REVIEWING THE SITUATION

Marc Massó and Miquel A. Alós, Inprocess Technology and Consulting Group, Spain, describe the steps that should be taken during a flare network capacity assessment, using both a conventional approach or dynamic simulation.

A gas plant was originally designed to produce 2.1 billion ft^3/d of net sales gas. The owner operator wanted to increase the production to 2.2 billion ft^3/d and run three out of the four onshore gas treatment trains; this is called train downgraded operation (TDO). The study aimed to determine the safety limitations related to the TDO at 2.2 billion ft^3/d and, in particular, the revalidation of the pressure safety valves (PSVs) protecting the discharge sales gas compressor line and the impact on the flare network.

In order to reach the objectives of the study, Inprocess applied commercial process simulation features: both steady state and dynamic process simulation were used to provide an accurate analysis of the plant behaviour during the sizing emergency scenario under TDO conditions. The following software packages were used to complete the study: Aspen HYSYS (including its safe sizing analysis features), Aspen Flare Analyser (AFA) and Aspen HYSYS Dynamics from Aspentech, Flaresim from Softbits and IPSV-DB from Inprocess.

The use of dynamic simulation showed that the current facilities were appropriate for accommodating the relief loads, whereas the steady state-based conventional methods suggested that a revamping of the overpressure protection equipment was required.

Methodology

Figure 1 represents the project methodology workflow used to complete the study. One model representing the normal operation at 2.1 billion ft^3/d was developed using Aspen HYSYS. The model was validated against the heat and material balance (H&MB) provided by the owner operator. The model was then upgraded to produce 2.2 billion ft^3/d

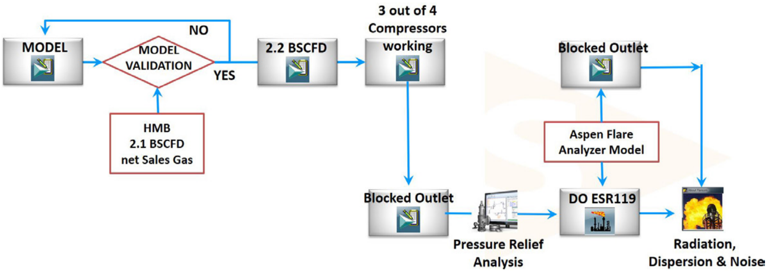

Figure 1. Project methodology workflow.

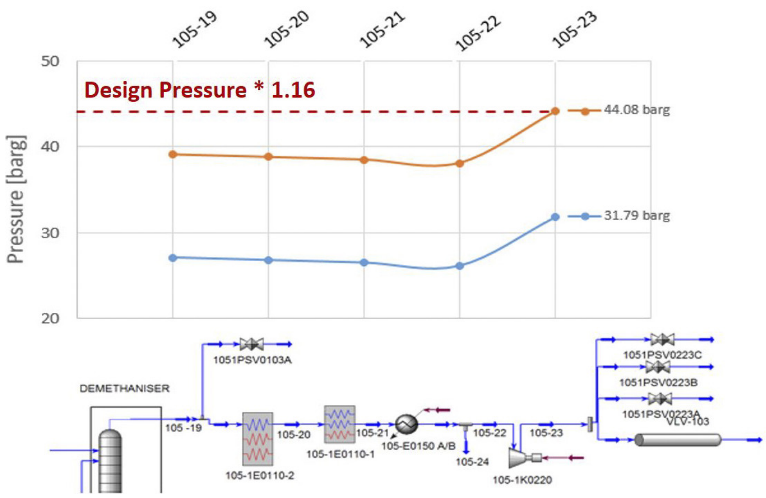

Figure 2. Pressure profile.

and later downgraded to operate with three out of four onshore gas treatment trains.

The Aspen HYSYS model was used to analyse the sizing case scenario, which is a blocked outlet at the export gas line. The equipment is protected by three PSVs located at the compressor discharge line. A fourth spare PSV may be put in service, depending on the study results. The calculation of the required relief area for the TDO conditions was carried out using the pressure relief analysis feature included within Aspen HYSYS. The reporting of such information was delivered using the IPSV-DB documentation tool from Inprocess.

The blocked outlet scenario occurs together with the blowdown of a second process unit. Therefore, a model of the flare network system was required to analyse the limitations of the relief disposal equipment. After that, flow rates from the blowdown and relief design rates from the blocked outlet scenario were introduced into the AFA model and the design constraints were checked. Flaresim software was used for the radiation, dispersion and noise analysis at the flare stack.

