Overpressure and Vacuum Protection Challenges for Low Pressure and Atmospheric Storage Tanks

Low pressure and atmospheric tanks, both refrigerated and non-refrigerated, are common in the manufacture and storage of fertilizer products. These tanks have requirements for protection from overpressure and vacuum conditions. The recognized industry standard for determining the overpressure and vacuum protection requirements for tanks is API-2000. While this standard is useful it should be applied with caution. This paper presents some of the unique challenges associated with overpressure and vacuum protection of low pressure and atmospheric storage tanks. Proposed guidelines specific to ammonia and aqua ammonia are proposed and examples are presented where relieving scenarios have been missed resulting in tank failures.

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Introduction

When considering overpressure and vacuum protection for low pressure and atmospheric tanks found in fertilizer manufacturing and storage facilities, the available industry standards must be cautiously applied. Nothing replaces good engineering judgment.

Background

Storage tanks, regardless of the code or standard to which they are constructed, have requirements to be protected against overpressure and vacuum.

In general, there are two considerations for overpressure — the normal venting, referred to as out-breathing (note: this does not necessarily mean venting to atmosphere) — and emergency venting. Minimum normal venting is specified as the combination of the liquid-transfer effects, such as liquid in-load, and thermal effects. It is, however, up to the end-user to determine if the minimum is acceptable. All venting requirements above this minimum are considered emergency venting to prevent overpressure.

Similar to overpressure, there are two general considerations for vacuum — the normal venting, referred to as in-breathing — and emergency venting.
venting. The minimum in-breathing is specified as the combination of liquid-transfer effects (liquid out-load) and the thermal effects. Emergency venting are all the scenarios over and above the normal in-breathing, which must be managed to prevent damage from vacuum.

The recognized and generally accepted good engineering practice (RAGAGEP) for normal and emergency venting of low pressure storage tank is API 2000\(^1\) (and its equivalent ISO 28300). The RAGAGEP for pressure relieving systems is API 521\(^2\) (and its equivalent ISO 23251).

**Tank Design and Construction Codes – Emergency Venting**

**API 620 – Large Welded Low Pressure Storage Tanks**

For tanks constructed to API 620\(^3\), such as atmospheric refrigerated ammonia storage tanks, the emergency vent must be sized for largest single contingency, or any reasonable combination of contingencies. Frangible seams (at the shell to roof area) are not specifically referenced as an option to handle any emergency venting, and the authors do not consider them as an option to manage any risk associated with over-pressure, in contrast to Orooji and Hosseinia\(^4\). Without frangible roof-to-wall seams, all emergency venting requirements must be met by mechanical devices or high integrity protection systems (HIPS).

**API 650 – Welded Tanks for Oil Storage**

Tanks constructed to API 650\(^5\), the most common style of welded storage tank in industry, require that the tank vent be sized for normal venting. Emergency venting allows use of frangible roof-to-wall seam in lieu of adequately sized vent(s).

**Non-Steel Tanks**

Tanks that are not constructed of welded steel, such as fiber reinforced plastic (FRP) may not necessarily be designed and constructed to recognized standards. However, two standards often specified include API 12P\(^6\) and ASME RPT-1\(^7\). API-12P applies to tanks with a maximum internal pressure equal to the liquid static liquid head plus 6 inches water column (0.22 psig / 1.5 kPag) and a vacuum of 2 inches water column (0.07 psig / 0.5 kPag). ASME RPT-1 applies to tanks with a maximum internal pressure of 15 psig (103 kPag) and up to full vacuum. As with API-620, all emergency vent requirements must be met by mechanical devices.

**Important Considerations**

It is important to keep in mind that all circumstances apply to all tanks, and it is the owner’s responsibility to ensure that the combination of normal and emergency venting capacity is sufficient to prevent failure of the tank. While API 2000 provides a very narrow definition for normal venting, it is the owner’s discretion whether or not to include other scenarios in the normal venting design basis or the emergency venting design basis.

