BEYOND GUESSWORK

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During a flare release, the temperature of the flare network has a strong dependence on the relief source and on ambient conditions. During a relief of hot gases, contraction of the gases could occur due to the cool-down to ambient conditions. The rate of contraction velocity is accelerated if cooling leads to condensation of the contained gas components. The risk associated with this contraction is the depression of the header below atmospheric pressure, allowing outside air to enter into the flare system. Infiltration of air can lead to flame burn back, which in turn could initiate a destruction detonation in the system. The most common method for the prevention of air infiltration through the stack exit is to introduce purge gas. The amount of purge gas required depends on the released gas and on the gas purge composition, as well as the size and design of the flare.

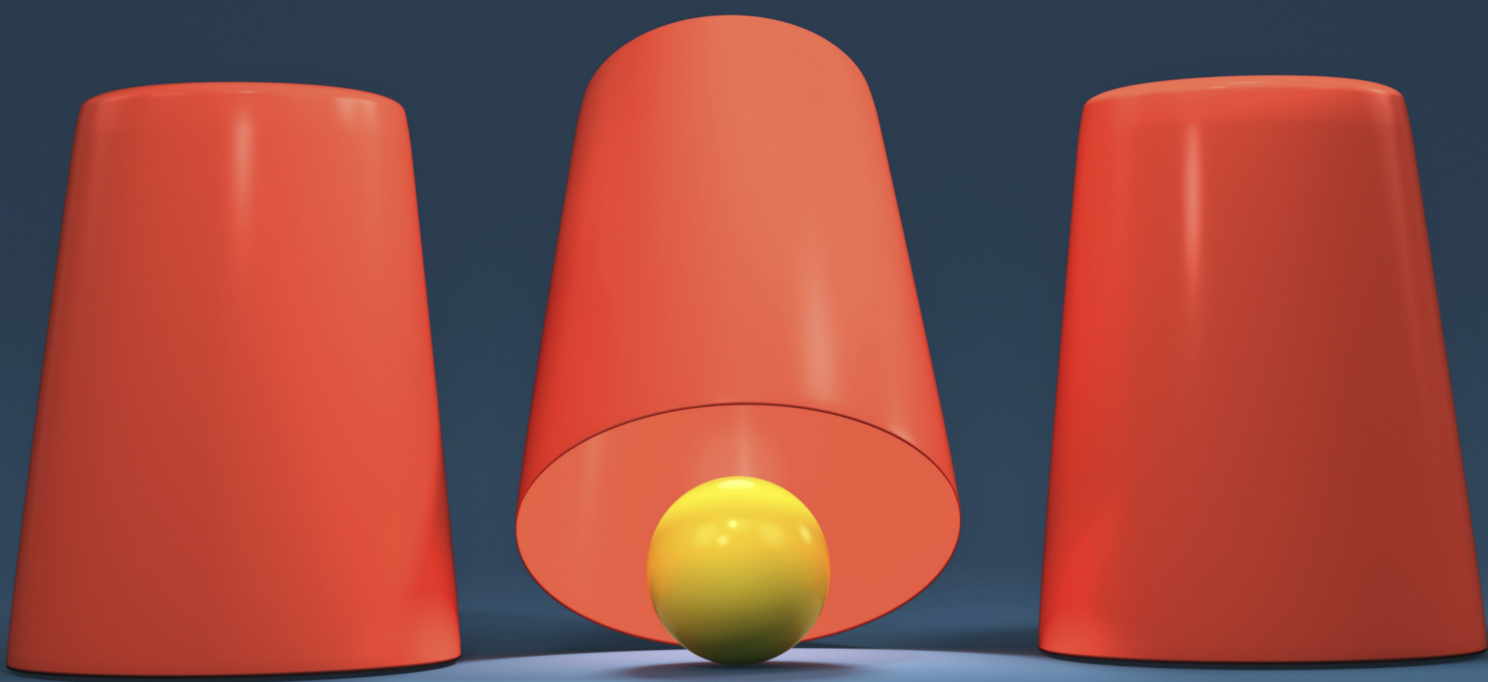

Table 1. Source of relief loads

	Relief loads from Unit A	Relief loads from Unit B	Relief loads from Unit C
Vapour fraction	1	1	1
Pressure (kPa)	149.1	149.1	149.1
Temperature (˚C)	277.9	226.5	378.8
Mass flow (tph)	20	5	61.6
MW	182.8	148.9	183.9
LHV (kJ/kg)	34 200	40 550	34 120

