Relief and Flare Systems Statics vs. Dynamics

For Want of a Horseshoe Nail the Kingdom was Lost

An ioMosaic White Paper

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1 Introduction

The landscape of relief systems and general process safety management compliance is evolving. This evolution is due in part to enforcement or potential enforcement of recognized and generally accepted good engineering practices (RAGAGEP).

Because of RAGAGEP [1, 2] considerations, oversizing a relief device is no longer acceptable or desirable from an engineering perspective and from a legal liability perspective. For example, recent citations and enforcement by OSHA have considered the lack of toxic/flammable dispersion analysis and the lack of thermal radiation analysis for releases going directly to atmosphere. Other considerations include explosion risk, relief piping vibration risk [3], runaway chemical reactions [4, 5], PRV stability [6, 7, 8, 9, 10], embrittlement due to cold temperatures, metal failure [11] due to overheating [1], multiphase flow [12], etc.

The evaluation and/or design of emergency relief, vent containment, and flare systems require deep expertise and specialization. Many facilities place their trust in their engineering contractors to possess that deep level of expertise and to provide them with safe and compliant designs and evaluations.

2 What do we mean by statics?

What we mean by statics is the use of steady state methods without any consideration for the time dependent nature of process events, equipment behavior, operator intervention, control systems, safety instrumented systems, etc.

3 What do we mean by dynamics?

What we mean by dynamics is the use of full dynamics or quasi-dynamics where the time dependent nature of process events and equipment behavior are considered on a bulk basis (quasi-dynamics) such as a depressuring vessel considered as one node, or a pipe is broken into thousands of nodes to better capture pressure wave interaction with a PRV spring/mass system (full dynamics). Many industry standards and guidelines (such as API [13]) now recognize the use of dynamics for the evaluation of relief and flare systems.

4 Why Statics are used?

Statics are used to calculate a required relief rate and relief flow area. Almost always, the technical user takes comfort in knowing that the vent size will be overestimated and therefore concludes that safety is guaranteed. The technical user also takes comfort in that such estimates can be done quickly, with limited effort, and can be revised quickly when needed.

[1] A PRV only protects against overpressure and not overtemperature

Statics are without a doubt convenient to use. However, their proper and only use should be for screening. Answers obtained by statics should be considered tentative until confirmed by dynamics before a plant accepts such pessimistic findings as deficiencies and unwittingly undertakes a legal and ethical commitment to complete needless mitigation and unnecessary risk reduction in a timely manner.

An oversized relief device is not equivalent to a safe device. Oversized relief devices place more demand on downstream effluent handling equipment, require more structural support, require bigger separation equipment, place more demand on flare headers, lead to higher thermal radiation, larger flammability dispersion footprints, larger toxicity dispersion footprints, and higher explosion potential impacts for reliefs going directly to atmosphere. Some of the dispersion estimates may be reportable under EPA or other additional regulatory requirements. Larger PRV devices are more likely to exhibit chatter or instability because they are oversized for the actual demand. In extreme cases where depressuring occurs via an oversized fast acting rupture disk (or opening), explosive boiling and re-pressurization inside the vessel can lead to catastrophic vessel failure [14].

For existing plants, statics often lead to overly pessimistic findings that more relief systems are inadequate because of inlet line pressure loss or backpressure issues (on average 20 % to 30 % especially for old plants). Unfortunately, these findings become legal lightning rods or beacons once the statics estimates are completed and are in the company possession regardless of whether the company accepts them or does not accept them. Statics will almost always indicate that most relief systems exhibiting multiphase flow and/or chemical reactions leading to multiphase flow will be inadequate. The loss of high pressure/low pressure interface scenarios (loss of liquid level and vapor breakthrough [15]) and heat exchanger tube failure [16] scenarios also fall in that category.

For example, the cost of cutting a new nozzle in a vessel will range from $50,000 to $300,000 dollars per vessel depending on the complexity of the piping and process. While this is only likely for 20 % or 30 % of the non-reactive systems analyzed, it may be as high as 70 % or 80 % of the reactive systems analyzed (if they can be analyzed adequately with statics in the first place). A statics analysis that will typically result in findings where 20 % to 30 % of the relief devices are found to be inadequate does not provided economical or safety benefits to the company owners, employees, and/or other stakeholders.

