SAMPLING LIQUIDS IN A SAMPLE CYLINDER: VAPOR SPACE AND OUTAGE TUBES

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Sinopsis

When sampling liquids using sample cylinders, there are few things more important than overpressure protection. Liquids typically have higher rates of thermal expansion than the metal sample cylinders in which they are contained, which can cause problems if the temperature of the cylinder rises after the sample is taken. Due to the incompressible nature of liquids, this expansion of the liquid can create immense hydraulic pressure that can damage or even rupture the sample cylinder.

The cylinder can be protected using rupture discs or relief valves, but both solutions usually result in the reléase of the sample, or a portion of the sample, to the atmosphere. This presents a myriad of problems, especially if the sample is toxic to the environment or to the personnel transporting the cylinder to the laboratory. As such, when taking liquid samples in a cylinder, rupture discs and relief valves are commonly seen as secondary methods of overpressure protection, not the primary method.

The most common primary method of overpressure protection is to avoid filling the cylinder 100% liquid-full in the first place. Leaving some gas, also known as a vapor space, in the cylinder with the liquid sample provides that sample a place into which it can expand in the event of a rising temperature. Because this vapor space is compressible, the liquid can expand into the space, compressing that gas. This will still result in a pressure rise but not the exponential and catastrophic increase that can be experienced by a cylinder that is 100% liquid-full.

There are many methods that can be used to create a vapor space, a few of which will be described. However, one of the most simple and effective methods is to use an outage tube. The intent of this paper is to describe the use of outage tubes, explain how they can be used to create the requisite vapor space, and describe how to ensure that the resulting vapor space is sufficiently sized for the application.

Introducción

Outage tubes are commonly used when collecting liquid samples in sample cylinders. They are intended to create a vapor space in the cylinder, thereby allowing for thermal expansion of the liquid. However, most designers do not understand how outage tubes work and how they can be affected by the operating parameters of the sampling system. By understanding how sample system design features, pressures, and operating procedures impact the function of outage tubes, designers can perform simple calculations to accurately predict performance of outage tubes.

Desarrollo

Outage tubes

Sometimes called an ullage tube or dip tube, an outage tube is installed at one end of a sample cylinder. With the cylinder oriented vertically, the outage tube creates a vapor space from which gas cannot escape. See Figure 1. As liquid fills the cylinder from the bottom up, the liquid will reach the tip of the outage tube. At that point, the gas trapped in the vapor space forces the liquid to flow up and out of the outage tube.

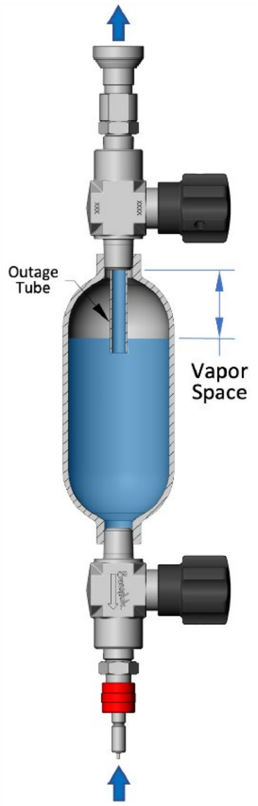

FIGURE 1. CYLINDER WITH OUTAGE TUBE

Note that the term vapor space refers to the volume of gas captured in the closed cylinder. Outage, on the other hand, expresses the volume of that vapor space as it relates to the overall volume of the sample cylinder, typically expressed as a percentage. Therefore, a 1000mL cylinder with 20% outage would be filled with 20% gas (200 mL vapor space) and 80% liquid (800 mL sample size). The required outage percentage is often defined by industry standards, plant/company procedures, and established best practices.

The primary advantage of using an outage tube is that it does not rely on the operator to create the vapor space. If implemented properly, an outage tube guarantees that a vapor space will be present. However, there is a major drawback in that there are a number of factors that can impact the volume of that vapor space. The pressure of the sample, the pressure of the sample return, the design of the sampling system, and the sampling procedure can all impact the volume of the vapor space. This can result in a vapor space that is too small to accommodate the thermal expansion of the captured liquid sample, potentially leading to problems.

Understanding vapor space compression

Though an outage tube is designed to create a specific volume of vapor space, compression of that vapor space can result in a significantly smaller outage than expected. This compression, which can exceed 95% in some cases, is a function of pressure, procedure, temperature, and sample system design.

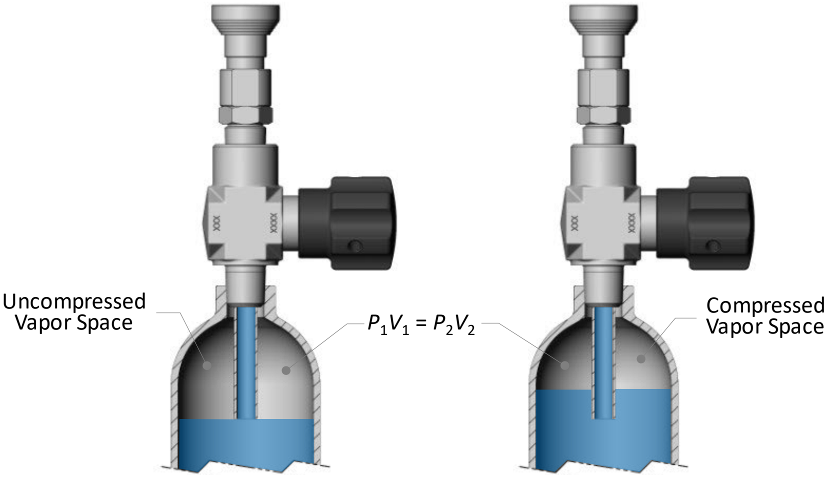

FIGURE 2. VAPOR SPACE COMPRESSION

Once a liquid fills the sample cylinder to the point where the liquid level reaches the tip of the outage tube, the vapor space will be compressed by the sample supply pressure, P_S, and return pressure, P_R, according to Boyle's law:

