Influence of Overpressure in Pressure Vacuum Safety Valves on Emission Reduction and Explosion Risk Minimization of Atmospheric Storage Tanks

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Abstract

Containment of emissions from atmospheric or low-pressure tanks is, for economic reasons, a welcome feature by plant operators in the choice of Pressure Vacuum Relief Valves (PVRV), beside the necessary requirement of explosion risk minimization. Best engineering practice is to select a valve with high seat tightness close to set pressure and a minimum overpressure.

This paper compares two methods for estimating product losses when no measurement is available. Regarding the estimated product losses, different venting technologies are compared with overpressures ranging from 10 %, as usually required for safety relief valves (SRV) on pressurized tanks, to 100 %, which is the common technology for PVRV on the market. The experimental tests confirm that gaseous emissions are minimized by using the 10% overpressure technology without compromising the safety of the tank.

The results presented in this and previous papers by PROTEGO® were a cornerstone for the improvement of the blowdown requirement in the API 2000 standard.

1. Introduction

In today's economically competitive environment it is important to utilize a venting technology on storage tanks, like Pressure Vacuum Relief Valves (PVRV), which provides the maximum degree of safety from explosion of flammable liquids for the protected item and personnel coupled with minimum product losses. In API 620 [1] pressure relief valves are required to open at latest when the pressure at the top of the protected tank reaches the nominal pressure rating of the tank and they must discharge enough capacity to avoid exceeding the maximum allowable accumulated pressure (MAAP) of the tank. The difference between the set pressure, when the valve begins to open, and the relieving pressure is called overpressure. By choosing a valve with little overpressure the set pressure can be specified to be as close as possible to – without exceeding - the nominal pressure rating for the tank in conformity to API 620. Most of the available PVRV on the market require overpressures of 80% to 100% of the set pressure to reach full relieving capacity [2], which is far above the 10 % requirement for high-pressure safety valves [3,4]. This results in very low set pressure levels and supposedly increased emission losses due to increased operating cycles. At the moment there is almost no study to assess the impact of overpressure on emissions from low-pressure tanks.

This paper summarizes some recent studies done at PROTEGO® on the impact of overpressure on product loss. Some of the results described here were already discussed by Bosse and Davies [2] and others have been presented at conferences without papers. Although the results in this paper are not new, the approach given here is more scientific and rigorous. The paper begins with a comparison between the calculation methodology in the API Bulletin 2516 [5] and the one within VDI 3479 [6] in terms of leakage prediction in tanks of several sizes and nominal pressures. The second part of the paper focuses on the impact on leakage by the specification of set pressure and overpressure of the relief device.

2. Evaporation losses from low pressure tanks

The conservation of mass imposes that the change in mass for a tank is the difference between the mass flow rates via pumping and the loss of product, as given in Eq. 1.

$$\dot{m}_{tank} = \dot{m}_{pump-in} - \dot{m}_{pump-out} - \dot{m}_{losses} \quad \text{[Eq.1]}$$

When more liquid is pumped in the tank than the amount which is removed, than product is added into the tank: the rising liquid surface presses up the gases and vapors in the gaseous phase until the tank pressure is so high that the relief valve opens. At that moment the tank is losing product to the ambient

In the following chapters the evaporation rates as according to API Bulletin 2516 [5] and VDI 3479 [6] are described and commented. In order to avoid any future misunderstanding, the standard referred here deal with tanks breathing to or from ambient air.

3. Product losses as per API Bulletin 2516

The API Bulletin 2516 applies to tanks whose pressure is between 2.5 and 15 psig (172.4 and 1034.2 mbar-g) and whose vacuum is between 1 and 2 oz./in² gauge (4.3 and 8.6 mbar-g) .

