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MANAGING OVERPRESSURE-MORE THAN SAFETY RELIEF PROTECTION

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SUMMARY

Overpressure protection of pressurized storage vessels handling pressure liquified gases should consist of a number of elements. These include not only proper sizing and selection of the relief devices but also a recognition that relief protection alone will not suffice under all overpressure incidents. This paper is written by an author whose experience has been gained in the refining and petrochemical industry and therefore reflects the practices of that industry. Devices are provided on all storage vessels sized for the events which could result from accidental overfill and external fires. However, in many cases, additional means of limiting overpressure are frequently employed. These will also be discussed. Industry practices are routinely updated as events and experience demonstrate such a need. Some discussion is devoted to relate proposed revisions in the applicable American Petroleum Institute (API) standards for overpressure protection.

INTRODUCTION

In order that a designer can provide for overpressure protection of vessels containing pressure liquified gases, an understanding is required of the potential changes that can occur with both the contents as well as the vessel during overpressure events. With a full appreciation for these changes, the designer has a number of options available to accommodate the overpressure. For the purpose of this paper, the events to be discussed are overfill, vacuum, and fire. Some liquids might experience an exothermic chemical reaction leading to overpressure if proper control is not maintained during storage. As the subject of run-away reactions is dependent on the properties of the liquids stored, this aspect of overpressure is not discussed.

There are a number of industry standards that address overpressure protection. Although they have the same typical events in mind, the overpressure protective device can vary in size due to variation in assumptions made as to the possible affect of the events and level of mitigating factors assumed. This paper is written primarily on the basis of practices followed within refinery and petrochemical facilities and as detailed within American Petroleum Institute (API) recommended practices.

PROTECTION DURING FILLING

The possible consequences from overfilling dictates careful evaluation of protecting the storage vessel in this event. A possible option, although usually not the economic choice for large storage vessels, is to design the vessel to withstand the maximum pressure from the filling operation. Assuming the vessel design pressure is not adequate, a pressure relief device is required sized to handle the liquid fill rate at the allowed overpressure condition.

In the past, the sizing and selection of pressure relief valves for liquid service was limited to using valves at less than optimum criteria. Until recently, many valves available for liquid service required about 25% overpressure in order to flow at a rated capacity, i.e., with full lift of the disc. In the case where the valve set pressure is equal to the vessel maximum allowable working pressure (MAWP), the accumulation is limited to 10%. In this case, the valve flow is limited by the lift of the disc and the valve size (orifice) selected must be somewhat larger. This results in a valve that limits the flow rate to less than optimum conditions and may be unstable. The designer should carefully select such valves making certain the valve is designed to operate reliably at the conditions specified.

The ASME code was recently modified to require flow test certification of liquid service relief valves. In recent years, relief valves have become available which are designed and tested to relieve liquids at 10% overpressure with full lift of the disc. As a result, more capacity is available in the same orifice sizes and the valves work reliably under vapor relief as well as liquid flows. The availability of such relief valves now makes it possible to fully satisfy the ASME code for all contingencies using a relief valve that is certified in both liquid and vapor service. Due to the increased capacity in the same orifice size, this has allowed increased design fill rates on existing facilities, without necessarily increasing the size of the relief valve.

Equally important as sizing and selection of the relief valve is the choice of method for disposing of the relieved fluid. Where feasible, a closed relief system is advocated by many. Such a closed system must be carefully designed to accommodate all the probable combinations of relief events. This requires evaluating the total liquid and vapor flow rates that are likely, the consequent backpressure on each relief device, the temperatures that will occur (especially where auto-refrigeration is significant), the required separation and accumulation of liquids, and proper disposal of the vapor. The capacity and operating limits of such a closed system must be fully appreciated and maintained in all future operations and when changes or modifications are made in the future they must be competently evaluated for their impact on the closed system. As a closed flare system serving several independent vessels is rarely challenged to its limits, it is easy to be lulled into a false sense of security that seemingly minor additions or modifications which were not thoroughly evaluated are satisfactory as nothing has happened since the additions were made.

Storage vessels in many installations are installed without the benefit of a closed relief system. In most cases, the designer routes the relief devices directly to the atmosphere. This may be done because of the complication and cost of providing and maintaining a reliable closed relief system. Where devices are routed to the atmosphere, many operators provide reliable means of preventing the final overpressure and discharge of the relief device. In some cases, this is done by providing redundant high level instrumentation on the storage vessels. Where such instruments are used, they should provide for alarm at locations where people are present at all times and are trained to take proper remedial action to stop or divert flow. Obviously, the alarms must be set to alarm while leaving adequate time for response of the operators. Some operators provide a final high-high level switch that is instrumented to stop the flow to the storage vessel. Where instruments are installed to prevent overfilling and liquid discharge of the relief valve, they should be designed and maintained to provide adequate reliability.

