Attachment K

Technical Review of Pneumatic Controllers

by David A Simpson, P.E.

Comments by EPA in the preamble to proposed 40 CFR §60, Subpart OOOO indicate that the agency may not have a good fundamental understanding of the variability in pneumatic controller design and operation. Preamble comments, combined with proposed rule text, lead to uncertainty in industry with regard to EPA's intent in regulating gas-driven pneumatic controller emissions. In comments, API seeks to clarify what it believes is EPA's intent, which is that applicability of the rule is limited only to continuous bleed pneumatic controllers. The technical discussion that follows provides EPA with the necessary information on pneumatic controller design and operation, to support limiting regulation only to continuous bleed gas-driven pneumatic controllers.

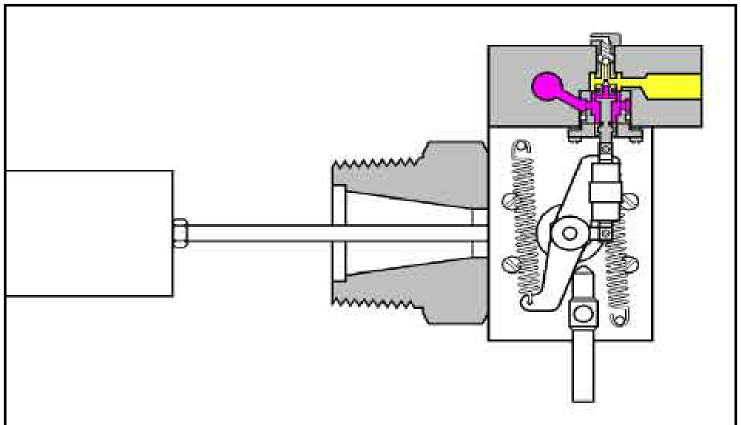

Figure 1 Intermittent Vent Controller (Courtesy of Kimray, Inc)

Pneumatic controllers are devices that can detect the value of physical parameter of a process variable and send a pressure signal to an end-device to change the value of that process variable. Common process variables are liquid level, system pressure, differential pressure across a known restriction (often a surrogate for flow rate), and temperature. There are many ways to classify pneumatic controllers, but you can completely define one with two parameters: (1) is it used for on/off control or does it throttle the process (on/off vs. throttle); and (2) does it bleed control gas continuously or does it vent control gas at the end of the on cycle (continuous bleed vs. intermittent vent).

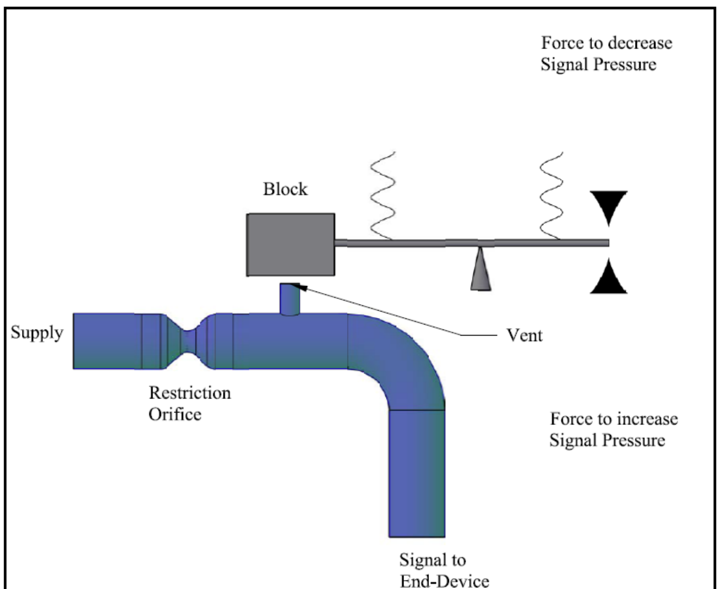

Figure 2 Continuous Bleed Controllers

We often discuss controllers as "snap acting" vs. "variable opening". A snap acting controller will never send a partial signal, 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 will snap shut. A variable-open controller will send a throttled signal as soon as the input value increases above a minimum and as the input continues to increase the signal will strengthen. Either on/off or throttle controllers can be either snap-acting or variable-input and this is not a defining characteristic.

Service (On/Off vs. Throttle)

On/Off controllers are often used to control on/off "dump valves" in level-control service. These level controllers (see Figure 1) have a float that senses the fluid level. When the level increases to the set point (usually when the float is at its maximum upward travel), a spring-loaded valve within the controller is forced open which sends a pressure signal to a "dump valve". The valve opens to drain the liquid. When the condition is satisfied (e.g., when the float is at the bottom end of its travel), the spring-loaded valve shuts off supply pressure to the end-device and vents the gas that was used to operate the end-device to atmosphere (through the top port in Figure 1). The time required for the end-device to go shut is a function of control gas pressure, the volume of gas in the piping and valve bonnet, and the size of the vent orifice.

