White Paper

Selecting the Right Overfill Prevention Technology

For Process Vessels and Bulk Liquid Storage Tanks

EMERSON

Selecting the Right Overfill Prevention Technology

Abstract

As high-profile incidents such as the Buncefield fire in 2005 have shown, failure to identify and prevent overfilling of tanks and vessels containing hazardous and explosive materials can have catastrophic consequences. It is essential for companies to implement Overfill Prevention Systems (OPS) to minimize risk and improve safety.

Figure 1. Tank Overfill is the Most Common Cause of Incidents in Tank Farms

Automation technology is increasingly being deployed to replace mechanical devices and human factors, but it is important to understand that there is no "one size fits all" solution for overfill prevention. This white paper looks specifically at the level sensor within the safety loop, outlines the challenges posed by the most common applications and the technology solutions available, before making recommendations as to the most appropriate solution for each application.

Introduction

Worryingly, there are hundreds of tank spills of hazardous materials every day (United States Environmental Protection Agency, 2014) and the overfilling of tanks and vessels has been a leading cause of serious incidents in the process and bulk liquid storage industries. Within the process industry, the materials involved are often hazardous, flammable and even explosive. Should an overfill occur in these scenarios, it has the potential to cause personnel injuries or even fatalities, significant damage to assets, and harmful environmental issues.

Figure 2. Puerto Rico Accident in 2009

The cost of such an incident can, in the worst cases, be measured in billions of dollars, and a company's reputation can be seriously blighted by the ensuing adverse publicity and legal consequences.

Standards and guidelines

The explosions and subsequent fires in 2005 at the Texas City Refinery and Buncefield oil storage depot were a direct cause of overfilling and lack of overfill prevention technology. The disasters led to the introduction of new standards and safety guidelines, which the process industry is adopting widely. For those companies storing such materials, investment in a robust overfill prevention solution is essential to comply with current safety standards. The IEC 61511 standard provides best safety practices for the implementation of a modern Safety Instrumented System (SIS). IEC 61511 is a process industry-specific adaptation of IEC 61508, which is an industry-independent standard for functional safety. Additionally, for those involved in the bulk storage of petroleum, the API 2350 standard provides minimum requirements to comply with modern best practices in the specific application of non-pressurized above-ground large petroleum storage tanks. Although focused on a specific application, the main purpose of this standard is to prevent overfills, so many of its recommendations and guidelines are adopted in other applications as Generally Accepted Good Engineering Practice.

Figure 3. Industry Guidelines Covering Overfill Prevention Globally

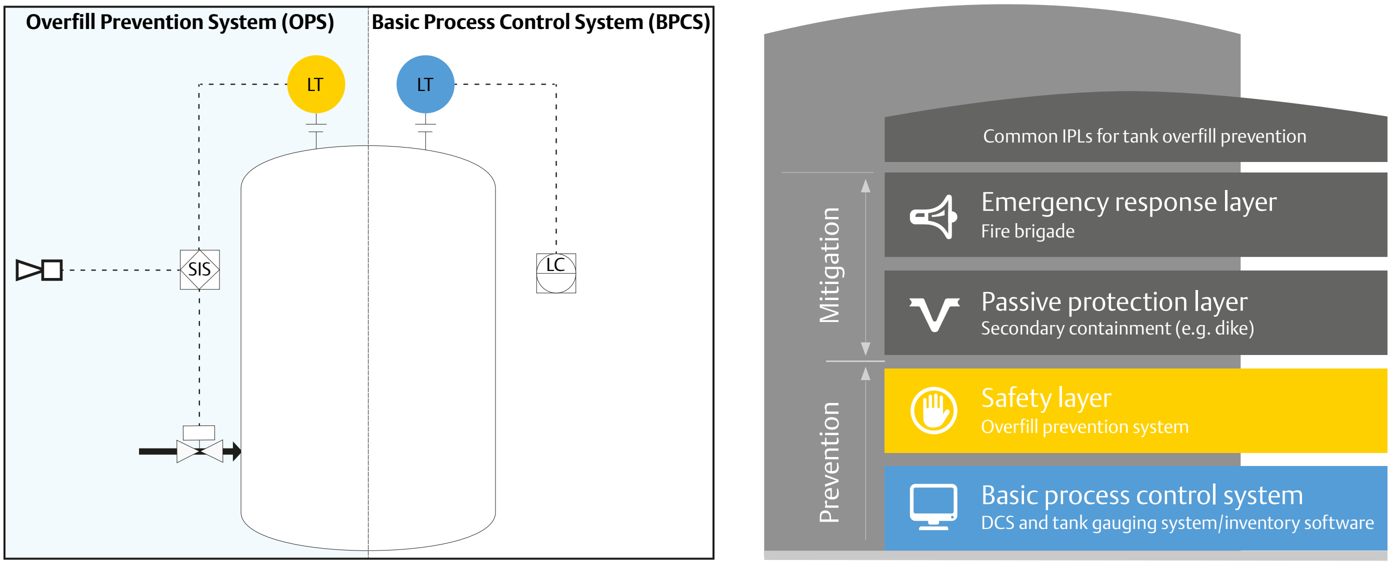
For the OPS, depending on the requirements, the level sensor should be certified for overfill protection according to IEC 61508.

