Making Relief Load Estimates Match Reality

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Abstract

A pressure relief system designer must make some assumptions when looking at a relief systems analysis. Some assumptions may result in costly modifications of the system, so knowing when to apply certain assumptions is paramount with the ability to accurately size a relief valve. When looking at systems, industry standards should be consulted before taking certain credits based on the given scenario. For example, the designer may be able to reduce the relief load by looking at a reduced reboiler duty and a temperature pinch during an overpressure event. When evaluating an inlet control valve failure, some credits may be taken for the minimum turndown for the outflow. However, when looking at how a downstream system may respond to the overpressure event, credit for flow continuing may not be acceptable and flow may be assumed to be lost. The application of assumptions is common practice in relief systems analysis; however, an assumption that does not match the true operational limits may lead to problems with the relief system that do not actually exist. These invalid assumptions could cost millions of dollars to fix the problem.

1. Introduction

When doing a Relief Systems Documentation Analysis, the ability to accurately model a "worst case" relief scenario is paramount to ensuring the system is protected from the overpressure event. The engineer is undoubtedly limited to the availability of equipment data and accuracy of the process simulation developed to predict upset conditions. However, if some conservative yet unrealistic assumptions are used, the relief device can be labeled as providing inadequate protection in the event of the initiating event. [1] Physically modifying the system to fix the problem, as well as the loss of profit from having to shut down the unit to perform the update, can cost the facility large sums of money. However, performing a detailed analysis on the system may better predict the “worst case” scenario, avoiding unnecessary modifications. The ability to make relief load estimates match what may happen out in the field can still be accomplished, but knowing the difference between a realistic conservative assumption and an unrealistic conservative assumption is paramount. The pressure relief system designer should consult industry standards (e.g. API 521or NFPA) to see how to estimate relief loads for given overpressure scenarios and what assumptions for mitigating items/actions are acceptable. This paper will look at two cases where relief load estimates were reduced and one where by matching the physical constraints of the system to reality resulted in a larger relief load estimate.

2. When Realistic Assumptions Lower Relief Estimates

Oftentimes relief estimates are based on normal operating flow rates, heat exchange, and/or flow paths continuing during the upsets. With the amount of optimization and debottlenecking, these assumptions may not be realistic. Equipment capacities that are right on the design limit may not be able to produce the same flow rate or heat transfer under upset conditions. Flow paths that are available under normal operation may be isolated or otherwise not be available during upsets. The following are three examples that show these effects in a typical plant situation. The first two are examples of assumptions that tended to increase the relief rate while the last example illustrates an optimistic assumption that under-predicted the relief requirements.

2.1 Reduced Reboiler Duty

When looking at a column system, the primary relief loads tend to consist of a combination of continued heat input with the loss of cooling. The relief load estimates can be complex due to the very nature of the system. The ability to do a detailed analysis of the column may be able to better predict upset conditions. The authors have seen many cases where a detailed column analysis prevented the relief device modifications from being made based on inaccurate sizing basis. The ability to accurately model the relief scenario is paramount because an error could lead to events such as an unnecessary facility modification or a loss of containment from an undersized relief device. When a pressure relief system designer looks at the loss of overhead cooling on a column system, the scenario is a transient event. The case can start with the loss of overhead condensing with the reflux continuing for a short duration. After some time, the loss of condensing and continued overhead liquid product output results in the loss of level and reflux flow. To estimate this relief condition, the column system is modeled as two steady state cases to bracket the relief load. Under either of these conditions, the bottoms temperature may increase due to the increase in system pressure, but this phenomenon may be offset by the reduction in separation; therefore, a reduced duty calculation should be performed for both calculation sets to ensure that the reboiler is capable of transferring the same heat into the column system as during normal operating conditions. When looking at the loss of overhead cooling with the reflux continuing, the reboiler duty may not be able to be reduced due to increased light component traffic in the tower (as compared to the top tower reflux failure) when compared to the high temperatures in the reboiler and lower duties expected during the top-tower reflux failure scenario due to the loss of the light ends liquid traffic in the column. Taking credit for the reduced duty is still a reasonable assumption as an upper conservative limit when the assumption is based on the maximum duty possible for the installed reboiler and is limited by equipment capacity. The design equation for heat exchangers is given below [2]:

