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Design Options for Overfill Prevention for Aboveground Storage Tanks

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Abstract

Overfilling of a tank is an important safety hazard. It may result in loss of tank fluid and potentially severe consequences if the fluid is flammable or environmentally sensitive. Additionally, it is necessary to preserve the mechanical integrity of a tank. This article describes different design configurations where overfilling is a possibility.

1. Introduction

Overfill is a major reason for industrial accidents. Since the Buncefield fire and explosion at the Buncefield UK oil storage facility on 11 December 2005, many organizations have updated or produced new standards based on information from the incident. In addition to overflow of hazardous fluids, overfill may encompass fluids that are safe to discharge to the atmospheric drains. A risk assessment is one of the important elements in an overfill management system. One goal of the risk assessment is to develop the tank control configuration. There are many ways that a tank may be configured and this paper presents an overview of possible configurations.

The configurations discussed in this paper are as follows:

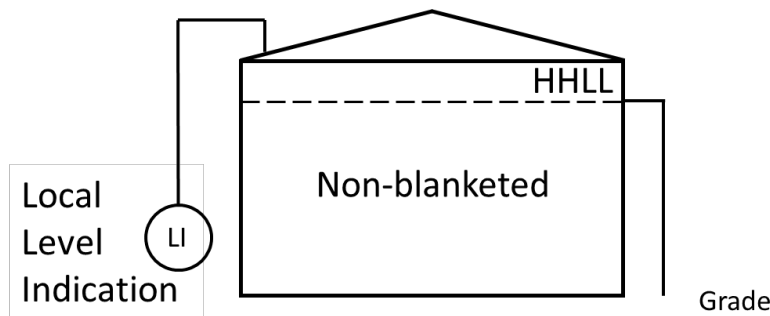
1. Fluids Safe to Release to Atmosphere
 - 1.A. Non-blanketed
 - 1.B. Blanketed or non-blanketed (3 options)
2. Fluids Not Safe to Release to Atmosphere
 - 2.A. Categories per API-2350
 - 2.B. Other alternative categories

2. Overfill Protection for Fluids Safe for Atmospheric Release

Overfill is typically mitigated by an overfill line or instrumentation, depending on the nature of fluid. Following is guidance on overfill lines. Types A, B, C, D are used for discussion purposes only, and have no code/regulation association. It is presumed that all designs discussed have appropriate and redundant (if needed) level transmitters and alarms installed and that periodic tank gaging, inspection and monitoring procedures are in place.

2.1 Type A: Tanks without Inert Gas Blanket

The first, and the simplest, option is that of providing a discharge line that is adequately sized for the incoming fluid flow rate and located at an elevation commensurate with the maximum allowable capacity of the tank. The outlet of this drain pipe should be directed to a sump to prevent the discharging fluid from splashing on the ground and exposure to the personnel in the vicinity. The tank content for such simple overfill protection must be safe for direct environmental discharge and have no exposure concerns to humans or animals. In these tanks, there is no requirement for the tank contents to be protected from long term air or oxygen contact; therefore, such tanks do not require any blanketing by inert gas. Since there is no requirement to maintain a pressure inside tank, the overflow line does not need a seal leg. No instrumentation in addition to those already mentioned above is required. See Figure 1.



Type A Overfill Protection Option

Figure 1

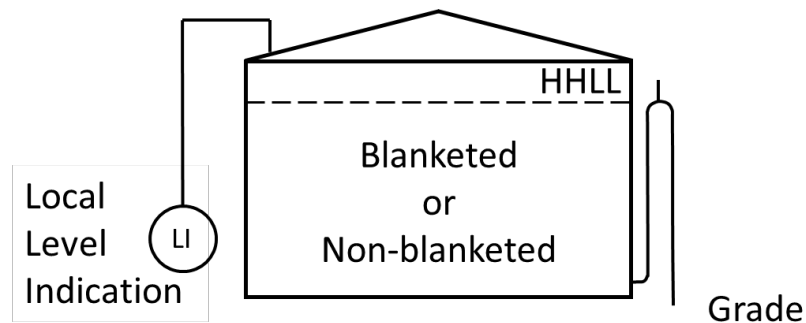
2.2 Type B: Tanks Blanketed with Inert Gas – Inverted U-Loop

The second type of overfill protection is for fluids that require blanketing with inert gas such as nitrogen because the tank fluid is sensitive to or reactive to oxygen or air. The liquid itself may

degrade in quality with prolonged contact with air. Replacing air/oxygen with an inert gas mitigates such a possibility. The tank is operated under a pressure of blanket inert gas higher than atmospheric pressure to ensure that the inert blanket is maintained inside the tank. The pressure-vacuum breathers and emergency vents are still installed on the tank as the last line of defense.

