8.30 Inert Gas Blanketing Controls

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Applications:	Inerting systems are required for tanks containing flammable gases and vapors. Their goal is to keep the oxygen concentration in the vapor space of the tank below the minimum oxygen for combustion (MOC).
Range:	The MOC of most flammable gases and vapors is below between 5 and 12%; therefore, the setting of oxygen levels above 10% will not serve fire protection (Table 8.30e). Automatic inerting units can control the oxygen concentrations down to 0.1%.
Inaccuracy:	Automatic inerting systems can control the vapor space oxygen concentration within 0.1% of set point. The control system set point should be selected to provide a 30% safety margin below the MOC, because of the uneven mixing of the gases in the vapor space.
Reliability:	Inerting controls that do not include the measurement and control of oxygen may not be reliable. These systems, depending on the control of pressure or flow, provide no positive guarantee of safety and require long time periods of purging. Others are reliable but use a lot of inert gas.
Costs:	A manually operated combination of variable-area flowmeter and valve can be installed for less than \$200. A pressure control system costs \$500 to \$1000, depending on the required flow rate. An automatic system, with oxygen sensing and control, costs \$1000 to \$2000 for a single point of installation. The cost of multipoint systems adds about \$500 per channel.
Partial List of Suppliers:	Air Liquide (www.us.airliquide.com) Air Products (www.airproducts.com) Alpha Omega (www.aoi-corp.net) Delta F (www.delta-f.com/) Linde (www.us.lindegas.com) Neutronics (www.neutronicsinc.com) NTRON (www.ntron.com) Revolution Sensor Company (www.rev.bz) Teledyne Analytical Instruments (www.teledyne-ai.com)

INTRODUCTION

Inerting or inert gas blanketing is a fire- and explosion-prevention method that works by lowering the oxygen concentration of a flammable gas mixture. The technique is used to blanket the vapor space in tanks containing flammable process liquids, combustible dusts, fibers, and particulate solids. The applications for inerting systems include chemical reactor vessels, mixers, centrifuges, web coating lines, and mills. Although inert gas blanketing is also used to protect nonflammable process materials from discoloring or other forms of degradation, this section concentrates on inert gas blanketing (inerting) for the purpose of fire prevention.

In the process of inert blanketing, the vapor space of the tank is filled with inert gas in order to prevent fire and explosion. The term *inert gas* refers to any gas that will not support combustion. The inert gas most commonly used is nitrogen, although it is also possible to use CO_2, argon, or other gases that are oxygen deficient, such as steam, or the products of combustion.

Pollution and Personnel Safety

Many processes use volatile organic compounds (VOCs) as solvents that, when the vapor space of a storage tank is purged, are released to the atmosphere along with the inert gas exhaust. Therefore, the less inert gas is used in the process of inerting, the less VOCs will be lost to the atmosphere.

Minimizing VOC emissions is important for both safety and environmental reasons. As will be seen in the discussion below, the oxygen-based inerting systems are the best candidates for minimizing the use of inert gas and, therefore, also minimizing VOC emissions to the atmosphere.

A vapor space that has been purged by inert gas to obtain a low oxygen concentration, in order to prevent fires, also has too little oxygen for breathing. Therefore, plant operation should make sure that this does not result in a low-oxygen hazard to personnel.

Inert gas that is exhausted to the room normally has little effect on breathable air. A potential problem could arise, however, if an operator opens a hatch of an inerted vessel and leans into it for any reason. Therefore, alarms or interlocks must be provided to protect against such possibility.

THE COMBUSTION PROCESS

Combustion is a chemical oxidation process that occurs rapidly enough to produce heat and light in the form of a flame or glow. Combustion is called deflagration if the rate of propagation of the combustion zone is slower than the speed of sound in the unreacted medium.[1] If the propagation speed is greater than the speed of sound, it is called detonation. An explosion is the bursting of an enclosure due to internal pressure generated by a deflagration.