Layers of protection

These standards recognize that overfills are predictable and therefore preventable. It is also widely recognized that when implementing a suitable protection system there is a need to employ a multitude of Independent Protection Layers (IPL) to minimize the risk of tank overfills.

The primary layer is the Basic Process Control System (BPCS). In place principally to monitor and control the production processes, it ensures that the plant is running smoothly, day in and day out. If functioning correctly, the BPCS will prevent the need for the other layers to become active. The second layer of protection is the safety layer, typically denoted as an OPS, which must remain separate and independent of the BPCS to provide redundancy. This acts as the safety system preventing an overfill incident from occurring should there be a failure or problem with the BPCS. The next layer is known as the passive protection layer. This provides secondary containment such as dikes or concrete walls. Finally, there is the emergency response layer, which as the name suggests, involves alerting the fire brigade and other emergency services.

Figure 4. Different Protection Layers are Used to Prevent or Provide Mitigation Against Overfills



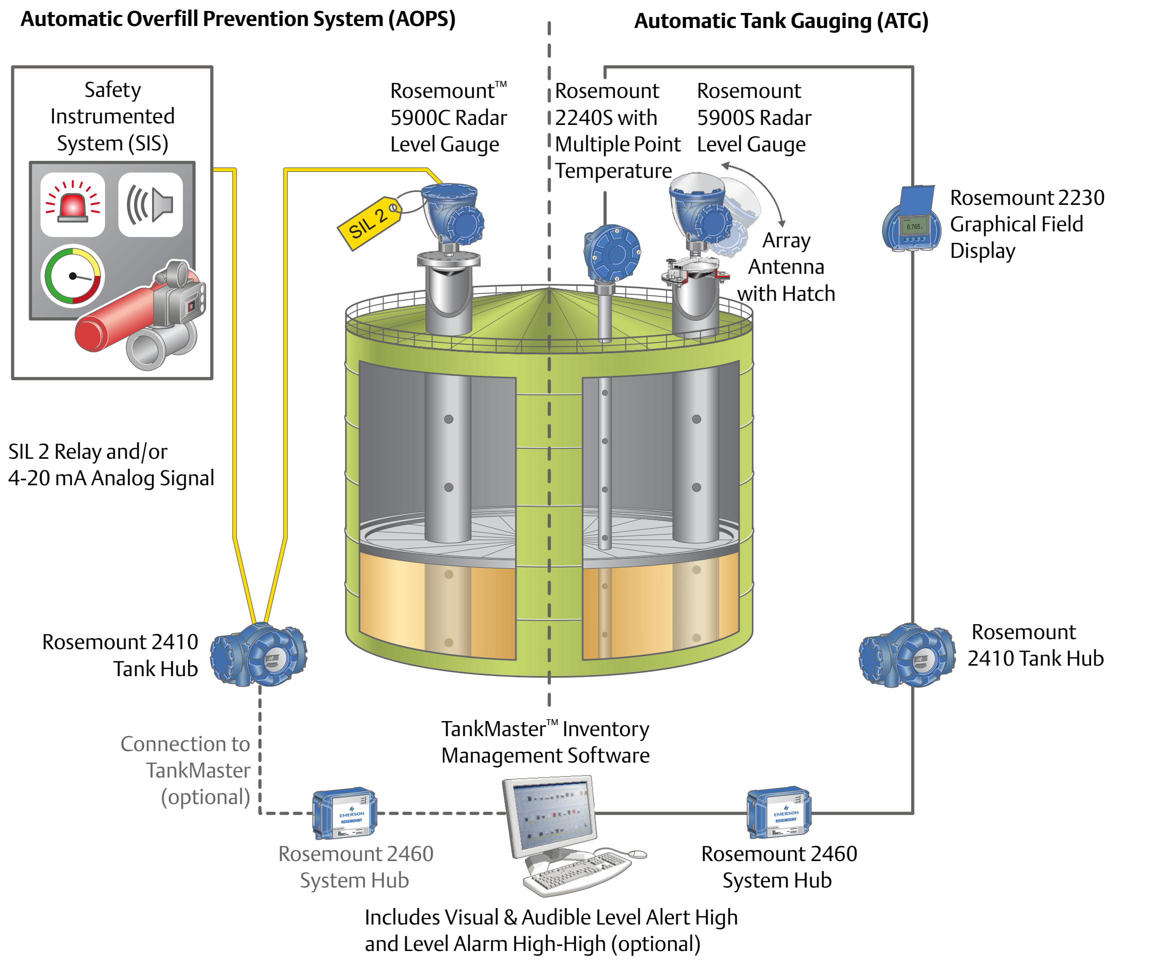
The BPCS and the OPS are installed to prevent an overfill, but should an incident occur the passive protection and emergency response layers are there to minimize the consequences. This white paper focuses on the OPS and specifically the sensor technology at the heart of these systems.

