Effects of Process Variables on Peak Relief Rates Estimated by Dynamic Simulation for a Multiple Distillation Column System

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Prepared for Presentation at
American Institute of Chemical Engineers
2013 Spring Meeting
9th Global Congress on Process Safety
San Antonio, Texas
April 28 – May 1, 2013

UNPUBLISHED

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Keywords: dynamic simulation, VMG Sim, distillation columns, sensitivity analysis, pressure relief valves

Abstract

Process engineers and designers have recently turned to using dynamic analysis as a more realistic method for sizing relief systems. The primary goal of using dynamic analysis is to ensure that modifications are truly required instead of making unnecessary and costly upgrades of relief systems based on overly conservative calculations. In work previously presented by the authors, it has been shown that, for certain overpressure scenarios, the dynamic relief rates predicted by dynamic simulation are significantly affected by certain operating conditions [1].

This paper shows the effects of process variables on the relief loads estimated by dynamic simulation for multiple columns. This paper will also show how these effects would impact the flare load for a unit with multiple columns. The multiple column system is based on a system the authors have encountered at a refinery. The sensitivity analysis shows that changes in the column liquid levels significantly affect the initial relief times, relief loads, and relief durations.

1. Introduction

To stay in compliance with industry, regulatory, and typically corporate guidelines, it is important for a plant to conduct and document analyses of their relief systems. It also allows for plant engineers and designers to see the effects of their process on existing or proposed relief systems. Relief system analyses traditionally use steady-state equations to determine the relief rate used to size relief devices. For complex systems, these equations are based on conservative simplifying assumptions. This usually results in a larger relief rate that requires a larger relief device. The drawback to using traditional methods, when analyzing an existing system, is that they can overstate the required relief rate. Sometimes this results in the recommendation of costly relief systems upgrades where only minor modifications are needed.

Dynamic analysis of complex systems involves creating a simulation that calculates changes to the system over time. This analysis can be used to better estimate the relief requirements to protect from overpressure for a specific relief scenario. The primary goal of dynamic relief system analysis is to better understand how the system will respond to the upset scenario. An additional benefit is that the detailed analysis can be used to support making limited changes in lieu of more extensive modifications. The fundamental differences between these two methods are important to understand in order to make sure they are both being used to determine relief rates that are conservative.

Equation 1 shows a simplistic steady-state equation that can be used to determine the relief rate through a relief valve installed on top of a distillation column that has lost cooling, feed, and reflux, but has continued heat input (a typical total power failure scenario).

$$\dot{M}_{relief} = \frac{\dot{Q}_{reb}}{\Delta H_{vap}} \quad \text{[Eq. 1]}$$

In order to use the above equation, the right hand side of the equation would be evaluated at relief conditions, which may vary from normal operating conditions [2]. Assumptions such as the composition of the fluid on the process side of the reboiler can have effects such as a lower heat of vaporization or a larger reboiler duty that will increase the predicted relief rate.

Equation 2 is an example of how the above equation would be represented in a dynamic environment. It shows the same equation as functions of time as well as initial process conditions such as pressure, temperature, etc.

$$\dot{M}_{relief}(t, P_i, T_i, etc) = \frac{\dot{Q}_{reb}(t, P_i, T_i, etc)}{\Delta H_{vap}(t, P_i, T_i, etc)} \qquad \text{[Eq. 2]}$$

Dynamic simulations calculate the changes in the system based on incremental time steps from an initial starting point. Therefore, the selection of initial conditions is important and will affect the results [1]. These initial conditions are typically based on operating conditions that represent the normal operations of the facility. Operating conditions are controlled in ranges, and depending on the specific item, there may be no such thing as a normal condition. Liquid levels, temperatures, pressures, and reflux rates for distillation columns can vary during operation and can change due to upsets elsewhere in the plant. This is important to consider when global relief scenarios like power failure and cooling failure affect the entire plant, as these variables are all essentially assumptions.

