Heat Integration and Relief Systems Design

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Abstract

Heat integration is commonly skipped when evaluating a process' relief systems design. Failing to evaluate the heat integration (or energy balance) for a process can result in overly conservative results and possibly lead to costly expenditures. Evaluating the effects of heat integration in relief systems design is a process that evaluates the physical limitations of the system and does not require taking credit for control system response. It is important to understand the effects that heat integration has on both individual relief devices, and in some cases, the significant affect it can have on flare system design. This becomes even more imperative in cases where relief devices that once discharged to the atmosphere are modified to discharge into a closed flare system. This paper covers two examples where evaluating the effects of heat integration on the relief systems prevented costly modifications to those systems.

1. Introduction

Heat integration is a common practice in process optimization, and it is becoming more and more important in the oil, gas, and petrochemical industry. This optimization often involves increases in process throughput. The effects these changes have on relief systems and disposal systems are often misunderstood. Understanding the physical limits of a process during an upset condition can be very important and ignoring these limits can be a costly mistake.

Heat integration is process of utilizing energy already present in a system to minimize the utility consumption. An example of heat integration can be seen in Figure 1 and Figure 2. The column system is shown with a feed preheater and a product cooler prior to heat integration and a feed/product exchanger after a heat integration project. Employing heat integration is a common plan in new facilities and a common cost savings upgrade for existing facilities. Heat integration can pose start-up/shutdown concerns, along with control system difficulties; however, these concerns are not covered in the scope of this paper.

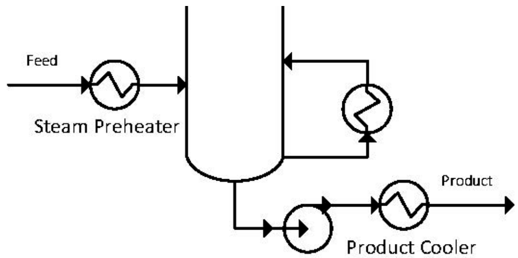

Figure 1 – Example of process prior to heat integration.

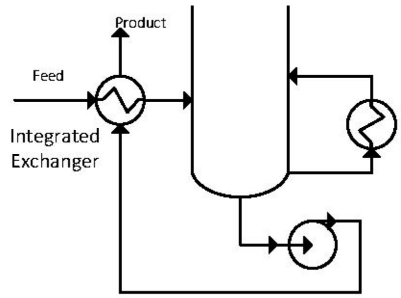

Figure 2 – Example of similar process after heat integration.

When evaluating relief systems design, either for existing facilities or for new construction, a conservative/consistent approach is taken. Due to the increased cost of the analysis, it is typical that the potential effects of heat integration are not recognized or considered. Many people also worry about what would qualify as taking credit for "positive control," which is not permitted by the regulating bodies. This paper discusses two projects in which the use of conservative methods would have resulted in millions of dollars in modifications and lost time. Sound engineering analysis was performed in a relatively short period of time, and both of these cases were resolved such that no modifications were required. This was not a risk assessment analysis or a risk ranking tool, but a practical application of understanding the situation at hand and assessing the true limits of the process during that situation.

2. Heat Integration Case Study 1

2.1 Problem Statement

A refinery was investigating implementing a heat integration project in their crude fractionation unit to increase the diesel fraction from the unit. The feasibility study identified that the existing relief devices may have inadequate capacity in the event of a partial power failure when many of the column's reflux/sidestream pumps are lost while the feed continues. The financial impact of installing additional relief capacity, which included modifications to the flare header, was high enough to warrant cancellation of the project. The effect of heat integration on the relief system was not fully considered during the analysis.

2.2 Analysis

In the partial power failure scenario, the previous calculation assumed the outlet temperature of the feed furnace would remain constant. The fuel gas to the burners is on temperature control and the fuel gas flow will increase in order to maintain a constant temperature. However, the majority of the heat input to the preheat train is lost during this power failure scenario, and the furnaces may not have sufficient heating capacity to maintain the normal outlet temperature. A simplified crude fractionator system with preheat train is shown in Figure 3 below. The pumps and exchangers shown in red are lost during this power failure scenario.

