

POTENTIAL FOR FLASHBACK THROUGH PRESSURE/ VACUUM VALVES ON LOW-PRESSURE STORAGE TANKS SYNOPSIS

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Low pressure or “atmospheric” storage tanks are commonly used for the storage of flammable hydrocarbons. In order to minimise losses of volatile organic compounds to the environment, these tanks are often fitted with pressure / vacuum valves (PV valves). These enable the tank to operate at pressures typically between +56mbar and -6mbar before the valve opens.

The atmosphere within the tank is often in the flammable region and hence during outbreathing, the vapours vented from the PV valve are also flammable. These may be ignited by an external ignition source such as static discharge or hot work occurring near the vent. The common assumption has always been that the tank would be protected from internal explosion by the presence of the PV valve on the basis that the flame could not pass back through the valve.[1]

This paper presents the opinion that ignition can, in fact, flash back through a PV valve based on consideration of flame speed, minimum experimental safe gap (MESG) and flow rates. Experimental work done by Protego will also be presented demonstrating that flashback can occur, especially under conditions of continuous venting. It is therefore recommended that consideration should be given to installing a flame arrester on tanks protected by a PV valve.

INTRODUCTION

Low pressure or “atmospheric” storage tanks are often used for the storage of flammable materials i.e. those with flashpoints of less than about 50°C. Thus, under normal operating conditions it is normal for there to be a flammable atmosphere inside the tank. In order to minimise vapour losses from the tank,

Taking into consideration the normal operation of LP storage tanks, it can clearly be seen that vapour will be periodically vented from the tank to atmosphere. The volume and flowrate of the emission will be dependent upon a number of factors such as:

- Pumping in (filling) rate
- Diurnal temperature changes
- Internal heating

Under certain conditions, flammable vapour may be vented from the tank for considerable periods, especially for larger tank sizes. Thus, there will be a cloud of flammable material vented, generally at high level, over the roof space of the tank.

In particular, during filling of a tank with a flammable liquid e.g. Hexane or similar, it is possible that a flammable mixture could be vented for a period of more than 30 minutes.

LOW PRESSURE STORAGE TANK DESIGN

One of the key features of these tanks is that they have extremely limited resistance to pressure with typical design limits of +56 and −6 mbar. Although these are the nominal design limits, tanks will, in practice, often withstand approximately +100mbar and −10 mbar. API 650 gives 100 mbar internal design pressure and more under fire relief cases. EN 14015 gives a test pressure of 100 mbar, a pressure often used as the full ope ning pressure for PV Valves. API 620 also allows 100 mbar Maximum Allowable Working Pressure and up to 120 mbar for fire relief. Ultimate protection for these tanks is provided by frangible roof seams. Note that each of these standards uses slightly different terminology.

Thus, compared to traditional pressure vessels, it can be seen that low-pressure tanks are very fragile. This causes certain design problems, especially in the design of pressure relief systems. Pressure and vacuum relief devices need to function with a minimum of pressure drop if required flowrates are to be achieved with reasonably sized devices.

It is often required to minimise emissions from tanks by minimising the amount of venting that takes place. This is achieved by maintaining the tank between the maximum and minimum design pressures. Thus, a relief device is required. Typical pressure relief devices are either lute pots or PV Valves. Lutes have generally fallen out of favour because of the inherent problems of maintaining the liquid seal and the attendant pollution problems. See diagram 1. The other method for maintaining a limited pressure in the tank is the Pressure/Vacuum Valve. These are now commonly used throughout the chemical and associated industries and are the standard method of minimising vapour emissions.

