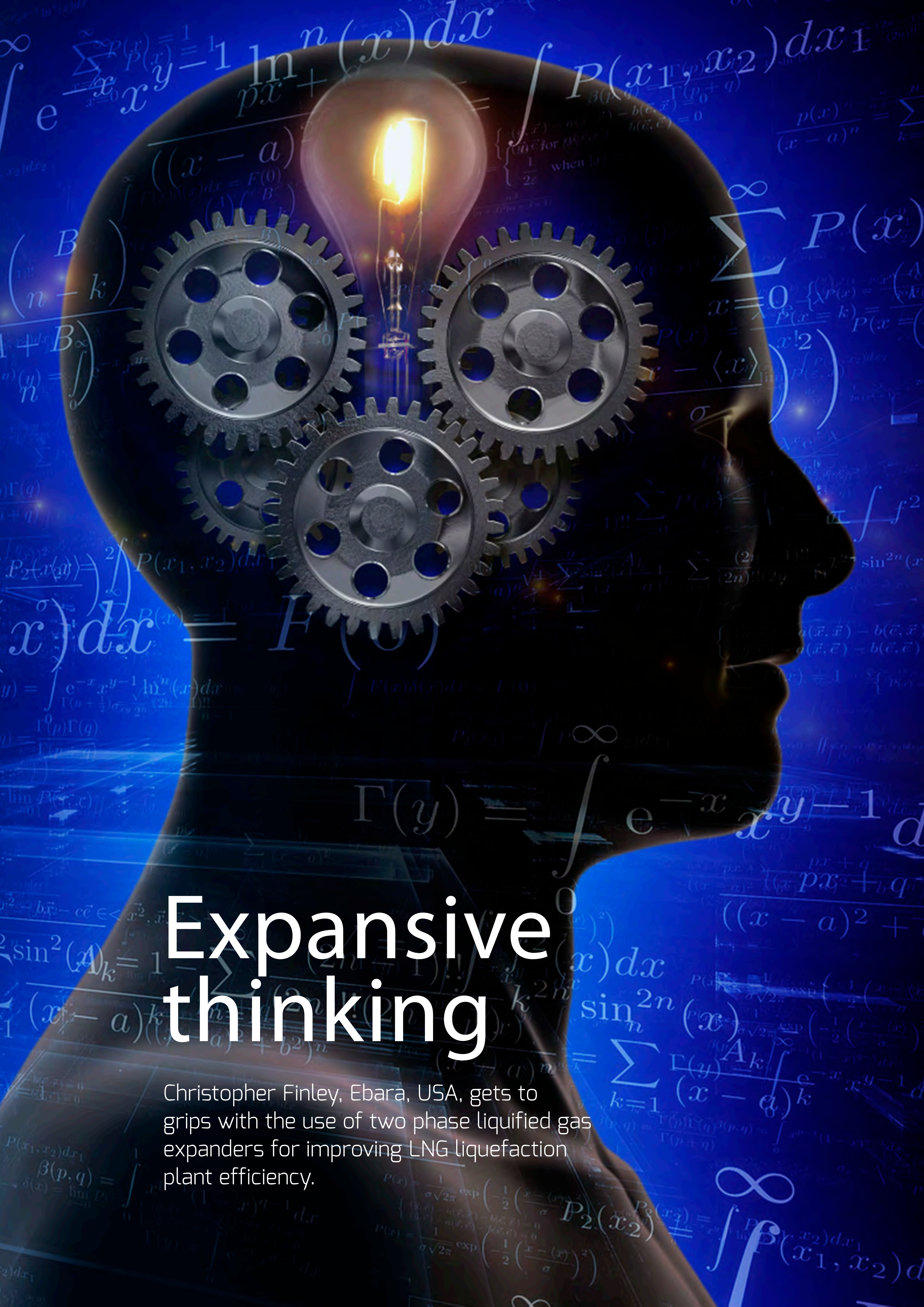

Expansive thinking

Christopher Finley, Ebara, USA, gets to grips with the use of two phase liquified gas expanders for improving LNG liquefaction plant efficiency.

