Emergency Depressurisation - Why 6.9 barg in 15 minutes is not always the answer

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Traditionally the depressurisation rate for emergency depressurisation systems on oil and gas facilities, and other process plant, has been specified to meet API 521. Generally, depressurisation systems are designed to allow the process inventories to depressurise to half the operating pressure or 6.9 barg, whichever is lower, in 15 minutes. However, this is an oversimplification of API 521 requirements as the "half inventory pressure or 6.9 barg in 15 minutes" criterion is based on a 1 inch thick carbon steel vessel exposed to a pool fire. API 521 states: "For vessels other than 25.4 mm (1 in.) carbon steel, the user may choose to apply the 50 %/15 min criterion, or some other criterion, or may choose to perform more specific calculations". When faced with these three options it is often the first option that is chosen as it is the "industry standard" (and simplest). However, the most appropriate choice may be the third option "perform more specific calculations". This paper demonstrates why option three may be the best option, and how this can be achieved in a cost-effective manner for new and existing facilities. The paper also illustrates how optimisation of depressurisation performance involves consideration of reducing the duration of fires resulting from process vessels leaks as well as assessment of protection for vessels that are impacted by those fires.

Introduction

Process vessels are manufactured from different materials of varying wall thickness. Vessels are also exposed to a variety of fire threats, including gas jet fires, and liquid pool and spray fires. For these reasons a depressurisation criterion of "half the operating pressure or 6.9 barg, whichever is lower, in 15 minutes", may not be appropriate for a large number of process vessels.

The variation in the degradation of strength of different materials at elevated temperatures can be significant. The likelihood of all vessels in a process plant being 1 inch thick is also very small, meaning some vessels are likely to be over or under protected if the 6.9 barg / 50% criterion is applied indiscriminately. Further, jet fires produce higher heat fluxes than pool fires and therefore jet fires will heat both vessel material and vessel contents faster than pool fires. This has the effect of reducing vessel wall strength at a faster rate and can also lead to a more rapid increase in the vessel internal pressure, beyond the assumed rate represented by the 6.9 barg / 50% criterion.

With the current availability of software and industry's better understanding of jet fires it is possible to perform analysis of the impact of the fires and the vessel response to allow an appropriate depressurisation rate to be specified for each vessel or process segment in a plant. This can be based purely upon consequence, i.e. worst case, or by taking a probabilistic approach that considers a balance between the consequences of a fire and its likelihood.

For existing plant it may not be possible to retrospectively apply large modifications to flare or gas disposal systems, but by considering both potential source and target inventories, current depressurisation systems may be optimised to reduce the risks of escalation. This can be achieved within a relatively modest budget, with an initial cost for a depressurisation study followed by relatively minor modifications to emergency depressurisation, for example, changing orifice plates.

This paper describes how MMI Thornton Tomasetti has optimised emergency depressurisation across a number of assets using readily available software tools. The paper demonstrates where the use of a "one size fits all" blowdown criterion can be either too onerous or too relaxed, and discusses the implications of following an inappropriate approach.

Current Industry Practice

Traditionally the depressurisation rate for emergency depressurisation systems on oil and gas facilities, and other process plant, has been specified to meet API 521. Generally, depressurisation systems are designed to allow the process inventories to depressurise to half the operating pressure or 6.9 barg, whichever is lower, in 15 minutes. This practice is followed closely (some may say blindly) and great effort is made to ensure this criterion is met both at design stage and throughout the plant's life span. This can have a significant effect on the overall design of an asset with the size of the flare system dominated by the requirement to depressurise in 15 minutes.

The ability to depressurise within a relatively short time and to a relatively low pressure is a good thing and significantly reduces the chance of escalation in a jet fire scenario. This paper does not set out to dispute the benefits of depressurisation within a short time, however it does contend that a "one size fits all" approach is not appropriate.