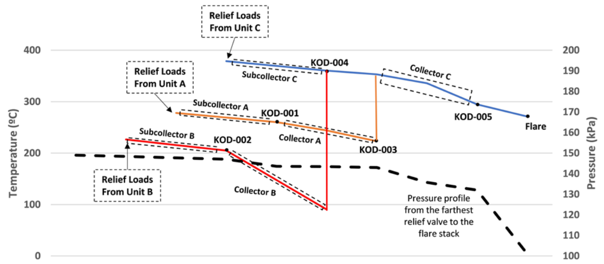

Figure 1. Temperature and pressure profile along the flare network system during a constant relief flow.

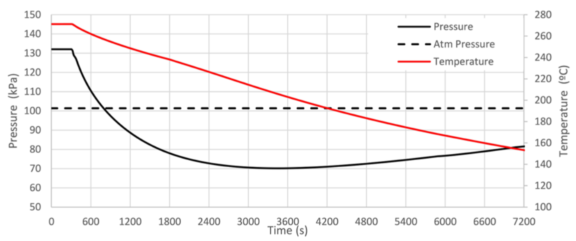

Figure 2. Temperature and pressure during the cool-down phase after the relief of hot gas.

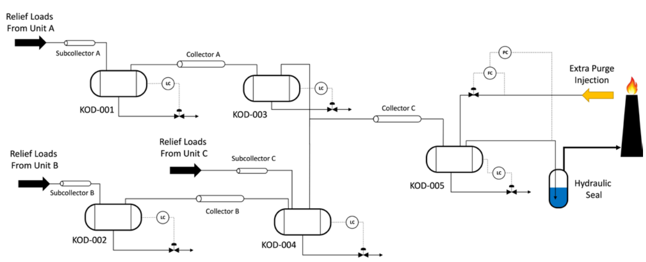

Figure 3. Flare network scheme and pressure and purge cascade controller.

For the case of air infiltration due to contraction during the cool-down after the release of a hot gas, J.S. Zink et al patented a control system in 1975 for the purge gas to flare.[1] In such a system, the thermodynamic state of the relief waste is measured, and the control system injects additional purge gas to compensate for the contraction during the cool-down episode. In this article, dynamic simulation is applied to calculate the required purge gas to avoid air infiltration using a control scheme inspired by the aforementioned patent. The study uses dynamic simulation to determine the controller parameters, the optimal location of the injection point of extra purge gas, and its required amount.

Hot gas flare relief scenario

The hot gas released to the flare network is coming from different plant unit resources. The dynamic simulation model takes into consideration the following assumptions:

- Constant flow across the different pressure safety valves (PSVs) during the relief. Pressure, temperature, mass flow rate, molecular weight (MW) and lower heating value (LHV) of the different sources are indicated in Table 1.
- The piping (stainless steel) is not isolated against ambient conditions (ambient temperature equal to 4˚C and wind velocity equal to 9 m/s).
- The pressure at the bottom of the stack is 131 kPa and the hydraulic seal has a pressure drop of 30 kPa.

Therefore, during the relief situation, fluid temperature decreases when travelling from the processing units to the flare stack. Figure 1 shows the temperature and pressure profile from the furthest relief valve to the flare stack.

When the source of pressurisation of the units is under control, the pressure relief valves (PRVs) close and relief loads from the units stop. The hold-up accumulated within the header cools down due to the heat losses to the surroundings. Such a temperature decrease contracts the gas volume and the pressure inside the flare system also decreases. The reduction in pressure could be accelerated if condensable gases are present. Figure 2 shows the pressure and temperature upstream of the flare stack, during the cool-down episode, if no additional purge gas is introduced.