$$P_1V_1 = P_2V_2 \qquad (1)$$

Where: P_1 = Initial pressure of the vapor space when liquid reaches the tip of the outage tube
P_2 = Final pressure of the compressed vapor space
V_1 = Initial volume of the vapor space when liquid reaches the tip of the outage tube
V_2 = Final volume of the compressed vapor space

Note that in this equation, the pressures must be expressed as absolute pressures. The volumes may be expressed using any typical units of volume, or as an outage percentage. Rearranging the formula to solve for V_2, it becomes evident that the volume of the compressed vapor space, V_2, is a function of the ratio of the pressure change.

$$V_2 = \frac{P_1}{P_2} \times V_1 \qquad (2)$$

Because the initial volume is defined at the point where the liquid is at the tip of the outage tube, V_1 will be equal to the nominal outage percentage. In other words, for a 20% outage tube, V_1 = 20%. Also note that because the volume is multiplied by the ratio of the pressures, it follows that the closer those pressures are to each other, the lesser the impact will be on the compression of the vapor space. In the worst-case situation, P_1 would be very low and P_2 would be equal to the sample supply pressure, P_S. As an example, suppose that the nominal outage percentage V_1 = 20%, the supply pressure $P_S = P_2$ = 10 bara, and the initial pressure P_1 = 1 bara:

$$V_2 = \frac{P_1}{P_2} \times V_1 = \frac{1\ bara}{10\ bara} \times 20\% = 2\%$$

In making this calculation, the final pressure, P_2, is typically known or assumed to be equal to the supply pressure, P_S. The nominal outage percentage, V_1 is also known. Therefore, only P_1 needs to be identified to calculate the outage of the compressed vapor space. But this initial pressure is more difficult to identify than it initially seems. To understand it, one must first understand how a cylinder fills.

How a sample cylinder fills

In most cases, sample cylinders are empty and unpressurized when initially coupled into a sampling panel. Opening the cylinder valves and the isolation valves on the sampling panel connects the cylinder to the process. At that point, the differential pressure between the sample supply, P_S, and the empty cylinder, P_C, causes liquid to flow into the bottom of the cylinder ($P_S > P_C$). However, note that in most applications, the sample return pressure, P_R, is also higher than the empty cylinder ($P_R > P_C$). Thus, without the use of a check valve or other device to prevent back flow, this differential pressure will cause liquid to flow backwards from the sample return into the top of the cylinder. It is this backwards flow that many designers fail to consider.

As the liquid flows into the cylinder from both ends, the air that was initially in the cylinder is compressed. It is prevented from escaping by the liquid flowing in through the top of the cylinder. This continues until the pressure in the cylinder equalizes with the sample return pressure ($P_R = P_C$). At that point, the incoming sample supply pressure causes the flow at the top of the cylinder to reverse ($P_S > P_R$). One of two scenarios will be present, depending on the return pressure. To determine which scenario will apply, both must be evaluated.

Scenario 1: Relatively low return pressure

If the return pressure is relatively low, the liquid level will be below the tip of the outage tube when the flow reversal happens, as shown in Figure 3. In this scenario, some of the air that was initially in the cylinder will escape out the top as the cylinder continues to fill from the bottom. Because the flow through the valve at the top of the cylinder will be air at a relatively low flow rate, the pressure loss through this valve will be negligible. Therefore, it is safe to assume that the pressure in the cylinder will be equal to the sample return pressure, P_R.