The way industry currently prescribes emergency depressurisation rates can be overly simplistic as it does not directly consider the effects of depressurisation on the size of fires emanating from source inventories, and the API 6.9 barg or 50% criterion is only appropriate for one inch wall thickness carbon steel vessels.

Optimisation Method

Emergency depressurisation should be considered from two perspectives – source inventories and target inventories, see Figure 1. The quicker the depressurisation of a source inventory, the quicker a fire will be starved of fuel and the shorter the fire's duration will be. This has obvious benefits as it reduces the chances of escalation and allows the situation to be brought under control more rapidly. In addition, where a release is not ignited, it can potentially reduce the size of an unignited gas cloud and reduce the duration and extent of a flammable atmosphere. From the perspective of a target inventory impinged by a fire, the quicker the source inventory is depressurised the less likely the target inventory is to fail and lead to further escalation.

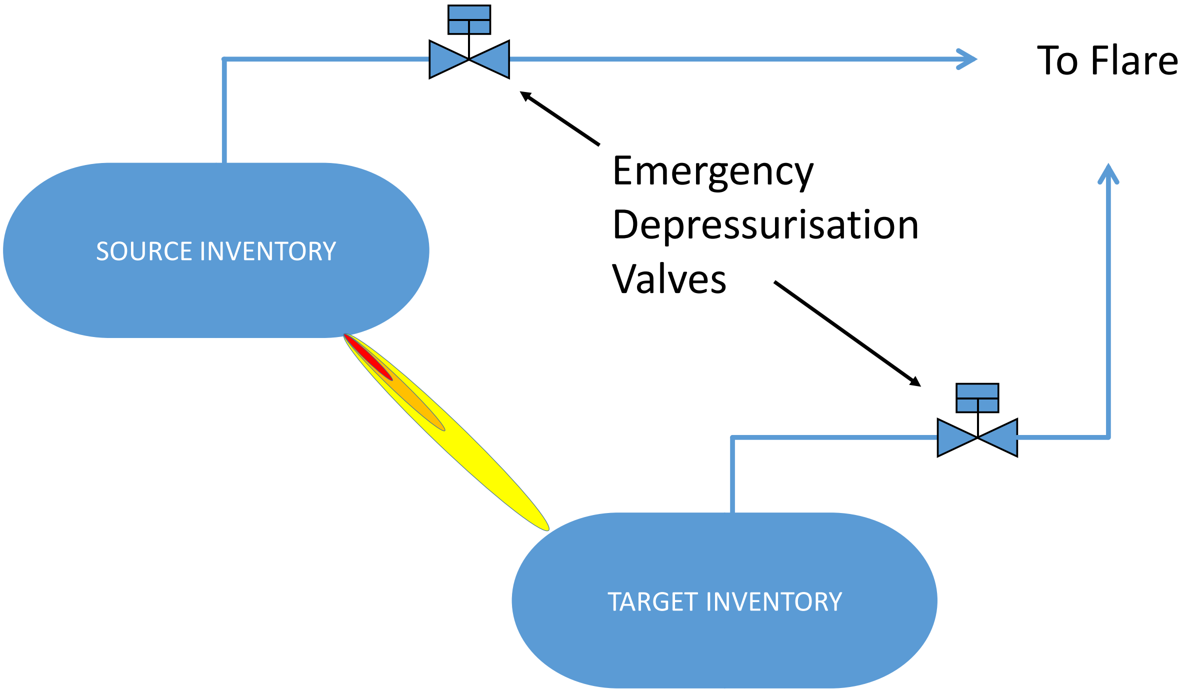

Figure 1: Diagram showing Source and Target Inventories

Source inventory

The source inventory is the inventory that leaks and gives rise to a fire. The source inventory is not the primary focus of the 6.9 barg / 50% criterion, which is concerned with reducing the likelihood of failure of vessels that make up target inventory.