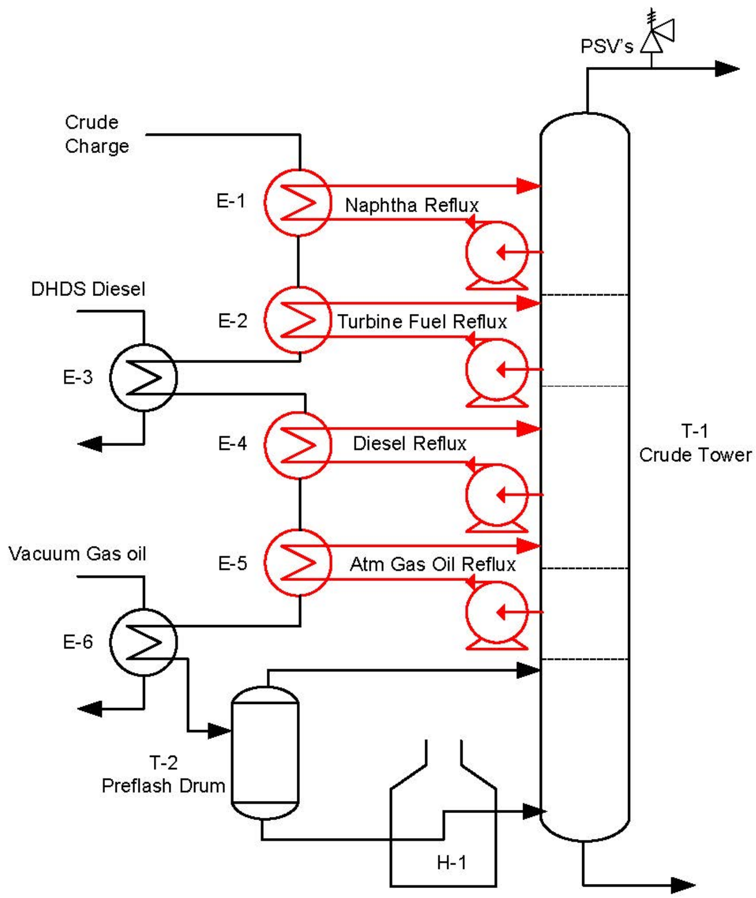

Figure 3 – Crude fractionator with preheat train

In order to estimate the temperature feeding the furnaces, the preheat train must first be modeled considering all exchangers that continue to provide heat input during the relief scenario. The exchangers in the preheat train should be modeled with their actual heat transfer coefficient (U) and surface area (A), along with the hot side fluid conditions, rather than merely modeled by applying the normal duty. During the relief scenario, there is a greater temperature difference between the hot and cold side of the exchangers in the preheat train; thus, the duties will be higher than normal. Applying the normal duty will underestimate the furnace feed temperature and is not conservative. The assumptions for the exchanger hot side flows and conditions will vary depending on the relief scenario. For example, it is important to consider factors such as any pumps in spare service and whether or not a column draw tray is expected to dry up. If the hot side of the preheat exchanger gets it's feed from the column being analyzed, then it is conservative to assume that draw is lost, resulting in additional cooling loss in the tower. There is typically a preflash drum at the end of the preheat train that flashes off the vapor and sends the liquid to the freed furnace. During a particular relief scenario, there may no longer be vapor present at the preflash drum; therefore, it is necessary to consider whether or not flow to the furnace will increase as the liquid level in the preflash drum rises.

Now that the new feed conditions to the furnace are determined, the maximum furnace duty is applied. The maximum furnace duty should be obtained from the manufacturer burner curves, with the furnace efficiencies applied. The crude tower can now be modeled with the new feed temperature and a required relief capacity can be calculated.

2.3 Results

Table 1 below shows the difference between the duties applied to the crude charge during normal conditions and during the power failure relief scenario. Notice that even though the furnace duty is significantly higher than normal, it is not enough to make up for the duty lost in the preheat train.

