AT THE HEART OF THE PROCESS

Brian Pettinato and Enver Karakas, Elliott Group, USA, discuss the various turbomachinery services that are at the heart of LNG plants.

LNG projects have been moving at a steady pace within the US and around the globe, with numerous projects hitting the commissioning phase and coming online throughout 2019. A number of projects are in the proposal stages in the US, with nine additional plants proposed to the Federal Energy Regulatory Commission (FERC) and still more in the works. Train sizes for these recent North American projects have mostly settled in the range of 4 – 6 million tpy.

According to the International Gas Union's (IGU) '2019 World LNG Report', as of February 2019, 101.3 million tpy of liquefaction capacity was under construction or sanctioned, with another US$200 billion in LNG projects in line to be approved over the next two years in the US, Russia, Australia, Canada, Qatar and Papua New Guinea.[1] Such plants cost billions of dollars and require reliable turbomachinery for their operations. In this environment, opportunities for equipment suppliers remain strong.

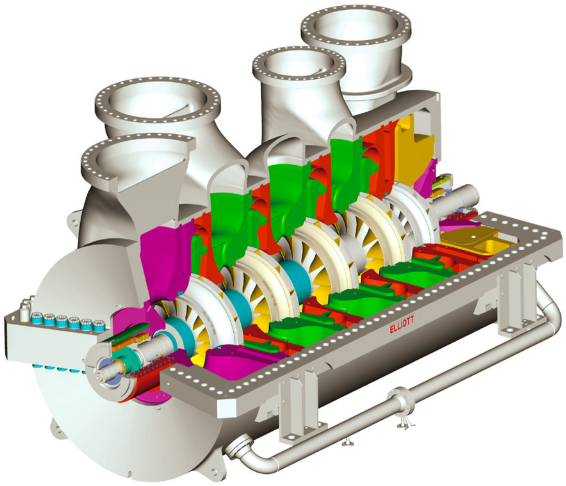


Figure 1. Elliott multi-side-load propane compressor.

Figure 2. Elliott 60MB6I high pressure mixed refrigerant (HPMR) barrel compressor.

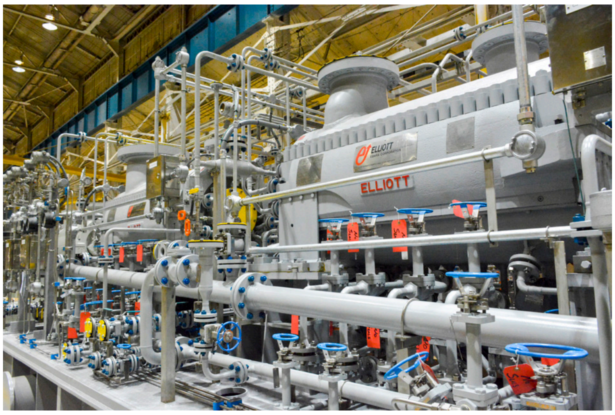


Figure 3. Elliott end flash gas compressors ready for shipment.

Turbomachinery services for the LNG plant

Numerous turbomachinery services exist within an LNG plant. Compression services within an LNG plant consist of main refrigerant compressors (propane, mixed refrigerant, etc.), as well as boil-off gas (BOG), end flash gas and stabiliser overhead compressors. Other turbomachinery services include cryogenic turbopumps for LNG loading and offloading, and cryogenic turboexpanders used to improve overall plant efficiency and to enhance the refrigeration process.

Main refrigeration service

In the case of the main refrigeration service in large scale LNG processes, multiple compressed refrigerants run through heat exchangers to chill the treated natural gas stream to a temperature of approximately -160°C, which results in liquefaction and some subcooling. Large refrigeration compressor strings are the critical machinery at the heart of this refrigeration process. The capacity of an LNG train, and by extension the entire production facility, is determined by the size of the main refrigeration compressors. To enhance the overall efficiency of the refrigeration process, the Joule-Thomson expansion valve (J-T valve) can be replaced with a cryogenic liquid expander. The liquid expander not only reduces the fluid pressure to a desired level while producing electricity, it also cools the fluid during the expansion process. This results in an overall efficiency improvement in the refrigeration cycle.

The Air Products & Chemicals, Inc. (APCI) process is one of the primary LNG liquefaction technologies driving US exports. This process consists of two closed-loop refrigeration streams, a propane refrigeration cycle and a mixed refrigerant (MR) cycle. The propane refrigeration cycle precools the gas to -35°C through a heat exchanger. It also acts to precool the MR. The MR refrigeration cycle further cools the natural gas from -35°C to -162°C in the main cryogenic heat exchanger (MCHE).