API 521 Section 5.22[3] states that if dynamic simulations are used for column relief system design, the model must be conservative with respect to the maximum relief load. It goes on to state that the assumptions used for the simulation *shall* be checked by sensitivity analyses to assess the impact on the column relief rate. A sensitivity analysis is the study of how the uncertainty of the input variables affects the output of a mathematical model. Therefore, the input variables of a dynamic simulation must be checked in order for the designer to ensure that the simulation is conservative.

2. Methodology

2.1 *Setting up the dynamics file*

A steady-state model containing 2 debutanizers, a depropanizer, a gasoline splitter, and 12 PSVs was created using VMG Sim. The flow diagram of this system is displayed in Figure 1.

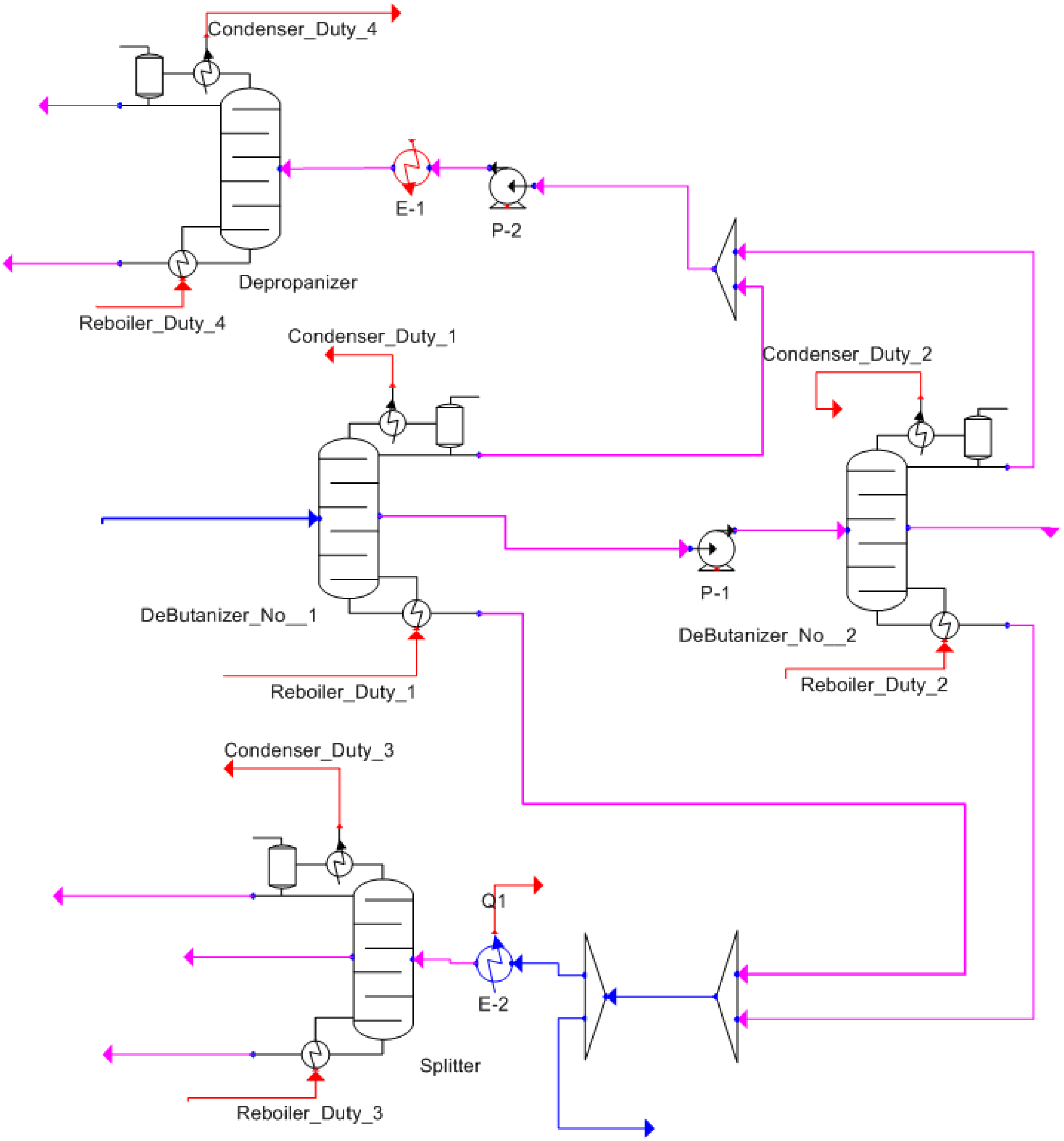

Figure 1 : Process Flow Diagram of a Multi-Column System

The steady-state model was used to create a dynamic model that uses 21 controllers set to match the operating parameters of the equipment. Controllers are used in dynamic simulations to achieve specified flowrates, pressures, temperature, and other physical conditions. The controller attempts to achieve the user's specification by opening or closing a valve located on a material or energy stream. This is different from a steady-state model where flowrates, duties, and physical properties are typically specified or calculated. The action of the controller is based on the tuning parameters provided by the user.

Twelve PSVs were added to the dynamic model to simulate relief. Table 1 displays information on these relief valves.

Table 1: Summary of PSV Information

Name	Location	PRV Size	Set Pressure (psig)
PSV-1	DeButanizer No. 1 vapor overhead	6Q8	184
PSV-2	DeButanizer No. 1 vapor overhead	6Q8	190
PSV-3	DeButanizer No. 1 accumulator	3L4	180
PSV-4	DeButanizer No. 2 vapor overhead	6Q8	190
PSV-5	DeButanizer No. 2 accumulator	1.5H3	190
PSV-6	Splitter vapor overhead	6R8	30
PSV-7	Splitter vapor overhead	6R8	30
PSV-8	Splitter vapor overhead	6R8	30
PSV-9	Splitter vapor overhead	6R8	30
