The key to efficient LNG

Enver Karakas, Ph.D, Elliott Group, USA, details LNG liquefaction and refrigeration process improvements that occur when using two-phase flashing expanders.

Natural gas has long been used worldwide as an alternative to other fossil fuels, such as coal and oil. As energy consumption and the need for energy continues to rise, the demand for natural gas sustains its position as a key energy resource. In comparison with other fossil fuels, LNG can be safely transported and stored, but the process can be energy intensive. The most common approach is to liquefy natural gas through cryogenic treatment for transport and storage applications.

The primary reason for liquefying natural gas is the significant reduction in volume for a given mass, which is approximately 1/600. Once liquefied, the LNG can be stored and transported in containers, tanks, and carriers. In order to store and transport natural gas in liquid form, the fluid is often cooled to approximately 265˚F (approximately -165˚C) under atmospheric pressure. During the liquefaction process, LNG is also cryogenically treated to separate hydrocarbons having a molecular weight higher than methane. The methane stream is frequently separated into individual components such as propane, ethylene, and ethane.

Overview of the LNG liquefaction process

Refrigeration and heat exchange are the critical processes of natural gas liquefaction. The liquefaction process is based on simple refrigeration vapour-compression cycles in stages, and heat exchange between different refrigerants or hydrocarbons.

A simple refrigeration vapour-compression cycle consists of a compressor, two separate heat exchangers (condenser and evaporator), and an expansion valve, as shown in Figure 1.[1] The expansion valve is a Joule Thomson (JT) valve which reduces the pressure of the refrigerant to the desirable pressure with an isenthalpic expansion. That is, the enthalpy of the refrigerant is the same at the inlet and outlet of the JT valve. The pressure drop at the JT valve is highly irreversible, providing no ability to extract work. Utilising an expander in place of a JT valve provides the ability to return the refrigerant to its original lower pressure state with a more isentropic path (Figure 2). There is an enthalpy differential between the inlet and outlet of the expander due to energy recovery, which also results in a cooler fluid temperature exiting the expander. With that, fluid exiting the expander will also have a lower percentage of vapour. These facts are important in consideration of the liquefaction and refrigeration of LNG.

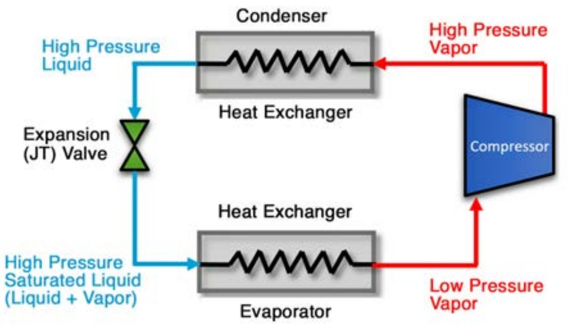

Figure 1. Simple refrigeration cycle with Joule Thomson (JT) valve and no enthalpy change, which results in a highly irreversible process (non-isentropic flow).

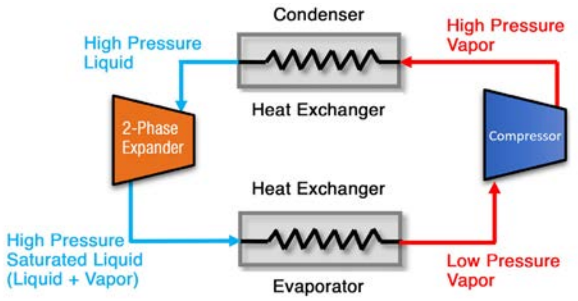

Figure 2. Simple refrigeration cycle with flashing expander, enthalpy change with energy recovery, and near isentropic flow. Enhanced cooling with the enthalpy change results in a higher percentage of liquid at the expander outlet.

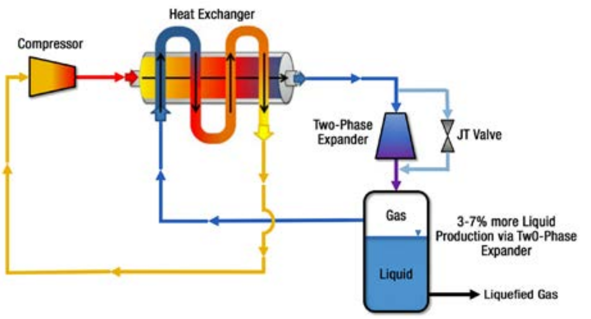

Figure 3. Typical cooling and liquefaction process with flashing two-phase expander.

