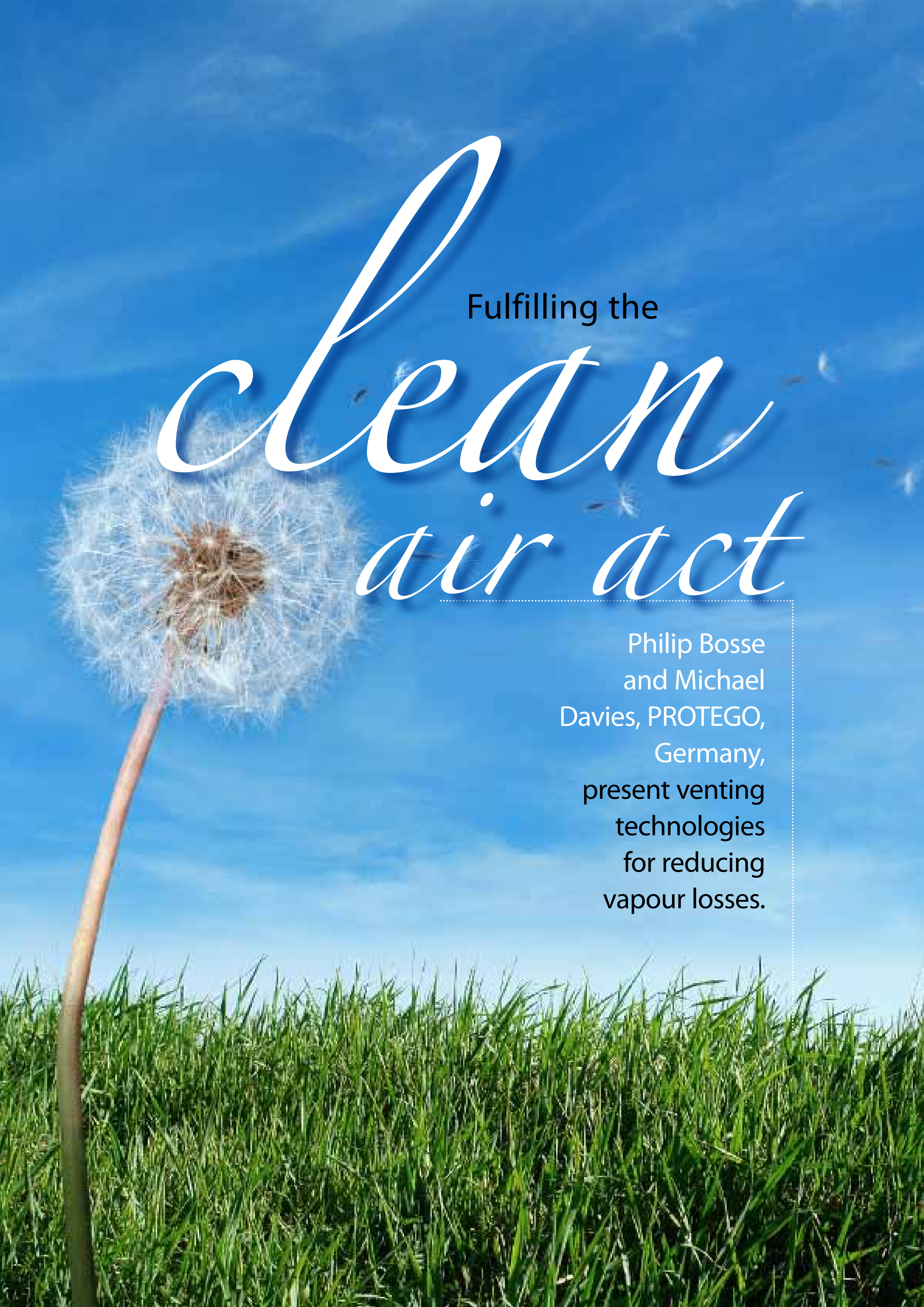


# Fulfilling the *clean air act*

Philip Bosse and Michael Davies, PROTEGO, Germany, present venting technologies for reducing vapour losses.

In a globally more and more competitive environment, it is important to utilise venting technology on storage tanks, which provides a maximum degree of safety and reduces vapour losses to a minimum.

