turndown ratio of 1:32,000. The very best meters currently 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.

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 above, 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. 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 that 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].

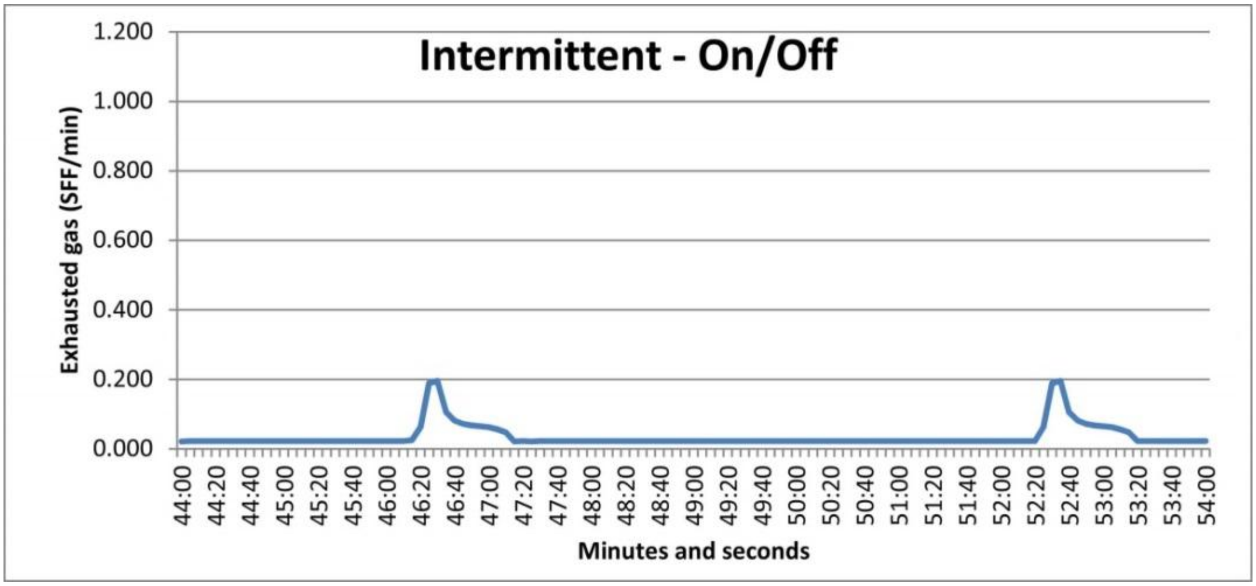

Figure 10: Intermittent-vent Theoretical exhaust Rate

Minimum Exhaust Rate. For intermittent vent controllers (Figure 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, 2009] has tabulated the at-rest seepage for their current generation of intermittent vent controllers (using 30 psig gas) as 0.407 SCF/day (0.017 SCF/hr) in snap mode and 0.610 SCF/day (0.025 SCF/hr) in proportional mode. These numbers are presented as maximums for a valve in good operating condition, and 0.610 SCF/day of natural gas equates to 4.9 kg/year.

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 Figure 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 19.7 SCF/hr minimum bleed rate (without specifying either the makeup of the gas or the supply-gas pressure).