Table 1 - Comparison between normal and relief duties when accounting for heat integration (MMBTU/hr)

Case	E-1	E-2	E-3	E-4	E-5	E-6	H-1	Total
Normal	65.8	35.1	27.2	62.3	50.7	47.6	235.7	524.4
Relief	0	0	45.0	0	0	106.5	317.9	469.4
Difference	-65.8	-35.1	17.8	-62.3	-50.7	58.9	82.2	-55.0

After modeling the crude preheat train and applying the maximum feed furnace duty, a lower tower feed temperature and required relief rate was calculated as shown in Table 2.

Table 2 - Required relief with and without considering heat integration

Case	Tower Feed Temp (^{o}F)	Required Relief (lb/hr)
Without considering heat integration	680	719,900
Considering heat integration	610	622,800

The reduction in required relief rate was enough for the existing relief devices to provide adequate relief capacity; thus, there was no need for spending a substantial amount of money on installing additional relief capacity and making flare header modifications. The calculations did not involve dynamic or rigorous modeling, so the associated engineering was able to be done in a short time frame at minimal cost.

3. Heat Integration Case Study 2

3.1 Problem Statement

A refinery was working to resolve some concerns pertaining the radiation levels identified previously for the controlling flare scenario (total power failure). The system in question can be best described as a fully integrated fluidized catalytic cracking unit (FCCU) and gas condensates unit (Gas Con) where the pump-arounds providing cooling to the FCCU fractionator are integrated exchangers also acting as the reboilers to the distillation systems in the Gas Con (as shown in Figure 4).

