Maximum Allowable Valve Passing Rate Review and Determination

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In the event of a process leak, Emergency Shut Down Valves (ESDVs) are required to limit the potential for escalation by restricting the amount of material available to be released. A newly installed valve will provide good isolation and not allow any material to 'pass' when in the closed position. For valves in service however, corrosion, erosion and other factors will serve to degrade the performance of the valve and lead to the valve passing when in the closed position.

Valve passing studies are required to determine what the maximum allowable passing rate should be for valves in service. For offshore riser valves, requirements are laid down by the HSE [1], however these guidance notes may be applied to other inboard ESDVs and ESD valves onshore also.

MMI has carried out a review of valve passing studies conducted by MMI and other consultancies for a variety of operators, and has failed to identify a single comprehensive methodology to cover all cases. In response to this, MMI have developed a valve passing methodology which is intended to clarify and simplify the overall valve passing study process.

This paper discusses the relative merits of previous methodologies, then provides a detailed description of MMI's consolidated approach to study this problem for flammable releases. An example assessment for a typical offshore installation is then provided using MMI's proprietary valve passing assessment software.

KEY WORDS: Valve Passing, Emergency Shut Down, Isolation

1. Introduction

In the event of a process leak, Emergency Shut Down Valves (ESDVs) are required to limit the potential for escalation by restricting the amount of material available to be released. A newly installed valve will provide good isolation and will allow very little material to 'pass' when in the closed position [2]. For valves in service however, corrosion, erosion and other factors will serve to degrade the performance of the valve and lead to the valve passing when in the closed position.

Valve passing studies are required to determine what the maximum allowable passing rate should be for valves in service. For offshore riser valves, requirements are laid down by the HSE [1] however these guidance notes may be applied to other inboard ESDVs and ESD valves onshore also.

Previous guidance [3] (now revoked) on riser ESDVs stated that leaks of 1Sm^3 / min of gas or 6 kg / min of oil could be permitted to pass through closed riser emergency shutdown valves. There are now no fixed criteria reported in HSE or other current industry guidance on what value should be accepted. The UK goal setting regulatory regime instead allows maximum rates to be set according to the installation's ability to safely control the hazards produced by such a leak.

This paper discusses the relative merits of previous methodologies, then provides a detailed description of MMI's consolidated approach to study this problem for flammable releases using an example assessment.

2. Current Approaches & Limitations

This Section describes approaches to valve passing studies used by different operators and consultancies. This authors experience is primarily with oil and gas thus the principal hazard from a degraded valve closure is an un-isolatable fire, or toxic release (e.g. H_2S). Explosions due to valve passing are generally not considered as valve passing rates are typically insufficient to maintain a large flammable cloud.

A very general approach to valve passing assessments is shown in Figure 1

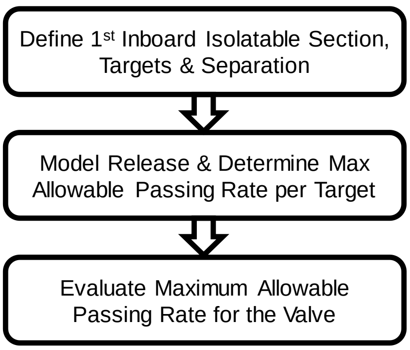


Figure 1: Generalised Approach used to Determine the Maximum Allowable Valve Passing Rate

2.1 Defining the 1st Isolatable Section, Targets and Separation

All valve passing assessments begin with the identification of the valves in question and the first isolatable section inboard of that valve. The isolatable sections need to be identified on P&IDs then the physical location of the pipework therein contained identified (see Figure 1). From MMI's experience, tracking the location of pipework can be performed via a review of platform drawings, piping isometrics, platform 3D models, or platform Panotours (similar to Google Street View) as a desktop exercise, or site visits.

Identification of the first isolatable section is not a contentious issue and the approach used by all consultancies and operators appears to be similar in this regard.