Manual and automatic systems

Within the safety layer there are two basic types of OPS – Manual Overfill Prevention Systems (MOPS) and Automatic Overfill Prevention Systems (AOPS). MOPS have been selected in the past for some applications because they are seen to be easier to implement and less complex, and have lower initial costs. MOPS typically consist of a level sensor or switch that transmits an audio-visual alarm to an operator, notifying them to take appropriate actions such as manually opening or shutting off a valve to prevent an overfill. Because humans are inherently unreliable, the risk reduction factor of MOPS is limited. Consequently, there is a strong trend towards replacing these systems with AOPS, and this paper will focus on this type of solution.

AOPS are preferred to MOPS because of the significant benefits they provide. These include the ability to achieve higher risk reduction factors, considerably reduced response times, a reduced workload for operators and an increase in the extent of the safety loop - for example, plant assets such as pumps can also be shut down and protected.

Figure 5. Example of a Tank Equipped with an Automatic Tank Gauging System (ATG) and AOPS



AOPS typically consist of a level sensor, a logic solver, and a final control element in the form of actuated valve technology. For very high risk or critical applications such as boilers, three sensors may be installed and a 'two out of three' voting logic used, but normally a single level sensor will be required.

Diverse and identical separation

There is a misconception that standards mandate that the technology used for the OPS sensor must be different from the technology used for the BPCS sensor, typically referred to as "diverse separation" or "diverse redundancy". However, this is not a requirement in any relevant standard. Specifically, IEC 61511-2 reads:

> *"Separation between the SIS and the BPCS may use identical or diverse separation. Identical separation would mean using the same technology for both the BPCS and SIS whereas diverse separation would mean using different technologies from the same or different manufacturer.*

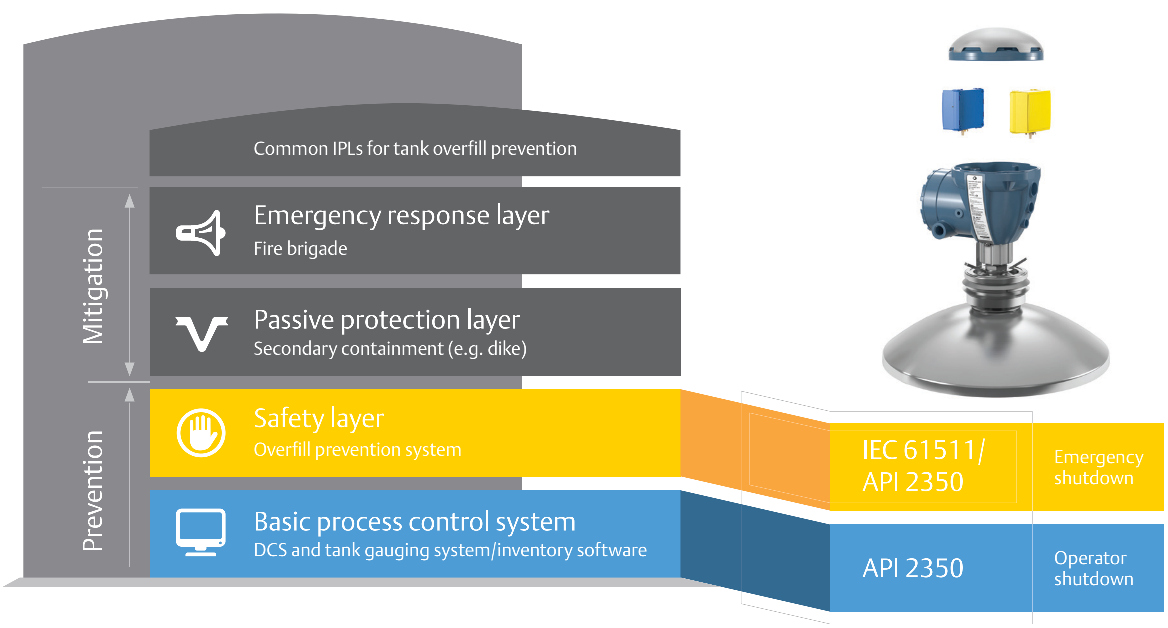
Compared with identical separation, which helps against random failures, diverse separation offers the additional benefit of reducing the probability of systematic faults affecting multiple channels at the same time and/or from the same cause and hence reduces correlated failure of multiple channels.

Identical separation between the SIS and BPCS may have some advantages in design and maintenance because it reduces the likelihood of maintenance errors. This is particularly the case if diverse devices are to be selected which has not been used before within the user's organization."

