

PRESSURE RELIEF CONSIDERATIONS FOR LOW-PRESSURE (ATMOSPHERIC) STORAGE TANKS

Tony Ennis

HAZTECH Consultants Ltd. Meridian House Business Centre, Road One,
Winsford Industrial Estate, Winsford Cheshire, CW7 3QG, Telephone +44(0)1606 553840,
Facsimile +44(0)1606 594144, www.haztechconsultants.com

Many storage tanks currently in use in the chemical and related industries are designated as “atmospheric” storage vessels. Experience with the design of pressure relief systems on such vessels has shown that the design and basis of safety for pressure relief of atmospheric tanks is often misunderstood leading to situations where the tank may be subjected to pressures outside of the design limitations.

This paper provides a summary of the design requirements for low-pressure storage tanks especially relating to the design and sizing of pressure relief systems. The various pressure relief cases applicable to storage tanks are considered and the appropriate sizing calculations discussed in order to provide safe venting of the system.

Various types of pressure relief arrangements are described and their application to differing process conditions and materials is discussed. The key differences between the various types of pressure relief devices and systems are highlighted in terms of the relevance to the storage of flammable and toxic materials. The design and use of nitrogen purging and padding and flame arresters on vents is also examined.

INTRODUCTION

In this paper, the term “tank” means atmospheric or low-pressure storage tank unless otherwise specified. It should be noted that this paper relates to only fixed roof tanks and specifically excludes floating roof construction.

Many bulk storage tanks used in the chemical and related industries are described in their documentation as having “atmospheric” design pressure. This is something of a misnomer because the tank has to operate both above and below atmospheric pressure to cope with inbreathing and out-breathing flows. Thus, “atmospheric” storage tanks should properly be described as “low-pressure” tanks. Typically this term refers to tanks having design pressures in the range of +56 mbar to –6 mbar although this may be extended to +140 and –10 mbar in some cases. Diagram 1 shows a graphical representation of the various pressures important for low-pressure tanks.

These vessels are very weak in terms of their resistance to pressure and particularly to vacuum and hence are subject to rigorous design restrictions in terms of their normal breathing requirements and also in terms of emergency pressure and vacuum relief. Indeed, these vessels may be damaged by under- or over- pressure situations that could be completely neglected in “normal” process vessels.

Many LP tanks have suffered terminal damage due to poor design of venting systems and lack of understanding of design and operational constraints. Damage usually occurs due to under-pressure rather than over-pressure because of the extremely limited vacuum resistance of these tanks which, in smaller sizes, may be constructed from plate as thin as 3–4 mm.

At best, damage may result in permanent distortion to the tank and at worst in the total destruction of the tank with loss of containment of the contents. This paper is not intended to provide detailed calculation methods as these can be found in the relevant standards which are included as references. This paper is intended to give an overview of the main factors relating to the design of pressure relief systems fitted to atmospheric and low-pressure storage tanks. It should be noted that refrigerated storage tanks are outside the scope of this paper due to their more complex nature given space limitations.

TYPICAL INCIDENTS

A cone-roof atmospheric storage tank was taken out of service for repairs. As part of the re-commissioning process, the tank was filled up to the overflow level with water in order to check for leaks. The contractor had instructions to drain the tank of water using the 4" valve located at the base of the tank. In order to speed up the draining process however, the contractor decided to simply remove the 24" access manway at the bottom of the tank completely. The tank venting arrangements were not capable of coping with the flowrate of water through a 24" hole and the tank was destroyed due to the vacuum created.

A hot aqueous process stream was wrongly directed to a tank full of cold hydrocarbon. The heat input from the aqueous stream caused rapid vaporisation of the hydrocarbon which then over-pressured the tank and caused a failure of the roof seam.

A tank was vented via a lute pot arrangement. The lute pot was originally filled with low viscosity mineral oil but due to a misunderstanding was topped up with water. The water froze in the bottom of the lute thus sealing the main vent line and the tank roof seam ruptured when liquid was pumped in.

