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How Dynamic Simulation Helped Mitigate Vapor Disposal System

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Abstract

Siemens recently completed a refinery wide pressure relief and flare analysis for two major refineries in the United States. Major deficiencies were identified on the existing flares if the relief loads calculated using steady state methods were relieved. The calculated relief loads based on the steady state method were overly conservative and resulted in relief devices and vapor disposal systems with inadequate capacities. A systematic approach to reduce the relief loads to the flare was conducted, which included performing dynamic simulation on major contributors to the flare. This systematic approach reduced the conservative assumptions and improved the predictions of the relief loads. Guidance for dynamic simulation was in line with approaches allowed per API-521[1].

The governing case was determined and analyzed for the dynamic analysis. Validation of the results from the dynamic study helped to understand the reason behind the reduction in relief load. The study also predicted potential reduction in relief load that can be achieved prior to running dynamic simulation which is dependent on type of distillation tower (i.e. tower with conventional steam reboiler vs atmospheric towers with feed furnaces) and global release (i.e. boil up vs loss of overhead cooling). Combined credits from dynamic simulation, instrumentation and Quantitative Risk Analysis (QRA) enabled the client to understand the risk, thus helping find the most feasible and economical engineering solution to address the concern. This paper will highlight results, benefits, basis and assumptions of the detailed dynamic simulation study.

Keywords: Mitigation, Vapor Disposal System, Dynamic Simulation, Mitigation, Flare

Introduction

API STD 521 §4.3.3 allows for doing dynamic simulation for calculating relief loads [1]. Conventional methods for calculating relief loads using steady-state approach are conservative and may result in concerns for existing plant relief systems, especially when there are throughput changes being made and plant is operating higher than their original design. Furthermore, API STD 521 §4.2.6 also allows for the favorable responses of conventional instrumentations in the design of relief system components such as flare header, flare knockout drum and flare tip [1].

1 Steady-State Results

After detailed pressure relief analysis and flare analysis, it was determined that Total Power Failure is the governing scenario for the relief system. This resulted in concerns related to excessive relief valve backpressures, radiation and inadequacy of flare disposal system. Table 1 below represents relief loads calculated for governing case for all participating systems to the flare.

Table 1: Steady-State Relief Loads

Steady State Relief Loads, lb/hr											
System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	Total Relief Load to Flare (lb/hr)
168,763	907,294	1,185,736	427,570	277,852	349,843	138,380	117,532	21,707	50,276	34,469	3,679,422

Mitigating the concerns related to excessive flare radiation was the highest priority. Therefore, we needed to account for all the potential credits and engineering methodology that could help to minimize overall relief load to the flare, before any additional mitigation or solution is recommended to reduce the radiation levels within acceptable limits.

2 Dynamic Simulation Modeling

Based on the above results, six of eleven contributing systems (e.g. systems 1 through 6) were picked for the detailed dynamic simulation study. These six systems were the major contributors to the flare for governing scenario.

The most significant difference between steady-state and dynamic simulation is that steady-state assumes that variables are constant with respect to the time. This means that in steady-state there is no accumulation in the system, so the overall mass and energy input matches its output. Conversely, dynamic models consider the mass and energy rate of accumulation within the system, which allows one to determine the how long it would take to reach a stable condition starting from a specified initial state. Since there are many variables that goes in to developing the dynamic model, it was very important for the team to ensure that behavior of dynamic model is aligned with the equipment operation in field, while at the same time it is conservative from relief load prediction standpoint. Main focus of this paper is to highlight the reduction obtained in relief loads by performing detailed dynamic simulation. Overall methodology, guidelines and assumptions on developing dynamic simulation should be developed by project team based on standard industry practices.

2.1 Results of Dynamic Simulation

Detailed Dynamic simulation was performed on systems 1 through 6 for the governing case Total Power Failure. Tables below summarizes various results obtained from the dynamic simulation.