This procedure fulfills the conventional approach for the analysis of the relief disposal equipment. However, the approach is recognised as conservative and may lead to the oversizing of plant equipment. Blowdowns and reliefs to the flare are intrinsically dynamic phenomena. In this study, an Aspen HYSYS Dynamic Simulation model of the flare network is developed and connected to the gas plant model. The results from the blocked outlet scenario and the simultaneous blowdowns are compared with the previous results coming from the conventional approach.

Blocked outlet scenario

The capacity upgrade from 2.1 to 2.2 billion ft^3/d only represents 5% of the production throughput. However, the downgrade from four to three trains will increase the flowrate across each train by 33% (from 25 to 33% in terms of total production). It may appear easy to extrapolate the required capacity of the relief system, protecting the discharge line at each train, that should be increased accordingly in case of a blocked outlet.

Once the TDO has been simulated and the production has been increased to 2.2 billion ft^3/d, the sale gas flowrate at the compressor discharge is 629 t/hr. In order to calculate the required relief area, the discharge line of the compressor needs to be pressurised at 116% of its design pressure. By moving the compressor operation to such discharge conditions, the simulated flow rate to be relieved is 687 t/hr. This calculation is obtained directly from the model as it takes into account the performance curve of the compressor provided by the compressor supplier. Therefore, the required capacity must be 687 t/hr divided by three PSVs. The results obtained from the simulation model are introduced in the pressure relief analysis tool within Aspen HYSYS in order to revalidate the PSVs. The calculated relieving capacity, which is based on the thermodynamic equation of state provided by the process simulator, shows that the actual PSV rated capacity is 194.2 t/hr. Thus, a relieving capacity of 194.2*3 PSV, 583 t/ hr, is available. Consequently, the conventional analysis study conclusions noted that three PSVs would not be enough, meaning that the spare valve must be placed in service in order to cover the required capacity. According to this, the available capacity (194.2*4 PSV, 777 t/hr) would be higher than the required one (687 t/hr).

Figure 2 shows the pressure profile from the demethaniser to the export gas line. Pressure values are shown at different pipe locations: pipe 105-19 is downstream of the demethaniser and pipe 105-23 is upstream of the PSV, which is protecting the discharge line. A scheme of the process model is included in the figure, showing the different unit operations involved in the pressure profile.

The blue plot in Figure 2 corresponds to the pressure profile at normal operating conditions. The orange plot represents the pressure profile at the relieving conditions. When the compressor discharges at 116% of the PSV's set pressure (SP) – SP is 44.08 barg to protect the discharge pipeline – the demethaniser operates at 39.5 barg. However, this pressure is significantly higher than the SP of the PSV, which is protecting the column (38 barg). Consequently, the PSV protecting the column should open. In fact, if this PSV is incorporated to the simulation, it will open with a discharge of 150 t/hr. These results allow one to conclude that the area of the PSV protecting the column is also available in the case of a blocked outlet and, therefore, the spare valve is not necessary.

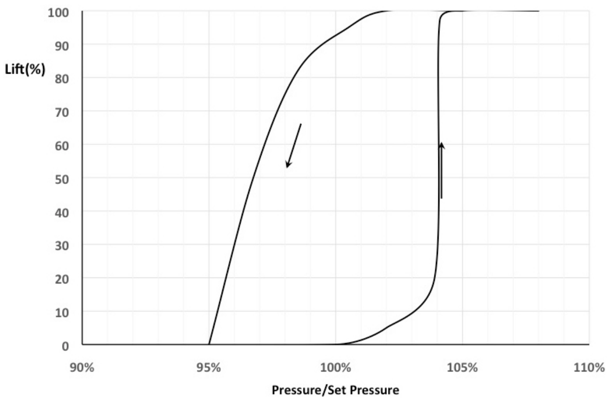

Figure 3. PSV lift curve.

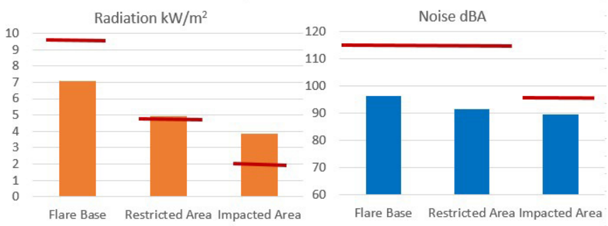

Figure 4. Flare radiation and noise.

Even though the final result of the relieving model reaches steady state conditions, the system requires a unique solution, which incorporates the compressor performance and PSV lift curve to the pressure flow hydraulic behaviour of the system (column, piping and valves). Dynamic simulation links all the hydraulic behaviour of the process, including the dynamics of the PSV and the performance curve of the compressor, and allows an accurate and easy analysis of the whole system behaviour. Special attention must be paid to the PSV lift curve, the percentage of overpressure to get the PSV fully opened and the hysteresis curve. Figure 3 shows a typical PSV lift curve.

