

## MASS TRANSFER EQUIPMENT DESIGN CONSIDERATIONS FOR CRYOGENIC ABSORBERS, DEMETHANIZERS AND DEETHANIZERS

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### Abstract:

Cryogenic fractionators for natural gas liquids recovery plants have special design considerations for the mass transfer equipment owing to the fluid physical properties for fractionators that operate at high-pressure near the critical point. Over the years, the industry has equipped these NGL recovery units with trays and packings for tower revamps and new vessels. This paper considers the selection of packing, towers internals and trays for NGL recovery units. The mass transfer efficiency and hydraulic flow parameter of packing is shown for high-pressure distillation tests and plant operating data. The design of feed inlet devices and draws for the unusual fluid physical properties for these units is considered. The paper provides a comparison of equipment design strategies to cope with process issues such as sub-cooled feeds and hydrates.

**Keywords:** gas, recovery, cryogenic, absorber, demethanizer

### 1. Introduction

Most natural gas liquids (NGL) are produced from pipeline gas that contains more than 4 mole% propane and 4 mole% butanes. Some units in North America are designed to recover ethane in the NGL bottoms residue. Units located outside of North America are typically designed to reject ethane from the bottoms residue, so that the overhead sales gas contains mostly methane and ethane. The decision to operate NGL plants in ethane recovery or ethane rejection mode is dependent on the market demand for ethane in the residue, and the calorific value of the sales gas. Every modern NGL recovery process requires at least one distillation or absorption column to perform fractionation of light hydrocarbons, and at least one cooling system and one separator in the process. Modern NGL recovery plants have to meet demanding product specifications while maintaining energy efficiency.

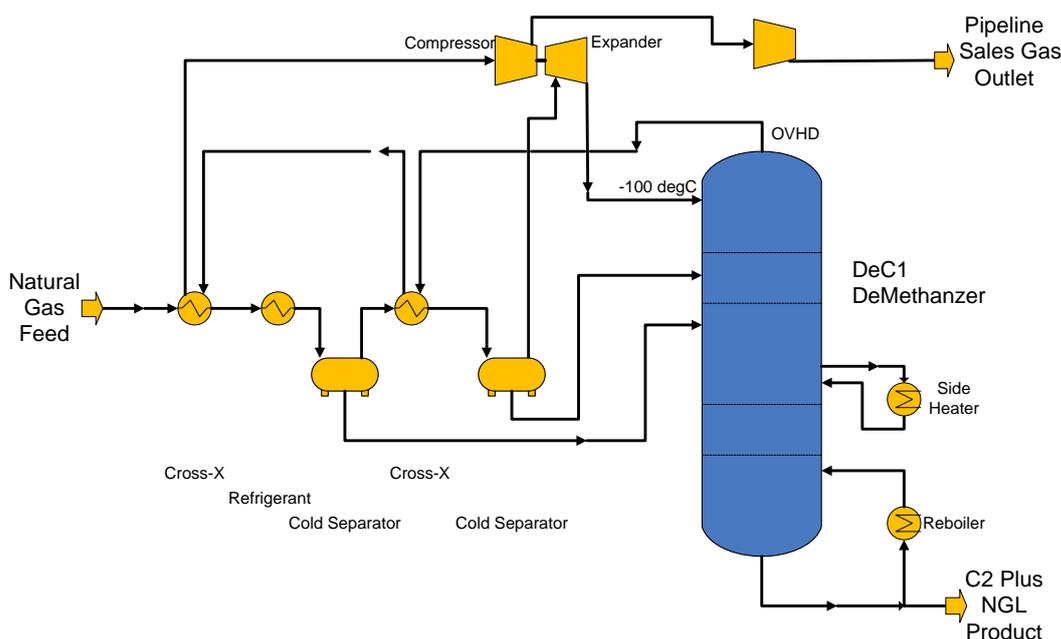


Figure 1. Process Flow Diagram for Simple GSP Plant

### 1.1 Gas Sub-cooled Process (GSP) Turbo-Expander Plants

Turbo-expander plants can typically achieve ethane recoveries of 75% to 85%, and some plants with optimized design reach up to 95% ethane recovery. The first turbo-expander plant was introduced by Ortloff Engineers, and these plants are the most frequently utilized in the NGL recovery industry. The Demethanizer features a large diameter top section for processing the expander gas, with a smaller diameter stripping section equipped with one or more side reboilers. Changing the heat duty of the side reboilers can alter the recovery or rejection of ethane from the bottoms product from the Demethanizer.