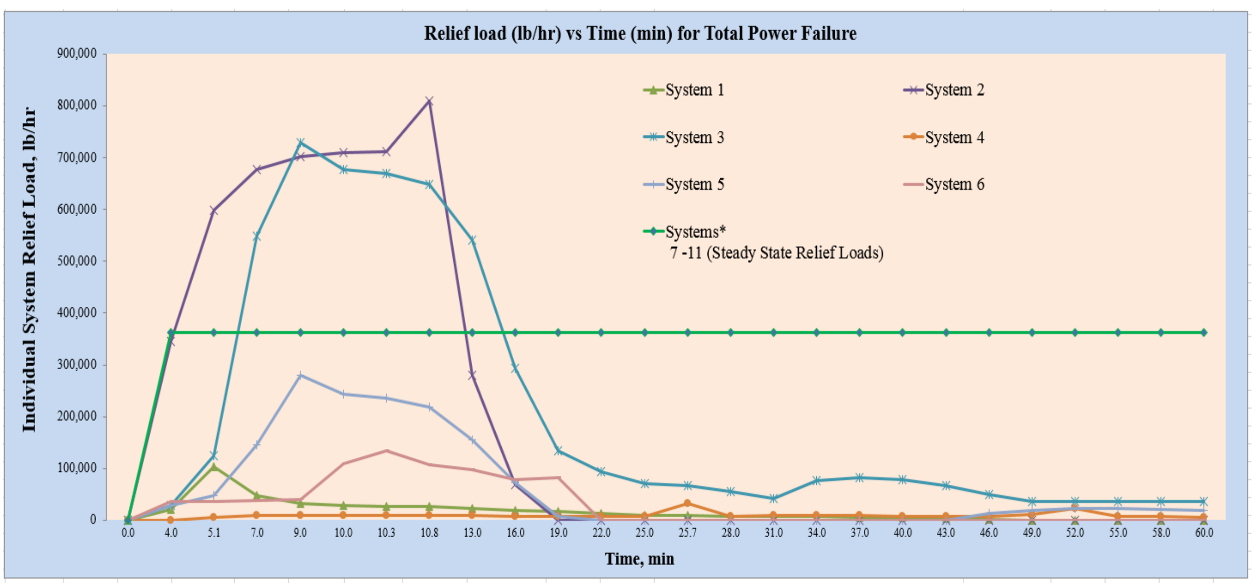
Table 2 below summarizes the individual peak relief loads calculated from the dynamic simulation for systems 1 through 6. Dynamic simulation on systems 7 through 11 was not performed and therefore, relief loads are kept same as calculated using steady-state approach (per Table 1 above). This resulted in reduction of total relief load going to the flare by 33% (in comparison with total load calculated using steady-state approach as mentioned under Table 1 above).

Table 2: Peak Relief Loads from Dynamic Simulation

Peak Relief Loads from Dynmic Simulation, lb/hr											
System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	Total Relief Load to Flare (lb/hr)
102,857	809,146	729,339	31,912	280,623	133,365	138,380	117,532	21,707	50,276	34,469	2,449,605

Note that each system that is studied for the detailed dynamic simulation is different and unique when it comes to the equipment configuration, dimensions, instrument response time and process/operating conditions. Therefore, when initiating event is triggered in the dynamic model, time to overpressure the system, time to reach peak relief load, magnitude of peak relief load and time at which relief ends was observed to be different for different systems. Peak relief from each individual system does not occur simultaneously; as a result of this, total relief load going to the flare system is not sustained but varies over the period depending on starting and ending duration of release for each individual system releasing to the flare. Please refer to Plot 1 below, which summarizes the relief load vs time data obtained from the dynamic simulation for systems 1 through 6, and sum of total relief load for systems 7 through 11 is represented via straight line.

