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Case Study of Relief Analysis of Compressor Stations

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Abstract

A compressor station is a facility which helps the transportation process of natural gas from one location to another. Compressor stations include several key component parts, the primary being the actual compressor unit, either centrifugal or reciprocating. They also typically include scrubbers, strainers or filter separators which remove liquids, dirt, particles, and other impurities from the natural gas. This study will give an overview of the relief analysis conducted for multiple compressor stations. The relief analysis was system based as opposed to relief device based so as to identify any unprotected systems that may need overpressure protection. It will discuss the overpressure scenarios identified for these systems. It will provide some general statistics on the total number of applicable overpressure scenarios. It will give a detailed breakdown of the various concerns found including, but not limited to, undersized devices, unprotected systems, installation concerns, data needs, and documentation discrepancies. The study will discuss possible mitigation solutions for these concerns.

1. Introduction

Compressor stations are typically located along a natural gas pipeline to facilitate the compression of the gas to a specified pressure, which allows the gas to flow along the pipeline to a target location. Since these pipelines typically extend for several hundreds of miles, the gas tends to lose pressure frequently. This necessitates the requirement to compress it frequently during the transportation process.

The size of the station and the number of compressors (pumps) varies, based on the diameter of the pipe, and the volume of gas to be moved. Compressor stations include several key components, the primary being the actual compressor unit, either centrifugal or reciprocating, scrubbers, and strainers or filter separators which remove liquids, dirt, particles, and other impurities from the natural gas.

It is critical to ensure that the natural gas transported to its intended target is free from any contaminants. This is accomplished through four mains steps. The first step is contaminant removal, which occurs upstream of a compressor station near the well head. Here, the raw natural gas, at very high temperature and pressure, is passed through separators in order to remove oil, water, sand etc. It is then passed through a slug catcher, typically located within the compressor station, to remove any leftover condensate. The third contaminant removal step occurs downstream of the compressor unit (after the gas has been pressurized) via a contactor unit that predominantly removes liquid water and carbon dioxide using triethyleneglycol (TEG) as the absorbent. The TEG that separates out at the bottom of the scrubber unit, carrying the water and carbon dioxide with it, is typically regenerated in a glycol regenerator unit before it is recirculated back into the scrubber unit. The final step prior to delivery of the gas to its intended target is to remove any leftover TEG in the gas using a scrubber unit. There are also several tanks within the compressor station for storage of the condensates and TEG. Additionally, the compressor stations contain several components that are part of the glycol regenerator unit including filters, flash tank separators, pumps, heat exchangers, etc. A general process flow diagram of the compression station is shown in Figure 1.