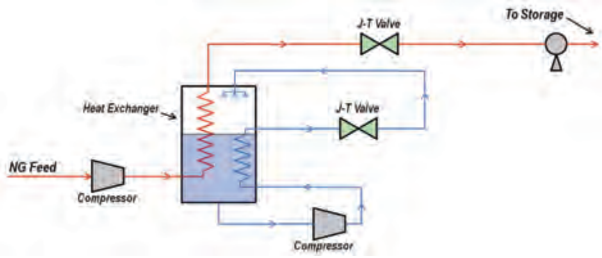

Figure 1. Simplified isenthalpic liquefaction process.

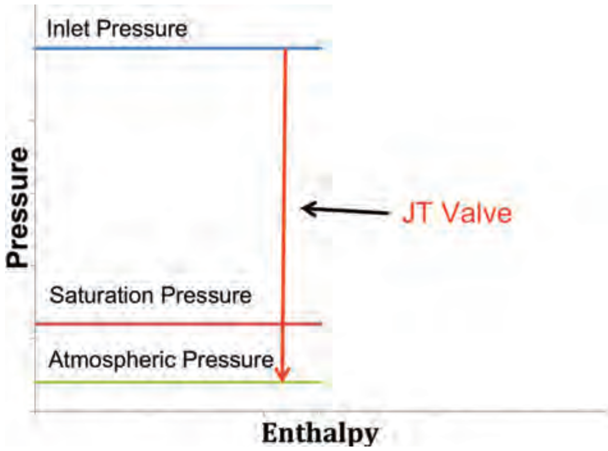

Figure 2. P-h diagram of J-T valve pressure reduction.

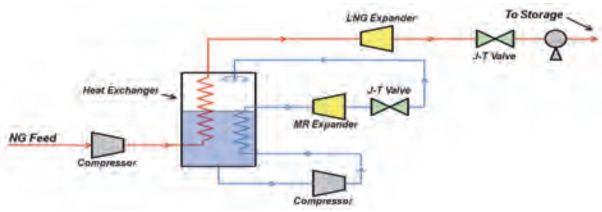

Figure 3. Liquefaction process with single phase cryogenic expanders.

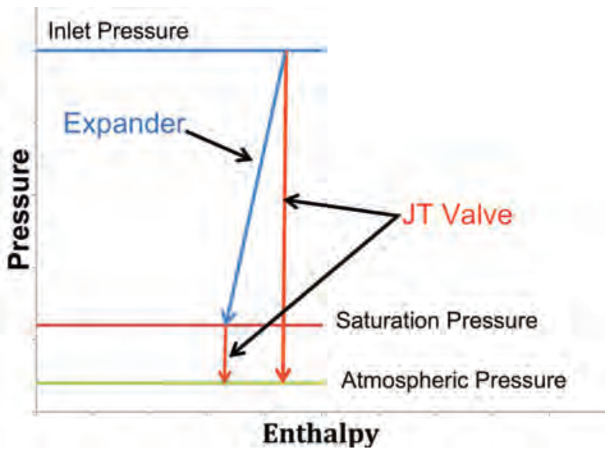

Figure 4. P-h diagram of liquefaction process with cryogenic expander.

LNG liquefaction plants have utilised cryogenic expanders for years to improve their overall efficiencies. By reducing a portion of the pressure of the LNG and mixed refrigerant streams across an expander instead of a Joule-Thomson (J-T) valve, the enthalpy of the stream is reduced, resulting in lower boil off losses and cooler outlet temperatures. Traditionally, these expanders only reduced the pressure of the LNG and mixed refrigerant streams to a value above the saturation pressure, to avoid any possible vapour generation within the machine. The final pressure reduction was then achieved by flashing the expander outlet stream across a J-T valve in an isenthalpic process.

