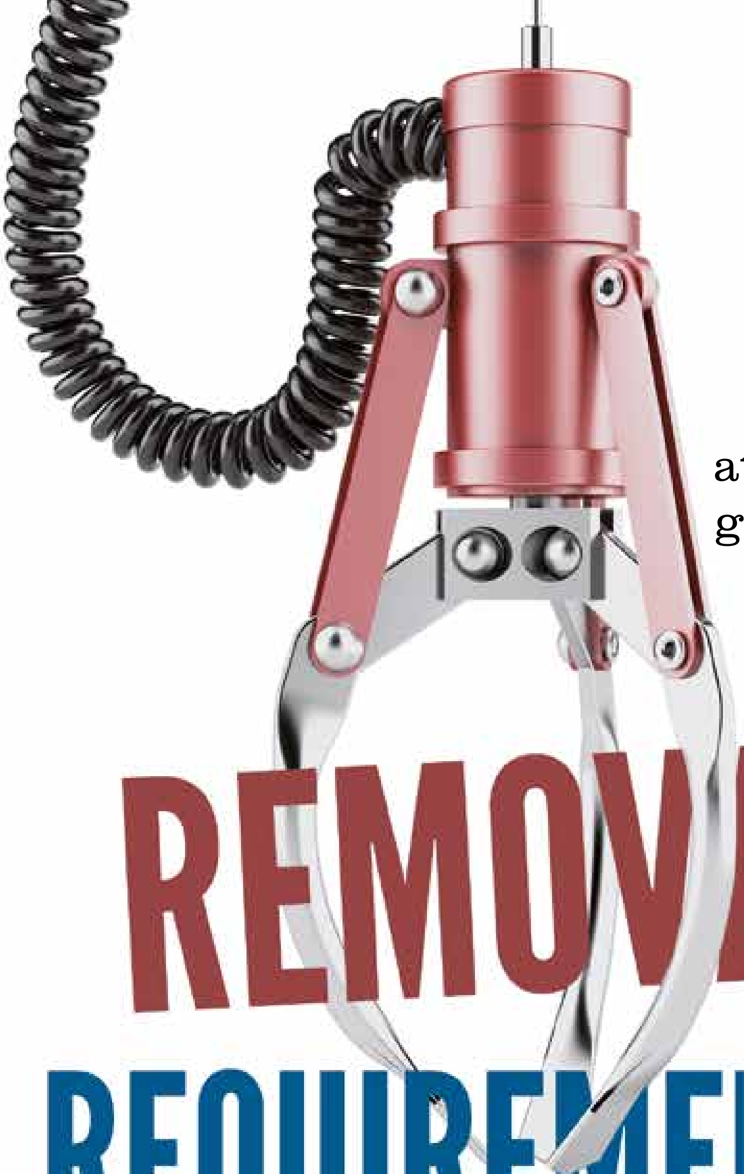

REMOVAL REQUIREMENTS

Inga Bettina Waldmann and Tom Haylock, KANFA Aragon, Norway, look at why special attention should be given to the design of CO_2 removal systems on FLNG units.

For almost all natural gas feedstock, CO_2 is an inevitable component to be dealt with. As CO_2 freezes during the liquefaction process of the natural gas, CO_2 removal is a critical system in any LNG production pre-treatment train. Freezing of CO_2 is particularly unwanted in the liquefaction heat exchanger where channels are small and potential for clogging is high. The risk is lower production and over-pressure in the system if de-icing activities are not performed in time.

There are fields where CO_2 is almost negligible in natural gas. However, if one is so lucky to have such a gas feed, the question is then whether or not to include a CO_2 removal system. On the other hand, there are common misconceptions by some in the industry that pipeline gas has an almost insignificant requirement for pre-treatment. Typically, pipeline gas quality has a maximum allowance of 2.5 mol% CO_2. This is a requirement set forth by the gas distribution regulations to reduce the risk of corrosion in pipelines and to control the Wobbe index. In LNG production the maximum allowance is typically 50 ppmv. This is 500 times less than 2.5 mol%.

When designing the CO_2 removal system for a floating LNG (FLNG) plant, the basic functional requirements are more or less the same as for an onshore LNG facility. What differs in FLNG design is that special considerations have to be made to adapt to the floating/offshore environment. For example:

- The process must be robust to vessel motions, while offering process simplicity.
- Minimised weight and equipment count.
- Simple operations and maintenance requirements.
- Use of technology proven offshore and on floating installations.
- Compliance with stricter safety requirements.