Inerting

An inerting system can prevent combustion of flammable materials in almost any sealed space by keeping the oxygen concentration below the level that could support the minimum oxygen for combustion (MOC). The most common application of inerting systems is to protect the vapor space (headspace) of a vessel containing a flammable liquid. The flammable liquid and the headspace in an agitated tank are shown in Figure 8.30a.

A flammable gas or vapor is one that will burn in air at normal temperatures and pressures, if it reaches a certain minimum concentration. Liquids can generate flammable vapors if they are above their flash point. The flash point of a liquid is its lowest temperature (at normal atmospheric pressure) at which the rate of evaporation is sufficient to form a combustible mixture near the liquid surface.

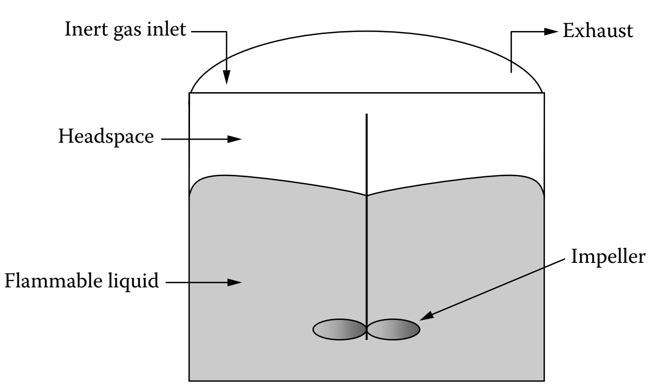

FIG. 8.30a
Fire protection is provided by introducing inert gas into the headspace of a mixing vessel that contains flammable liquids.

Alternatives to Inerting

For each flammable vapor or gas, there is a range of concentrations in air over which combustion is possible. This is the flammable range and is the range between the lower flammable limit (LFL) and the upper flammable limit (UFL)

Below the LFL, the gas concentration provides insufficient fuel to propagate a flame. Above the UFL, the gas concentration is too rich (not enough oxygen) to propagate a flame. If the gas concentration falls between the two limits, then it can be ignited and act as the fuel in a combustion process. In industrial applications, where process vessels contain flammable liquids at temperatures above their flash points, it is assumed that the vapor space can contain a flammable range of vapor concentrations. Therefore, fire prevention is necessary to ensure the safety of personnel and equipment.

As an alternative fire-prevention method to inerting systems, one can maintain the gas or vapor concentration above the UFL, where the flammable vapor concentration is too rich to support combustion (not enough oxygen). This is an acceptable method of prevention only in vessels that are normally sealed, with no entry of air allowed.

Another alternative method is to maintain the gas or vapor concentration below the LFL, where there is insufficient fuel concentration to support combustion. This is accomplished by purging with a nonflammable gas and can be used when the flow of flammable gas is low, or the flammable vapor is not being generated at a high rate during the normal operation of the process.

The Combustion Triangle

In order for combustion to take place, three requirements must be satisfied. These are the presence of a fuel, an oxidizer, and an ignition source (Figure 8.30b). In most cases (except with

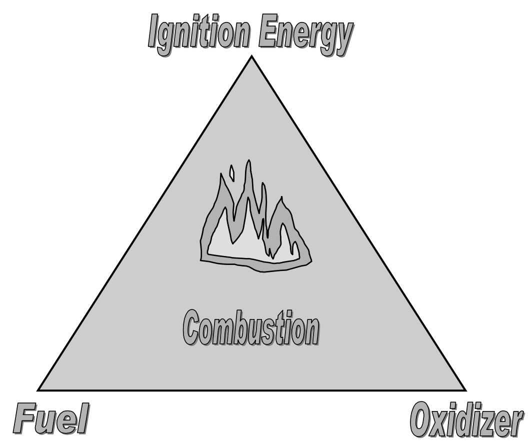

FIG. 8.30b
The prerequisites of combustion.

