Cover Story

ON THE UP

Michael Cords, Ebara International Corporation, USA, presents the benefits of upward flow cryogenic liquid expanders.

Cryogenic liquid expanders have become an important component in the liquefaction process train. Used in lieu of a Joule-Thomson valve, a cryogenic liquid expander typically increases liquefied natural gas (LNG) production by 3 - 5%. With such a valuable return on investment, it is no wonder that cryogenic liquid expanders have become virtually standard equipment for new LNG production plants.

A fierce development pace continues as the machines have grown in capacity, differential head and power generation. A number of design improvements have been made to the overall configurations to maintain this development pace and improve performance. One of the latest and most beneficial improvements is the upward flow configuration (bottom inlet, top outlet). By changing the direction of the flow, several advantages can be gained.

History

The first generation cryogenic liquid expander was put into service at the Malaysia LNG Dua plant in 1996.[1] The machine featured variable geometry inlet guide vanes (wicket gates) and an external generator. The second generation of cryogenic liquid expanders was introduced by Ebara International Corporation (EIC) in 1999 at the Oman LNG plant and presented a different approach to the technology. EIC's machine incorporated a submerged generator mounted on a common shaft to the hydraulic components. The performance was controlled via variable speed drive. Both generations of machine utilised a downward flow configuration, which was an extension of the concept from the original prototypes based on a reverse running pump.

The next major evolution in the product line occurred in 2003 with EIC's delivery of the two phase (gas and liquid) cryogenic liquid expander to the Polish Oil and Gas Krio plant. Further evolution of the design was continued with the installation of additional two phase expanders to the same site (Figure 1). In nitrogen rejection service and with the requirement for the machine to operate at up to 50% vapour by volume, the downward flow configuration presented a serious problem. As vapour forms, it naturally tends to rise and travel against the direction of the flow within the machine. This can lead to disruption of the flow path, unsteady operation and negative effects on machine performance and lifetime. The simple solution of reversing the orientation of the machine mitigated these issues.

With the introduction of the upward flow two phase expander, the logical question arises: Would the upward flow configuration provide any improvements to the standard cryogenic liquid expander? As it turns out, there are significant advantages that are obtained with any liquid expansion service by incorporating an upward flow configuration.

Proven technology

The basis of the upward flow expander is derived from the proven downward flow configuration. The difference is in the mounting configuration of the expander within the containment vessel. The rotating assembly and the hydraulic design remain the same, regardless of orientation. This is simplified in those machines that have a submerged generator. There is no need for the shaft to exit the vessel, thus the change in orientation is achieved entirely with the configuration of the expander casings to allow the desired mounting. Internal components (such as bearings and wear rings), materials and cooling/lubrication concept remain unchanged (Figure 2).

The site civil engineering and piping interface of a submerged cryogenic liquid expander is limited to the containment vessel. The configuration of the expander within the vessel impacts only the inlet and outlet connection nozzles; top inlet/bottom outlet for a downward flow expander and bottom inlet/top outlet for an upward flow expander (Figure 3). The existing technology developed from over 90 submerged cryogenic liquid expanders delivered to date is directly applicable to the upward flow configuration. The technological stepout is limited.

Natural pressure gradient

Liquid expansion is a natural occurrence seen in everyday life. From thermal geysers to teapots to champagne bottles, liquid expansion occurs in an upward direction. The pressure gradient tends to align with gravity such that lower pressure liquid rises above higher pressure liquid. In a typical downward flow expander, the induced pressure gradient through the machine is opposed to the liquid's natural tendency to align with gravity. Though small, the machine must fight this tendency to push the expanding liquid out the bottom.

By reorienting the expander in an upward flow configuration, the induced pressure gradient of the hydraulics is aligned with the natural pressure gradient of liquid expansion. There is no counterbalance of forces to compete with the desired operation of the hydraulics. When compressibility of the liquid is considered, the buoyant force of the lower density liquid at the outlet is also properly aligned with the flow direction in an upward flow expander.

Figure 1. Upward flow two phase cryogenic liquid expander as delivered to Polish Oil and Gas, 2003.

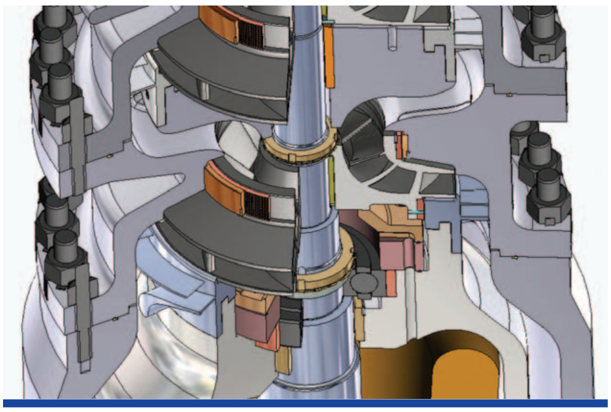

Figure 2. Cutaway of expander hydraulic section.