$$Q = UA\Delta T_{LM}$$

Reduced duty calculations, limited to process/process or process/utility exchangers (e.g. shell and tube exchangers), are not typically performed on fired heater reboilers. The exchanger data sheet, if up-to-date, is the best resource for determining the heat transfer characteristics of an exchanger. Most process simulators can simulate the duty of shell and tube exchangers by specifying the clean UA and, if applicable, the utility stream (e.g. 50# steam). The duty for the exchanger may change as reflux is lost to the system, which the upset may result in hotter bottoms temperature to the reboiler. The reduced duty may reduce the relief load estimate, as there is less vapor generation as compared to using the process duty under normal conditions. Figure 1 shows a screenshot from a process simulator that estimates the rate for a column system with continued feed and heat input, but a loss of cooling and reflux.

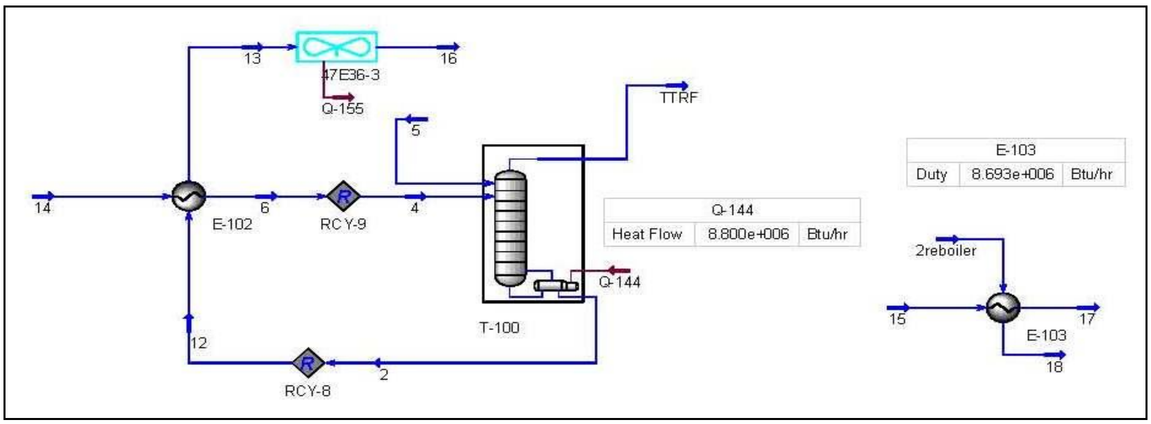

Figure 1: Example of a simulation for a column with loss of cooling and top-tower reflux failure with a reduced duty calculation performed.

2.2 Using the correct composition and physical properties

Generally the capacity of the reboiler (e.g. the reduced or LMTD pinched duty) will vary greatly if the calculation is based on the normal bottoms product as compared to the overhead reflux/liquid product. In the case of system upsets, the actual liquid inventory in the bottom of the tower may be lighter than normal. The pressure relief system designer is cautioned to use a composition in the reboiler to estimate the reduced duty that is consistent with the overpressure scenario being reviewed.

2.3 Inlet Control Valve Failure Credits

Another common overpressure scenario is the failure of automatic controls. Per API 521, this scenario is the complete failing open of a control valve (irrespective of its fail safe position).[3] If this upset condition results in overpressure, a relief device may be required to protect downstream equipment. When looking at an inlet control valve failure, the first common assumption pressure relief system designers make is to estimate the full capacity of the control valve and then verify if the relief valve can pass that fluid at the appropriate overpressure. The designers verify if the capacity of the relief device is greater than the control valve. If this estimation results in insufficient relief valve capacity, then some credits may need to be taken to make the relief load estimate more realistic.