This bulletin defines breathing losses as the losses of product from a tank due to thermal expansion of the vapors or due to an increase of vapor pressure caused by heating the contained liquid. The minimum tank pressure to prevent breathing losses is given in Eq. 2.

$$P_2 = 1.1\,[P_{atm} + P_1 - p_1] - [P_{atm} - p_2] \quad \text{for} \quad P_{atm} + P_1 \geq p_1 \text{ [Eq. 2]}$$

In Eq. 2, P_2 and P_1 are respectively the gauge pressures when the pressure and the vacuum valve open and p_1 and p_2 are the vapor pressures at the liquid surface temperature of 90°F (32.2°C) and 100°F (37.7°C). In order to prevent breathing losses, the absolute vacuum vent pressure must be higher than the saturation pressure at 90°F. In other words, some air from the last inbreathing should be present in the vapor space. No correlation is provided to estimate the breathing losses.

Indeed, at higher tank pressures breathing losses are minimized but evaporation is facilitated and therefore the so called boiling losses must be accounted for. Boiling losses are present in a tank when the tank pressure equals or exceeds the saturation pressure at the liquid surface. It is here expected that the saturation pressure at 90°F is higher than the absolute vacuum vent pressure. No correlation is given for the boiling losses as well.

Indeed, the standard proposes a correlation for the working losses as percentage of the pumped-in load F_v, which is given in Eq. 3. The working losses are the product losses through the pressure relief valve when the tank pressure exceeds the set pressure of the valve. Additionally, to the symbols in Eq. 2, p_v is the vapor pressure at the liquid surface. Eq. 3 is valid under the assumptions that the vapor pressure and temperature remain unchanged during filling.

$$F_v = \frac{p_v}{p_u} \cdot \frac{P_{atm}+P_1-p_v}{P_{atm}+P_2-p_v} \quad \text{with} \quad p_u = 33.3\,psi \qquad \text{[Eq. 3]}$$

No formula is given either for the leakage losses from lax flanged connections between the tank and the valves as they differ from one tank to another randomly.

4. Product losses as per VDI 3479

The calculation method in VDI 3479 is valid for fixed-roof tanks with an internal available floating deck. The annual mass losses L_{tank} in Eq. 4 are the leakages, which cannot be prevented by using the floating deck. In this equation η_{SD} is the efficiency of the floating deck (in German: *SchwimmDecke*), η_{VD} (in German: *VakuumDruckventile*) is the efficiency of the pressure and vacuum valves, f is the coating factor, L_A and L_B are respectively the breathing and filling annual leakages. Some examples of coating factors f are given in Table 1 for different shades of gray.

$$L_{tank} = (1-\eta_{SD}) \cdot [(1-\eta_{VD}) \cdot f \cdot L_A + L_B] \quad \text{[Eq. 4]}$$

The breathing and filling leakages could be measured. In case no measurement is available VDI 3479 gives a conservative estimate via Eq. 5. According to this equation the annual breathing losses can be calculated as the weighted sum of the daily mass losses during summer and winter days, L_{As} and L_{Aw}. For simplicity a year is broken into d_s summer days and d_w winter days.

Table 1. Some examples of coating factors for shades of gray taken from VDI 3479

Types of gray	Coating factors
White	1.0
Silver	1.1
Light gray	1.3
Mouse gray	1.6

The mean daily breathing mass losses can be estimated as the product of the dimensionless saturation level f_A, the saturation concentration density c and the volumetric flow rate V_n, which is the daily change of the gas volume in the tank. The saturation level f_A is the ratio between the actual concentration and the one at saturation.

$$L_A = L_{As} \cdot d_s + L_{Aw} \cdot d_w = f_{As} \cdot c_s \cdot \dot{V}_{ns} \cdot d_s + f_{Aw} \cdot c_w \cdot \dot{V}_{nw} \cdot d_w \quad \text{[Eq. 5]}$$

The efficiency of the pressure and vacuum valves is the percentage amount of the losses L_A, which does not leave the tank through the valves, L_{AVD}. Based on Eq. 5 the efficiency of the valves can be calculated as shown in Eq. 6. In this equation V_{nsVD} and V_{nwVD} are the daily volumetric rates through the relief valves due to vapor expansion or contraction.