5 Why Dynamics are needed?

We dont design chemical plants or at least we should not design chemical plants by guessing or obtaining just a screening level answer. We can always overdesign a system, but that may not be economical and may in fact increase plant operating risks and legal exposure risks instead of decreasing risks. What is missed by the technical user in general are lifecycle considerations for relief systems. The application of simple API sizing formulas (statics) only addresses one limited aspect of an optimal overall safe design.

The use of statics often obfuscates unnecessary high mitigation costs and legal compliance exposure from upper management. The technical user is not always focused on solutions that yield the most effective risk reduction from an overall or a lifecycle perspective.

Dynamics are just as easy to conduct as statics. The data used by dynamics is the same data collected and used by statics. Dynamics will almost always result in smaller relief requirements and provide substantial and significant insights. More importantly efforts associated with executing large site wide relief systems studies using dynamics end up saving time, reducing risks, and costing less because the need for unnecessary corrective actions and mitigation considerations are reduced substantially from the get-go. Many site wide relief systems are highly interconnected. Proper and adequate relief requirements usually involve multiple equipment and optimization is often required.

For example, dynamics can provide useful information on how long it takes a vessel to reach liquid full conditions and whether operator action can be relied upon according to industry standards and guidance. In many instances where the dynamics consider the transient nature of venting during an overfill scenario it may not be possible to overfill the vessel. Dynamics will provide information about how much time is available for emergency response and firefighting for a vessel exposed to a liquid pool fire or even a jet fire.

For systems where inlet and discharge line pressure losses are considered, dynamics can provide a clear picture of transients, and whether a relief device can operate in a stable manner despite excessive backpressure or inlet pressure loss. For example, a PRV can be pushed into a stable lift because it takes a certain amount of time to fill the relief discharge line that is not packed initially or a PRV can operate at reduced lift because the inlet line is less than the critical stability length requirement.

6 Risk Reduction Return on Investment (ROI)

Table 1 illustrates how dynamics can produce a significant return on investment (ROI) for necessary mitigation and risk reduction. The estimates look at a small site with 100 relief devices, a medium site with 500 devices, and a large site with 1000 devices. Table 1 assumes a cost differential of \$1,000/device between statics and dynamics, where the dynamics cost an additional \$1,000/device for analysis. The ROI shown assuming a replacement/mitigation cost of \$50,000/device is substantial even if only 3 % of the statics deficiencies requiring mitigation/risk reduction were eliminated by dynamics.

Table 2 shows the same analysis, except with a higher mitigation/replacement cost of \$100,000/device. It is possible that higher costs are required when cutting a new vessel nozzle depending on piping, equipment, and process complexities.

Neither Table 1 nor Table 2 show the spill over and incremental benefits related to overall system optimizations that are realized by using dynamics.

7 Column System Example

A recent static analysis of a complex column system (see Figure 1) depicted as a simplified sketch in Figure 1 indicated that a partial loss of power will overfill one of the columns and that the

Table 1: Dynamics vs. statics overall ROI at a risk reduction cost of $50,000/device

Basic Assumptions	Increase in No. of Devices Identified to Require "Mitigation" by statics but were shown to be sized properly when using Dynamics	$ Cost savings or cost Avoidance by using Dynamics for all PRDs at small, medium, and large sites			Dynamics incremental cost return on investment (ROI %)
		Small Site 100 PRD's	Med Site 500 PRD's	Large Site 1000 PRDs'	
Dynamics cost differential relative to statics: $1,000 / PRD $50,000 to replace/mitigate an undersized device identified using statics only	3%	50,000	250,000	500,000	50.0%
	5%	150,000	750,000	1,500,000	150%
	10%	400,000	2,000,000	4,000,000	400%
	15%	650,000	3,250,000	6,500,000	650%
	20%	900,000	4,500,000	9,000,000	900%

existing relief devices did not provided adequate protection. A $5,000 investment in performing dynamics estimates using SuperChems™ Expert, a component of Process Safety Office®, showed that that it is not possible to overfill the column and that the liquid level will in fact reach a steady state value of 65 % (see Figure 2). The dynamics analysis also showed that the existing relief devices have adequate capacity and that there is enough time for an operator to respond of 15 minutes or more. The $5,000 investment in dynamics saved the facility well in excess of an estimated cost of more than $100,000 for unnecessary risk mitigation, yielding a substantial ROI.