PSV-10	DePropanizer vapor overhead	6Q8	290
PSV-11	DePropanizer accumulator	3K4	274
PSV-12	DePropanizer accumulator	3K4	274

In order to perform the sensitivity analysis, different column liquid levels were used as operating conditions. Setpoints of the respective level controllers for the columns were adjusted to achieve the desired liquid levels. Three simulations were created for a low liquid level of 20%, a medium liquid level of 40%, and a high liquid level of 60%. These percentages represent the fraction of liquid height in the lower section of the column that does not contain trays.

2.2 Initiating relief

Cooling water failure was chosen as the overpressure scenario to review as it affects all of the four columns simultaneously. Total loss of cooling water is expected to result in the loss of overhead condenser duties, which may lead to overpressure in the column due to excess vaporization. This was accomplished by specifying duties of zero for all condensers. It was assumed that all of the condensers lost cooling at the same time.

All controllers in the dynamics model were turned off (set to manual) to avoid taking credit for positive controller action. This was done in accordance with API 521 Section 4.2.4[3]. Changing the controller mode from “automatic” to “off” causes the controlled valve to hold its position during relief.

For each liquid level, the integrator (essentially an electronic strip chart recorder in VMG Sim) was turned on and recorded the pressure in the columns as it slowly increased. The overhead PSVs opened at their respective set pressures and flow data was collected. The sum of the mass flow rates relieved by the PSVs was recorded in order to view the total load into the flare.

3. Results

Graphs of dynamic relief for the three liquid levels are displayed below. PSV-5 was not graphed as it does not contribute a significant relief load. The initial time (t = 0), is the time at which the cooling to the tower was stopped and the overpressure scenario began. Note that the change in liquid levels shifts the magnitude of the relief rate and the peak point in time for some of the towers.