(IEC 61511-2:2016; A.11.2.4).

In other words, diverse and identical separation are both valid options but they provide different benefits. There is a growing insight that reducing maintenance and similar "handling errors" is critical – by some estimates 75 percent of accidents in industry are traceable to organizational and human factors. In this context, the Buncefield incident provides a case in point. Buncefield had redundant and diverse technology for overfill protection, but the high-level alarm was inoperable due to human error. It had been taken offline for testing and had not been reinstalled properly – it was no longer functioning. It can be argued that diverse separation introduces extra complexity and increases the likelihood of human error, as personnel need to learn about installing, configuring and proof-testing two different technologies rather than just one.

Figure 6. 2-in-1 Technology Serving the Two Layers of Overfill Prevention Independently



A further option for providing redundancy between the BPCS and the OPS is offered by the latest non-contacting radars (NCR), which feature 2-in-1 technology. This enables a gauge, installed on a single tank opening and containing two separate electric units within its transmitter head, to work simultaneously as an automatic tank gauge (BPCS) and as a sensor in an independent AOPS.

Level monitoring technology

Within overfill prevention solutions, there is no "one size fits all" technology and system. Different applications have their own specific challenges and it is important to select the appropriate technologies that meet these. The level sensor is the specific element of the OPS that offers several alternatives. A range of level monitoring and measurement technologies can be applied, from simple electro-mechanical float and displacer switches through to advanced modern solutions, including vibrating fork switches, Guided Wave Radar (GWR) and NCR.

Figure 7. Various Technologies Could be Used as Overfill Sensor

Finding the technology that best fits a specific application requires good knowledge of the technology itself as well as the application, and it is important to choose the most suitable technology, as that will result in the highest possible safety for your plant.

Electro-mechanical float and displacer switches

Electro-mechanical float and displacer switches are used for point level, interface, and density applications where the buoyancy of the displacer in the fluids is the primary measurement principle. Density of the fluid is a key factor in determining the sizing of the displacer and stability of the applications, and any deviation from the initial density will impact the measurement accuracy. Displacers have moving parts that require frequent cleaning and replacement. They are affected by mechanical vibration and turbulence, the mechanical parts can give false readings, and maintenance costs can be expensive. Displacers are increasingly being replaced by more modern electronic technologies that offer greater diagnostics, reliability and lower life-cycle cost. For new switching installations, vibrating fork switches are almost always recommended instead of a float switch.

Vibrating fork switches

Vibrating fork switches are a point level technology which operate using the concept of a tuning fork. Two prongs are immersed into the process vessel and an internal piezo-electric crystal oscillates these prongs at their natural frequency. This frequency varies as the fork is immersed in the medium. Any changes are detected by the electronics, providing an effective means of detecting the presence or absence of liquids. With no moving parts to wear or stick, vibrating fork technology is less prone to failure compared with other technologies. Furthermore, operation is virtually unaffected by flow, turbulence, bubbles, foam, vibration and changing density making vibrating fork switches highly reliable in overfill prevention applications.

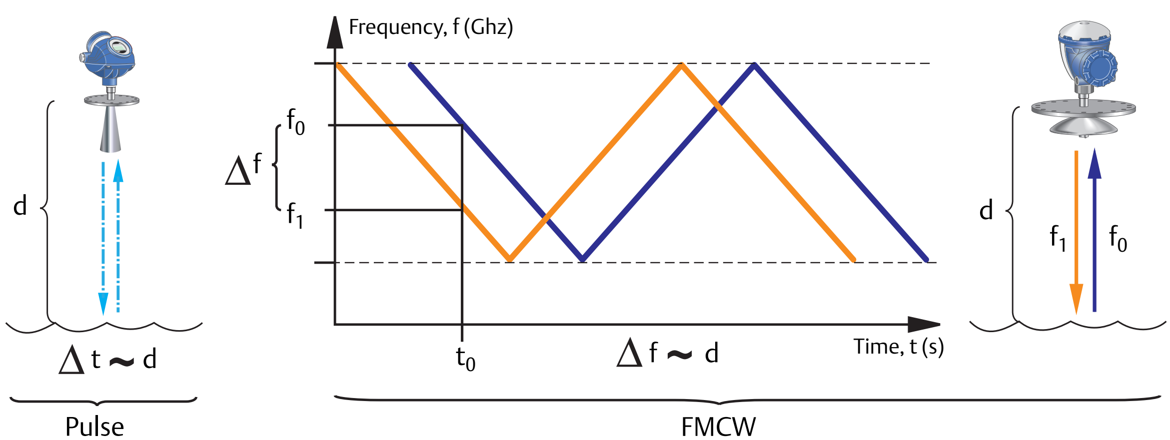
Guided Wave Radar (GWR)

GWR is based on microwave technology. The device guides low energy microwave pulses down a probe, which is submerged into the process media. When the microwaves are reflected from the product surface back to the transmitter, this enables the level to be measured. Because a proportion of the emitted pulse will continue down the probe, an interface can also be detected. GWR level transmitters are ideal for the challenging measurement of liquids, slurries, and solids. They are easy to install, and no compensation is necessary for changes in density, dielectric, or conductivity of the medium. Changes in pressure, temperature, and most vapor space conditions have no impact on measurement accuracy; GWR is unaffected by high turbulence or vibrations and build-up has practically no effect, meaning that there is no need for recalibration. Radar devices also do not have any moving parts so maintenance need is very low.