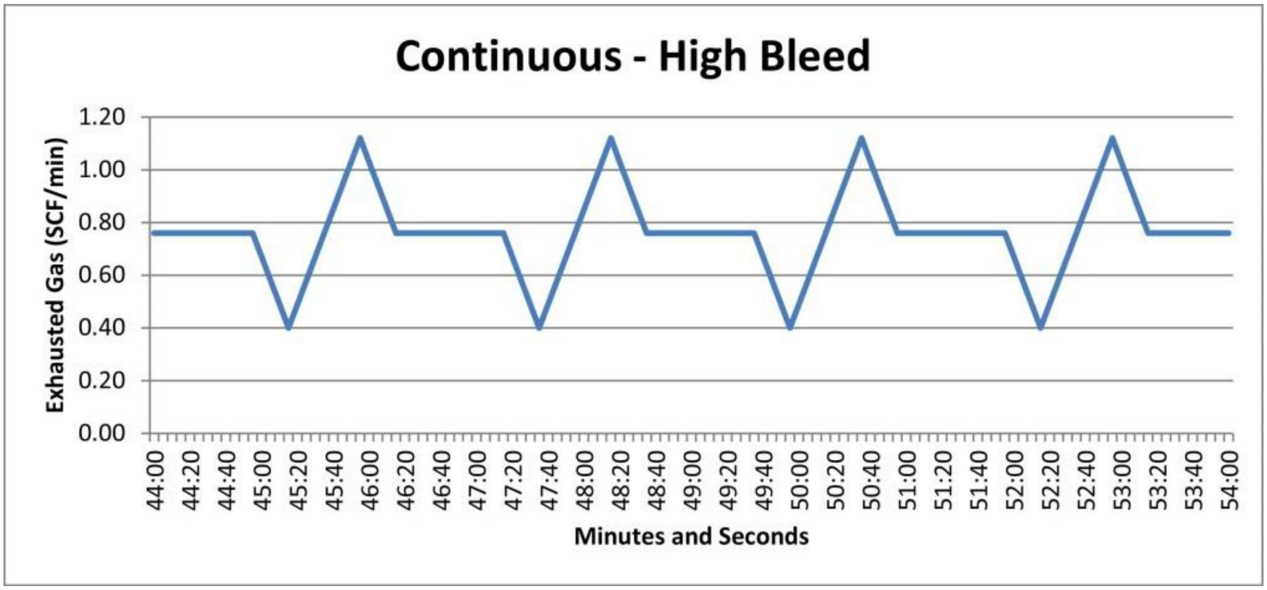

Figure 11: Continuous-bleed theoretical exhaust rate

Actuation Rate. With the categorization above as shown in Table 2, all controllers can be broken 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 to 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 Equation (1) below:

$$\mathrm{Vol}_{\text{system}} = \mathrm{Vol}_{\text{pipe}} + \Delta\mathrm{Vol}_{\text{bonnet}} = \frac{\pi}{4}\mathrm{ID}^2_{\text{pipe}} \times L_{\text{pipe}} + \Delta\mathrm{Vol}_{\text{bonnet}} \tag{1}$$

This volume is only useful with regard to standard conditions that allow gas volumes at different pressures and temperatures to be aggregated. Since 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:

$$\mathrm{Vol}_{\text{SCF}} = \left(\frac{\pi}{4}\mathrm{ID}^2_{\text{pipe}} \times L_{\text{pipe}} + \Delta\mathrm{Vol}_{\text{bonnet}}\right)\left(\frac{P_{\text{control}} + P_{\text{atm}}}{P_{\text{std}}}\right) \tag{2}$$

For example, if a supply gas system is operating at 25 psig at sea level (P_{atm} equal to 14.7 psia), using $^3/8$ in. OD tubing (ID is 0.026 ft) that is 10 ft long to operate an end device with a 110 in.^{3} (0.064 ft^3) $\Delta\mathrm{Vol}_{\text{bonnet}}$, 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 get a generalized exhaust SCF per cycle, but it is not reasonable to convert that into a typical vented volume per unit time since exhausted volume is a function of how many times the device operates.

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 Equation (2) yields Equation (3):

$$V_{event} = \frac{V_{unitTme}}{N_{actuations}}$$
$$\mathrm{Vol}_{\mathrm{SCF/unitTime}}\left(\frac{\pi}{4}\mathrm{ID}_{\mathrm{pipe}}^{2}\times L_{\mathrm{pipe}}+\Delta\mathrm{Vol}_{\mathrm{bonnet}}\right)\left(\frac{P_{\mathrm{control}}+P_{\mathrm{atm}}}{P_{\mathrm{std}}}\right)\left(\frac{\mathrm{V}_{unitTime}}{\mathrm{V}_{event}}\right) \tag{3}$$

The “V_{event}” is in process units. It might be the magnitude of a temperature change (e.g., 10°F per 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 per actuation). It is calculated one time and used for all future calculations.