Low pressure safety relief valves are highly sensitive devices, which have to fulfil nearly the same requirements as conventional safety valves with regard to safety and set pressure tolerance. Tightness up to set pressure, minimum set pressure tolerance, minimum pressure increase to fully open results in maximum vapour saving potential.

This article will show calculation results comparing venting technology, which only needs 10% overpressure to reach full lift compared to standard technology available on the market. Calculation methods for estimating the vapour losses of storage tanks using equations derived from live field testing are shown. The official engineering guideline used for the calculation was the VDI 3479 standard (verein deutscher ingenieure). These validated equations show that vapour emissions can be reduced by using 10% overpressure technology which can be set closer to the desired design pressure than with conventional designs. Higher set pressures reduce the opening cycles, and breathing losses are minimised. In this report, calculations of the API 2516 standard are compared to those of the VDI 3479 standard. The resulting vapour emissions calculated based on the API 2516 standard are higher than those of the VDI 3479 standard. To achieve a conservative approach on showing the vapour saving potential the VDI 3479 standard will be used. Both standards do not determine the differences in vent technology towards leak rate. API 2000 assumes that leakage may occur at 75% of the set pressure. In addition, it is stated that weight loaded vents have a 0% blow down. Both assumptions are incorrect. In addition to all leak rate discussions in this report, it is recommended to check different vent designs and make sure that the reseating pressure (blow down) of the vent does not exceed the blanketing gas regulator pressure. Should the reseating pressure fall below the regulator set pressure, high blanketing gas losses may occur.