Per API 521§ 5.10.2,

> "in evaluating relieving requirements due to any cause, any automatic control valves that are not under consideration as causing a relieving requirement and that would tend to relieve the system should be assumed to remain in the position required for minimum normal processing flow. In other words, no credit should be taken for any favourable instrument response." [3]

For example, if the outlets from the system are expected to remain open, the calculation may assume that some of the fluid will flow through the normal path, see Figure 2. This credit is usually at the minimum turndown rate, as common industry practice is to assume that other control system remains in place and does not respond (unless it exasperates the single failure).[3] If the relief scenario is liquid, credit can be taken for the liquid outlet to reduce the fluid from the control valve that needs to be relieved by the pressure relief device by the minimum turndown rate. If the liquid outlet does not provide enough credit, the vapor outlet can be sized to take some relief as long as the vapor line is not lost by passing the liquid. A common example of this would be that a high-level alarm would trip a compressor; in this case, the relief device would have to pass both the liquid and the vapor feed to the vessel as the increased liquid level caused multiple failures. As long as the pressure relief system designer verified the liquid could flow through the vapor line and accumulate in the downstream system, credit can be taken through the vapor line. If the relief scenario is vapor, credit may be taken for flow through the vapor line at the minimum turndown rate (though the potential for credit for vapor flow through the normal liquid outlet is normally not considered). Consideration should be given for the difference in the relief fluid and the normal fluid and to adjust the credit based on the actual volume rate.