Over the years, there have been several process developments that have improved upon the energy integration of GSP plants. These include various process arrangement of introducing sub-cooled and secondary reflux streams into the fractionation unit. Modern NGL and LNG recovery facilities increasingly utilize more advanced technology to more efficiently utilize energy and minimize energy consumption. Figure 1 shows the process flow diagram for a simple GSP plant.

### 1.2 NGL Facilities

Modern NGL recovery facilities increasingly utilize advanced technology to minimize energy consumption. Some factors that can influence the operating conditions for Demethanizers are:

- The Demethanizer mass transfer column is one component in the overall GSP plant. The plant designers optimize the energy and material balance over all components in the GSP plant to achieve the recovery objective. The energy and material balance over the heat cross exchangers, flash separators and the turbo-expander can have considerable influence in the operating conditions of the Demethanizer and the NGL recovery achieved by the plant.
- The inlet feed composition to regional GSP plants can vary from location to location. The inlet feed composition of pipelines that feed some GSP plants fed by major pipelines can vary from week to week. In the USA, some GSP plants are designed based on multiple cases that are richer or leaner in NGL residue components.

NGL plant Demethanizers are specifically designed to recover residue from natural gas pipelines. Demethanizers and Deethanizers are also designed to recover residue from refinery or syn gas plants.

- Demethanizers that service natural gas pipe lines typically include N<sub>2</sub>, CO<sub>2</sub> and hydrocarbons from methane through pentanes.
- Demethanizers that service refinery or synthetic gas plants can include hydrocarbons from methane up to decane, aromatic components, cyclic hydrocarbons (cyclopentane and cyclohexane) and olefins (ethylene, propylene and butylenes).
- Additionally there are NGL recovery plants equipped with Deethanizers that operate under cryogenic conditions to recover propane plus residue. They are similar to Demethanizers and have different process flow diagrams, some using side heaters and some utilizing cold separators. NGL plants optimized to recover propane have Deethanizers to recover ethane overhead, and propane plus in the bottoms. A number of plants have a Cryogenic Absorber processing the Deethanizer overhead gas.
- There are NGL plants designed to achieve an overhead gas that meets a specific Wobble number, if the overhead gas is used for a high performance burner.

### 1.3 Side Heaters

Every Demethanizer and cryogenic Deethanizer is equipped with a bottom reboiler. The overall energy efficiency of these units can be improved with the use of one or more side heaters in the stripping section. A side heater utilizes energy from another process stream to boil the light-ends to improve the overall energy efficiency of an integrated NGL processing facility. Therefore, modern GSP Demethanizers are typically equipped with at least one side heater, while two side heaters are used in advanced modern facilities. The addition of side heaters has a small penalty of adding vessel height for a draw-off chimney tray and equipment to handle the mixed-phase side heater return. Most Demethanizers are designed to return mixed-phase fluid from the side heaters on a tray located below the draw-off tray. This simplifies design for the tower internals. Typical ethane recovery mode of operation uses all side heaters, while the ethane rejection mode may shutdown one or more side heaters.

The use of a side heater has the effect of increasing the vapor load in the stripping section above the side heater, and slightly reducing the liquid load in the stripping section below the side heater. This can allow the designer to reduce the bed height by using a smaller size packing or reduced the diameter of the bottom stripping section. In general, no side heater contributes more than 50% of the overall heat duty. Side heaters that contribute less than 15% of the overall heat duty have little effect on the overall separation efficiency, and are typically not considered.

The Demethanizer middle section has a total draw chimney tray that directs liquid to the side heater. The heated fluid is a mixed-phase feed that is returned below the total draw chimney tray. This mixed-phase can be introduced above a gallery tray through a feed baffle. The gallery tray is designed to allow vapor to disengage and flow upwards, while liquid is directed to the deck of the orifice pan distributor located below. The typical side heater arrangement utilized in Demethanizers is shown in Figure 2 below.