Unlike the Type A design, the overfill line from a blanketed tank cannot be open directly to atmosphere because the blanket gas would be continually escaping to the atmosphere through it. The tank must be kept sealed by a liquid seal leg. A liquid seal can be maintained by two methods.

In one, an inverted seal, the discharge line is connected near the bottom side of the tank at or below the low-low liquid level, and forms an inverted U. The top of inverted U is at an elevation that corresponds to the maximum allowable liquid level in the tank. A siphon break is provided at the top of the seal to avoid siphoning the whole tank content to the drain. In this design, the seal is inherently maintained by a liquid level in the tank, and therefore, no instrumentation is required to monitor and maintain the seal. Only if the tank is essentially empty, is there a chance for the blanket gas to blow-by to the atmosphere protected by lower explosive limit (LEL). The location and elevation of the final discharge point of the siphon break must still meet the 'discharge at a safe location' requirements. See Figure 2.

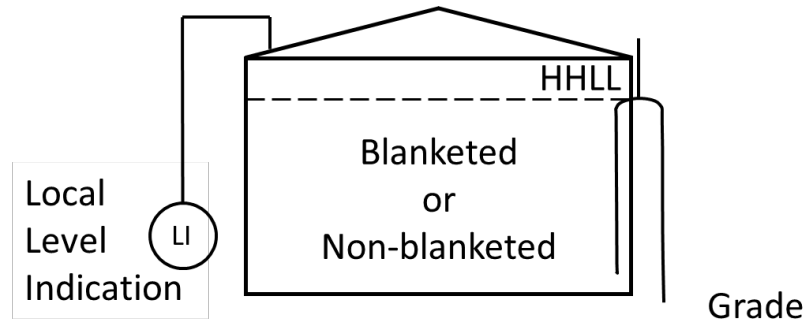


Type B Overfill Protection Option

Figure 2

2.3 Type C: Tanks Blanketed with Inert Gas: Inverted Loop inside Tank

In a slight variation of Type B design, where overflow line cannot be directly released to atmosphere, part of the discharge pipe may be located physically inside the tank, i.e. extending from near the bottom of the tank, and exiting at the side of the tank, with the pipe ultimately draining to a safe disposal location. Here too a siphon break should be provided at the top of the inverted U, and located outside of the tank. See Figure 3.



Type C Overfill Protection Option

Figure 3

Tanks that may have a slight layer of lighter material on the top but not blanketed may also use this inverted U-pipe design, to prevent the material from reaching the drain, since the discharge is from the bottom water layer. The material layer will continue to accumulate in the tank and would have to be vacuumed out periodically and disposed of safely. In this design, appropriate consideration must be applied to ensure that the liquid level inside the tank does not exceed the elevation for critical overfill height. If the tank is essentially empty, is there a chance for the blanket gas to blow-by to the atmosphere protected by lower explosive limit (LEL). Therefore, the location and elevation of the final discharge point and the siphon break must still meet the ‘discharge at a safe location’ requirements.

While calculating the height of the inverted U-loop, it is important to take into account the tank operating pressure because the height of the liquid in the discharge leg will be higher than the liquid level inside the tank by the height of the hydrostatic head. Similarly, appropriate consideration must be taken into account while determining the height of the inverted U loop, in cases where immiscible liquid of different densities exist inside the tank. The liquid in the loop would be the liquid in the bottom layer and, therefore, of higher density than the liquid in the top layer inside the tank. From hydrostatic considerations, the liquid level inside the tank could be different from the height of the inverted U loop at the start/stop of the overflow discharge from the tank.