Non-Contacting Radar (NCR)

NCR level gauges also provide continuous level measurements, but without making contact with the liquid being measured. Pulse radar or Frequency Modulated Continuous Wave (FMCW) techniques are used to perform the measurement.

Figure 8. Pulse and FMCW Techniques Used in Non-Contact Radars



With pulse radar, microwaves are emitted towards the process media and reflected to the sensor, with the level being directly proportional to the time taken between transmission and reception of the microwave signal. With FMCW, the radar transmits a continuous signal sweep with a constantly changing frequency.

The frequency of the reflected signal is compared with the frequency of the signal transmitted at that moment. The difference between these frequencies is proportional to the distance from the radar to the surface, thus the level is measured. The advantages of this technology are that it provides highly accurate and reliable level measurement for liquids or solids, including those with wide temperature and pressure requirements; it is unaffected by process conditions such as density, viscosity, and conductivity, and little affected by coating and vapors. It is easy to install and commission; it can be isolated from the process by PTFE barriers or valves; and it handles a variety of tank geometries. Finally, because there is no contact with the medium and the radar has no moving parts, NCR hardly requires any maintenance at all.

Proof-testing and diagnostics

The latest solutions offer various advantages over older, mechanical technologies, especially through their diagnostics capabilities and their ability to perform partial proof-tests remotely.

The diagnostics capabilities of vibrating fork switches enable operators to monitor the health of a device and be sure it will perform correctly in the event of an overfill. Some manufacturers also provide remote diagnostics capability, whereby data is continuously transmitted to the control room, therefore eliminating the need to perform routine manual checks. The latest generation forks go even further, with ability to detect emerging conditions such as corrosion or build-up before reliability is affected, thus allowing preventative maintenance to be scheduled around planned downtime. Vibrating fork switch technology also enables a proof-test to be performed in process without the need to alter the liquid level or remove the device from the vessel. Latest generation devices have a fully-integrated remote partial proof-testing capability which can be performed from the control room with no additional point-to-point wiring, saving time and testing costs. Process availability, efficiency and worker safety are increased since devices will not require a comprehensive proof-test for several years.

The on-board diagnostics of NCR level transmitters support preventative maintenance, and provide actionable information, streamlining the troubleshooting process. The diagnostic capabilities of these devices provide operators with early alerts in case of antenna build-up, weak power supply or abnormal surface conditions. Also, a local memory enables full insight into measurements, alerts, and echo profiles from the previous seven days. The ability of these transmitters to perform proof-testing and site acceptance tests remotely saves time, increases worker efficiency and reduces the reliance on highly experienced staff.

GWR transmitters feature diagnostic functionality which enables the condition of the probe to be checked while remaining in service. This provides information that supports a preventative maintenance program, therefore reducing safety risks. These devices also provide an automated high-level alarm testing function that does not require the device to be removed from the tank, or the level in the tank to be manually raised, therefore increasing the safety of both plant and workers. Verification reflector functionality is designed for applications requiring periodic transmitter integrity tests to ensure that the device is functioning correctly. In addition to meeting the recommendations of API 2350, it reduces the risk of accidental spills, and the high-level alarm testing process can be completed more quickly. It also tests the loop from the device to the DCS as well as the device itself. Compared with traditional diagnostics, which only monitor the transmitter electronics, the verification reflector can also be used to diagnose problems with the upper parts of the probe inside the tank, such as product build-up, corrosion monitoring and other process-related conditions.

