

EFFECTS OF PROCESS VARIABLES ON PEAK RELIEF RATES ESTIMATED BY DYNAMIC SIMULATION FOR A MULTIPLE DISTILLATION COLUMN SYSTEM

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Introduction

- Process engineers and designers have recently turned to dynamic analysis as a more realistic method for modeling upsets used to size relief devices. Dynamic analysis is used to suggest making modifications of relief devices instead of costly upgrades suggested by traditional methods that are more conservative.
- Dynamic analysis involves creating a simulation of a process with control valves that operate in either manual or automatic mode. The simulation calculates process conditions (pressure, temperature, etc.) that vary with time as a result of a change in the process. This can be used to simulate a relief scenario like cooling failure or a blocked outlet. With the addition of a relief valve, the simulation can calculate a peak relief load used for sizing the valve.
- 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 suggested by traditional methods.
- In previous work presented by the authors, it has been shown that relief rates predicted by dynamic simulation are significantly affected by certain operating conditions. [1]

Differences between Dynamic Analysis and Traditional Methods

- The fundamental differences between dynamic and traditional steady-state methods are important to understand in order to make sure they are both being used to determine relief rates that are conservative.
- The following theoretical relief rate equations for distillation column boilup illustrate the differences between steady-state analysis and dynamic analysis.

$$\dot{M}_{relief} = \frac{\dot{Q}_{reb}}{\Delta H_{vap}} \quad \dot{M}_{relief}(t, P_i, T_i, etc) = \frac{\dot{Q}_{reb}(t, P_i, T_i, etc)}{\Delta H_{vap}(t, P_i, T_i, etc)}$$

Steady-state; No time dependence Dynamic version; Changes with time and initial conditions

- Both equations calculate the relief rate using the heat input from the reboiler and the latent heat of vaporization of the relief fluid. The steady-state equation can use conservative assumptions such as a design duty for the reboiler (increasing the numerator) or using the top tray composition as the relief fluid (lowering the denominator) to increase the relief rate.
- The theoretical dynamic equation utilizes the same basic theory as the steady-state equation, but it has become complicated due to everything becoming a function of time and initial process conditions. In order for the analysis to be conservative, the effects of initial process conditions on the relief rate must be known.
- Analyzing the effects that input variables have on the outcome of a mathematical model is known as a sensitivity analysis. API 521 Section 5.22 states that assumptions used for the simulation shall be checked by sensitivity analyses to assess the impact on the column relief rate in order to ensure that the model is conservative. [2]

Dynamic Analysis of Cooling Failure Relief

- A system of four distillation columns in a refinery unit was simulated using VMG Sim. Figure 1 displays the process flow diagram of the system.

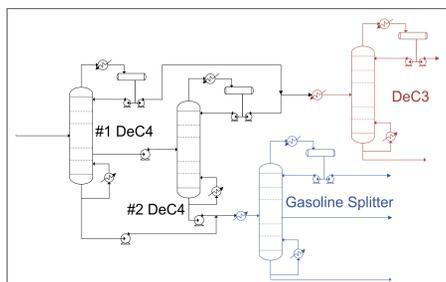


Figure 1: Process flow diagram for a multiple column system

Dynamic Analysis of Cooling Failure Relief (Continued)

- The first step was to create the process in steady-state mode. Dynamics mode was initiated after automatic control valves were placed to maintain pressure, temperature, liquid levels, etc. in the system.
- The simulation ran until the controllers reached a semi-steady state. Cooling failure was simulated by specifying duties of zero in the overhead condensers. All controllers were switched from automatic to manual to avoid taking credit for positive controller action in accordance with API 521 Section 4.2.4. [2]
- Pressure inside the columns increased due to an accumulation of vapor until the set pressures of the respective relief valves were reached. The dynamic relief rates through the relief valves were logged for analysis.
- In previous work by the authors, it was shown that changing column liquid levels had a significant impact on the relief rates estimated by dynamic analysis for individual columns. To observe this effect in the multi-column system, liquid levels in the columns were varied from their normal levels (40% of level bridge height) to low levels (20%) and high levels (60%). [1]

Results – How Column Liquid Levels Affect Relief Rates

- Figures 2 through 4 display the loads from relief valves on top of the four column systems with respect to time. The initial time of zero is when all columns lost cooling duty. 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.