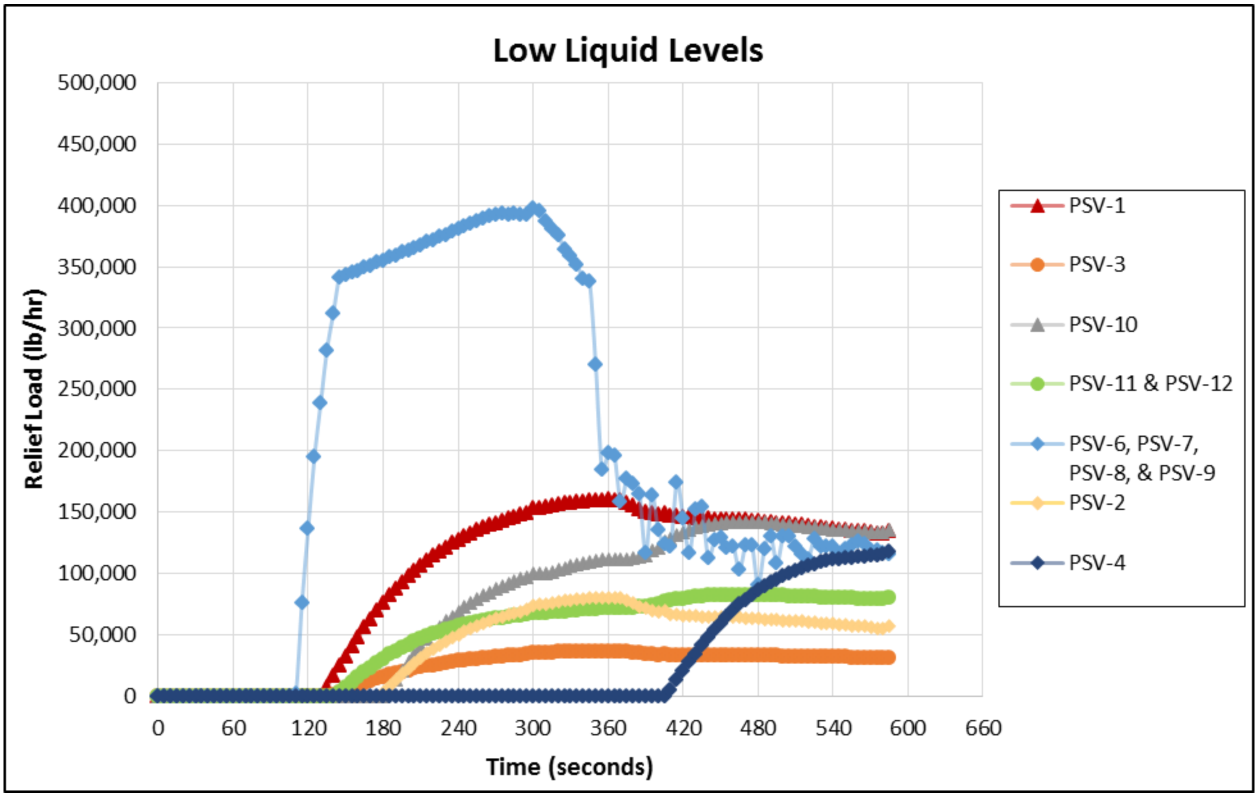

Figure 2: Cooling failure relief rates with low liquid levels

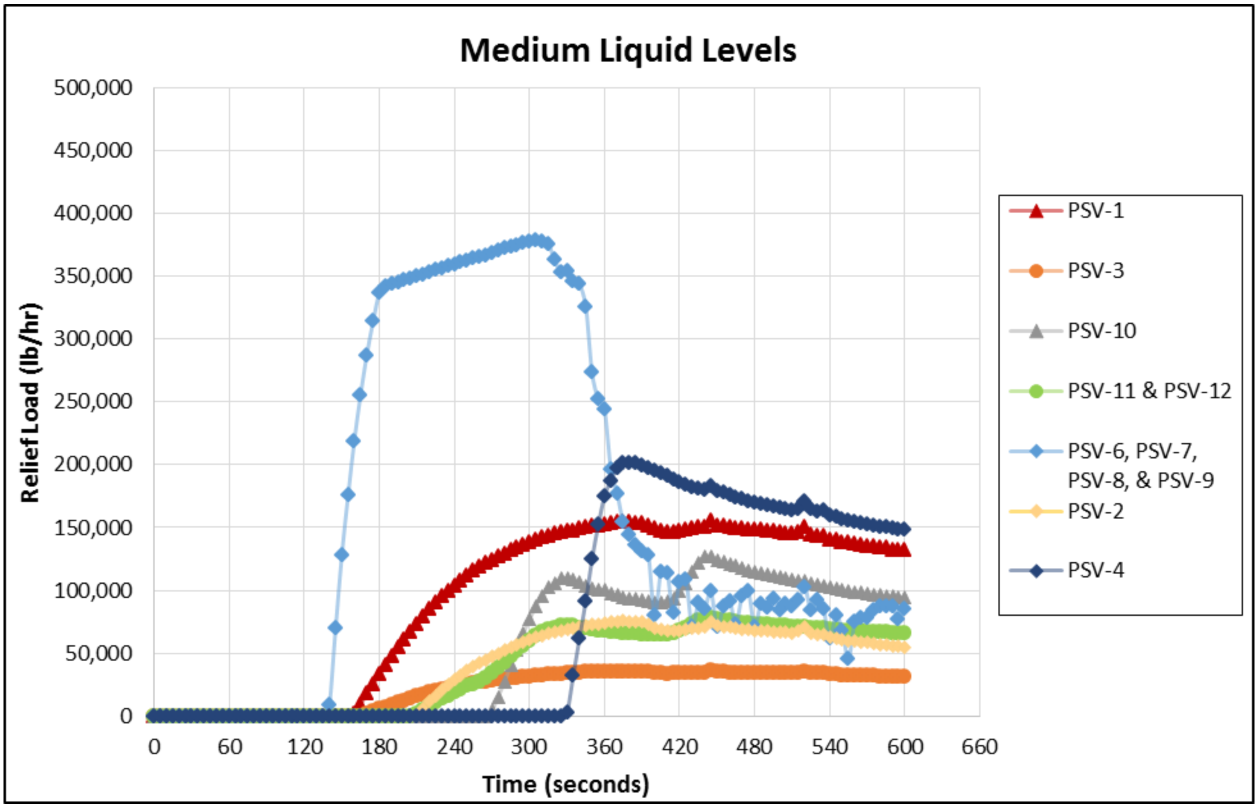

Figure 3: Cooling failure relief rates with medium liquid levels