Multiple streams across the propane precooling heat exchanger increase the thermal efficiency of the process. These multiple streams can be handled by a single propane compressor arranged with multiple sections with incoming side loads having kettle type evaporators. Per design, the side-load compressor is well suited for refrigeration applications where the refrigerant is introduced at progressively lower temperatures to the lower pressure sections. Gas temperature increases in a given section are reduced by the mixing of the side-stream flow into the suction of the following section of the compressor.

Propane compressor

LNG propane compression is one of the more difficult compressor applications, typically accommodating wide operational conditions with multiple side-load inlets, a high molecular weight gas and low temperatures. Figure 1 shows a three-quarters cross section of such a compressor having three side loads (one inlet is not pictured due to the cutout). This compressor is used in a 4.7 million tpy plant.

The compressor shown in Figure 1 has the following features:

- Drive-through shaft with gas turbine main drive at one end and starter motor at other end.

- Horizontal split casing for simplified maintenance (compressor resides between a gas turbine and motor).
- Five nozzles: one main inlet, three side loads and one discharge.
- Internal side-load mixing.
- Up nozzle arrangement necessitates piping removal for maintenance. Optional mezzanine mounting with down nozzles eliminates this requirement.
- Balance piston recycle line.
- Not pictured: piping arrangement with anti-surge recycle lines.

The presence of side loads makes the aerodynamic design a bit more challenging. Ongoing research into side streams has led to enhancements with respect to performance, mixing and flow distribution. Computational flow path analyses and proprietary models confirm an enhanced design of the merging flow paths to minimise losses. This technology has been featured in Elliott's side-load compressors for approximately 10 years, and has been implemented as an upgrade in certain cases.

MR compressor(s)

The LNG MR compressor is not as aerodynamically challenging as the propane compressor, but it does have some unique challenges in the form of large heavy casings operating at higher pressures that often require large frame barrel designs (Figure 2). Here again, continuous improvements and gradual step outs in experience occurring over long spans of time are allowing new offerings in high-pressure casings. As the size of the compressor casing increases, so too do the deflections that occur under pressure, such that the compressor size and its pressure handling capability are inversely related. Handling either the large frame size or the high pressure can be quite challenging, but the primary original equipment manufacturers (OEMs) for LNG equipment have been doing both routinely, offering large compressors at relatively high pressures. Elliott has demonstrated considerable experience in such large compressor offerings having over a dozen large barrel compressors in LNG service alone and many times more operating in the petrochemical sector with offerings reaching up to 1000 psi in casings that exceed 100 in. internal diameter.

End flash gas and BOG compressors

After liquefaction, BOG and flashed vapours are produced through expansion, pressure drops and heating. Processing these gases is required to avoid flaring or venting. Compressors are used to transport and pressurise these gases, which can be used as fuel gas, sent back for reliquefaction, or transported for other distribution.

End flash gas compressor(s)

The liquefied gas stream is often sent to a separator where end flash gas is produced, consisting mostly of methane, but also removing most of the nitrogen and non-condensible trace constituents, thereby ensuring the quality of the remaining LNG stream. An end flash gas compressor (Figure 3) is used to pull this end flash gas off the top of the separator, pressurise and transport it. The compressor inlet gas temperature is close to the liquefaction temperature at steady-state operating conditions. Such cold service applications require stringent material specification, certification and testing.

BOG compressor(s)

After separation, the remaining gas stream is pumped to storage tanks or loaded onto a ship. BOG compressors are used to pull BOG from the top of storage tanks, thereby keeping pressures within allowances. The amount of BOG can vary considerably, and operational flexibility is extremely important for this application. Such compressors typically employ either a variable speed drive or adjustable inlet guide vanes (Figure 4) to enhance their range.

Cryogenic pumps

Cryogenic in-tank pumps are often used to move the LNG for storage and ship loading. Storage tanks require pumps capable of being safely installed and removed as necessary, without emptying or decommissioning the immense tanks. In-tank cryogenic pumps are therefore retractable, that is, installed and removed from the top of the tank. The dielectric properties of LNG enable the pump and motor to be designed as a single unit and submerged in the LNG.

