Refocus the energy

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describe how liquid and two-phase expanders are designed to boost the efficiency of LNG liquefaction.

Natural gas continues to increase in use worldwide as an alternative fuel to coal and oil. LNG production increases accordingly as there is global trade between gas producing and gas consuming locations. LNG allows for safe and practical transportation of products, but it is a relatively energy-intensive process. Adding energy-generating expanders to the process can increase both plant efficiency and yield.

In the early 1990s, Elliott Group's Cryodynamic Products business introduced LNG expander technology, with a submerged generator, to the liquefaction process as an alternative to the commonly used Joule Thomson (JT) valves. Since then, Cryodynamic Products has continuously advanced cryogenic LNG expander technology in order to provide more capable, reliable, efficient, and compact units. Recently, Elliott's research and development group has focused on developing two-phase expanders to use in certain liquefaction and other processes, where liquid expansion beyond vaporisation is possible within the expander. This technology was first implemented in the late 1990s and has been used in an LNG plant with success for the purpose of nitrogen rejection to increase the thermal energy of the process liquid. In this article, the fundamentals of the two-phase (flashing) expander technology and the advantages of these expanders over the commonly used JT valves will be introduced.

Liquid and two-phase expanders in LNG liquefaction plants

A typical LNG liquefaction process is shown in Figure 1. The feed or lean gas compressor increases the natural gas pressure, and then a refrigeration cycle cools it to liquefy the gas prior to its pressure being reduced across a JT valve, or alternatively, through a liquid expander. The LNG liquefaction process requires the high-pressure LNG from the cooling process to be within an acceptable low-pressure range for safe storage and transport. The main idea of liquefaction is to store the LNG more effectively, as its density changes significantly based on its phase. The volume of the LNG liquid is approximately 1/600 of the gaseous volume at atmospheric conditions.[1] The outlet condition of the LNG expander for the last step of the liquefaction process is a liquid phase with a certain sub-cooling. Vapour formation must be avoided at this stage, since the boiled gas needs to be either burned via flare or fed back to the compressor for reliquefaction, which will result in a decrease in the overall process efficiency and reduced LNG production. A liquid expander can improve the efficiency of the process by removing more heat with respect to a JT valve during expansion. While the mechanical energy of the fluid is converted to electricity via the generator, enthalpy of the process fluid must decrease thermodynamically. This will result in improved cooling of the fluid, minimising the vaporisation. For every 1 million tpy in the liquefaction process, an expander can provide a return of up to US$17 million/y (with respect to a JT valve) in terms of LNG production and recovered electrical energy.[2]

For the aforementioned application of pressure reduction for safely storing the process fluid, a two-phase expander is not necessary. The cooling process of liquefaction, such as refrigeration of hydrocarbons in stages (methane, ethane/ethylene, and propane/propylene), can utilise two-phase expanders (flashing expanders), as in the ConocoPhillips Optimised Cascade process for LNG, or processes where the product is required to be refined by separation, such as the rejection of certain substances (heavy hydrocarbons or nitrogen).[1,3] During these processes, phase change can enhance the refrigeration process. Traditionally, a single-phase expander, utilised with a JT valve downstream, will achieve phase change as shown in the refrigeration cycle in Figure 1. A two-phase expander can replace the single-phase expander configuration (along with the JT valve) to further improve the isentropic efficiency of this process. Figure 2 is a simplified schematic view of the ConocoPhillips Optimised Cascade process. Each cold box, which is fundamentally a heat exchanger, cools the natural gas by using propane, ethane, and methane refrigeration loops in stages.

There is a pressure reduction, and process fluid at each loop expands across JT valves. For each loop, it is common to have multiple stages of cooling, which requires more than one JT valve for each process fluid. Expansion across the JT valve is isenthalpic, such that there is no enthalpy change across the valve and no energy is being recovered. Figure 3 shows the difference of expansion in terms of enthalpy and pressure change with a liquid-only expander and JT valve compared to a two-phase expander.