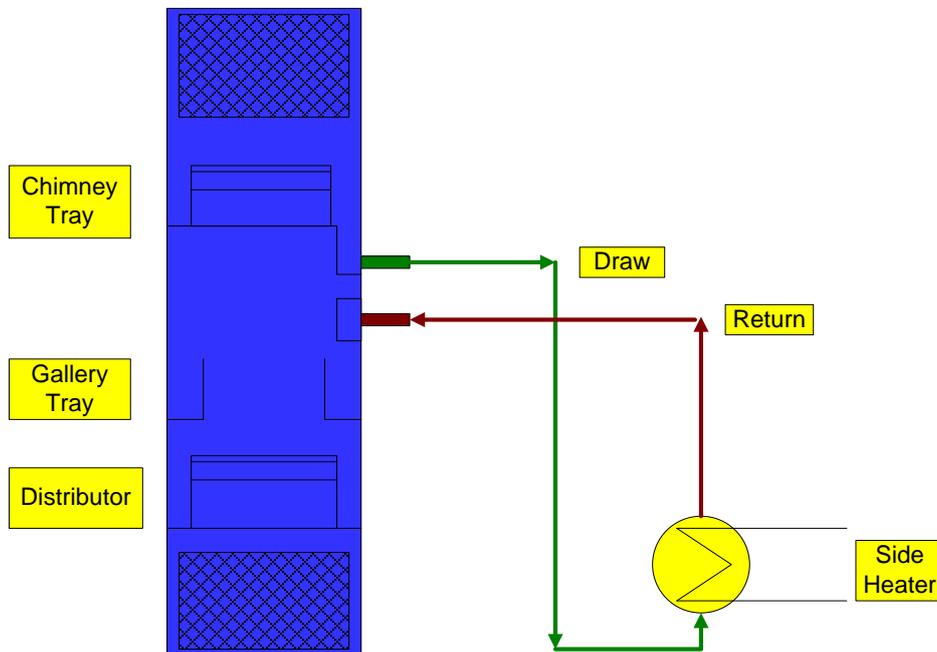


Figure 2. Typical Side Heater Arrangement

#### 1.4 Reflux Considerations

Some advanced turbo-expander plant processes perform sub-cooling of the reflux to improve ethane recovery in the residue and increasing thermodynamic energy efficiency of the plant. There are significant changes in the mass flow rates and physical properties in the top section of packing that should be considered in the packing hydraulic calculations if the reflux is sub-cooled. Typically, the packing height is increased by about one theoretical stage to account for the heat transfer associated with latent heat transfer and condensation associated with significant sub-cooled reflux. A small amount of sub-cooling can increase the liquid load in the top section of packing by 10% to 20% from theoretical stage one to theoretical stage two in order to liquefy some ethane from the gas. Large amounts of sub-cooling can nearly double the liquid load from between stages one and two. Some vapor is condensed on the outside surface of the liquid distributor for sub-cooled reflux. It is preferable to utilize a liquid distributor with discrete flow points.

#### 1.5 Demethanizer and Deethanizer Arrangements

Typical Demethanizers feature two vessel diameters, and few units have three vessel diameters. The purpose of the Demethanizer is to recover methane overhead, and recover propane and butanes in the bottoms. The high gas flow rate above the main feed requires a large diameter top section compared to the bottom stripping section. The top rectification section, also known as the expander section, is the largest diameter section of the vessel. A mixed-phase reflux is introduced to the top, contacted with the expander gas from the swage section. The reflux is typically 5% to 20% vapor by

volume, and about -100°C. The expander feed is typically greater than 90% vapor by volume, and has the highest feed flow rate introduced to the unit. Most turbo-expander plants feature a single mass transfer section of packing or trays in the top rectification section.

The bottom stripping section is smaller diameter compared to the top rectification section, owing to the high amount of methane in natural gas, and lower traffic of ethane, propane and butanes which become liquefied. There are two or more mass transfer sections divided by side reboilers, and a cold separator liquid secondary feed stream. A bottom reboiler provides most of the heat transfer duty. The feeds to these stripping sections are typically mixed-phase feeds. Chimney trays are required to collect liquid to drive side heaters and reboilers. Chimney trays or gallery trays are used to disengage vapor from liquid for the mixed-phase feeds.

## 2. Mass Transfer Equipment Considerations

Trays were applied in many cryogenic NGL recovery towers in the 1970's and 1980's. New vessels were usually equipped with valve trays. A number of units were later retrofitted with high-performance trays, like the VGPlus™ or Shell HiFi™ trays. In the mid-1980's, random and structured packing was utilized in the retrofit of some units equipped with trays, and for the design of small diameter units. The top section of a Demethanizer is characterized by high vapor load and low liquid load. In general, the vapor load decreases and liquid load increases in the bottom stripping sections from the middle to the bottom of the tower. Most DeC1 top sections and Cryogenic Absorbers operate with liquid loads of 12 - 30 m<sup>3</sup>/m<sup>2</sup>/hr. Stripping sections have liquid loads that usually exceed 48 m<sup>3</sup>/m<sup>2</sup>/hr.

### 2.1 Considerations for Trays

There are several benefits for the application of trays in NGL recovery towers:

- Cost of standard trays is usually lower compared to the internals of a packed vessel, especially in mid-size to large diameter vessels.
- Trays can more easily accommodate mixed-phase feeds and draws.
- Trays can be easily designed for high liquid loads encountered in the stripping section.