Air ingress prevention

Once the header is under atmospheric pressure, there is the risk of air penetration into the system, as can be seen in Figure 2.

In order to prevent air ingress due to the contraction of the gas, a pressure sensor could be located upstream of the hydraulic seal. This sensor actuates as a master controller for a cascaded flow controller, which introduces extra purge gas. Figure 3 shows a scheme of the flare network and the pressure cascade controller, which actuates on the flow of extra purge gas into the flare system. In this case, the location of the extra gas injection is placed directly in KOD-005 (Option I).

The benefits of such a controller include keeping the flare pressure over the atmospheric pressure, while the extra purge gas flow added is minimised. The simulation model is used to calculate the amount of extra purge gas required under the following additional assumptions:

- The gas purge composition used in the study is the one reported in Table 2.

- The proportional and integral parameters of the slave and master controllers are indicated in Table 3.
- The set point for the master controller is 131 kPa. This value has been calculated to keep the minimum pressure at the bottoms of the stack, which guarantees the purge gas flow to the burner.

Figure 4 shows the extra purge gas required to keep the pressure upstream of the flare stack at the set point value.

The scenario has been carried out assuming that the relief loads are constant for 5 minutes. At this point, the relief loads stop, and the simulated scenario starts. It can be observed that 1.5 minutes after the PSV closes, the pressure upstream of the flare stack (location of the pressure sensor) reaches the minimum safe pressure for the system (set point of the pressure controller). At this moment, the controller begins to act, introducing the extra purge gas to the flare network to ensure the pressure is kept above the safe system pressure (131 kPa). It can be observed that the extra purge flow introduced by the controller increases quickly during the first minutes. This is due to the cool-down velocity of the system, which is higher at the beginning of the scenario. The maximum peak of extra purge is around 2.4 tph at 5 minutes after the scenario starts. Once the system is stabilised, the extra purge flow necessary to keep the pressure controlled is reduced continuously because of less gas contraction due to the decrease of the cool-down of the system.

The total extra gas added during the first 30 minutes is around 364 kg, calculated as the integral of the mass flow rate curve.

Where to locate the injection of purge gas

One of the benefits of having a simulation model available is that it opens the option for analysing different design alternatives; in this case, the location for injecting the extra purge gas. In the previous simulation case, the injection location was directly at the KOD-005, the one closest to the flare stack. The following simulations have considered two different possible locations: Option II, which is upstream of header C (at the KOD-004); and Option III, which is upstream of header A (at the KOD-001). Both alternatives are marked with yellow arrows in Figure 5.

Figure 6 shows the extra purge gas required to keep the pressure upstream of the flare stack at the set point in both injection location alternatives.

As can be observed, the curve shape of the pressure profiles upstream of the flare stack are similar to the previous one. The main difference is related to the maximum peak of extra purge flowrate required to recover the desired pressure setpoint during the first minutes after the scenario starts. The results show a maximum peak of 2.41 tph, 2.73 tph, and 2.88 tph, when the location of the extra purge injection is located in KOD-005 (Option I), KOD-004 (Option II) or KOD-001 (Option III), respectively. In addition, the total extra gas added during the first 30 minutes is around 364 kg, 364 kg, and 433 kg for Options I, II and III respectively (calculated as the integral of the mass flow rate curve).

From Figure 6, it can be observed that the larger the holdup volume between the location of the extra purge

Table 2. Gas purge composition

Natural gas	Composition (mol%)
H_2	0.02
O_2	0.01
N_2	0.5
CO_2	0.3
Methane	94.7
Ethane	4.2
Propane	0.2
i-Butane	0.02
n-Butane	0.02
i-Pentane	0.01
n-Pentane	0.01
Hexanes plus	0.01

Table 3. Proportional (Kc) and integral (Ti) parameters for the controller

	Pressure controller (master)	Flow controller (slave)
Kc	2	0.5
Ti (s)	120	15
Td (s)	–	–