An internal explosion of a stoichiometric hydrocarbon mixture will generate pressures in the region of 7–8 bar (if totally confined in a strong vessel). A low-pressure storage tank will explode at a much lower pressure. It is not feasible to design storage tanks to withstand this level of internal pressure, especially in larger sizes. It is, therefore, necessary to provide some form of protection against an external ignition entering the tank via the vent lines. External ignition can occur due to several reasons:

- Electrostatic discharge e.g. lightning
- External hot work e.g. maintenance
- Failure of external electrical systems e.g. lights, instruments
- Portable electrical equipment e.g. misuse of mobile phones
- Impact spark e.g. due to dropping tools

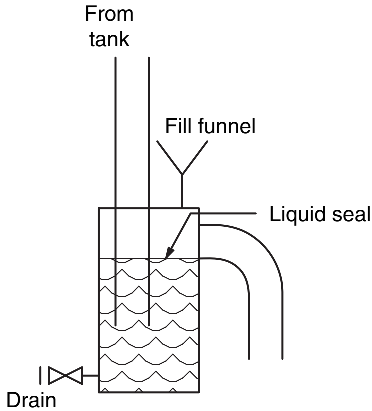


Diagram 1. Typical lute pot installation

FLASHBACK PROTECTION

It has always been assumed, at least within the UK, that protection against the flashback of an ignition into the tank is provided by the provision of a Pressure / Vacuum Valve (PVV) on the vent line. This has generally been endorsed by the HSE[5] with the result that the vast majority of tanks containing flammable materials which are equipped with PV valves do not have associated flame arresters in the vent line. A typical PV Valve configuration is shown in Diagram 2 below. Operation of the valve under pressure and vacuum are shown in diagrams 3 & 4.

Theoretically, in order for the protection to be effective, one of two conditions must be met as follows:

Either:

The velocity through the valve must be greater than the turbulent flame velocity

Or:

The gap between the valve pallet and the seat must be less than the Maximum Experimental Safe Gap (MESG)

Some typical MESG values are:

Gas	MESG (mm)
Propane	0.965
Methane	1.14
Ethylene	0.65
Hydrogen	0.50
Hexane	0.95
Cyclohexane	0.94
Ethyl acetate	1.04

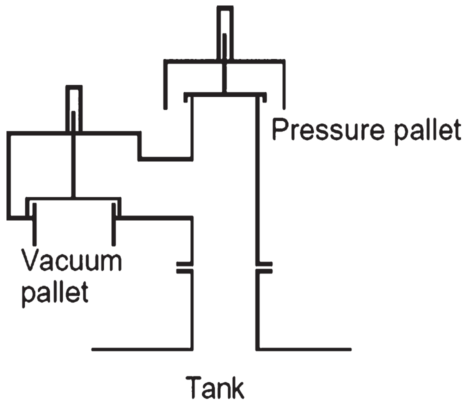


Diagram 2. Typical PV valve configuration

It can be seen that these values are a maximum of just over 1mm.

Note: The MESG is the largest gap through which a flame will not pass. This parameter is used in the specification of flame arresters to ensure that a flame will not pass through the arrester. MESG is measured for stoichiometric mixtures (the worst case).

Taking a typical 3″ (75 mm) diameter PV valve, the opening for the pallet is in the order of 2″ (50 mm) at a flow in the order of 600 m^3/h[6]. It can be seen that the opening is far greater than the MSEG and thus it must be assumed that, if the flame has sufficient velocity, it may pass back through the PV Valve.

