Innovative Way to Recondense Boil-Off Gas

Boil-off gas (BOG) is a by-product generated during the transport of liquefied natural gas (LNG) in LNG carriers and during the offloading and storage of LNG in receiving and regasification terminals. Typically, excess BOG is recondensed and recirculated as LNG. Conventional BOG recondenser units are relatively large columns equipped with structured packing. Sulzer has developed an innovative way to recondense BOG using its static mixing technology. Tremendous space and weight reductions are the main benefits of this alternative technology. They make this static mixer design the preferred solution in offshore applications.

1 Inside part of the innovative BOG recondenser, which is based on Sulzer's static mixing technology.

Shrinking material for transport purposes and unshrinking it upon arrival at the destination is a dream in many industries. The natural gas industry has managed to realize this. Cooling down natural gas to approximately –161°C (–258°F) allows to liquefy natural gas and reduces the volume of the gas by about 600 times. The liquefied natural gas (LNG) is transported with special carriers to LNG receiving and regasification terminals. A modern carrier ship is capable of transporting over 260 000 m^3 LNG. Such ships deliver gas — independent of pipelines — to the international markets.

LNG — From production to transportation to consumption	
1	Natural gas production
2	Removal of hydrocarbon condensate and aqueous liquids / Removal of dissolved water, mercury, CO_2, and H_2S
3	Gas refrigeration and liquefaction at approximately –161°C (–258°F)
4	LNG storage and batch loading on LNG carriers
5	LNG transportation (including BOG recondensation on modern LNG carriers)
6	LNG offloading and regasification at LNG terminals (including BOG recondensation)
7	Distribution of vaporized natural gas to end-users, including power plants and homes

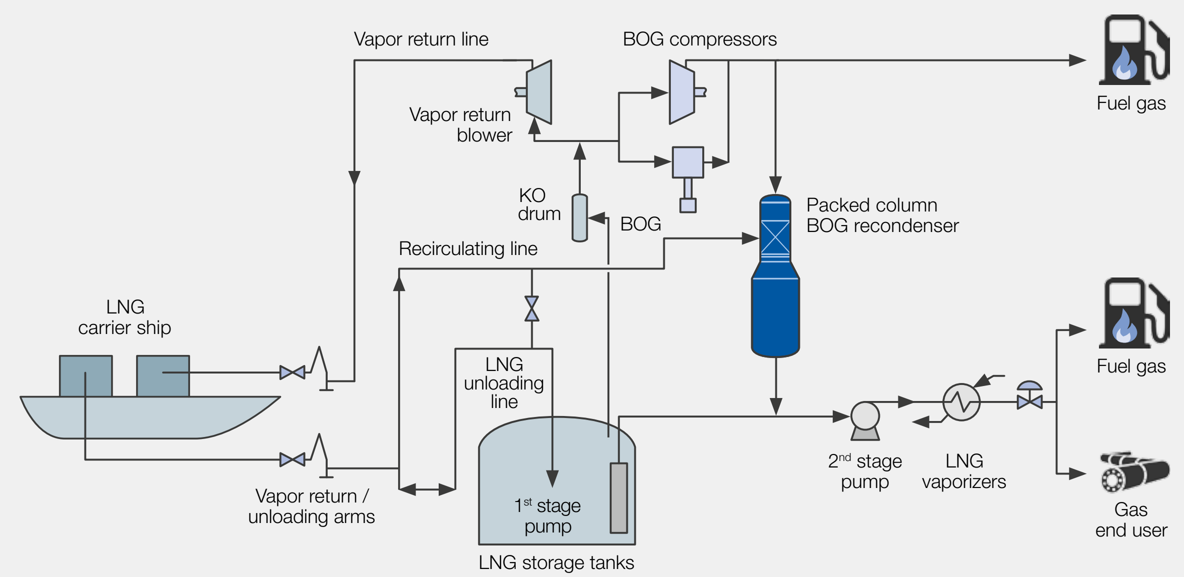
2 LNG — From production to transportation to consumption.

The LNG supply chain

LNG production is an elaborate process. After raw natural gas is harvested from gas wells, special pretreatment steps are required prior to refrigeration and liquefaction (Fig. 2). Hydrocarbon condensate and aqueous liquids (containing monoethylene glycol or methanol) are removed in separators. Dissolved water, mercury, hydrogen sulfide, and carbon dioxide are sequentially removed in specialized process unit operations. Finally, the treated natural gas is refrigerated in a main cryogenic heat exchanger (MCHE), and it then becomes LNG. This LNG product is stored in LNG tanks, and it is loaded onto LNG carriers for export to other parts of the world. During transportation, BOG is generated from LNG by evaporation. In modern LNG carriers, BOG recondensation saves costs and increases sustainability because the boil-off gas is recirculated.