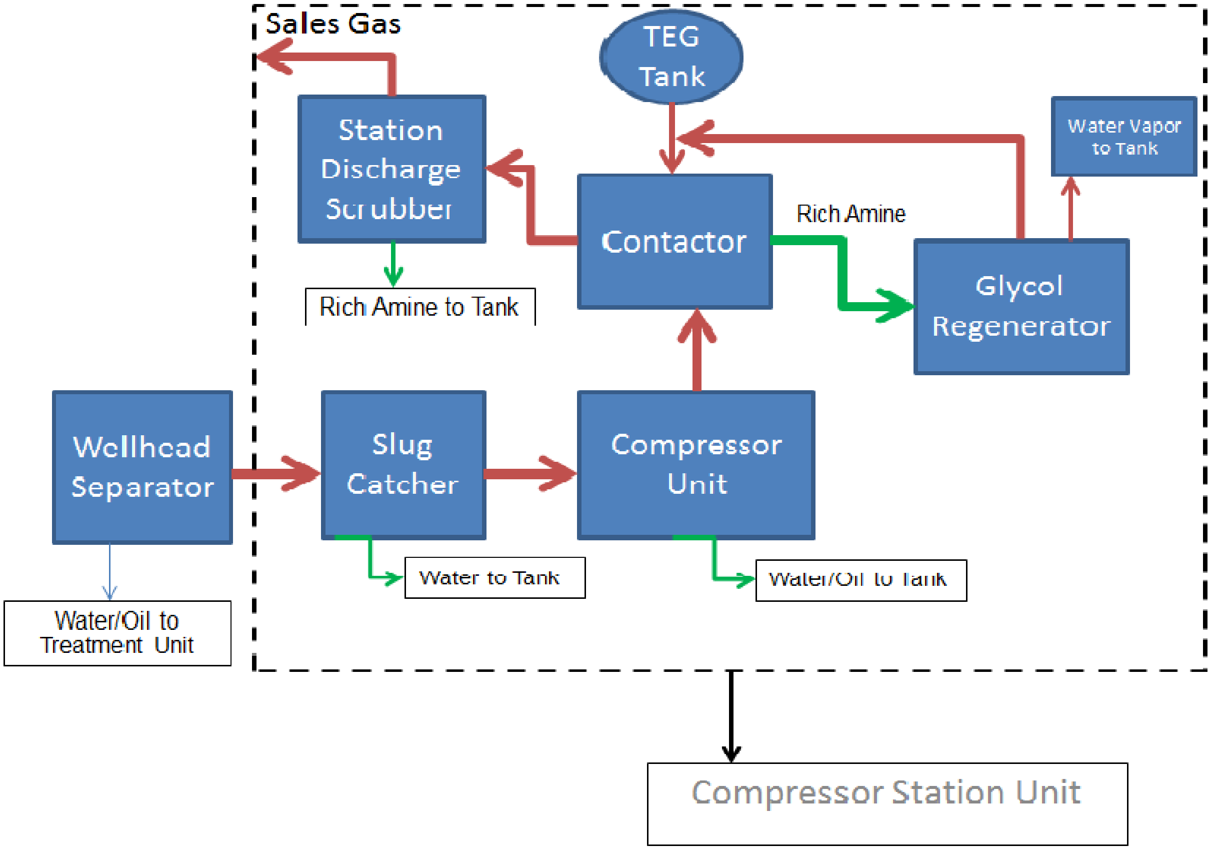

Figure 1: Process flow diagram of Compressor Station

2. Relief Analysis

For this case study, twenty separate compressor stations were analyzed. Specifically, the steps required for performing the analyses, different applicable scenarios, and all the concerns identified with mitigations options are presented. The analysis was conducted using API 520 Part 1 and Part 2 standards, while considering the client's design philosophy as well.

2.1. Steps involved in Relief Analysis

The relief analysis, which is a system based analysis performed for each equipment in the unit, is a methodical four step approach including data and design documentation collection, contingency analysis, pressure relief calculations, concern identification and mitigation. These steps are discussed in detail below.

Data and Design Documentation Collection: Since the client for whom the relief analysis is being performed may not always provide all the information necessary to conduct the analysis, it is imperative that all necessary data and documentation required is collected at the client site prior to commencing the project. Examples of such data collected include isometrics for PSV inlet and outlet piping, PSV and control valve information, equipment and relief device name plate information, U-1A forms, equipment drawings etc. Usually, the piping and instrumentation diagrams (P&IDs) and heat and material (H&M) balance are provided by the client in order to complement the other data collected. All the data collected is then entered into a client project database.

Contingency Analysis: Prior to commencing the contingency analysis, the compressor station is divided into various systems, with each system consisting of several equipment. The interface of systems is defined based on where block valves are situated within the P&ID. Once the systems have been defined, a contingency analysis is performed where all scenarios that could possibly result in an overpressure condition are identified. For the 20 compressor stations that were analyzed in this case study, the following eighteen contingencies were identified: Power Failure, Cooling or Reflux Failure, Steam Failure, Instrument Air Failure, External Fire, Blocked Outlet, Isolated with Heat Input, Equipment Failure, Inadvertent Valve Operations, Failure of Automatic Controls, Gas Breakthrough, Internal Boundary Failures, Reverse Flow, Run Away Reaction, Accidental Mixing, Change in Conditions, Vacuum, Other (applicable scenarios other than listed above).

Calculations: Once the contingency analysis is finished, the required flow rate of the applicable overpressure scenario and the capacity of the relief device (based on the relief device ASME orifice area) are calculated. The inlet and outlet pressure drops, Mach number and sound power level of the piping is also calculated based on the dimensions of the relief device.

Concerns Identification and Mitigation: After the calculations are completed for a system, all the concerns are identified and documented in the database. This is as per the guidelines provided in API 520 Part 1, 2 and the design philosophy provided by client. The concerns are identified based on the calculation results and discrepancies and assumptions made during the analysis. Once all the concerns are identified, recommendations for implementation of mitigation strategies are provided to the client.