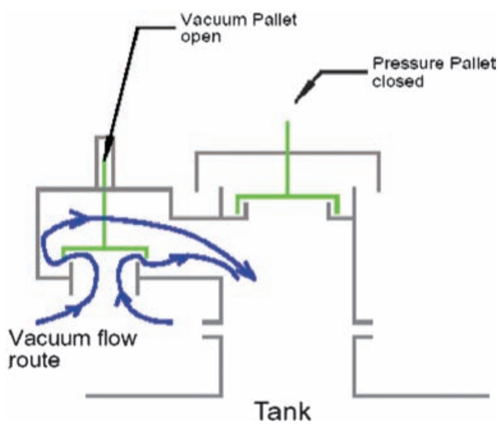


Diagram 3. PV valve under vacuum

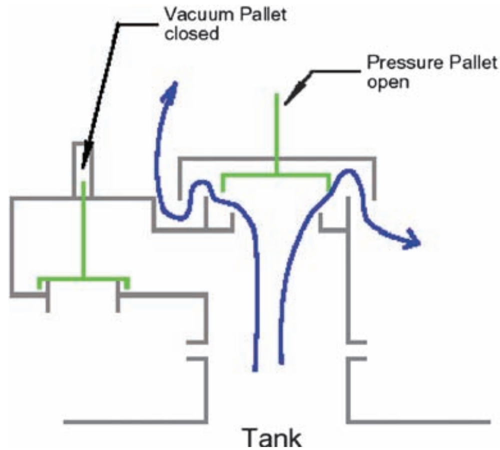


Diagram 4. PV valve under pressure

A 2″ (50 mm) pallet lift gives a superficial gas velocity in the order of 14 m/s through the valve based of Protego flow capacity charts for the DN80/3" valve[6], although this could be significantly less for lower tank design pressures where higher lift is required for to achieve the desired flow under normal operating conditions. It can be seen that this is a relatively low velocity for turbulent flame speed. In fact, the superficial gas velocity through the valve could be as low as 2-3 m/s with a lift of 5mm or more, considerably more than the MESG.

BURNING VELOCITY & FLAME SPEED

A key consideration in the transmission of flame through the valve is the velocity at which the flame propagates. There are two factors involved in this, these being the fundamental burning velocity and turbulent burning velocity. The fundamental burning velocity (sometimes known as the laminar flame speed) is a constant of a given flammable mixture and is the speed at which a flame will travel in a laminar flowing mixture. Typically, these are in the region of a few cm/s for most common hydrocarbons and somewhat higher for hydrogen. Some examples for common materials are[7,8]:

Methane/air = 35 cm/s
Propane/air = 45 cm/s
Hydrogen/air = 350 cm/s
Acetylene/air = 158 cm/s

Fundamental burning velocities are measured under strictly controlled conditions where the flow of the gas is strictly controlled to ensure a laminar and linear flow through the measuring apparatus, normally a long straight tube. Measures are taken to ensure that the gas flow is as laminar as possible, including a very smooth tube wall and a long, straight upstream tube.

Laminar flame speed, is, however, of little use in a real-world situation such as lowpressure tank vents because the nature of the flows and equipment that are in use are far more likely to result in turbulence within the gas mixture. The key factor in the transmission of the flame is the turbulent flame speed. The turbulence of the gas mixture has a significant effect on the flame speed as does the degree of confinement. Turbulent mixtures in confined spaces (such as pipelines) can reach speeds of 300 m/s.

Turbulence in the gas will increase the flame speed since the size of the flame front will be increased by eddies resulting in increased reaction rate. Increased reaction rate and flame speed form a positive feedback loop by causing an increase in turbulence and hence the flame can accelerate. In extreme cases, flame speeds of greater than 1000 m/s can be reached in long pipelines where deflagration can transition to detonation.

In practice, under real-world conditions, there is always a degree of turbulence associated with venting from tanks. Considering a typical LP tank vent system configuration it is clear that under many of the flow conditions that may commonly occur the flow through the system will be turbulent. The turbulence will be caused partially by the changes in section and direction within the system and partly related to the velocity (as the Reynolds number increases).

Note that these maximum velocities are achieved by near-stoichiometric mixtures and flame velocities do fall off away from stoichiometric mixture. However, flame velocities are still high enough to be greater than the flow velocity through the vent system (including the PV valve).

