PRESSURE RELIEF SYSTEM REACTION FORCES – THE IMPORTANCE OF EVALUATING EXISTING INSTALLATIONS

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1. Introduction

- Overpressure protection analysis has evolved significantly since the inception of the PSM standard, but the mechanical stress applied to the piping during overpressure events appears to have been overlooked. The purpose of this study is to allow an existing facility to focus resources on the relief device installations most likely to fail due to reaction forces. A series of representative installations were evaluated in order to determine which parameters associated with pressure relief have the strongest impact on the installations, with particular concentration on the dynamic effects of the release. A pressure safety valve is a relief device that controls the amount and disposition of material during a process upset, while simultaneously protecting the process equipment from the overpressure damage caused by the upset.

- Much engineering research, testing, and analysis has been devoted to determining a PSV's suitability to protect equipment from overpressure; however, analyzing the structural integrity of the relief device during an emergency event has less prescriptive requirements.

- The pressure safety valves in the pictures below lack structural integrity:

2. Reaction Force Analysis Methodology

- During an overpressure event, the discharge of a pressure relief valve imposes a load, referred to as a reaction force, on the collective installation. If the valve lacks structural integrity, the stress caused by the reaction force is propagated into and through the relief valve and then into the inlet piping and vessel nozzle.

- API 520 Part II (American Petroleum Institute, 2008) states that pressure relief valve outlet piping should be independently supported and properly directionally aligned.

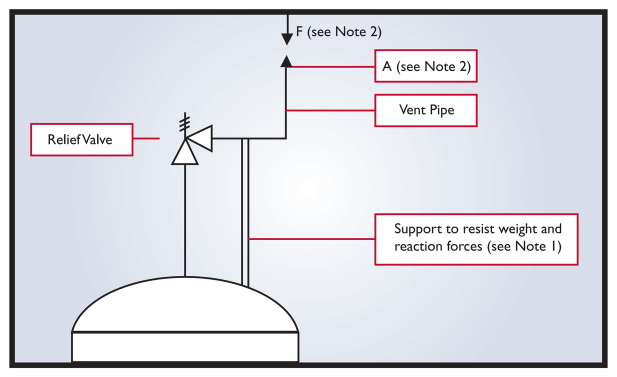
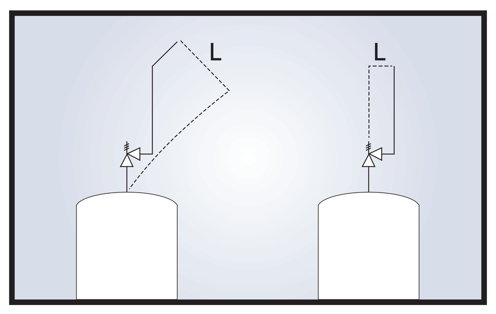


Figure 1 – Recreation of Figure 7 from API 520 for a typical relief valve installation
Note 1 – The support should be as close as possible to the centerline of the vent pipe.
Note 2 – F = Reaction Force, A = Cross- sectional Area of discharge pipe.

- The guidelines from the Design Institute for Emergency Relief Systems (DIERS) are similar to API's guidance; however, DIERS also suggests piping layouts to help avoid excessive lever arms, as demonstrated in the following figure.

- Reaction forces from all credible overpressure scenarios need to be evaluated.



3. Reaction Force Case Study Analysis

- Static loads are those which are applied slowly enough that the piping system has time to react and internally distribute the loads, thereby remaining in equilibrium.

- With a dynamic load – a load which changes quickly with time – the piping system may not have time to internally distribute the loads, so forces and moments are not always resolved, resulting in unbalanced and potentially concentrated loads and pipe movement.

- The analysis was used to determine if a flange leak was likely. In all cases, the dynamic condition was determined to be the governing condition for the structural integrity of the piping system. The model used in the current evaluations has been confined to "welding reducing tees."

Material	Allowable Stress B31.3 Table A-1 (psi)	Allowable Stress Occasional Load (psi)	Yield Stress B31.3 Table A-1 (psi)	Tensile Stress B31.3 Table A-1 (psi)
A 234 (tee)	23,300	30,990	40,000	70,000
API 5L B (Pipe)	20,000	26,600	35,000	60,000
A105 (Flange)	21,900	29,130	36,000	70,000

Table 1 – Sample of allowable stresses used in screening study

- Caesar II 5.30 - The relief valves were modeled as "Open Discharge" with a vertical pipe discharging directly to atmosphere, and the process connection mounted on a pipe header with a welding reducing tee.

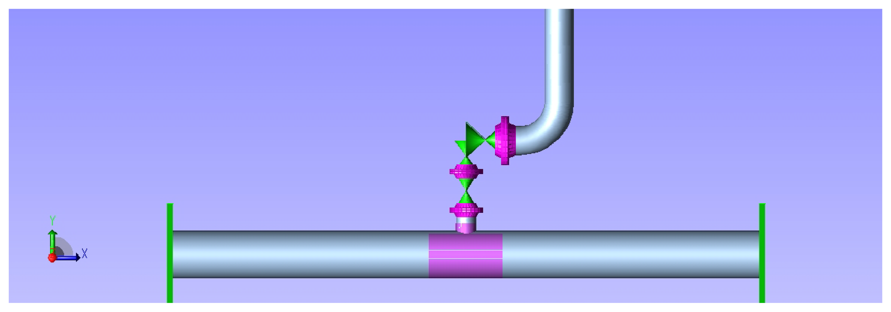


Figure 2 – Sample of the model basis as developed in Caesar II.