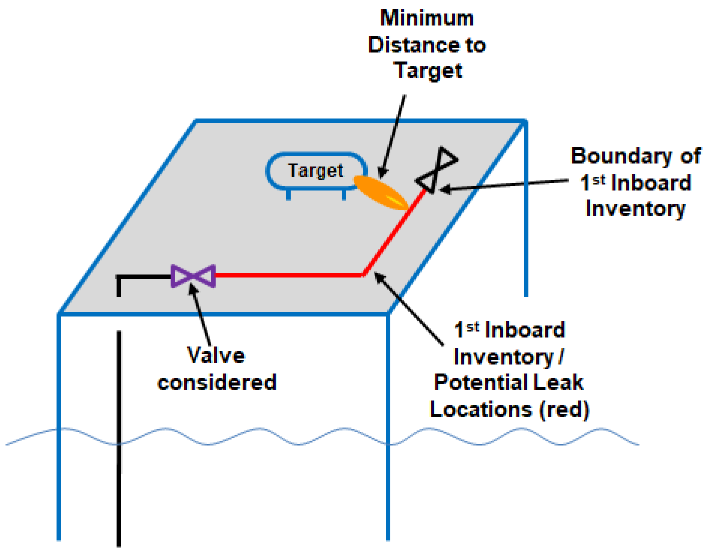


Figure 2: Simplified drawing showing Valve assessed for leakage rate, location and extent of 1st inboard inventory, and distance to target

In the event of a leak from the 1st inboard inventory, ESDVs are designed to contain the leak. If the outboard valve passes material, isolation of the inventory may not be possible. HSE state that 'minor internal leakage past the ESDV may be accepted providing it does not represent a threat to safety.' [1]. To determine what threats to safety may arise from an un-isolatable leak, 'targets' are identified in the vicinity of the 1st inboard inventory, the failure of which may lead to a loss of life over that of that of the initial event. It is at this point where methodologies differ as different authors have different opinions. From a review of studies, common targets include:

- The TR, Control Room, and supporting structure;
- Risers and Riser ESDVs;
- Large vessels, especially those identified as having a BLEVE potential;
- Key EER equipment such as bridges, and stairwells. Consideration should be given to the provision of diverse escape routes and whether it is credible to impair all ERR or just a part of it;
- Primary steel, the failure of which may lead to major process escalation.

Other targets identified in a minority of studies have included process / topside pipework, secondary steel work to varying degrees, and items associated with the leaking inventory itself, however MMI would not recommend their inclusion unless strongly justified on a personnel risk basis. Targets such as life rafts and TEMPSCs are not included as they will have likely been impaired by the initial fire event in a very short time, thus a smaller fire sustained by valve passing could not do any more damage. Some studies identify items as 'asset', 'minor', or 'non critical' targets, thus a passing rate can be established to protect the item if the asset feels it necessary. For each target, an endurance time and associated heat flux is specified, after which target impairment is predicted.

The further away a target is from a hazardous inventory, the larger the fire required to impair it. For a target to be impaired due to valve passing, most (not all) methodologies would predict a larger valve passing rate is required for targets located further away from the inventory. The distance from the 1st inboard inventory to the target is therefore required and has proved a very subjective exercise. Some studies measure the distance to the target from the closest point on the 1st inboard inventory even if that is continuous piping. Other studies do not consider a release from continuous piping credible, but do consider it from piping elbows and tees. Similarly other studies have only considered the distance to the target only from piping items such as valves, flanges and instruments. Some studies have not calculated the distance from a flange to a target if they are not orientated perpendicular to each other.

HSE guidance states that the establishment of an acceptable valve passing rate should be performed on a 'consequence' basis [1]. This implies that while unlikely, leaks from all locations including continuous process piping should be considered. There is the danger however that a compounding of conservative assumptions on top of conservative assumption leads to a very onerous conclusion that cannot be achieved thus the whole process is devalued. For a leak from an inventory to first occur, then be ignited, then not fail the target due to the hole size or orientation, then for the subsequent smaller fire due to valve passing to be correctly orientated and to fail the target is an unlikely event to design against in the first place. To add to this the fact that the leak occurs from a piece of continuous piping stretches the bounds of credibility. In MMI's experience including leaks from continuous piping leads to a very onerous requirement on the maximum allowable valve passing rate and recommends against it.

MMI has considered leaks from continuous piping however on platforms where issues with corrosion or erosion have been experienced by the operator. In these cases, a leak from piping is much more likely. Similarly, where there is increased risk of dropped object, leaks from continuous piping should be considered.

2.2 Modelling the Release and Determining the Passing Rate

In the event of a leak, multiple scenarios exist depending on the original hole / leak size, blowdown, times for detection and isolation, valve passing rates, and the associated modelling of all these parameters. To explain all the methods would be a very onerous task so only a summary of key attributes is given.