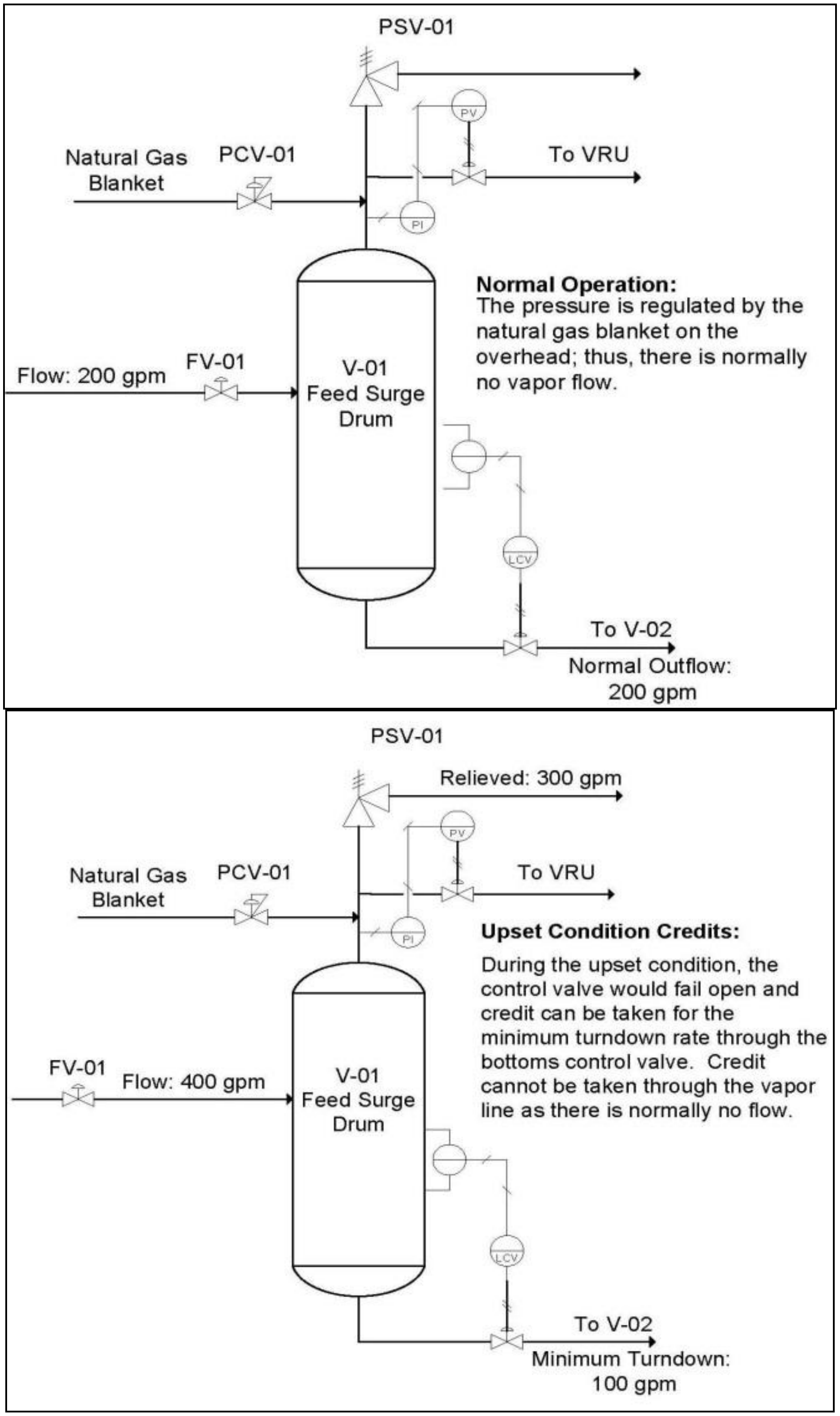

Figure 2: Looking at a feed surge drum during inlet control valve failure can lead to credits to be taken as long as they are reasonable for the system. Credit cannot be taken through the vapor line as there is normally no flow.

There is a special control valve failure case that pressure relief system designers need to be aware of. When a liquid control valve fails open, the vessel may de-inventory and gas may flow through the liquid control valve into the downstream vessel. This scenario, typically called a gas blow-by, should be reviewed for all control valve failures where there is liquid and gas in the upstream vessel. Figure 3 shows a typical system where gas blow-by may occur.