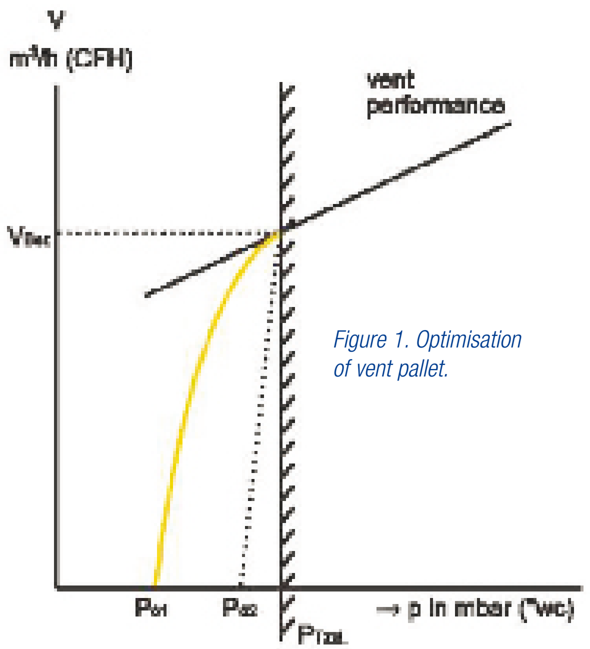



*Figure 1. Optimisation of vent pallet.*

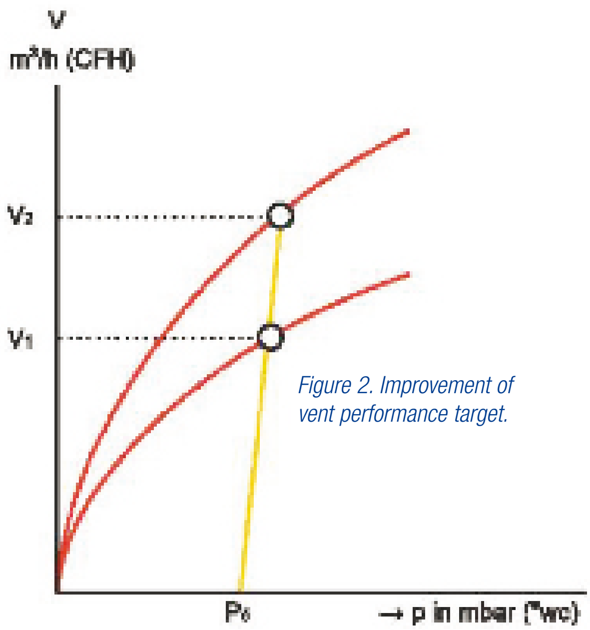



*Figure 2. Improvement of vent performance target.*

## Difference venting technology

Global companies are now strongly focusing on emission reduction for meeting environmental requirements. This emission reduction or vapour loss prevention and nitrogen blanketing gas reduction results in capital savings. Looking into the general performance diagram shown in Figure 1, the set pressure $p_ö = p_{ö1}$ should be as close as possible to the maximum allowable tank pressure $p_{Tzul}$ (like $p_{ö2}$), to realise a better and wider operating range in the tank. At this new set pressure $p_ö = p_{ö2}$ the performance (the flow rate) will be additionally increased by an optimised design of the housing (Figure 2). The better the design of the housing, the higher the volume flow V.

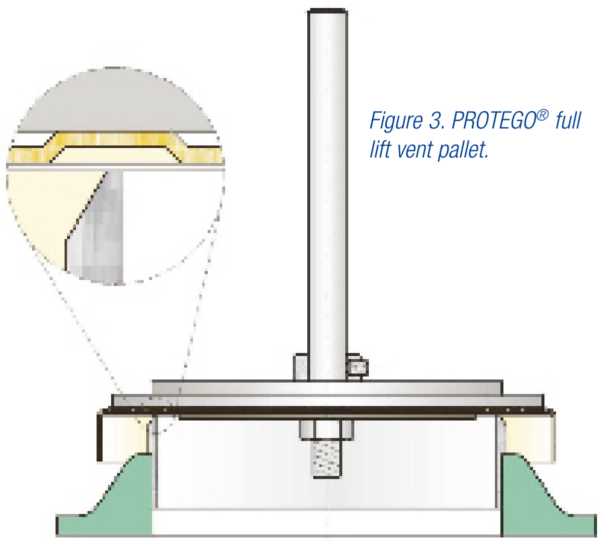


*Figure 3. PROTEGO® full lift vent pallet.*

To meet these goals, a new series of conservation vents have been developed, which only require 10% overpressure above the pressure set point to reach full performance. Flat standard discs were developed further up to full lift disc vent pallets having a design similar to those of safety valves. This means that set pressures closer to the maximum allowable working pressure (MAWP) of the tank can be used.

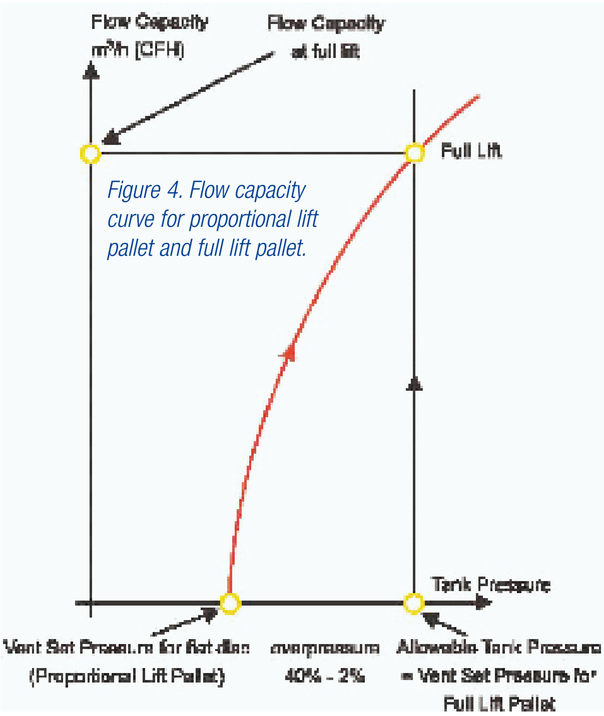



*Figure 4. Flow capacity curve for proportional lift pallet and full lift pallet.*