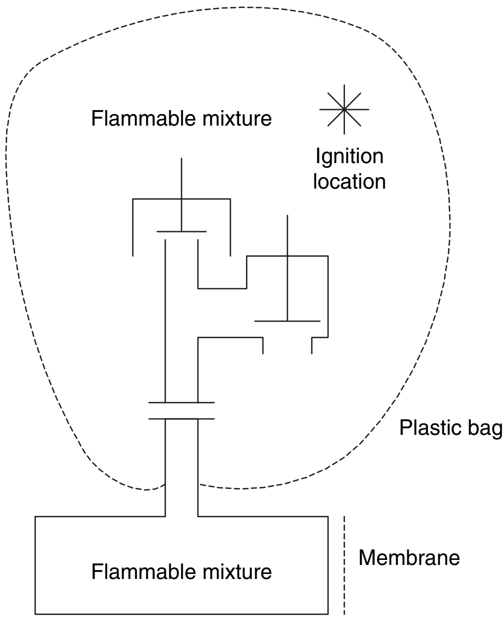
PROTEGO TESTS

Tests done on conventional PVVs by Protego in Germany indicate that PVVs may, in some circumstances allow an ignition to pass through the valve into the tank. Obviously, this would result in an internal explosion and destruction of the tank. Three tests are shown with this paper, these are as follows:

IGNITION IN GAS MIXTURE OUTSIDE CONVENTIONAL PV VALVE

In this test, a flammable gas mixture was held inside a polythene bag secured outside the test valve. The gas mixture was then ignited with both pallets of the valve closed. The flame accelerates through the mixture towards the valve and flashes back through into the vessel. In this case, the test vessel is a short section of open ended pipe. This simulates the remote ignition of a cloud of flammable gas that has been vented from the PV Valve. In this case, the cloud was confined in a polythene bag simply to prevent the dispersal of the flammable cloud. The bag does not have a significant effect on the flame propagation or behaviour.

The most likely source of the passage back into the vessel is via the vacuum pallet. Since the vacuum pallet is designed to open at pressures less of than −10 mbar, it is possible that the pressure outside the valve caused by the burning gas can lift the vacuum pallet against its' weight thus allowing passage of the flame, pressure outside the valve being equivalent to a vacuum inside.



It is known that vapour cloud explosion do not produce a great deal of pressure unless in congested or confined regions, it is, however, foreseeable that an energetic (near stoichiometric) gas mixture might foreseeably generate more than 10 mbar overpressure in the region of the valve, especially if the region around the valve is congested by pipework etc. The issue here is that ignition of a reasonably sized vapour cloud outside of and surrounding a PV Valve may foreseeably result in the generation of sufficient pressure to lift the vacuum pallet. This will then provide a clear route for the flame back into the vessel.

ENDURANCE BURNING

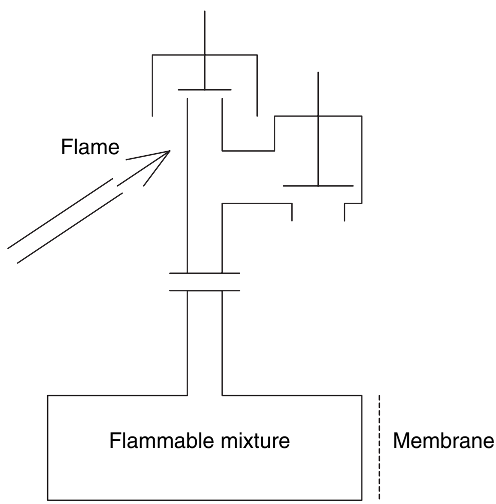
If vented material from the PV Valve continues to burn for an extended period then it is foreseeable that the valve cap, pallet etc will become hot. If this continues to the point at which the temperature of the metal reaches the autoignition temperature of the vapour then a flashback may occur. This test shows flashback through the valve occurring after approximately six minutes. Note that during this test the flame was not played directly onto the valve but was directed to one side and had no significant effect on the heating of the valve.

Thus, heating of the valve occurred solely as a result of the burning of the gas coming out of the PV Valve.