It is also important to understand the basis of the formulae presented in API 2000. The formulae are based on representative correlations, many empirical, for the typical hydrocarbon streams found in an oil treating and oil refinery. They are not applicable to all fluids and do not replace good engineering judgment and detailed calculations.

**Normal Operation Venting Basis – Non-Refrigerated Tanks**

The normal operation out-breathing from a non-refrigerated tank seems fairly straight forward. The out-breathing flow, which requires venting, is the sum of the displaced and generated (flash-
ing) vapor from the liquid in-fill rates and the thermal effects. While it is apparently straightforward, the actual basis is not. The decisions made on the design basis will affect the requirements for emergency venting. It is recommended to consider normal venting and emergency venting together, especially where use of the emergency vent is not desirable.

**Out-Breathing - Liquid In-Flow**

The liquid in-fill rate must, as a minimum, be the normal in-flow. For most tanks, there is an in-load system that is controlled in some manner. It may be a batch in-load, for example the filling of an amine storage tank, or it may be continuous. Provided there is no vapor in the liquid (e.g. two-phase flow, vapor flash from a hot liquid stream), the vent size is based on the equivalent actual volume of vapor displaced by the volume of liquid per unit time. If there is vapor in the inlet stream, or vapor will be generated – for example, the drain-down of a hot urea/water solutions – the vent size basis must include the vapor.

**Out-Breathing - Weather Effects**

There are two weather effects that must be considered when determining venting requirements. API 2000 provides guidance for thermal effects (e.g. night to day temperature change) for normal venting, but does not discuss atmospheric pressure change. Presumably, API 2000 considers atmospheric pressure changes to only apply to emergency venting.

The correlation found in API 2000 for thermal out-breathing (equation 5 in the referenced standard) provides corrections for the site latitude and insulation. The basis is the expansion of air in the vapor space of the tank due to heating, with the vapor space based on the full tank volume. Even though the vapor space may contain other components, the correlation is valid since all vapors behave relatively ideal at the low pressures in storage tanks. Also, since the volume is based on an empty tank, it is applicable for all modes of operation.

**Out-Breathing Vent Sizing Basis**

If there is no vapor generation associated with the in-fill operation, the actual volume of liquid in-flow is equivalent to the actual volume of air displaced at ambient conditions. Ensure that this actual volume is converted to standard volume (or a mass flow) so that it is on the same basis as the standard volume calculated for thermal effects.

If there is vapor associated with the in-fill operation, it is recommended to do the calculation as follows:

1. Determine the sum of actual displaced volume from the liquid and the actual displaced volume from the generated (flash) vapor.
2. Calculate the standard volume (or mass flow) of air that is displaced by the actual volume calculated in 1 at the normal ambient conditions (accounts for the first displacement from the tank is air). Determine the vent size.
3. Calculate the mass flow of vapor displaced from the actual displaced volume in 1 at the conditions of the vapor. Determine the vent size.
4. Select the larger of the two vent sizes from 2 and 3 as the design basis.

For a fill process that takes place over several hours, the thermal effects must be included and added to the values calculated in 2 and 3 above. For a tank that is filled in short duration batches, such as an hour or two, it can be argued to not include the thermal effects, but if thermal effects are not included, they must be considered in the emergency vent sizing basis. For a tank where no vapor is generated with the in-flow, the size required for the thermal effects can easily be as large, or larger, than the in-fill vent requirement.

Example: Filling an atmospheric storage tank with hot, low pressure steam condensate, results
in a good deal of flashing. The steam that is generated may only be 5% of the total in-flow, but it represents 99% of the displaced volume. Sizing a vent for an in-flow rate of 20 gpm (4800 kg/h) of condensate, the free vent size required to safely manage the displaced volume and the flash steam is 2 inch (50 mm) nominal pipe size. The free vent size required to safely manage the displacement of the air present on the initial fill (or at the start of every fill for a batch fill process) is 3 inches (75 mm).