Throttling controllers are used to maintain a process variable within a defined range. For example, if it was important to maintain a particular-component pressure in a narrow range by operating a control valve some distance away from the component, a throttling controller could be used. Figure 2 shows a simplified version of a throttling controller. In this version, the restriction orifice is slightly smaller than the vent opening, so when the block is off the vent, all of the gas that can get through the orifice exits through the vent and releases the pressure to the end device. As the system calls for an increased signal, the block is forced onto the vent to restrict flow. This increases the pressure in the line going to the end device and operates it. As the signal to increase pressure moves toward a maximum, the block moves down on the vent to completely seal the vent flow and send maximum pressure to the end device.

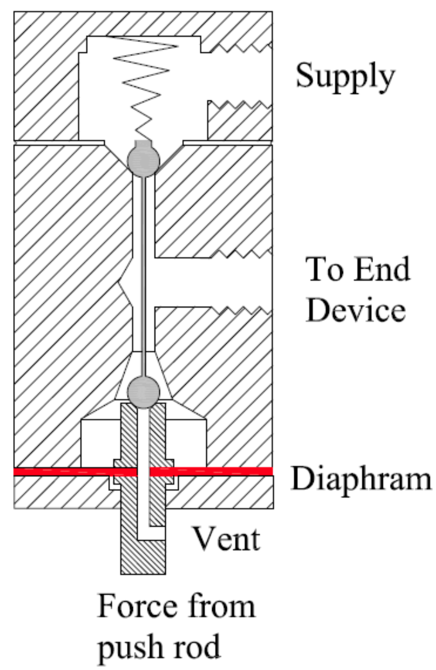

Figure 3 Intermittent Vent, Throttle Pilot

Depressurization Method (Continuous Bleed vs. Intermittent Vent)

Any pneumatic controller must release pressure when it needs to lower the signal. This pressure release can be more or less continuous or can be intermittent. A device like Figure 2 that does not have any mechanical barrier to isolate the supply from the load is considered a "continuous-bleed" device. The amount that it bleeds off is controlled by the position of the block over the vent. At times the amount of vented gas is nearly zero and pressure builds in the supply line to operate the end device. At the end of the pressurization cycle, the gas that was used to operate the end device is vented at a rate similar to the vent rate seen by an intermittent vent controller for a short period, this is sometimes called the "strong stream"

When the block is fully off the vent, the amount of vented gas will approximately equal the amount that enters the controller through the inlet orifice—this is sometimes called the "weak stream" because the pressure difference between the supply piping and atmosphere is at a minimum. The weak stream represents the maximum continuous bleed rate.

Intermittent-Vent controllers are usually associated with on/off service, but that is certainly not the only use. The device shown in Figure 3 is an intermittent venting controller in throttle service. During steady operation, both valve balls are tight in their seat. If less pressure is required for the end-device, then the push rod will move downward which pulls the seat away from the bottom ball and gas is vented. 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 top ball off the seat against spring pressure (while holding the vent tightly closed) and allows supply pressure to increase to the end device.

Continuous-Bleed controllers such as the device in Figure 2 are always allowing some amount of pressure to bleed off (except for the short period when they are fully against the block). The distinction between "venting" and "bleeding" is often subtle, but a clear line can be drawn—if there is a mechanical barrier between the supply pressure 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"

Controller Exhaust Volumes

With the categorization above, 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. The method for calculating the vented volume is different for each group.

Intermittent vent controller in on/off service

Control gas is sent to the end-device when an "on" condition is called for. The pressure on the end-device quickly reaches control-system 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 to exit to atmosphere. Every single time the device shifts from "on" to "off", the same volume of gas is vented. This volume can be calculated by:

$$Vol_{system} = Vol_{pipe} + Vol_{bonnet} = \frac{\pi}{4} ID_{pipe}^{2} \cdot L_{pipe} + Vol_{bonnet} \tag{1.1}$$

Where:

- ID_{pipe} Inside diameter of the tubing (ft)
- L_{pipe} Length of the tubing (ft)
- Vol_{bonnet} Volume of the bonnet at the end of full travel (ft^3)

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

$$Vol_{SCF} = \left(\frac{\pi}{4} ID_{pipe}^{2} \cdot L_{pipe} + Vol_{bonnet} \right) \cdot \frac{P_{control} + P_{atm}}{P_{std}} \tag{1.2}$$

Where:

- P_{cntl} Control gas supply pressure (psig)

- P_{atm} Local atmospheric pressure (psia)
- P_{std} Standard pressure (generally 14.73 psia in Oil & Gas operations)

For example, if a control gas system is operating at 25 psig at sea level (P_{atm} equal to 14.7 psia), using 3/8 inch ID tubing (0.03125 ft) that is 10 ft long to operate an end device with a 0.03 ft^3 bonnet, then the volume per cycle is 0.079 SCF/cycle which would be the "characteristic volume" of this piping configuration at 25 psig at sea level.