This is but one example of a myriad of scenarios where dynamics can demonstrate that risk reduction efforts are better devoted to where risk reduction is necessary. Other scenarios where dynamics will almost always provide a better and more accurate representation of the actual risk include fire exposure, loss of liquid interface and gas blow through [15], inlet pressure loss exceeding 3 %, backpressure exceeding allowable limits, overloaded depressuring systems, overloaded flare systems, etc.

8 How can we help?

In addition to our deep experience in the conduct of large-scale site wide relief systems evaluations by both static and dynamic methods, we understand the many non-technical and subtle aspects of compliance and legal requirements. When you work with ioMosaic you have a trusted partner that you can rely on for assistance and support with the lifecycle costs of relief systems to achieve optimal risk reduction and compliance that you can evergreen. We invite you to connect the dots with ioMosaic.

Table 2: Dynamics vs. statics overall ROI at a risk reduction cost of $100,000/device

Basic Assumptions	Increase in No. of Devices Identified to Require "Mitigation" by statics but were shown to be sized properly when using Dynamics	$ Cost savings or cost Avoidance by using Dynamics for all PRDs at small, medium, and large sites			Dynamics incremental cost return on investment (ROI %)
		Small Site 100 PRD's	Med Site 500 PRD's	Large Site 1000 PRDs'	
Dynamics cost differential relative to statics: $1,000/PRD $100,000 to replace/mitigate an undersized device using statics only	3%	200,000	1,000,000	2,000,000	200%
	5%	400,000	2,000,000	4,000,000	400%
	10%	900,000	4,500,000	9,000,000	900%
	15%	1,400,000	7,000,000	14,000,000	1400%
	20%	1,900,000	9,500,000	19,000,000	1900%

