A DYNAMIC FUTURE FOR FLARE DESIGN

James Marriott, Process Systems Enterprise Ltd, UK, and Brian Marshall and Alexis Haro, Softbits Consultants Ltd, UK, illustrate how modern computer dynamic analysis and detailed evaluations can yield significant savings in both weight and cost of flare and relief systems.

Determining the minimal required flare system size, layout and equipment during the early stages of the design is essential in order to minimise costs and avoid late design changes. Existing flare and relief systems are often potentially bottlenecked when considering plant upgrades and expansions.

Conventional steady state calculation methods can result in flare systems being over designed requiring larger and more costly flare stacks, tips, network headers and relief valves. Revamp and expansion projects may be jeopardised by this unnecessary higher cost.

This article shows how up to date computer dynamic analysis and detailed evaluations can yield significant savings in both weight and cost of flare and relief systems.

Traditional methods are conservative in assuming:

- Simple fire relief calculations.
- No interaction between different process units and control systems.

- No line packing in the flare header.
- Simple radiation analysis.

Particular attention will be paid to:

- Generation of equipment relief loads using dynamic analysis.
- Consideration of flare header design using dynamic flow analysis.
- Detailed evaluation of incident radiation and sizing of flare stacks.

Relief load generation

Rigorous dynamic models allow the prediction of transient behaviour in process units, which is impossible to analyse with steady state methods, by modelling:

- Varying liquid holdups in columns and pressure vessels.
- Pressure and flow changes in headers, vessels and process piping.
- Changes in flow rates in a distillation column as the unit undergoes an upset.
- Multiple unit interaction and control system responses.

Fire case study

The conventional approach is to calculate the amount of heat absorbed by the vessel exposed to fire and then evaluate the relief load based on the latent heat of vaporisation, λ. Simple steady state analysis not only simplifies the λ value used but also ignores the change in wetted surface area of the vessel on falling liquid level.

Table 1. Relief rates for alternative calculation methods

		Steady state (conventional)	Dynamic (API 521)	Dynamic
	Constant	Wetted area & LHV	Wetted area (API 521)	-
Vessel wetted area	m^2	8.0	8.0	Varying with time
Heat input	KJ/hr	856 000	856 000 (fixed)	Varying with time
Liquid lat HT vap	KJ/kg	313	varying	Varying with time
Peak relief rate	Kg/hr	2734	2834	2834
Required orifice size	mm^2	215	178	121
Actual orifice size	mm^2	324 (G Orifice)	198 (F Orifice)	126 (E Orifice)
Time to peak flow	min.	n/a	42 min.	33 min.

Table 2. Conventional versus dynamic column upset relief loads

Example	Failure	Conventional calculation	Dynamic simulation	Reduction	Reference
		kg/hr	kg/hr	%	
1	Cooling water	114 000	76 475	32	(3)
2	Total power	386 956	37 720	90	(3)
3	Cooling water	97 486	73 140	25	(4)
4	Power	156 337	87 526	44	(5)
5	Power	175 903	77 079	56	(5)
6	Seven various scenarios			Avg 60	(6)

Dynamic simulation provides an alternative to conventional calculation methods and provides substantially lower relief loads. For fractionation towers with wide boiling ranges, significant flare load reductions are possible. Dynamic simulation accounts for the limited inventory of light components and the sensible heat required to boil off the heavier components.

Scenario 1: vessel under fire

Compare the conventional calculation method to a dynamic run where the heat input and latent heat vary with time. API 521 recommends the wetted area be treated as constant whereas in real situations it varies with time.

Heat absorbed

$$Q = C_1 F A^{0.82} \qquad (1)$$

Q = heat absorption to wetted surface, Btu/hr or KJ/hr.
C_1 = factor, 21 000 (field) 155 201 (metric).
F = environmental factor.
A = total wetted surface, ft^2 or m^2.