Plot 1: Relief load vs Time Data Calculated from Dynamic Simulation



As seen in the plot above, duration and magnitude of peak relief is different for all six systems studied and peak relief from each individual system do not occur simultaneously. Therefore, credit for the staggering of the relief load can be taken to further reduce total relief load going to the flare. Table 3 below summarizes the relief load calculated from the dynamic simulation for systems

1 through 6 at the instance when peak flare load occurs accounting credit for the relief load staggering. This resulted in further reduction of total relief load going to the flare by 11% (in comparison with total load mentioned under Table 2 above).

Table 3: Relief Load from Dynamic Simulation When Peak Flare Load Occurs

Relief Loads from Dynmic Simulation When Peak Flare Load Occurs, lb/hr											
System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	Total Relief Load to Flare (lb/hr)
26,269	809,146	648,923	9,230	218,805	107,658	138,380	117,532	21,707	50,276	34,469	2,182,394

As mentioned earlier, dynamic simulation on systems 7 through 11 was not performed and therefore, relief loads are kept same as calculated using steady-state approach (per table 1 above).

2.2 Credit for the Existing Instrumentations and Safeguards

As noted earlier, API STD 521 §4.2.6 allows taking credit for the favorable responses of conventional instrumentations and safeguards in the design of relief system components. Based on this, credit for the existing instruments and safeguards (i.e. triconex trips, APS on spare pump etc.) was applied to further reduce relief load going to the flare. Table 4 below summarizes relief loads from each individual system after taking credit for the existing safeguards.

Table 4: Relief Load with Credit for Existing Safeguards

Relief Load After Taking Credit for All But Two Existing Safeguards, lb/hr											
System 1	System 2	System 3	System 4	System 5	System 6	System 7	System 8	System 9	System 10	System 11	Total Relief Load to Flare (lb/hr)
102,857	809,146	729,339	31,912	12,048	133,365	34,608	117,523	5,446	16,094	34,458	2,026,795

Note that each safeguard is assigned a probability of failure on demand (PFOD) which indicates the safeguard’s reliability. As a result of this, failure of certain number of safeguards needs to be accounted, which depends on the safeguard’s reliability, its PFOD, and client-specific guidelines. In current study, credit for a total of six safeguards (on systems 2,3,5,7,9 and 10, one per system) was considered between total of eleven participating systems, and based on the client-specific guidelines, two of six safeguards which provide the largest reduction in relief load needed to be failed. Note that failure of safeguard was based on the probability theory for the safeguards that are 98 percent reliable on demand, with no more than a 1 in 1000 chance that more than two safeguards will fail out of the total six safeguards as per the client-specific guidelines. As shown in Table 4 above, credit for safeguards for systems 2 and 3 (highlighted in red) was removed, as they provided largest reduction in the relief load. Therefore, relief loads for these two systems were updated to be same as calculated from the detailed dynamic simulation study, such that no credit is taken for safeguards. Credit for the remaining four safeguards was considered to continue (on systems 5,7,9, and 10). This resulted in further reduction of total relief load going to the flare by 8% (in comparison with total load mentioned under Table 3 above).

As part of the sensitivity study, total relief load to the flare was calculated accounting credit for all six existing safeguards. As result of this, relief loads accounting credit for the safeguards on system 2 and system 3 was calculated and documented under Table 5 below.

Table 5: Relief Load with Credit for All Existing Safeguards

Relief Load After Taking Credit for All Existing Safeguards, lb/hr											
System 1	**System 2**	**System 3**	**System 4**	**System 5**	**System 6**	**System 7**	**System 8**	**System 9**	**System 10**	**System 11**	**Total Relief Load to Flare (lb/hr)**
102,857	**202,256**	**7,218**	**31,912**	**12,048**	**133,365**	**34,608**	**117,541**	**5,436**	**16,103**	**34,471**	**697,815**

It can be observed that when all six existing safeguards functions as intended, total relief load going to the flare has reduced significantly.