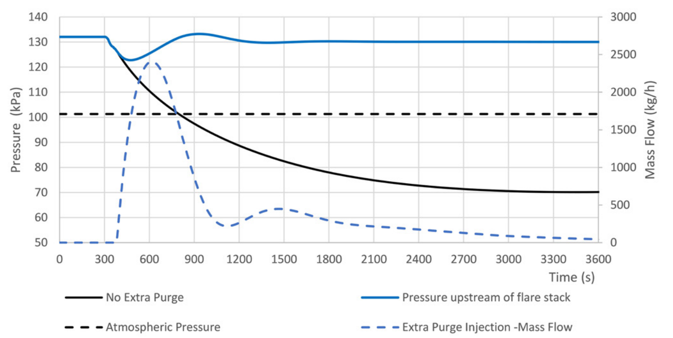

Figure 4. Effect on pressure of the addition of extra purge gas.

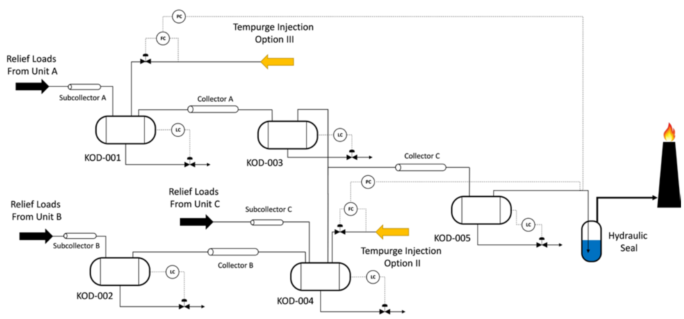

Figure 5. Alternative locations for the injection of the extra gas.

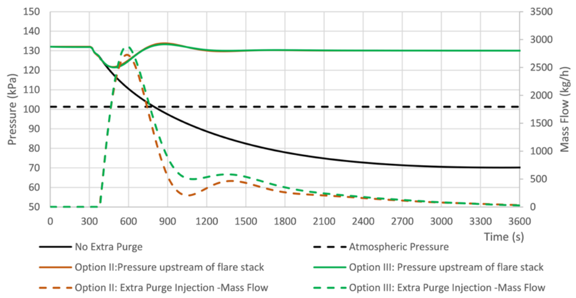

Figure 6. Effect on pressure upstream of flare stack: alternative locations for the injection of the extra gas.

gas injection and the location of the pressure sensor is, the higher the peak flow rate.

The header volume has a shock-absorbing effect in relation to the impact of the injected extra gas in the controlled pressure. As a consequence, such an effect increases the amount of required extra purge gas and the pressure controller also shows a more abrupt behaviour.

From the point of view of the total amount of purge gas injected, the location of the gas injection has a significant impact. The results show that the total purge gas addition in Option I and II are very similar. The larger volume in the network is produced in header C and therefore, the larger gas contraction during the cool-down after the release of a hot gas. When the extra purge gas is injected in a piece of equipment connected to this header, the total amount of gas purge to keep the pressure in the desired values is very similar. However, the total extra purge gas consumption is higher for Option III. If the location of the purge gas injection is in other headers or sub-headers upstream of the equipment connected with the header C, the results show higher consumption of purge gas. The main difference is due to the quick cool-down that is generated in header A because the extra purge gas is colder, in comparison with the header temperature. This effect produces a higher purge gas consumption than Options I and II.

Therefore, the results show that the distance from the gas injection to the pressure sensor, and the number of headers and sub-headers between them, produces higher consumption of purge gas.

Conclusions

The amount of extra purge gas required to avoid air infiltration through the stack after a hot gas release depends on the relief gas and gas purge compositions, as well as the size and design of the flare header. Dynamic simulation has been shown as a helpful tool to estimate this amount and to determine an optimal location and configuration of the controller that keeps the system pressure above atmospheric values.

Reference

1. ZINK, J.S., REED, R.D, and SCHWARTZ, R.E., 'Temperature-Pressure Activated Purge Gas Flow System for Flares', U.S. Pat. 3,901,643, (26 August 1975).