Relief load

$$W = Q/\lambda \qquad (2)$$

W = relief load, lbs/hr or kg/hr.
Q = total heat absorbed, Btu/hr or KJ/hr.
λ = latent heat of vaporisation, J/kg or Btu/lbs.

In this case the results show how dynamic modelling of the vessel under fire has predicted a higher relief flowrate occurring albeit at 33 min. after the start of the fire. Due to the relieving fluid properties at this time a reduced size PSV is sufficient. The resultant relief curve for the valve also indicates a much reduced flowrate in the first 10 - 15 min. of relief. This will prove important when combined with other dynamic relief flow curves in determining the total flare load.

Scenario 2: distillation column reflux failure

Loss of reflux in distillation columns caused by power failure or cooling medium loss causes a series of events, which ultimately lead to overpressure and relief to flare. The benefits of performing dynamic simulation on these types of column upset scenarios are well documented and all go to prove that significant savings in flare relief loads are possible. It is not the purpose of this article to repeat those simulation details. Reference to the results however is made.

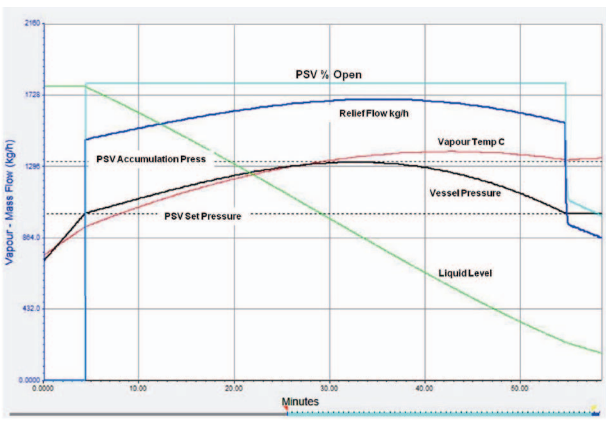

Figure 1. Dynamic simulation results for fire relief.

Flare header design using dynamic simulation

Conventional flare header design techniques use steady state simulation based on peak relief flows to assess system capacities and determine PSV backpressures and header flow.

The steady state assumption can lead to a gross overdesign, as:

- The actual relief flow is at the maximum only for a short period of time.
- There is no possibility of taking credit for staged/staggered relief, in which different units are relieved at different times.

The dynamic simulation capabilities of modern tools such as gPROMS Flare provide a number of options for analysing the flare header design to determine safety compliance based on a much more realistic representation of behaviour.

For new designs this can lead to a reduction in header size, resulting in significant capital savings. For existing headers it provides a means to establish whether there is sufficient capacity to accommodate new sources, thereby avoiding the need for a new header and flare.

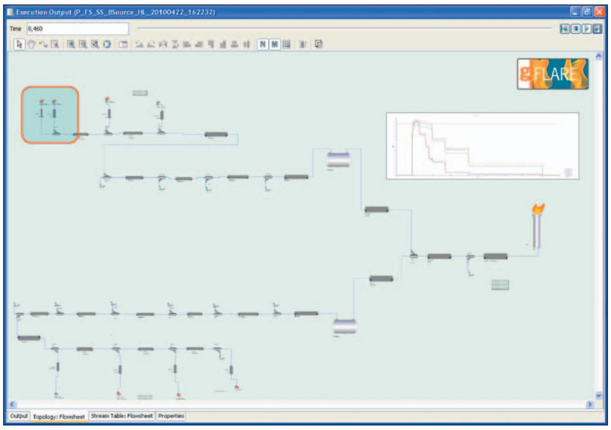

Figure 2. New sources added to existing header. These and some of the existing sources are coloured red, indicating MABP violation.