VACUUM PROTECTION

Depending upon the positive MAWP of the vessel, its size, and properties of the fluid stored, protection against vacuum conditions may be needed (Ref. 1). Vessels designed to store propane or higher vapor pressure gases at atmospheric temperature will usually have inherent strength to withstand full internal vacuum. However, gases with lower vapor pressure, such as pentane and, under some conditions, butane, will have vapor pressure less than atmospheric during portions of the vessel operation.

Some operators provide vacuum relief valves for this condition if the vessel is not designed for full vacuum. Such an installation when operating under vacuum will admit air to the vessel and represents some risk to internal explosion should a flammable atmosphere occur simultaneous with an ignition source. Where this is a major concern, provisions for maintaining a minimum positive pressure either by inert gas padding or by use of vaporizer can be used.

PROTECTION DURING EXTERNAL FIRE EXPOSURE

Industry practice recognizes that storage vessels may be at risk to external fires as a consequence of liquid spills. The industry standard followed in the design and installation of storage vessels may be different depending on the vessel service and location. Although the suggested design formulas for calculating the required relief capacity due to fire may be different between the various documents, they are derived from the same empirical data. Their differences result from assumptions in the exposed vessel surface area that transmits heat from the fire to the vessel contents and to possible mitigating factors to limit fire heat input. An excellent article that explains these differences was presented at the 1983 API Spring CRE meeting (Ref. 2).

One API standard (Ref. 3) suggests the vessel surface which contributes to heat transmission to the vessel contents is limited to the wetted surface up to 25' above grade or the vessel equator in case of a sphere. This implies that for large vessels, the entire vessel surface will not be heated at a flux level significant to generate vapor. This document also assumes that good ground surface drainage is provided under the vessels such that burning liquids will not accumulate under the vessels. In addition, it is assumed that adequate fire fighting measures are available and will be deployed in a timely manner. These inherent assumptions in the total heat input to the storage vessels results in a basic heat flux of 21,000 BTU/hr-ft^2. Even though these assumptions have been clearly defined in the past editions of RP-520, many casual readers have not noted these limits to its use. As a consequence, the API subcommittee responsible for oversight of the document is rewriting the section on fire exposure to emphasize that where such mitigating factors are absent the heat flux rate is 34,500 BTU/hr-ft^2.

Other documents or industry standards which give guidance for calculating relief rates for fire exposure assume the total vessel surface to be wetted and exposed to the fire regardless of vessel size. In addition, they may assume no mitigating conditions for reducing the heat flux.

For most storage vessels containing pressure liquified gases, the fire relief load determines the size of the relief device. Once the rate of heat transmission to the vessel contents are derived, the heat is assumed to be absorbed as latent heat in the liquid and the relief load is assumed to be all vapor. As the liquid begins to boil the liquid surface in a partially filled vessel will rise or swell. The level of swell is a complicated function of a number of factors, such as heating rate, fluid properties, and shape of the vessel. If the liquid surface reaches the entrance to the relief valve, liquid will be entrained in the vapor and will affect the flow capacity of the valve. A recent article which outlines a method of estimating this affect is given in Reference 4. Using this method may result in an increase in size of required relief size by a factor of perhaps 10. The possible benefit of such a significant increase of relief valve sizing is questioned by many, including the author. Many incidents that have been analyzed indicates that larger relief valves would not significantly alter the outcome of the events. This is a subject that will require further consideration by those responsible for writing the industry standards applicable to this matter.

The designer and operator of storage vessels should appreciate that even where a generous sized relief valve is provided, its protection is only of finite value to preventing vessel rupture in an extended fire exposure. As the relief valve can only maintain the pressure in a narrow range, the vessel stress remains at or above the design limit. As the vapor space in the vessel increases, the temperature of the vessel wall in this region will increase significantly until short term creep-rupture will occur. This condition is discussed in RP-520, and this section is being rewritten to clearly emphasize the limits of relief protection during extended fire exposure. As an example, a vessel with a design stress of 17,500 psi could experience a stress of about 21,000 psi during overpressure relief from fire exposure. If the vessel wall was heated to 1200°F rupture might occur within about 5 minutes and if the wall temperature reaches 1300°F, failure could occur in less than one minute. Information in RP-520 indicates a one-inch thick plate heated by flame from one side can reach 1200°F in about 14 minutes and 1300°F in 17 minutes. Such an effect indicates the desirability of providing additional means of protecting storage vessels from fire exposure.