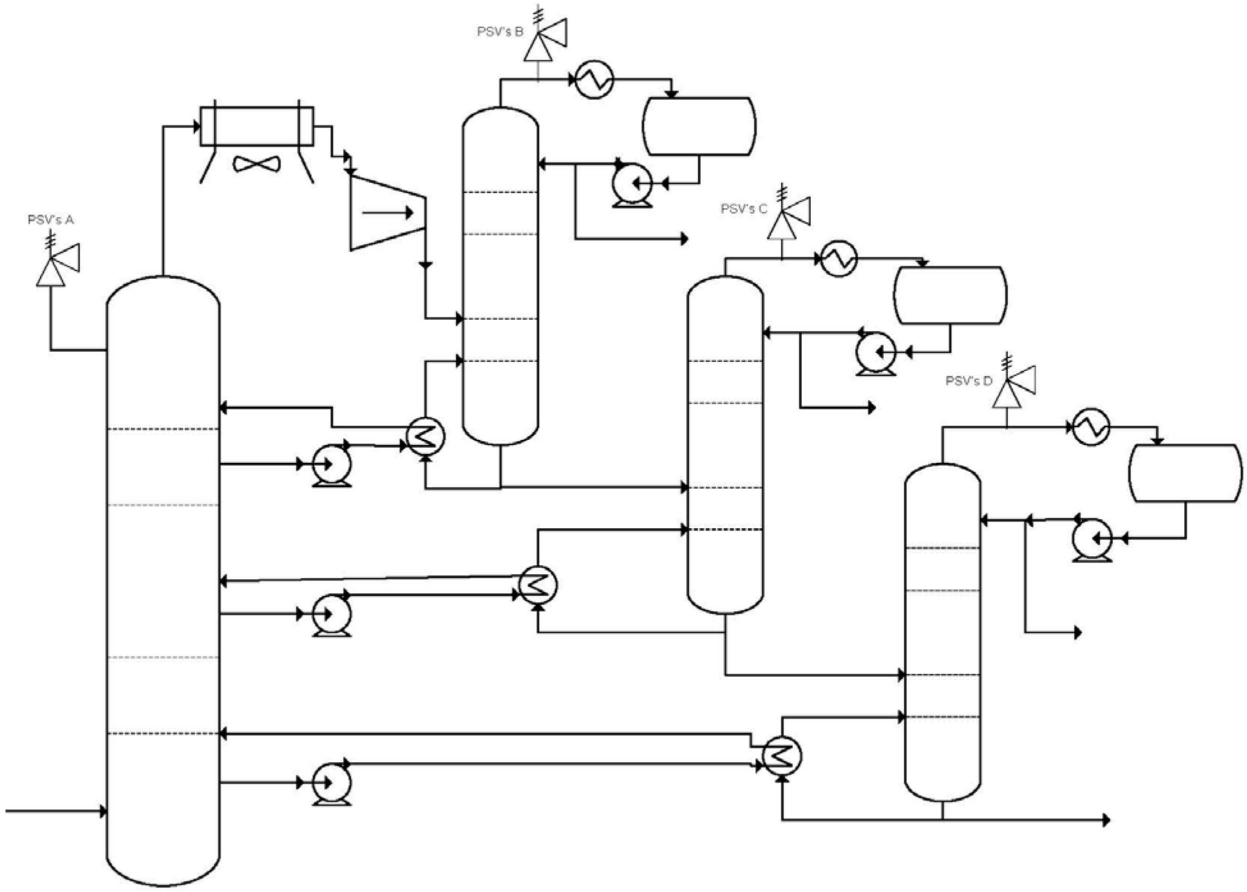

Figure 4 - System sketch of FCCU and Gas Con integrated exchangers.

The previous analysis used data generated from the individual relief device sizing reports that did not address the effects of heat integration. The loads from the relief systems (multiple valves used in most of the above cases) are represented in Table 3.

Table 3 - Load summary prior to heat integration analysis.

Valves	**Location**	**Load (lb/hr)**
PSV's A	FCCU Fractionator	454,123
PSV's B	Gas Con De-Propanizer	151,400
PSV's C	Gas Con De-Butanizer	433,700
PSV's D	Gas Con De-Isobutanizer	148,900
Total	FCCU and Gas Con	1,188,123

3.2 Analysis

The key to the analysis is to understand the scenario at hand. For any of the individual relief systems, there did not appear to be any errors. The pump-arounds that may or may not fail in the event of the power failure (due to steam driven spares) must be analyzed as the worst possible case for individual systems. When analyzing the fractionator, the pump-arounds provide cooling duty to the system and the failure of these provides the conservative sizing basis for the relief valves. When analyzing the tower systems in the Gas Con Unit, continued heat from the reboilers provides the conservative sizing basis for these relief valves and the pumps are assumed to remain in operation.

For the analysis of the flare, the conservative loads are not additive and it is overly conservative to do so. The pump-arounds cannot simultaneously fail and remain on, which the original analysis would indicate. For the purposes of the flare analysis, one or the other must be assumed. The secondary problem that comes from this is the inability to estimate which of the possible cases is actually the "worst case" for the flare. For this reason, both circumstances must be considered as shown in Figure **5**.