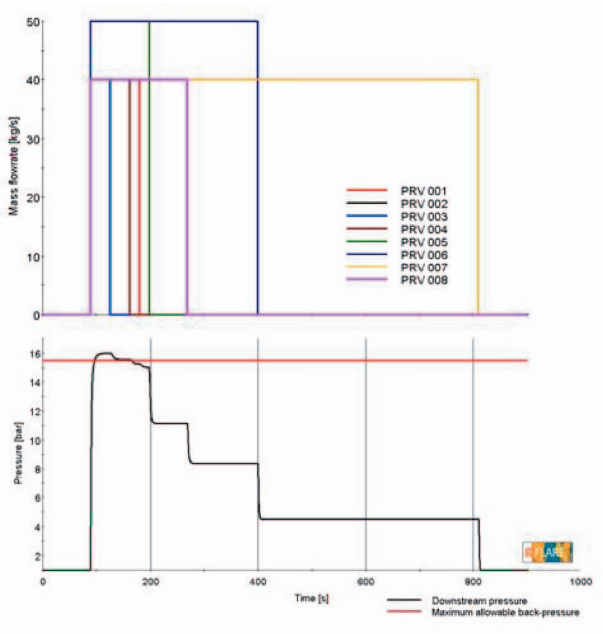

Figure 3. Option 1 backpressure profile for PRV 3 from dynamic simulation (lower) using square wave relief flows (upper).

The techniques described below can be applied to many different scenarios, such as fire, cooling water or power failure, or vessel depressurisation. The approach is best illustrated by an example.

Example: adding sources to an existing flare header

For the purposes of illustration the example uses a relatively small 'representative' system where two new sources (Figure 2, top left corner) are to be added to an existing header that previously operated within backpressure constraints for all scenarios.

Conventional steady state analysis of the new configuration shows that maximum allowable backpressures (MABPs) are exceeded in certain PRVs (Figure 2, red warnings and Table 3) in the size determining scenario. According to these results, there is not sufficient capacity to accommodate the new sources and a new header will be required.

At this point it is worth questioning the highly conservative assumption of using maximum steady state flowrates.

In fact there are a number of further analyses based on dynamic simulation that can be performed to refine the results in order to represent the real system with an increasing level of accuracy. These can be applied progressively from the most simple to the more complex, thus ensuring that time and effort are spent only where required. If at any point all constraints are satisfied, the system can be considered compliant; if not, analysis proceeds to the next option.

Option 1: determine the effects of line packing

The potential for reduced pressures owing to line packing can be explored by undertaking a dynamic simulation of the flare system using the same maximum flowrates as the original steady state analysis, but applying each relief flow only for its expected duration. The only additional information required is an estimate (and this can be a conservative one) of the relief duration. The resulting square wave relief flows are shown in Figure 3.

The relatively small header volume and coincidence of large flows means that the backpressures rise to similar values as in the original case (Table 4, option 1 results). The packing does of course have an impact on the duration of the backpressure violation, which can now be gauged for the first time. Figure 3 shows a relatively small violation occurring over approximately a minute. Attention can now be focused on reducing the relief flows during that period.

Option 2: investigate staggered or staged relief

If there is not sufficient line packing effect, the next option is to investigate staggered or staged relief, in which different units are relieved sequentially.

Table 3. New sources (7 and 8, blue) added to existing header, backpressures in red now exceed the MABP

PRV	Steady state flowrate, kg/s	MABP, bar	Backpressure, bar	
			Original configuration	New configuration
1	40	15.5	15.41	16.25
2	40	15.5	14.29	15.21
3	40	15.5	15.27	16.12
4	40	15.5	14.98	15.85
5	40	15.5	8.19	15.98
6	40	15.5	8.03	15.10
7	50	15.5	-	16.47
8	50	15.5	-	16.46

In this case the same square wave flows are used; however the relief from PRV 1 begins after the relief from all PRVs except PRV 5 is completed.

The option 2 results in Figure 4 show all but three of the PRV backpressures now within constraint. Backpressure plots show that the remaining violations are relatively small and their duration is now down to approximately half a minute. Given that API-521 is a recommended practice rather than a standard, engineering judgement can be exercised to determine whether these constitute a real danger or are an acceptable risk.