The release will be driven by the source inventory, with the resulting discharge rate and any consequent fire size predominantly governed by the system pressure, the composition and density of the discharged fluid, and the release hole size. Of these factors, hole size is an uncertainty. Different methods can be used to predict potential hole sizes, however none is perfect, and all have limitations. Using a large range of hole sizes is a potential solution but this has the drawback of being computationally resource heavy. Using a range of "representative" hole sizes, in the manner of quantitative risk assessments (QRA), potentially overcomes this but can lead to cliff edge effects and so should be used with caution. Sensitivity analyses are one means of exploring these effects.

Target inventory

The target inventory is the inventory that is impinged by a fire from a source inventory. The API 521 6.9 barg / 50% in 15 minutes criterion includes the assumption that the target inventory is a one inch wall carbon steel vessel. This is provided as a rule of thumb but with significant variables such as: impacting fire type (jet or pool), fire size (large or small) and vessel contents (mass/volume, specific heat capacities and volatilities); it can be a gross oversimplification. API 521 does provide a significant amount of guidance on these factors, however despite these recommendations many in the industry still expect to see an inventory depressurise to 6.9 barg in 15 minutes during a depressurisation test. In a fire scenario, depending on the contents, the fire may cause sufficient flashing of the vessel contents and result in the pressure being significantly higher than 6.9 barg 15 minutes into the fire event.

A better option is to model the depressurisation and likelihood of vessel failure in a fire scenario using more detailed calculations that consider particular fire scenarios and model the response of the specific vessel of interest. Using worst case fires or a probabilistic approach allows representative scenarios to be modelled. Modelling should consider the heat up of the vessel wall and consequent reduction in the wall's material strength. In addition, the modelling must consider the effects of the fire on the vessel contents including the effect on the pressure inside the vessel as components change from the liquid phase into the gas phase. Due to the complexities of this modelling it is recommended that a software package is used. HYSYS is a sophisticated software package that can model heat input into the process fluids, however it is not necessarily the best tool for performing a fire load response analysis of a vessel. Software such as VessFire that has been specifically designed to model vessels under fire load is a better option.

Example

Using an initial design or the configuration of an existing facility, fires can be modelled, and distances between leak sources and target vessels can be measured. This allows fire impact durations to be calculated. These impact durations can then be compared with the calculated survival times of the target vessels using design or actual depressurisation curves. Figure 2 presents a graph of two depressurisation curves of the same source vessel for two different depressurisation rates and plots two survival times of a target vessel with two different depressurisation rates. If the target vessel can survive for longer than the fire impacts the vessel then the depressurisation rates for both the source and target inventories are acceptable.

If the target vessel is impacted for a longer duration than its predicted survival time then three options are available:

1. Increase the depressurisation rate of the target vessel so that it survives for a longer duration than the fire impingement from the source vessel (This is represented by the blue square in Figure 1 moving to the location of the red square).
2. Increase the depressurisation rate of the source vessel to reduce the fire impact duration to a shorter duration than the target vessel's survival time (represented by the blue line in Figure 1 moving to the location of the red line).
3. Increase both the source and the target inventory depressurisation rates to decrease the duration of impingement on the target vessel and increase the target vessel's survival time.

In the majority of case there will be more than two process vessels in a plant. Figure 3 shows an approach that optimises the depressurisation rates for a large number of process vessels on an existing offshore asset. In this case the concern was jet fires, as there were a number of existing mitigation measures that addressed the pool fire hazard. The work considered both small and large jet fires, as defined by Norsok S-001 (small >0.1 kg/s <2kg/s, large >2kg/s) the longest duration small and large jet fires were calculated for each vessel for two cases, one using the installed depressurisation orifice and the other using the full bore of the depressurisation pipework as the depressurisation orifice. This gave bounding cases of the current depressurisation rate and the maximum possible depressurisation rate. Next, for each vessel, fire load response analyses were performed to calculate the vessel's survival time under small and large jet fire impingement scenarios and for both the bounding depressurisation rates. This provided the bounding cases for the vessel survival times. All of this information was then plotted onto graphs, combined with the distance between the vessels. Figure 3 shows the graph of the small jet fire scenarios from the Test Separator. Vessels that do not appear on the graph are either out of range or there is no line of sight between them and the Test Separator. Analysis showed that increasing the Test Separator depressurisation rate had a much greater effect than increasing the target inventory depressurisation rates. This is a consequence of the relatively large inventory of the test separator.