- SolidWorks was used to determine the physical properties along the vent pipe required to calculate the thrust and momentum forces.
  - – Average velocity along the vent pipe
  - – Average temperature across the outlet of the vent pipe
  - – Average velocity at the elbow
- Assumptions - The following assumptions were made regarding the analysis:
  - – Process fluid is vapor
  - – Manufacturer's certified orifice diameter from National Board Relief Device Certification NB -18 was used in place of standard API orifice diameters to provide more realistic discharge flow. Crosby JOS valve orifice data was used.
  - – Valve opening and closing time is 8.0 milliseconds. Venting will last for (1) one second. While these numbers are specific to the valve manufacturer, they appear to be typical throughout the relief valve industry.
  - – Wind loadings were not considered.
  - – All piping considered to be Schedule 40 carbon steel.
  - – Relief valve inlet flanges: as required for process considerations.
  - – Relief valve outlet flanges: ANSI RF 150#.

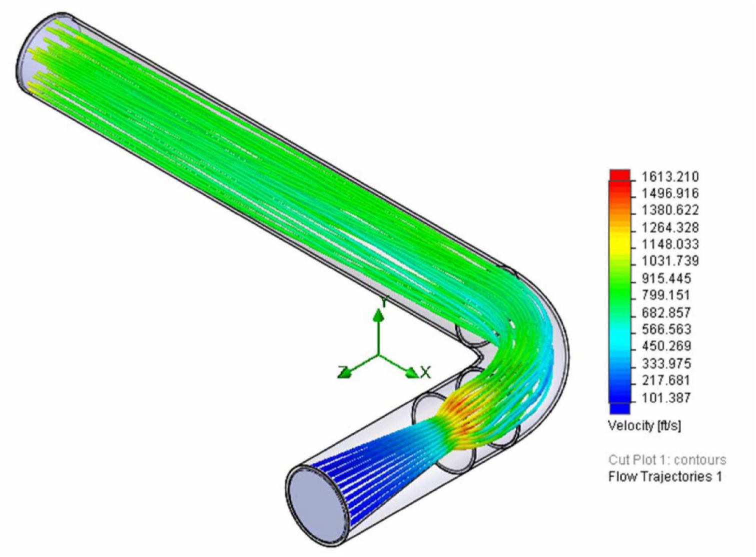


Figure 3 – Sample of velocity profile output from SolidWorks Flow Simulation

References:
1. Relief System Reaction Forces in Gas and Two-phase Flow, 1991, 25th Annual AIChE Loss Prevention Symposium
2. Emergency Relief System Design Using DIERS Technology, 1992, New York, NY, American Institute of Chemical Engineers
3. Thrust Force Calculations for Pressure Safety Valves, 2006, Process Safety Progress, 203-213
4. Pipe Stress Engineering, 2009, New York, NY, American Society of Mechanical Engineers
5. American Petroleum Institute, API Standard 520, Sizing, Selection, and Installation of Pressure-relieving Devices in Refineries, API
6. American Society of Mechanical Engineers, 2004, B31.3 Process Piping Guide, American Society of Mechanical Engineers
7. CCPS - Center for Chemical Process Safety, 1998, Pressure Relief and Effluent Handling Systems, New York, NY, American Institute of Chemical Engineers

4. Screening Study Results

- All relief valves discharging to a closed disposal system are adequately supported for an individual release
- All liquid and 2-phase relief contingencies require detailed analysis
- All non-standard pressure relief valve sizes require detailed analysis
- Pressure relief valve installations can be characterized as either "Typical" or "Complex"
- Pressure relief valves installed and sized for the external fire contingency only will not require reaction force evaluation
- Pressure relief valves installed and sized for the liquid hydraulic expansion contingency only will not require reaction force evaluation

Qualitative Screening

- Based on assumptions presented above

Qualitative Step	Relief Valves Remaining	Relief Valves Requiring Analysis	Relief Valves Not Requiring Analysis
Starting Point	189	0	0
External Fire Only	186	0	3
Thermal Expansion Only	168	0	21
Discharge to Closed System	157	0	32
Non Standard Device Sizes	152	5	32
Liquid or 2-phase Relief	112	45	32

Table 2 – Stepwise results of decision tree of qualitative results to determine relief devices that require detailed engineering analysis.

Quantitative Screening

- For typical installations a threshold value of 90% was used when comparing the installation to screening tool generated stresses for each relief valve size
- For "complex" pressure relief valve installations the threshold value was lowered to 70% of the occasional loading/yield stress limits.

Installation Type	# of installations	Requiring detailed analysis	Require Support
Typical	145	4	15
Complex	58	5	13
Total	189	9	28

Table 3 – Quantitative Screening Results for Pressure Relief Valve Installations based on Complexity of the Installation

5. Overall Results

- A sample from each of the three categories was taken and detailed analysis was performed to verify these results. Of that sample all relief device installations predicted to require support did indeed require support to avoid exceeding the yield stress; likewise all sampled installations predicted to be adequate were found to be adequate. Of the sampled devices predicted to require detailed engineering analysis, all but one resulted in exceeding the yield stress, and that installation did exceed the allowable stress.

- The purpose of this study was to provide a solid screening tool in order to prevent the cost of performing detailed engineering evaluation on every relief device installation, and the end result proved to succeed at this.

Action Item	Quantity
Relief Devices Requiring Support	28
Relief Devices Requiring Engineering Analysis	34
Installations Predicted to be Adequate with Respect to Reaction Forces	127
Total	189

Table 4 – Overall Results based on Reaction Force Screening

Conclusion

- For the facility studied, ~2/3 of the pressure relief valve installations were predicted to be adequate with respect to reaction forces with the remaining installations being broken into two categories; those requiring support, and those requiring further analysis. Proving that in practice, a significant percentage of pressure relief valve installations do not meet the desired structural integrity when considering reaction forces. This study demonstrates a screening tool that allows plants to focus resources on the relief valve installations most likely to fail due to reaction forces.