3. Results of Case Study

3.1. Relief Device Identification

For the twenty compression stations that were analyzed as part of this case study, the relief devices included all the relief valves, pressure and vacuum vents (PVRVs), goosenecks, and rupture disks. Usually, the relief valves and rupture disks were situated on the pressure vessels while the PVRVs and goosenecks were situated on the low pressure tank. A total of 1099 relief devices were identified for the 20 compressor stations. Depending on the type of relief device, the method of calculation may vary. For example, in the case of PVRVs and goosenecks, it is not necessary to calculate the pressure losses.

The breakdown of the percentage and number of the relief devices, by type, that were analyzed in this study are shown in Table 1 and Figure 2 respectively.

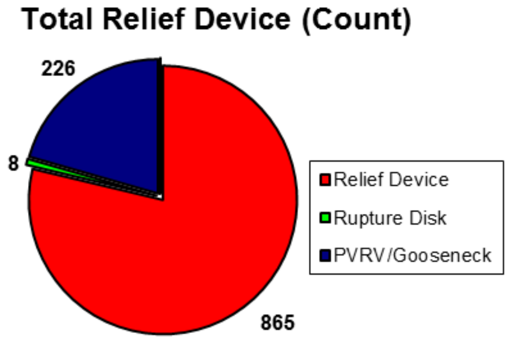

Figure 2: Actual number of different relief devices, by type, for the twenty compressor stations

Table 1: Percentage of different relief devices by type

Relief device Type	**Percentage**
Relief valve	78%
Gooseneck/PVRV's	21%
Rupture Disk	1%

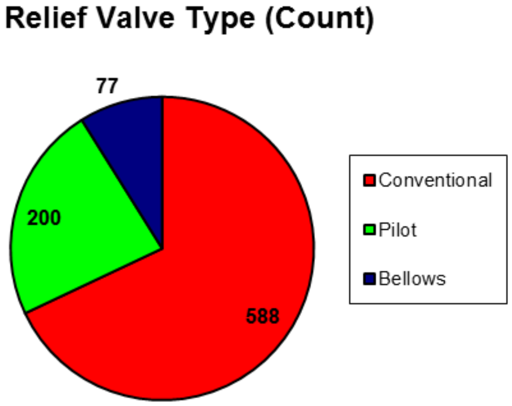

Figure 3: Actual number of relief valves, by type for the twenty compressor stations

3.2. Relief Valve Type

There are three types of relief valves that are typically used in the oil and gas industry: conventional, bellows, and pilot valve. Based on the type of valve, the outlet pressure drop limits vary; hence it is important to identify the relief valve type. As shown in Table 2, out of a total of 865 relief valves identified, the majority of the valves in the compression stations analyzed were conventional relief valves,. The breakdown of the number and percentage of the relief valve that were analyzed in this study are shown in Table 2 and Figure 3 respectively.

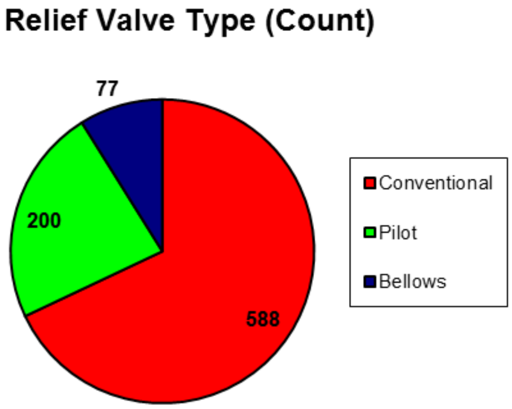

Table 2: Percentage of different relief valves, by type

Relief Valve Type	Percentage
Conventional	68%
Pilot	23%
Bellows	9%

3.3. Equipment Type

Based on the equipment type, the overpressure scenario may be applicable or not and the data required to do the analysis will be different. Hence, it is very important to identify the type of the equipment. A total of 2014 equipment were identified in all the compressors stations, of which majority were pressure vessels.

The breakdown of the percentage and number of the equipment type that were analyzed in this study are shown in Table 3 and Figure 4 and respectively. Note that the “Other” type of equipment includes compressors, glycol regenerators etc.