GENERAL RELIEF DESIGN PHILOSOPHY

A clear understanding of the design philosophy for protection of the tank against over- or under- pressure is required to ensure safety. Without understanding the basic reasons of how and why the tank must be protected an efficient relief system cannot be designed and installed.

It is necessary that all low-pressure vessels should be protected by a suitable device or combination of devices that will prevent the pressure from exceeding the maximum design conditions specified. (It may be possible to protect using instrumented protective systems but these are outside the scope of this paper.)

At all times, the principles of Inherent Safety should be considered:

- Can the source of over- or under-pressure be eliminated
- Can the magnitude of the effects be reduced

- Can the hazard be contained thus removing the need for a relief system (unlikely for a low-pressure tank)
- Minimise the size of relief system required

APPLICABLE STANDARDS & GUIDANCE

There are numerous standards applicable in some way to the design of low-pressure storage tanks. In terms of the design and fabrication of the tank, BS 2594, BS 2654, API 620 and API 650 are the most commonly used.

API 2000 is the most commonly used standard for the calculation of pressure relief in tanks. API 520 and 521 are aimed more towards pressure vessels than low-pressure tanks. Some very limited guidance may be found in Parry although it should be noted that there were some errors in the earliest copies of this work. Lees, however, appears to have little information on the design of relief systems for tanks.

Thus, whilst there are several standards relating to the design of various components such as the tank itself, and the various fittings, there is extremely little guidance on the integration of these components into an efficiently functioning system.

IDENTIFY RELIEF CASES

There are five possible “Primary Events” which could cause a requirement for pressure relief:

- A. External fire
- B. Process abnormality
- C. Equipment or service failure
- D. Changes in ambient conditions

There are also four plant or process conditions which might lead to a relief requirement:

1. **System boxed in** – inlets and outlets both isolated but system subject to energy input (most commonly heat transfer)
2. **Restricted outlet** – maximum outlet flow less than sum of potential inflows and rate of expansion or vapour generation within the system
3. **Restricted inlet** – maximum inflow less than the sum of potential outflows and rate of condensation or contraction of tank contents
4. **Chemical reaction** – a chemical process taking place in the tank causing a rise or fall in pressure within the system i.e. at a greater rate than vents can cope with

ESTIMATE RELIEF DEMAND FLOWRATE (RDF) FOR EACH CASE

Each of the Primary Events (A–D) needs to be considered against each of the Process Conditions (1–4) in order to identify all possible events leading to over- or under-pressure in the system. Using the 4×4 matrix of cases thus developed, the required RDF can be determined for each case.

When determining the RDFs, it is recommended that the worst case conditions for weather are used and that, where applicable, a safety margin is added to the calculated RDF.

SCREENING OF CASES

It is essential to differentiate between normal operational requirements and emergency venting cases because emergency relief cases may have significantly greater flow requirements than the greatest normal venting flow and therefore require special venting arrangements.

It should, however, be noted that it is not generally practicable to design LP tank vents to relieve internal fire, explosion or chemical reaction or “roll over” effects caused by mixing of layers having different temperatures or compositions. These cases have exceptionally high Relief Demand Flowrates. In these cases, it may be necessary to specify a tank design having a frangible roof or weak roof to shell seam in order to minimise the amount of damage to the tank. Obviously, the failure of a frangible roof or tank roof seam is a serious event in itself and this form of emergency pressure relief system should be regarded as a last resort because the tank will require considerable time and money to repair, if economic repair is even possible.

API 2000 states that for tanks having frangible roof to shell attachments emergency relief venting need not be provided. The author does not necessarily agree with this view because there are a number of foreseeable situations where emergency relief may be justified without resorting to lifting the tank roof. Wherever possible, non-destructive emergency relief systems such as lifting manway lids should be employed to deal with any frequently occurring scenarios and the use of a frangible roof should be restricted to relief situations such as internal explosions or roll-over for which it is not practicable to provide sufficient relief area by any other means.