There are some important design considerations for trays in NGL recovery towers:

- The physical properties of these systems can complicate tray and downcomer designs. The use of high-performance trays can sometimes improve capacity for retrofits.
- High liquid load in the bottom sections might require multi-pass or multi-downcomer trays.
- Vapor/liquid disengagement issues in tray downcomers require a more severe system factor compared to packing in cryogenic service. Vessels equipped with conventional trays are slightly larger diameter compared to packed vessels.
- Trays require specialized feed pipes and inlet baffles for mixed-phase feeds.

### 2.2 Considerations for Packing

There are several benefits for the application of random packings in NGL recovery towers:

- New packed vessels have slightly smaller vessel diameters compared to units designed based on standard trays.
- Packing can provide a greater range of operation compared to trays provided the liquid distributors are designed for the range of liquid flow rate.
- There is potential for retrofit of the packing to increase the number of mass transfer stages.
- Small diameter packed columns can be designed for applications below 750mm diameter.

There are also disadvantages for packing in NGL recovery towers:

- The equipment cost of packing and tower internals is higher compared to trays.
- Packed towers require careful design of devices associated with mixed-phase feeds to ensure good operation at high capacity.
- The overall vessel height can be increased due to the height of mixed-phase feed arrangements required for packed towers.

Modern random packings are considered the ideal device for high-pressure light hydrocarbon vessels associated with NGL recovery plants. Packing is suited to handle the moderate liquid loads, low surface tension and density difference for cryogenic units that operate near the critical point. Random packing does not suffer the effects of vapor back-mixing compared to trays when operated near the critical point.

### 2.3 Liquid Distributors

Several types of liquid distributors can be used in NGL recovery columns are shown in Figure 3. Demethanizers and Deethanizers can be equipped with orifice pan distributors, owing to their moderate to high liquid flow rates. The Sulzer VSI™ distributor consists of risers and ground holes. The Sulzer VSIR™ distributor includes flow tubes and raised orifice holes with side discharge into the flow tube. A standard VSI distributor with ground holes is limited to about 3:1 range of operation, while the use of multiple holes allows the VSIR to achieve range of operation of up to 10:1. The top section of Demethanizers is often specified with VKR2™ trough type liquid distributors, due to the low liquid loads.

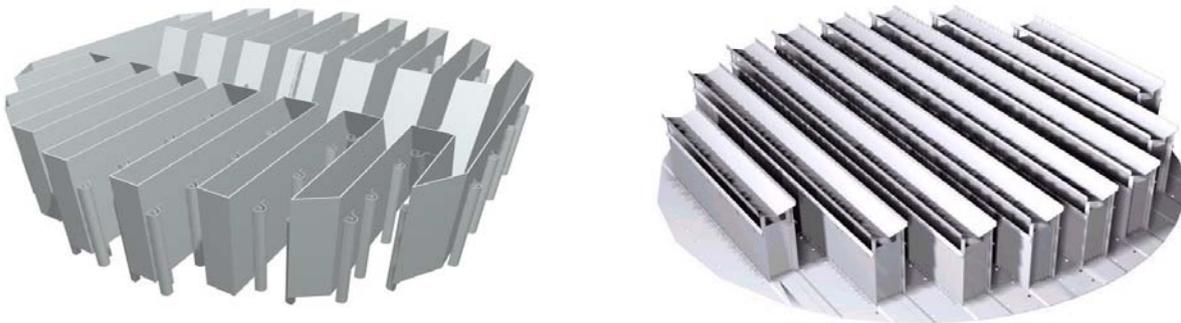


Figure 3. VKR2 and VSI Liquid Distributors

### 2.4 Chimney Trays and Gallery Trays

Chimney trays are specified for applications with a mixed-phase reflux or where liquid draw-off is required to drive a side heater or the bottom reboiler. They are excellent at handling liquids and their residence time disengages vapor from liquid. The chimney trays used feature a recessed draw-off sump, V-hats, and are seal welded construction. There is little benefit for low pressure drop in high-pressure applications, so chimney trays have riser areas of approximately 15% to 20%.