Note: The hydrostatic equation useful in determining the heights of liquids of two different densities at the same applied pressure is:

$$H_2 = \rho_2/\rho_1 * H_1$$

Where:

H_1 = Height of a column of liquid, 1 m (ft)

H_2 = Height of a column of liquid, 2 m (ft)

ρ_1 = density of liquid, 1 kg/m³ (lb/ft³)

ρ_2 = density of liquid, 2 kg/m³ (lb/ft³)

$H_T = H_1 + H_2$

2.4 Type D: Tanks Blanketed with Inert Gas – Liquid Seal Leg

In this design, the take-off point for the overflow drain is at the location of the maximum allowable fill level for the tank. A liquid seal leg is placed at the end of the discharge line located at or below grade. This type of overflow line is suitable for the case where it is acceptable to dispose of the top layer-the lighter fluid- to drain. The liquid in the bottom layer would then be periodically vacuumed-out for waste processing.

A level gage is installed at the leg to visibly monitor the presence of liquid seal and a low-level alarm is also provided to alert the operator in case of loss of liquid seal. The seal leg is designed to match the tank blanket design pressure. The disposal location is carefully selected in the event that the liquid seal is lost and personnel exposure may happen because of nitrogen blowing through the seal leg. As mentioned above, additional instrumentation is required in this overflow protection design.

Again, if phase separation or stratification were to occur in the tank because of immiscible liquids, appropriate consideration must be made to account for the different densities of the liquids while determining the liquid seal height, because the exiting liquid will be the one at the top layer and, therefore, would be the fluid that would create the liquid seal. See Figure 4. Note: The height of the liquid seal can be determined by the hydrostatic head formula:

In metric units:

$$H = P / \rho * g$$

Where:

H = Height of a liquid seal (m)

ρ = density of liquid (kg/m³)

P = Tank design pressure (kPa)

g = acceleration due to gravity (9.81 m/s²)

In US Customary units

$$H = 1728 * P / \rho$$

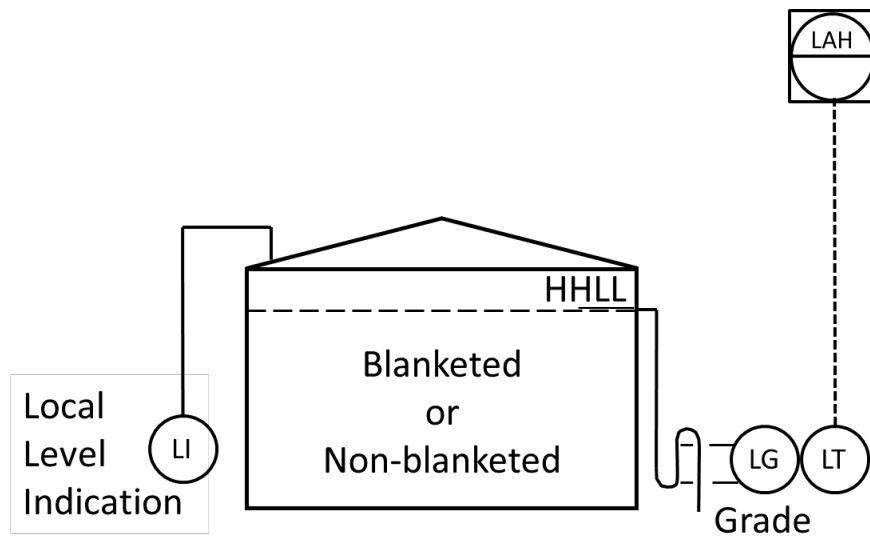
Where:

H = Height of a liquid seal (in)

ρ = density of liquid (lb/ft³)

P = Tank design pressure (psig)

It should be noted that the seal is still effective even when the liquid level in the seal leg is at least at $[\frac{1}{2} \times H]$ or higher. This is so because even with half the liquid seal leg, the liquid leg can be pushed to a height H before gas blow-by can happen.