To increase liquefaction process efficiency even further, Ebara International Corporation has developed a line of two phase cryogenic expanders able to operate with outlet pressures below saturation. These expanders are similar in technology to the company's single phase expander design, however the addition of one rotating stage called an exducer and one fixed hydraulic stage, the condensation cone, helps extract the additional energy generated during the vapourisation process. By reducing the outlet pressure of the expander below the saturation pressure, the overall process efficiency is increased, while the need for a downstream J-T valve during normal operation is eliminated.

Expander background

To liquefy hydrocarbon gasses for storage and transportation, liquefaction plants use various techniques to cyclically compress and cool the gas until it liquefies. This results in a liquefied gas that is both high pressure and low temperature. As most storage and transport equipment requires that the liquid be at or near atmospheric pressures, the liquefied gas' pressure must be reduced. Until the mid 1990s, this expansion was performed solely through J-T valves in an isenthalpic process.

After expanding through a J-T valve, the final pressure is low enough for storage, however the isenthalpic process results in no change to the internal energy of the process liquid. Because the final pressure of the liquid is below the saturation pressure, a certain portion of the liquid vapourises and must be either recompressed or flared off as waste.

Process and equipment engineers began to address these boil off losses in the mid 1990s by installing single phase cryogenic liquid expanders upstream of the J-T valve. These expanders reduce the pressure of the liquefied gas stream in a near isentropic process, thereby lowering the enthalpy of fluid. The reduction in enthalpy then results in reduced boil off waste, colder liquid temperatures, and electricity generation, improving the liquefaction site's overall efficiency by as much as 5%.

The first cryogenic expanders produced by Ebara International Corporation (1997) were based on previous decades of cryogenic submerged pump technology. This technology includes hydraulic axial thrust balancing, variable speed controllers and a sealless, submerged expander and generator assembly. Since their first installation, these types of expanders have become standard equipment throughout the world.

In specific terms, the value of the reduced boil off waste is directly related to the price of the liquefied gas and the size of

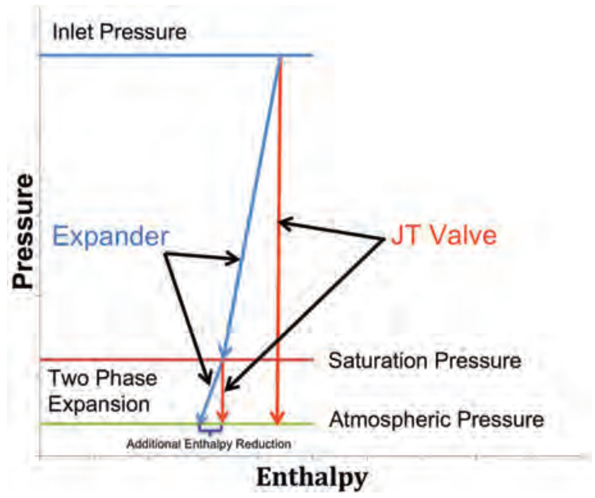

Figure 5. P-h diagram of two phase expansion.

Table 1. Reclaimed LNG/y, single phase

Tpy				
4 million	US$ 30 806 938	US$ 38 508 672	US$ 46 210 407	US$ 61 613 876
3 million	US$ 23 105 203	US$ 28 881 504	US$ 34 657 805	US$ 46 210 407
2 million	US$ 15 403 469	US$ 19 254 336	US$ 23 105 203	US$ 30 806 938
1 million	US$ 7 701 734	US$ 9 627 168	US$ 11 552 602	US$ 15 403 469
	→ → Thousand btu → →			
	US$ 8	US$ 10	US$ 12	US$ 16

Table 2. Energy savings/y, single phase

Tpy				
4 million	US$ 2 055 764	US$ 2 305 789	US$ 2 480 049	US$ 2 500 253
3 million	US$ 1 541 823	US$ 1 729 342	US$ 1 860 037	US$ 1 875 190
2 million	US$ 1 027 882	US$ 1 152 894	US$ 1 240 024	US$ 1 250 126
1 million	US$ 513 941	US$ 576 447	US$ 620 012	US$ 625 063
	→ → Electricity (US$) kW hrs → →			
	US$	US$	US$	US$
	2005	2007	2009	2011