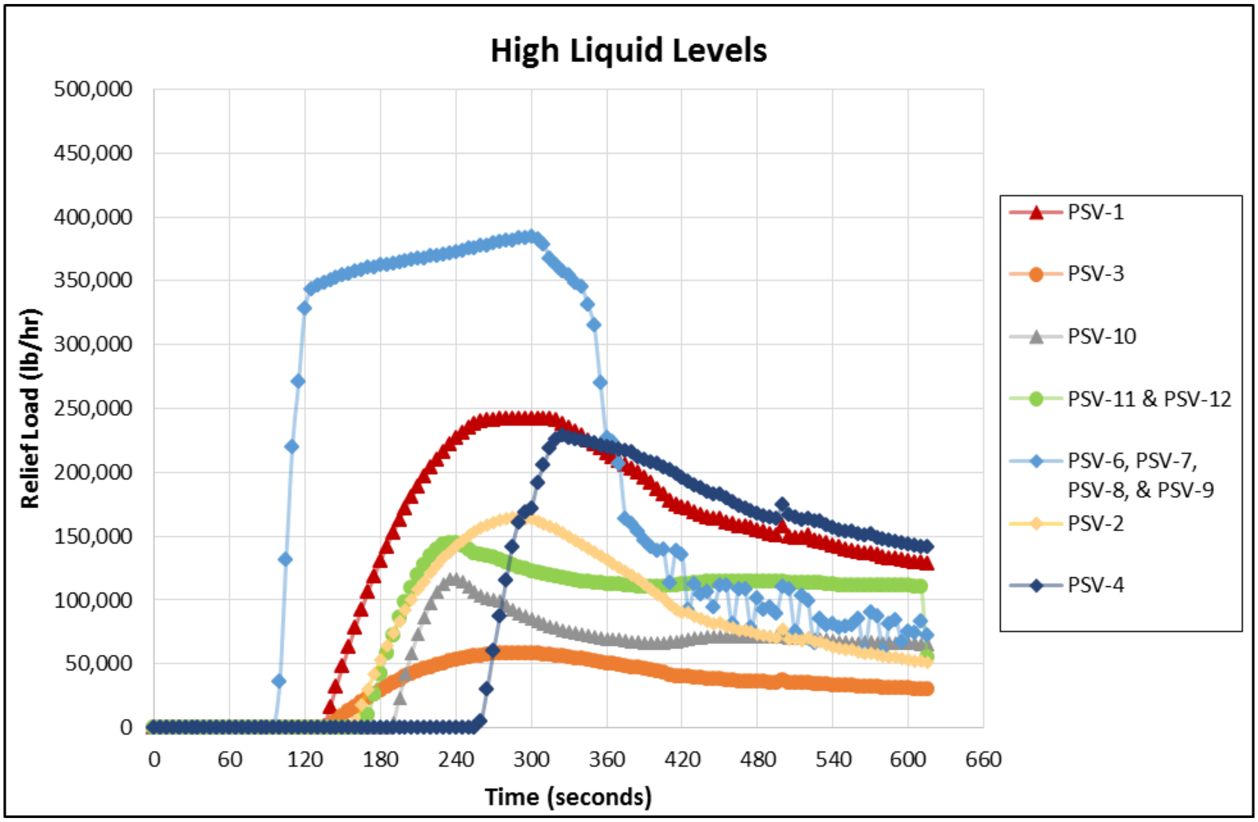

Figure 4: Cooling failure relief rates with high liquid levels

Figure 5 shows the combined flare loads for the three liquid levels. The curves were made by adding the relief loads from the previous graphs over the same time frame. The combined load represents the load that would enter the flare header. The horizontal line represents the steady-state relief load for the four columns estimated by traditional methods.

