Design of Gas-Liquid Separator for Complete Degasing

Tamagna Uki, Subhash T. Sarda, and Thomas Mathew

***Abstract*—Entrapment of Gas in Liquid flow stream can cause substantial problems in process plant operations. Release of gas slug can possibly lead to unwanted release of Chemicals into the environment. Hence, design of Gas-Liquid Separator (GLS) becomes very important in a process plant. The GLS should be properly sized to discretely separate gas and liquid phases. The paper discusses a Case study of a problem faced by the authors in one of their operating plants and the remedy for it. It outlines the sizing procedure used for design of GLS for industrial application and its impact on the process.**

***Index Terms*—Gas-liquid separator, design, case study.**

I. Introduction

One of our Process Plants had gone through several stages of modifications for capacity enhancement and cost reduction. The plant was commissioned in 1980s and is currently operating at 190% of its initial designed capacity. Duringimplementation of one such scheme we faced a problem of entrapment of inert gas in a liquid stream that prevented the new scheme to perform as designed. Investigations revealed limitation in one of the old equipment. Subsequent sections discuss the problem, solution implemented and benefits realized.

II. Problem Root Cause Identification

The affected unit (Fig. 1) has a Reactor whose Vent Gas goes to Heat Recovery Unit (HRU). Part of the liquid condensate from HRU is circulated back to the reactor; the rest is processed in a distillation column. Uncondensed inert gases are sent to a separate Gas Handling Unit (GHU). Dynamic Simulationofthe system predicted 12 % entrapment of inert gases inthe liquid leg due to limitation in Vent Gas Condenser Separator (VGCS). It disturbed the column and Low Boiling Chemical Processing (LBCP) unit. Replacing VGCS was not economically feasible. Hence, it was decided to install a GLS in the affected stream to de-gas the liquid.

III. Designing of the Gas-Liquid Separator

The main challenge in the design of GLS was that, the available pressure drop between the gas outlet of the GLS and the operating pressure of the gas-handling system was only 0.1 Bar. However, the liquid outlet of the GLS and the downstream liquid processing system had adequate available pressure drop (15 Bar). The GLS design is divided into three sections;

- Design of the main vessel and Gas outlet nozzle.
- Design of the feed inlet deflector
- Design of the Liquid outlet nozzle and the Vortex Breaker.

A. Design of the Main Vessel and Gas Outlet Nozzle

The sizing main vessel of the GLS is based on the design procedure stated in *GPSA Data book* [1]. The vessel is designed with an assumption that, the drum designed will not allow liquid droplets of size greater than 100 microns (D_p) and spherical in shape, to entrain into the vapor space of the vessel.

The gas space of the GLS is designed first. This determines the diameter of the vessel and the height of the gas space to obtain optimum separation of the gas and liquid. Liquid droplets in a vessel separate under the influence of gravity, which has to be more than the drag force acting on the droplet. The coefficient of drag (C') is determined using the following equation:

$$C'(N_{Re})^2 = \frac{1.31X10^7 \rho_g D_p (\rho_L - \rho_g)}{\mu^2} \quad (1)$$

$$\rho_L = Density\ of\ liquid$$

$$\rho_g = Density\ of\ gas$$

$$\mu = Viscosity\ of\ gas$$

Corresponding Reynold's Number (N_{Re}) for the system can be obtained from *GPSA Data book* [1] Fig. 7-3. Since N_{Re} for this case lies between 2 and 500, Terminal settling velocity (V_t) is determined using Intermediate Law equation:

$$V_t = \frac{2.94 g^{0.71} D_p^{1.14} (\rho_L - \rho_g)^{0.71}}{\rho_g^{0.29} \mu^{0.43}} \quad (2)$$

$$g = Acceleration\ due\ to\ gravity$$

The velocity of the gas (V_g) separating in the GLS should be less than V_t.For a conservative approach,V_g is kept33% less than V_t i.e.

$$V_g = \frac{2}{3} V_t \quad (3)$$

This velocity along with the volumetric flow rate of the gas (Q_g) can be used to determine the diameter of the vessel. (D_v) by using the following equation:

$$D_v = \sqrt{\frac{4Q_g}{\pi V_g}} \quad (4)$$

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The authors are with Reliance Industries Limited, Mumbai, India (e-mai: amagna.ukil@ril.com)