The relief requirement may be grouped into the following four types:

1. Exposure to thermal radiation from external fire
2. Movement of liquid into or out of the tank
3. Normal tank breathing due to changes in atmospheric conditions
4. Equipment failures and operating errors (including utilities)

EMERGENCY RELIEF CAUSES

1. Failure of internal heating system e.g. steam coil
2. Failure of vent treatment system e.g. condenser, carbon absorption unit
3. Utility failure (resulting in failure of valves etc.)
4. Chemical reaction
5. Exposure to external fire

INERT GAS PADDING

Many storage tanks are padded with an inert gas e.g. to prevent the formation of a flammable atmosphere or prevent oxidation of the contents. The inert gas system

needs to control the pressure in the vessel within the design limits of the tank. It is usual to use an inert gas pad in combination with either a Pressure/Vacuum Valve (PVV) or lute pot system to prevent unrestricted losses of the pad gas. The padding system is set to maintain the tank pressure between the pressure and vacuum relief settings of the pressure relief device. A typical inert gas padding system is shown in diagram 2.

The IP Nitrogen supply usually operates in the range 50–100 psig and it is necessary to drop this in two stages to the tank pressure. The LP main usually operates in the range 5–10 psig and may supply gas to several tanks. Manual maintenance valves on the pad gas supply are usually locked open to prevent inadvertent closure and a Permit To Work is required to close them.

It should be noted that the padding system may also have to be used to purge the tank after maintenance. For this, a bypass arrangement is often installed as shown in the diagram. The bypass is usually locked closed since it is only required during maintenance. Again, operation is by PTW only. A restrictor orifice is required in the purge gas line to prevent overpressurisation of the tank and must be sized such that the maximum purge gas flow is less than the relief capacity available taking into account any other outbreathing requirements that might be occurring simultaneously with the purge. It is good practice to arrange the branches such that the purge gas enters the tank at the opposite side from the vents in order to promote sweeping oxygen out of the tank.

A Low Pressure alarm is often installed on the tank to warn of the potential ingress of oxygen. This may also be configured to trip certain pumping operations to prevent air ingress. Oxygen analysers may also be installed on the tank and/or LP Nitrogen main where oxygen content is critical. Analysers may also have alarm and trip functions in certain cases.

LIQUID OVERFILLING

It is practically impossible to eliminate the risk of overfilling a storage tank by instrumented protective systems (IPS) e.g. high-level alarms and trip systems, and hence it is normal to install a liquid overflow. High integrity IPS can be used but are generally considered too expensive for this type of application.

Liquid overflow provision is therefore usually provided in the form of a branch on the vertical wall of the tank below the roof joint. The branch and any of the associated disposal pipework must be large enough to cope with the maximum foreseeable liquid inflow whilst maintaining the liquid level below the roof joint. It should, however, be noted that this type of overflow protection cannot be used for low temperature storage tanks.

Where tanks are nitrogen padded, or the vapour is hazardous, some sort of seal is required to prevent venting from the overflow. Thus, the overflow may be protected either by a lute pot or a bursting disc or, one of the existing venting devices may be utilised for liquid venting. Lute pots and their associated design features are described below. If

a bursting disc is installed on the overflow line then provision has to be made to prevent condensation in the overflow leg from building up and rupturing the disc.

It is, in some circumstances, permissible to use one of the existing tank relief devices e.g. a PVV to vent liquid in the case of overflowing however this requires careful consideration of:

- The requirement for venting both vapour and liquid simultaneously
- The liquid relief capacity of the device
- Pressure (hydrostatic head plus maximum operating pressure) on the roof of the tank has to be sufficiently low to prevent rupture of the roof seam
- Maximum pressure during venting must also be less than the uplift pressure required to lift the tank roof plus walls
- Disposal system for vented liquid

PVVs are designed for gas / vapour flow and not specifically for liquids. Some manufacturers may not be able to provide data for the performance of the valve under liquid flow conditions. The use of PVVs for liquid flow is not generally recommended for this reason and also that any liquid flowing from a PVV will flow over the top of the tank in an uncontrolled manner.

In general, experience has shown that the normal venting system should not be combined with the liquid overflow because it can result in the improper operation of one or both functions. The most common failure experienced with combined systems is the tank being sucked in due to siphoning of liquid down the overflow. It is also possible to overflow the tank if two-phase flow occurs in the overflow line since the flow capacity of the line in the two-phase flow regime may well be significantly less than under liquid flooded conditions.