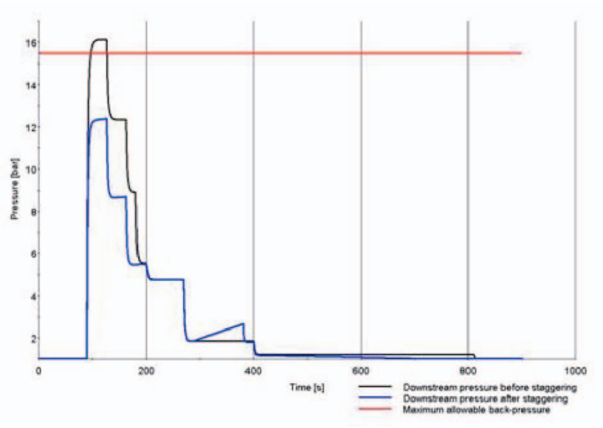

Figure 4. Option 2 profiles for PRV 3 before and after staggering PRV 1 relief.

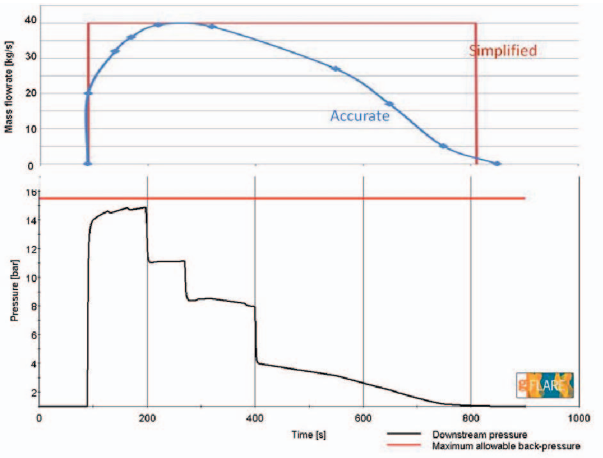

Figure 5. Option 3 profile for PRV-5 (lower) with full relief curve (upper).

Option 3: use accurate relief curves

Up until now the improvements demonstrated have been achieved at very little cost and effort. Generating accurate relief flow profiles of the type described previously involves more effort, but is worthwhile where the stakes are high. In fact it is not necessary to address all flows in this way, only those that have a significant impact in the region of violation.

Figure 5 shows the PRV 5 relief flow curve. This is applied and the simulation is rerun.

The figure shows the resulting backpressure profile for PRV 5, the worst offender. The option 3 results in Table 4 demonstrate that the flare system is fully capable of accommodating the new relief flows.

Flare radiation analysis

Radiation and temperature

This final section demonstrates how using dynamic simulation in flare stack design can lead to lower radiation and temperatures levels and result in cost saving.

Two methodologies have been applied to perform the radiation and temperature impact on a metal instrument cabinet during a blowdown operation:

- Traditional calculations based on fixed flow rate.
- Dynamic analysis based on varying flow.

The depressuring curve shown in Figure 6 has been used in order to determine the variable flow rate and gas physical properties of the dynamic study.

As can be seen in Figure 6 the radiation levels at the instrument cabinet decrease with time based on decreasing flow rate due to depressurisation. Static analysis assumes fixed radiation level during the whole blowdown operation.

However in this case the resultant temperature is more of concern than radiation. The temperature rise is an incremental calculation that uses the net input from a balance between radiation and heat loss due to reradiation and convection at the current temperature to calculate the next incremental temperature.