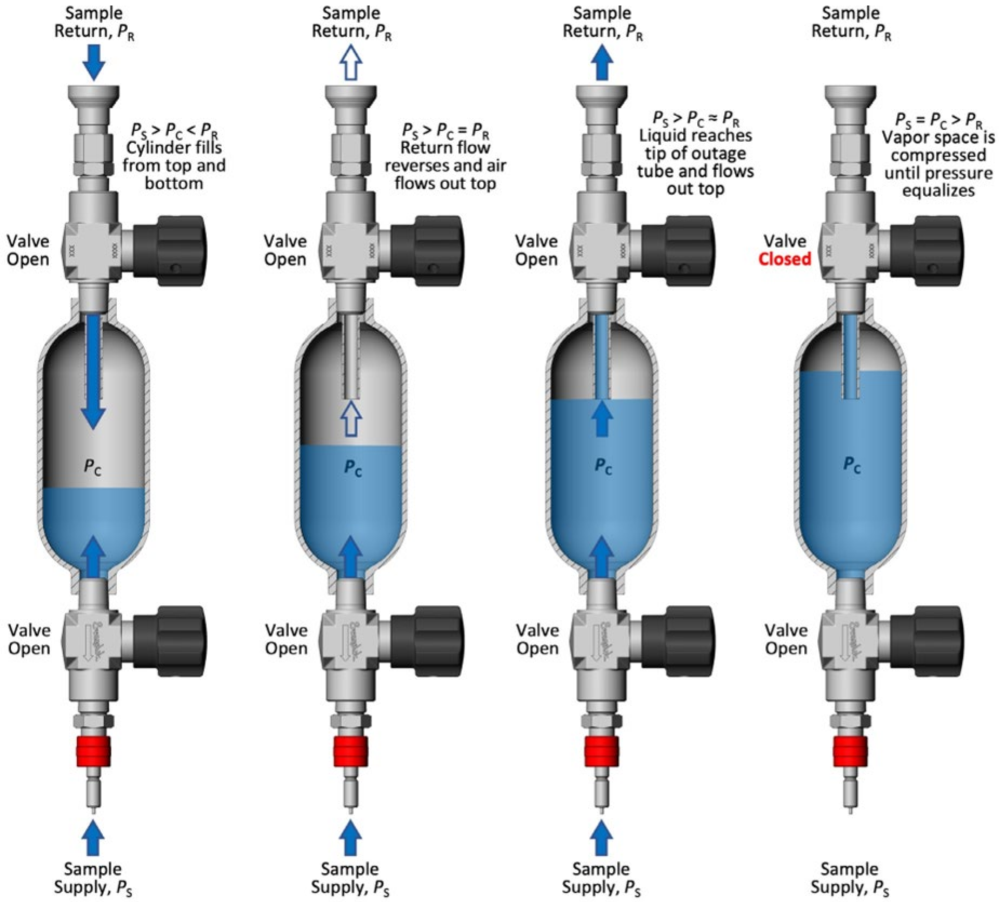

FIGURE 3. HOW A CYLINDER FILLS, SCENARIO 1

This continues with $P_C = P_R$ until the liquid level reaches the tip of the outage tube, at which point the liquid will flow up the outage tube and out the top of the cylinder. The worst-case situation that would result in the smallest, most compressed vapor space would be when the sample return (outlet) valve is then closed, and the sample supply (inlet) valve remains open. This would allow liquid to flow into the cylinder until the cylinder pressure equalizes with the supply pressure. This compression can be calculated using Equation 2 with $P_1 = P_R$. and $P_2 = P_S$.

Returning to the example in the previous section, if the supply pressure $P_S = 10$ bara $= P_2$ and the return pressure $P_R = 4$ bara $= P_1$:

$$V_2 = \frac{P_1}{P_2} \times V_1 = \frac{4\ bara}{10\ bara} \times 20\% = 8\%$$

This illustrates the significant impact that the return pressure can have on the volume and compression of the vapor space. By increasing P_1, the amount of compression is significantly decreased and therefore the volume of the vapor space is increased.

Scenario 2: Relatively high return pressure

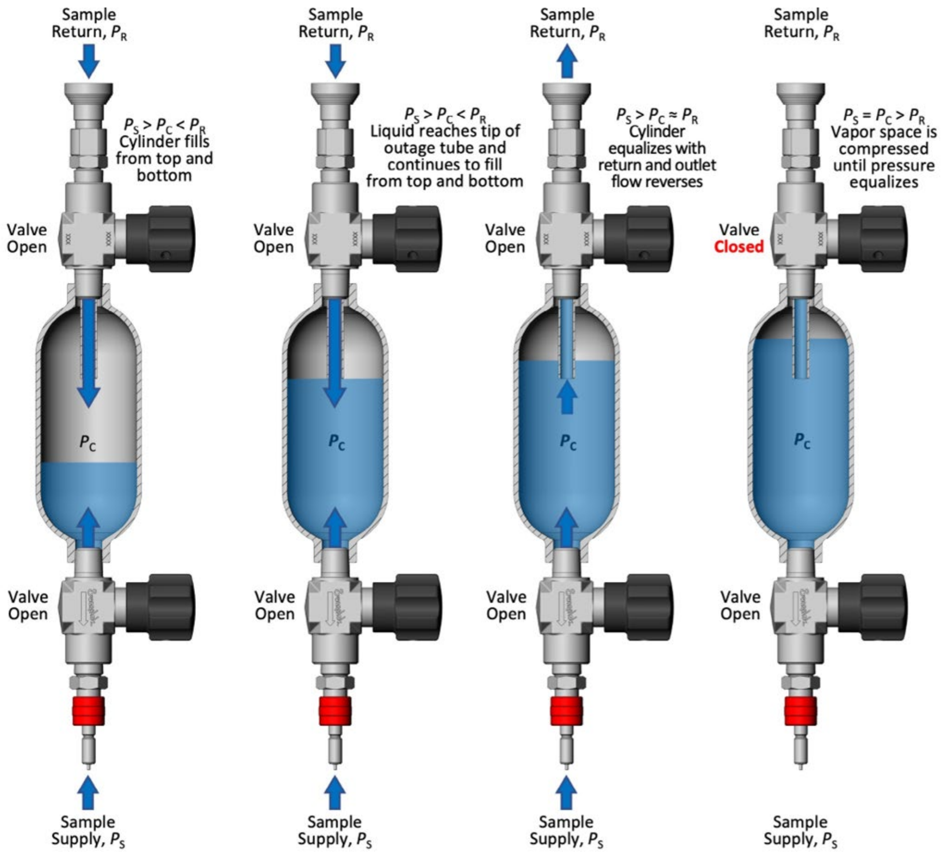

FIGURE 4. HOW A CYLINDER FILLS, SCENARIO 2

If the return pressure is relatively high, then the liquid level will be above the tip of the outage tube when the flow reversal happens, as shown in Figure 4. In this scenario, no air will flow out of the cylinder because it will already be trapped in the vapor space by the outage tube. Only liquid will flow out the top of the cylinder. All the air that was initially in the cylinder is compressed and remains trapped in the vapor space at the top of the cylinder.