For a "Venting Controller in On/Off Service" this calculation provides results that are both accurate and repeatable. It is reasonable to generalize the system volume and to convert the generalized volume into a "typical" 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.

Far better 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 1.2, yields:

$$Vol_{SCF/month} = \left(\frac{\pi}{4} ID_{pipe}^{2} \cdot L_{pipe} + \Delta Vol_{bonnet} \right) \cdot \left(\frac{P_{control} + P_{atm}}{P_{std}} \right) \left(\frac{cycle}{Vol_{liquid}} \right) \left(\frac{Vol_{liquid}}{month} \right) \qquad (1.3)$$

If a facility accumulates 1 bbl (42 gal) in a day and observations show that it cycled 11 times in the day, then the average volume per cycle is 3.82 gal/cycle (0.091 bbl/cycle). If the liquid accumulation in a month was 10 bbl (420 gal) then you know the controller cycled 110 times. In the 25 psig control gas pressure example above, the exhaust volume is 8.6 SCF/month.

In the Barnett Shale (4.81% VOC by weight on average), the VOC emissions for the example above would be 0.000109 tonne of VOC/year. If it costs $72/controller to fill out the paperwork to report the emissions on this controller then the cost effectiveness for regulating intermittent vent controllers in on/off service is on the order of $659,304/VOC tonne just for the administrative costs.

Intermittent Vent controller in throttle service

These devices vent so little gas, so irregularly, that it is 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 2-3 times per day. Trying to estimate this volume as other than zero would create a great burden on users of the device that 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 Figure 2 is in the "off" position (i.e., the block is clear of the vent), then the flow rate out the vent is [Ref: GPSA Engineering Data Book, eq 3-12 converted to SCF/day]:

$$Vol_{scf} = 16330 \cdot \left[1 + \left(\frac{d}{D} \right)^4 \right] \cdot d^2 \cdot \left[\left(H_{cntl} \right) \left(29.32 + 0.3 \cdot H_{cntl} \right) \cdot \left(\frac{SG_{ref}}{SG_{cntl}} \right) \cdot \left(\frac{T_{std}}{T_{cntl}} \right) \right]^{0.5} \cdot \frac{\left(P_{cntl} + P_{atm} \right)}{P_{std}} \quad (1.4)$$

Where:

- d Inside diameter of bleed restriction orifice (inches)
- D Inside diameter of tubing (inches)
- H_{cntl} Control gas gauge pressure (inches of mercury, 1 psig = 2.036 inHg)
- P_{cntl} Control gas gauge pressure (psig)
- P_{std} Standard Pressure (14.73 psia)
- P_{atm} Local atmospheric pressure (psia)
- T_{cntl} Control gas temperature in Rankine (°F+460°=R)
- T_{std} Standard temperature (60°F=520R)
- SG_{ref} Reference specific gravity (0.6)
- SG_{cntl} Specific gravity of control gas (air = 1.0)

In the example used above for a *Venting controller in on/off service* with gas from the Barnett Shale:

- d 0.03 inches
- D 0.375 inches
- H_{cntl} 25 psig = 50.9 inHg
- P_{std} 14.73 psia
- P_{atm} 14.7 psia (sea level)
- T_{cntl} 80°F+460°=540R
- T_{std} 60°F+460°=520R
- SG_{ref} 0.6
- SG_{cntl} 0.6337

Equation 1.4 works out to a weak stream of 1,800 SCF/day for 25 psig control gas at sea level (the strong stream is irrelevant since the gas that flows to the end device during the operation cycle will be vented at the end of the cycle and the net result is approximately the same as if the weak stream was never interrupted). Using the Barnet Shale example above (VOC 4.81% by weight) results in this stream venting 0.66 MMCF/year of natural gas (0.7 tonne VOC/year). The net heating value of this gas stream is 0.944 MMBTU/MCF so selling this stream has a benefit of $660/year at $4/MMBTU. The cost effectiveness of capturing a high-bleed stream for sales (assuming $72/year administrative cost) is -$840/tonne.