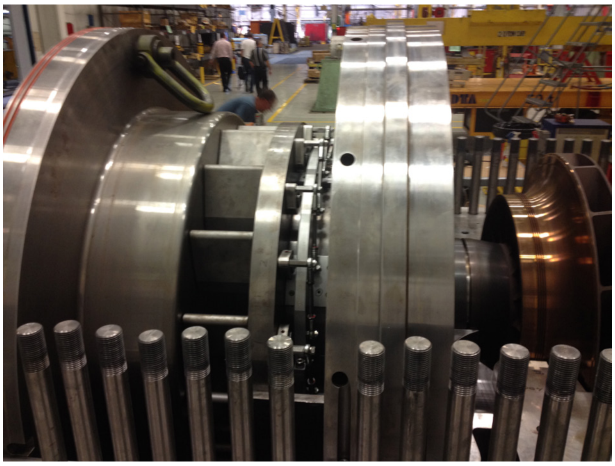
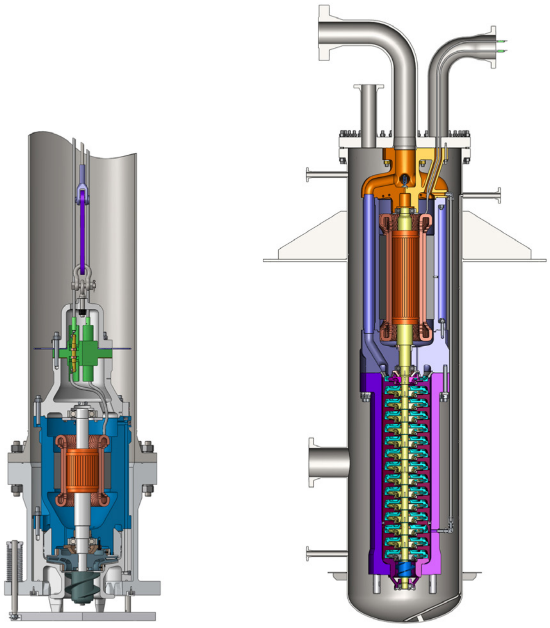


Figure 4. Adjustable inlet guide vane mechanism.



(a) (b)

Figure 5. (a) Retractable pump, (b) multi-stage vessel mounted pump.

Suction vessel mounted pumps are used as single-stage transfer or process pumps. Flow capacities are available up to 3000 m^3/hr, and differential heads up to more than 2500 m (depending on flow and power). The multi-stage pumps traditionally used for vaporiser send-out applications can have as many as 18 stages (Figure 5).

Cryogenic expanders

For many years, the traditional method to let down pressure in a liquid stream was a J-T valve. An improvement in the overall efficiency of this let-down process can be achieved by replacing the J-T valve with an expander. In doing so, and depending on the machine, the overall plant efficiency may increase by up to 8%, reducing operating costs and increasing LNG production.

Cryogenic expanders are a radial inflow reaction with an induction generator mounted on an integral shaft. The entire unit, including the turbine and generator, is submerged in the cryogenic fluid. This design essentially eliminates the need for dynamic seals, shaft couplings, generator support structure, and any concern for possible misalignment between the turbine and generator. By eliminating possible leakage from rotating seals, the design is extremely safe, especially when hazardous fluids are being handled.

Customised solutions

The value solution for LNG liquefaction is often determined by operational and market realities that affect plant size and LNG train arrangements. OEMs look to provide a customised solution for each quotation by balancing range, efficiency, price and experience, in accordance with the customer's needs and expectations. Improvement in aerodynamic technology has led to the development of high-flow staging that pushes well beyond previous flow coefficient limits. Other new staging has also been developed that has achieved some modest efficiency gains, but with rather significant space reduction, thus allowing application of smaller compressors that can achieve better results. In other cases, a single compressor body can be offered up where two were required before. And in other cases, parallel compressor arrangements are required in accordance with the operational needs of the plant to provide greater operational flexibility. All of these changes have been the result of continuous development by both the OEMs and process licensors with numerous step outs adding up to significant gains over time. **LNG**

References

1. IGU 2019 World LNG Report.
2. PILLARELLA, M., LIU, Y. N., PETROWSKI, J. and BOWER, R., (2007), 'The C3MR Liquefaction Cycle; Versatility for a Fast Growing Ever Changing LNG Industry', Air Products and Chemicals Inc., (Pennsylvania, US).
3. OMATICK, T. and CARPENTER, K., 'The Heart of Liquefaction', *LNG Industry*, (September 2014), pp. 50 – 54.
4. WILKES, J., PETTINATO, B., KURZ, R., HOLLINGSWORTH, J., ZHANG, D., TAHER, M., KULHANEK, C., WERDECKER, F., BUCHE, D., and TALABISCO, G., 'Centrifugal Compressors, in Compression Machinery for Oil and Gas', 1st Edition, Gulf Professional Publishing, (2019), Klaus Brun and Rainer Kurz, ed.
5. EBARA Cryodynamics, 'Your Expander Investment Payback', http://www.ebaracryo.com/your-investment-payback
6. MEHER-HOMJI, C., SANDBERG, M., and BEARD, J., 'Compressor Selection for LNG Liquefaction Plants', (2019), Proceedings of the Forty-Eighth Turbomachinery Symposium, Houston, Texas.

MKT.5230.1119