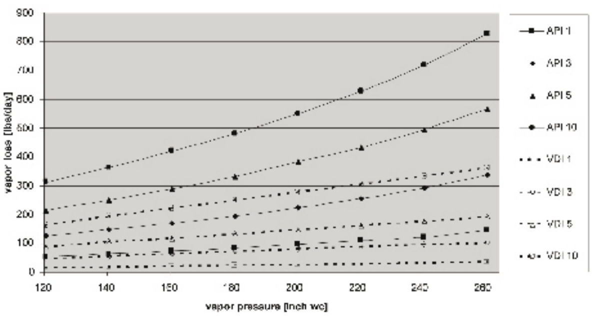



*Figure 5. Vapour losses as function of vapour pressure.*

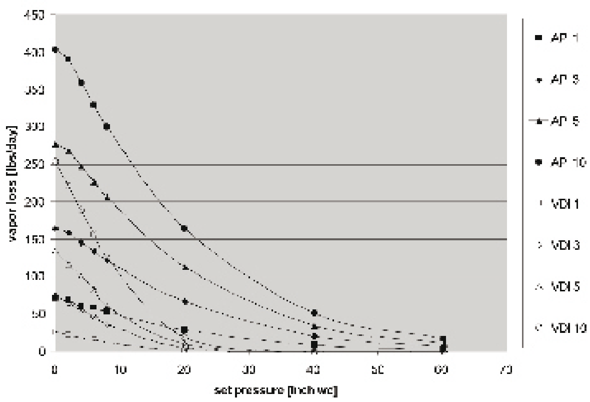



*Figure 6. Vapour losses as function of positive set pressure.*

For small flow rates a flat standard disc vent has an operating range, which is more or less unstable. The vent pallet operation of those vents, which are permanently working in the low pressure range, is the real problem, the pallet flutters or chatters. The solution to the problem was a type of vent pallet, which releases the complete cross section due to full lift immediately after opening.

Actually, full lift pallets are nothing new. Nevertheless, correct sizing of the rim and the relation between vent seat diameter and the height, rim angle and diameter of the rim as well as the sophisticated technique to produce the rim without distortion of the pallet are the fundamental factors that influence the vent performance, especially for low set pressures. Moreover, fluttering in the unstable range is prevented by proper adjustment of lift stop. The vent opening pressure can be selected very close to the MAWP. The idealised pressure increase until fully open is nearly zero. Reproducible and lower leakage is achieved either by metallic sealing or at low pressure settings supported by air cushioned FEP (Teflon®) gaskets under the crimped disc (Figure 3). The design and accurate imprint of the crimp with texture free metal sheets and a special high performance FEP surface assure an impressive result.

The flow capacity curve for the vent equipped with the flat disc (= proportional lift pallet) on the one hand and the full lift type disc on the other hand is shown in Figure 4. The diagram shows pressure versus volume flow. The pressure increase for the full lift type pallet vent at the design flow rate is nearly zero from start of opening until full lift, in contrast to the 40% pressure increase allowed, as a maximum, by DIN 4119 or even 100% by API. The advantage is using nearly the complete pressure range up to the tank design pressure for vents with real full lift. This is an advantage for the environment, because the vents start to open later and are therefore closed longer, which also reduces losses of blanketing gas, inerting gas or direct product losses.

## Theory of emission reduction

The VDI 3479 standard enables industry to determine overall emission losses in tank storage operations. The emission mass flows and concentrations in accordance with this standard are based on average values. These values are not applicable for explosion risk and the determination of corresponding safety precautions. Any safety rules or regulations will not be affected by

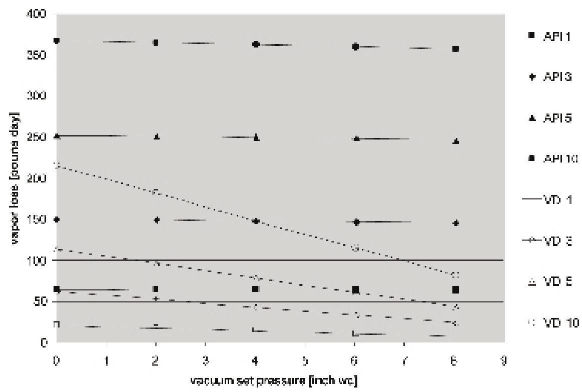



*Figure 7. Vapour losses as function of negative set pressure.*

this standard. To demonstrate the different approaches of the VDI 3479 standard and the API 2516 standard the results are compared. The overall emission losses resulting from the API calculation model are on average 10% above the VDI standard.[1] The focus of this report is mainly on the breathing losses. In this case the results of the API standard are more than 10% above the results of the VDI standard as discussed later, even though the API standard does not consider the losses resulting from pump out within the breathing losses.