Technology selection

For CO_2 removal, a number of different technologies exist:

- Regenerative absorption into a liquid (e.g. amine-solutions, Selexol).
- Regenerative adsorption on a solid (e.g. molsieve).
- Permeation through a membrane (e.g. cynara membranes from Cameron or separex membrane technology from UOP, a Honeywell Company).
- Non-regenerative methods (e.g. scavenger).

There is, unfortunately, no such solution that is the best for every project. The optimal technology selection is dependent on a number of factors, including the following:

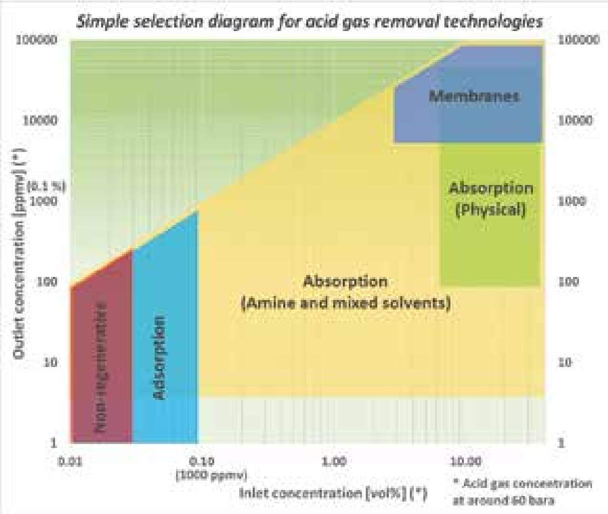

Figure 1. Technology selection for sour gas (CO_2) removal.

- Feed gas CO_2 concentration.
- Feed gas rate.
- Operating pressure.
- Other sour contaminants, such as H_2S or mercaptans (RHO).
- Motion characteristics.
- Available free heat through waste heat recovery units.
- Capex and Opex.
- Environmental regulations.

Simple and durable technologies are most suited to FLNG applications and should be preferred over highly sophisticated process solutions in most cases. For removal of CO_2 down to 50 ppmv there are also limitations for some technologies (see Table 1). In some cases, a combination of technologies is even the best. Figure 1 gives an indication of technology selection, but each field development should be carefully evaluated in order to find the best solution.

Table 1. Sour gas technology limitations

Removal principle		CO_2 and H_2S removal		RSH removal	
		Removal capacity	Meet LNG specification	Removal capacity	Meet LNG specification
Regenerative absorption	Physical solvents	Total/bulk	No*	Total	Yes
	Amine solvents	Total	Yes	Limited	No
	Mixed solvents	Total	Yes	Total	Yes
Regenerative adsorption		Polishing	Yes	Polishing	Yes
Membrane		Bulk	No	Limited	No
Non-regenerative	Liquid scavengers	Polishing	Yes	Polishing	Yes
	Solid/fixed beds	Polishing	Yes	Polishing	Yes

**Physical solvents can, in theory, meet the CO_2 specifications, however no references exist*

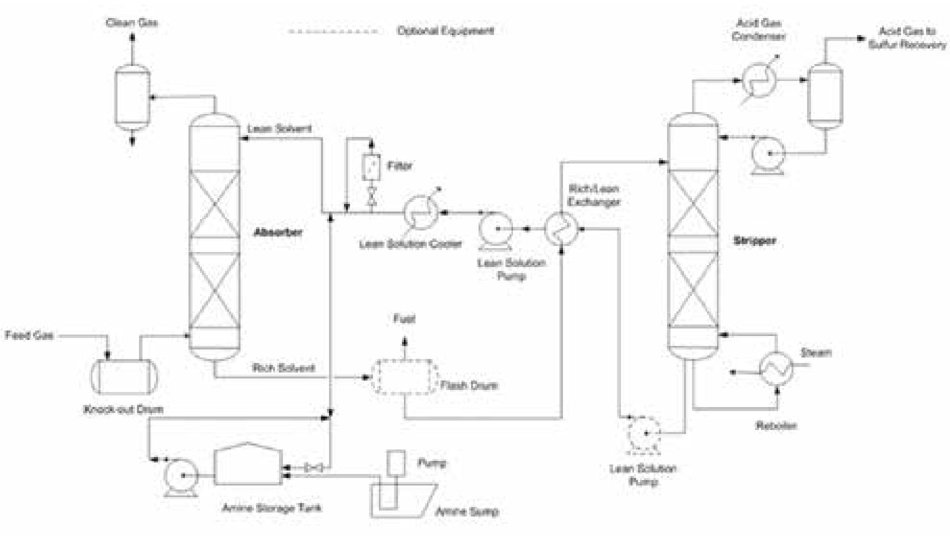

Figure 2. Typical process scheme regenerative absorption process.

