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FLARE FOR DESIGN

Dhiren Madlani, Flaretot, UK, demonstrates how total flare system design can be achieved using one integrated suite of software applications.

An integrated flare system design involves the key disciplines of process and safety engineering. The design tasks for an integrated flare analysis and design cover hydraulic analysis of the flare header and piping components, the radiation and dispersion calculations and associated noise, wall temperature and flare knockout drum sizing calculations. Usually these tasks are split between the process and safety groups within an organisation. Performing these key tasks in an efficient and integrated manner addresses the technical challenges of interfacing the results from each application to a resulting component, giving a better representation and design.

Designing the flare system for any hydrocarbon processing plant entails the use of various software to evaluate the different components of the flare system design: depressurisation rates, sizing of relief devices, defining relief loads, network design, radiation and dispersion, and noise calculations. There are a number of software applications in the market that address these calculations using separate programs. However, there is an integrated flare design application that allows all the major components of the flare system to be designed using a single piece of software.

In order to demonstrate the essential facets of the software and total flare system design, actual project data from previous study has been used. The facilities entail processing heavy sour crude with gas separation and treatment, and have been built on a brownfield site alongside of existing operating facilities. The flare system must take into account these additional constraints. This study deals with a general description of the acid, low pressure and high pressure flare network for the new plant to be located at the existing facility. The purpose of the study was to finalise the design parameters for the flare and depressurisation network for the new plant. Sizes for main flare headers were finalised based on the hydraulic study carried out for the controlling relief cases.

All the elements for the flare system were modelled using Flaretot software. The single model was used to verify the size of the main flare headers within the new plant, to verify flare knockout drum sizes and relief rate for two phase flow safety valve sizes using the Diers HIM method, and to finalise backpressures on various safety valves and blow down valves. The final confirmation and selection of safety valves was based on the back pressures.

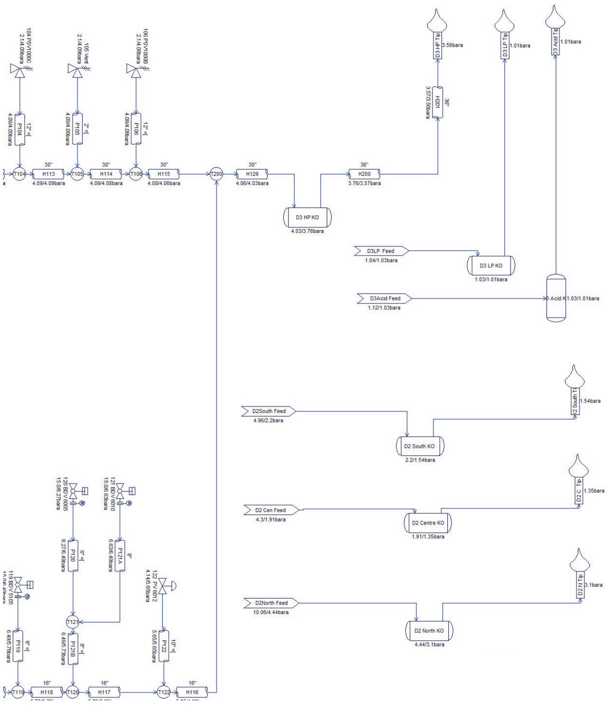

Figure 1. Expanded view of both the existing flare system and new flares to be installed at the site.