A common assumption in all assessments is that the leak is ignited instantly, and that ESD functions within the times set in the associated performance standard. The first deviation between modelling methods is as to whether blowdown is credited or not. HSE guidance [1] initially states that blowdown can be credited in studies, but later states that *'a conservative approach to gas releases will assume that ESDV leakage is released entirely through the breach rather than vented via the blowdown connection'*. From these seemingly contradictory statements, this author believes the correct methodology is to credit blowdown until a steady state with the valve passing rate is met, at which point blowdown should not be considered. It is felt that contradicting HSE's *'conservative'* approach would be a very difficult exercise to justify.

The duration of release is a significant function of the hole size considered. Different studies have approached this in a variety of ways. Hole sizes as per the installation QRA, or other more arbitrary hole sizes have been used. Similarly, if corrosion has been identified as an issue, hole sizes of smaller diameter have been investigated more thoroughly. Where only small-bore pipework is associated with the inventory, or part of the inventory, the hole size may be justifiably limited to the maximum size of piping or piping item. As stated previously, the HSE guidance document state valve passing rate should be performed on a 'consequence' basis [1]. As such, it is the opinion of this author that a comprehensive range of hole sizes should be considered, far in excess of the number used in QRA. In our experience, there will typically be an unusual range of hole sizes (e.g. 32-42 mm) in which impairment of an item may occur, but which may be missed if using a limited number of holes sizes.

Some studies use a concept of a 'critical hole size' for assessment. This method involves finding the exact hole size at which a target may be impaired with no valve passing. At hole sizes larger than this, the inventory is depleted before impairment of the item occurs. At hole sizes smaller (to a point), the item will be impaired. The critical hole size is therefore an upper limit hole size that may lead to escalation. The concept of a stabilised jet fire is then introduced typically referencing FABIG TN11 [4]. This document states that at pressures below 2 bara, the flame becomes much more buoyant (tendency to burn vertically), wind affected (flame will change direction with the wind) and unstable (i.e. prone to be blown out, requiring a permanent pilot to remain ignited). This type of fire is often described as a diffuse flame and is not considered able to cause process escalation. Since the passing rate into the system is small, and a relatively large hole size is being considered, it is conservative to calculate the flow rate through the hole, and hence maximum allowable passing rate, as that that gives 2 bara in the process piping.

This method is slightly counter intuitive as for some cases, targets that are further away from the inventory demand a smaller valve passing rate. In addition, the act of the flame impinging on a target inherently stabilises the flame, meaning it is unlikely to be blown out.

Some studies simply ignore the modelling of the leak scenario prior to it reaching steady state. All the gas passing through the valve is assumed to pass through the inventory breach and subsequent fire. For gas leaks, the length of the associated jet fire make no assumption on the holes size considered, and instead uses formula requiring only the release rate to determine flame size [5]. This option provides a simple, intuitive process for assigning an allowable passing rate and would certainly be recommended as an adequate first pass approach to modelling.

2.3 Additional Considerations

Additional points sometimes missed in studies include:

- All the methods proposed essentially assign a maximum allowable leak rate into an inboard inventory. Where multiple risers, or other large inventory source can feed into a section, the maximum allowable leak rate should be apportioned between all valves that may feed into it.

- In gas processing there may be significant adiabatic cooling as the gas passes across a valve, especially where large passing rates have been calculated as being permitted. This may take items outside of their design envelope and could lead to a brittle fracture.
- As per HSE guidance [1], fractions of the maximum allowable passing rate should be used as trigger points to initiate further investigation (25%) and for repairs and maintenance (50%)
- Where two ESDVs are in series with little space between, it may be prudent to assign the valves a combined allowable leakage rate with both closed.
- If a large allowable passing rate is calculated, it does not necessarily follow that it is ALARP to use that value if it is reasonably practicable to improve the integrity of the valve. Corporate standards on what an organisation accepts as the upper limit maximum allowable passing rate for a valve should be established.

3. Proposed Consolidated Methodology for Future Assessments

Based on the findings and conclusions described above, MMI has developed the following comprehensive methodology to establish a maximum valve passing rate.

3.1 Define Isolatable Sections & Targets

The definition of the isolatable section, targets and associated separation distance should be conducted as described in the previous Section. As there is little ambiguity on how to achieve this, no further details are given.