Regenerative absorption

By far the most accepted solutions within the FLNG industry are regenerative absorption solutions, such as amine-systems.

The absorption process (see Figure 2 for a principal regenerative absorption process) can be divided into the following general classifications based on the nature of the interaction between the gas component (CO_2 in this case) and the absorbent:

- Reversible chemical reaction.
- Physical solution.
- Mixed solvent.

Reversible chemical reaction involves a chemical reaction between the gaseous component to be absorbed (CO_2) and a component of the liquid phase (absorbent). Example processes include the following:

- Alkanolamine based processes (e.g. MEA, DEA, MDEA, aMDEA).
- The alkali salt based process (e.g. potassium carbonate (K_2CO_3), Benfield process, sodium hydroxide (NaOH), Merox process).

A physical solution is a type of technology where the component to be removed (CO_2) is more soluble in the liquid absorbent than other components of the gas stream. The absorption follows no chemical reaction, simply Henry's law (P_A=H_A·C_A), hence the equilibrium is strongly dependent on the partial pressure in the gas stream. Most physical solutions are also suitable for removing components that will not react with amines (e.g. RSH, COS). An example of this technology is the Selexol process (by UOP/Dow).

A mixed solvent is a mixture between a physical and a chemical solvent. It combines the benefits for both physical and chemical solvents as more components can simultaneously be removed in one unit. An example of this technology is SULFINOL (developed by Shell Global Solutions).

All of these types of technologies require the use of high columns where the liquid absorbent is running in counter-current contact with the gas flowing upwards to absorb the CO_2 from the gas. These columns, also referred to as contactors, are, in most cases very tall, often above 30 m, and the performance of these tall vessels is highly influenced by motion. Any slip-through of untreated gas will cause off-specification outlet concentration and risk for freezing of CO_2 in the liquefaction heat exchanger. It is crucial that the detailed design of the columns is carried out in collaboration with vendors that have models and experimental data for column design exposed to motions.

Design of CO_2 removal columns

Column internals

The mass transfer internals and the liquid and gas distribution devices installed inside the column play a vital role in column performance. The main purpose of the column is to ensure contact between the liquid and vapour streams being fed into the column. As a result, the design of the mass transfer internals are of specific concern (see Figure 3).

The most common mass transfer internals for columns are fractionation trays, structured packing, and random (dumped) packing.

Thanks to experience from the floating production storage and offloading (FPSO) industry, it is a known fact that structured packing is the preferred and recommended choice for columns exposed to motions. Structured packing typically consists of thin corrugated metal plates or gauzes arranged in a way that forces fluids to take complicated paths through the column, thereby creating a large surface area for contact between different phases. Using structured packing also results in lower pressure drop, increased capability of handling turndown and lower footprint/weight. Fractionation trays, having a liquid level on each tray, are not suitable and random packing is not sufficiently efficient and increases the overall Capex.

Liquid distribution is crucial for good packing performance, and in particular for structured packing. The industry standard liquid distributor is an open type with small drip holes (gravity type distributor). When subject to motion, the liquid distributor must be closed in order to avoid splashing and overflow. This means a tube type (pressurised) distributor consisting of a grid of tubes with small drip holes. The pressure drop across the holes must be large enough to provide even distribution.

Effects from motions on the column

Floating applications (such as FLNG) can be several kilometres from land or right on the coast. They can be a shipshape hull, circular hull, or even an ultra-large barge. The motion characteristics will be an inevitable phenomena for all solutions