In a typical liquefaction process, cooling is generally accomplished by heat exchange with one or more refrigerants or hydrocarbons. The refrigerants can be arranged in stages, and each refrigerant is employed in a closed refrigeration cycle.

In the methane refrigeration configuration, a liquid only LNG stream from a relatively high-pressure source (often times greater than 40 bar) is fed to a vessel which is at near atmospheric pressure for safe storage and transport. The resulting vapour and liquid are separated in a separation vessel. Vapour at the separation vessel is recompressed and circulated back to the process, while the LNG liquid is stored or transported, as shown in Figure 3. Utilising a two-phase flashing expander in this cooling and liquefaction process provides:

- Energy recovery and reduction in compression requirements by mechanical integration or electrical feed to the compressor.
- Enhanced cooling by enthalpy change, which improves LNG production by reducing vapour percentage at the flash process, which in turn directly reduces the vapour recompression requirement.

To eliminate process downtime, the JT valve is retained within the process (Figure 3), but only used if the two-phase expander is removed from the system for maintenance.

The recovered energy from two-phase expanders can be used to power the compressor or other process machinery. Mechanical integration between the expander and the compressor in the same process is also possible.

A case study conducted by Elliott Group shows that a considerable amount of LNG production is attainable by utilising two-phase LNG expanders in lieu of expansion valves. An overall LNG production increase of 4 – 7% with a 0.6% thermal efficiency gain is reported.[2,3,4]

Two-phase flashing expanders

Under the Cryodynamics® brand, Ebara International Corporation, now Elliott Group – Cryodynamic Products, designed and built the very first two-phase flashing expander as a prototype in 2000, and it has been in operation ever since. The reliability of this unit has met and exceeded expectations, and the customer has since expanded the application to add additional two-phase expanders to the process. All of these units are used in nitrogen rejection facilities to improve the efficiency of the cooling (refrigeration) cycle. A 3 – 5% increase in LNG production is reported for this particular application.[4] These units are designed to handle outlet fluid quality (vapour mass/total fluid mass) of 0.2 at most, with the inlet being subcooled (liquid only). This is to ensure the vapour formation is limited to certain hydraulic components within the expander.

Elliott Group's cryogenic liquid and two-phase expanders have a submerged generator design to eliminate the need for a mechanical seal between the generator and the hydraulics. This design feature greatly minimises reliability issues, and eliminates the need for hazardous area certification for the generator and the related electrical components that are submerged in the process fluid. Figure 4 shows the cross-sectional view of the first generation Cryodynamics two-phase expander. This unit is fundamentally a radial inflow Francis-type turbine with a jet exducer located towards the outlet of the machine. The jet exducer primarily handles the flashing of the process fluid. The phase change takes place across the jet exducer, and the rest of the components are designed for liquid phase only. For these types of two-phase expanders, the inlet condition must be subcooled (no vapour), and the phase change occurs across the last stage where the jet exducer is located. The overall isentropic efficiency of these turbines is approximately 80% at their best efficiency point.[5]

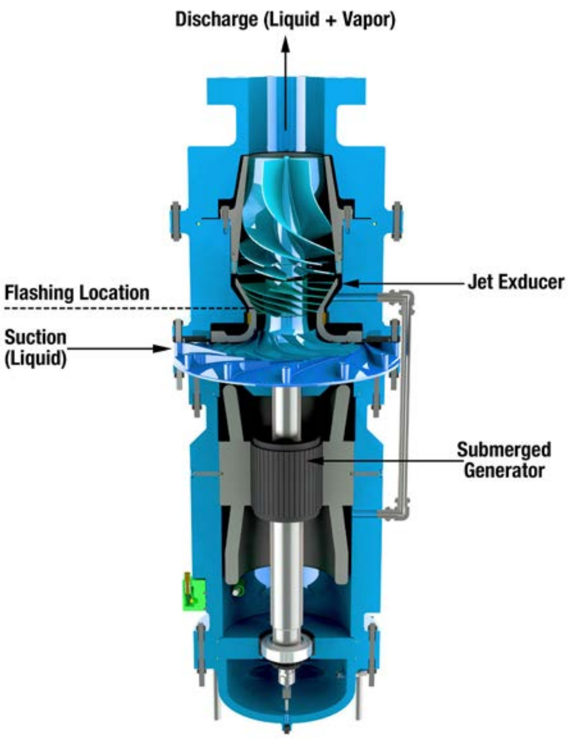

Figure 4. First generation Cryodynamics® two-phase (flashing) expander.