The “$V_{unitTime}$” is the aggregate of the process units over the time that actuations were being counted. It might be a cumulative temperature change (e.g., the sum of the temperature increases is 1700°F in a month), an amount of liquid accumulated (e.g., 1.5 bbl/hour), etc.

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 “V_{event}” is 3.82 gal (0.091 bbl). If the liquid accumulation in a reporting year was 3840 bbl, then the dump actuated 42,197 times. In the 25 psig supply-gas-pressure example above, the exhaust volume is 933 SCF/year for the 110 in.^{3} bonnet and 10 ft of ^{3}/8 in. tubing.

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

In addition, the volume of the valve actuator must be considered when evaluating emissions from an intermittent controller. In the level control example above, 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 ~378 cycles, or about 1 cycle every 9.5 sec. These control valves are not designed to operate that frequently and would fail in short order.

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 2 to 3 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.

Table 3: Intermittent Vent, On/Off Level Controller Example Emissions

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

Continuous Bleed Controller in on/Off Service. When the device in Figure 8 is in the at-rest position (i.e., the block is clear of the bleed port), then the flow rate out the bleed port can be calculated using a standard orifice calculation shown below (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]:

$$\mathrm{Vol}_{\mathrm{scf/day}} = 16{,}330\left[1+\left(\frac{d}{D}\right)^{4}\right]d^{2}\left[\left(H_{\mathrm{cntl}}\right)\left(29.32+0.3H_{\mathrm{cntl}}\right)\left(\frac{T_{\mathrm{std}}}{T_{\mathrm{cntl}}}\right)\left(\frac{\gamma_{\mathrm{ref}}}{\gamma_{\mathrm{cntl}}}\right)\right]^{0.5}\left(\frac{H_{\mathrm{cntl}}+H_{\mathrm{atm}}}{H_{\mathrm{std}}}\right) \qquad (4)$$

Note that Equation (4) is an empirical equation that should be solved in the units provided in the Nomenclature section. Using other units will not result in correct answers unless the constants are properly converted and that conversion is obscure. Equation (4) will yield higher results than reported by some manufactures 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 in lieu of Equation (4).

In the example for a *Venting Controller in On/Off Service*,

d	0.030 in.
ID	0.313 in.
H_{cntl}	25 psig = 50.9 inHg
H_{std}	29.99 inHg
H_{atm}	29.93 inHg (sea level, 14.7 psia)
T_{cntl}	80°F + 460° = 540 R
T_{std}	60°F + 460° = 520 R
γ_{ref}	0.6
γ_{cntl}	0.63

Table 4: Continuous Bleed On/Off Level Example Controller Emission Factors

Supply Gas Pressure	**0.030 in. Orifice SCF/hr**	**0.010 in. Orifice SCF/hr**
10 psig	26.4	2.9
15 psig	40.5	4.5
20 psig	56.8	6.3
25 psig	75.3	8.4
30 psig	96.0	10.7
35 psig	118.9	13.2
40 psig	144.1	16.0
45 psig	171.4	19.0
This table was developed for γ_{gas} of 0.63. Other gas specific gravities result in different values that must be calculated using Equation (4).		

Equation (4) works out to 1807 SCF/day (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 effectively 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), allowing pressure to build 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. Figure 11 shows a theoretical bleed cycle. The end result of the bleed cycle in Figure 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 example above 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 restrictive 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, Colorado (atmospheric pressure 12.1 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 using Equation (4) is still appropriate for most situations.

Estimating exhaust volumes from a continuous bleed controller in throttle service requires capturing actuation pressure. Since this volume will always be lower than 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 Well Mark Company, LLC. This device uses the mechanical movement of the block in Figure 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.