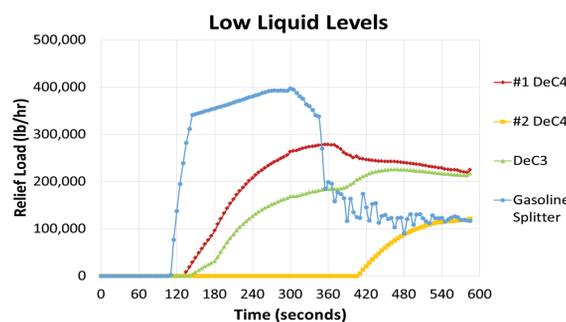


Figure 2: Cooling failure relief rates with low liquid levels. (Steady-state loads are as follows: #1 DeC4 - 409,820 lb/hr, #2 DeC4 - 92,386 lb/hr, DeC3 - 201,081 lb/hr, Gasoline Splitter - 287,107 lb/hr)

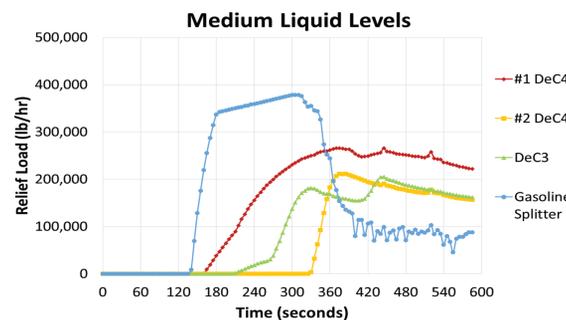


Figure 3: Cooling failure relief rates with medium liquid levels. (Steady-state loads are as follows: #1 DeC4 - 409,820 lb/hr, #2 DeC4 - 92,386 lb/hr, DeC3 - 201,081 lb/hr, Gasoline Splitter - 287,107 lb/hr)

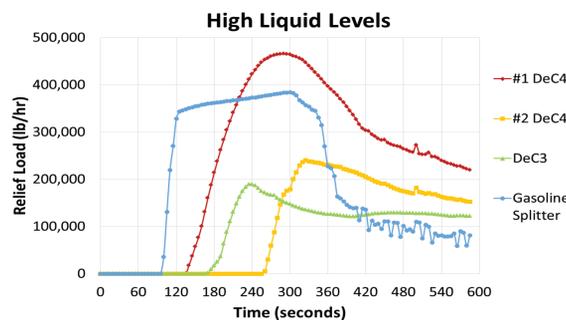


Figure 4: Cooling failure relief rates with high liquid levels. (Steady-state loads are as follows: #1 DeC4 - 409,820 lb/hr, #2 DeC4 - 92,386 lb/hr, DeC3 - 201,081 lb/hr, Gasoline Splitter - 287,107 lb/hr)

Results – How Column Liquid Levels Affect Flare Sizing

- 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.

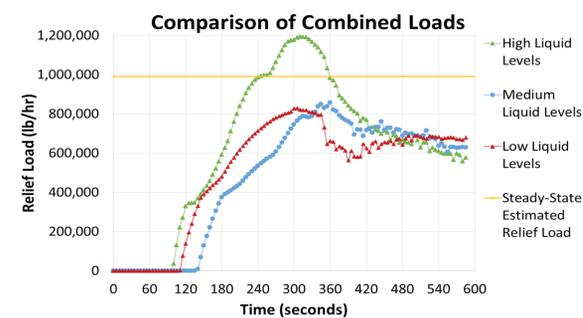


Figure 5: Combined cooling failure loads for different column liquid levels

- The steady-state calculations of the column relief loads assume that the reboilers have a reduced capacity due to the reduction in the log mean temperature difference. 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. [3]
- The three curves in the comparison chart have similar shape and time of peak flow. The noticeable difference is the magnitude of the high liquid level curve compared to the other curves. There is a 43% increase in the peak of the combined relief load for all PSVs when the liquid levels are increased by 50%.
- The increase in the combined peak load appears to be caused by two factors. The peak flow for the #1 debutanizer increased by 57% from normal liquid levels to high liquid levels. The peak time for the #2 debutanizer lowered when liquid levels increased, which resulted in the #2 debutanizer contributing significantly to the combined peak load. 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 systems. This behavior is present to a lesser extent in the other two systems.

Conclusion

- 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 that are traditionally used. 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 changes in process variables can have a large impact on the relief rate used to size a flare. 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 the increase in the peak flowrate of the #1 debutanizer and the shifting of the #2 debutanizer towards the combined load peak for all four columns.
- Consideration must be given to the effects process variables can have on the relief load estimated by dynamic analysis that are used to size a flare or individual relief devices. These effects include 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.

References

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