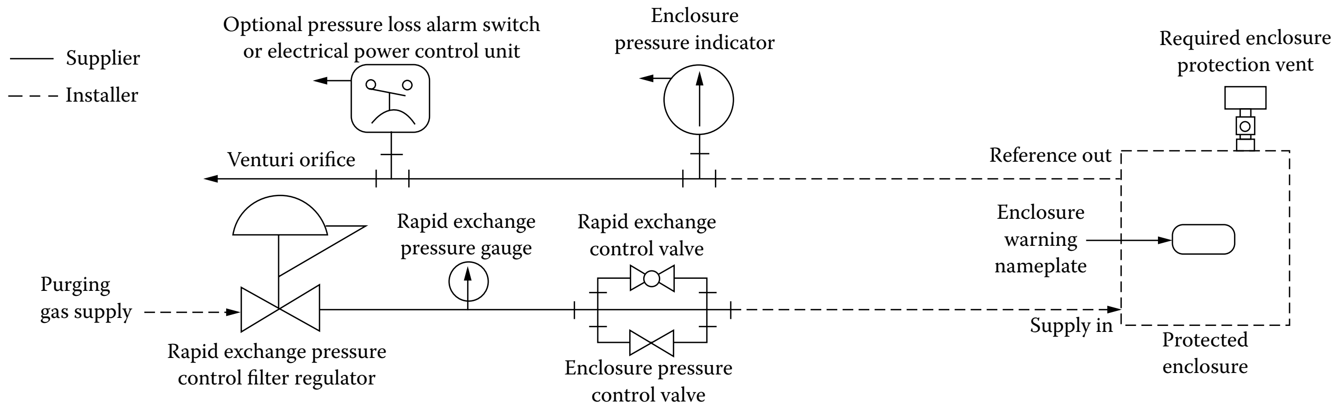

FIG. 8.30c
Packaged purge systems are marketed for Class 1 area and are provided with rapid exchange purging capability. (Courtesy of Bebco Industries.)

certain materials that contain their own oxidant), removing any one of these three prerequisites will prevent combustion.[2]

Fuel can be defined as a flammable gas or vapor within the combustible range of concentration, or a combustible fiber, dust, or other particulate material. This prerequisite of combustion is a given, so the design engineer must concentrate on the removal of at least one of the other two.

Common sources of ignition are electric sparks and heat. An electrical discharge can come from the opening of an electrical contact, a broken wire, or a discharge of static electricity. Heat can be generated by the process, by heaters, or by electrical faults.

The use of intrinsically safe (IS) electrical systems can eliminate some electrical ignition sources, but cannot protect against process-generated heat or static electricity discharge. Many industrial processes generate static electricity by mixing or agitating dielectric materials. For these reasons, the complete elimination of ignition sources, even when an IS electrical system is installed, is not always possible. Therefore, in many instances, the removal of the oxidizer by inert blanketing is the most practical means of fire and combustion protection.

The oxygen concentration of atmospheric air is about 20.9%, the remainder being mostly nitrogen. This percentage concentration remains the same over different pressures (and, therefore, different altitudes), although it is affected slightly by changes in relative humidity. If the air within the tank can be replaced with an inert gas, then the oxidizer prerequisite in the combustion triangle is removed. This is the goal of inert blanketing. A manual purge system is shown in Figure 8.30c.

Fibers, Dusts, and Particulate Solids Some dusts and finely divided powders, such as those of magnesium and zirconium, can deflagrate with no additional oxygen being present in the atmosphere. Therefore, their storage tanks cannot be protected by inerting.

Some magnesium or lithium compounds can react with nitrogen, and so argon is used as the inert gas supply for the gas blanket. Sometimes, fibers can continue to smolder after blanketing with inert gas, only to burst into flame when exposed to air later.

In addition, the mechanical difficulty of ensuring homogenous dispersion of an inerting gas throughout porous solid materials requires special attention. Inerting of the gas space above a process liquid contained in a vessel is a fairly straightforward process, but inerting of combustible fibers, dusts, and particulate solids requires a careful evaluation of the specific properties of the materials involved.