Table 3: Percentage of different equipment, by type

Equipment Type	Percentage
Pressure Vessel	48.5%

Tower	8.1%
Pumps	8.9%
Exchangers	16.6%
Fired Heater	0.1%
Low Pressure Tanks	6.1%
Piping Component	6.4%
Others	5.3%

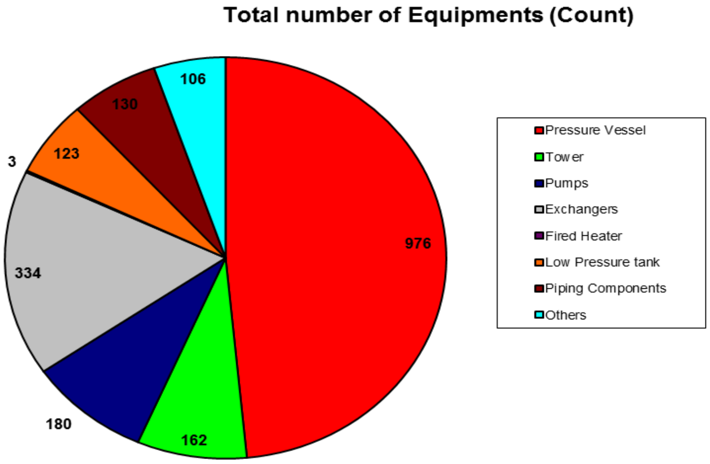

Figure 4: Actual number of equipment, by type, for the twenty compressor stations

3.4. Applicable Overpressure contingencies:

All the applicable scenarios, for each system, were identified after reviewing the P&IDs and other available data. This section shows all the applicable scenarios identified. The breakdown of the percentage and number of the applicable contingencies that were analyzed in this study are shown in Table 4 and Figure 5 respectively. Of a total of 3026 applicable contingencies, the majority of the contingencies in the compression stations analyzed were external or pool fire and blocked outlet.

Table 4: Percentage applicable contingencies by type

Contingency Type	Percentage
External fire	22.8%

Cooling or reflux failure	0.1%
Blocked Outlet	22.6%
Failure of automatic controls	13.3%
Gas breakthrough	8.5%
Inadvertent valve operation	5.6%
Instrument Air failure	2.9%
Internal boundary failure	1.6%
isolated with Heat Input	6.4%
Power failure	0.9%
Reverse flow	3.2%
Vacuum	7.1%
Other	5.0%

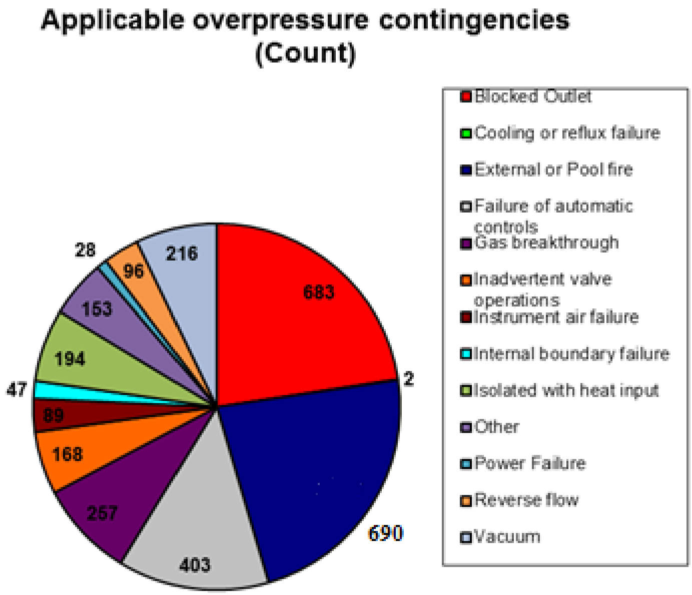

Figure 5: Actual number of applicable overpressure contingencies, by type, for the twenty compressor stations

3.5. Concerns Identification:

This was one of the most important steps in the relief analysis. Based the calculation results, assumptions, discrepancies etc., all the concerns were identified and documented based on the guidelines. The concerns were divided into five major categories: Undersized Concerns, Installation Concerns, Unprotected Systems, Data Requirement, and Documentation Updates. It is important that assumptions made during this stage be documented, verified and approved by the client. The undersized concerns, installation concerns and unprotected system concerns were assigned a higher priority since they could have a direct impact on the operation and failure of the compressor station. Hence, it was recommended that these concerns be mitigated immediately.

The breakdown of the percentage and number of the concerns that were analyzed in this study are shown in

Table 5 and Figure 6 respectively. Of a total of 3278 applicable concerns that were identified in this case study, the majority of the concerns in the compression stations were related to Data Requirements.