The reason for the ignition of the gas so quickly is that the pressure pallet is of light construction, as required for the duty, and thus will heat up comparatively rapidly. In the video it can clearly be seen that the steel valve bonnet reaches red heat very quickly. This item is generally constructed of light gauge steel since it is only there to provide weather protection. This kind of temperature will also rapidly destroy any polymeric seals on the pallet destroying the valve integrity.

It is noted that this circumstance does rely on the sustained ignition of the gas mixture leaving the valve and the resultant heating of the valve material. It is, however, foreseeable that there will be circumstances, such as during tank filling, where venting may occur for an extended period.

Thus, this is another event that may be considered credible, if a rare event.

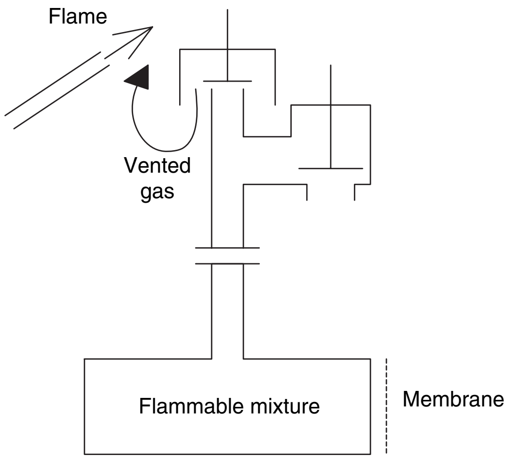


IGNITION OF VENTED GAS MIXTURE

In this test, a flammable gas mixture was vented from the PV valve with an ignition source located outside the valve and not impinging on the valve body. It can be clearly seen on the video that as the valve pallet lifts and flammable gas it vented, it ignites from the pilot flame. The flow of gas results in pallet lifts of approximately 25 – 30 mm. The flame resulting from the ignited gas is seen surrounding the valve. The pallet then drops back until another pulse of gas is emitted. This cycle occurs several times until the flame flashes back through the valve. The resultant pressure results in the destruction of the valve pallet and bonnet.

Since the pallet lift is clearly greater than the MESG of the mixture, the mechanism for transmission must be the turbulent burning velocity of the gas being greater than the superficial gas velocity leaving the valve.

This is considered to be a credible event since the combination of pallet lift and an external ignition source are a foreseeable combination.



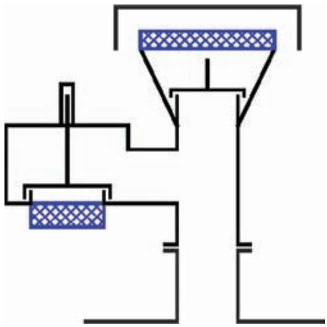
CONCLUSIONS

It can be seen that the installation of a PV Valve on a low-pressure storage tank containing a flammable vapour does not provide total protection against the flashback of an external ignition into the tank. The combination of the lift of the PV Valve pallet (which will, in the vast majority of cases be greater than the MESG of the vapour), the turbulent flame speed and the superficial gas velocity coming out of the valve can result in circumstances where it is theoretically possible for the flame to pass into the vessel.

Based on the tests conducted by Protego, is is clear that this theoretical consideration is, in fact, borne out in reality under test conditions. The test conditions used, whilst they might be considered to be arduous, are, in fact credible, especially in the third case where the ignition of the gases venting from the valve results in flashback into the vessel.

Equally of concern is the flashback through the valve occurring when the valve is closed (the first case) where ignition of an external flammable cloud flashes back through the vacuum pallet.

Thus, it is concluded that there is a small but significant risk of flashback through a PV Valve under conditions of external ignition. On this basis, consideration should be given to the provision of a flame arrester in the vent system in order to provide additional



Flame arrester elements shown in blue. Note that other configurations are possible

Diagram 5. PV valve with integral flame arresters

flashback protection. The flame arrester could be located either at the inlet to the valve (between the valve and the tank, Diagram 5) or else on the outlet of the valve.

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