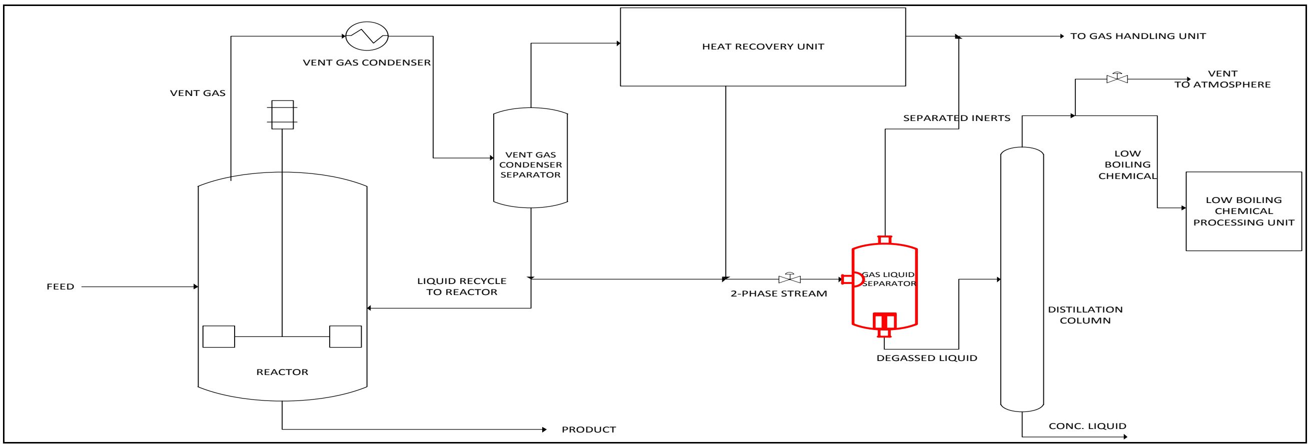

Fig. 1. Affected unit of the plant and location of GLS Subsequent sections outline the steps followed to size the GLS and its internals.

Height of vapor Space(L) can be determined by assuming that the time taken by the gas to travel from the feed inlet to the gas outlet nozzle is same as the time taken by the liquid droplets to settle from the gas phase to liquid.L can be determined by:

$$L = \frac{4Q_g}{\pi V_g D_v} \tag{5}$$

Velocity of the outgoing gas (V_{go}) is kept at 0.3 m/s (minimum allowable velocity for gas pipelines) considering minimum pressure drop across the gas outlet nozzle. The diameter of the outlet nozzle (D_o) can be determined by the following equation:

$$D_o = \sqrt{\frac{4Q_g}{\pi V_{go}}} \tag{6}$$

Simulations show a pressure drop of only 0.004 bar across the gas outlet nozzle.

Sizing the liquid space of the GLS, involves assumption of residence time (t_r) of the liquid in the vessel. As per *GPSA* [1], the $t_r$for a vessel for Gas-Condensate separation should be within 120 to 240 seconds. We consider a $t_r$of 120 seconds. The height of vessel (L_l) required for holding the liquid for specified $t_r$can be determined by the following equation:

$$L_l = \frac{4Q_l}{\pi D_V^2} \times t_r \tag{7}$$

$$Q_l = Volumetric\ Flow\ of\ liquid$$

In addition to L_l, some extra height must be provided to the GLS forlevel controllability. GPSA [1] states that:

- The distance between center line of the feed inlet nozzle and the maximum allowable liquid level should be twice the diameter of the feed nozzle.
- The distance between lowest allowable level of the liquid and the Bottom Tan Line of the vessel must be apart by a distance of 0.17 times the diameter of the GLS.

Following the above steps, the GLS that was designed had diameter (D_v) of 1300 mm and Tan-to-Tan height of 2000 mm. 2:1 ellipsoidal Dish-ends are provided at the bottom and top of the vessel.

B. Design of the Feed Inlet Deflector

The importance of inlet device with respect to separation performance has been identified recently, through the use of Computational Fluid Dynamics (CFD) modeling. Main functions of inlet device are:

- Reduce the momentum of the inlet stream and enhance flow distribution of the gas and liquid.
- Efficient separation of the bulk liquid phase from the gas.
- Prevent droplet shattering and re-entrainment of bulk liquid phase.