Table 3. Total annual savings, single phase

Tpy				
4 million	US$ 32 862 701	US$ 40 564 436	US$ 48 266 170	US$ 63 669 639
3 million	US$ 25 160 967	US$ 30 937 268	US$ 36 713 569	US$ 48 266 170
2 million	US$ 17 459 232	US$ 21 310 100	US$ 25 160 967	US$ 32 862 701
1 million	US$ 9 757 498	US$ 11 682 932	US$ 13 608 365	US$ 17 459 232
	→ → Price of electricity and gas → →			

Table 4. Total annual savings, two phase

Tpy				
4 million	US$ 35 336 238	US$ 43 886 517	US$ 52 355 329	US$ 68 939 923
3 million	US$ 26 502 179	US$ 32 914 888	US$ 39 266 497	US$ 51 704 943
2 million	US$ 17 668 119	US$ 21 943 259	US$ 26 177 664	US$ 24 469 962
1 million	US$ 8 834 060	US$ 10 971 629	US$ 13 088 832	US$ 17 234 981
	→ → Price of electricity and gas → →			

the liquefaction facility. Table 1 describes the potential annual savings of installing a cryogenic expander as a function of liquefaction train size and liquefied gas price.

In addition to the reduction in boil off gas, the cost of the electricity produced can also provide significant value. Table 2 shows the annual value of the electricity produced for various liquefaction train sizes and electrical costs. In total, the annual (estimated) savings as a result of utilising a single phase liquid expander are described in Table 3.

Upward flow expander

The design of the first generation of cryogenic expanders was based on reverse running pumps that were used as prototypes during the initial development of cryogenic expander technology. As such, the flow direction of these expanders is from the top down (submerged cryogenic pumps flow from the bottom up). As development of cryogenic expanders continued, it was proposed that changing the flow direction provided several benefits over the traditional downward flow design.

To understand the benefits of the upward flow cryogenic expander, one must first understand the fluid density distribution within the machine. Due to the design of cryogenic liquid expanders, the fluid's pressure is continuously decreased from the inlet to the outlet. This causes the fluid's density to be at its highest at the expander inlet (at the top of the machine), and its lowest at the expander outlet (at the bottom of the machine). This density distribution causes the sum buoyant forces to act in an upward direction, which goes against the flow in downward flow cryogenic expanders. Although small, this force reduces the potential efficiency of the expansion process. By changing the flow direction to upward, the fluid's buoyant forces become aligned with the expander flow direction, improving overall efficiency.

Another benefit realised in upward flow expanders is a reduction in the force necessary to balance the hydraulically induced axial thrust. In downward flow cryogenic expanders, the force caused by the weight of the rotating element and the hydraulically induced axial thrust are both in the downward direction. In upward flow machines however, the hydraulically induced axial thrust is in the upward direction. This difference results in a reduction in the required balancing force of two times the weight of the rotating assembly.

To ensure that the expander's bearings do not experience any axial thrust loading, a portion of the operating fluid is used to hydraulically balance this thrust, resulting in no axial load on the expander bearings. This system, called the Thrust Equalizing Mechanism (TEM®), automatically adjusts to varying flow and pressure conditions. As the portion of the fluid used to balance the thrust bypasses the expander runner, it can be considered a parasitic loss. The amount of fluid required to balance the thrust is proportional to the amount of thrust to balance. This means that the lower required

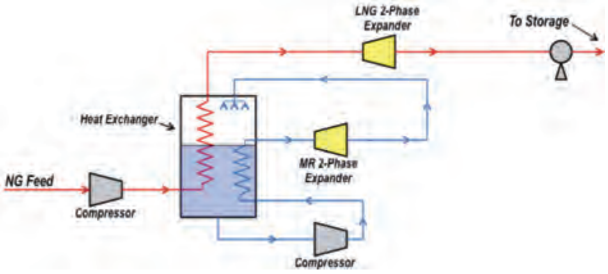

Figure 6. Simplified liquefaction process using two phase expanders.