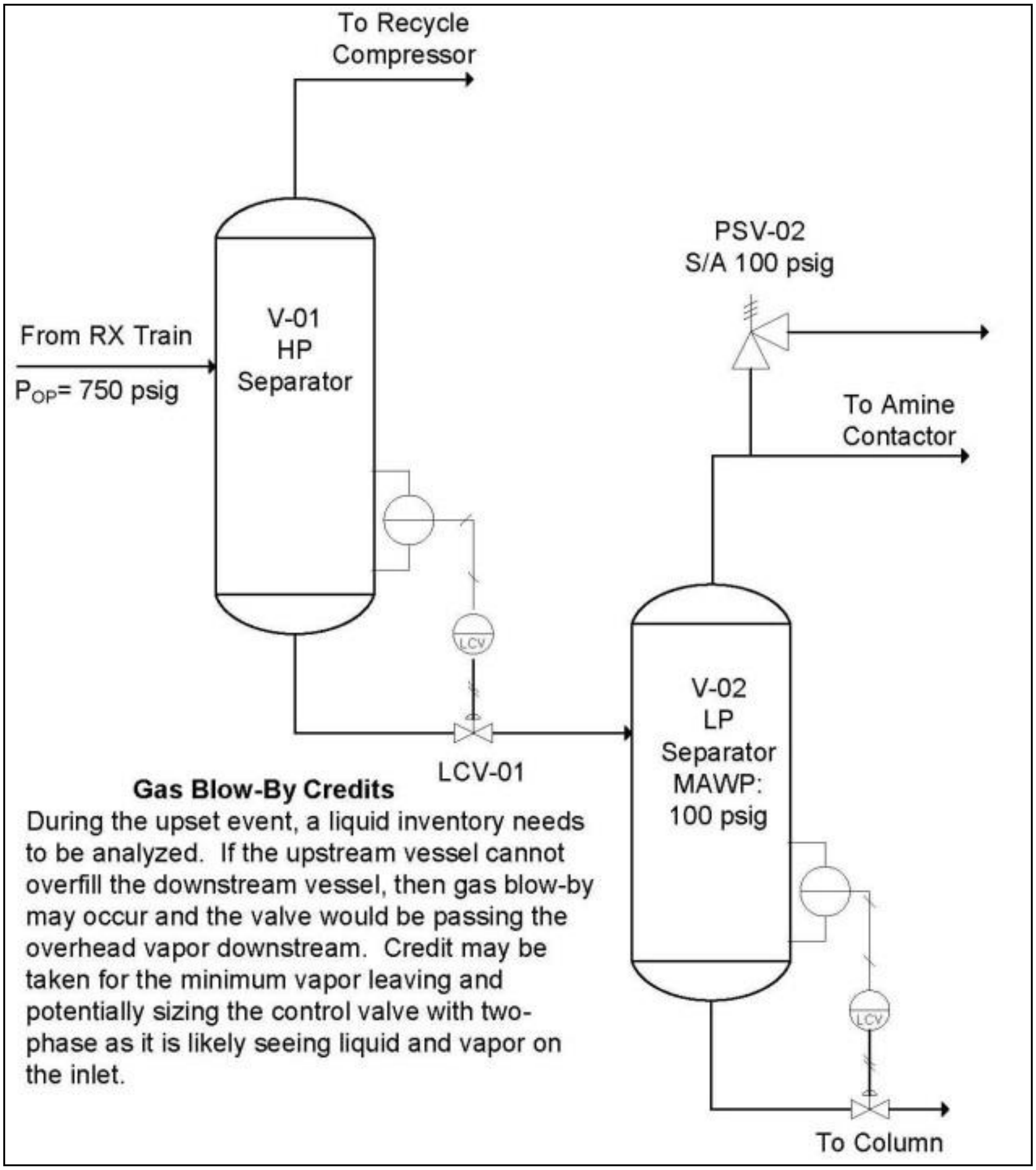

Figure 3: Example of when gas blow-by may occur. When looking at a low pressure separator, the sizing event should be vapor breakthrough the control valve from the upstream high pressure separator.

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3. When Realistic Assumptions Make the Estimates Worse

3.1 Compressors Downstream of the System

In some instances, making relief load estimates match closer to reality may lead to a larger relief load estimate. In these cases, the pressure relief system designer must ensure that the relief system is accurately modeled and that the designer uses the larger rates and does not allow designs based on nonsensical assumptions to be used as the basis. There are many different assumptions that could cause this case to be true; the example that we are going to highlight is when the cascading effect of one failure causes the normal plant control system to take an action and increase the relief requirements for a pressure relief device. Oftentimes, a pressure relief system designer may want to take credit for some of the relief effluent to outflow from the system through a compressor. As stated above, this would not be a viable flow path for liquids, as almost all compressors have a high level trip on the inlet drum, but what about vapors? Depending on the scenario, the compressor may pass vapors at the upset conditions or the compressor could trip and result in a blocked outlet. Examples that may cause a compressor to trip under upset conditions include a higher inlet gas temperature trip, a high amp / power requirement trip (due to the increased suction pressure), high temperate trip (due to the potential loss of cooling to the compressor), vibration trips, and etc.[4,5] It is useful for the pressure relief system designer to discuss the scenario with personnel who are familiar with the operation of the compressor (usually either the operators or unit process engineer) to ensure that any assumptions made are consistent with operational history. Figure 4 shows a case where a compressor trip would not result in a larger relief load.