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 via an intermittent vent external pilot. The external pilot is set up to send an actuation signal on loss of pressure. This adaptation does not significantly change the emissions factors of a continuous bleed controller, 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 where it represents the lowest emissions. This can be demonstrated with a level control example. The separator in Figure 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 level controller is operating two end devices, and 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 (8200 bbl/day) 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 go shut without the vessel blowing dry. Figure 12 shows the comparative emissions.

Intermittent Vent Controller in Throttle Service

In level control, this controller only introduces gas or vents gas when the liquid inflow rate to the separator changes. From the standpoint of emissions being due to 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 Figure 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, intermittent vent controllers in on/off service can often be the best emissions-control choice. In Figure 12, the intermittent vent controller in on/off service line crosses the low continuous bleed on/off line at 369 bbl/day. Below this number, the intermittent vent device has lower emissions.

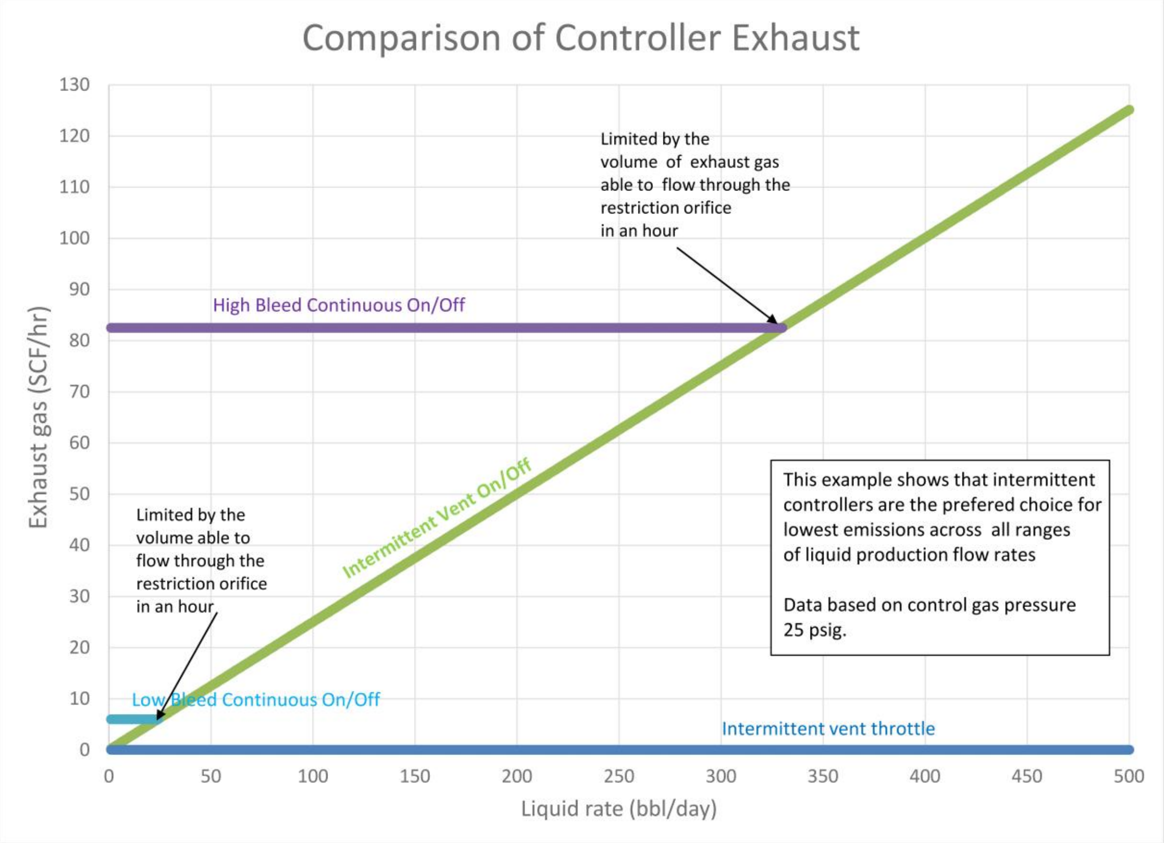

Figure 12: Exhaust-gas Comparison for a separator with two controllers

This is important since in 2003 the average water/gas ratio (WGR) in the United States was 0.436 bbl/MSCF [Welch, 2004]. Well counts and gross dry production from the EIA for 2003 and this WGR indicate that an average onshore gas well would make less than 60 bbl/day. 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 bbl/day/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 pass 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 sec), then the liquid will reach LS and trip the site ESD on high-high separator level. This flow rate converts to 470 bbl/day. 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 bbl/day 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 where 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 sec. This leads to a maximum capacity of 12,000 bbl/day and lower emissions than an intermittent vent device above 4,600 bbl/day.

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

	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 where 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 end device many times per second.
High Continuous Bleed	Lowest emissions in very high flows.	No scenario where this has lowest emissions.

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 recently completed seem to be dominated by a small number of malfunctioning devices. This is likely due to 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 significantly overstating emissions.

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 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 similar emissions as a continuous bleed controller (with the "*d*" term in Equation (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 results of the failure on the exhausted gas.

Intermittent Vent Controllers in Throttle Service.