Type D Overfill Protection Option

Figure 4

3. Overfill Protection for Fluids not Safe for Atmospheric Release

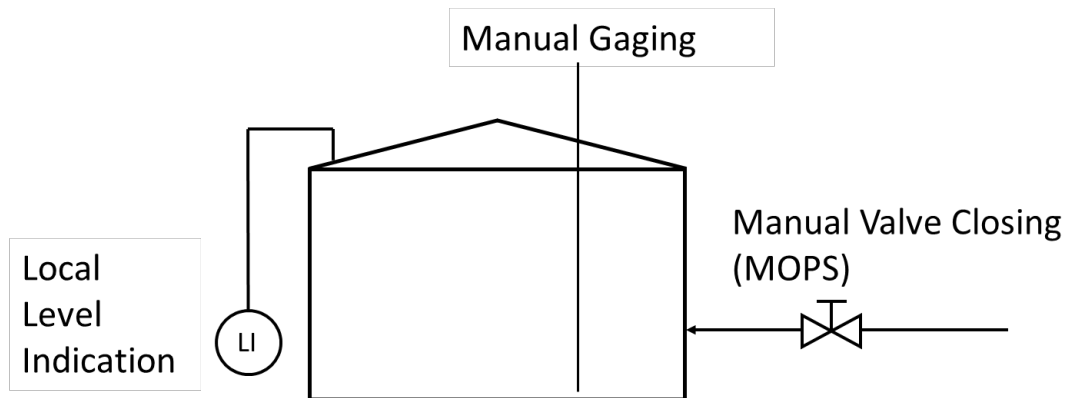
In case of hazardous, toxic, or flammable liquid, it is not acceptable to discharge the fluid to the atmosphere for reasons of fire, danger to personnel safety and health or its environmental impact. Such tanks, therefore, do not have any overfill lines as depicted in the previous sections. Tanks containing Class I (flammable) or Class II (combustible) organic fluids fall into this category. These tanks are generally characterized by the presence of inert gas blanketing.

Broadly speaking these tanks can be divided into two types – those that are covered under API 2350, and those that are outside of it. A brief description follows.

According to API 2350, tanks are classified into three main categories based on the features for overfill prevention.

3.1 Category 1 Systems

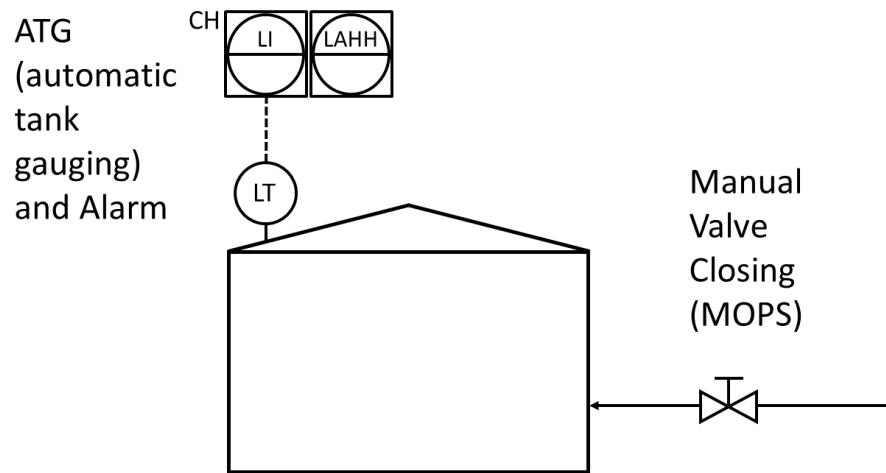
These preventive systems are characterized by manual operation for tank gaging and stopping/diversion of filling operation. Level instrumentation, if any, is local and no data is transmitted to the control room. On-site personnel surveillance is required throughout the filling operation. See Figure 5.



API Category 1 System
Figure 5

3.2 Category 2 Systems

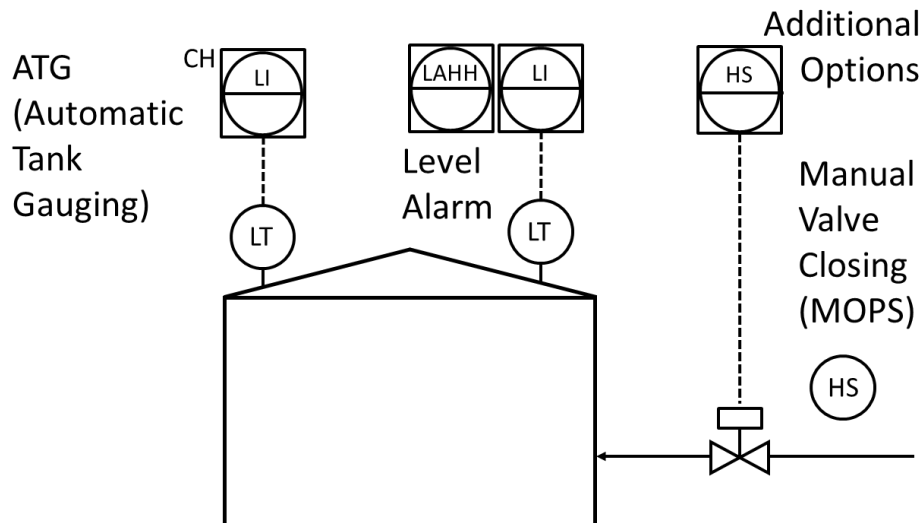
At this level of overfill prevention, automatic and continuous tank level information (also known as ATG – automatic tank gaging) is transmitted to the control room. The level sensor is also used to generate a high-high level alarm. Transmission of alarm data to the control room i.e. remote sensing is the main difference between Category 1 and Category 2 Systems. However, the termination/diversion of filling operation can still be accomplished through manual intervention. See Figure 6.