INERTING CONTROL SYSTEMS

Inert blanketing systems can be operated on pressure, flow, or oxygen control. Flow-controlled inerting is also called a "timed-volume" system, while oxygen-based inerting is often referred to as "automatic control."

Flow-Controlled Inerting

A *flow-based* inerting system is also called a *timed-volume* control system. It consists of a purge flowmeter in combination with a differential pressure regulator that acts as a self-contained flow regulator (Figure 8.30d). The inert gas flow through a standard purge flow controller is usually adjustable between 0.2 and 2 SCFH (6 and 60 slph). Over this 10:1 flow range, the flow control error is within 5% of full scale. The standard pressure and temperature ratings are 150–300 PSIG (1–2 MPa) and 212–572°F (100–300°C). The purge flowmeter can be obtained in much larger sizes to control higher flow rates as required.

At start-up, the required total initial charge of the inert gas is set to be about five times the volume of the vapor (dilution ratio[1] of 5) space of the vessel. This amount of inert gas, if introduced at a high enough velocity to create turbulent flow, will usually lower the oxygen concentration in the vapor space of the tank to under 0.5%. The purge flowmeter is

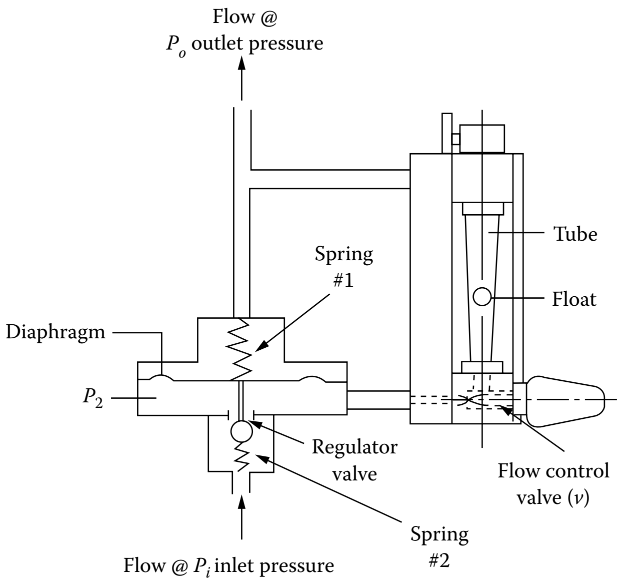

FIG. 8.30d
Purge flow regulator consisting of a glass tube rotameter, an inlet needle valve, and a differential pressure regulator. (Courtesy of Krone Inc.)

usually sized such that it will deliver this initial volume of inert gas into the tank's vapor space in an "initial purge time" of about 5 min.

When the inert blanketing system is manually operated, the operator is usually provided with an instruction sheet that is mounted next to the purge flowmeter. The first line on the instruction sheet gives the initial purge time period and the corresponding flow setting that the operator should use during start-up.

After the initial purge is completed, the purge flow rate is lowered to the continuously maintained rate that is required. This second flow rate is selected to make sure that the oxygen level in the vapor space will not reach the minimum oxygen for combustion level for the material in the tank.[1] If the start-up and the continuous purge rates are drastically different, a single purge meter might not be able to control both, and two purge meters have to be installed in parallel.

The continuous purge flow rate has to be set high enough to keep the oxygen concentration in the vapor space under MOC limits even during periods when a valve or a hatch has to be open to the atmosphere in order to add an ingredient or remove a product. Table 8.30e provides MOC values for a variety of flammable materials. For other material, consult Reference 1.

Flow-based inerting systems are usually used because of their simplicity and low installed cost. Their disadvantage is that the controlled variable (oxygen concentration in the vapor space) is only assumed, but not measured. Another disadvantage is their higher operating cost, because they tend to consume more inert gas than the other inerting systems.