Table 5: Percentage of concerns identified, by type

Concern Type	Percentage
Undersized	10.4%
Installation	24.6%
Unprotected Systems	9.5%
Data Requirement	50%
Documentation Updates	5.5%

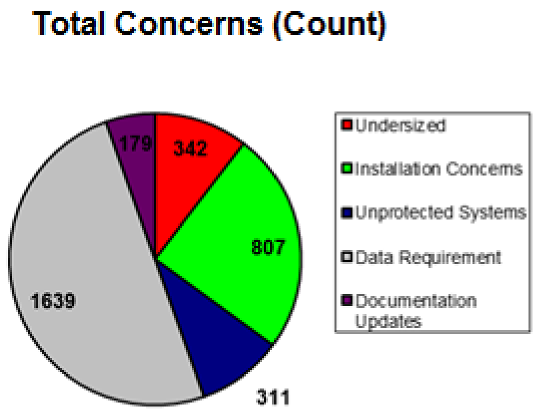

Figure 6: Actual number of different concerns, by type, for the twenty compressor stations

Undersized Concerns:

When the required relief flow rate is more than the capacity of the relief device, the relief device is defined to be undersized. This section shows the overpressure scenarios which were undersized. This includes all the contingencies for which the relief devices were undersized. The most common reasons for relief devices to be undersized were identified as being because of incorrect upstream pressure, incorrect composition of the relief stream, or that the contingency was not identified at all in the previous study.

The breakdown of the number and percentage of the undersized concerns that were analyzed in this study are shown in

Table 6 and Figure 7 respectively. Of a total of 342 undersized concerns that were identified in this case study, the majority of the contingencies in the compression stations were Vacuum, Gas Breakthrough, External or Pool Fire and Failure of Automatic Controls.

Table 6: Percentage of type of contingency within undersized concerns

Contingency Type within Undersized Concern	Percentage
Blocked outlet	11.1
External fire	15.2

Failure of Automatic Controls	15.2
Gas breakthrough	15.5
Inadvertent valve operation	1.1
Internal Boundary failure	8.2
Reverse flow	8.5
Vacuum	24
Other	1.2

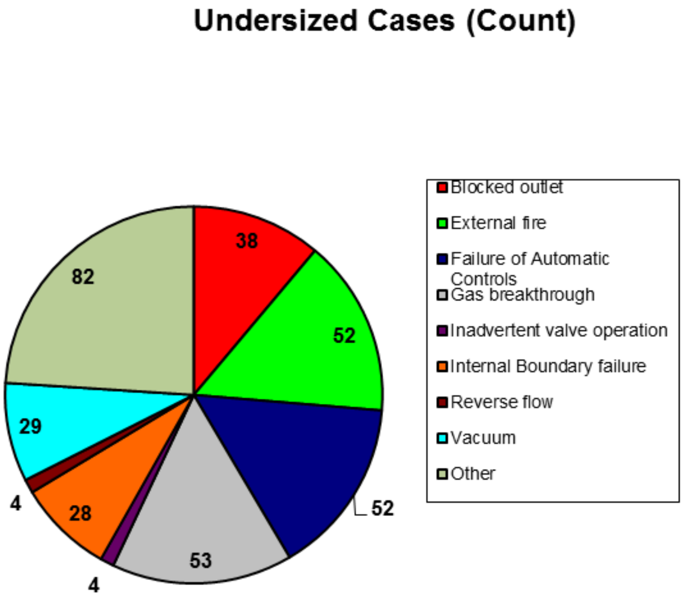

Figure 7: Actual number of different contingency types within the undersized concerns for the twenty compressor stations

Installation Concerns:

The installation concerns (total of 807 were identified) are divided into eleven sub categories as shown below. This is based on the guidelines used to perform the analysis.

Inlet Pressure Drop: The inlet pressure drop is calculated based on the relief device capacity. This includes all the scenarios for which the inlet pressure drop is greater than 3% of set pressure. As per API 520, if the inlet pressure drop exceeds 3%, the potential for capacity reduction and/or mechanical damage may exist for the relief valve. Note that inlet pressure drop concern was not identified for the relief devices which were undersized for one or more overpressure scenarios.