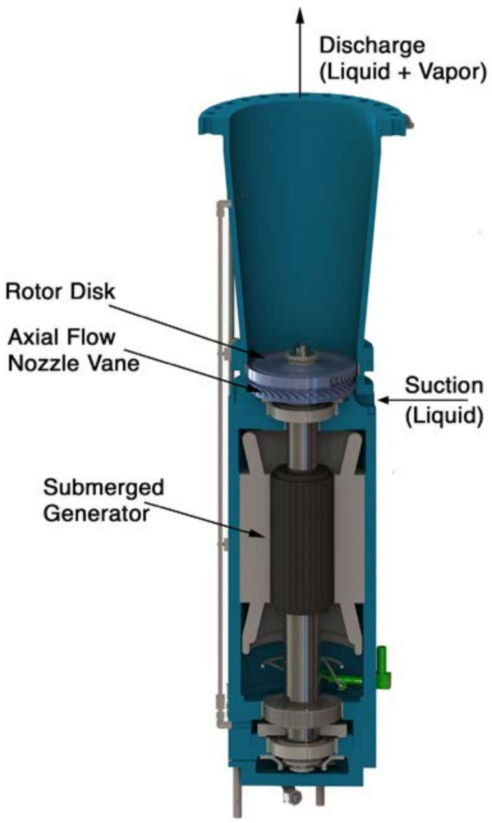

Figure 5. Elliott's second generation two-phase (flashing) expander.

For applications where the outlet vapour formation is in excess of 0.3 in terms of fluid quality, axial flow impulse-style expanders are preferred. These types of expanders can tolerate any vapour formation as long as the expansion does not result in a choke point in terms of the ratio of the fluid velocity with respect to the speed of sound. Elliott has been offering axial flow impulse expanders for steam applications since 1947 in their YR turbine product line. These turbines have axial flow impulse rotors (rotor bucket assembly) with inlet jets integrated into the nozzle ring that can handle both liquid and gas phases.[6] For applications with high torque and energy recovery, a reversing bucket assembly can be implemented along with a second rotor. Elliott's R&D team converted the flow path of these turbines into cryogenic two-phase expanders with submerged generators, which are now being offered in the field of liquefaction and refrigeration processes as two-phase flashing expanders with relatively high vaporisation capability in cryogenic hydrocarbon applications. Figure 5 shows the cross-sectional view of Elliott's second generation two-phase Cryodynamics expanders. The isentropic efficiency of these units is estimated to be approximately 60%, depending on the size (mass flow rate and pressure drop) of the unit. Both Francis and impulse two-phase cryogenic expanders have generator nameplate ratings ranging from 300 kW to 2.2 MW for a single unit. If the process requires high-flow output, these units can be installed and operated in parallel configuration.

Conclusion

Elliott's second generation Cryodynamics two-phase flashing expanders for LNG liquefaction, refrigeration, and separation processes improves the overall efficiency of each process. An LNG production gain of 3 – 7% is reported based on simulations and actual nitrogen rejection processes.[2,3,4] Each expander is custom designed and built to specific process requirements to enhance cooling, energy recovery, and improved LNG production. **LNG**

References

1. CENGEL, Y., BOLES, M., and KANOGLU, M., 'Thermodynamics: An Engineering Approach', 9th Edition, (20 March 2018).
2. YATES, D., 'Thermal Efficiency – Design, Lifecycle, and Environmental Considerations in LNG Plant Design', *Gastech 2002*, Doha, Qatar, (October 2002), https://static.conocophillips.com/files/resources/smid_016_thermal_efficiency.pdf
3. KARAKAS, E., and ROSS, S., 'Expanding LNG Options', *Hydrocarbon Engineering*, July 2021, (July 2021), https://issuu.com/palladianpublications/docs/hydrocarbonengineering_july_2021/s/12686084
4. KIMMEL, H., and BERGER, E., 'Flashing Two-Phase LNG Expanders', *AIChE Spring Meeting and Global Congress on Process Safety*, (2014), www.aiche.org/conferences/aiche-spring-meeting-and-global-congress-on-process-safety/2014/proceeding/paper/123e-flashing-two-phase-lng-expanders
5. KARAKAS, E., 'Gas and Hydraulic Turbine Specific Speed,' *LNG Industry*, November/December 2015, (November 2015).
6. ELLIOT, G. D., 'Theory and Tests of Two-Phase Turbines', *NASA – Jet Propulsion Laboratory*, (15 March 1982), www.osti.gov/servlets/purl/5346135.

MKT.5263.0623