GPSA *Data book* [1] discusses various types of inlet devices. In this case, we have selected Half-Pipe inlet device (after evaluating various options, viz. Cyclonic feed entry, diverter plate etc. on the basis of aforesaid parameters) to distribute the flow across the circumference of the vessel. Sizing of the inlet device is based on the convention that; diameter of inlet device (D_d) is twice the diameter of inlet nozzle (D_i).

$$D_d = 2 \times D_i \tag{8}$$

CFD model of the Half-Pipe inlet (Figure-2) for the GLS shows the flow pattern inside the vessel

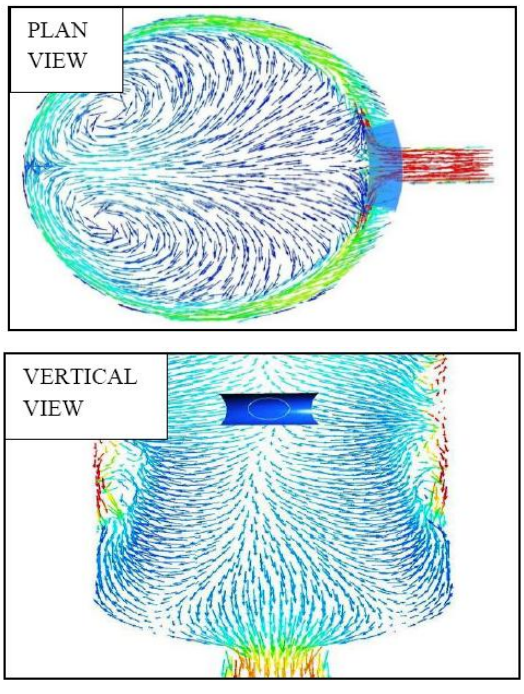

Fig. 2. Influence of inlet distributor on Flow Pattern of feed inside the GLS

C. Design of the Liquid Outlet Nozzle and Vortex-Breaker

The liquid outlet for this GLS is designed with the objective to prevent any entrainment of the incoming gas with the liquid. In-order to ensure that no gas escape with the liquid phase, the following measures were taken;

1) Sizing the liquid outlet nozzle

Ukil et al. [2] states that diameter of the liquid outlet(*D"*) for Gas-Liquid Separators should be sized using the Froude's Number (N_{Fr}) analysis. This helps in providing Self-Venting capability to the outlet Nozzle. Self-Venting nature of the nozzle enables it to automatically vent any entrained gas from the liquid stream. N_{Fr} for the liquid outlet can be calculated by the following equation:

$$N_{Fr} = \frac{V_o}{\sqrt{gD"}} \tag{9}$$

$$V_o = Velocity\ of\ Liquid\ across\ the\ outlet\ nozzle$$

Estimate of V_o are mentioned in the article published by *Ukil et al.* [2]. *Simpson et al.* [3] State that nozzle with N_{Fr} <0.31 is inherently capable of self-venting any entrapped gas.

Ukil et al. [2]state that if the height of the liquid inside the vessel (*h*) is less than a conservative estimate, then there are chances that the gas will get entrapped into the liquid that leaves the vessel, due to the swirling flow patterns of Gas and liquid inside the vessel. *h* can be determined by using Harleman's Equation, which is;

$$\frac{V_0}{\sqrt{gD"}} = 3.24 \times \left[\frac{h}{D"}\right] \tag{10}$$

h can be considered as the lowest allowable liquid level in the GLS.

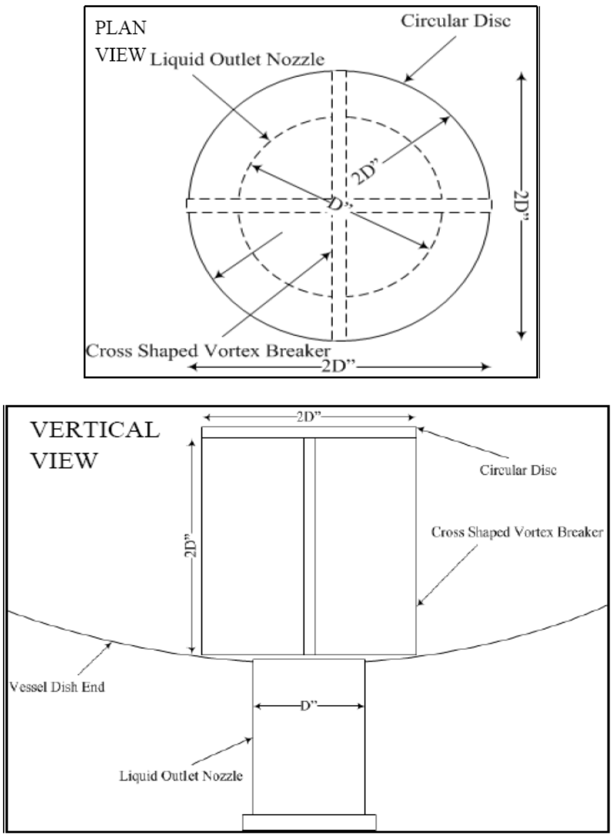

Fig. 3. Schematic of the Vortex-breaker installed in the GLS

2) Sizing the vortex-breaker

When the flow inside the vessel is rotational, there are chances that the liquid phase inside the vessel can develop a Vortex flow pattern similar to a whirlpool. This can lead to sucking of the gas in to the liquid phase. A properly sized Vortex-Breaker can prevent such a phenomenon.