## Basic theory on vapour savings with pressure vacuum vents

Storage tanks are generally equipped with pressure/vacuum conservation vents (P/V vents) to reduce vapour losses. The function of the P/V vent is to keep the vapour space closed during variations in gas volume changes that occur from changes in atmospheric pressure and/or temperature until set point is reached.[2] The goal is to avoid in-breathing of ambient air and out-breathing of e.g. hydrocarbons. The P/V vent mainly influences the thermal breathing losses. Main influencing parameters for emission reduction are:

- Set pressure and set vacuum.
- Temperature difference within the vapour space of the tank.
- Vapour pressure of the stored product.

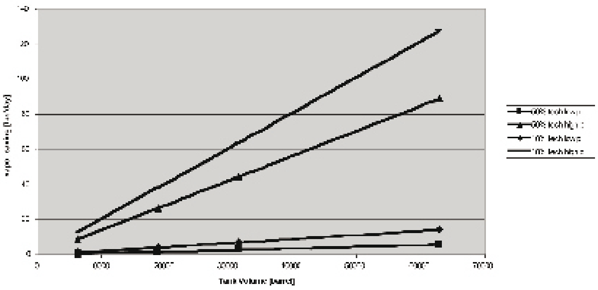


*Figure 8. Vapour saving potential as function of 50%, 10% full lift type technology and increased MAWP and MAWV.*

**Table 1. Leakage rates according to the PROTEGO® standard, but also lower leakage rates are available**

| Nominal width DN | | Admissible leakage rate | | Test time |
|---|---|---|---|---|
| Over | Up to | Bubbles/million | cm³/million* | Million |
| | 40 | 6 | 1.8 | 1 |
| 40 | 100 | 18 | 5.4 | 1 |
| 100 | 150 | 27 | 8.1 | 2 |
| 150 | 200 | 36 | 10.8 | 2 |
| 200 | 150 | 45 | 13.5 | 2 |
| 250 | 300 | 54 | 16.2 | 2 |
| 300 | 350 | 63 | 18.9 | 2 |
| 350 | 400 | 72 | 21.6 | 2 |
| 400 | 500 | 90 | 27.0 | 2 |

*1 bubble equals approximately 0.3 cm³

The P/V vent has to be set in accordance with the maximum MAWP of the tank. This pressure should not be exceeded; otherwise tanks may explode or implode.

In industry, different valve technologies are in use for achieving this goal. The API 2000 standard shows that most of the technologies require an 80 - 100% overpressure to reach full relieving capacity.[3] This results in very low set pressure and increased emission losses due to increased operating cycles. This can be reduced by using full lift type technology (10% overpressure) P/V vents. To calculate the emission reduction through full lift type technology, one has to understand that the emission mass flow of a tank consists of:

$$\dot{m}_{tank} = \dot{m}_{\ldots} + \dot{m}_{\ldots} + \dot{m}_{\ldots} \qquad (1)$$

The total breathing losses of a fixed roof tank without any P/V vents are defined as:

$$\dot{m}_{A,S} = f_{A,S} \cdot 4.4 \cdot 10^{\ldots} \cdot p_v \cdot \bar{M} \cdot \frac{T_n}{p_n} \cdot \left( \frac{p}{T_{1S}} - \frac{p}{T_{2S}} \right) \cdot V_0 \cdot d_S + f_{A,W} \cdot 4.4 \cdot 10^{\ldots} \cdot p_v \cdot \bar{M} \cdot \frac{T_n}{p_n} \cdot \left( \frac{p}{T_{1W}} - \frac{p}{T_{2W}} \right) \cdot V_0 \cdot d_W \qquad (2)$$