3.2 Calculation of Safe Valve Passing Rates as Function of Hole Size

The most disparity between the methods identified in the previous Section arose from how to model the release event. None of the studies reviewed comprehensively looked at every valve passing rate and hole size combination to see whether target impairment could occur. Instead, assumptions to exclude the initial depressurisation event, or blowdown, or creating a critical hole size were introduced.

Transient calculations should be carried out at a range of hole sizes and valve passing rates. Figures 3 to 5 give an example of how plots of safe valve passing rate as a function of hole size are generated for each target. An example target with a withstand time of 5 minutes (300 seconds) and 7 m from the leak location is considered. Initially, the range and resolution of hole sizes and valve passing rates to be considered is defined in Figure 3.

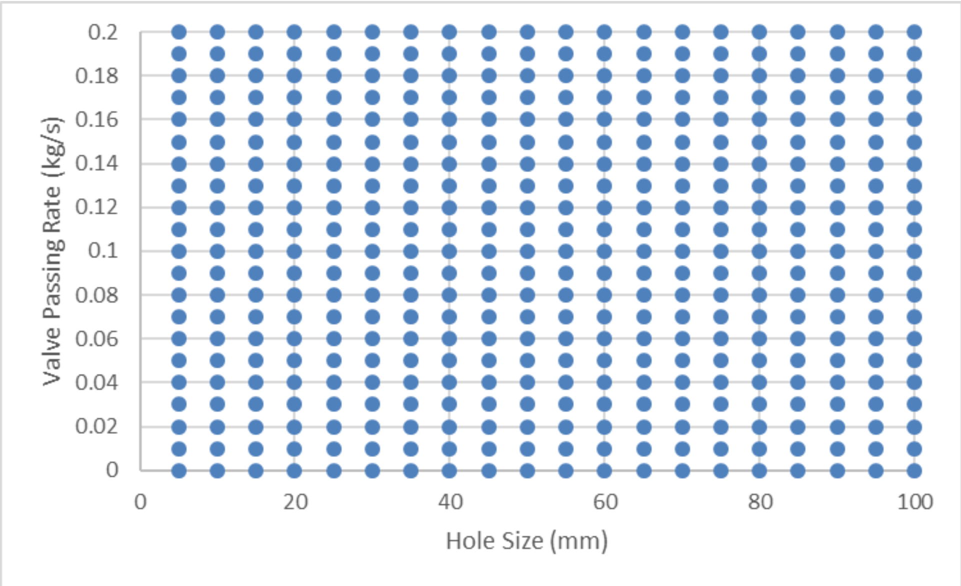
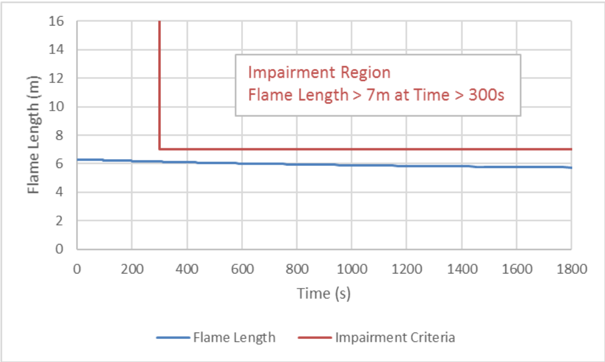


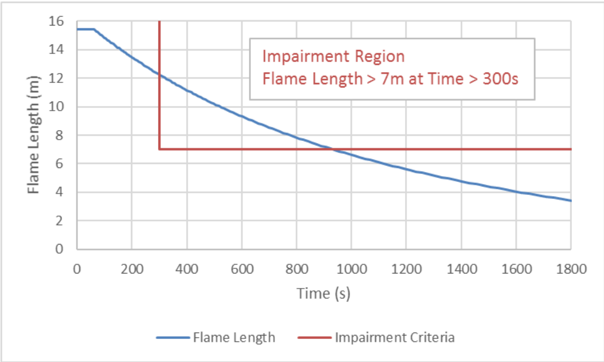
Figure 3 - Example Transient Calculation Inputs – Each point represents a single transient calculation. In this example, hole size is varied from 5-100 mm in 5 mm increments, while Valve Passing Rate varies from 0-0.2 kg s^{-1} in 0.01 kg s^{-1} increments.