$$\eta_{VD} = 1 - \frac{L_{AVD}}{L_A} = 1 - \frac{f_{As} \cdot c_s \cdot \dot{V}_{nsVD} \cdot d_s + f_{Aw} \cdot c_w \cdot \dot{V}_{nwVD} \cdot d_w}{f_{As} \cdot c_s \cdot \dot{V}_{ns} \cdot d_s + f_{Aw} \cdot c_w \cdot \dot{V}_{nw} \cdot d_w} \quad \text{[Eq.6]}$$

The filling losses in Eq. 7 are defined in a similar way as Eq. 5 for the breathing losses with f_B and c_B being respectively the saturation ratio at a reference value of 0.85 and the saturation concentration density during filling and Q being the annual filled-in volume.

$$L_B = f_B \cdot c_B \cdot Q \quad \text{[Eq.7]}$$

4. Comparison between the two methodologies

For the comparison between the two methodologies the authors refer to the experimental data in the DGMK Forschungsbericht 225 [7] for a middle European climate. In Fig. 1 the vapor losses as a function of the vapor pressure calculated using the methodologies in API RP 2516 and VDI 3479 are compared for different tank volumes. For this study the tank no. *X* has a volume of *X* times 1000 m³ (35 315 ft³), so the tank sizes range from one to ten thousand cubic meter. The curves show that the methodology in API RP 2516 estimates always higher vapor losses than VDI 3479 for any combination of tank nominal pressure rating and size. However, both methodologies agree that the vapor losses for a tank of given size increase with the vapor pressure, i. e. the working pressure in the tank.