The key difference between each case in Figure 3 is the magnitude of the change in enthalpy, which often relates to the amount of cooling and isentropic efficiency of the process. In the case of a two-phase (flashing) expander, the change in (h_{inlet} – h_{outlet}) enthalpy is much greater. This will result in a much colder fluid at the exit of the expander. In terms of thermodynamic comparison, there is a clear advantage of implementing a two-phase expander to each refrigeration cycle. However, there are challenges in the machine design, as some of the internal components cannot tolerate cavitation and bubble formation. The next section outlines the internals of the two-phase expanders and describes some of the specific components that Cryodynamic Products uses in two-phase expanders.

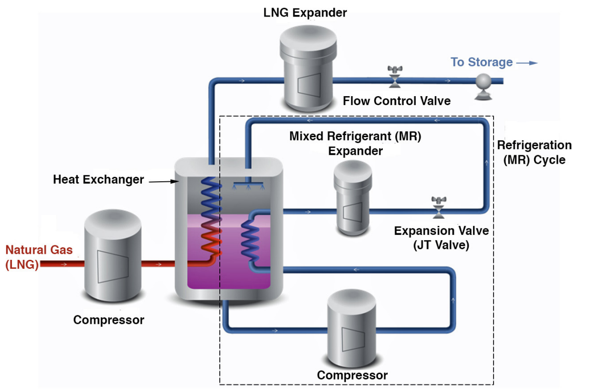

Figure 1. Typical schematic view of the liquefaction process.

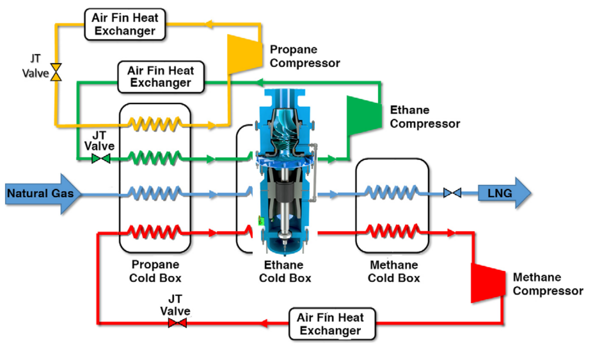

Figure 2. Schematic view of the ConocoPhillips Optimised Cascade process.

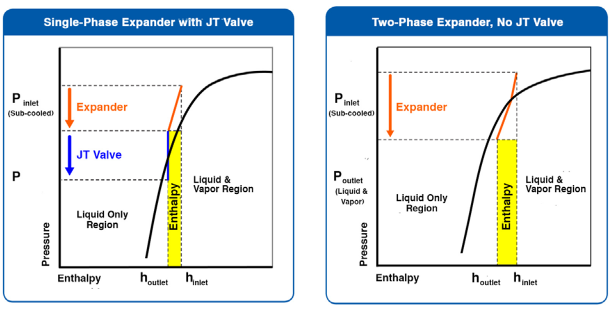

Figure 3. Pressure vs enthalpy for a single-phase expander with a JT valve and two-phase expander.

Two-phase expanders

Cryodynamic Products designed and built the first two-phase flashing expander as a prototype in 2000, and it has been in operation ever since. The reliability of this unit met and exceeded the customer's expectations, such that the customer added additional two-phase expanders to its process. All of these units are used in nitrogen rejection facilities to improve the efficiency of the cooling (refrigeration) cycle. An increase of 3 - 5% in LNG production for this particular application has been reported.[2] These units are designed to handle outlet fluid quality (vapour mass/total fluid mass) of 0.2 at most. This is to ensure the vapour formation is limited to the certain hydraulic