Performance advantage

In a typical LNG process train, the high pressure liquid exits the main cryogenic heat exchanger (MCHE) and undergoes an isentropic Joule-Thomson expansion through the cryogenic liquid expander. Downstream of the expander further expansion will take place across a control valve before the liquid/vapour is separated in an end flash unit. The amount of expansion occurring across the expander is controlled via the desired outlet pressure required for the process. Even with higher outlet pressures there is a small amount of vapour formation due to localised losses as the expansion process is not perfectly isentropic. Vapour formation within the typical downward flow expander is limited to avoid potential reliability issues due to fluid turbulence and component cooling.

Ideally, the desired expansion should occur mostly within the expander rather than through the downstream valve. The reason is the greater efficiency of the expander to generate condensate product for a given pressure drop. The higher the proportion of desired expansion through the expander, then the greater the LNG production of the process train. In other words, the LNG production can be increased with a decrease of the expander's outlet pressure. An upward flow expander can operate with lower outlet pressure due to its ability to handle increased vapour percentage at the outlet, providing an increase in LNG production over an equivalent downward flow machine.

As discovered from the development of the two phase cryogenic liquid expander, an upward flow expander can tolerate a larger percentage of vapour at the outlet, i.e. lower outlet pressure. The components that are most susceptible to effects of vapour (e.g. the main bearings and in the case of a submerged generator, the generator itself) are located below the main hydraulic flow such that any vapour formed at the outlet travels upward with the flow stream and away from these components.

Another advantage of upward flow with respect to vapour formation is the inherent anti cavitation property. Cavitation is a negative phenomenon whereby the formation of vapour bubbles collapses under pressure. The energy released under this collapse can damage components and also results in undesirable flow turbulence and vibration. With the continuously decreasing pressure gradient aligned with the natural tendency of vapour bubbles to rise, the vapour bubbles are never subjected to an increase in pressure, therefore the bubbles do not have a chance to collapse and cavitation is avoided.[2]

Even in single phase expansion, an upward flow expander can operate with lower outlet pressure such that the ever present residual vapour formation has no negative impact. A lower outlet pressure leads to more liquid production for a given feed gas volume. This results in increased production flexibility providing a larger available operating range for the production train.

Thrust balance

In an expander, there is a significant amount of axial thrust load developed. All expanders must balance this thrust load either with thrust bearings or with a hydraulic balance system. In a downward flow machine, this thrust load is in the downward direction. The weight of the rotating assembly is downward due to gravity, so the balance method must counteract the combined thrust load and assembly weight.

By contrast, an upward flow machine has the liquid momentum thrust in an upward direction. The net axial load required to be balanced by the thrust bearings or hydraulic balance system is the difference between the thrust load and assembly weight. In other words, the weight of the rotating assembly assists in reducing the net axial thrust load. The balancing load required by the thrust bearing or the balance system is reduced by twice the rotating assembly weight compared to an equivalent downward flow machine. For a large machine, say over 1.5 MW, this is not insignificant.