In-Breathing – Liquid Out-Flow

The liquid out-flow rate must, as a minimum, be the normal withdrawal rate from the tank. For most tanks, there is a pump that sets the normal withdrawal capability of the system, although it could be done with gravity. If a pump is used, the in-breathing should be based on the maximum capacity of the pump. A gravity flow system requires a hydraulic model, although if a control valve is used, it is easiest to base the withdrawal rate on the maximum flow through the control valve with the maximum pressure differential.

In-Breathing - Weather Effects

The weather effects for in-breathing are similar to out-breathing, just in the opposite direction. API 2000 provides guidance for thermal effects (e.g. day to night temperature change) for normal venting, but does not discuss atmospheric pressure change or rain effects.

The correlation found in API 2000 for thermal cooling provides corrections for the site latitude, insulation, storage temperature, and vapor pressure of the stored material. The basis is the contraction and/or condensation of vapors in the tank considering the entire tank volume is filled with vapor. Since the volume is based on an empty tank, it is applicable for all modes of operation.

Back-calculating, one can determine the cool-down rate assumption for the API correlation.

For example, at a latitude between 42° and 58°, the cool-down rate basis is approximately 2 °F (≈1 °C) per minute. This correlation may be adequate for the types of hydrocarbon liquids stored in the oil and gas business, but it should not be relied upon for all stored liquids.

A similar caution for the effect of rain on uninsulated tanks must be made. As per Annex A (informative) of API 2000 “The condensation of vapours can be significant when little or no bulk liquid exists in the tank…”.

In-Breathing Sizing Basis

Determining the required vent size for in-breathing is fairly straightforward. The actual volumetric change in the vapor space due to liquid out-flow and thermal effects are replaced by an equivalent volume of air. Ensure that this actual volume is converted to standard volume (or a mass flow) so that it is on the same basis as the standard volume calculated for thermal effects.

If emptying the tank takes place over several hours, the thermal effects must be included and added to the out-flow. For a tank that is emptied in short duration batches, such as an hour or two, it can be argued to not include the thermal in-breathing, but if thermal effects are not included, they must be considered in the emergency vent sizing basis.

Lastly, and most importantly, understand the nature of the fluid that is stored. For a system that needs to consider purely vapor contraction and no condensation, the correlation in API 2000 is adequate. For systems where a moderate amount of condensation occurs, API 2000 is still adequate. However, systems where a large amount of vapor condensation occurs, API 2000 is not adequate and one must rely on property tables or thermodynamic correlations. For example, consider a tank storing 24 wt% aqua solution. For a storage temperature of 68 °F (20 °C) the API 2000 correlation for thermal cooling agrees with a first principles calculation.
and results in a 2 inch (50 mm) nominal pipe size free vent. For the same aqua solution at 95 °F (35 °C), API 2000 still requires a 2 inch free vent, but a sizing from first principles results in a 3 inch free vent.

**Effect of Vent Treatment Systems**

It is very common for non-refrigerated storage tanks to have a vent treatment system to reduce or recover vapors that would otherwise be emitted to atmosphere due to normal out-breathing. Examples of vent treatment systems include the following:

- Vapor recovery lines connecting a tank to a supply vessel, such that displaced vapors return to the supply vessel when filling.
- Scrubber systems to capture vapors.

A common practice with aqua ammonia tanks is the use of a simple “water trap” to any displaced ammonia vapors. In this case the tank vent is routed to a small vessel or drum filled with water with the vent discharge below the water surface.

These devices can themselves create overpressure or vacuum scenarios in the tank. The impact of the hydraulics of these systems, especially those that involve scrubbing with liquids, or the failures of these systems must be considered in the emergency vent sizing.

**Normal Operation Venting Basis – Refrigerated Tanks**

There is no vent for normal operation of a refrigerated tank. The out-breathing vapor is managed by the associated refrigeration system capacity, but potential in-breathing must be managed by an emergency vent. The refrigeration capacity is typically based on the same out-breathing basis as the non-refrigerated tanks – in-flow and thermal effects, but the actual calculation techniques are very different.