TABLE 8.30e
MOC (Minimum Oxygen for Combustion) Values of Some Flammable Materials

Flammable Material	*MOC (%)*
Carbon monoxide	5.5
Gasoline	12.0
Hydrogen	5.0
Methane	12.0

Naturally, the manual mode of operation is only an option, not a necessity. Inert blanketing systems can also be controlled automatically. In that case, automatic on/off valves are required to start up the system, and timer controls are needed to automatically switch the purge flow rate set point from the start-up to the continuous rate.

Pressure-Controlled Inerting

Figure 8.30f illustrates the configuration of a pressure-controlled inerting control system. The start-up phase of the operation is the same as it was in the flow-controlled inerting system. During the start-up period, the purge valve is opened and the purge flowmeter is set for the initial purge rate. Once the initial purge time has expired and the vapor space of the vessel has been sufficiently diluted, the purge valve is closed.

After the purge valve has been closed, the pressure control valve (PCV) maintains the pressure in the vapor space at a safe value, determined by the design pressure of the tank and its associated equipment, including emergency and conservation vents.

Pressure-based inerting controls can reduce the inert gas consumption if the leakage rate is small because of tight vessel construction. If the tank operation is such that the inert gas flow needs to be drastically increased periodically (say, because of the need to open a hatch), the PCV has to be oversized, which can result in leakage and overpressuring during normal operation.

Similarly to the flow-based purge controls, the operation of the pressure-based inerting systems can also be automated by the use of a timer that operates an automated purge valve.

Oxygen-Controlled Inerting

While the pressure- or flow-based inerting systems indirectly lower the oxygen concentration of the vapor space, the measurement of oxygen is a direct and automatic method of keeping that concentration under the MOC limit. There are a number of methods of detecting oxygen concentration (see Section 8.42 in Chapter 8 in the first volume of this handbook), and once the measurement signal is available, it can be used in on/off or continuous control configurations.

The Oxygen Sensor In an oxygen-based automatic inerting system, the oxygen sensor is usually either the electrochemical

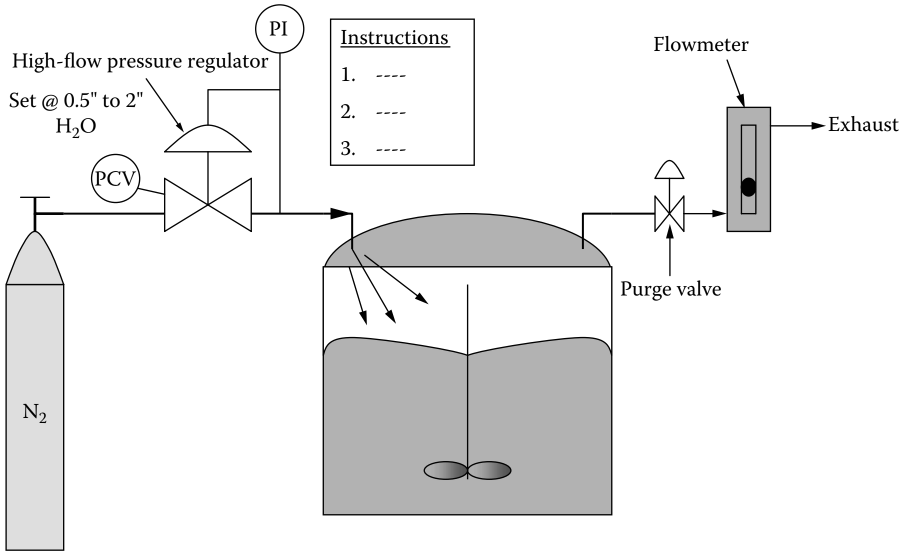

FIG. 8.30f
The main components of a pressure-based inert blanketing control system.

fuel cell-type design or the paramagnetic type. Fuel cells are small and relatively inexpensive, and can measure oxygen as a percentage by volume. They generate an output current by oxidizing an internal material, such as lead. Fuel cells also have an inherent true zero, i.e., no output is generated if no oxygen is present. The true zero means that no zero gas is needed for checking the calibration of the fuel cell.