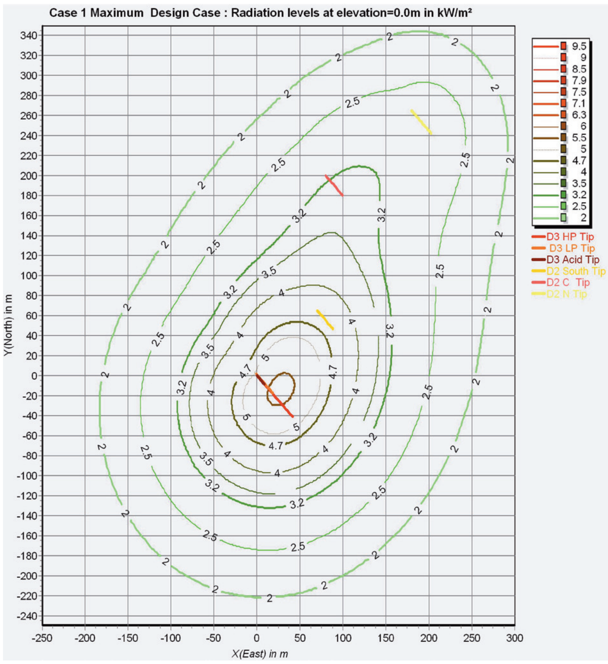

Figure 2. Combined radiation from all six flares operating simultaneously.

Relief load calculation

For estimation of the relief loads, the following relief scenarios were considered:

- External fire.
- Inlet valve failure.
- Blocked outlet.
- Gas blow by from upstream equipment.
- Heating system control failure.
- Tube rupture.
- Utility failure.

External fire

In the case of fire, two applicable scenarios were considered:

- Liquid vaporisation due to external fire.
- Gas expansion due to external fire.

No credit was taken for decreased heat transfer due to insulation.

Inlet valve failure

This case considered the failure of the inlet emergency shut down (ESD) valve to close on demand or an inadvertent opening of the manual valve (for example, the choke valve). The relief flow rate was based on the estimated flow coefficient (Cv) of the choke valve and the design capacity of the vessel.

Blocked outlet

This case considered the failure of the gas outlet valve. The normal fluid handling capacity at the relieving pressure was considered as the relief flow rate.

Gas blow by from upstream equipment

In the event of the upstream equipment having a higher design pressure, there exists a possibility of a gas blow by from the upstream equipment. For the purpose of the relief load calculations, the upstream equipment is assumed to be operating at the maximum operating pressure: at pressure alarm high (PAHH) setting if available or pressure safety valve (PSV) set pressure. The downstream equipment was assumed to be operating at the relieving pressure or at maximum equal to the overpressure considered in the valve. Based on the above conditions, the flow rate through the upstream control/manual valve was calculated using an estimated Cv. This flow rate was verified upon finalisation of the control valves.

Heating control failure

A heating medium control valve fully open case was considered for the relief calculations relating to the equipment provided with heating systems (for example, the reboiler). Maximum flow through the valve was estimated and this value was used to rate the normal blocked discharge relief requirement. No credit is taken for the log mean temperature difference (LMTD) decrease due to the increase in boiling point at relieving pressure.

Flare network design

Location of the new D3 high pressure, D3 low pressure and D3 acid flares were calculated to be 800 m from the knockout drums, which were located within the new plant boundary. The location of the flare stack was chosen so that the new flares were closer to the existing flare. The pressure required at the bottom of the new high pressure flare stack was considered as the controlling case.

The objective of the study was to size the high pressure flare header so that backpressures on the safety valves fall within the limits. The minimum set pressure in the system is for low pressure separator safety valve, which is set at 10 barg. The maximum allowable back pressure for this pilot operated safety valve is 7 barg. In addition, the blow down valves, which are connected to a high pressure flare, are required to depressurise the system to 7 barg. For this, the backpressures must be below 7 barg during the depressurisation operation considering the decreasing flow rates of depressurising valves.

The main sizing cases considered for the flare header sizing case were as follows:

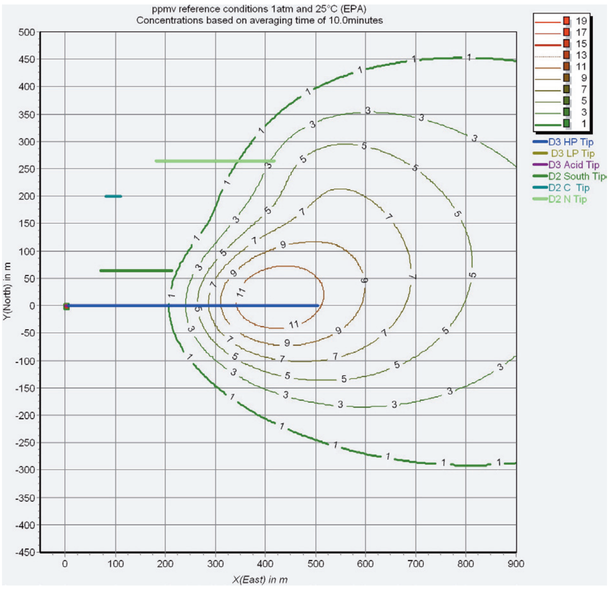

Figure 3. Combined H_2S dispersion contours from all six flares operating simultaneously.

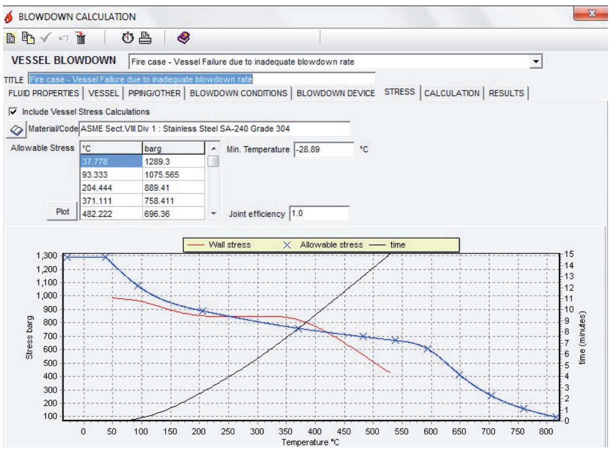

Figure 4. Stress results of the vessel that is under fire. These show that the vessel can fail under stress due to inadequate orifice size.

Case one: emergency flaring

In case of ESD level 0, the ESD valve closes on inlet manifold and the manifold PSVs open, resulting in total plant depressurisation (total for all systems).

In case of fire in the plant, the unit will be automatically shut down. As the plant shuts down, the manifold PSV may open. The depressurisation of the plant may be required for deinventorying the system and this will be done automatically in case of ESD level 0. No other fire case relieves are higher than this complete depressurisation load, so they are not considered as coincidental in this emergency relief scenario.

Case two: blocked outlet at first stage separator outlet

This case considers that the separator is operating at normal capacity and failure of the inlet ESD valve on demand. All the outlet valves on the separator are closed.

Case three: simultaneous gas blow by from the existing plant and new plant

As well as the gas produced in the new plant, an additional facility was considered in the design to handle extra gas from the existing plant (maximum 200 million ft^3/d). Controlling the gas blow by case will be via simultaneous gas blow by through slug catcher.

Case four: maximum continuous flaring

When gas compression and fuel gas systems are down, the complete gas is sent to the flare.

Case five: normal continuous load

This case considers average normal flow through high pressure flare header.

Case six: continuous load and gas compression train blow down

The high pressure flare load was based on average of maximum relief plus compressor depressurisation.

Case seven: fire in oil area and blow down of gas and oil systems

In the case of fire in the plant, ESD level 0 will be activated. This will result in closing of ESD valves on inlet manifold and PSVs on the production lines may open. Simultaneous automatic blow down operation of all the systems in the plant also will occur. Maximum expected load on the flare would be same as that in case seven.

Case eight: maximum fire case

Maximum fire case in the plant is from the desalter area.

Flare network calculation basis

Based on good engineering practice, the following design criteria were followed for sizing the headers and sub headers in the new plant.

- Minimum line size 2 in.
- Back pressure consistent with relieving capacity of pressure relieving devices and with design pressure of the protected equipment.
- Velocity and ρV^2.
- Intermittent flow.
  - Lines downstream of relieving devices and sub headers: 0.7 Mach maximum and $\rho V^2 < 150\ 000\ kg/m/s^2$ considering the maximum capacity of the relieving devices even if this figure exceeds the actual maximum flow rate due to process

limitation and the relevant occurrence. If relief is a gas liquid mixture, these criteria reduce to 0.25 Mach (based on gas superficial velocity) maximum and $\rho_m V_m^2 < 50\ 000$ kg/m/s^2.