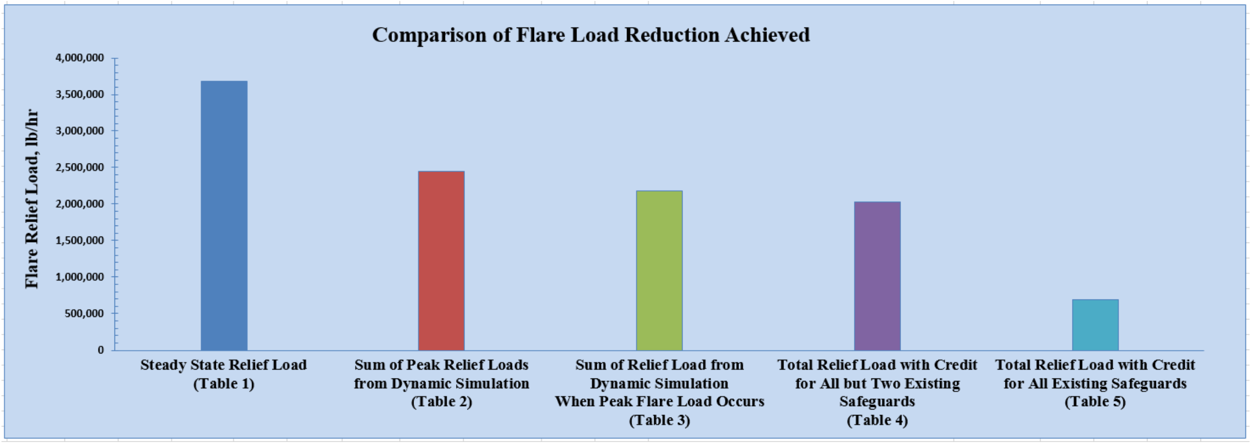
3 Recommendation and Conclusions

Results of the sensitivity study (as mentioned under previous section), which accounts for the credit of all existing safeguards can be utilized during the mitigation stage, to determine if reliability on existing safeguards is increased to the level such that either less number of safeguard failure or no safeguard failure can be achieved (i.e. SIL-3 reliability), to further reduce relief load going to the flare and mitigate various concerns related to excessive back pressure and radiation. If safeguards are less or greater than 98 percent reliable or greater or lower number of safeguard credits are present, the total number of safeguard failures are different based on the client specific guidelines. An option of recommending new safeguard/s of specific reliability can also be considered and reduction in the total flare load can be determined. This data then can be taken to the next step, which is performing a Quantitative Risk Assessment (QRA). QRA may help determine if the results comply with local regulations, API STD 521, and the owner's risk tolerance criteria, whichever is more restrictive [1]. Note that the risk acceptance criteria are the sole responsibility of the owner. Please refer below paper as reference, which details Flare QRA [2].

Based on the reduction in the flare load calculated using various approaches as mentioned above, it can be concluded that steady-state relief loads are often conservative. While these are utilized for relief valve sizing purposes, they should not be taken as the basis to check the adequacy of the vapor disposal system.

Bar chart below summarizes the reduction in the total flare load which was achieved using systematic approach of detailed dynamic simulation study with credit for the existing instruments and safeguards.

Plot 2: Comparison of Flare Load Reduction Achieved



As a result of above-mentioned systematic approach, overall reduction in the flare relief load was calculated to be 45% (in comparison with total load mentioned under Tables 1 and 4 above). As mitigating the concerns related to excessive flare radiation was the goal of the study, radiation was re-run for the reduced flare load calculated per Table 4 above and as a result of this, significant reduction in flare radiation was also achieved.

Acronyms A-Z	
API	American Petroleum Institute
QRA	Quantitative Risk Assessment
PFOD	Probability of failure on Demand
APS	Automatic Pump Start-up

References:

1. *Pressure-relieving and Depressuring Systems, API Standard 521 6th edition.*
2. *Ben Pratt and Nancy Faulk, "What is My Flare Capacity, Really? Best Practices for Flare QRA Tools," 15th Global Congress on Process Safety (April 2019), New Orleans, LA*