Outlet Pressure Drop: The outlet pressure drop is calculated based on the capacity of the relief device. This includes all the scenarios for which the outlet pressure drop is greater than 10% of set pressure for single conventional valves, or greater than 16% of set pressure for multiple conventional valves except for fire case, greater than 21% of set pressure for conventional valves for external fire, and greater than 50% of set pressure for bellows valves. As per API 520, if the outlet pressure drop exceeds the limit, the potential for capacity reduction and/or mechanical damage may exist for the relief valve. Note that outlet pressure drop concern was not identified for the relief devices which were undersized for one or more overpressure scenarios.

High Exit Velocity: The exit velocity and sound power level of the relief valve piping can affect its stability. All overpressure contingency with Mach number greater than 0.8 and sound power level greater than 155 was documented. Note that the high mach number concern was not identified for the relief devices which were undersized for one or more overpressure scenarios.

High set pressure: The relief device with set pressure greater than maximum allowable working pressure (MAWP) of the equipment was identified since the relief valve can no longer protect the system if this condition exists.

Isolation valve: This includes the block valves that are not chain locked open as required (the most common ones were the block valve on relief device inlet and outlet piping).

Pocketed Piping: In the event of liquid release and if the relief device is pocketed, the liquid can accumulate in the piping and hence the stability of the piping can get affected; hence it is very important to correct this concern.

Restricted line: In the event the inlet segment of the relief device piping is greater than the inlet nozzle as per API 521, these segments needs to be identified and documented.

The breakdown of the number and percentage of the installation concerns that were analyzed in this study are shown in Table 7 and Figure 8 respectively. Of a total of 807 installation concerns that were identified in this case study, the majority was the high outlet pressure drop concern.

Table 7: Percentage of installation concerns by type

Installation Concern	**Percentage**
High inlet Pressure drop	17.2%
High Outlet pressure drop	24.8%
High Exit Velocity	5.9%
Pocketed Piping	5.3%
Restricted Line	1.7%
Isolation Valves	11.8%

High Set Pressure	0.9%
No Weep Hole	20.8%
Liquid to Atmosphere	1.5%
Valve Stem Rotation	4.0%
Other	6.1%

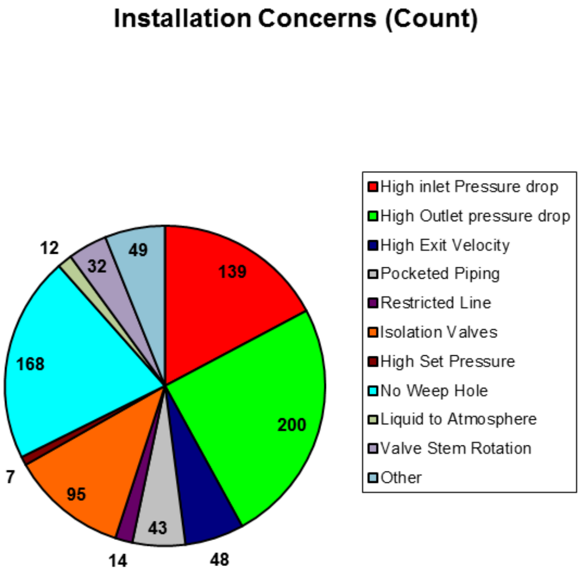

Figure 8: Actual number of installation by type for the twenty compressor stations

Unprotected Systems

These concerns were identified only for those systems that had applicable scenarios without any relief device protecting them. Contingency analysis for all the systems which didn’t have any relief device protecting them was performed. As the case study was conducted on system based analysis, it was easier to identify these systems. The systems which had an internal relief device were considered to be unprotected. There were few cases in which there was a block valve present between the system and the relief device; hence these systems were considered unprotected. This list also includes the overpressure contingencies which resulted in over temperature of vessel in the event of external fire. Of a total of 3278 concerns identified, 311 were categorized as unprotected concerns.

Data Requirement

All the assumptions which were made during the analysis were documented under this category. During the analysis, a data need log was created if a proper supporting document was not provided and any follow on assumptions made due to the lack of documentation was approved by the client. Some general assumptions which were made were liquid levels, MAWP of the system (usually was assumed to be same as relief device set pressure), and relief valve information. Of a total of 3278 concerns identified, 1639 was data requirement concerns.

Documentation Updates

During the analysis, some discrepancies were found between different documents such as the U1A-form and the P&ID and these discrepancies were documented, with the correct information needing to be updated on the relevant documents. Documentation updates are usually a low priority concern as they may not impact the operation and safety of plant significantly. Of a total of 3278 concerns identified, 179 were documentation updated.