When the pressure reaches the SP, the PSV shoots and it becomes fully opened when the pressure reaches 104% of the SP. At a pressure of 102% (of the design pressure) the PSV starts to close and, once reaching 95% of the design pressure, is fully closed. Obviously, the pressure at which the full area available is reached has a strong impact on the flow dynamic behaviour across the PSV. In particular, for this case study, it was found that if the PSV reached the fully open position at 110% of the design pressure, the relieved flow rate during the scenarios across the demethaniser PSV is around 50 t/hr, meaning that the spare valve is required. However, if the fully open position is reached at 105%, the flow rate is around 150 t/hr and the spare valve is not necessary. This range of possible obtainable solutions reinforces the necessity of having the safety valve characteristics (the lift curve) available when running the emergency scenarios, in order to obtain a consistent conclusion of the assessment study. Therefore, in order to provide a concise conclusion to the study, it is highly recommended to have the PSV's functional lift curve available.

Summarising the analysis, the conventional approach indicated that the spare valve was needed in service to provide the required capacity. However, a more detailed analysis, incorporating the compressor map and PSV curve lift to the hydraulics of the unit, revealed that the relieving capacity available with the current configuration was sufficient. This calculation was completed easily using Aspen HYSYS in the dynamic mode.

Flare network capacity

In the event of a blocked outlet in the sale gas discharge line, a simultaneous blowdown of unit 200, containing nine parallel export compressor lines, will happen with a total flow peak of 1230 t/hr. Since the PSV's design flow rate is 687 t/hr, the total load sent to the flare is 1918 t/hr. Maximum flare capacity is 1800 t/hr. Therefore, if the blowdown discharge and the shot of the PSV occurs at the same time, the total flow sent to the tip, 1918 t/hr, will exceed the flare capacity by 6%.

Design constraints for the flare network piping are: Mach number = 0.7; momentum ρv^2 (kg/m/s^2) = 150 000 maximum; and design pressure in a range from 13.5 bara to 18.8 bara, depending on the tail pipe. A simulation model is developed using the standard AFA software (previously known as Flarenet). Design relief PSV flow rates and blowdown peak flow rates are introduced into the model in order to check the design criteria momentum and Mach number at all the sub-headers and headers along the flare network. The model includes loads from 6 PSV and 17 blowdown valves (BDV).

According to AFA results, one can observe that only the back pressure for the unit discharging through the BDV 200-BDV-007 (15.7 bara) is above the design limit (13.5 bara).

The last step of this analysis is to determine the impact on radiation, noise and emission caused by the relief loads. Radiation must be lower than 9.5 kW/m^2 at the flare base, 4.7 kW/m^2 at the restricted area and 2 kW/m^2 at the impacted area. Noise must be under 115 A-weighted decibels (dBA) at the flare base and restricted area, and under 95 dBA at the impacted area. The composition and mass flow rate values at the flare tip are obtained from the AFA model and introduced into the FlareSim simulation software for the estimation of these design variables. Figure 4 shows the calculated radiation and noise in different areas, together with the maximum allowable value represented by the red lines.

It can be observed in Figure 4 that all the values are acceptable, with the exception of the radiation at the impacted area. In this case, the value is 100% higher than the maximum radiation.

Regarding flammable gas dispersion, H_2S dispersion and SO_2 dispersion, no issues were found due to the very low content of H_2S and SO_2 in the flare loads. Furthermore, the flammable level, considered 100% lower flammable limit (LFL), does not reach the ground either inside or within the vicinity of the plant.

In summary, the conventional approach shows that, in the event of a blocked outlet and a simultaneous blowdown in unit 200, the flare is overloaded by 6% of its capacity, back pressure is not acceptable downstream of the 200-BDV-007 restriction orifice (RO), and radiation at the impacted area is 100% higher than the allowable value.

Dynamic analysis of the flare network during the release

Some additional topics are taken into consideration when dynamic simulation is applied to a relief analysis:

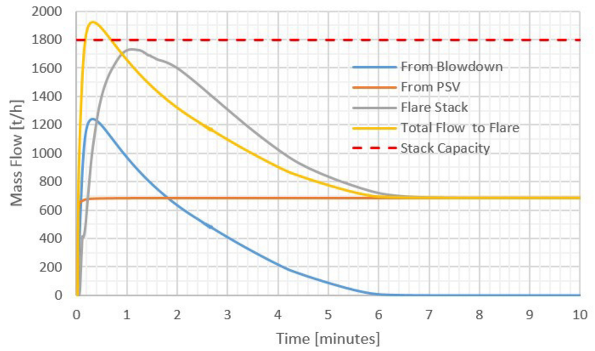

Figure 5. Flare network mass flow during blowdown.