For each point marked by a blue dot in Figure 3, a transient simulation is run and the results are categorised as either impairing or not impairing the target. Examples of flame length transients explaining the criteria for target impairment are given in Figure 4. On the graphs, the red horizontal line denotes the distance to the target from the closest leak location (7 m in this example) and the red vertical line denotes the withstand time of the target if impinged by fire (300 seconds in this example). Any transient which passes through the marked ‘Impairment Region’ leads to impairment of the target for that combination of section, hole size and valve passing rate.



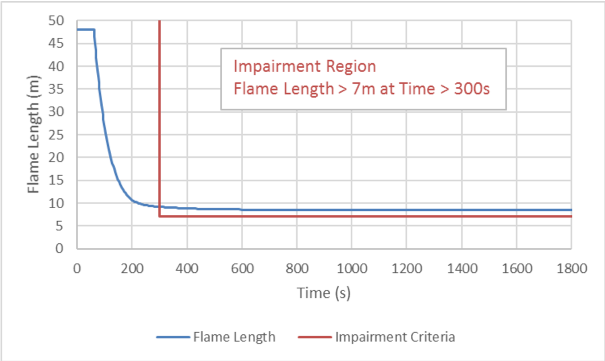
a)

Flame Length insufficient to impair target.



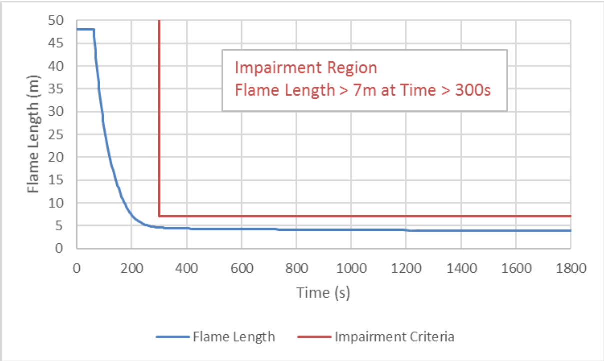
b)

Flame Length greater than target distance beyond withstand time due to initial inventory. Steady state flame length is less than target distance.



c)

Flame Length greater than target distance beyond withstand time as steady state flame length is greater than target distance.



d)

Flame Length sufficient to impair target. Initial inventory is depressurised sufficiently quickly to not impair target and steady state flame length is less than target distance.

Figure 4 – Example Transients. All cases have some degree of valve passing.

Figure 4a shows no impairment of the target. At the hole size modelled, there is insufficient mass flow through the hole in the section to sustain a flame long enough to impinge on the target (i.e. the distance to the target from the closest leak location is greater than the calculated flame length), even at full section pressure.

Figure 4b shows impairment of the target due to the initial inventory of the section. The flame length is initially over 15 m, but reduces to below the target distance of 7 m at around 900 seconds (15 minutes). However, the target withstand time is only 300 seconds, so the target is impaired. This is shown in Figure 4b as the flame length transient passing through the impairment region outlined in red. In this example figure, the steady state flame length that would occur due to valve passing is shorter than the distance to the target.

Figure 4c shows the results for a greater hole size and passing rate than for Figure 4b. This is evident from the higher initial flame length and higher steady state flame length. This example also causes impairment of the target. The section depressurises and reaches close to its steady state rapidly, but the effect of valve passing is that the steady state flame length is greater than the target distance. This is shown in Figure 4c as the flame length transient passing through and remaining inside the impairment region outlined in red.

Figure 4d is from the same section and hole size as in Figure 4c, but with a lower valve passing rate. As before, the section depressurises and reaches close to its steady state rapidly but the lower valve passing rate means that the steady state flame length is less than the target distance. This example causes no impairment of the target. In Figure 4d the flame length transient passes below the impairment region outlined in red.

Each point modelled in Figure 3 is categorised as causing impairment or not as discussed in the above examples, and the maximum valve passing rate which does not cause impairment ('safe valve passing rate') is determined as a function of hole size. This is shown as the solid black line in Figure 5, in which the red dots show inputs which caused impairment and the green dots inputs which did not cause impairment. The defined line runs through the green dots, i.e. it is the maximum safe valve passing rate (except where no safe valve passing rates were found and it is set to zero).