API Category 2 System
Figure 6

3.3 Category 3 Systems

A Category 3 overfill prevention system differs from Category 2 System in that it uses one independent sensor for automatic continuous tank gaging (ATG). It uses a separate level sensor for high-high liquid level detection for Overfill Protection System (OPS) alarm. The level sensor for alarm activation can be a point level device or a continuous level device. The termination/diversion of filling operation upon alarm is but can be local or through remote hand switch electrical, pneumatic or other operator on the valve. See Figure 7.

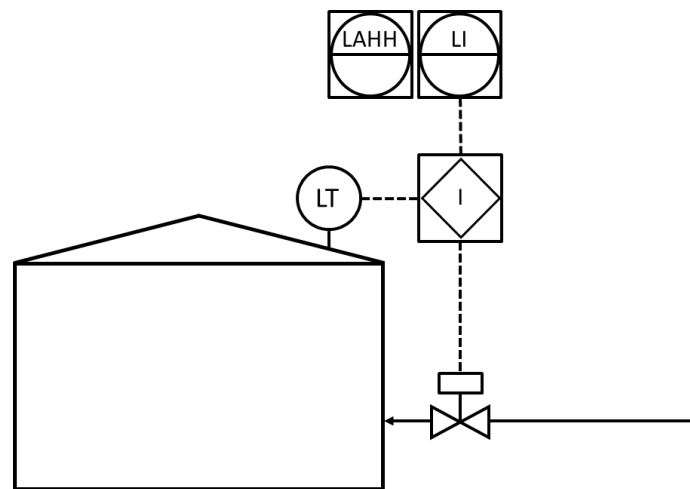


API Category 3 System
Figure 7

3.4 Automated Overfill Prevention Systems (AOPS)

The defining characteristic of an AOPS is that the termination of filling operation is automatic and activated by an independent high level signal. The AOPS is in addition to both the ATG and the independent OPS alarm. Tanks in fully automated operation in unattended facilities are usually equipped with AOPS. Codes [1], [4], [5], [17] recommend an AOPS for tanks with flammables and complex operations. The essential elements of AOPS are shown in Figure 8.

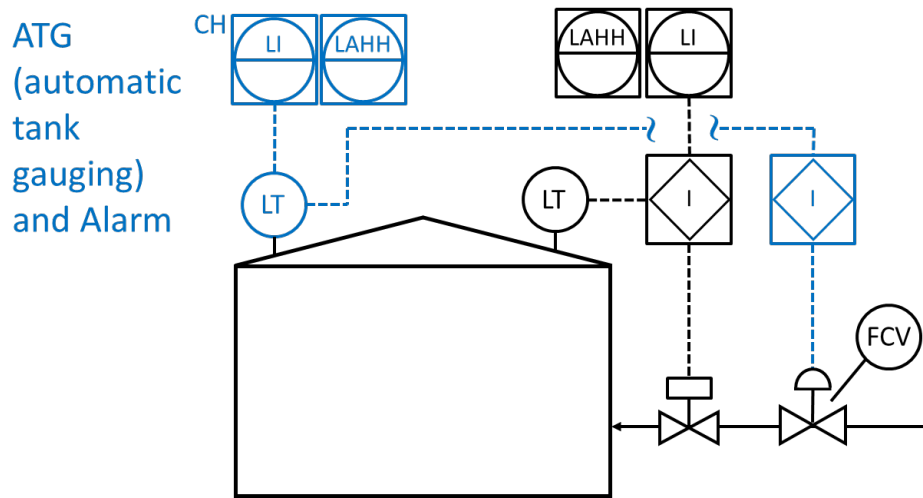
The termination of the filling operation can be achieved by automatic closure of the receipt valve. This is shown in Figure 8. Alternatively, the automatic tripping of the feed pump, or closure of the process valve, or both can be also be accomplished, however, a valve independent of the process control system is preferred. Risk analysis is performed to determine the safety integrity level (SIL) required to ensure that the tank is adequately protected against the severity consequence of overfilling. Generally a SIL of 1 or 2 is required. With the safety interlock and SIL rating, the automated valve closure instrumentation is located in the SIS. Additional redundancy (Independent Protection Layers) may be provided to increase the SIL protection level.