ADDITIONAL PROVISIONS OF VESSEL PROTECTION

Many operators of major storage vessels provide additional protective features to reduce the effects of a potential liquid spill fire. These may include firewater deluge system, internal vessel water flooding, vessel fireproofing or emergency vapor depressuring.

Storage facilities which have adequate firewater available, external application of firewater to the vessel surface may be employed to reduce heat to the vessel. The design rate of water application varies between operators. A new API Standard, 2020, which is due to be released in the near future, indicates application rates to be 0.1-0.25 gpm/ft^2 for pressurized storage vessels. The author's company uses a design rate of 0.15 gpm/ft^2 for spheres and 0.20 gpm/ft^2 for horizontal cylindrical storage vessels. This results in about 1180 gpm for a 50' sphere and 3020 gpm for an 80' diameter sphere. The method of water application is important to provide a reliable uniform continuous water film. We typically use water deluge applied by discharging the water on top of the vessel into a flooded underflow weir. The firewater line to the top of the vessel is maintained in a dry state between the remote manual valve and the pipe outlet. This arrangement is preferred over use of an array of spray nozzles which are considered more difficult to design and maintain.

Some operators provide a method for injecting firewater into storage vessels, i.e., water flooding, should a leak occur in the liquid region, especially in the vessel bottom, which cannot be isolated by valves. Water is injected until the water level floods the point of leakage. The flow of water is then maintained commensurate with the leak rate, thereby allowing extinguishing any fire that might have resulted and implementing repair procedures. Obviously, adequate water pressure and delivery rate must be available to overcome the vessel pressure. In some cases, this is accomplished with portable booster pumps. The point of injecting water must be located such that it will be accessible in case of a fire and should have a method of connecting fire water in a timely manner. This might consist of a pipe branch connection in the vessel supply or outlet line, and would include a check valve, isolation valve, and blind. Fire water should not be permanently connected to the process line.

Fireproofed covering applied to the vessel proper is used by some operators to reduce the heat input from potential fires. This can consist of any number of materials including insulation or proprietary coatings which are considered inert or inactive until exposed to a fire. The covering either is an inherent insulator or will reduce the heat transfer from the fire through some chemical or physical reaction such as ablation, intumescence, or sublimation. The choice of materials should account for such effects as weathering, physical abuse, resistance to heat of a fire and dislodgement from fire water application. API is currently writing a document, API Publication 2218, which is intended to give guidance on use of fireproofing for equipment and should be published in the near future.

Fireproofing is very important to the protection of major vessel supports such as sphere legs. Failure of these supports in several fires has led to major vessel failures and spreading of the fire to surrounding equipment. Even where supports are fireproofed, its effectiveness can be seriously compromised if adequate inspection and timely repair of the fireproofing is not followed during the life of the equipment.

With the appreciation that a vessel exposed to fire, especially in its vapor space, will suffer a significant loss of strength, it is understandable that some operators employ emergency vapor depressuring to reduce the stress in case of fire. The design and installation of such a system can be a challenge, especially for a large storage vessel and where a flare system is not available. To be of value, the depressuring must be accomplished in a timely manner. Reference 3 suggests that the vessel should be depressured to less than half its design pressure in 15 minutes following activation of the depressuring valve. The depressuring valve and downstream piping should be capable of passing all the vapor generated in the event while maintaining the pressure at less than half the design pressure. During the beginning of depressuring, the vapor rate can be significantly greater than the relief rate based on fire as it will include the vapor from density change in the vapor space, vapor due to flashing of the liquid, and the vapor due to fire heat input. In addition, it is possible that significant liquid entrainment will occur in the initial part of the depressuring, especially if the vessel is nearly full.

The depressuring valve should be remotely operated and its operator should be made secure from fire exposure. In addition, the valve should be made reliable against inadvertent opening as such an event would be very undesirable at best. Where a vessel is fitted with 100% spare relief valves, one might consider instrumenting all the relief valves to open by remote signal where the combined capacity might be adequate for depressuring. This can be accomplished easily where the relief valves are of a pilot type by supplying a remote signal to unload the main valve piston or diaphragm. In the case where relief valves discharge to the atmosphere above the vessel, consideration might be given to routing the depressuring stream in a similar fashion. The vapor discharge from such an installation is at risk of ignition from the fire and the radiant affect on the vessel and surroundings should be evaluated.

CONCLUSION

Large pressure liquified gas storage vessels represent a potential risk that warrants the best efforts in design, operation and maintenance. By applying our best efforts such installations can be operated with risk commensurate with those encountered by other facilities and activities. Properly designed and well maintained pressure relief protection is critical to minimizing the risks. Equally important are provisions for minimizing the occurence of overpressure and for reducing the consequence of such overpressure incidents.

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