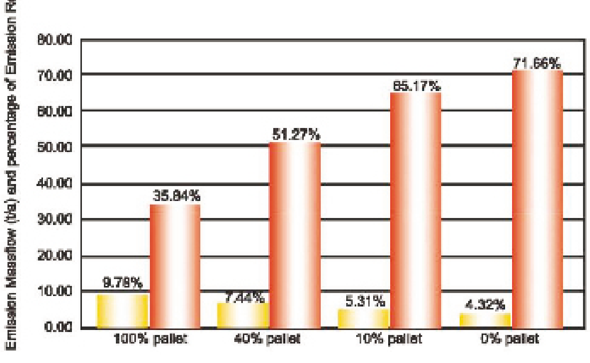
For receiving the reduced emission mass flow of a fixed roof tank using P/V vents, the total breathing loss has to be multiplied by the efficiency factor:

$$\eta_{VD} = 1 - \frac{f_{A,S} \cdot c_n \cdot d_S \cdot \dot{V}_{n,S(VD)} + f_{A,W} \cdot c_n \cdot d_W \cdot \dot{V}_{n,W(VD)}}{f_{A,S} \cdot c_n \cdot d_S \cdot \dot{V}_{n,S} + f_{A,W} \cdot c_n \cdot d_W \cdot \dot{V}_{n,W}} \qquad (3)$$

In Equation 3 the volume flow in the summer and winter time is defined by equation:

$$\dot{V}_{n,S(VD)} = \frac{T_n}{p_n} \cdot \left( \frac{p_1}{T_{1,S}} - \frac{p_2}{T_{2,S}} \right) \cdot V_0 \cdot \frac{1}{t} \qquad (4)$$

*Figure 9. Vapour savings potential for a tank farm (VDI 3479).*




| **Table 2. Test pressures as a function of the adjusted set pressures for measuring the admissible leakage rates** | | |
|---|---|---|
| **Adjusted set pressure** | | **Test pressure as percentage of adjusted set pressure** |
| In mbar (in. wc) over up to | | % |
| | 5 (2.0) | 75 |
| 5 (2.0) | 10 (3.94) | 80 |
| 10 (3.94) | 20 (7.87) | 85 |
| 20 (7.87) | | 90 |

and:

$$\dot{V}_{n,W(VD)} = \frac{T_n}{p_n} \cdot \left( \frac{p_1}{T_{1,W}} - \frac{p_2}{T_{2,W}} \right) \cdot V_0 \cdot \frac{1}{t} \qquad (5)$$

## Calculated pressure vacuum vent losses

To take a technological approach, the calculation of most of the results of this chapter is based on the data published in Forschungsbericht 225.[1] The parameters used are the results of the measurements of the Deutsche Wissenschaftliche Gesellschaft für Erdöl, Erdgas und Kohle (DGMK) research report 4590. The measured results of this report are typical data measured in a middle European climate.

### *Vapour breathing losses as a function of the vapour pressure*

Figure 5 shows the calculation results of the vapour losses in lbs/d as a function of the vapour pressure of API 2516 compared to the results of VDI 3479. The curves show the API results are more conservative, meaning higher vapour losses results for the same tank pressure and size. For this calculation the tank size was varied from API 1 = 6290 bbls, API 3 = 18 869 bbls, API 5 = 31 449 bbls, to API 10 = 62 898 bbls and the vapour pressure was varied from 120 in. wc to 260 in. wc. The expected results are that the increasing vapour pressure increases the tank breathing losses and that more vapour losses occur from tanks with greater storage volume. This also means that if the set pressure of a tank can be set closer to MAWP, the vapour losses are reduced.

### *Vapour breathing losses as a function of the set pressure*

The curves in Figure 6 are a clear indicator for the vapour emission loss reduction if tank set pressures can be increased. In this case, the tank volume and positive set pressure was varied. Again the tank volume was varied from API 1 = 6290 bbls, API 3 = 18 869 bbls, API 5 = 31 449 bbls, to API 10 = 62 898 bbls. The tank pressure was varied from 0 in. wc to 60 in. wc. For the negative tank pressure (vacuum) a value of 0.68 oz/in.[2] was set constant. For the VDI 3479 Guideline, the gradient for vapour loss reduction through set pressure increase is steeper than for the API 2516 equations. The VDI 3479 Guideline results show that from a set pressure of 40 in. wc no vapour losses occur from breathing