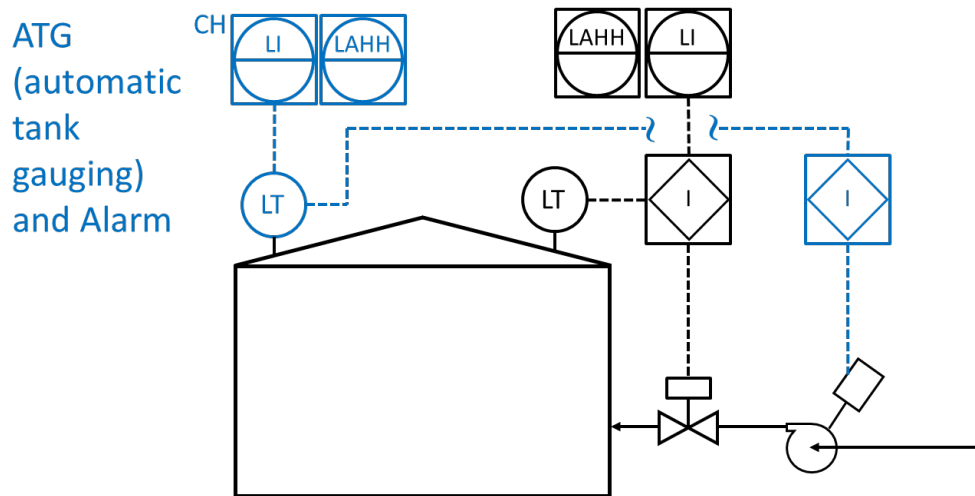
API Automatic Overfill Protection System (AOPS)

Figure 8

In practice, the automatic termination of filling operation feature can be incorporated in any of the other three categories but typically it is used with Category 2 or Category 3 System. See Figures 9 and 10 as examples of added to API Category 2 System. Also, note that although either a high-high level switch or a continuous level transmitter can be used, the latter is preferred because it is easier to detect an error or malfunction in the instrument [5],[10].



API Automatic Overfill Protection System (AOPS) Added to Category 2
Figure 9

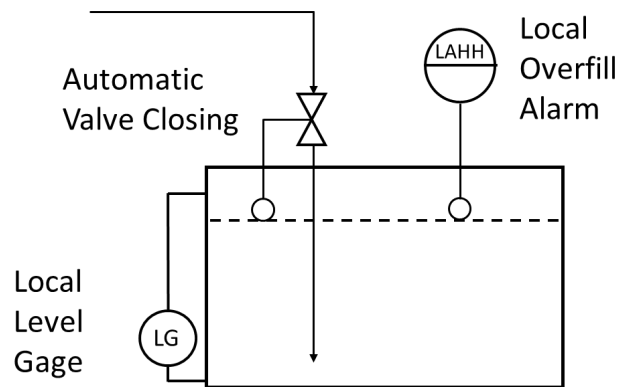


API Automatic Overfill Protection System (AOPS) Added to Category 2
Figure 10

3.5 Shop Fabricated Tanks

Shop fabricated tanks fall outside of scope of API-2350 and are covered under PEI Recommended Practices 600 for overfill protection. Such tanks are used in storage and supply of liquid petroleum products and alternative fuels such as motor fuels dispensing, emergency

generator systems, residential and commercial heating oil supply systems and used oil storage and supply. Overfill prevention in these tanks are typically mechanical or electrical flow shut-off devices. Such devices are typically installed as a component of the fill connection such as a mechanical float, or an electrical switch to stop the inflow of the liquid. Electric switches can also be used to cut-off power to the pump. An additional feature of the overfill prevention is the presence of an overfill alarm. See Figure 11.