**Liquid In-Flow**

Unless the material is refrigerated (flashed) to the storage tank pressure and then pumped into the storage tank, the liquid in-flow operation will generate vapors. This flashed vapor must be included in the refrigeration capacity basis along with the displaced volume.

The flash calculation basis in API 2000 is valid, although it is approximately 6% low for ammonia. It is better to use actual ammonia property data (e.g. P-T-H table) or an equation of state proven for ammonia, for an isenthalpic flash.

**Weather Effects**

The thermal out-breathing correlation from API 2000 should never be used for refrigerated tanks. For a nearly empty tank, the thermal leak (calculated from a rigorous heat transfer analysis) on an atmospheric ammonia storage tank can result in vapor expansion 5.5 times larger than that calculated by the API correlation. While it may not be practical, or necessary — depending on the design for the return of the condensed liquid to the tank — to include all the vapor expansion in the refrigeration system design, it is important to note this fact when designing the overall vent system.

**Emergency Venting Design Basis**

API 2000 provides a good overview of the most common scenarios that may cause overpressure or vacuum and must be reviewed when sizing the emergency vent. These scenarios should not be viewed as the only potential scenarios. Another good document to use as a guideline when identifying potential scenarios is API 521.

Even with the industry standards as guidance, these scenarios must not be analyzed in isolation. When analyzed in isolation, it is easy to overlook scenarios that are further removed from the storage tank. A good technique is to use a multi-discipline team in a Process Hazard
Analysis to specifically review what-if or guide word scenarios for their effect on the storage tanks.

**Venting and Emergency Venting Considerations – Non-Refrigerated Tanks**

Emergency venting is considered mass or energy flows that exceed the normal design flows for in-breathing and out-breathing (including thermal). The emergency vent may be included in the normal vent design, or partially included, or it may be satisfied by a separate vent system such as pressure relief valves, weighted manways or hatches, frangible roof-to-wall seams, or in the case of vacuum, vacuum relief valves. In all cases, the entire venting requirements, normal and emergency, must be considered together. Note: if a tank is fitted with a single free vent, such as many non-refrigerated tanks, it must be sized to satisfy all normal venting (pressure and vacuum) and emergency venting (pressure and vacuum).

Flammable product storage – if environment in tank is in combustible region (e.g. due to in-breathing) then a deflagration vent (recommend end of line) must be used to prevent inadvertent ignition of vapor space in tank. Alternatively, supply an inert pad – impacts emergency venting requirements.

**Overpressure Emergency Venting**

API 650 allows the use of a frangible roof-to-wall seam to manage emergency venting and prevent overpressure, but this option should only be considered for the extreme case such as fire. The more common potential events for overpressure should be considered in the normal operational vent design, or managed with an emergency vent. The more common overpressure events are as follows:

- Abnormal heat input from heating coil control failure
- Vent treatment system blockage or failure (e.g. scrubber)
- Known potential chemical reactions that generate heat and vapor
- Atmospheric pressure reduction (especially if liquid is at or near its bubble point)
- Vapor breakthrough from pressure transfer
- Steam out venting (maximum expected steam rate = flow from ‘x’ hoses)

Scenarios that are often missed in vent design considerations are associated with abnormal operations. For example, one tank failure occurred from overpressure when a large sulfuric acid tank was washed in preparation for inspection and maintenance. The sludge at the bottom of the tank contained a high concentration of sulfuric acid and was too deep to open the tank manways, which was the typical way that water was introduced to washout the tank. Water was introduced to the tank through 3” (fire) hoses connected to the liquid outlet line. The tank failed (see Figure 1) as a result of the steam and heat that was generated.