As before, the worst-case situation would be where the sample return valve is closed, and the sample supply valve remains open. Because none of the air has escaped, the initial volume of the air, V_1, was equal to the entire volume of the cylinder, 100%, and that air was initially at some pressure, P_1. Knowing that the final pressure of the air, P_2, is equal to the supply pressure, P_S, it is relatively easy to calculate the final volume of that air using Equation 2. Returning to the example and assuming $P_1 = 1$ bara:

$$V_2 = \frac{P_1}{P_2} \times V_1 = \frac{1\ bara}{10\ bara} \times 100\% = 10\%$$

Which scenario applies?

Which scenario applies to a given situation? As it turns out, the scenario that results in the smallest outage percentage is the one that will be applicable. Therefore, it is necessary to calculate both scenarios and use the lesser value produced by the two calculations.

The determining factor is the sample return pressure. If it is high enough to prevent any of the air that was initially in the cylinder from escaping, then Scenario 2 would apply. If the return pressure is relatively low, then some of the air will escape from the cylinder and Scenario 1 would apply. To see why, it is beneficial to further examine Scenario 2 and calculate the pressure of the vapor space at the point where the liquid level first reaches the tip of the outage tube. Again, Boyle's law, Equation 1, can be used, rearranging to solve for pressure:

$$P_2 = \frac{V_1}{V_2} \times P_1 \qquad (3)$$

Like the previous calculation in Scenario 2, the initial volume of air, V_1, is simply equal to the total volume of the sample cylinder. For this calculation, the final volume, V_2, would be the nominal outage percentage. Knowing that the air was initially at some pressure, P_1, Equation 3 can be used to solve for the final pressure, P_2, which is the pressure at the nominal outage percentage. Returning to the previous example:

$$P_2 = \frac{V_1}{V_2} \times P_1 = \frac{100\%}{20\%} \times 1\ bara = 5\ bara$$

In this specific example, the calculated pressure is higher than the sample return pressure (4 bara). Of course, this is not possible. The cylinder would reach the sample return pressure at some point before the liquid level reaches the tip of the outage tube. Once that happens, rather than being compressed further, air would simply flow out the top of the cylinder until the liquid reaches the tip of the outage tube. This matches our description of Scenario 1, so the Scenario 1 calculation would apply.

The effect of backpressure

The previous example assumes that the sample return pressure acts directly on the top of the cylinder. But what if there is some other device/component installed between the sample cylinder and the sample return? What impact will that have on how the cylinder fills and how the sample is compressed? There are three common components that could possibly create a backpressure and influence the volume of the vapor space – a check valve, a backpressure regulator, and a needle valve.

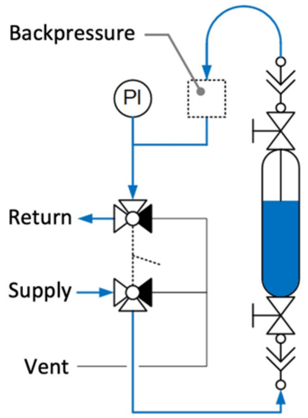

FIGURE 5. GRAB SAMPLE PANEL WITH BACKPRESSURE DEVICE

Check valve

Installing a check valve downstream of the sample cylinder has two primary effects on the sample panel:

1. By design and intent, the check valve prevents flow from the sample return into the sample cylinder. Therefore, the cylinder will only fill from the bottom up.
2. The check valve creates an additional backpressure that inhibits the air in the cylinder from escaping. This backpressure is caused by the force of the spring in the valve and by the sample return pressure pushing on the back side of the valve's poppet.

Effect number 1 has no practical impact from a vapor space compression perspective. However, effect number 2 does have an impact. Because Scenario 2 (from the previous section) does not take sample return pressure into account, this added backpressure does not impact the Scenario 2 calculation. However, the additional backpressure increases the chance of encountering Scenario 2 because there is now additional pressure that the air in the cylinder must overcome before it can escape. This extra pressure factors into the calculation from Scenario 1. The same calculation can be made, except that the initial pressure, P_1, from the Scenario 1 calculation would now be the summation of the sample return pressure, P_R, and the backpressure added by the check valve itself, P_{SPRING}, as shown in Figure 6. Note that P_{SPRING} is a differential pressure and therefore there is no need to convert it to an absolute pressure. Simply use the cracking pressure supplied by the valve manufacturer. Returning to the example and assuming the check valve has a 2-bar cracking pressure, Equation 1 gives:

$$V_2 = \frac{P_1}{P_2} \times V_1 = \frac{P_\mathrm{R} + P_\mathrm{SPRING}}{P_2} \times V_1 = \frac{4\ bara + 2\ bar}{10\ bara} \times 20\% = 12\%$$

The resulting 12% outage is larger than the outage in the Scenario 2 calculation (10%), so Scenario 2 would be used to determine the volume of the vapor space. But still, adding the check valves did increase the outage percentage from 8% (original Scenario 1) to 10% (Scenario 2). Therefore, the addition of a check valve can be used to increase the outage when the sample return pressure is low.