PEI-600 Tanks

Figure 11

4. References

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Further Reading and References

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- [23] AS-1940; *Storage and Handling of Flammable and Combustible Liquids*, Australian Standard, 2004
- [24] Myers, P.E., *Consider Robust Tank Overfill Prevention and Independent Alarm and Gauging Systems*, February 2014, pp 71-74, Hydrocarbon Processing.

5. Appendices

Appendix 1

Additional Considerations

The configurations discussed in this paper are a starting point for the design of an overfill protection system for an atmospheric tank. There are other considerations, some noted below, that are not discussed in this paper. They are, however, extensively covered in the open literature.

- Risk Analysis and establishment of safety integrity levels (SIL)
- Sensors and Controllers: One important subject is the use of switches. Several codes [5], [1] do not recommend switches but instead recommend sensors with capabilities such as continuous sensing, on-line diagnostics, fully testable without requiring entry into the tank and without raising tank levels, and SIS certified.
- Valve characteristics, including type of valves, fire-safe valves, type of operators, location of initiation on and fail-safe position
- Testing of sensors, logic solver and final elements and testing intervals/frequency.
- Response times
- Fire protection

Appendix 2

Comparisons of Level Definitions between Various Codes

Although most level definitions are consistent with API-2350-2012, 4th Edition (2012), there are differences between other standards and earlier versions of API-2350. Please refer to the standards for guidance on levels and actions initiated.

Action for each Level (Note 1)	Definitions of Levels or Tank Capacity			
	API-2350-2012(4 th Edition) [1]	Energy Institute [4] & PSLG [8]	PEI-600 [10]	API-2350 (3 rd Edition)
Tank overflow and damage (Note 2)	Critical High (CH)	Maximum Capacity (overflow level)	Overfill Level (maximum design capacity)	Overfill Level (design capacity)
Alarm to initiate AOPS stoppage (Note 3)	High-High level (HH for AOPS)	Not specified	Not specified	Not specified
Alarm to initiate manual stoppage (Note 3)	High-High level (HH for OPS)	Tank Rated Capacity (HH)	Shutoff Level	Safe-fill Height (tank rated capacity)
Alarm that routine working level has been exceeded	Not specified	High level (H)	Alarm level (H)	High level (H)
Operational procedures	Maximum Working (MR)	Normal Capacity (normal fill level)	Maximum Operating Level	Normal Fill Level (normal capacity)
Alarm for minimum level	Minimum Working (low level)	Not specified	Not specified	Not specified

Note 1 – Refer to codes for recommended and optional levels, response times, actions and alarms. The level may differ between fixed roof, internal floating roof or external floating roof.

Note 2 – Depending on the code, an alarm or notification may be recommended at CIH

-- API-2350 says should have notification- pages 12 and 27

-- BSLG [8] and EI [4] says no alarm, only action

-- PEI [10] implies alarm – page 4 and definition page 26

Note 3 – If an AOPS is used, which is additional and independent of the OPS and ATG, then the HH level for AOPS will be higher than the HH for the OPS.

Appendix 3

Pressure Relief Protection Used as Overfill Protection

Pressure relief devices should not be used for overfill protection for the following reasons. Even though API-650 12th Edition 2013 suggests that a liquid relief valve may be used, API-650 and the other codes referenced specify overfill protection using the options in this paper.

- **Tank Design Pressure**

The tank may not be designed for the pressure that occurs when the liquid level is at the relief valve height. The mechanical integrity of the tank could thus be comprised.

- **Relief through pressure-vacuum breather vent or fire relief vent**

Weight loaded vapor breather and fire vents are not designed to relieve liquids. They may not open at the set pressure, may require high overpressure to be fully open and may not have the capacity to allow the full flow of incoming liquid. Additionally, the backpressure may affect the pressure at which the valve will open.

- **Relief through pilot operated liquid relief valves**

Pilot operated breather relief valves are available for liquid relief. For one vendor the minimum set pressure is 0.07 barg (1 psig, 28" WC) which would require a high tank design pressure resulting in a more expensive tank. Some codes (e.g. Australian) may not allow pilot operated valves in liquid service for tanks.