Disposal of the liquid overflow also requires careful consideration in order to minimise both safety and environmental impact of any emissions.

PRESSURE RELIEF CALCULATIONS

Basic calculation methods for calculating required relief rates are given in API 2000.

Experience has shown that the requirements for normal process inbreathing may not be adequate for all situations, especially for weak vessels. On this basis it is recommended that a safety factor of 50% be added to the required relief flowrate.

It should be noted that API 2000 covers tanks operating in the range of full vacuum to 15 psig (+1034 mbar).

FIRE RELIEF

For the case of fire relief, a number of reductions may be made to the heat flux received by the tank as follows (based on bare tank value = 1.0):

No.	Description	Factor
1	Fire insulation (specifically designed for fire insulation and capable of handling thermal shock and impact of fire water)	0.3
2	Graded area sloping such that liquid is removed from the area of the tank (slope at least 1 in 40)	0.5
3	Water drench system	No reduction
4	Rapid emptying facilities	No reduction

No reduction is allowed for (3) or (4) because of the inherent unreliability of these systems which have an extremely low demand rate and are often non-functional when a real demand occurs. If (1) and (2) are used together then a factor of $0.3 \times 0.5 = 0.15$ may be applied subject to judgement as to the particular circumstances that apply.

FLOW INTO OR OUT OF TANK

This requires calculation of the maximum credible flows into or out of the system taking into account any restrictions such as restrictor orifices, non-return valves and the discharge coefficients (CVs) of any control valves. The physical properties of the materials flowing into or out of the system are also important, bearing in mind that the physical properties of flows from another source may differ significantly to the material in the tank. The characteristics of any pumps also need to be taken into account, in particular the variations in the pump curve under abnormal conditions.

The calculations need to be carried out for each high-pressure source that is identified as being capable of causing inflow to the tank. It must be assumed that:

- All valves have failed fully open
- Single non-return valves have failed completely, double non-return valves have up to 10% of the flow area available
- Trip systems fail to danger i.e. condition having the highest relief rate requirement
- Pumps, compressors etc operating at maximum design condition

For blocked outlet conditions, it is assumed that all outlet routes are completely blocked. The flows from all credible simultaneous events need to be summed to find the maximum RDF. Common mode failures must be taken into account.

Heat input from the flows into the tank also need to be considered when calculating the required relief rates.

AMBIENT HEAT TRANSFER

This heading covers heat transfer due to such things as:

- Solar heating
- Cooling due to rain falling on a hot tank

- Wind cooling
- Fall in ambient temperature

Solar radiation in the UK is typically in the order of 400 – 500 W/m². (API RP 521 uses a figure of 1000 W/m² for latitudes 40°S to 40°N, the UK lies between 50 and 60°N). For preliminary estimation, a figure of 1000 W/m² is recommended since the resulting relief rate is usually very small when compared to other flows. A more exacting approach may be justified in some circumstances. It should be noted that equipment surface temperatures of 30°C above ambient can be reached at times of high solar radiation, in the UK, however, this is more like 15–20°C.

Loss of heat due to rain falling on a warm tank or sudden cold wind can cause a relatively large inbreathing requirement. It should be noted that for small tanks (less than about 300 m³ capacity) API 2000 may underestimate the breathing requirement. It is therefore recommended that a minimum rate of 50 m³/h should be used for all tanks of less than 300 m³ liquid capacity. In practice this is readily achievable without using an excessively sized relief device. For larger tanks, API is considered adequate.

TYPE OF RELIEF DEVICES

PRESSURE / VACUUM VALVES (PVVS)

PVVs are commonly used on tanks containing flammable liquids because they allow for the use of inert gas padding systems. It should be noted that the operating characteristics of PVVs differ significantly from traditional pop type safety relief valves in that:

- There is no “pop” characteristic i.e. the valve starts to open slightly at the set pressure (as distinct from a traditional pressure relief valve which pops wide open at the set pressure and reaches the design capacity at 10–30% overpressure)
- The valve lift is proportional to the pressure drop across the valve and the flow is proportional to the pressure drop across the valve and thus the valve lift
- It is permissible to operate a PVV in the fully open condition with a pressure above the valve maximum opening pressure

PVV manufacturers supply operating curves for their products in order to allow for optimum sizing to meet relief requirements. These should be used when specifying the relief device in order to ensure that it meets the complete range of operating requirements.