Borghei et al. [4] state that Vortex Breaker should be a cross (+) formed by welding two metallic plates. The dimension of the cross should be typically twice the diameter of the outlet nozzle. This provides best performance in terms of preventing vortex formation. But, the CFD simulations (Fig. 2) show that the Half-Pipe liquid inlet distributor used in the vessel has high potential to induce vortices in the liquid space of GLS. Hence, to further reduce the chance of vortex formation, a circular disc of diameter twice that of the liquid outlet nozzle is welded on the top of the crossed plates of the Vortex Breaker (Fig. 3).

The figure below represents the schematic of the designed GLS with the notations used in this paper

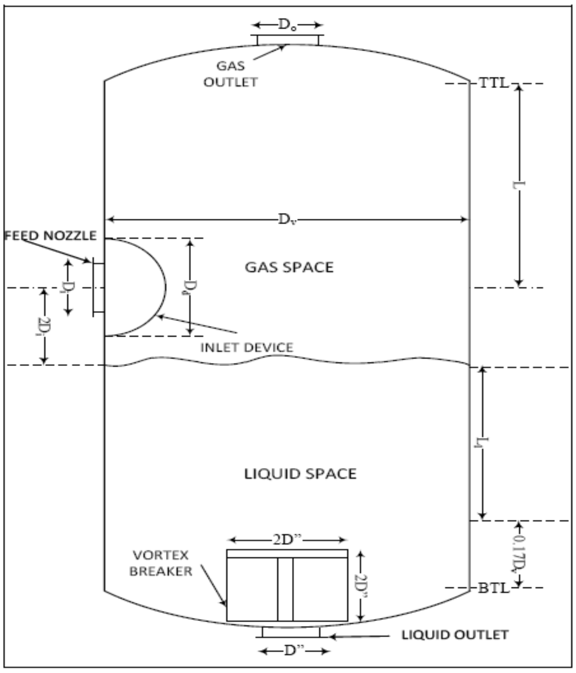

Fig. 4. GLS as designed

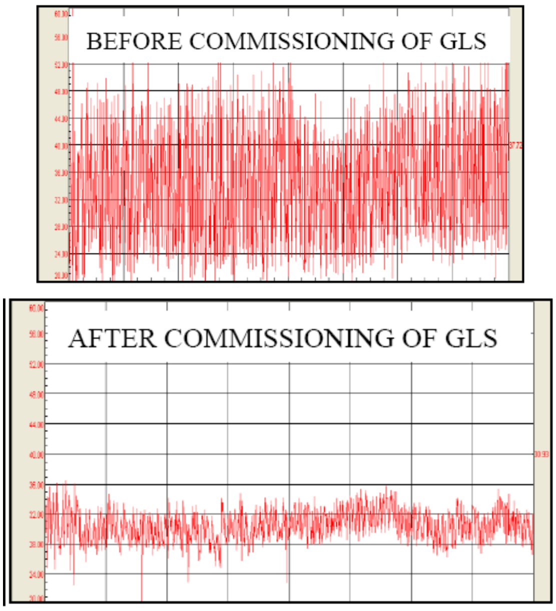

Fig. 5. Trend of Liquid Feed to the Distillation Column

IV. Conclusion

The GLS aswas commissioned in our manufacturing plant in June, 2012. Benefits experienced since then are;

- Decrease in flow fluctuations (Fig – 5) in the feed to Distillation Column at the downstream of GLS.
- Stoppage of Volatile Organic Compound(VOC) emission to atmosphere from distillation column top vent.
- Benefit realized amounts to 0.54 Million USD by stabilizing the downstream LBCP unit.
- Created avenue for energy saving of0.7 Million USD by reducing steam usage in distillation column.

References

[1] GPSA *Engineering Data Book*, 12th Edition, Chapter 7, pp 1-18

[2] T. Ukil and M. Thomas, “Reduce Gas entrainment in Liquid lines,” *Chemical Engineering*, June-2011.pp 42-44

[3] L. L. Simpson, *Chemical Engineering*, 1960, pp 191

[4] S. M. Borghei, “Partial Reduction of Vortex in vertical intake pipe,” *Scientiairanica*, vol. 17, issue 2.