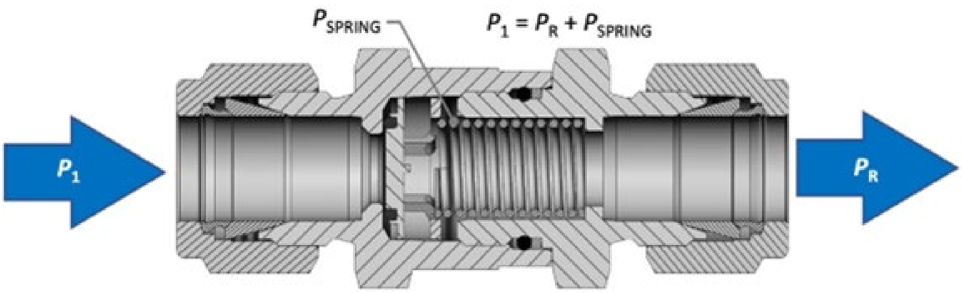

FIGURE 6. CHECK VALVE BACKPRESSURE

Backpressure Regulator

Installing a backpressure regulator has a similar effect to a check valve. While a backpressure regulator does not absolutely prevent back flow, it severely restricts it to the point where it is rather unlikely in most applications. However, the regulator's primary purpose is to add an artificial backpressure downstream of the sample cylinder. Where it differs from a check valve is that the backpressure introduced by the regulator is referenced to atmosphere, not the downstream sample return pressure.

Therefore, instead of a differential pressure, this backpressure can be considered an absolute pressure that is only negligibly impacted by the sample return pressure. The caveat is that the backpressure will not be less than the return pressure, P_R. As such, when calculating Scenario 1 using Equation 2, the initial pressure, P_1, would be equal to the backpressure regulator setpoint, P_{SPRING}, or the return pressure, P_R, whichever is greater. See Figure 7. Supposing for this example that the backpressure regulator is set to 7 bara (P_{SPRING}) and the return pressure (P_R) is still 4 bara:

$$V_2 = \frac{P_1}{P_2} \times V_1 = \frac{\max(P_{\text{SPRING}}, P_{\text{R}})}{P_2} \times V_1 = \frac{\max\,(7\,bara, 4\,bara)}{10\,bara} \times 20\% = 14\%$$

Like with the example for the check valve above, the resulting 14% is larger than the outage in the Scenario 2 calculation (10%), so Scenario 2 would apply.

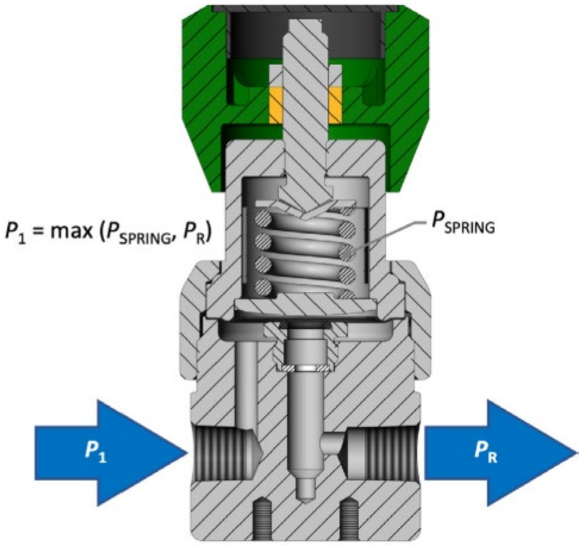

FIGURE 7. BACKPRESSURE REGULATOR

Needle Valve

Needle valves are often installed downstream of a sample cylinder to control the flow of liquid through the system. It may be paired with a flowmeter to measure/indicate the flow rate or it could be installed by itself. In either case, the needle valve creates a backpressure, but only when liquid is flowing through it.

The needle valve will typically be adjusted to some setting that achieves the desired flow rate for the liquid being sampled. However, when flowing a gas through the same valve at that same setting, the backpressure will be negligible because the gas is so much less dense and viscous than the liquid. Likewise, if the flow is stopped, whether gas or liquid, the backpressure will be zero because the backpressure created by a needle valve is dependent on the flow.

Like with the check valve and the backpressure regulator, Scenario 2 is not affected by backpressure and would therefore not be impacted by a needle valve. Scenario 1 is impacted by backpressure, but remember that the initial pressure, P_1, that is fed into Equation 2 is the pressure inside the cylinder when the liquid level first reaches the tip of the outage tube. However, at that point in time, it would be air that is flowing out the top of the sample cylinder and through the needle valve, not liquid. As noted previously, flowing air through the needle valve (which is set for a specific liquid flow rate) will result in only a negligible backpressure. Therefore, it can be assumed that the pressure acting on the cylinder is equal to the return pressure, P_R, and that the needle valve has no impact on the volume of the vapor space.

The effect of Sampling procedure

In addition to the pressure, the sampling procedure can also have a significant impact. The orientation of the sample cylinder and the sequence in which the valves are operated will influence the size of the vapor space.

Sample cylinder orientation

All of the previous calculations and examples assume that the cylinder is held in the vertical orientation with the outage tube installed at the top. It is recommended that the sample panel be designed in such a way that it is impossible for the operator to install the cylinder in any other orientation. Having a clamp or cradle that holds the cylinder vertically is a best practice. Another best practice is to install quick connects of opposing genders on opposite ends of the cylinder (stem on one end, body on opposite end). This prevents the cylinder from being installed upside down.