All gas sensors should be routinely maintained so that their calibration is validated on a schedule. With an oxygen fuel cell, only a span gas is needed for calibration. Almost universally, fresh air is used to calibrate an oxygen fuel cell that reads in percent by volume. It can be adjusted to 20.9% in fresh air (ignoring the small changes that are due to changes in relative humidity). If using a membrane-type fuel cell that measures partial pressure, allowance may be made for changes in the atmospheric pressure.

For its measurement, the paramagnetic oxygen sensor relies on the force of alignment of oxygen molecules along the lines of flux in a strong magnetic field. In one design, this force generates a small motion that is measured through the use of a mirror, a light source, and a pair of optical sensors. Because a paramagnetic oxygen sensor measures the partial pressure due to oxygen, it is affected by atmospheric pressure, similarly to a membrane-type of fuel cell.

One limitation of paramagnetic oxygen analyzers is that a major repair is required if the sensing cell is damaged, and replacement is fairly expensive. In contrast, with a fuel cell, the sensing element is disposable and can be replaced at a nominal cost.

On/Off Oxygen Controls When the vapor space oxygen concentration is detected, there is no need to calculate the time required to complete the initial purge cycle during start-up, because the switching to the continuous mode of purging occurs automatically (Figure 8.30g).

At the beginning of a start-up cycle, the oxygen analyzer is likely to detect 20.9% oxygen (the concentration that is present in a normal atmosphere). Therefore, the solenoid valve on the inert gas supply line will open. As the inert gas displaces the vapors in the headspace of the vessel, the oxygen sensor will detect a steady decrease in the oxygen level.

When the oxygen level has dropped to the set point of the inerting controller, a green light goes on, indicating that it is safe to start up the process. During normal operation, the solenoid valve is cycled on and off as necessary to keep the oxygen level under control. (This system was invented by the author in the late 1970s.)

To reduce the amount of cycling, a dead band around the set point is provided in the on/off control switch. In normal operation, a red light illuminates when the solenoid is open and the oxygen level is being lowered to the set point during start-up. That light goes out and a green light comes on when the oxygen level is within the dead band of the set point's control range. A yellow light cycles on and off as the solenoid cycles on and off during normal operation.

Two control points are set by the user, depending on the MOC of the particular flammable materials present in the vessel. For example, if the published MOC of the stored liquid is 8.0%, the user might set the alarm point at 5.0% and the high and low control points (the control band) between 4.0 and 3.0%. With such settings, the solenoid valve will then open at or above 4.0%, and close at or below 3.0%.

This way, there is a safety margin between the MOC of 8.0% and the alarm point of 5.0%, while the minimum amount of inert gas is used. This control system also provides a continuous indication of the safety and operating status of the vessel.

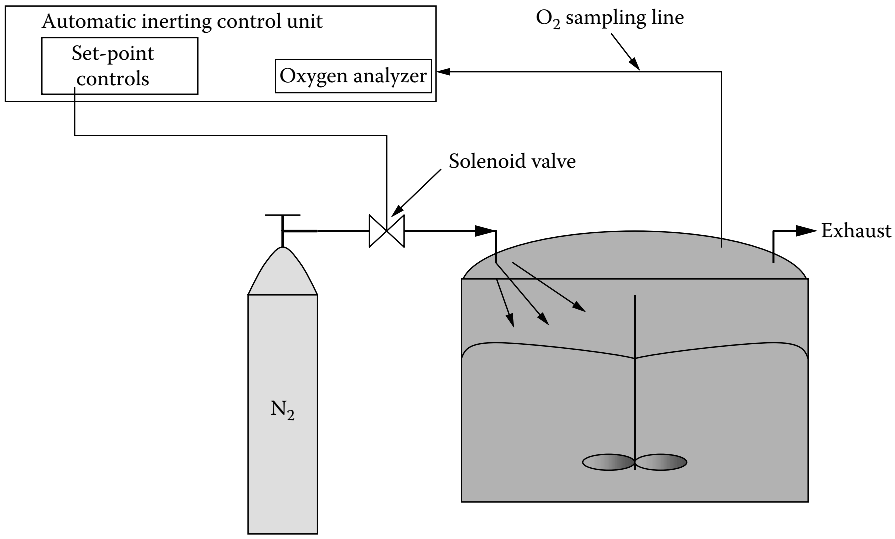

FIG. 8.30g
Automatic, oxygen-based, on/off inerting control system.