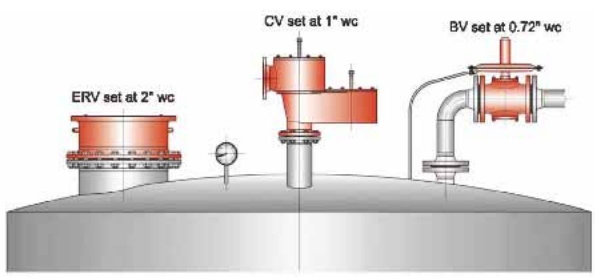



*Figure 10. Example, design problem with 100% overpressure technology. ERV = emergency relief valve, CV = conservation vent, BV = blanketing vent.*

losses. One of the boundary conditions to be fulfilled for this is a 0 leakage vent at 40 in. wc.

### *Vapour breathing losses as a function of the vacuum setting*

In Figure 7 the API 2516 standard does not show any significant vapour loss reduction potential in dependence of increasing the negative set pressure. The VDI 3479 Guideline shows an effect of the negative set pressure on the vapour losses reduction. Considering that the VDI 3479 Guideline includes the pump out saving in the breathing losses. This makes sense, because according to the physical equilibrium a leaning of the vapour head space through inbreathing results into liquid turning into the vapour phase. So if the negative set pressure can be increased the breathing cycles are reduced, which should result in vapour saving.

### *Vapour saving potential*

Figure 8 shows the vapour saving potential if 50% overpressure or 10% full lift type technology is used. In this diagram curve ‘50% tech low p’ shows the vapour mass saving potential per day for a tank with a MAWP of 1.0 oz/in.$^2$ and a MAWV of 0.5 oz/in.$^2$ Curve ‘10% tech low p’ shows the vapour mass flow saving for the same MAWP and MAWV. The tank sizes have been varied from 6290 to 62 898 bbls. As assumed, the vapour saving potential increases with increasing tank sizes. In addition, Figure 8 also shows the vapour saving potential if the design pressure would be increased to MAWP = 4.54 oz/in.$^2$ and MAWV = 2.27 oz/in.$^2$ It is very interesting to see that the vapour saving potential for the 50% technology is approximately 11% saving and for the 10% full lift type technology vent is 27%. It is even more interesting to see that the combined effect of 10% technology with increasing the MAWP and MAWV gives a total saving potential of 42%. This is one of the reasons why the German tank standard typically rates tanks on the vacuum side to 2.27 oz/in.$^2$ and on the pressure side to 4.54 oz/in.$^2$ It is recommended to do a life cycle analysis on tanks including the vapour loss reduction as a function of the set pressure. Furthermore, it should be considered that EPA regulations force petrochemical companies into vapour balancing, recovery and destruction. Also in these cases greater tank design pressures are of advantage, because a higher energy reservoir can be utilised.

According to API 2000 the typical opening characteristics of weight loaded conservation vents are characterised by an overpressure of 80 - 100%. Knowing that higher set pressures can reduce emission and vapour losses significantly, the full lift type technology vent pallet (with 10% overpressure) is a beneficial asset to increase set pressure close to the MAWP.

Figure 9 shows the overall vapour saving potential of a tank farm for a 100%, 40%, 10% and a theoretical 0% overpressure. These calculations are based on the VDI 3479 guideline. Figure 9 shows that compared to a no pressure holding device (freely vented tank), a 100% pallet achieves a vapour saving of approximately 36%. A 40% pallet achieves a vapour saving of about 51% and a 10% pallet saves an additional 14%. The theoretical value of a 0% pallet would increase the vapour saving by another 6.5%. Replacing 100% vent technology by 10% full lift technology can reduce vapour losses up to 30%. PROTEGO® vents have an overpressure rating as small as 3 - 6% depending on size and construction of the devices, for this reason they included the 0% pallet as an example. For safety reasons, Protego does recommend using the 10% rating for design purposes.