![Figure 1 - Sulfuric Acid Tank Failure due to Overpressure during Water Wash](image-url)
The hazardous scenarios where frangible roof-to-shell seam may be considered are:

- Internal explosion or deflagration
- External fire
- Internal heating device failure (specifically a heat coil failure with steam release)
- Inadvertent introduction of hot product causing flashing

It must be noted that frangible roof-to-wall seams are not the default design, as commonly thought. Another concern is that they cannot be tested, so they are completely dependent on being constructed as per API 650. They must be specified during the design phase, and it is recommended that they are verified by a knowledgeable and experienced inspector (although rare, the author has experience with oil storage tanks where over-enthusiastic welders either did not know the proper weld design or did not follow the specified design resulting in a non-frangible seam). An example of a tank that failed due to vapor breakthrough during the draining of the MDEA system where the owner assumed the tank had a frangible roof-to-wall seam to manage such “rare” contingencies is shown in Figure 2.

![Figure 2 - MDEA Tank Failure from Overpressure due to Vapor Breakthrough](image)

A final consideration is the possibility that the tank roof is launched during an overpressure event, potentially injuring someone.

Emergency venting options other than frangible roof-to-wall seam:

- Install a larger vent, or more free vents, than that required for normal venting
- Additional pressure relief vents or conservation vents
- Weighted manways or ‘thief’ hatches (cannot be easily tested once installed)
- Rupture disc or blowout panel

**Vacuum Emergency Venting**

Frangible roof-to-wall seams are not applicable for preventing vacuum hazards. The common vacuum scenarios that must be considered in designing the emergency vent system are:

- Condensation of steam during steam-out operations due to thermal cooling (day to night) or rain
- Atmospheric pressure increase (especially for high vapor pressure liquids) and
- Known potential chemical reactions that reduce vapor in the vapor space (e.g. water addition to an aqua ammonia storage tank with ammonia in the vapor space)

Scenarios that are often missed in vacuum vent design are also associated with abnormal operations. For example, a 16 ft (tan-to-tan) x 17 ft diameter 32,000 gallon (4.9 m x 5.2 m diameter, 119 m³) fiber-reinforced plastic dissolver tank, shown in Figure 3, in a potash circuit failed due to steam condensation during startup after an operational procedure change. Previous to the failure, a large manway at the top of the tank, circled in blue, was opened to monitor the vessel level during startup. After the installation of a radar level gauge, the manway did not have to be opened. During a startup after a maintenance outage, the steam that leaked into the tank from a leaking heat exchanger (which was normally blocked in on shutdown but was missed) rapidly condensed when cold brine was introduced.
The 4 inch vent (circled in red in Figure 3) - sizing basis unknown, was insufficient. The result is shown in Figure 4 (red circle is the missing tank wall and shell that was found lying inside the tank).

In another example, a 6,000 gallon (22 m³) FRP aqua ammonia tank, shown in Figure 5, failed due to a vacuum condition that resulted when a lower concentration aqua ammonia was inadvertently added to the tank. The tank normally contained 29.4 wt% aqua ammonia with a vapor pressure of 14.64 psia (100.9 kPa) at 80 °F (27 °C). At these conditions the vapor space contains 97.3 mol% ammonia. A 19.1 wt% (Wt.) aqua ammonia solution was added to the tank contents through the vapor, with a vapor pressure of 5.85 psia (40.3 kPa) at 80 °F (27 °C). The ammonia in the vapor space reacted with the incoming 19.1 wt% aqua ammonia solution driven by the difference in vapor pressure. This rapid absorption of ammonia caused the vapors in the vapor space to collapse creating the vacuum condition in the tank. The vent line was submerged in a water trap that effectively served as a seal leg, and there was no other means of vacuum relief. The tank cracked the full 360 degree circumference near the liquid level.

In a third example a 10,000 gallon (38 m³) 304 stainless steel aqua ammonia tank containing 19.1 wt % aqua ammonia failed due to a vacuum condition. This tank had operated for 10 years without incident. While the cause of the vacuum condition has yet to be disclosed, the initial investigation showed that the atmos-
pheric tank was not equipped with a vacuum relieving device. The tank drawings did show a vacuum relieving device, however, this device was never installed. This example illustrates the importance of a thorough review of all normal and emergency relieving scenarios, including rare, but potential scenarios, and the importance of proper installation of relieving devices.