The lower radiation levels obtained in the dynamic analysis result in a reduction in the net input for every step considered and consequently a smaller temperature increase. This shows a more realistic approach

Table 4. Results of simulation using relief flow curve

PRV	Steady state flowrate, kg/s	Release time, s	Start time, s	MABP, bar	Backpressure, bar			
					Steady state	Option 1: flare packing	Option 2: staggered relief	Option 3: relief curve
1	40	90	90	15.5	16.25	16.25	6.20	6.20
2	40	180	90	15.5	15.21	15.21	12.07	11.91
3	40	36	90	15.5	16.12	16.12	12.54	12.39
4	40	72	90	15.5	15.85	15.85	12.43	12.30
5	40	720	90	15.5	15.98	15.98	15.56	14.86
6	40	180	90	15.5	15.10	15.10	14.66	13.93
7	50	108	90	15.5	16.47	16.47	16.08	15.42
8	50	310	90	15.5	16.46	16.46	16.06	15.40

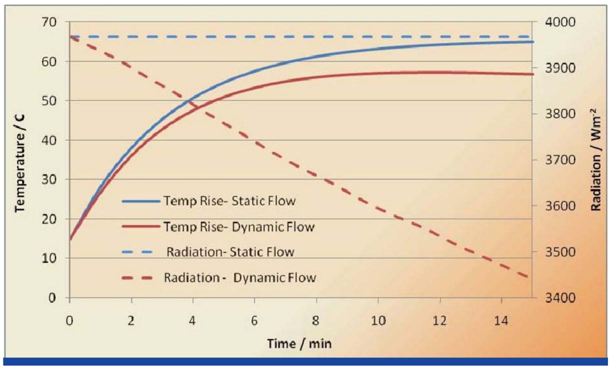

Figure 6. Static and dynamic radiation and temperature profiles.

indicating a final temperature 5.3 ˚C lower at the instrument cabinet after the end of the blowdown operation.

Stack height

The above analyses have been performed with a fixed stack height, however dynamics can also be applied in flare stack sizing.

Continuing with the same system parameters, a fixed maximum temperature constraint at the receptor point has been defined in order to analyse the variation in stack height between static and dynamic models.

Consider a maximum limit of 65 ˚C at the instrument cabinet after 10 min. of depressurisation.

Steady state analysis calculates a stack of 100 m to meet this constraint. Dynamic analysis calculates a required stack height of 92.5 m. This 7.5% reduction in height will result in a significant reduction in fabrication and material costs. For an offshore platform the benefit would be even more substantial.

Summary

This article has shown that there are three significant areas where dynamic simulation can reduce the required size and cost of flare system design.

Not all designs or revamp studies will benefit from a high level analysis of all three aspects presented here. In many cases a single area of investigation or indeed some good engineering judgement will realise acceptable reductions in loads and size.

In applying progressive analysis a dynamic simulation can reliably demonstrate that there may be sufficient capacity available within existing equipment where there had initially appeared to be none.

Future integration of the analysis tools can only lead to further refinements and savings in cost and weight of flare systems.

References

1. American Petroleum Institute, API RP 521, 'Guide for pressure relieving and depressuring systems,' 5th edition, Jan 2007.
2. American Petroleum Institute, API RP 520, 'Sizing, Selection, and Installation of Pressure Relieving Devices in Refineries', 8th Edition Dec 2008.
3. NEZAMI, P. L. Jacobs Engineering, Houston, Texas. Distillation column relief loads-Part 1 Compare conventional calculation methodology with dynamic simulation. *Hydrocarbon Processing*, April 2008.
4. NAIR, A., WILLETTS, I. Invensys SimSci-Esscor, WADE, A. University of Oxford, Simsci White Paper. Assessing the Impact of Safety Instrumented Systems on Distillation Column Pressure Relief Load using Dynamic Simulation.
5. VAN WASSENHOVE, Wim, Business Consultant, HYSYS Dynamics & Pressure Relief AspenTech Webex Awareness Series 2008.
6. DEPEW, C. and DESSING, J., 'Dynamic Simulation Improves Column Relief-Load Estimates'. Hydrocarbon Processing, December 1999.