| **Equation parameters** | |
|---|---|
| $c_n$ | Saturation concentration of hydrocarbons in vapour phase |
| $d_s$ | Number of summer days per year |
| $d_w$ | Number of winter days per year |
| $f_{A,S}$ | Saturation ratio in summer |
| $f_{A,W}$ | Saturation ratio in winter |
| $\dot{m}_{tot}$ | Emission mass flow for total tank |
| $\dot{m}_{withdrawal}$ | Emission mass flow for withdrawal |
| $\dot{m}_{breathing}$ | Emission mass flow for breathing |
| $\dot{m}_{filling}$ | Emission mass flow of filling |
| $\dot{m}_{a,a}$ | Annual emission mass flow (withdrawal + breathing) |
| $\overline{M}$ | Mean molar mass of hydrocarbons in vapour space |
| $p$ | Atmospheric pressure |
| $p_T$ | Vapour pressure of product |
| $p_n$ | Standard pressure |
| $T_n$ | Standard temperature |
| $T_S$ | Average temperature vapour space in summer |
| $T_W$ | Average temperature vapour space in winter |
| $V_G$ | Volume of vapour head space |
| $\dot{V}_S$ | Average volume flow of summer days |
| $\dot{V}_W$ | Average volume flow of winter days |
| $t$ | Reference time |

## Leakage rate

Higher set pressures and lower leakage rates have a direct impact on complying with EPA requirements. Due to the fact that full lift type vent technology can only save vapour losses if no substantial leakage occurs, it should be the goal of every operator to use devices which have an extremely low leakage rate. Among other things the leakage rate depends on the size of the device (Table 1). Depending on set pressure, the leakage rate is measured at a test pressure of 75%, 80%, 85% or 90% of the set pressure (Table 2). Therefore leakage rates often are not comparable. For pressure settings lower than 10 mbar (4.0 in. wc), a low leakage rate is only achievable with a proper design (FEP to metal sealing) and a high quality.

In addition to the previously mentioned vent standards, the full lift type pallet technology has advantages in nitrogen blanketing applications (Figure 6). For example, in the US typical set pressures of nitrogen blanketing, regulators are 1.8 mbar (0.72 in. wc), the MAWP of the tank is 5 mbar (2.0 in. wc), that means a 100% overpressure pallet has to be set at 2.5 mbar (1.0 in. wc). Considering the blow down, the vent closes below 1.8 mbar (0.72 in. wc), therefore the pallet floats if the nitrogen regulator has opened once. This results in expensive losses of nitrogen. With the full lift type technology the vent can be set higher and reseats above the nitrogen regulator set pressure. In this way nitrogen losses are reduced and vapours are saved. A blow down of 0%, as mentioned in API 2000, table C-1 (operating characteristics of venting devices), is only a theoretical value and can never be achieved in reality.

## Conclusion

To fulfil such severe demands as of the German clean air act, it was necessary to develop state of the art vent technology, with improved sealing capabilities and vapour reduction potential by also increasing the application range of the devices. The goal was met through vents which only need 10% overpressure before reaching full flow performance. Through this design feature, vents can be set closer to the maximum allowable operating pressure and working cycles, which reduces vapour losses to a minimum.

In addition to the vapour loss reduction the new technology also reduces blanketing gas losses. In a lot of cases devices typically sold need 100% overpressure to full lift. Some designs already feature 50% overpressure to full lift. However, in both cases blow down does occur, and if the blow down value is not known, especially in API 650 applications, the reseating pressure may fall below the set pressure of the blanketing gas regulator. In this case the blanketing gas regulator will not reseat and excessive blanketing as bleeding can be the result. An additional design advantage of the full lift type technology is the higher flexibility in setting the vent closer to the set pressure of the emergency relief vents without forcing these into the chattering zone.

With the presented vent technology, plant venting installations are beneficially improved by saving vapour and nitrogen losses. Furthermore, low leakage rates achieved through accurate manufacturing and quality control help to meet more stringent EPA requirements. Considering the best available practice ensures safe operation for the benefit of the environment and in addition reduces financial losses.

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3. API Standard 2000 'Venting Atmospheric and Low - Pressure Storage Tanks' Nonrefrigerated and Refrigerated, Fifth Edition, April 1998, API publishing Service Washington, DC 1998.