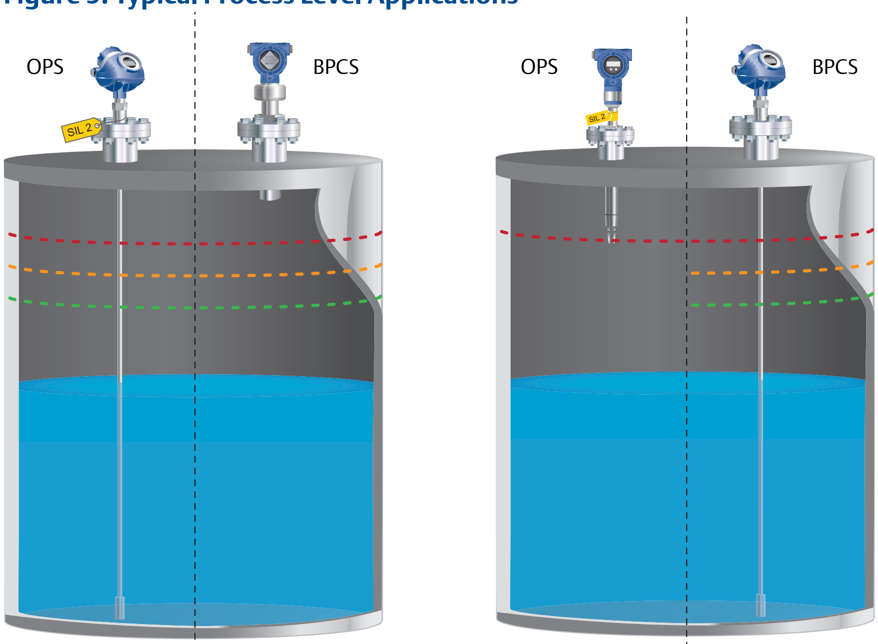
Typical applications

There are three general application types in the process and bulk liquid storage industries where overfill prevention measures are employed. These are process vessels and storage tanks within process applications, and storage tanks deployed within the bulk liquid handling industry. Each of these applications presents different challenges, and therefore the most appropriate overfill protection technology differs in each case.

Process vessels

Process vessel is a general term used to describe vessels, tanks or container applications in which a specific industrial process, or part of an overall process, takes place. This includes the preparation, blending, separation, distillation, reaction, cooling and purification of liquids.

Figure 9. Typical Process Level Applications



For this type of application, the choice of technology to use as part of the AOPS depends on several factors, including the shape, size and design of the process vessel. For example, on cone shaped tanks, level sensors are top-mounted which creates several options, including GWR level transmitters, NCR level transmitters and vibrating fork switches. Many vessels have restrictions including agitators, heat exchangers and other internal structures that require the use of a separate chamber to perform the level measurement. For these applications GWR level transmitters are recommended. Should a side-mounted solution be required or preferred, vibrating fork switches provide the ideal solution.

Within distillation columns, involving high temperatures where vapors rise through the column, different components will condense at different temperatures and accumulate for withdrawal. Here chambers are required, and GWR level transmitters are commonly used for the AOPS.

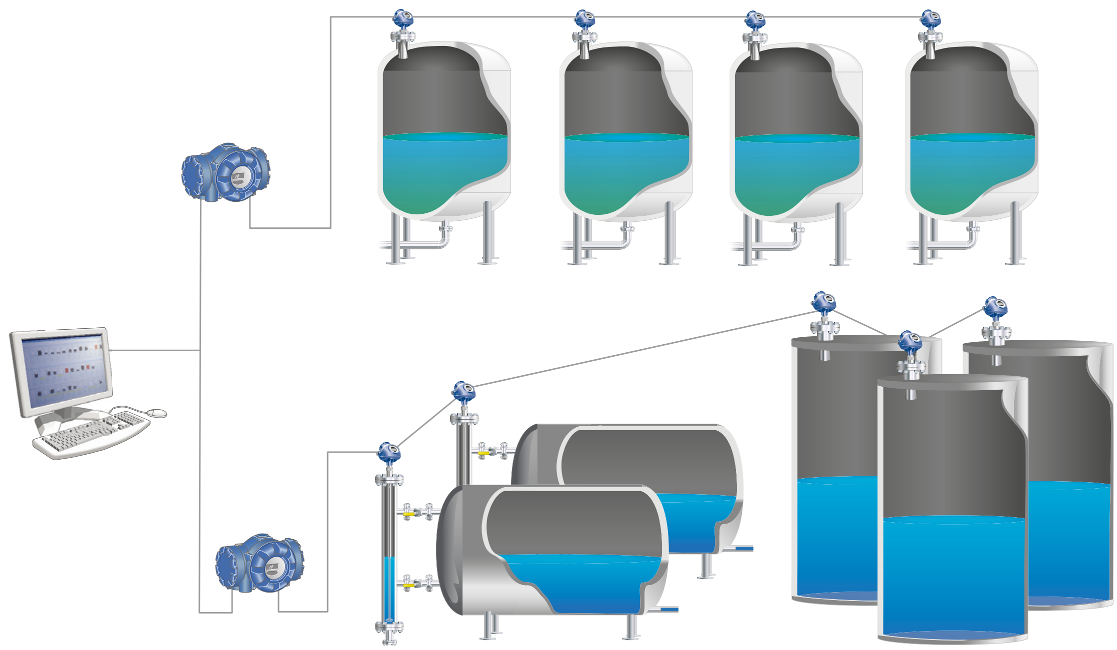
Blending tanks have agitators, which places restrictions on sensors that protrude into the tank. Using a top-mounted NCR is usually a good solution for an AOPS sensor. Sloshing, rapid level changes, vortices, and foaming are common in this application, making it important to select a modern and highly capable radar device.