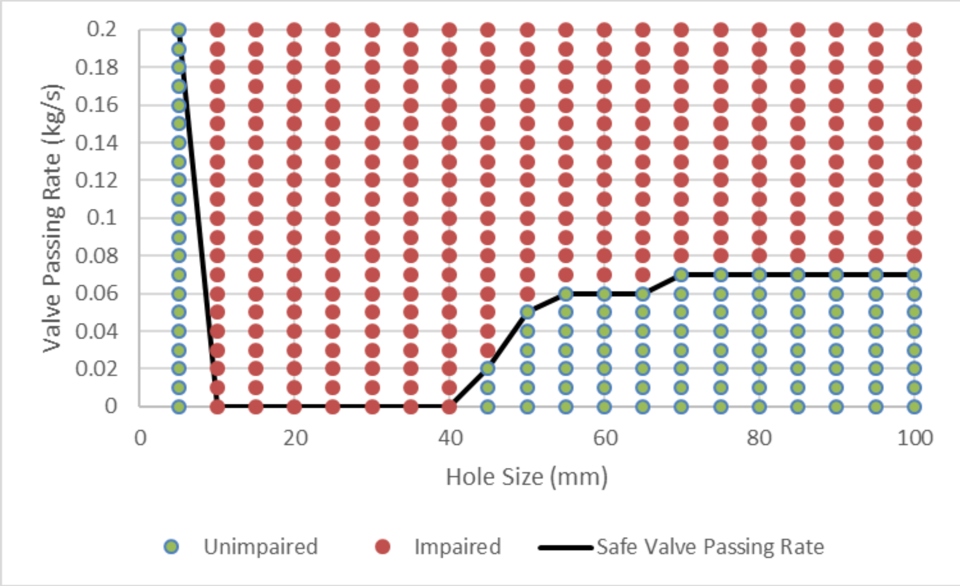


Figure 5 – Example Impairment Results – Each transient is judged to cause impairment (red) or not (green). The Safe Valve Passing Rate is defined as the highest value of valve passing rate for each hole size which does not cause impairment of the target (black line).

This process is repeated for each target, such that multiple curves of safe valve passing rate can be plotted on a single graph for each isolatable section considered in the assessment.

It may not be possible to protect some targets. The release from the inventory itself without valve passing may be sufficient to cause failure, particularly for targets which are very close or have short withstand times. This is indicated by the black line on Figure 5 running through red dots at a passing rate of zero kg s^{-1} for hole sizes between 10 mm and 40 mm; and where this occurs is similarly denoted by a safe passing rate of zero in the graphs presented in the next section.

3.3 Discussion on the Evaluation of the Maximum Allowable Passing Rate for the Valve

The method given above addresses a number of issues with previous valve passing methodologies, such as ignoring transient effects, and provides a clear physical basis for the determination of safe valve passing rates. How the curves of safe valve passing rate for a number of targets are condensed into a single number for the entire section, is more open to engineering judgement, and this section explains a couple of issues that we have uncovered.

3.3.1 Trends in Safe Valve Passing Rates

An example graph of safe valve passing rates as a function of hole size is given in Figure 6. There are four distinct regions shown:

- For small hole sizes, no impairment occurs regardless of valve passing. This is due to insufficient release rate to sustain a flame of sufficient length to impair the target (see the example presented in Figure 4a).
- For medium hole sizes, there may exist a region where the target is impaired even if the valve does not pass (see the example presented in Figure 4b). No valve passing rates will prevent the target from being impaired.
- A transitional region may exist between medium holes, where the initial inventory is dominant, and the large holes where the valve passing rate is dominant.
- For large hole sizes, the section is rapidly depressurised and the steady state scenario of the release rate equalling the valve passing rate is reached within the target withstand time. In these cases, the valve passing rate must be insufficient to maintain a flame of sufficient length to impinge on the target. Typically, the graph shows a plateau at large hole sizes, with the safe passing rate given as the flow rate required to sustain a flame just shorter than the distance to the target.