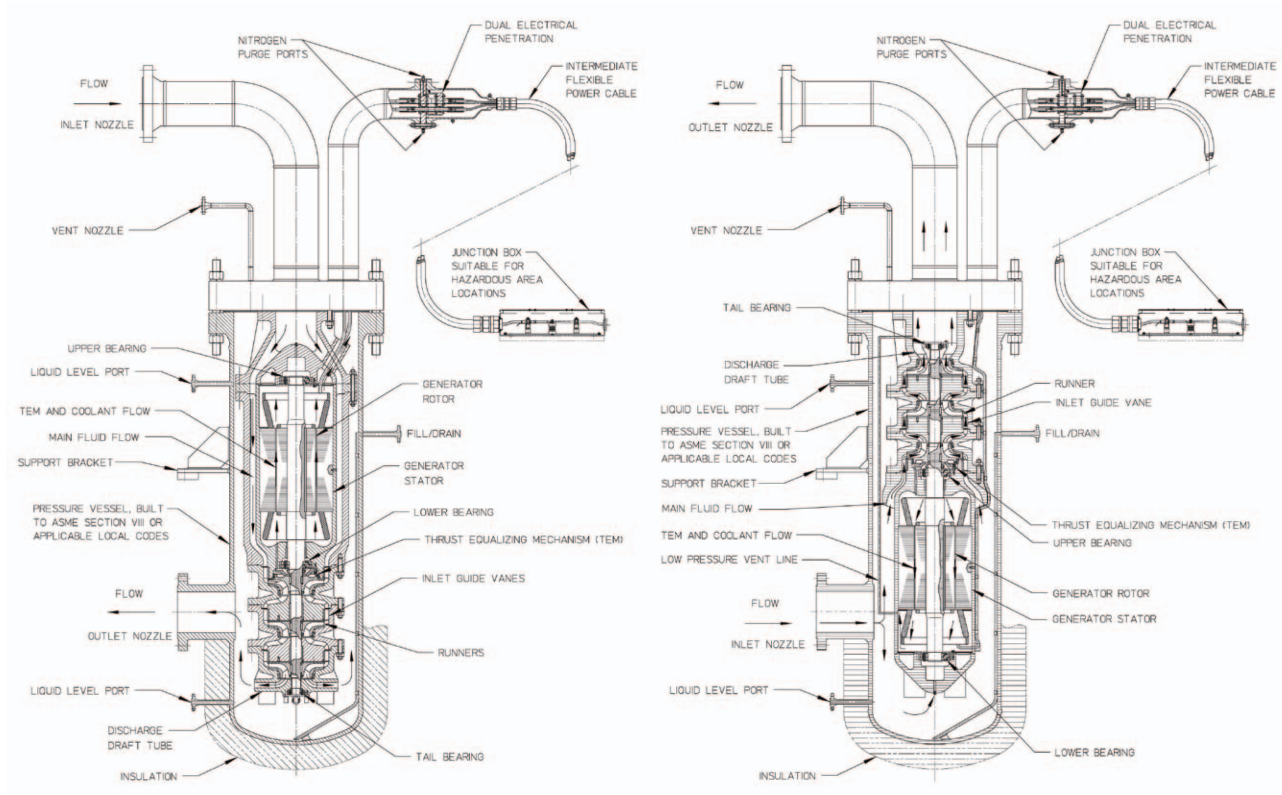

Figure 3. Comparison of downward flow configuration (left) and upward flow configuration (right).

Considering the case of a submerged generator cryogenic liquid expander, there is another advantage in the form of improved efficiency. All submerged cryogenic machines utilise some form of hydraulic balance system. This may be a balance drum, impeller/runner balance holes, or EIC's Thrust Equalising Mechanism (TEM®). Each method requires some parasitic flow to be routed through the balance system. Because the resulting thrust to be balanced is less in an upward flow machine, the required balance flow is also reduced. This means that more flow is expanded through the machine rather than routed internally for balance, resulting in less internal losses and increased efficiency.

Two phase adaptability

Because an upward flow expander shares the same general configuration with the two phase cryogenic liquid expander, the line separating the two is blurred. The upward flow expander can handle increased vapour formation at the outlet, as operation within the two phase region is desired. A two phase expander combines the isentropic expansion and the end flash in one machine.[3] The key feature of the two phase expander is the jet exducer installed as the final stage component to extract the energy of the two phase expansion. An upward flow expander only needs to include the addition of the jet exducer component to allow deliberate operation in the two phase region.

It is possible to include the provision of a space for the future installation of a jet exducer. That is, the upward flow expander need not be initially designed as a two phase expander. As the process requirements change throughout the life of the plant, the requirements of the expander may change as well. At any point in the life of the machine, it may be retrofitted for two phase operation. This retrofit is performed during routine maintenance of the expander. The external containment vessel and associated piping remain unaffected. The upward flow expander becomes a versatile machine whose performance characteristics can be dramatically altered as needs arise, with minimal impact to civil engineering and piping requirements. Such flexibility allows adaptation to changing conditions of the process train, making an upward flow expander ideal for future debottlenecking.

Mechanical robustness

A necessary hazard for any plant during the initial months after commissioning is the presence of construction debris in the piping. It is not unknown for a machine to suffer damage due to the presence of sand, weld splatter and other fine debris. A fine mesh filter is commonly used upstream of certain equipment to offer protection, though routine maintenance of the filter is required to prevent clogging.

The upward flow configuration has the benefit of the inlet piping feeding to the containment vessel as compared to a typical downward flow machine where the inlet piping feeds directly to the internals of the expander. For the upward flow configuration, debris has the opportunity to settle into the bottom of the vessel and is less likely to make its way into the internals of the expander, thus protecting the tight running clearances and critical components, such as bearings.

Conclusion

While necessary for the development of the two phase cryogenic liquid expander, an upward flow configuration offers many benefits to the standard cryogenic liquid expander as well. By orienting the expander flow in the direction of the natural pressure gradient, improvements in efficiency, thrust balancing, mechanical wear and tear as well as elimination of cavitation can be achieved. Risk is minimised by maintaining the internal machine and hydraulic design that has been field proven over the last decade since the introduction of cryogenic liquid expanders.

While cryogenic liquid expanders are a relatively young product in the rotating machine business, their benefit has been well established. With each new generation of expander providing improvements upon its predecessor, new areas of development are opened up and the liquefied gas industries reap rewards. The upward flow expander is just the latest development in an exciting and promising product line.

References

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3. KIKKAWA, Y. et al, 'Completing the Liquefaction Train by Using Two-Phase LNG Expanders', AIChE Spring National Meeting, 2009.