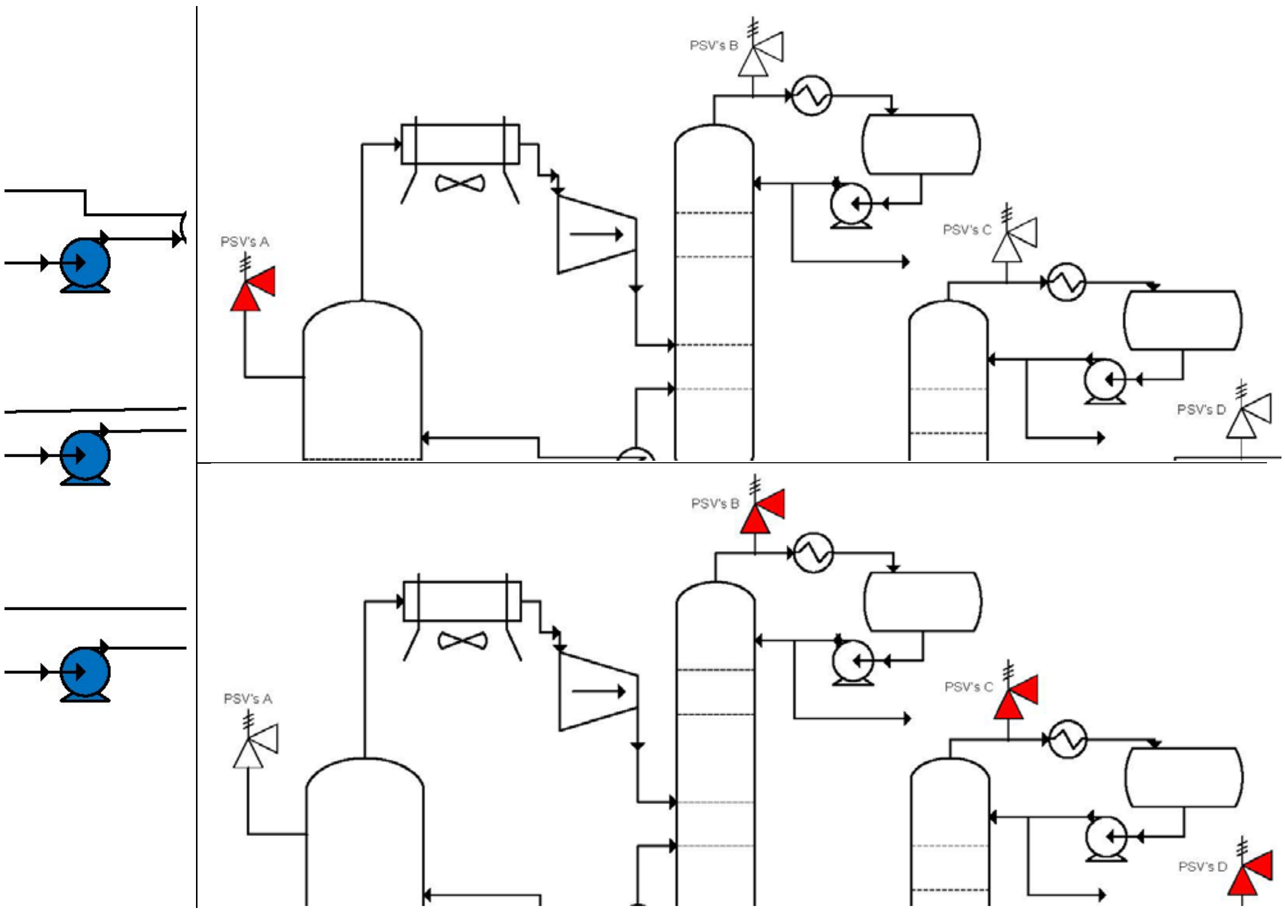

Figure 5 - Summary of the analysis clockwise from the left: the 3 pumps in question; the first case analysis with only the relief valve shown in red discharging; the second case analysis with the 3 relief valve discharging shown in red.

3.3 Results

By simply understanding the physical limits of the system, the flare loading was significantly reduced as shown in Table 4. To emphasize the importance of analyzing both cases, it should be noted that Case 1 provided more severe back-pressure issues (due to the lower set pressures in the fractionator system) while Case 2 provided the controlling scenario for flare radiation (due to the higher mass flow).

Table 4 - Load summary after the heat integration is accounted for.

Valves	Location	Case 1 Load (lb/hr)	Case 2 Load (lb/hr)
PSV's A	FCCU Fractionator	454,123	0
PSV's B	Gas Con De-Propanizer	0	151,400
PSV's C	Gas Con De-Butanizer	0	433,700
PSV's D	Gas Con De-Isobutanizer	0	148,900
Total	FCCU and Gas Con	454,123	734,000

4. Conclusion

Heat integration has become significantly more common in the oil, gas, and petrochemical industry to reduce utility costs. The basic premise of heat integration is that heat (typically from a product stream) is transferred to a different stream (typically a feed stream) through a process heat exchanger rather than using heating/cooling utilities to add/remove this energy. By understanding the effects it has on relief system evaluations, one can avoid over predicting required relief loads that may result in significant financial impacts. Understanding heat integration is also important so that required relief loads are not under predicted, which may result in unsafe design. It was demonstrated by the examples in this paper that examining the limitations of the system does not require significant time or rigorous modeling software. A relatively simple steady state analysis can be performed that captures the limitations of the systems and still provides a conservative result that does not take any credit for positive control. By simply understanding how heat is conserved in the process, numerous engineering hours and countless dollars can be saved.