Continuous Bleed controller in throttle service

In throttle service, bleed rate is difficult to determine. Pressure in the line after the restriction orifice will always be at an intermediate pressure between supply pressure and local atmospheric pressure. Further, the vent diameter ("d" in equation 1.4) is the exhaust orifice (instead of the restriction orifice) which is larger than the restriction orifice, but partially closed by the block. The most accurate way to calculate this flow rate is to use the flow from the control-gas system through the restriction orifice, with "H_{cntl}" equal to the difference between control gas pressure and pressure to the end device and P_{cntl} equal to control gas pressure.

For example, if the end device is controlling its parameter at a steady value with 15 psig on a 25 psig control gas system, then you would need to use 10 psig (20.4 inHg) as H_{cntl} in Equation 1.4 to get a daily vent volume of 632 SCF/day instead of 1,802 SCF/day. For a given controller, this value could change many times in a 24 hour period and changes are significant to exhaust calculations. For estimating fugitive emissions, it is reasonable to assume that flow rate is 1/3 to 2/3 the on/off flow rate.

After Market Retrofit Kits

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 Figure 2 to operate an "actuation poppet" on an on/off controller. A *Continuous Bleed On/Off Controller* with this sort of kit installed becomes an *Intermittent Vent On/Off Controller* and the emissions factors should be calculated based on 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 idle than actuated. To capitalize on this observation, operators can turn the controller upside down (so that at idle the block is hard on the vent and in the actuated position the block is off the vent) and actuate an external pilot. The external pilot is set up to send an actuation signal on loss of pressure. These devices reduce vented/bleed emissions, but not by much.

High Bleed vs Low Bleed

In the calculations above, the restriction orifice was assumed to be 0.03 inch diameter. This value results in a flow rate of 75 SCF/hr at 25 psig control gas pressure. EPA is drawing a hard line at 6 SCF/hr as the difference between high bleed and low bleed. To reach this value at 25 psig would require a 0.00848 inch orifice (8% of the size of a standard orifice). In the Barnett Shale example we've been using, going to 6 SCF/hr would lower the VOC from 0.7 tonne VOC/yr to 0.06 tonne/VOC/yr.

If control gas pressure is 45 psig (standard orifice flow rate 171 SCF/hr), then to reach 6 SCF/hr would require an orifice size of 0.00562 inches (3.5% of the flow area of the standard orifice). Using orifices this small significantly reduces the operating speed of end devices (which can increase overshoot and lead to control instabilities).

Also, orifices this small have a significant risk of plugging. The 45 psig orifice above is 143 microns across—this is the beginning of the range of the class of equipment called "filters" instead of flow orifices. The possibility of an opening this small plugging in any given year is approximately 100%.

Achieving a bleed rate of <6 SCF/hr with an intermittent vent pneumatic controller is quite reasonable since you eliminate the continuous bleeding of a controller. Achieving 6 SCF/hr with a continuous bleed pneumatic controller is fraught with operational difficulties and hidden costs. Encouraging the use of such devices is not recommended.

Conclusion

If each controller were placed in a category based on Service (on/off vs. throttle) and Depressurization Method (Intermittent Vent vs. Continuous Bleed) then the emissions impact of that device can be easily calculated. Determining either the VOC emissions or the gas lost to sales is reasonably straight forward. The key to achieving emissions targets is to develop clarity and precision in the definitions and categorization of the various controllers so that recognition of what controller technology is appropriate to meet these targets is possible.

With a requirement for a bleed rate of <6 SCF/h, it is more likely that an operator will use an intermittent vent type controller to ensure reliable controller operation, rather than using a continuous bleed controller with a low bleed orifice.

Author Biography

David Simpson has 31 years experience in Oil & Gas and is currently the Proprietor and Principal Engineer of MuleShoe Engineering. Based in the San Juan Basin of Northern New Mexico, MuleShoe Engineering addresses issues in Coalbed Methane, Low Pressure Operations, Gas Compression, Gas Measurement, Field Construction, Gas Well Deliquification, and Produced Water Management.

A Professional Engineer with his Master's degree, David has had numerous articles published in professional journals, has contributed a chapter on CBM to the 2nd edition of Gas Well Deliquification, by Dr. James Lea, et al, and has spoken at various conferences, including the 2000 SPE *International Conference on Health, Safety, and the Environment in Oil & Gas Production* in Stavanger, Norway where he presented a paper on the transition from continuous bleed pneumatic controllers to intermittent vent pneumatic controllers (SPE61030). He has been a featured speaker at the bi-annual *Four Corners Oil & Gas* Conference for the last 6 years and is a regular instructor at short courses at the annual ALRDC *Gas Well Deliquification Workshop* in Denver. David was Program Chair for the highly successful SPE Advanced Technology Workshop titled "Managing the Performance of Low Pressure Gas Wells and Associated Facilities" held in Ft Worth, TX in October, 2008. His consulting practice includes clients in 12 countries.