- **Relief through frangible roof**

Frangible roof tank with a weak seam would lift as the liquid level rises in the tank beyond the seam such that the hydrostatic pressure exceeds the seam design pressure. API-650 12th Edition 2013, paragraph 5.10.2.6 states that "frangible roofs are not intended to provide emergency venting for ...overfill." However, the roof may not open at the design point. More importantly, case histories demonstrate that cases exist where the roof has lifted and landed by the side of the tank. When an overfill situation occurs, the liquid would overflow to grade uncontrollably, creating a hazard if the liquid is flammable. Refer to reference [3] for more information on frangible roofs.

Appendix 4 -Buncefield Fire and Explosion – December 11, 2005

Early on Sunday morning of December 11, 2005, Tank 912 at the Buncefield oil storage facility was being filled from a pipeline. The tank was equipped with an automatic level gauge and transmitter / controller which displayed the level and initiated three levels of alarms in the control room (user-high; high-level; high-high-level). The tank was also fitted with a high-level switch (set above the gauge high-high-level), which was independent of the level gauge. The switch was intended to alarm and close the valve on the tank feed line from the pipeline.

The level gauge was stuck, as it had intermittently on previous occasions. The high-level switch was not operating since the lever used for testing the system was positioned in a mode that disabled the switch. The emergency shutdown button to close the feed valves had never been wired so it was not activated. Gasoline (“petrol”) filled the tank and overflowed the top. Subsequently, the bund retaining wall surrounding the tank failed at the joints. The tertiary drainage system was overwhelmed with hydrocarbon and fire water. Over 66,000 gallons (250,000 liters) of gasoline overflowed the tank and retaining walls, producing a vapor cloud, which ignited and exploded. The resulting fire burned for five days, destroying 20 fuel tanks and adjacent buildings and producing widespread environmental damage. Although there were no fatalities, about 40 people were injured and approximately 2,000 people were evacuated. Five companies were convicted of charges relating to the incident, including the facility operators, the pipeline company, and two vendors of the instrumentation.

The conclusion outlined in the COMAH Report, 2011 [20] was: “In the Buncefield incident, the story of the sticking gauges and the inoperable high-level switch tells us about the immediate (technical) causes of the incident. However, the underlying managerial failures by others were equally important and have wider implications across all major hazard industries. These managerial failures encompass the cause of an incident and the mitigation processes.”



Courtesy of Royal Chiltern Air Support Unit, from <http://www.buncefieldinvestigation.gov.uk/images/index.htm>



Day 1 of the fire. Courtesy of HSE, *The Buncefield Investigation Progress Report 1*

Appendix 5**API 2350 Tank Levels of Concern and Corresponding Instrumentation**

(ATG: Automatic Tank Gage, AOPS: Automated Overfill Prevention System)

	Category 1	Category 2	Category 3	AOPS
Personnel Attendance & Monitoring	Local operation & local monitoring	Local operation. Local monitoring with sometimes redundant remote monitoring	May be unattended remote operation & monitoring. Alternative, may be local	May be unattended with remote operation & monitoring
Gauging System	manual	ATG	ATG	ATG
• HH level (High-High)	manual indication	Automatic indication with alarm (remote & local)	Automatic indication with alarm (remote & local)	Automatic indication with alarm (remote & local)
Overfill Protection Systems (OPS)	Manual	Use ATG	Independent OPS	Independent AOPS
• CH level (Critical High)	Use manual gauging	• ATG indication with alarm (remote & local) • Initiate spill management (manual)	• Independent OPS indication with alarm (remote & local) • Initiate spill management (manual)	• Independent AOPS indication with alarm (remote & local) • Initiate spill management (manual)
• AOPS level	N/A	N/A	N/A	• Independent AOPS indication & alarm (remote & local) • Automatically actuated stoppage (remote)
• HH level (High-High)	Use manual gauging	• ATG indication with alarm (remote & local) • Initiate stoppage (local manually actuated)	• Independent OPS indication with alarm (remote & local) • Initiate stoppage (remote manually actuated & local manually actuated)	N/A
• MW level (Maximum Working)	Use manual gauging	ATG indication (remote & local)	Independent OPS indication (remote & local)	Independent AOPS indication (remote & local)
• H level (High)	Not generally noted	Not generally indicated or alarmed	Not generally indicated or alarmed	Not generally indicated or alarmed

Note 1-Remote means at control center not at equipment

Note 2- Local indication, alarm and action is included in all categories

Note 3- A higher level of control may be applied to any category

Note 4- Alarms are to be both audible and visual