Demethanizers are equipped with a chimney tray below the expander feed at the top of the stripping section. These chimney trays are often equipped with downpipes or boxed downcomers in order to bypass liquid when a side heater is shut off during the ethane rejection mode of operation. It is recommended to equip chimney trays with V-hats that drain liquid to the deck without contacting gas flow. The low surface tension and low density ratio encountered in cryogenic applications makes these units susceptible to liquid entrainment. It is not recommended to allow the liquid from the V-hat to contact gas flow from the riser, as the low density ratio ( $\rho_L/\rho_G$ ) and low surface tension for this application makes chimney trays sensitive to the effects of liquid entrainment. Considerations for chimney trays associated with the main expander feed at the swaged section:

- For large diameter units, it is possible to consider the use of a chimney tray below the expander feed designed with downcomer pipes or boxes to feed a VKR2 trough liquid distributor.
- The preferred arrangement is to use a SK™ chimney tray or SKG™ gallery tray below the expander feed. If a SK chimney tray is used, it could be equipped with large diameter flow holes equipped with guard chutes under the tray deck that direct liquid towards the perimeter of the distributor. If a gallery tray is used, the liquid should rain on the outside perimeter.
- The standard practice is to use a butterfly GDP™ baffle for covering the expander feed nozzle. The exhaust width of the GDP is the same for the top and bottom, and the top and bottom plates are horizontal.

Mixed-phase feeds associated with the top reflux or stripping section side heaters can be equipped with SKG gallery trays. These are specialized chimney trays with a single, large center riser with high open area, and equipped with large peripheral perforations for discharge of liquid to the VSI or VSIR liquid distributor. Gallery trays are utilized in conjunction with inlet feed baffles to discharge the mixed-phase feed into the perimeter raceway, and VSI or VSIR liquid distributors. Figure 4 shows various views of a Sulzer SKG gallery tray and a GDP inlet baffle.

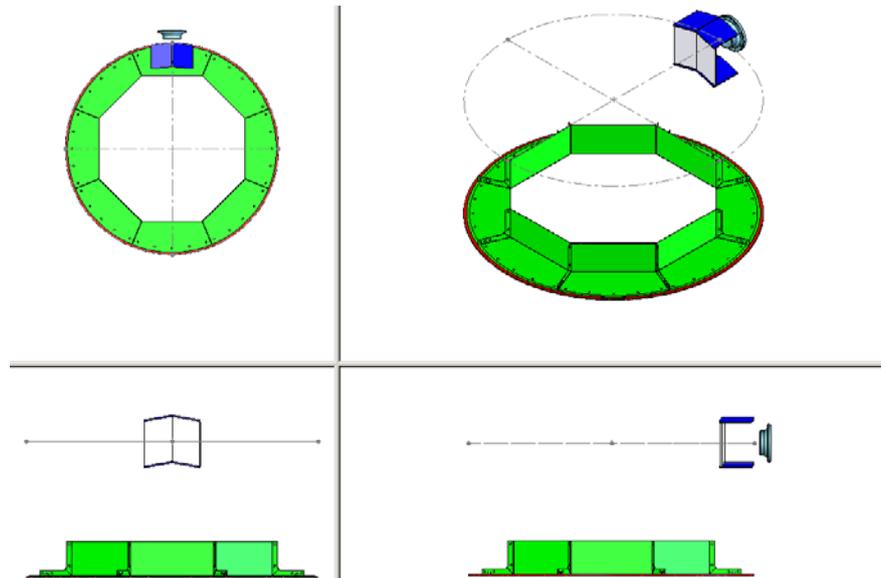


Figure 4. Sketch of SKG Gallery Tray with GDP Inlet Baffle

### 3. Gas Hydrates and Freezing

The low temperature of vessels operating under cryogenic applications is accompanied by the risk of the formation of hydrates during operation. There are two general problems:

- Water hydrates that form due to high inlet water concentration in the feed inlet due to inadequate dehydration of the inlet gas into the GSP plant.
- Carbon Dioxide freezing due to accumulation of CO<sub>2</sub> as a middle boiler in the fractionation column and in the associated separators.

Plant process considerations are the primary means of combating these issues. Chimney trays and tower internals should be designed to eliminate stagnant areas that could become sites for hydrates and freezing materials.

### 4. Summary and Conclusion

The design of cryogenic fractionators for NGL recovery plants and LNG fractionators involves light hydrocarbon components that are below their critical temperature, and components that are close to their critical pressure. It is necessary to understand the process considerations for the plant, the various feeds and draws in order to specify the proper trays, packings, and internals. The design of plants often considers multiple design cases for lean and rich gases, and utility systems based on summer and winter conditions. Following completion of the process design and simulation, it is necessary to make decisions for the mass transfer equipment for the rectification and stripping sections. The decision between the use of standard trays, high-performance trays and packing will be followed by the selection of auxiliary equipment for the mixed-phase feeds and heater draws. The design of mixed-phase feeds for high pressure cryogenic applications can involve some specialized equipment features. This paper provides an example and methods that assist the designer in keeping the process considerations in perspective.