A cylinder that is installed horizontally will render any outage tube ineffective. However, because of the air trapped in the larger diameter of the sample cylinder, this orientation will result in a vapor space, even without an outage tube. The effect will be similar to Scenario 1 with a 50% outage tube. Despite this benefit, the bottom half of a horizontal cylinder will tend to collect sediment and other contaminants. For this reason, a horizontal cylinder is not recommended for most applications.

Valve sequence

Varying the sequence in which valves are opened/closed can result in a vapor space of varying volume. In the previous example, the worst-case situation (smallest vapor space) was when the sample return valve was closed, and the sample supply valve was kept open. This allowed liquid to flow into the cylinder until the cylinder pressure equalized with the supply pressure, compressing the vapor space.

Conversely, if the supply valve were to be closed first, then the pressure in the cylinder would decrease until it equalizes with the sample return. In this case the volume of the vapor space would increase. However, such a pressure drop could be problematic if sampling a volatile liquid and the return pressure is low. It might allow a portion of the sample to vaporize, which would compromise the representativeness of the sample.

The ideal sampling procedure would be one where the sample supply and return valves are closed at the same time, avoiding both of these situations. This can be addressed via procedure, but eventually the procedure will be misunderstood, ignored, or otherwise not followed. The best practice is to gang these two valves together so that they must be operated together, as shown in Figure 8.

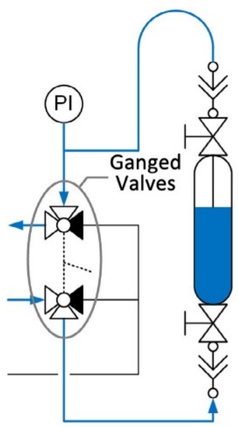

FIGURE 8. SAMPLE PANEL WITH GANGED VALVES

If these valves are closed/switched simultaneously, then the cylinder pressure, P_C, will be somewhere between the sample supply pressure, P_S, and the sample return pressure, P_R ($P_S > P_C > P_R$). This cylinder pressure would then be inserted for P_2 in the Scenario 1 and 2 calculations. It is not always clear what the value of P_C will be, though it can generally be estimated using manual calculations or flow simulation software.

The terms sample return valve and sample supply valves refer specifically to the valves on the sampling panel. However, closing the cylinder valves in the same sequences would result in the same situations described previously. Therefore, it is best to close the cylinder valves only after closing/switching the sample supply and return valves. At that point, the fluid in the cylinder will be static and the sequence for closing the cylinder valves will not have any impact.

Volatile liquids and liquefied gases

When sampling highly volatile liquids or liquefied gases, there is another danger that is not readily apparent. As the volatile liquid enters the cylinder and the pressure drops, the liquid will begin to vaporize. This vapor will mix with and can possibly displace all the air in the cylinder. If the sample return valve is then closed and the sample supply valve is left open (the worst-case scenario previously mentioned), liquid will continue to flow into the cylinder, repressurizing the vapor. As the vapor is pressurized, it will condense, allowing even more liquid to flow into the cylinder. This process will repeat continuously to the point where the cylinder is 100% liquid-full, regardless of whether an outage tube is installed. Because all (or most of) the air was displaced by the sample vapor, the entirety of the vapor space can condense and leave the cylinder without a vapor space at all. This is illustrated in Figure 9.

To prevent this situation, the air must be prevented from escaping the cylinder. The surest way to do this is to introduce backpressure on the sample return that prevents the air from flowing out. The backpressure needs to be high enough to cause the vaporized sample to condense, or better yet, prevent it from vaporizing in the first place. If the sample return has enough backpressure, then maybe no further design changes are necessary. But if the sample return pressure is low or if the sample return is connected to a low-pressure vent/flare, then the sample system design should be modified to create a backpressure.