The graph shown in Figure 3 was created for each vessel for both small and large jet fire scenarios. In some cases it was found that the depressurisation rate was faster than required to prevent vessel failures, but more commonly it was found that a faster depressurisation rate could prevent some vessels from failing under jet fire impingement.

A number of factors in the analysis have a significant effect on the results. These factors include whether jet fires impact on the wetted or unwetted areas of target vessels, and the capacity and temperature limits of the flare system. A fire that impinges on the wetted area of a vessel will heat up the liquid contents of the vessel more quickly than a fire that impacts the unwetted wall. This in turn leads to a more rapid pressure increase in the vessel as the liquid vapourises. The analysis includes consideration of heat loads from direct impingement and "background" heat flux. Depending on the configuration of the asset and process plant, and the nature of the releases, it may be necessary to conduct a number of sensitivity analyses to determine the influence of these factors.

In the plant that was the subject of the study illustrated by Figure 3, the biggest constraint on increasing depressurisation rate was the capacity of the flare. This was set and could not be changed as it was an existing facility. Where possible, additional capacity was created by reducing depressurisation rates of vessels that were able to survive longer than required with their current depressurisation rate and where reducing the depressurisation rate did not cause another vessel to fail as a result of a longer fire duration from the vessel. However, in the end it was not possible to prevent all vessels failing through depressurisation means alone, and other means of protection such as passive fire protection were required. However, this illustrates the benefits of this type of analysis early in the design to optimise depressurisation rates across a plant, rather than on a vessel by vessel basis.