In boiler drum applications, SIL3 GWR level transmitters are required for AOPS, usually with triple redundancy. GWR has an advantage over other measurement techniques in boiler drums because it is not affected by changes in process conditions.

Tank monitoring system

Tank monitoring system applications include those consisting of multiple small or medium-sized vessels or a smaller tank farm, typically 5-20 tanks, requiring an automated system to provide level monitoring, but not necessarily control. These systems ease the workload by removing manual measurements, and increase personnel safety by reducing the need to climb tanks. Tank monitoring would typically involve gross volume calculations, but not fiscal measurements.

Figure 10. Typical Tank Monitoring System Layout



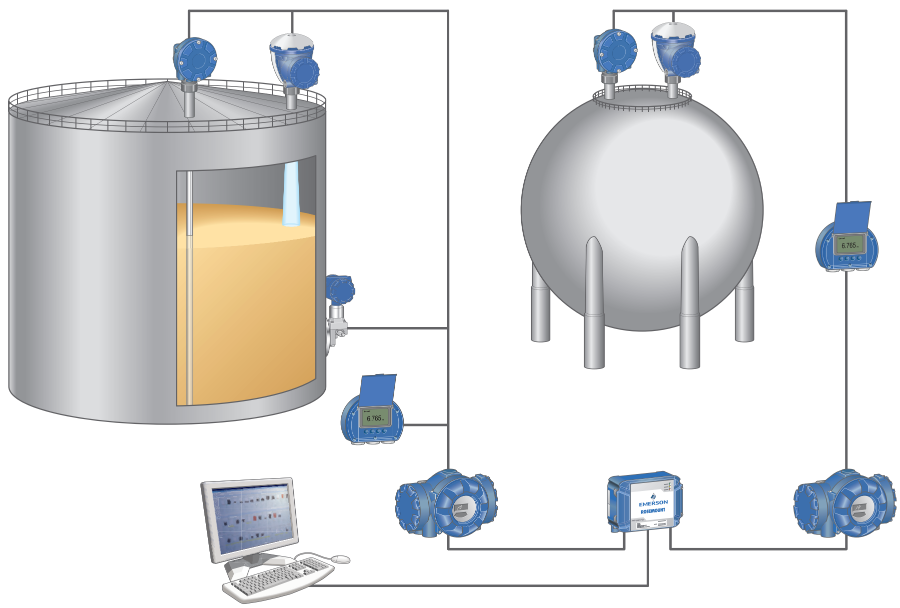
Traditional monitoring methods have involved mechanical equipment as well as manual measuring and recording techniques. Because mechanical devices have moving parts that are prone to failure, this creates excessive maintenance. Manual measurements create the possibility of human error and place workers at greater risk of an accident. End users are therefore looking for automated solutions, which is in line with overfill prevention requirements.

For these type of applications, the recommendations for overfill sensors are similar to those provided earlier for single vessel applications. Correct sensor choice would therefore be determined by the tank type, the available tank openings, and the liquids stored in the series of vessels or tanks.

Bulk liquid storage

In bulk liquid storage applications, an Automatic Tank Gauging system (ATG) is typically used as the BPCS, to measure level and calculate inventory.

Figure 11. Automatic Tank Gauging System Used for Inventory Control and Custody Transfer