Figure 1: Column system simplified sketch

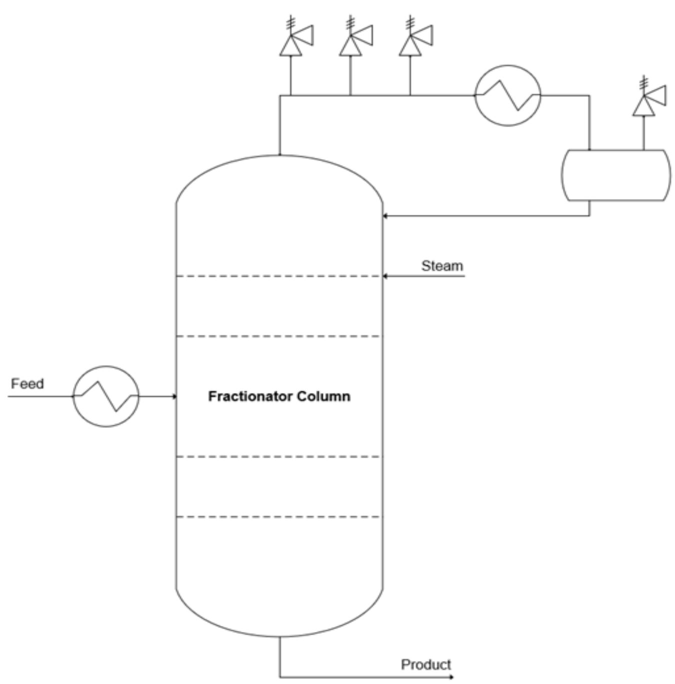

Figure 2: Dynamics liquid level time history

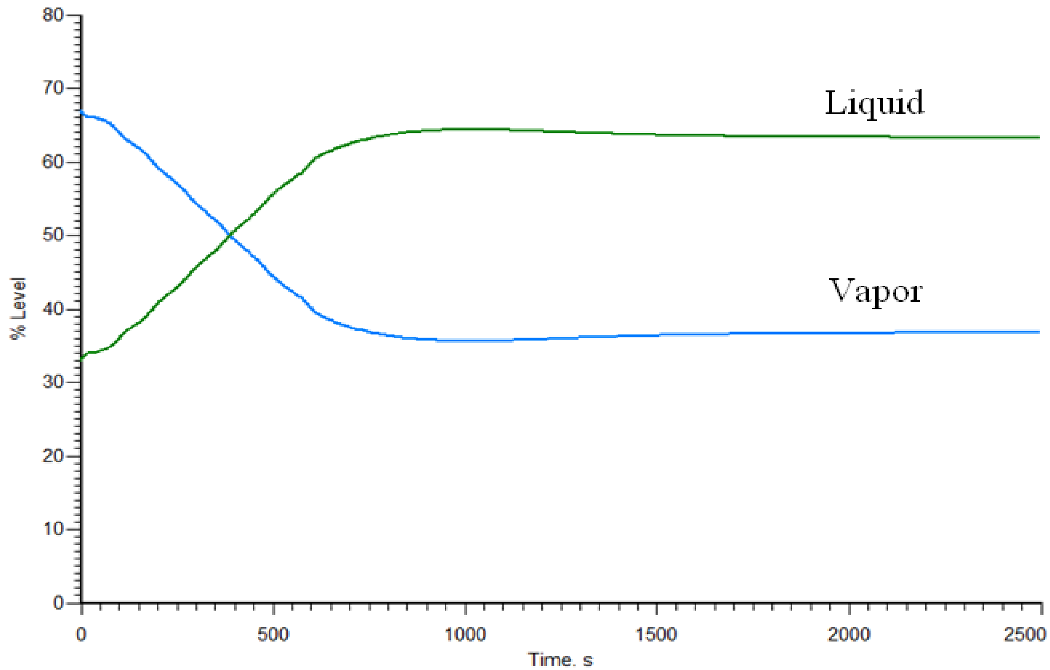

Figure 3: Connect the dots with ioMosaic

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About the Author

Dr. Melhem is an internationally known pressure relief and flare systems, chemical reaction systems, process safety, and risk analysis expert. In this regard he has provided consulting, design services, expert testimony, incident investigation, and incident reconstruction for a large number of clients. Since 1988, he has conducted and participated in numerous studies focused on the risks associated with process industries fixed facilities, facility siting, business interruption, and transportation.

Prior to founding ioMosaic Corporation, Dr. Melhem was president of Pyxsys Corporation; a technology subsidiary of Arthur D. Little Inc. Prior to Pyxsys and during his twelve years tenure at Arthur D. Little, Dr. Melhem was a vice president of Arthur D. Little and managing director of its Global Safety and Risk Management Practice and Process Safety and Reaction Engineering Laboratories.

Dr. Melhem holds a Ph.D. and an M.S. in Chemical Engineering, as well as a B.S. in Chemical Engineering with a minor in Industrial Engineering, all from Northeastern University. In addition, he has completed executive training in the areas of Finance and Strategic Sales Management at the Harvard Business School. Dr. Melhem is a Fellow of the American Institute of Chemical Engineers (AIChE) and Vice Chair of the AIChE Design Institute for Emergency Relief Systems (DiERS).

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About ioMosaic Corporation

Through innovation and dedication to continual improvement, ioMosaic has become a leading provider of integrated process safety and risk management solutions. ioMosaic has expertise in a wide variety of areas, including pressure relief systems design, process safety management, expert litigation support, laboratory services, training and software development.

As a certified ISO 9001:2015 Quality Management System (QMS) company, ioMosaic offers integrated process safety and risk management services to help you manage and reduce episodic risk. Because when safety, efficiency, and compliance are improved, you can sleep better at night. Our extensive expertise allows us the flexibility, resources, and capabilities to determine what you need to reduce and manage episodic risk, maintain compliance, and prevent injuries and catastrophic incidents.

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