- Headers: 0.7 Mach maximum and $\rho V^2 < 150\ 000$ kg/m/s^2 considering the maximum flow rate due to process limitations and for the relevant occurrence. However a velocity of 0.8 Mach could be accepted for a long straight line without elbows and connections (for example, stack or line on bridge).
- Studies are required for a $\rho V^2 > 100\ 000$ kg/m/s^2 vibration and line support.

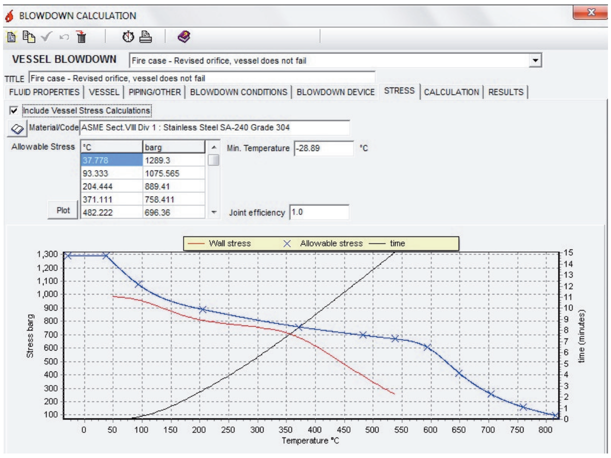

Figure 5. Stress calculation based on revised orifice calculation.

Figure 6. Flares in operation, with the three newest flares shown in the foreground.

- Continuous flow.
  - Gas: velocity < 0.35 Mach and $\rho V^2 \leq 50\ 000$ kg/m/s^2.
  - Liquid gas mixture: superficial gas velocity < 0.25 Mach and $\rho V^2 \leq 50\ 000$ kg/m/s^2.
- The flare tip pressure drops for the maximum relief cases had to be calculated for carrying out the network analysis. Hence, a hypothetical flare stack/tip diameters are used in the simulation model.
  - High pressure flare stack: back pressure at the base of the stack is 1.8 bara for high pressure flare relief scenario case three.
  - Low pressure flare stack: back pressure at the base of the stack is 1.1 bara for low pressure flare relief case three.
  - Acid gas flare stack: back pressure at the base of the stack is 1.1 bara for acid gas flare relief case two.
- The maximum allowable back pressures for the depressurisation valves were limited to 50% of the inlet pressure to ensure critical flow is maintained across the depressurisation orifice.

High pressure flare network calculation

The flare network was modelled using Flaretot software and the pressure drop calculations were carried out for various controlling cases to determine the limiting sizes for the main flare header. Figure 1 shows the model simulated on Flaretot.

Radiation and temperature calculations

Once the hydraulics were finalised, the same input file was used to carry out Flaretot's radiation and temperature calculations (Figure 2). The stack height was defined by the radiation intensity levels on personnel, equipment and structure at the plant during the maximum flaring cases and was designed so that allowable radiation limits are satisfied based on the flare stack configuration. Remedial actions can be offered where necessary. The objectives of radiation calculation are to:

- Define clearly the basis and the assumptions for the radiation calculations, including the acceptable radiation criteria.
- Define the relief scenarios that lead to the design cases in terms of flare radiation, for both instantaneous and continuous flaring.
- Calculate the flare stack height at the allowable radiation levels associated with the design cases at the different points of interest (considering both personnel and equipment).
- Establish the required flare stack height.
- Perform the isopleths for the main design cases.

Dispersion calculation

Details of the dispersion calculation can be seen in Figure 3.

Depressurisation calculations

The objective of these calculations was to check stress calculation during depressurisation of a very high pressure vessel under fire case (Figures 4 and 5).

Conclusion

The findings and recommendation of the review were implemented in the design and the flare system is now operating successfully.

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