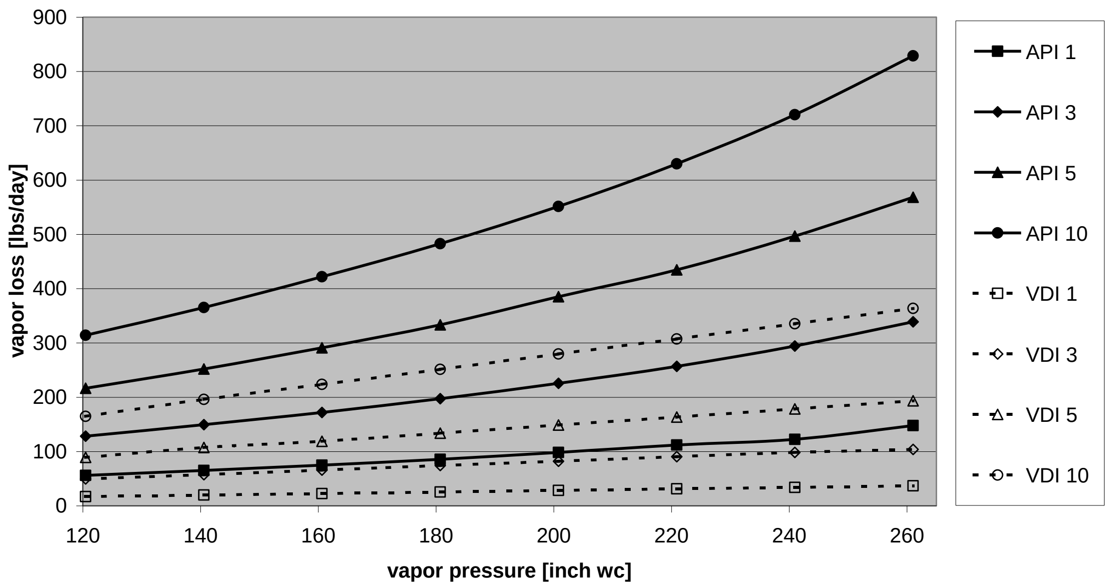

Fig. 1 Vapor losses in function of vapor pressure for various tank volumes

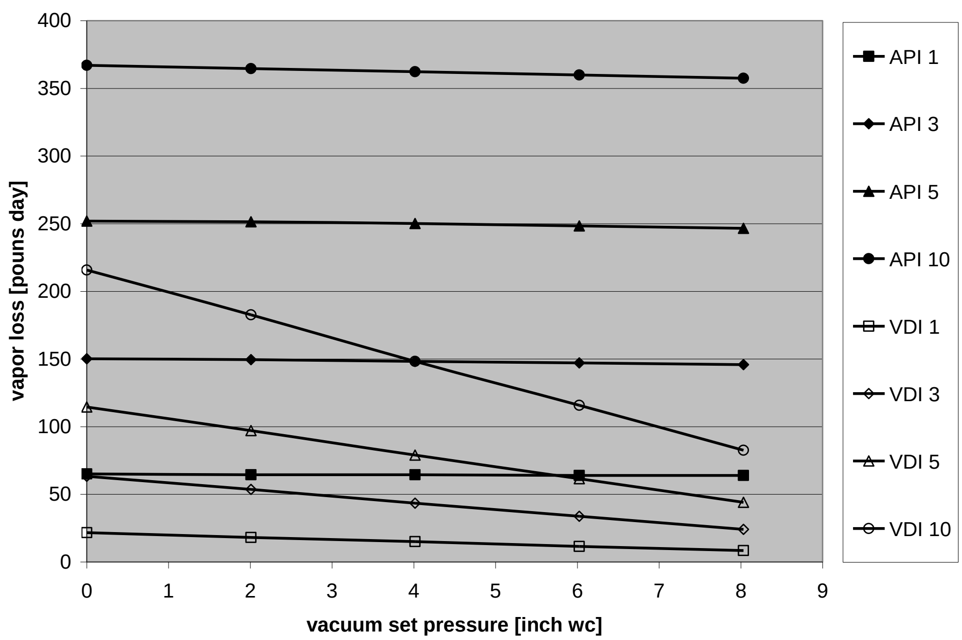

Fig. 2 Vapor losses in function of vapor vacuum for various tank volumes

In Fig. 2 the API 2516 standard does not show any significant change in the vapor losses by increasing the vacuum, as instead VDI 3479 does, since the latter includes the pump-out saving in the breathing losses.

From Fig. 1 and 2 it can be evinced that the emissions calculated using the API Bulletin 2516 are roughly two times those of the VDI 3479 standard.

5. Set pressure and overpressure effect on emission minimization

Independently from the methodology used to assess the pressure losses, for a tank of given nominal pressure rating and size, pressure relief valves with a smaller overpressure and therefore with higher set pressures are expected to deliver less leakage. In other words, a valve like those of PROTEGO® that require 10 % overpressure for full lift, a technology many readers already know from high-pressure safety valves, are expected to be subject to less leakage than valves that require higher overpressures. In order to validate this expectation, PROTEGO® has developed a portable test rig to measure small leakages from pressure relief valves up to DN 200 (8 inch) in adherence to the API Bulletin 2521 [8]. In agreement with that standard leakage tests should be conducted at a pressure equal to 75 % of the set pressure.

In Fig. 3 two tests are shown; for both tests the valves were supposed to be fully open at 1 oz./in² (4.3 mbar) gauge. The first test was performed at a set pressure of 0.5 oz./in² (2.15 mbar) gauge and a pressure at leakage of 0.375 oz./in² gauge; this set pressure has been chosen since many PVRVs require an overpressure of 100 % to reach full opening. The second test was performed at the set pressure of 0.9 oz./in² (3.88 mbar) gauge and at a leakage pressure of 0.675 oz./in² (2.98 mbar) gauge. Fig. 3 clearly shows that competitor valves, which require a much higher overpressure, fail to remain tight at low tank pressures. In economic terms high leakages translate into huge product losses and high pollution taxes to the EPA or similar agencies worldwide.