Figure 6 – Stainless Steel Aqua Ammonia Tank after Vacuum Event

Installation Considerations

Simple is best – open to atmosphere with little or no piping to minimize back pressure will keep the relief sizing to a minimum. If product recovery is a concern (e.g. environmental) then careful evaluation of discharge piping to ensure that the backpressure on the vents must be made. For sub-sonic flow, the backpressure is a critical factor.

Venting and Emergency Venting Considerations – Refrigerated Tanks - Overpressure

The discussion presented in this section is exclusively for a low pressure, refrigerated, ammonia storage tank.

Overpressure

Emergency venting for a refrigerated storage tank is similar to the non-refrigerated tank, except that the design basis does not include consideration for normal venting to atmosphere. Since the normal venting requirements is managed by a vapor recovery (refrigeration) compressor, it is critical to consider the credibility that the compressor is online during the scenario being analyzed. There are contingencies that the emergency vent system must be able to handle all venting requirements – normal and emergency.

Frangible roof-to-wall seams are not recommended due to the environmental and safety impact. Once the seam fails, it is difficult to contain the vapors and the end result will damage a company’s reputation even if it does not pose a credible offsite health threat.

Loss of Vapor Recovery (Refrigeration) System

API 2000 identifies the loss of the refrigeration system as a scenario for the emergency vent sizing. Provided the refrigeration system capacity is properly designed, this one scenario should cover off several others such as thermal heat leak and liquid movement into the tank. It is important not to assume that the system has adequate capacity and a review of the thermal leak and liquid in-load must be done. From experience, refrigeration systems are often undersized (especially as the tank insulation degrades over time) and some sites will use a flare to offset this capacity limitation to maintain in-load rate.
Weather Effects - Atmospheric Pressure Changes

A rapid decrease in atmospheric pressure can easily overwhelm the vapor recovery system capacity. The most common atmospheric pressure change in North America occurs with summer storms – the more severe the storm, the more rapid the pressure change. Low pressure “cells” associated with storms are of particular concern since they are most often associated with electrical storms that can cause power outages. Thus, an important consideration for the emergency vent sizing is to consider the possibility that the vapor recovery system will be lost at the same time.

With respect to the actual maximum pressure change, API 2000 provides some guidance, but it is still at the discretion of the owner operator. A conservative approach that has been adopted by some companies is to use the greater of actual measured atmospheric data at site (or nearest weather station) over a specified period of time (e.g. most recent 50 years) or 2000 Pa/h (0.3 psi/h).

The most severe pressure change is associated with tornados. It is so fast, and so localized, that very little data has been successfully collected. What data has been collected has measured peak pressure changes as high as 2.8 psi (19.4 kPa) over a 4 second period shown in Figure 7. A study concluded that it is unreasonable to design the emergency vent system for such a localized scenario for the following reasons:

1. The low probability of a storage tank experiencing the absolute pressure change associated with a tornado (requires a direct hit by the tornado); and
2. The short time duration of the event is insufficient for the ammonia in storage to reach equilibrium.

In addition, the larger risk to the storage tank is damage due to the high speed winds from the tornado.

The atmospheric pressure changes associated with a hurricane are not a concern. They happen over relatively long periods of time (12 to 24 hours) and while the total change may be large, the maximum rate of change is an order of magnitude less than an electrical storm. For example, hurricane Katrina had a total barometric pressure change of 0.87 psi (6000 Pa), but the maximum rate of change was only 0.07 psi/h (500 Pa/h).

The correlation provided in API 2000 for determining the emergency vent requirement for barometric pressure changes should not be used for the following reasons:

1. The correlation is based on pressure differential rather than the ratio of the absolute pressures and, therefore, does not agree with any gas law for the expansion of vapor.
2. The method does not include the vapor generated by the heat leak, which should be included.