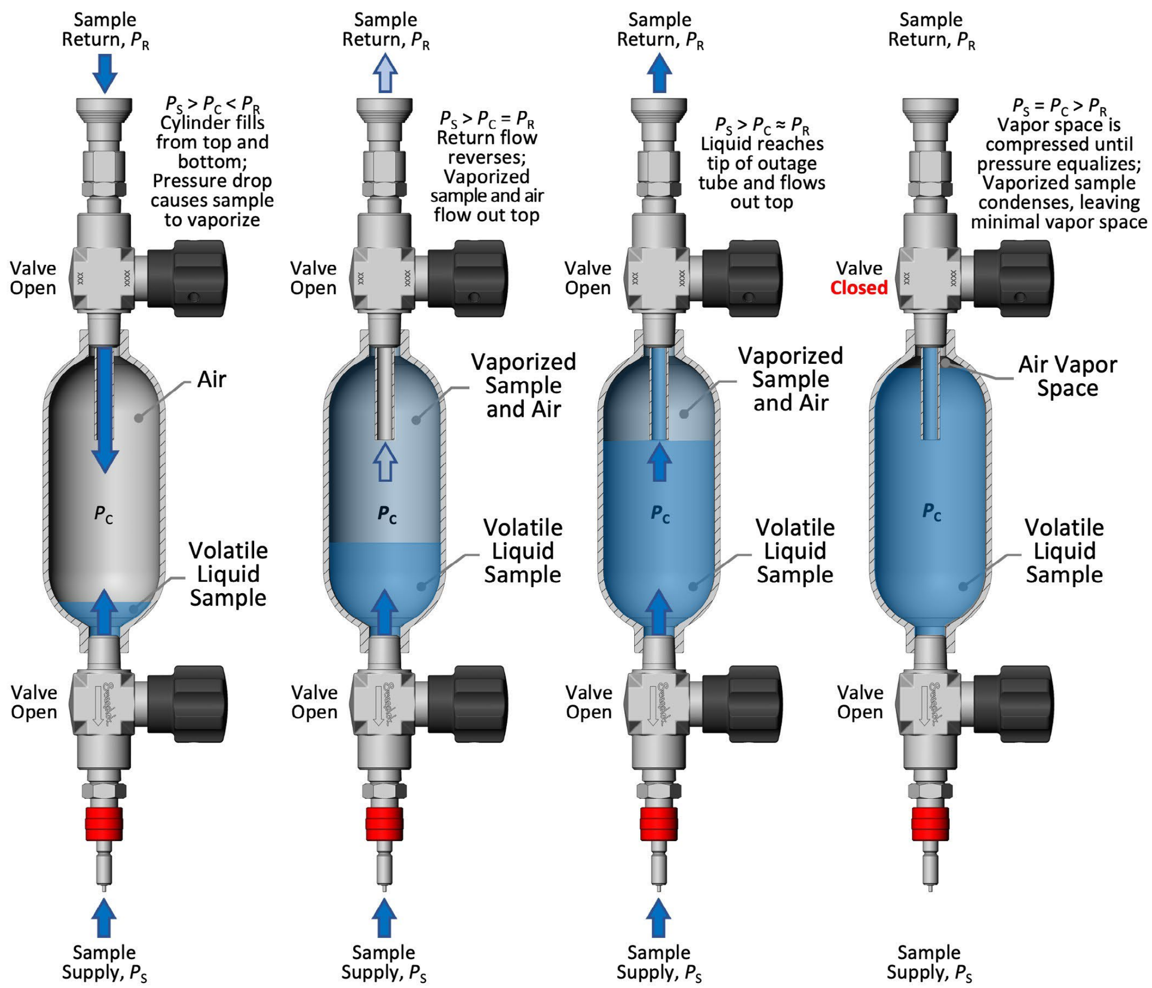

FIGURE 9. FILLING CYLINDER WITH VOLATILE LIQUIDS

The easiest and least expensive way to create backpressure would be to install a check valve or backpressure regulator. These can trap the air in the cylinder until the pressure reaches the set point/cracking pressure. If the check valve or backpressure regulator is set high enough, then the pressure in the cylinder can build to the point where any vaporized sample will reliquefy. In this case, since the air will not have escaped, the vapor space calculations will be the same as for a nonvolatile liquid.

Even better would be to combine the use of a backpressure device with a sample cylinder that was precharged with pressurized air/nitrogen. If precharged above the sample's vapor pressure, this elevated pressure in the cylinder can prevent the sample from vaporizing.

Thermal expansion of Liquid sample

Once the volume of the vapor space is known, the next step is to consider the potential thermal expansion of the liquid sample to determine if the vapor space is sufficient. If the thermal expansion is less than the volume of the vapor space and the pressure in the cylinder is not too high, then the outage tube implementation will be sufficient. If not, then the sampling system will need to be altered to ensure safety.

Final sample volume

Calculating the change in volume of the liquid is relatively easy. It is simply a function of the liquid's density at the initial and final temperatures. Starting with the formula for density:

$$\rho = \frac{m}{V} \qquad (4)$$

Where ρ = Density of the liquid
m = Mass of the sample
V = Volume of the sample

This formula can be rearranged to solve for the mass:

$$m = \rho V \qquad (5)$$

It is known that the mass of the sample will not change – the cylinder valves trap the sample in the cylinder so no mass can escape. Therefore, it can be said the initial density and volume of the sample liquid will equal the final density and volume:

$$\rho_1 V_1 = \rho_2 V_2 \qquad (6)$$

Where ρ_1 = Initial density
V_1 = Initial volume
ρ_2 = Final density
V_2 = Final volume

The initial volume is known since it can be calculated as explained previously. The initial density and final density of the sample at the given temperatures can be found in various published references and/or software such as REFPROP. Therefore, the only unknown is the final volume of the sample which can be solved for by rearranging Equation 6:

$$V_2 = \frac{\rho_1 V_1}{\rho_2} \qquad (7)$$

In the previous example, it was calculated that in Scenario 1, there would be an 8% outage and therefore the sample volume, V_1, would be 92% (100% - 8%). For this example, it will be assumed that the sample fluid is butane, which was initially collected at 0°C and then allowed to warm up to 30°C. Given these initial and final temperatures, Figure 10 can be used to determine the initial density, ρ_1, and final density, ρ_2.