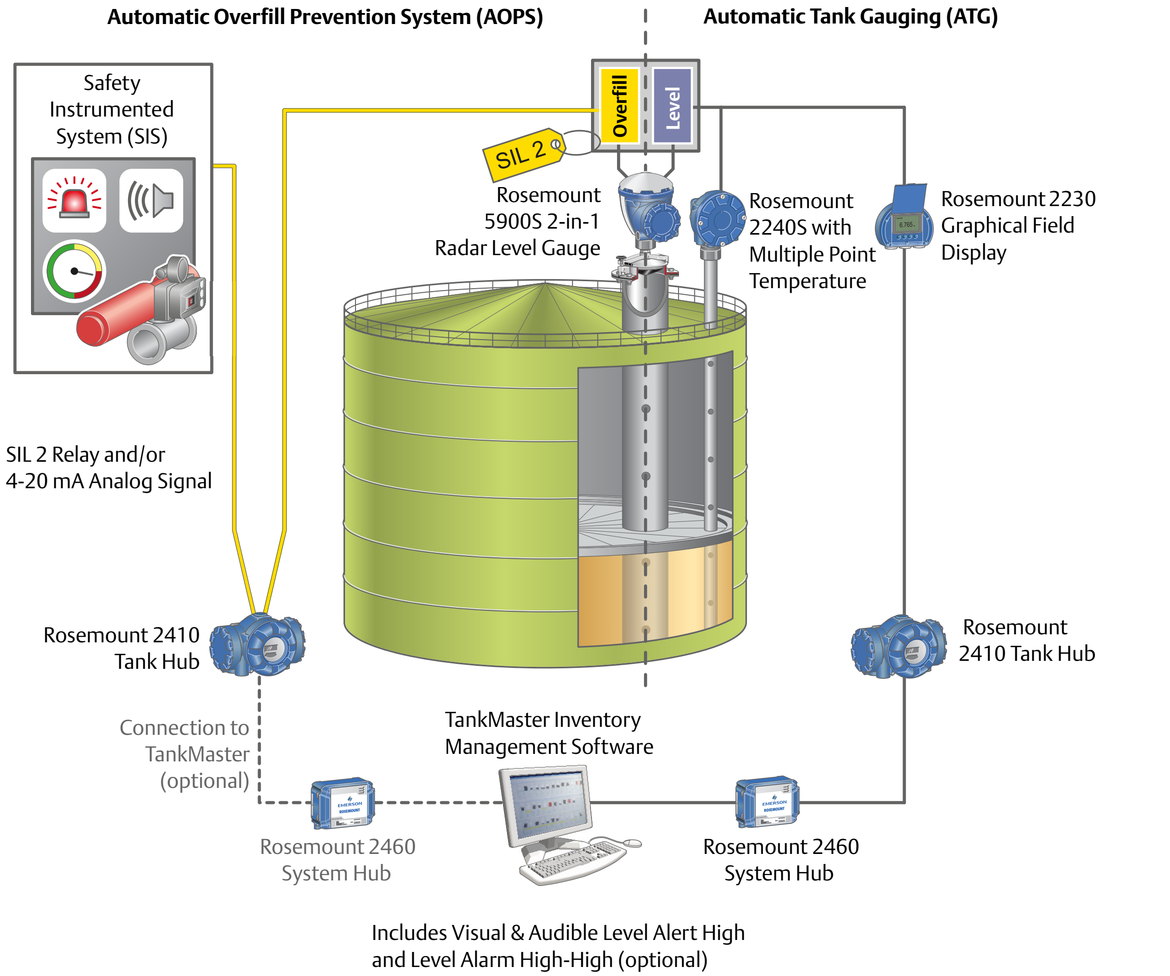


These systems deploy radar technology offering exceptional levels of accuracy, which is required due to the very large storage tanks and value of liquid being measured. A small inaccuracy of the level can equate to thousands of gallons of volume uncertainty. The AOPS for bulk liquid storage tanks typically consists of a NCR level gauge, a logic solver and an actuator. Alternatives to NCR would be to use a vibrating fork switch or a GWR level transmitter.

Many bulk storage tanks have floating roofs, which place special demands on the level measurement and overfill prevention solution. Best practice is to measure through a still-pipe which requires high precision NCR to do it accurately. If the tanks do not have a still-pipe, an option is to “shoot the roof”, which entails putting a reflective metal target on top of the roof to capture the radar beam.

2-in-1 radar level gauges can be used simultaneously for ATG and OPS. This type of gauge consists of two separate and independent electrical units and a common antenna. When connected with the cables separated in different cable trays, a single gauge can be used for both level measurement and separate OPS purposes, in compliance with both IEC 61511 and API 2350. The use of this technology is based on the foundation that the antenna has a very low failure rate in comparison with the electronics. The most obvious benefit of using 2-in-1 technology is that it requires only a single tank opening. This solution allows for cost-efficient safety upgrades of existing tanks by replacing a single ATG or AOPS sensor with two continuous level measurements, with little or no tank modifications required.

Figure 12. 2-in-1 Radar Level Gauge Installed on a Floating Roof Tank Used for Both BPCS and AOPS



A deviation alarm between the OPS and ATG level sensor can be used to verify the integrity of both systems. A single continuous level sensor can be used for multiple alarms and alerts such as high-high, high, low, and low-low. It is not unusual that a single continuous level sensor replaces four separate point-level sensors. Continuous level measurement allows for adjustment of alarms and alerts. In practice, identical level sensors are often used for both OPS and ATG. This approach is usually selected because the OPS level sensor can act as back-up in case the ATG fails and thereby minimizes downtime. It also reduces the need for device-specific configuration tools and education, and inventory of spare parts is minimized.

Conclusion

As overfills in the process and bulk liquid storage industries can involve hazardous, flammable or explosive materials, any such incident can have catastrophic and costly consequences. Effective overfill prevention systems, which reduce risk and comply with the relevant standards, are therefore vital. There is no "one size fits all" technology for these systems, as each application has its own challenges. However, older mechanical technologies are gradually being replaced as more operators realize the significant benefits that more modern technologies can offer, such as high reliability, low maintenance requirements, continuous monitoring, remote proof-testing capability and powerful built-in diagnostics.

For more information, see Emerson.com/OverfillPrevention.

To discuss overfill prevention solutions with an Emerson Expert, go here, Emr.sn/yC8P.

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