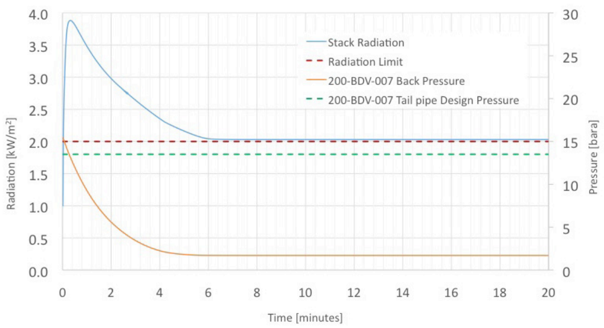

Figure 6. Radiation and back pressure during the blowdown.

- Impact of thermodynamics on the flow composition to the flare during the blowdown.
- Dynamic interaction between the utilities and process equipment.
- Impact of hydraulics and equipment size and geometry.
- Pipe packing effects on the flare network.

All these phenomena provide valuable information that is missed during the conventional approach based on steady state assumptions.

The dynamic Aspen HYSYS simulation model is expanded once the flare network and the unit 200 have been incorporated. The blocked outlet scenario and the simultaneous blowdown in unit 200 is carried out. Figure 5 shows relief mass flow during the scenario. The brown curve, which is almost constant during the transition event, represents the flow rate through the PSV. The blue curve, with a peak of 1230 t/hr, represents the sum of all the flow rates from the blowdown unit at the restriction orifices.

The conventional approach conclusions are obtained by considering a constant flow rate equal to the yellow line peak flow (sum of brown and blue lines). This value is 6% higher than the stack capacity, represented by the dashed red line. However, dynamic simulation shows that the stack is only overloaded for under 45 seconds.

However, the main contribution from incorporating the flare network within the dynamic simulation model is the ability to check the impact of the flare network volume, which must be pressurised during the relief. In fact, the grey curve shows the flowrate values at the flare stack. The peak of flow is approximately 1700 t/hr, slightly lower than the stack capacity of 5.6%. The peak also reaches the flare stack 75 seconds after the start of the blowdown operation. Both phenomena are related to the flare network packing effect. Evidently, the reduction of the overload and the shorter time required by the peak to reach the flare strongly depend on the size of the flare network.

Figure 6 shows the other two process variables, which were above the design limits of the conventional approach: stack radiation, blue curve, and back pressure at 200-BDV-007, orange curve.

Stack radiation was 3.8 kW/m^2 while the limit was 2.0 (dashed red line). However, the dynamic study shows that such a limit is only exceeded along the first six minutes (blue line) of the emergency situation, and it is higher than 3 kW/m^2 only along the first two relief minutes.

Figure 5 also shows the back pressure downstream of the 200-BDV-007 RO, which was exceeding the design pressure of the tail pipe, 13.5 bara (dashed green line). Similar to the radiation curve, the design pressure is only observed to have exceeded along the first 20 seconds of the emergency situation (orange curve).

Therefore, the benefits from the dynamic simulation analysis of the sizing relief scenario may be summarised as follows:

The conventional approach shows that, for the flare network sizing case:

- The flare capacity is exceeded by 6%.
- Back pressure is above the design pressure in the BDV 7 tail pipe.
- Radiation at the impacted area is 100% higher than its allowed value.

While the dynamic simulation analysis shows that:

- There is still 6% of available capacity. This is due to the flare network packing effect which reduces by 12% the peak of load at the flare stack.
- The back pressure in the 200-BDV-007 tail pipe is only above the design pressure for less than 20 seconds.
- The radiation at the impacted area limit is only exceeded along the first six minutes. It is only 50% higher than its allowable value two minutes after the blowdown shot.

Conclusion

Conventional analysis, based on steady state simulation assumptions, advises placing the spare PSV in service to provide enough area. The dynamic simulation analysis of the complete plant demonstrates that the PSV protecting the demethaniser is relieving part of the flow to the flare, so, therefore, the current area available would be enough to protect the discharge line in case of a blocked outlet.

When performing the analysis of the flare relieving equipment, the conventional approach leads to the conclusion that the flare capacity is exceeded by 6%, back pressure is above the design pressure in one of the BDV's tail pipes, and radiation at the impacted area is 100% higher than its allowable value. While the dynamic simulation analysis shows that there is still 6% of available flare capacity, back pressure in the BDV tail pipe is above the design pressure for less than 20 seconds, and the radiation at the impacted area is only 50% higher than its constraint value for the first two minutes and six minutes after it is below the maximum allowable value.