BURSTING DISCS

Bursting discs are not generally used on low-pressure tanks because of the difficulty in manufacturing them accurately for the low pressures required. Typically, bursting discs designed for rupture pressures of less than 500 mbar have a tolerance of 25–30% on the rupture pressure. This is not generally acceptable for LP tanks as it can result in overpressure. Lower tolerance discs can be manufactured to special order but experience has shown that these are difficult to obtain, subject to manufacturing difficulties and therefore

tend to be very expensive compared to discs designed for higher pressures. Bursting discs can, however, be used successfully in certain circumstances for emergency relief with tanks constructed to API 2000 where the design pressure is up to 15 psig. Obviously, with a bursting disc, once ruptured, the vent cannot be re-sealed, which may result in air ingress and consequently an explosion hazard. Thus, bursting discs are generally only recommended for emergency relief situations.

LUTE POTS

Lute Pots are often used to provide a similar effect to PV valves where the tank is equipped with an inert gas blanket. There are, however, several issues with lute pots which means that they are often not as effective as intended:

- Pressure surge in the tank can cause ejection of the lute pot liquid seal and consequent seal failure ^{Ref:}
- The liquid seal can freeze causing blockage of the vent line
- Seal liquid can become contaminated by the process fluid causing polymerisation, solidification or chemical hazards
- Seal liquid can evaporate over a period of time causing loss of seal pressure and wastage of pad gas

The traditional design of lute pot with a pot diameter equal to twice the vent line diameter is particularly prone to ejection of the seal liquid under surge conditions due to entrainment of the seal liquid. References 10 and 11 offer good design guidance to prevent this occurring. Diagram 3 shows a typical conventional lute pot and diagram 4 one of improved design based on Reference 10.

The design of lute pots is a complex issue and it can be clearly seen they are not suitable for many circumstances. If lute pots are used then they must be frequently inspected and the liquid level and composition checked and maintained as necessary.

Lifting Manway Lids are generally regarded as an emergency vent only since they are suitable for large flows. They are not generally used as normal process vents because of the potential for ingress of air into the tank. Manway lids are not generally available for vacuum relief. Probably the most common use of manway lids is for the fire relief case which tends to be larger than other relief scenarios.

Liquid Overflow Systems for low-pressure tanks need suitable consideration and it is not generally acceptable to allow for simultaneous liquid and gas flow in a vent line unless the line is specifically designed to cope with these conditions. Failure to apply the correct design criteria to a two-phase flow combined overflow and vent may result in over- or under-pressure of the tank.

It should be noted that lute pots can be set to relieve either pressure or vacuum but operate effectively as check valves in the opposite condition i.e. they do not allow for back flow through the lute. The examples shown below are designed for pressure relief and will not pass any flow under vacuum conditions.

FLAME ARRESTERS

In many applications, flame arresters are applied to the vents of tanks containing flammable liquids (usually where not inert gas padded). Flame arresters may be used on normal vents but should not generally be used on emergency vents because of the potential for blockage of the arrester element. Blockage may be caused by polymerisation, corrosion or even birds' nests.

The effect of the flow resistance of the flame arrester needs to be taken into account in the design of the vent, especially under inbreathing conditions where the pressure differential is extremely limited. Arrester manufacturers can advise on the pressure drop under various conditions. It should be noted that Lute Pots can also be used as flame arresters but are subject to severe design restrictions.