It is recommended to use actual ammonia property data (e.g. P-T-H table) or an equation of state proven for ammonia, for an isenthalpic flash from the initial tank pressure at time zero (see note below) and the pressure at time one hour (using the design pressure change).
Note: The initial pressure should be the PRV set pressure plus accumulation to account for the potential that the refrigeration system has tripped and the tank pressure has built due to the pressure change. Using the normal operating pressure of the storage tank as the initial pressure has, in some cases, led to the conclusion that the emergency vent did not have to be sized for this contingency.

**Rollover**

Rollover is a phenomenon where a lower density liquid, at or near its bubble point, becomes stratified below a higher density liquid. The head from the higher density liquid is effective in preventing the lower density liquid from flashing are reaching vapor-liquid equilibrium at the tank vapor space pressure. At some point, the lower density liquid rises as a single mass through the higher density liquid and rapidly flashes as the head pressure decreases. Since it is not possible to determine the mass of lower density that could collect, it is not possible to determine the total mass of vapor that may flash from the liquid, and sizing emergency relief for this scenario is near impossible. The concept is from the petroleum industry where it is possible to inadvertently introduce different oil fractions into a storage tank with very different densities and vapor pressure than the fraction that is already in the tank. API 2000 does not provide guidance on how to calculate the rate of evaporation during a rollover event and no correlations exist in open literature.

More importantly, a rollover in an ammonia storage tank, which contains a single component, is not possible. There is a density difference between the liquid at the bottom of the tank and the liquid at the top of the tank, but this density difference is natural and is due to the head of the liquid. This pressure gradient, due to liquid head, is constant. If liquid is introduced to the bottom of the tank, it will reach vapor-liquid equilibrium based on the pressure at the point of introduction. The end result is that this ‘new’ liquid is at the same temperature, pressure and density as the liquid in the tank and rollover is impossible.

The one documented case of suspected rollover in an ammonia storage tank in Lithuania\(^7\) was refuted by a follow-up paper\(^11\). The follow-up paper demonstrated that the liquid head due to the liquid in storage at the time of the incident did not prevent the warm ammonia (the refrigeration system was down at the time) introduced to the bottom of the tank from flashing. This flash ensured vapor-liquid equilibrium of the ammonia at the tank bottom, and the amount of vapor flashed exceeded the capacity of the emergency vents on the tank. Subsequent calculations\(^12\) determined that the tank could have reached as high as 200% of the design pressure before it failed.

**Use of High Integrity Protection Systems**

The event in Lithuania\(^8\) and the event in Iran\(^4\) demonstrate that not considering scenarios for emergency vent sizing due to double-jeopardy may not be a wise choice for ammonia storage tanks. In both of these cases, a stream of abnormally warm ammonia was introduced to the storage tank from two seemingly independent failures – the refrigeration system not on line or operating with higher than normal pressure, and inadvertently introducing the hot ammonia to the storage tank through human error. The resulting vapor from the flash overwhelmed the pressure relief valves and resulted in a tank failure. Since it may be difficult or impossible to determine all the combinations of potential errors (especially the potential temperature and pressure of the liquid stream under all upset conditions) consideration for a high integrity protection system\(^2\) (HIPS) should be included in the emergency vent analysis. The HIPS can be configured to stop the liquid flow to the ammonia storage tank on any one (or combination) of the following conditions:

1. High pressure in the ammonia storage tank;
2. High pressure in the final flash vessel upstream of the ammonia storage tank;
3. High temperature of the ammonia flowing to the storage tank.
Pressure is the preferred input for the HIPS since temperature has a time lag that reduces the response time of the HIPS.

Fire

The correlations and guidance provided in API 2000 are sound and should be followed. The guidance and requirements that must be met before considering insulation can be considered to reduce the heat flux are especially useful — the insulation is not much help if it melts, catches fire, or is stripped off from the water cannons.