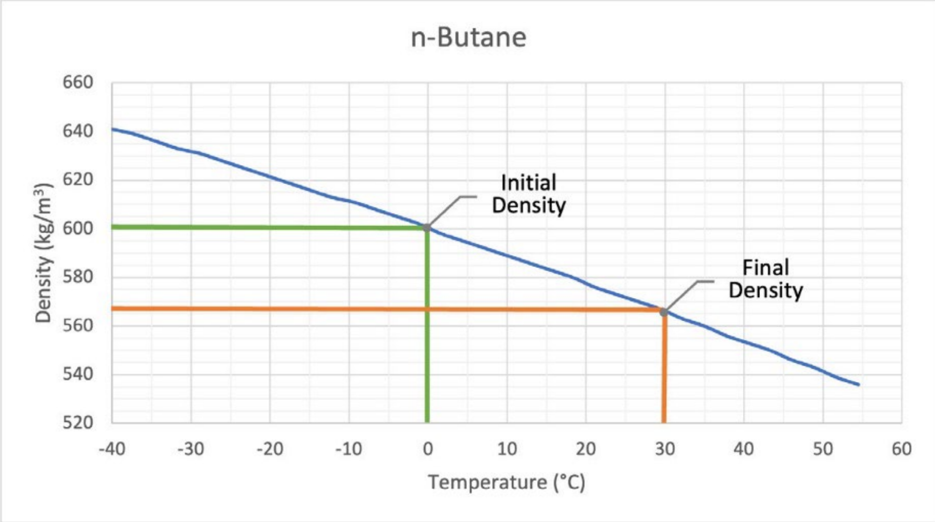

FIGURE 10. TEMPERATURE VS. DENSITY FOR N-BUTANE

Entering these values into Equation 7, along with the initial volume:

$$V_2 = \frac{\rho_1 V_1}{\rho_2} = \frac{600\frac{kg}{m^3}\ 92\%}{566\frac{kg}{m^3}} = 97.5\%$$

Here, the final sample volume of 97.5% is less than the total cylinder volume 100%, so the cylinder is unlikely to rupture. However, to verify this, the final cylinder pressure must also be determined.

Final cylinder pressure

To calculate the final pressure of the cylinder, Boyle's law is once again used. In this case, the initial pressure, P_1, and volume, V_1, are the pressure and volume of the vapor space prior to thermal expansion, 10 bara and 8%, respectively. The final volume is 2.5% (100% - 97.5%). These values can be inserted into Equation 3 to solve for the final pressure:

$$P_2 = \frac{V_1}{V_2} \times P_1 = \frac{8\%}{2.5\%} \times 10\ bara = 32\ bara$$

This calculated pressure is then compared to the rated pressure of the sample cylinder. Most sample cylinders are rated to 125 bara, so in this example, the sample pressure is well below that rating and there is little risk of rupture.

If the vapor space is not large enough

If the final sample volume is larger than the cylinder volume or if the final cylinder pressure exceeds the rated pressure of the cylinder, then the sampling system will need to be changed. There are a number of strategies that can be employed:

- The easiest and most obvious solution is to use a longer outage tube to increase the initial volume of the vapor space.
- Alternatively, a check valve or backpressure regulator could be installed immediately downstream of the sample cylinder assembly. When there is a low sample return pressure, the backpressure added by a check valve or backpressure regulator can help prevent air from escaping the cylinder. This will force the cylinder into Scenario 2, described previously, which will result in the largest possible vapor space.
- Another strategy is to precharge the cylinder with air, nitrogen, or some other gas. This helps to increase the initial pressure, P_1, in the Scenario 1 and 2 calculations. However, precharging the

cylinder makes it more likely that the cylinder will be in Scenario 1, which means that some of the precharge will flow into the process by way of the sample return. As such, the process must be tolerant of the precharge gas.

- As noted in the Valve Sequence section above, it can also help to ensure that the sample supply and return valves are opened/closed at the same time. This is most reliably achieved by using valves that are ganged together to operate with a single handle.

Conclusiones

When collecting a liquid sample in a sample cylinder, it is crucial to ensure that there is a vapor space in the cylinder to absorb any thermal expansion of the liquid. One of the most widely used and simple methods to create this vapor space is the outage tube. However, this simple device is not well understood by most designers, and it is not as foolproof as many believe. With an understanding of the fluid mechanics inside the sample cylinder and through careful sample system design, an outage tube can be an effective tool to ensure the safety of the sampling operation.

Evaluating the performance of an outage tube requires an analysis of the system pressures and the way that the sample cylinder fills. Through basic calculations, a system designer can accurately estimate any vapor space compression that may occur. Combined with an analysis of the sample's thermal expansion and the resulting pressure rise in the cylinder, the designer can determine if the size of the vapor space is sufficient or if the design needs to be modified to suit the application.

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Breve Cv de los autores

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Título y lugar de estudio: BS, Mechanical Engineering, Ohio Northern University.
Cargo actual en la empresa: Global Technical Lead, responsable for consulting on projects large and small, educating customers and also associates within the Swagelok Organization about how our products are applied and identifying industry trends/applications and their implications.
Trayectoria (diferentes empresas en las que hizo su carrera): 27 years with Swagelok in different roles such as Engineering Services, Custom Solutions, manufacturing, welding and assembly engineering.

Presentador 1: Esteban Natanael Sansó.
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Cargo actual en la empresa: Regional Field Engineer, member of the Global Field Engineering Team at Swagelok where he specializes in process analyzers sample systems, mainly for the oil&gas, petrochemical and refining industries. In recent years Esteban has participated in many sample systems field surveys. Also involved in Swagelok Analytical instrumentation collaborative team.
Trayectoria (diferentes empresas en las que hizo su carrera): 10 years at Swagelok starting as Custom Solutions Engineer and then transitioning into the Swagelok Field engineering team.

Presentador 2: Germán Federico Rodríguez
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Cargo actual en la empresa: Regional Field Engineer, performing evaluation of Customer fluid systems to identify áreas of improvement (E&AS). Select and recommend products into specific Customer applications. Provide training and technical support on products and applications. Collaborate with other field engineers on technical applications and solutions.
Trayectoria (diferentes empresas en las que hizo su carrera): 18 years at Swagelok, starting as internal sales associate, then changing his role to Custom Solutions manager. Currently he is part of the Swagelok Engineering Services team.