The demand for safe, efficient and cost-effective compression systems for handling boil-off gas (BOG) in LNG plants, and especially LNG receiving terminals, is greater than ever before. The increased size of LNG terminals and LNG carriers has led to an increase in BOG flow of approximately 20% for single loading and up to 50% for simultaneous loading.

The increase in LNG yield can also be seen in the fact that by the end of 2014 there were more than 370 carriers with a capacity exceeding 30,000 m³, including vessels that are capable of carrying as much as 265,000 m³ of LNG. Not only that, but out of 68 vessels ordered in 2014, 85% of them will have a capacity greater than 170,000 m³.²

Handling the increasing amount of BOG flow in the traditional way adds unnecessary space, weight and equipment. Combining reciprocating compressors in cold duty with single-body, single-shaft, multi-stage turbocompressors can be an attractive and favourable economic solution for LNG receiving terminals.

A conventional arrangement: LNG export terminals
The current level of BOG demand can be handled by a concept that features a single-body (barrel-type), single-shaft, multi-stage, centrifugal compressor. This compressor design is optimised for small and medium BOG volume flows and is capable of automatic start/stop operation (direct online) from ambient conditions, as well as from cold conditions with no cool-down required.

Sven-Erik Brink and Christian Belting-Clar, Dresser-Rand business within Siemens, Germany, present a safe and cost-efficient approach to handling boil-off gas.
Along the whole LNG chain – during production, transportation and regasification – BOG is constantly evaporating from the LNG, which is bunkered in storage tanks at cryogenic temperatures and atmospheric pressure. According to its nature, the BOG flow profile differs along the different steps of the value chain, thus the requirements on BOG compression also differ. 

BOG generation during LNG carrier transportation, while constant, is rather small. For LNG export plants and LNG import terminals, the maximum BOG volume flow is much greater and faces large fluctuations. This is due to the impact of increased heat leakage during ship loading (export plant) and ship unloading (import terminal).

In LNG export plants, the BOG generation rate is the highest along the LNG chain and the BOG flow undergoes large volume fluctuations defined in two major plant operating modes. 

Figure 1 shows the project-specific LNG BOG/end flash gas (EFG) generation profile over time with one almost constant BOG and EFG flow called ‘holding’ and a characteristic peak in BOG volume flow during ship loading.

The different BOG volume flows are caused by different heat leakage sources. In the holding (BOG/EFG) example, onshore LNG tank heat leakage and the flash effect from LNG production (main cryogenic heat exchanger pressure flashed down to storage pressure) are the key sources of heat leakage.

In the ship loading example, heat leakage comes from the six submerged LNG pumps (approximately 1 – 2 MW each), the jetty piping and the LNG ship cargo.

On the right side of Figure 1, the 2 x 50% overlapping BOG compressor performance maps have been flipped with different inlet guide vane (IGV) settings. The holding operating point (blue dot) is basically the main operating point and for that reason should run at good efficiency and without any bypass flow and LNG quench.

In Figure 2, the ship loading operating point (red dot) represents the peak volume flow, which occurs frequently and is covered by starting another BOG compressor train. The graphic also shows a BOG flowrate of 2 x 50 tph, which equals a 100% mass flow – a usual value for today’s typical LNG plant.

By serving the flow requirement with either one or two trains, all operating points are covered with a single-casing BOG compressor.

Figure 3. The application range of different compressor types.

Some loading operating points, especially at the beginning of the new loading cycle, temporarily increase the BOG temperature above the design point ranging from approximately -145°C (-229°F) down to -160°C (-256°F). Thus, volume flow increases and outlet pressure decreases.

Allowing minor LNG quench of approximately 3 – 5% for the initial loading operating point would provide a more compact compressor that can be maintained while featuring a 2 x 50% solution instead of a 3 x 33% arrangement. By this measure, recycle flow can be minimised, or even prevented, while outlet pressure can be maintained.

All specified operating duties can be covered with two identical tandem-casing BOG single-shaft centrifugal compressor trains. This solution for process optimisation would ensure minimum equipment count and the lowest installation volume, while still maintaining maximum operating reliability, availability and safety.

In LNG plants, the BOG, together with the EFG coming from the flash drum, is often used as fuel for gas turbines. Thus, the fuel gas pressure required by the turbine significantly affects the required BOG compressor concept. Despite inherent flow fluctuations, the BOG package needs to deliver the flow at a specified pressure to satisfy the fuel gas pressure requirement for the gas turbines in the facility.

Depending on the different fuel gas pressure requirements, single, tandem, or even triple-casing BOG compressors may be required (Figure 3).

An unconventional arrangement for LNG import terminals

In LNG import terminals (onshore or offshore), there are two major operating modes – holding mode and unloading mode – which determine the BOG duties.
For typical BOG sources and indicative flows for a floating storage and regasification unit (FSRU), refer to Table 1.

The relatively high maximum BOG flow and the difference in BOG volume fluctuations between holding and ship unloading require a combined compressor concept. In Figure 4, the spread ranges from 32 tph down to 2 tph, which can only be handled by combining both the strength of the single-shaft turbocompressor and reciprocating machines.