Venting and Emergency Venting Considerations – Refrigerated Tanks - Vacuum

As stated in API 2000, proper sizing and design of a refrigerated tank vapor recovery system (refrigeration) should prevent overpressure and vacuum conditions during normal liquid movement into out of the tank. For emergency venting, however, consideration must be given to credible scenarios where the vapor recovery system is operating under abnormal conditions.

Vapor Recovery (Refrigeration) Capacity

Potential exists on cold days with limited or no heat input to the tank for compressors to draw vacuum. Emergency venting should be sized for maximum compressor capacity while heat input is at a minimum and there is no liquid inflow.

Atmospheric Pressure Changes

Atmospheric pressure change can be very significant for refrigerated tanks as the liquid is being stored near its boiling point. After a storm passes and the barometric pressure returns to normal (increases) condensation can occur in the refrigerated tank resulting in a vacuum condition. Again it is recommended to use ammonia physical property data or an equation of state proven for ammonia to calculate the quantity of ammonia condensed due to the increase in barometric pressure.

Vent and Emergency Vent Sizing

A common practice to select the appropriate vent is to convert the largest emergency vent load to equivalent volumes of air and select the appropriate vent, or vents, based on their air flow test curves for various inlet pressures. The procedure is described in API 2000 and involves multiple steps. A simpler method to calculate the required vent area is to determine it with one calculation using the subsonic flow correlation. The following is the equation for standard units\(^{13}\) (metric unit equation is available in the reference):

\[
A = \frac{W\sqrt{TW}}{735KdP_1P_2\sqrt{M}} \quad \text{where}
\]

\[
F = \frac{\sqrt{k}}{k-1} \left[ \left( \frac{P_2}{P_1} \right)^{\frac{2}{k}} - \left( \frac{P_2}{P_1} \right)^{\frac{k+1}{k}} \right]
\]

\[A = \text{minimum required discharge area, in}^2\]

\[K_d = \text{discharge coefficient (reference valve manufacturer for data)}\]

\[k = \text{specific heat ratio of gas being relieved}\]

\[M = \text{molecular weight of gas being relieved}\]

\[P_1 = \text{relieving pressure, (set pressure of the relief valve + accumulation), psia}\]

\[P_2 = \text{pressure at the valve outlet (total back-pressure), psia}\]

\[T = \text{relieving temperature, } ^\circ\text{R}\]

\[W = \text{required relieving capacity, lb/h}\]

\[Z = \text{compressibility factor at relieving conditions}\]

The downside to the method described above is that it requires the proven discharge coefficient. Fortunately, the reputable vent manufacturers readily provide this data, often in online catalogs. Regardless of the method chosen, it is recommended to determine the vapor (and air)
properties from a property table or from a proven equation of state.

The same formulae can be used to size an open (free) vent of pipe using a $K_d$ of 0.975, provided that the backpressure (pressure loss) in the piping is known. Hooded free vents have $K_d$’s available from the manufacturer.

**Conclusions**

API 2000 and ISO 28300 provide good guidance for sizing normal vents and emergency vents to prevent overpressure and vacuum on storage tanks. For some of the products commonly stored and some of the practices commonly employed in the fertilizer business, these RAGAGEP are only guiding principles and cannot be used without good engineering judgment. Some areas to pay particular attention to when sizing normal and emergency vents are as follows:

- Use of steam to clean or sweeten tanks for maintenance;
- Use of frangible roof-to-wall seams on non-refrigerated tanks and risk of launching versus the risk of a failed floor seam;
- Impact of a vent treatment system on the venting, and emergency venting capacity, especially vacuum;
- Use of HIPPS to manage the potentially large relief scenarios associated with double jeopardy or scenarios or “remote” contingencies;
- Understand the limitations of the formulae presented in API 2000 and consider the (recommended) use of property tables or thermodynamic correlations when determining the emergency venting flow requirements; and
- Use of subsonic flow correlations to determine the size of a normal vent and emergency vent rather than converting to an equivalent standard volume of air and using sizing charts for vents.