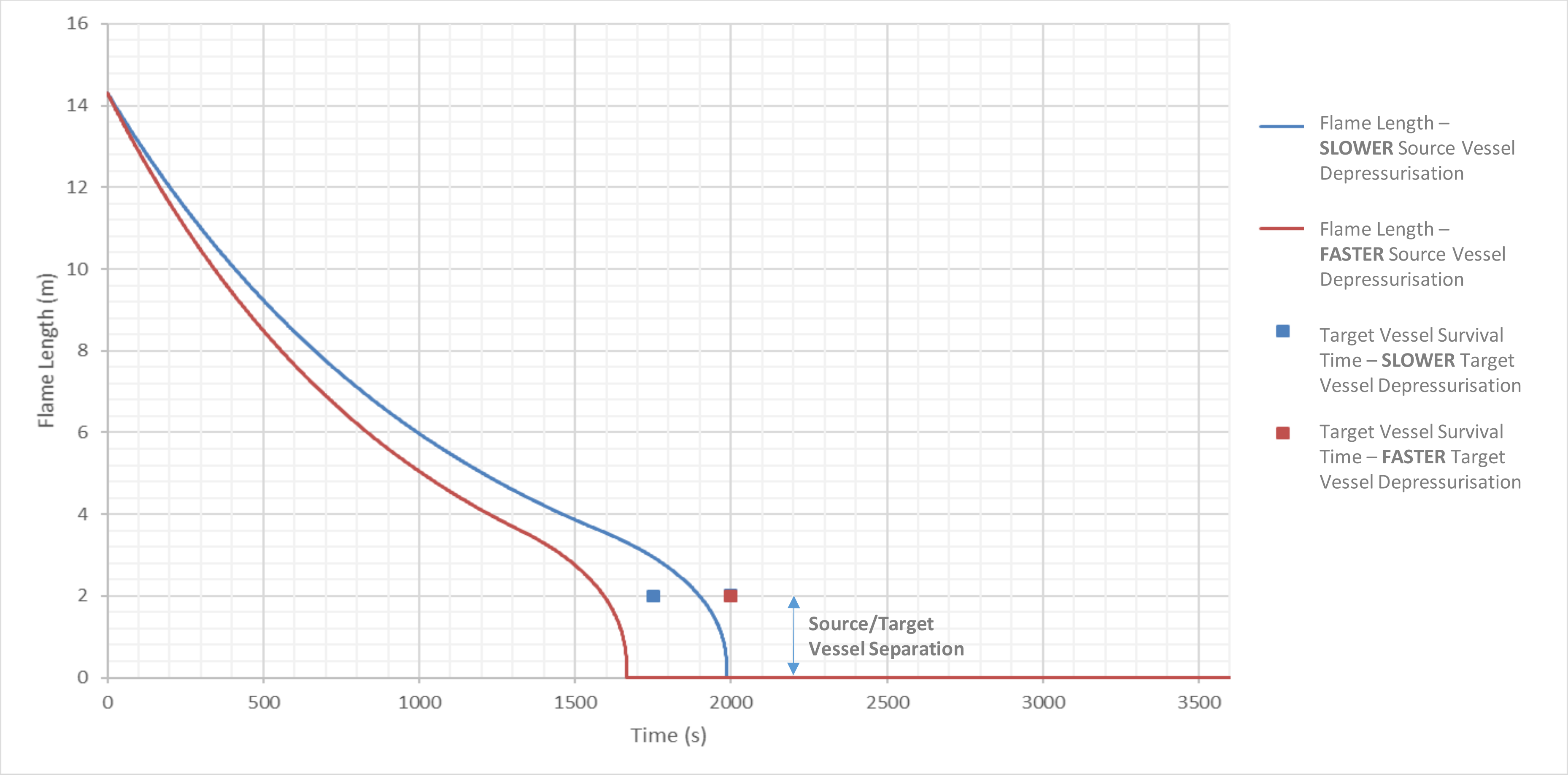

Figure 2: simple example with 2 vessels

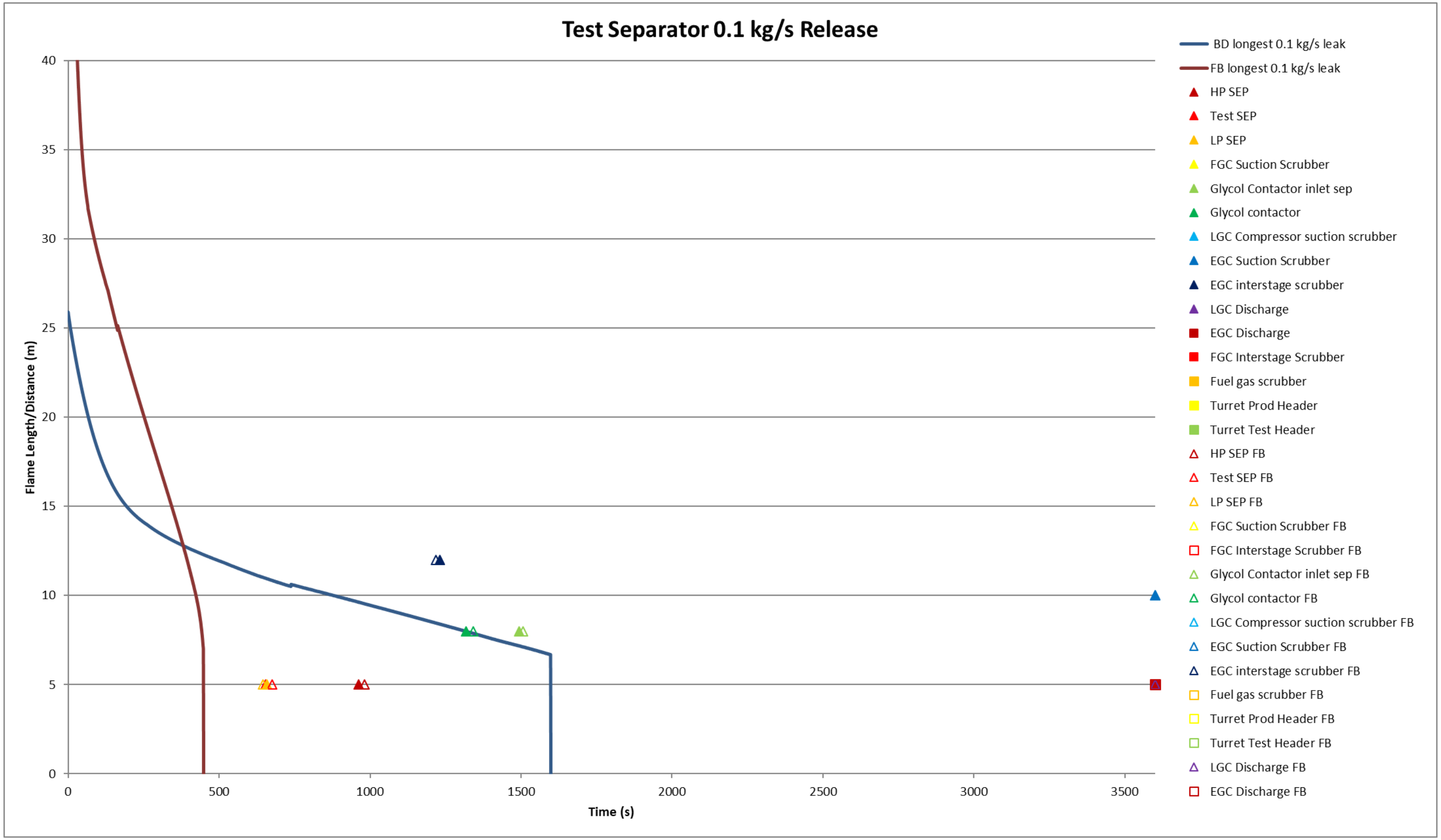

Figure 3: More complicated example with large number of vessels

Benefits of Proposed Method

If the methodology described above is employed at the design stage an optimised solution can be found to increase the effectiveness of emergency depressurisation and potentially negate the need for additional mitigation measures such as passive fire protection. This eliminates the associated problems such as corrosion under insulation (CUI) which can prove costly and lead to integrity issues.

As the methodology also considers the location of leak sources relative to inventories, modifications can be made to pipe runs and flange locations to reduce hazards between inventories. Additional isolation valves can be introduced to limit inventory sizes and locations. Considering these issues at a design stage forces a closer look at the design of an asset which can lead to overall inherently safer designs.

Conclusions

This paper outlines a method to satisfy the often overlooked third option in API 521: “For vessels other than 25.4 mm (1 in.) carbon steel, the user may choose to apply the 50 % / 15 min criterion, or some other criterion, or may choose to perform more specific calculations”.

The strongest case for selecting this third option is that is achieves a safer solution. Adopting the 50%/6.9 barg criterion and assuming that emergency depressurisation will prevent failure of a vessel in a fire when it may not can lead to the omission of alternative life saving mitigation measures from a design. Figure 3 shows that the LP separator failed in under 15 minutes as a result of a small jet fire impinging on it. Failure in a large fire will occur more quickly and the LP separator is likely to contain a large inventory of liquid hydrocarbons. The failure of such a vessel may lead to significant escalation before personnel have escaped from the affected area.

With improvements in computing power and the availability of faster and more sophisticated modelling packages at lower costs it is becoming easier to analyse the fire load response of vessels. This coupled with the alignment of fire load response analysis (FLRA) with the requirements of API 521 means that FLRA will increasingly become regarded as good practice rather than best practice. In this case FLRA will become a main plank in a robust demonstration that risks on a plant have been reduced to a level that is As Low As Reasonably Practicable (ALARP).

References

API Standard 521, Pressure-relieving and Depressuring Systems, Sixth Edition, January 2014

Norsok Standard, S-001, Technical Safety, Edition 4, February 2008