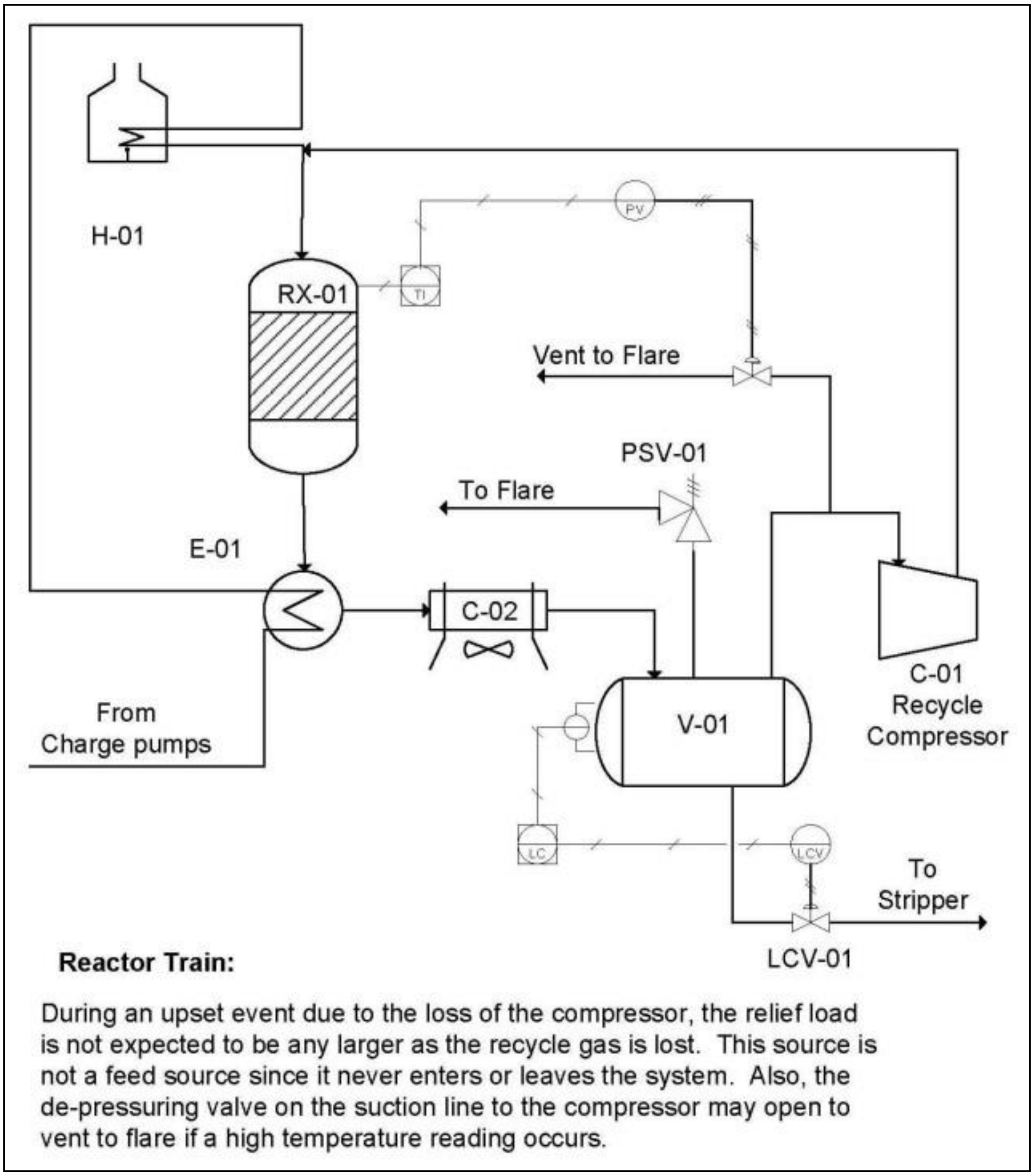

Figure 4: An example of how compressors can affect the relief load. The loss of the compressor would not result in any excess relief as the recycle gas is lost.

3.2 Example of Compressors Shutdown Analysis

A larger estimated rate may occur in a scenario where there is a partial loss of cooling in a column system that uses a compressor to move the off gas from the overhead accumulator to the downstream system (e.g. a FCC Main Fractionator, Coker Bubble Tower, Atmospheric Tower, and etc.). After the simulation is developed to model the column operation during the partial loss of cooling, the modified characteristics of the off gas (e.g. temperature, density) are consistent with conditions that trip the compressor. Additionally, the pressure relief system designer must ensure that the scenario itself (e.g. a unit wide power or cooling tower failure) could result in a compressor trip and result in this outlet being blocked. The relief load estimate would then need to include the cascading effects of the compressor shutting down and may be much larger than would be otherwise predicted (see Figure 5).