This oxygen-based on/off control system uses the least amount of inert gas and provides more safety than the flow- or pressure-based systems, because it directly detects the oxygen concentration. Its disadvantage is higher installed cost. The higher initial investment can usually be recovered through savings due to the reduction in inert gas usage.

COMPONENT DESIGN CONSIDERATIONS

The proper selection and installation of the purge control solenoid valves and of the purge flow rates deserve further discussion.

Do Not Use "Fail-Safe" Solenoids

On the surface it would appear that to select a fail-open solenoid valve (i.e., the valve is open when not energized) would guarantee safety, because it would open the inert gas flow to the protected vessel whenever power failed. In fact, such a design would mean that all of the solenoid valves on all of the inerted vessels would open up during a power failure.

This is undesirable if the inert gas supply system could not keep up with the demand and, therefore, no vessels would be adequately protected. Instead, the inert gas solenoid valves can be the energize-to-open design, and any failure (system or power) can require that the operation of the protected process be terminated until the problem is remedied.

The decision on the failure position of the solenoid should be based on the balance of the costs and consequences of the two solenoid failure options. Fail-closed solenoids can be used if the temporarily shutting down of the process is acceptable, while fail-open solenoids are the proper choice if providing a sufficiently high-capacity emergency inert gas supply system, which could supply all the failed open solenoids during periods of power failure, is feasible.

If fail-open solenoids are used (i.e., the valves open when energized), one area of concern is that the coil circuit wiring of a solenoid valve can open up (i.e., fail as an open circuit), while the controls are applying power to the valve circuit to open the valve when it is not. To protect against this, one can measure the current flow through the coil of the solenoid valve. This way, the solenoid valve will be reported to be energized only if current is flowing in its coil.

Purge Flow Rate Variation

In the flow-based inerting system, after the initial start-up purging cycle is completed, a continuous flow rate of purging is maintained. This rate must be large enough to maintain a low oxygen concentration even if the protected vessel has a substantial leak rate.

In addition, in case of an outdoor storage tank, on a hot and sunny summer day, the vapor temperature in the headspace will be quite high and will drop drastically during a thunderstorm. In that case, the tank will rapidly cool, reducing the gas volume, and tending to create a vacuum. If during such episodes outside air is drawn in, a hazardous condition can evolve.

The same applies to a process vessel from which the product is quickly discharged. During such episodes, it is necessary to quickly and safely break the vacuum by manually or preferably automatically switching to a higher capacity purge system.

The need for a variable flow rate is not a problem with a pressure-based or automatic systems, as long as the pressure-based system has a sufficiently high flow capacity. Similarly, the oxygen-based purge controls can also handle changes in purge flow demand as long as the inert gas supply and the size of the solenoid valve is sufficient.

CONCLUSIONS

The initial cost of flow- and pressure-based inerting systems is lower than that of oxygen-based ones. The flow- and pressure-based systems are indirect in the sense that they do not directly measure the oxygen content of the vapor space, and they also consume more inert gas and release more process vapors (including volatile organic compounds) into the atmosphere. Over the long run, when the operating costs of purge gas consumption are considered, oxygen-based systems can be less costly overall.

Each type of purging system requires routine maintenance to make sure that all valves and lines are clear and operational. In addition, an automatic system with oxygen concentration feedback requires maintenance of the gas sampling system and sensor. If an electrochemical fuel cell-type of oxygen sensor is used, it must be replaced once per year or when it fails to calibrate.

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