1. Debris on 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 Equation (4) estimated by the amount of the 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 Equation (4) estimated by the amount of the 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 similar emissions as a continuous bleed controller (with the "*d*" term in Equation (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 results on 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 frequently gets cut 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 after flow (i.e., flow of the process fluid after the controller sent an "end evolution" signal).

Conclusions

Pneumatic controls are here to stay for the foreseeable future. While concerns about venting controllers adding to climate change starting to wane, it is still prudent to minimize the gas that is discarded instead of being sold. Hopefully, this discussion will help clarify the language and key parameters of wellsite pneumatic controls.

Nomenclature

Variable	Description	FPS Units	SI Units
d	Inside diameter of restriction orifice	in	
D	Inside diameter of piping	in	
$N_{actuations}$	Number of actuation events that took place within a given time period	count	count
H_{atm}	Local atmospheric pressure	inHg (absolute)	
H_{cntl}	Supply gas supply pressure	inHg (gauge)	
H_{std}	Pressure designated by proper authority to represent the standard pressure to be used for aggregating volumes	inHg (absolute)	
V_{event}	The amount that a process variable changes each time the actuator is operated	units depend on variable being measured	units depend on variable being measured
$V_{unitTime}$	The cumulative amount that a process variable accumulates during a measured time period (e.g., bbl/month)	units depend on variable being measured	units depend on variable being measured
$\mathrm{ID}_{\mathrm{pipe}}$	Inside diameter of piping	ft	m
L_{pipe}	Length of all piping in 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
γ_{cntl}	Supply gas specific gravity (relative to air = 1.0)	fraction	

Variable	Description	FPS Units	SI Units
γ_{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 pressure to be used for aggregating volumes	R	
ΔVol_{bonnet}	The change in the physical volume of a pneumatic valve actuator when changed from at rest to fully actuated	ft^3	m^3
Vol_{pipe}	The physical volume of the piping connecting components	ft^3	m^3
$Vol_{scf/day}$	The amount of gas released per day converted to standard temperature and pressure	SCF/day	
Vol_{system}	The physical volume of a system of pipes and actuators	ft^3	m^3

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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 of 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 bleed port).

Electro-pneumatic 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 both be 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 proven to be very confusing and should not be encouraged). Intermittent vent controllers (which do not emit between de-actuation cycles) are often mistakenly referred to as "no-bleed" controllers.

Not at rest: The state of an end device where 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 moves above 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 that 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 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 1:10).