3.6. Mitigation of Concerns

Once the concerns were identified and documented, different recommendations were provided in order to mitigate the identified concerns. Usually, the clients choose to implement mitigation strategies predominantly for the higher priority concerns such as the unprotected concerns, installation and undersized concerns. An example list (not comprehensive) of the recommended mitigation strategies that were provided to the client for undersized, installation concerns and unprotected systems is detailed below.

Mitigation Strategies for Undersized Concerns

The provided recommendation to resolve undersized concerns depends on the overpressure contingency for which the relief device was undersized.

External Fire: In the event the relief device is undersized for external fire, it was checked if the vessel is insulated and whether credit of insulation could be taken. Usually, in order to overcome this concern, it was recommended that a bigger relief device be installed.

Blocked Outlet: In the event the relief device is undersized for blocked outlet, it was recommended that a bigger relief device be installed.

Isolated with Heat input: In the event the relief device is undersized for “isolated with heat input”, it was recommended that a bigger relief device be installed. An alternate recommendation was to see if the undersized concern could be mitigated using administrative controls.

Tank Draining (Vacuum): This was a major concern identified in low pressure tanks. This overpressure scenario was missed in previous studies and hence, a lot of undersized concerns were found. It was recommended that a restriction orifice be installed on the drain line. Another option recommended was to install a bigger PVRV.

Failure of automatic control: For this undersized scenario, it was recommended that a restriction orifice be installed on the line, while still ensuring that it can allow the normal flow through it; however it can regulate the maximum flow such that the relief device is adequately sized. Another option recommended was that a restriction orifice be installed so that the maximum C_v of the control valve can be reduced, which ensures that the relief valve is adequately sized. It was rarely suggested that a bigger relief device be installed for this case.

Inadvertent valve operation: These cases usually included the inadvertent opening of bypass valves around the control valve. For these cases, usually the pipe capacity calculation was reperformed based on the equivalent length of piping from source to destination to check if the concern still existed. If the concern still exists, it was recommended that the bypass valve be chain lock closed or a restriction orifice be installed.

Gas breakthrough: Majority of the time, the failure of automatic controls and inadvertent valve operations resulted in gas breakthrough. For these cases, usually the pipe capacity calculation was reperformed based on the equivalent length of piping from source to destination to ensure if the concern still existed. If the concern still exists, it was recommended that the bypass valve be chain lock closed or a restriction orifice be installed.

Reverse flow: This is one of the most common overpressure contingencies that can be missed while doing the analysis. That is one the reason why the relief device was undersized for this case. In order to overcome this concern, it was recommended that multiple check valves be installed in the direction of flow. An alternate option recommended was the installation of a bigger relief device.

Mitigation Strategies for Installation Concerns

Inlet & Outlet pressure drop: For pressure drop concerns, it was recommended that the concerned piping be modified. The equivalent length of the piping was provided such that it was within the prescribed limit. Alternately, if the relief device was oversized, it was recommended that a smaller relief valve be installed. In this scenario, it is important to still ensure that the relief device is still adequately sized. For inlet pressure drop, it was recommended that a pilot valve with a remote sensing line be installed. For outlet pressure drop, it was recommended that bellows or a pilot valve be installed.

Mitigation Strategies for Unprotected System

If the system is unprotected, the most common recommendation was to install a new relief device. An alternate option recommended was to chain lock open any open block valve to take credit for other relief device. The third option recommended was to mitigate the scenario with administrative controls. This option was common for heat exchangers which have only thermal expansion as the applicable overpressure contingency.

4. Summary

This case study provides an overview of the relief analysis conducted for multiple compressor stations. As stated previously, the relief analysis was system based as opposed to relief device based so as to identify any unprotected systems that may need overpressure protection. It is very important to use the correct operating conditions and fluid composition to perform the relief analysis. The study provided an overview of the various types of overpressure scenarios identified for these systems, with a statistical breakdown of the scenarios by type. It was found that external fire and blocked outlet were the most commonly identified overpressure scenarios. In addition, this case study provided a breakdown of the types of relief devices, a further breakdown of types of relief valves, and the different types of equipment in the compressor stations. A breakdown of the type of concerns identified during the compressor station revalidation was provided along with a general idea of the mitigations that can be implemented to resolve the concerns. When performing relief analysis for compressor stations, it is very important to look out for any contingencies previously not considered, possibly due to changes in facility design or changes in the guidelines.