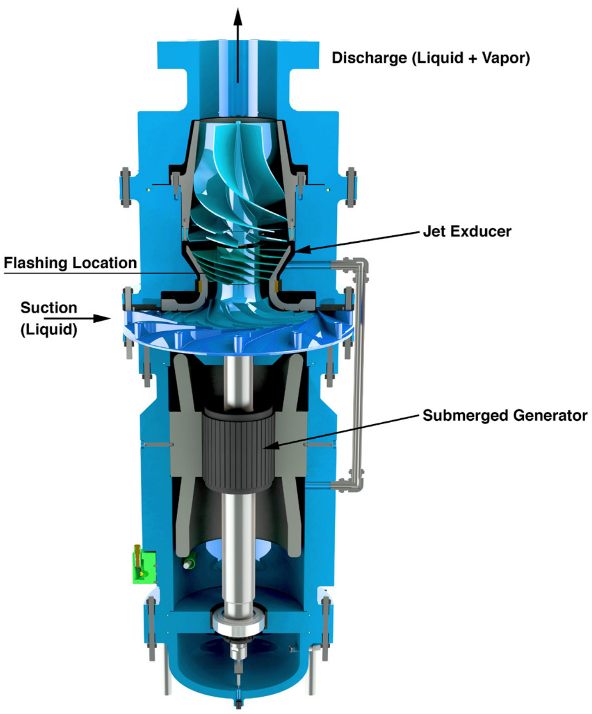

Figure 4. Francis-type radial inflow two-phase (flashing) expander.

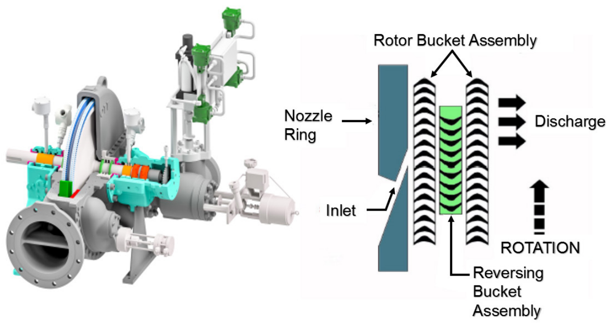

Figure 5. Axial flow impulse YR turbines.

components within the expander. As previously mentioned, Cryodynamic Products' cryogenic expanders have a submerged generator design in order to eliminate the need for a mechanical seal between the generator and the hydraulics. This design feature can greatly minimise reliability issues and eliminate the need for hazardous area certification for the generator and related electrical components that are submerged in the process fluid. Figure 4 shows a cross-sectional view of Cryodynamic Products' first two-phase expander. This unit is fundamentally a radial inflow Francis-type turbine with a jet exducer located toward the outlet of the machine, which 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 the liquid phase only. For these types of two-phase expanders, the inlet condition must be subcooled (no vapour), and phase change occurs across the last stage where the exducer is located. The overall isentropic efficiency of these turbo expanders is approximately 80% at their best efficiency point (BEP).[4]

For applications where the inlet condition is a saturated liquid with a certain amount of vapour, axial flow impulse-style expanders are preferable. 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 Group has been offering axial flow impulse expanders for steam applications since 1947. 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.[5] For applications with high torque and energy recovery, a reversing bucket assembly can be implemented along with a second rotor. Figure 5 shows a cross-sectional view of a typical YR steam turbine. Elliott Group's R&D team is now converting the flow path of these turbines into cryogenic two-phase expanders, which will be offered in the field of liquefaction and refrigeration processes as two-phase flashing expanders with relatively high vaporisation capability in cryogenic hydrocarbon applications. The isentropic efficiency of these units is estimated to be approximately 60% depending on the size (mass flowrate and pressure drop) of the unit. Both of Elliott's Francis and impulse 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.

Conclusions

Two-phase (flashing) expanders can be used as an alternative to commonly used JT valves to improve the overall efficiency of LNG liquefaction and other processes in LNG applications. Depending on the process requirements, in terms of the amount of vapour at the expander's outlet or inlet, an axial impulse or a Francis-type radial inflow expander can be implemented to meet the specific thermodynamic and overall performance requirements. Two-phase (flashing) expanders can not only enhance the efficiency of the process by better cooling with respect to a JT valve, they also recover the process fluid's hydraulic (mechanical) energy and convert it to electrical energy. **LNG**

References

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