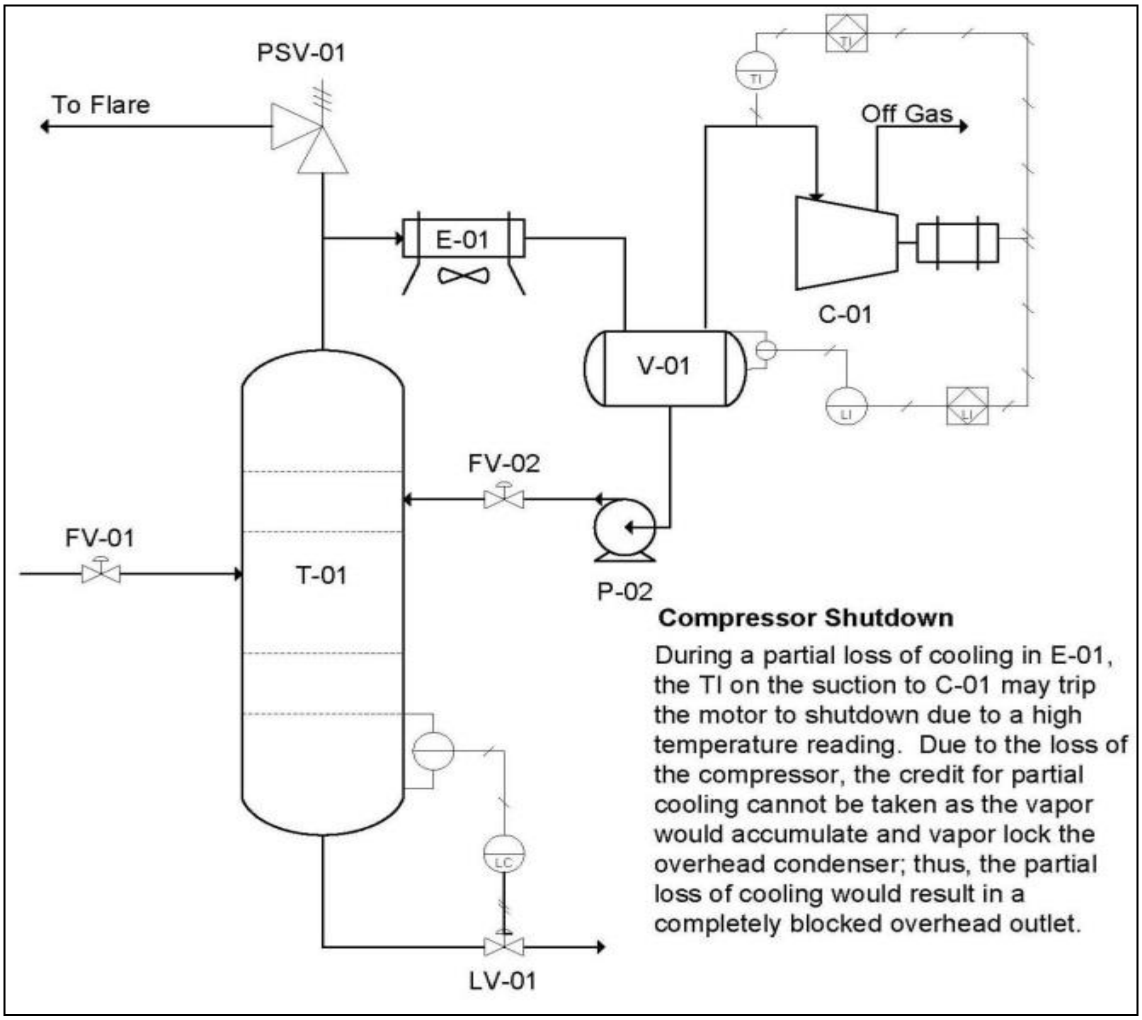

Figure 5: Example of how compressors can affect the relief load. On the right, the loss of the compressor would result in a larger relief as the vapor outlet is completely blocked.

4. Conclusion

To realistically represent the relief load estimate, the pressure relief system designer must understand the system, how it is operated, the limits and shutdowns of the associated equipment, and how these parameters interact during the specific overpressure event being reviewed. The pressure relief system designer must also ensure that all assumptions are consistent with industry, company, and regulatory requirements for the facility. There are many ways to check to see if the relief load estimate is based on realistic assumptions or on conservative/simplifying assumptions. In many cases, conservative/simplifying assumptions are acceptable as long as the assumptions don't result in deviations from standards or practices that result in spending more money. Oftentimes, conservative/simplifying assumptions do result in deviations, and the pressure relief system designer must then use more realistic assumptions to generate the relief load.

The pressure relief system designer must also be vigilant to not use simplifying assumptions that are not conservative. These assumptions tend to result in relief rates that may under-predict the true requirements in an overpressure event. Oftentimes industry, company, and regulatory requirements for the facility are set up to eliminate these scenarios, but the example in Section 3.2 illustrates the pressure relief system designer must check these assumptions (many of which can be implicit).

5. References

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