OPTIMIZATION OF AN ELEVATED STAGED FLARE FOR A LARGE REFINERY OR A GAS PLANT

In recent years most of the refineries, petrochemicals & gas processing plants are seen to be of larger capacities.

Flare system for such plant are required to operate at two extreme flow conditions, one very high flow rates (in excess of 1000 tons per hour or the maximum design capacity rate) as well as at minimum flow conditions (few 100 kg per hour). Further considering environmental issues the flares are expected to perform smokeless operation at certain specified capacities. All these at optimum operating cost pose a difficult challenge for flare design & how an optimum solution can be arrived:

- Optimum in terms of efficient operation.
- Optimum in terms of operating cost.
- Optimum in terms of smokeless operation control
- Optimum in terms of longer equipment life
- Lower CO2 emission. Carbon credits.

The most traditional configuration for a flare system is to provide a single elevated pipe flare. Flare stack riser & flare tip are generally sized based on the allowable pressure drop which is usually very low & these results in large diameters for the stack riser & the flare tip.

At normal plant operating conditions the relief gases to flare are very low (few leakages only) resulting in to very low tip exit velocities & together under the wind influence at high elevation the gases start burning much lower in to the flare tip body rather than at the exit (Burn back). Continuous operation as above results in to thermal degradation of the flare tip material calling for early replacement. Using high Nickel raw material for flare tip body does provide some extended life but thermal fatigue cannot be completely ruled out if the operation of the flare is continuously seeing such very low flow rates causing burn back.

To counter the burn back sufficiently high tip exit velocity is needed (1 to 3 FPS) to maintain a healthy flare tip life. If actual flow rates for the flare are low than an additional purge gas is required to be injected to avoid burn back. On large diameter flares this is a substantial quantity & can cause a big hole in the pocket.

Further flares are specified to operate smokeless at certain flows which again are much lower as compared to the maximum design case.

- To prevent smoke formation, sufficient energy is necessary to create turbulence and improve mixing of the flare gas & entrained atmospheric air. However due to large size of the flare tip (diameter sized based on flare maximum relief case & allowable pressure drop) steam assisted flare tip could generate fuel rich zones where smoke occurs because of bad steam/air penetration inside the core of the flaring gas, leading to reduced effectiveness of the smokeless process.

- Air assisted flare tips is an option could be employed but when analyzed got rejected due to the huge quantity of combustion air requirement, leading to tough mechanical design & installation issues for gas & air pipes. Also air assisted flare would call for flare tip size (abnormally large) which is not referenced in operation, and a weight that could be dangerous if supported by a single stack. Not a viable solution.

The unusual pipe flare tip diameter, combined with the wide range of flaring rates, presents problems with the flame stability, burn back (internal burning within the tip shell) and flashback
(which occurs in a flammable mixture of air and gas when the local velocity of the combustible mixture becomes less than the flame velocity causing the flame to travel back towards the stack). In the standby case of only purge gas flaring, the purge gas consumption required sustaining a uniform flame and to avoid burn back & flashback is very high, which dramatically increase the operating cost as well as the carbon dioxide emissions.

- The energy to promote uniform air distribution throughout the flame may also be present in the gas in the form of pressure (High pressure Sonic Flare tip). However, for a single flare, this gas pressure would only be available at high flow rates, not at smokeless rates. Moreover if a sonic flare tip is designed, it cannot be equipped with necessary ancillaries such as steam assemblies for smokeless flaring at low flows due to vibrations occurring as a result of a too high gas exit velocity at maximum design flow.

- Open multi-burner ground flares offer many advantages particularly where strict environmental issues have to be considered. They consist of a large number of small staged burners installed at ground level in a very large flaring areas surrounded by protective fencing. Staging allows operation of each group of burners (stage) to be at set pressures where smoking will not occur. The split of flow rate in many burners enables high smokeless capacities along with reduced visual impact. Multi-burner flare systems utilize the available pressure energy of the gas to entrain additional air, which improves combustion efficiency as flare gas is better mixed with the air. A smokeless flame is obtained only through the high exit gas velocities, and for low flaring rates this is achieved by providing a large number of stages that require higher pressure at the inlet manifold to manage the operation of the staging valves. This solution was not feasible due to low available pressure and also the presence of acid gases also flared inside the same available sterile area, would result in emissions levels not acceptable to prevailing site regulations. Although the exit velocity of gases is quite high, the source elevation is near to grade and this could result in exceeding pollution limits in the presence of sour products.

- Enclosed chamber ground flares enable flaring without the flame being visible from outside the chamber. However the capacity of this flare is limited and cannot match with the capacity of the elevated flare.

- Burn pits were not considered because of stringent pollution limits.

**Staged Elevated Flares**

In order to solve all the technical difficulties and problems listed above; safety, process, operability, environmental, mechanical and fabrication investigation studies have been performed with most modern software and technologies. An elevated staged flare system was considered the best flare configuration.

Under normal plant operation the flare gas quantity being very low the flare gas is routed on the primary stage & flared, the water cover for the primary stage water seal being lower in height as compared to second stage water seal. During the first stage operation the back pressure from the primary (small) flare constantly tries to overcome the water cover of the second stage water seal which has larger water cover in comparison to the first stage. As the flare gas quantity increases above certain range/value the resulting higher back pressure from the primary stage flare overcomes the water cover of the secondary water seal & the flare gas is able to break the seal & the gas flow is established to the second flare. Once the flaring rate reduces the water immediately seals the second stage flare & in such way the second stage becomes dormant or standby.

Segregating the total stream into different flares allows a reduction in the diameter of the each flare tip. The reduced diameter of the flare tips ensures proper smokeless operation, as the flare
tip of the first stage can be designed for the maximum continuous operational flaring rate, and can be fitted with steam facilities to ensure a smokeless flame. The second stage flare tip which comes in to operation only during some major upsets in the upstream plant need not be designed for smokeless operation which give great savings & very efficient smokeless operations. Most importantly the normal low flaring quantities being diverted to smaller diameter flare tip of 1st stage, there is no problem of burn back since the exit velocity is safe for this smaller diameter. Further the purge gas requirement is very low as compared to single large diameter since there is no question of burn back. The purge flow required are only that required by dynamic/gas seals to avoid air entry in to the system from the top, this are in the range of 0.01 FPS much saving as compared to 1 to 3 FPS required to counter the burn back.

Conclusion

The analysis to identify the best configuration for a flare to adequately manage the largest flaring rate from a single header confirms that a single large flare is neither practical nor convenient, as it presents technical difficulties to secure the stability of the flame, the safety of the system and to guarantee the smokeless requirements. The proposed alternative, consisting of an elevated staged flare, has shown the advantages of:

- Limiting the size of the flare tips, which do not introduce flame stability issue?
- Design 1st stage for smokeless operation gives optimum smokeless performance.
- Guaranteeing a longer lifecycle for the flare tips, as they are not prone to burn back.
- Do away with additional purge requirement to avoid burn back, a great saving.

References

2. API RP 537, Flare Details for General Refinery and Petrochemical Service.
3. DEP SHELL 80.45.10.10, Pressure relief, emergency, depressuring, flare and vent systems.