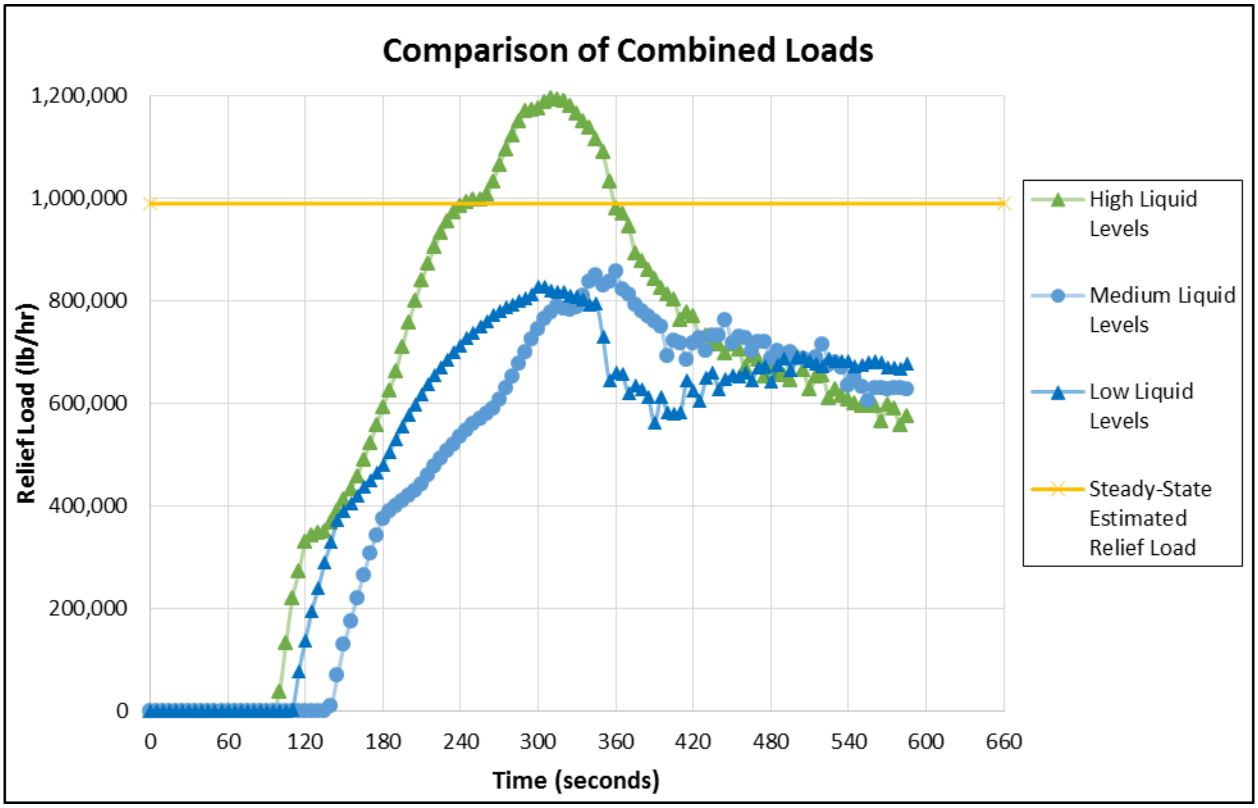

Figure 5: Combined cooling failure loads for different column liquid levels

The steady-state estimation of the combined relief load of the columns assumes that the reboilers have a reduced capacity due to the reduction in the log mean temperature difference (see Reference 1 for an additional explanation). The dynamic model was based on a constant heat input, and thus may over-predict the duties of the reboilers under upset conditions. A further improvement could be made by modeling the reboilers based on their individual UA characteristics.

The three curves in Figure 5 have roughly the same shape as well as time of peak flow. The noticeable difference is the peak relief load for the high liquid level curve. There is a 43% increase in the peak of the combined relief load for all PSVs when the liquid levels are increased by 50%. Lowering the liquid levels by 50% had little effect on the combined peak load.

The increase in the combined peak load appears to be caused by two factors. The peak flows of PSV-1 and PSV-2 located on the 1st debutanizer increased by 57% from normal liquid levels to high liquid levels. The peak time for PSV-4 located on the 2nd debutanizer lowered when the liquid level increased, which resulted in PSV-4 contributing significantly to the combined load peak. Changing the liquid levels in the columns affected the time to initial relief, the time to reach peak load, and the height of the peak for these valves. This behavior is present to a lesser extent in the other relief valves.

4. Conclusions

Dynamic simulation can be a useful tool to show how a system reacts to sudden changes and how the system uses control valves to stabilize itself. Dynamic analysis is very different from hand-calculated methods which are traditionally used to size relief systems. Although dynamic analysis can be used to size relief systems, it must be done knowing how process variations affect the relief rates.

The results show that variations in the liquid levels affect relief times and peaks for a system of multiple columns. Increasing the liquid levels of four columns in a system by 50% increased the combined peak load into the flare by 43%. This was due to increases in the peak flowrate of two PSVs and the shifting of a large peak towards the combined load peak.

This result shows that changes in process variables can have a large impact on the relief rate used to size a flare system. Consideration must be given to the effect process variables can have on the time of initial relief, the time to reach the peak load, and the magnitude of the peak flow.

Because there are multiple variables that can impact the peak relief rate for a flare, a full sensitivity analysis of a system with multiple columns would be time consuming and costly. However, if dynamic analysis is used to size a relief system, a sensitivity analysis must be performed to ensure that the analysis will lead to a safe design.

5. References

[1] Wilkins, John & Dustin Smith, P.E. *Effects of Process Variables on Dynamic Relief Load Estimates for a Depropanizer and Debutanizer*. Oct. 2012. Electronic poster presented at the AIChE Regional Process Technology Conference, Texas City, TX

[2] Cristea, Nicholas and Dustin Smith, P.E. *Making Relief Load Estimates Match Reality*. 2013

[3] ANSI/API Standard 521 5th Edition, ISO 23251, May 2008