At the LNG receiving and regasification terminal, the LNG is offloaded from the LNG carriers, stored in LNG tanks, and subsequently vaporized into high-pressure sales gas. There are two ways to distribute this gas to the end user: either via fuel stations or via domestic gas networks. During this process, part of the LNG will evaporate to form low-pressure BOG. Some of the BOG is returned via the vapor return line to the LNG carrier. It is used for pressure balancing during the unloading process. If the carrier is equipped with a gas-driven motor, some of the BOG is used as fuel gas for the ship. The remaining BOG is sent via the BOG compressor to the BOG recondenser (Fig. 3).

A conventional BOG recondenser is a relatively large column equipped with either random packing or structured packing. The BOG contacts subcooled LNG on the surface of the packing. The subsequent heat and mass transfer results in the absorption and condensation of BOG. The column is usually designed for co-current operation. It is typically operated at 3 to 10 bar and cryogenic temperatures (approximately –161°C).



3 Schematic diagram of a typical LNG receiving and regasification terminal.

Sulzer shrunk the BOG recondenser

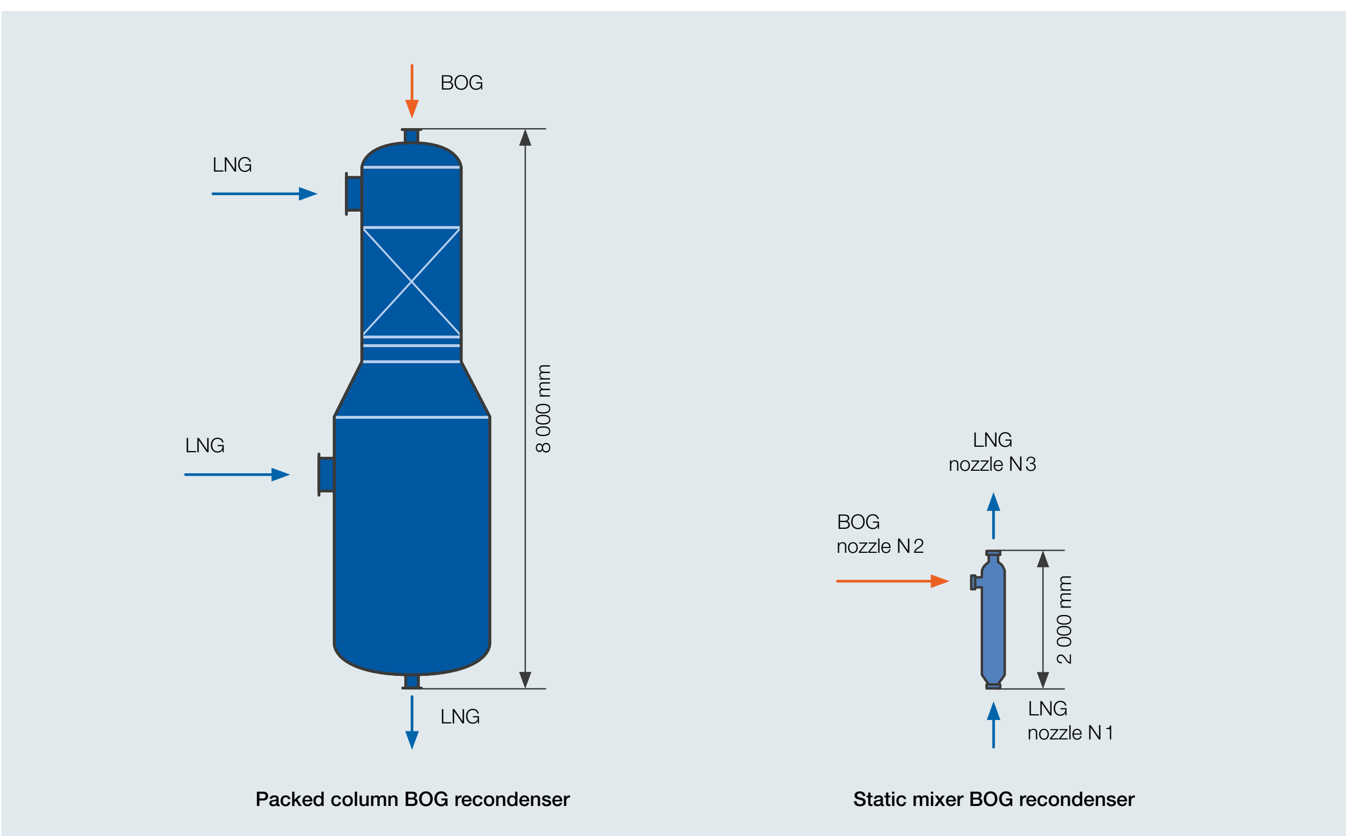
Always rethinking existing processes and searching for optimizing potential, the Sulzer process engineers came up with a new idea for the BOG recondensing process. This technology uses static mixing technology, which operates with a completely different mechanism. The static mixer design has a liquid continuous phase, in contrast to the packed column design, which has a gas continuous phase. The result is a considerably smaller and lighter BOG recondenser. This provides space, weight, and cost savings for the customer.