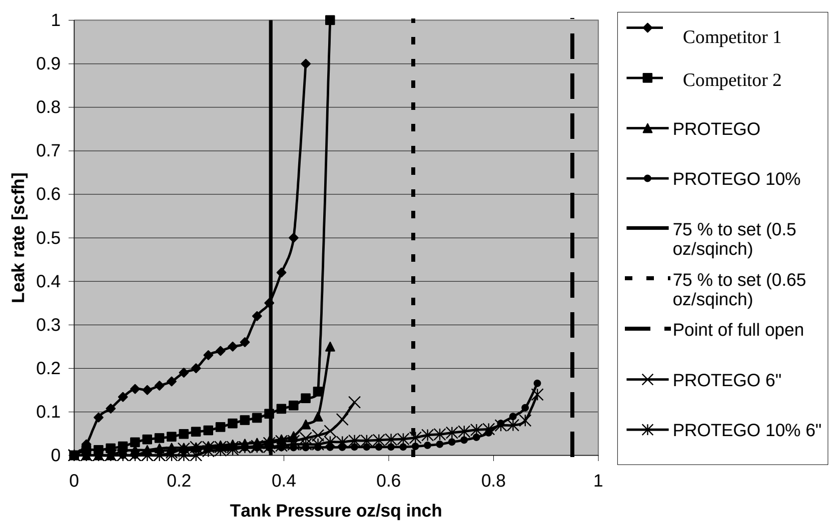

Fig. 3 Leakages in function of tank pressure for several

5. Improvement of API 2000 standard on leakage minimization

On the basis of PROTEGO® results there has been an improvement of the API 2000 standard. In the Fifth Edition [9] the leakage tests have to be conducted at an inlet pressure equal to 75% of the set pressure, since at that pressure the seat in the relief valve is assumed to be tight. A further point was that conservation vents, e. g. spring and weight loaded valves, must have a 0% blowdown, thus meaning that these valves should reclose at the set pressure. This requirement is not only too stringent; it is physically unfulfillable since the lift force on the disk when the valve is reclosing can be neutralized only with pressures below the set pressure, e.g. the blowdown.

According to the Seventh Edition [10] Annex C, seat leakage and the amount of blowdown are dependent on the relief-valve design. Seat leakage is assumed to start between 75 % and 90 % of the set pressure.

Nevertheless, there are currently many installed direct venting systems designed using API 2000 Fifth Edition [9] presenting high product losses in potentially explosive atmospheres. The simplest and most immediate recommendation would be to verify previous sizing using the Seventh Edition. Moreover, consideration should be given to selecting valves with minimal required overpressure against other devices with lower required set pressures. It would also be recommendable to monitor the protected tank and assess the product losses over a large period of time. Valves with low set pressures not only tend to leak more frequently but also to cycle more; for a plant owner it means a double expense both in terms of product loss and spare part purchase. These future costs may overcome the savings from the purchase of a cheaper device.

Furthermore, some PVRV manufacturers support the use of 50% overpressure. However, this requirement should be pondered seriously, especially when the reseating pressure may fall below the set pressure of the blanketing gas regulator. In this case the PVRV cannot reseat and continuous heavy losses due to bleeding of the blanketing gas may result.

6. Conclusions

This paper shows the leakage assessment methods in API Bulletin 2516 and in VDI 3479. At the moment there is no experimental validation which methodology delivers more accurate results. Some additional work is necessary in the field.

To fulfill the demands of stringent environmental legislations and effectively minimize the loss of product, plant owners should start considering the application of technologies with minimum overpressure over others that rely on far lower set pressures. A 10% overpressure, which many users know from high-pressure safety valves, should become a standard also for low-pressure relief valves, especially in virtue of the seat leakage test requirements in the newest API 2000.

An additional design advantage of the low overpressures is the higher flexibility in designing the set pressure of the conservation vent. The authors expect that a set pressure of the conservation vents which can be even 10% to 20% below the set pressure of the emergency relief valves should guarantee a chatter-free vent opening and avoid conflict with the valves.

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