It has been stated elsewhere that flame arresters are not necessary when PVVs are installed on non- inert gas padded tanks. The author does not subscribe to this view since the turbulent flame speed can be greater than the flow velocity through the PVV under some conditions. Thus there is a possibility that an ignition may pass back into the tank. If tanks are not inert gas padded then a flame arrester should be fitted to all normal process vents. It is not generally practicable to equip emergency vents with flame arresters due to the size of flows and potential for blockage of the arrester and hence it is essential that normal process vents and emergency venting scenarios are

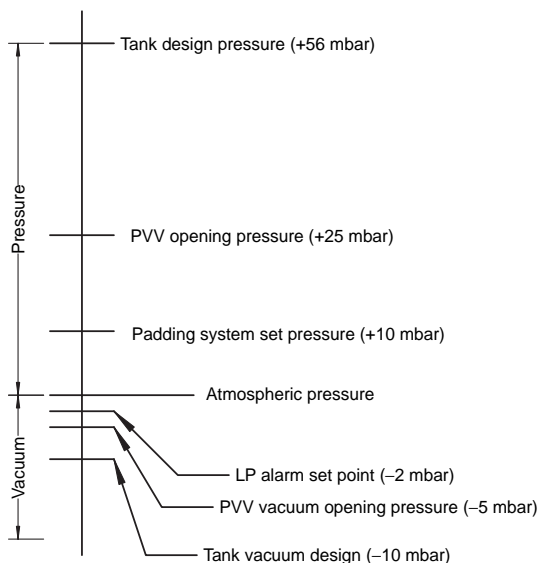


Figure 1. Operating & design pressure chart

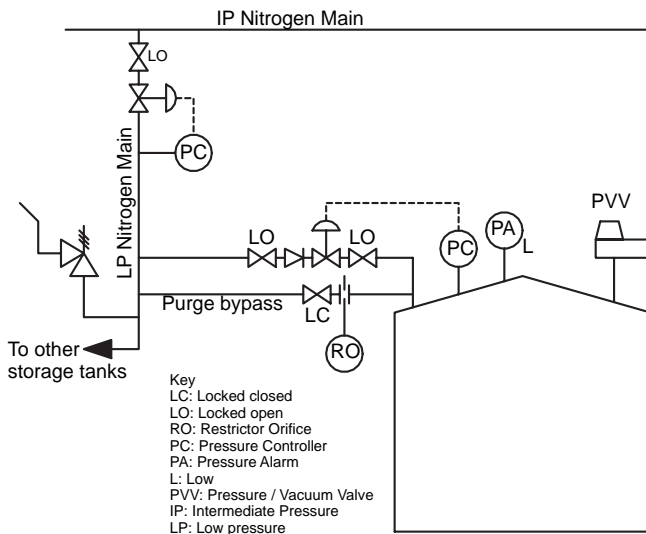


Figure 2. Design of inert gas padding system

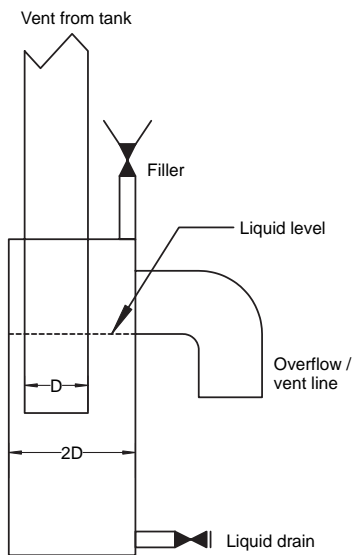


Figure 3. Typical lute pot

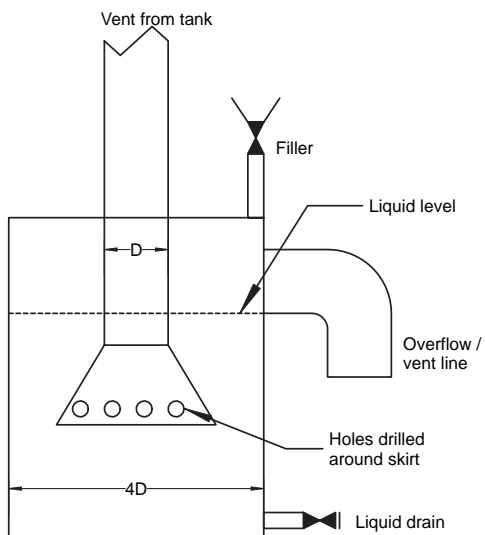


Figure 4. Improved lute pot design

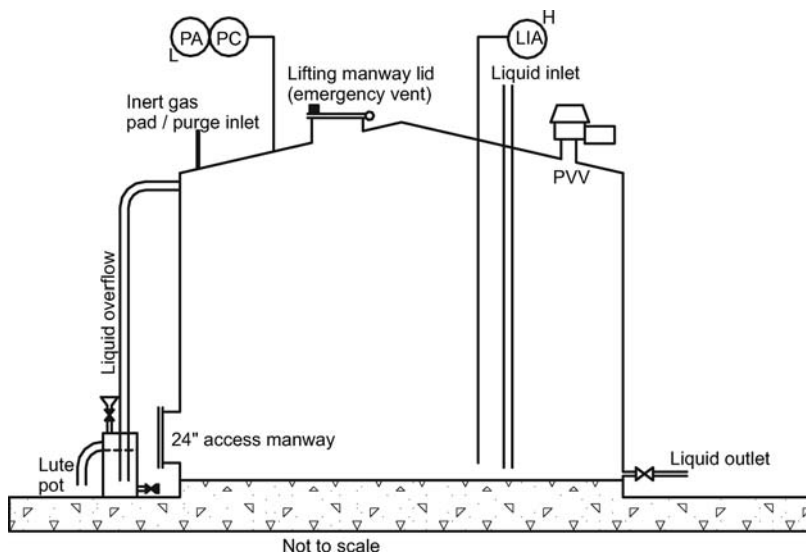


Figure 5. Typical LP storage tank configuration

properly identified at the initial design stage. A number of designs that effectively combine the functions of a PVV and flame arrester are now available commercially.

SUMMARY

The design of pressure relief systems for use on atmospheric and low-pressure storage tanks is more complex than often imagined. Whilst the basic RDF calculations may be found in the literature, principally API 2000, experience has shown that the fundamentals of the basic design features of pressure relief for tanks are often poorly understood. In particular, the identification of relief cases and the differentiation of normal process relief vents and emergency vents are critical steps in relief system design.