Working principles of the static mixer BOG recondenser

The static mixer design features a double-walled housing, and the static mixer elements are nested within the inner wall. The subcooled LNG is introduced to the central tube through nozzle N1, while the BOG is fed through nozzle N2 to the annular space between the inner and outer walls. The LNG leaves the BOG recondenser via nozzle N3.

Operating conditions and stream data		
Feed gas conditions	**Unit**	**Value**
Column top pressure	bar(a)	5.0
BOG feed flow rate	kg/h	10 000
BOG feed temperature	°C	1.0
BOG feed composition	mol%	2.0% nitrogen 98.0% methane
LNG feed flow rate	kg/h	95 000
LNG feed temperature	°C	–161.5
LNG feed composition	mol%	0.1% nitrogen 0.4% i-butane 0.5% n-butane 3.1% propane 8.0% ethane 87.9% methane

5 Operating conditions and stream data for the BOG recondenser case study.



4 Comparison of both BOG recondenser designs for the case study.

The BOG enters the central tube from the annulus through specially designed entry holes inside the inner wall (Fig. 1, page 16). The high entry velocities of BOG result in an intense mixing with the subcooled LNG, which flows upwards in the mixer. The proprietary static mixer elements lead to radial mixing and increased fluid turbulence, which results in heat transfer and temperature equalization. Compared with the packed column design, the static mixer technology achieves more efficient BOG condensation and absorption.

Additional benefits using the static mixer BOG recondenser

The static mixer technology offers high operational stability and flexibility. The BOG flow rate is typically not stable, and complex split-range controllers are often employed to maintain the operating pressure in the packed column. However, when using a static mixer, the liquid level in the annulus will vary according to the BOG flow rate, allowing the BOG recondenser to self-regulate. Thus, less process control instrumentation is needed as well, which makes the new technology cost-efficient for customers. The innovative BOG recondenser is also easier to operate thanks to a wider operating range than the conventional BOG recondenser. Peak-shaving facilities, where the LNG send-out rate varies substantially, benefit in particular from the wide operation range of the innovative BOG recondenser.

Pressure drop influences process security

The BOG recondenser with static mixer design requires a defined pressure drop for the operating process. While the pressure drop with BOG recondenser columns is about 10 mbar, the pressure drop using the static mixer is usually in the range of 300 to 500 mbar. The higher the pressure drop is, the less sensitive the technology is to tilt and motion conditions. The BOG recondenser with the static mixer design is, therefore, the ideal choice for offshore applications, such as floating storage and regasification units (FSRUs).

A case study performed for a European customer evaluated and compared the two different designs for an onshore BOG recondenser. Figure 4 shows the remarkable reduction in size. The BOG recondenser with static mixing is only 2.0 m high — compared with 8.0 m for a BOG recondenser column. The key operating parameters and stream data for the case study are summarized in Fig. 5.

Since 2012, proven and in use on a floating storage and regasification unit (FSRU)

The Nusantara Regas Satu FSRU, located in Indonesia, is the first FSRU in Asia. Originally, it was an LNG carrier known as Khannur. In 2011, it was converted into an FSRU (LNG World News, 2011). It has been operating successfully since 2012 (Golar LNG, 2016). The BOG recondenser with Sulzer's static mixer design is in operation since then on this FSRU. The customer's feedback emphasizes the operational stability of the innovative BOG recondenser. Despite fluctuating process conditions, such as the BOG flow rate, the innovative BOG recondenser maintains the complete BOG recondensation process.

Offshore application on FSRUs

An FSRU is a mobile LNG receiving and regasification terminal that is located on an offshore vessel. Especially with rough sea, the equipment of an FSRU is subject to tilt and motion conditions. Compared with onshore installations, the processes have to be adapted to the shaking movements; the hydraulic and mechanical designs also have to be adapted for offshore use. With tilt and motion, liquid and gas maldistribution might reduce the column performance in conventional BOG condensers. To ensure the recondensing function in these condensers, the design margins are increased for offshore applications, which leads to larger column dimensions. By contrast, maldistribution is no issue for the static mixer design. Therefore, the design margins for offshore application are minimal.

In conclusion, the static mixer BOG recondenser provides several advantages. The smaller size of the new BOG recondenser results in a lighter foundation and reduced capital expenditure costs for the whole installation. Process stability and flexibility combined with easy operation reduce errors and downtimes during operation. Size matters. The limited space on an FSRU makes the smaller BOG recondenser the preferred choice for offshore applications.

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