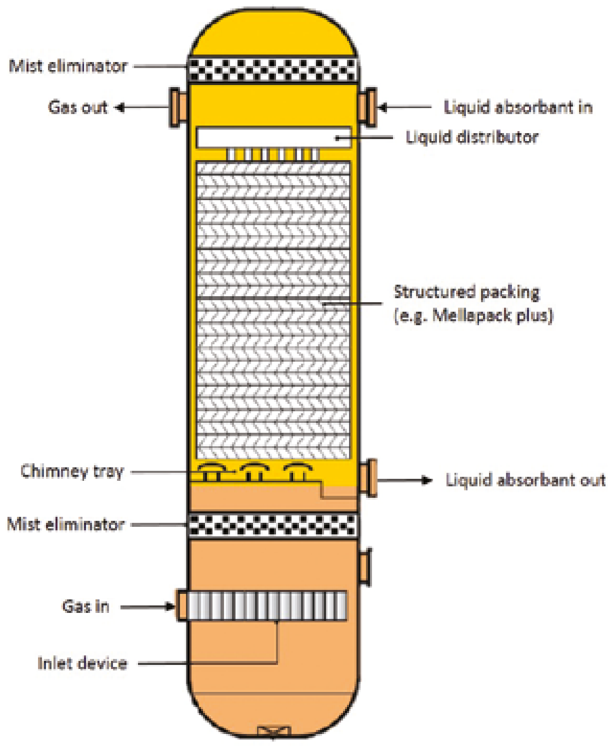

Figure 3. Simplified view of column internals. (Column drawing by Sulzer.)

that must be accounted for in column design and it is important that these characteristics are well defined:

- Periods and amplitude of motions for roll and pitch rotation.
- Static inclination, list and trim angles.
- Acceleration in x-axis and y-axis.

Static/permanent tilt, dynamic motions and accelerations will disturb the gas and liquid flow patterns, leading to reduced heat and mass transfer and reduced hydraulic capacity (the ability to flow gas and liquid without restrictions). It may also cause instabilities. As an example of one effect, a slip through of 1% of the inlet gas with a 5% volume of CO_2 in the feed will give 600 ppmv CO_2 in gas outlet.

Important factors that may affect the performance of the column include the following:

- Maldistribution of liquid due to liquid distributor malperformance.
- The appearance of non-wetted zones or zones with lower liquid flow in the packing, as illustrated in Figure 4.
- Liquid overload in the opposite side of the packing.
- 'Liquid on the wall' effects.
- Cross flow or unstable flow due to accelerations, which can become very large in the top of a high column.

Internals vendors and process licensors have in-house experimental data and plant performance data that documents the effects from motions, but also provides guidelines and methods for how to make a robust design that mitigates these effects. These vendors have concluded

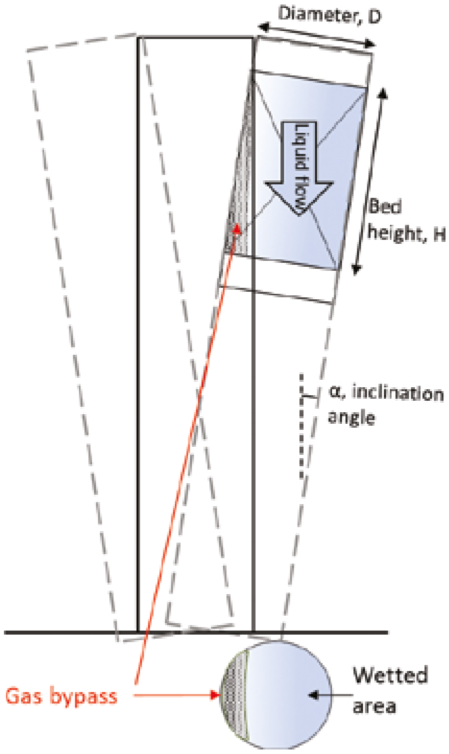

Figure 4. Packing maldistribution and non-wetted sections.

that static tilt is worse for the mass transfer performance than dynamic motions, and the permanent list/trim should be not more than 1°. This because a static tilt will cause a permanent maldistribution of liquid, while the dynamic motions will enable the liquid to redistribute when the angular deviation changes from one side to the other.

There are also other factors to consider in column design, which must be given thought from an early stage in a project. These include the following:

- The requirement for redistribution of the liquid in the column, i.e. having multiple packing sections.
- Location of the column of the topside.
- Selecting a realistic return period for operation design (e.g. 1 - 10 years; but not 100 years).

Conclusion

To produce LNG, CO_2 removal is almost as unavoidable as the liquefaction system itself, special focus should be given to the design of this system on an FLNG unit.

There is a wide selection of technologies available. KANFA Aragon has designed a number of FLNG topsides with CO_2 content ranging from 60% to very little at all.

To meet the strict removal requirements of 50 pmmv CO_2 in the gas, it is seldom that one does not use a regenerative absorption based technology. The use of this technology introduces tall columns, and with the vessel motions that affect any FLNG unit, it is crucial that the design of these columns is given special focus right from the start.

The engineering company must understand the unique aspects that the offshore challenges present, and the vendors of column mass transfer internals should always be involved with the detailed choice of internals and sizing and design. Following this advice will help optimise up-time and avoid unwanted impacts to production and project revenue. **LNG**