This paper has attempted to clarify the methodology required to clearly identify pressure relief cases and also some of the key features of pressure relief design. A typical design of tank with inert gas padding is shown in diagram 5.

It should, of course, be noted that any tank design should be subjected to a full Hazard Study process prior to construction or modification.

REFERENCES

1. Parry CF: Relief Systems Handbook 2nd Edition; 1994 Reprint; IChemE
2. API 2000, Venting Atmospheric & Low-Pressure Storage Tanks, Nonrefrigerated & Refrigerated; 5th Edition, April 1998
3. API RP 520 Parts 1 & 2; API 520-1 Sizing, Selection, and Installation of Pressure-Relieving Devices in Refineries; Jan 2000
4. API RP 521: Guide for Pressure-Relieving and Depressuring Systems; Mar 1997
5. API 620: Design and Construction of Large, Welded, Low-Pressure Storage Tanks, 10th Edition Mar 2002
6. API 650: Welded Steel Tanks for Oil Storage; Nov 1998
7. BS 2594; Specification for carbon steel welded horizontal cylindrical storage tanks; 1975 (Partially replaced by BS EN 12285-1:2003)
8. BS 2654
9. BS 4741
10. McAuley S; The Operation of Lute Pots, Research Project 1/5/96; University of Edinburgh, Dept of Chemical Engineering
11. Overhoff K-H et al; Investigation for the design of a new water trap flame arrester; 6th International Symposium Loss Prevention & Safety Promotion in the Process Industries, Paper 54, pp1-15, 19-22 June 1989, Oslo
12. Ogle RA, Schumacher JL; Investigation of steam explosion in a petroleum product storage tank; Process Safety Prog; Vol.17, No.3, pp171-175, 1998
13. Nevers N; Vacuum collapse of vented tanks; Process Safety Prog, Vol.15, No.2, pp74-79 1996
14. Lees FP; Loss Prevention in the Process industries; 2nd Edition.