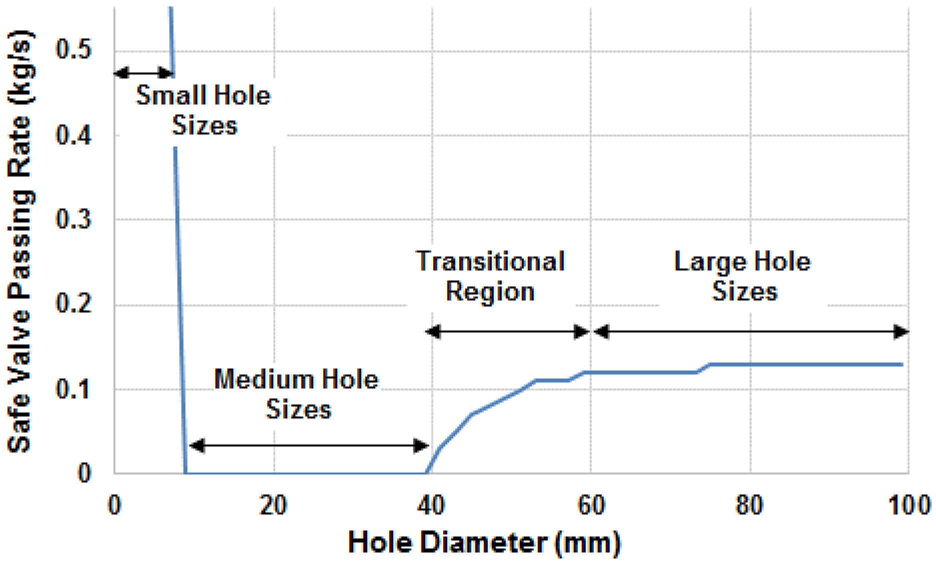


Figure 6 – Example Safe Valve Passing Rate as a function of hole size.

Depending on the particular section and target combination, further curve shapes are possible, and four examples are given in Figure 7. Determining valve passing rates from these curves, if each target is considered in isolation (i.e. as if the only target threatened by passing through a given valve), is discussed below.

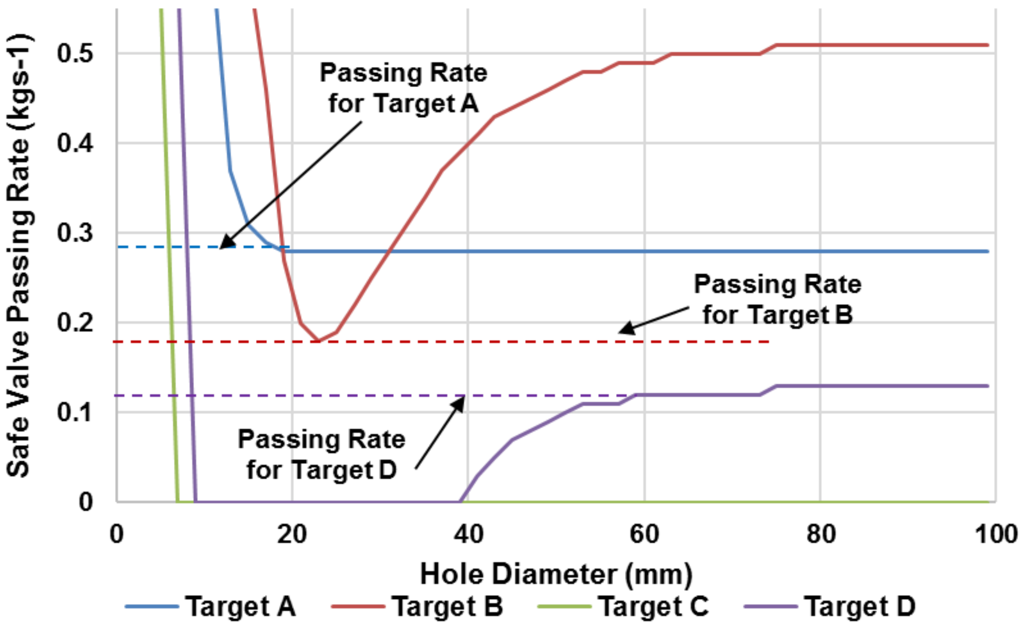


Figure 7 – Safe Valve Passing Rates as a function of hole size for four example targets. Suggested maximum acceptable valve passing rates are marked for each target.

Target A

The graph for target A shows a valve passing rate (0.28 kg s^{-1}) which protects the target for all hole sizes, and this value should be chosen. This represents a small inventory which is rapidly depressurised, so the steady state valve passing rate dominates for almost all hole sizes, except for very small holes.

Target B

For target B, no medium hole size region can be identified, although a clear minimum in the allowable valve passing rate is identified at a hole size of 23 mm. The initial inventory is never completely dominant, but, over a range of hole sizes between ~15 & 60 mm, has an effect on the safe valve passing rate. The minimum safe valve passing rate should be chosen in this case as 0.18 kg s^{-1}. In cases where this is overtly stringent, the steady state passing rate (0.51 kg s^{-1}) may be selected instead.