While the loading requirements are handled by one 100% turbocompressor package, the small holding operating points are operated by either existing terminal extensions, or new reciprocating compressor packages.

With the configuration outlined in Figure 4, optimised compressor BOG handling concepts become increasingly attractive. Rather than covering the whole BOG flow range by small LNG re-liquefaction units (single-cycle N2 LNG cooling), or multiple large reciprocating compressors (re-condensing concept), it is more energy efficient to cover the maximum BOG duty through a single-casing, single-shaft centrifugal compressor combined with reciprocating machines.

In summary, of the outlined concept descriptions and based on the factors of maximum BOG flow and minimum BOG flow, the following compressor concepts (visually portrayed in Figure 5) for BOG handling can be used:

- **Concept A (conventional arrangement for LNG receiving terminals):**
  - 2 x 50% (plus one spare) or 3 x 33% reciprocating compressor.
  - Unloading: all 2/3 compressor units run in parallel.
  - Holding: one unit runs under bypass control.

- **Concept B (most commonly used):**
  - 1 x 100% (no spare unit) or 2 x 50% single-casing, single-shaft centrifugal compressor.
  - Unloading: compressor unit runs at high IGV setting.
  - Holding: compressor unit runs at a minimum IGV setting in automatic start/stop frequency, leading to the most economic plant operation.
  - Special note: for offshore installations, such as an LNG carrier converted into an FSRU, the holding BOG flow is used to fuel the steam boilers for the onboard steam turbine driven power generators.

- **Concept C:**
  - 2 x 50% or 3 x 33% single-shaft centrifugal compressor packages.
  - Unloading: compressor units run in parallel at high IGV settings.
  - Holding: one compressor unit runs at different low IGV settings.

- **Concept D (hybrid):**
  - 1 x 100% (ship unloading compressor) single-casing, single-shaft centrifugal compressor running with high IGV setting during ship unloading, plus two small customised reciprocating compressors covering the holding mode.

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**Table 1. BOG sources – a typical case study**

<table>
<thead>
<tr>
<th>Source of BOG</th>
<th>Unloading mode (kg/hr)</th>
<th>Holding mode (kg/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flash due to ship cargo tanks operating at higher pressure than onshore LNG tanks</td>
<td>3600</td>
<td>–</td>
</tr>
<tr>
<td>Pumping heat from unloading pump</td>
<td>20 000</td>
<td>–</td>
</tr>
<tr>
<td>Unloading line heat leak (with 20% added for fittings, expansion loops, etc.)</td>
<td>1700</td>
<td>–</td>
</tr>
<tr>
<td>LNG tanker (ship) cargo tank heat leak</td>
<td>6000</td>
<td>–</td>
</tr>
<tr>
<td>Onshore LNG tanks heat leak</td>
<td>2000</td>
<td>2000</td>
</tr>
<tr>
<td>Vapour return to ship cargo tanks</td>
<td>(22 000)</td>
<td>–</td>
</tr>
<tr>
<td>Negative displacement due to LNG sendout</td>
<td>(1300 variable)</td>
<td>(1300 variable)</td>
</tr>
<tr>
<td>Displacement from LNG tanks due to unloaded LNG</td>
<td>22 000</td>
<td>–</td>
</tr>
<tr>
<td>Total</td>
<td>32 000</td>
<td>2000 maximum. Down to zero</td>
</tr>
</tbody>
</table>

---

**Figure 4.** Simplified BOG generation and operation profile (LNG import terminal), combining turbo and reciprocating compressors.
Unloading: single-shaft centrifugal compressor runs at high IGV setting only during LNG tanker unloading.

Holding: small, customised reciprocating compressor runs.

It is important to understand that the optimised BOG recovery concepts for LNG import terminals require compressors that are capable of direct online start/stop operation in order to avoid compressor cool-down with associated gas flaring, as well as utilising reciprocating compressors suitable for cryogenic gas applications.

Key design features for this achievement are the turbo-type compressor design, material selection and combination for cryogenic service, dry gas seals encapsulated in heated seal carriers, and an adjustable IGV compressor control system.

Single-body, single-shaft BOG centrifugal compressors are customised for exactly this purpose, as they are specifically designed and engineered for maintenance-free, intermittent (start/stop) operation from ambient, as well as from cold conditions, without any special cool-down procedures.

These unique features make the units the best technical and most reliable fit, and provide the highest possible start-up availability customised for the needs of today’s state-of-the-art LNG import and export terminals.

Conclusion

The demand for safe, efficient and cost-effective compression systems for handling BOG on both carriers and LNG receiving terminals is greater than ever before. This means that maximum BOG flows are increasing and require a custom engineered compressor solution (or configuration).

This scenario uses the advantage of cold gas reciprocating compressors for low-flow handling and turbocompressors for higher loads, which goes beyond the application range of reciprocating BOG compressors. LNG

Reference


Figure 5. The application range of different compressor types in receiving terminals.