Target C

For target C, impairment is caused for all but the smallest of the considered range of hole sizes, due to the large initial inventory which dominates over the valve passing. Regardless of valve passing, we would expect these targets to be impaired for all hole sizes. There is the potential that hole sizes greater than the upper bound considered in this assessment (100 mm) may not lead to impairment due to the duration of events being so small; however, holes of this size are not considered in this assessment due to their relatively low frequency.

For this case, no maximum acceptable valve passing rate can be defined for this target, and it should be discounted from the setting of the Maximum Acceptable Valve Passing Rate. Protection of this target should be provided through other means (e.g. PFP) if failure is considered to be unacceptable.

Target D

Target D has a clear medium hole size range where no safe valve passing rate can be defined, as well as a clear steady state region at larger hole sizes. It is likely that in most cases, the steady state safe valve passing rate should be chosen as 0.13 kg s^{-1}.

3.3.2 Determination of Maximum Acceptable Valve Passing Rates

Once a clear idea is obtained from the valve passing rate vs. hole size curves of the ranges of hole size for which targets can be protected, and the number of targets which can reasonably be protected, the level at which to set the maximum acceptable valve passing rate must be determined.

As discussed previously, 'Critical' targets associated directly with life safety may be identified as oppose to 'non-critical' targets which may only provide asset or business continuity protection. Assuming in this example that Target A is 'critical', and all other targets are 'non-critical', we can produce a plot of targets impaired as a function of valve passing rate for all targets as shown in Figure 8.

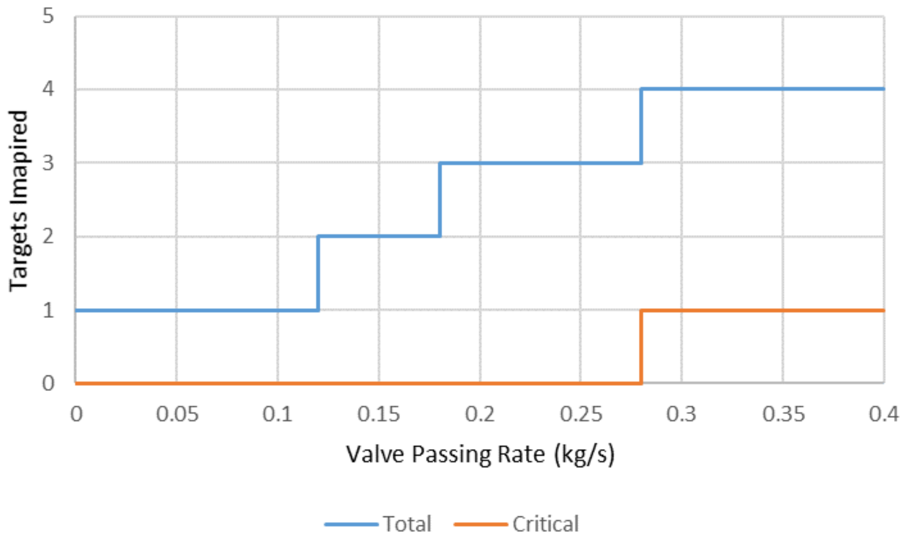


Figure 8 – Number of Critical and Total Number of Targets Impaired vs. Valve Passing Rate

The Data in Figure 8 shows that the Maximum Allowable Passing Rate should be set at 0.28 kg s^{-1} based on protecting Target A. A commercial decision may be made to set a more onerous Maximum Allowable Passing Rate of 0.12 kg s^{-1} or 0.18 kg s^{-1}.

4. Conclusions

This work has examined current methods of assessing acceptable valve passing rates and has found a great deal of variety in the methods used. It is this authors opinion that the details of the assessment are secondary to the requirement that it be consistent and conservative assessment.

An improved methodology is suggested which centres around the definition of curves of safe valve passing rate as a function of hole size for each target. While this utilises simple but rigorous consequence modelling, engineering judgement is required to turn these plots into a single figure for an acceptable valve passing rate.

5. References

[1] “Riser emergency shut down valve (ESDV) leakage assessment, SPC/TECH/OSD/49, HSE”.

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