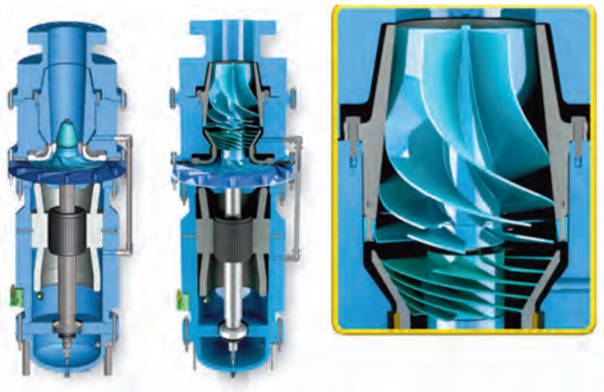

Figure 7. Cutaway comparison of single phase and two phase expanders.

balancing force for upward flow expanders results in improved expander efficiency.

Two phase expander

As process engineers look to improve the efficiency of their liquefaction trains, the differential pressure across cryogenic expanders is continually increased by lowering the outlet pressure. This increases the ratio of expansion across the expander as compared to the J-T valve, which lowers the enthalpy and further improves the overall efficiency of the system. Eventually, when the outlet pressure is reduced below the saturation pressure of the liquefied gas, traditional single phase liquid expanders can no longer be used.

To address this issue, Ebara International Corporation has developed a line of two phase cryogenic expanders. These types of expanders are designed to accept liquid at the inlet and can expand the fluid to over 50% vapour by volume. This enables process engineers to drop the full pressure required to achieve atmospheric outlet pressure without the need of a downstream J-T valve during normal operation.

There are several advantages of installing two phase expanders instead of single phase expanders with downstream J-T valves. The first advantage is an increase in process efficiency. As compared to single phase expanders, two phase expanders can drop the pressure of the inlet stream 5 – 10% further, resulting in more enthalpy reduction. With less enthalpy at the expander outlet, boil off losses are reduced while the electrical output of the expander generator is increased. This gives up to 10% more savings on an annual basis.

Another advantage of installing two phase expanders is that the liquefaction process under normal operation becomes simpler. As single phase expanders are not capable of handling two phase flow, downstream J-T valves are used to control the outlet pressure of the expander. This means that as pressure and flow conditions change at the expander inlet, downstream J-T valves must be continuously adjusted to ensure the outlet pressure of the expander remains above the saturation pressure of the operating liquid. When two phase expanders are installed, these downstream J-T valves are no longer required during normal operation, simplifying the process and reducing the amount of adjustment necessary.

The final benefit of these two phase expanders is that the technology is based on proven designs with years of operating experience. In fact, the difference between a standard single phase expander and a two phase expander is only two machine components: the rotating jet exducer and the stationary condensation cone.

In two phase expanders, the jet exducer is the final expansion stage of the machine. The jet exducer's design takes the axial fluid flow from the last expander runner stage and translates it to radial flow counter to the rotation of the expander, thereby adding additional torque to the expander shaft. The passages of the exducer blades are continuously diverging, causing the fluid's pressure to be reduced as it flows through. As the fluid's pressure is reduced through the exducer, it begins to vapourise, increasing its volume as well as its velocity. This high velocity flow acts as a jet, increasing shaft torque, which translates to higher generator power output.

Once the two phase flow exists, the exducer in the radial direction, it flows through a stationary condensation cone. The design of the condensation cone translates the high velocity radial two phase flow to axial low velocity flow. During this process, the kinetic energy of the fluid is converted back to pressure. This slight increase in pressure within the final stage of the two phase expander recondenses a portion of the two phase flow, resulting in even less boil off losses downstream.

Conclusion

As process engineers strive to improve the efficiency of gas liquefaction facilities, the demand for new equipment technologies has increased. By relying on decades of cryogenic rotating machinery experience, Ebara International Corporation has developed a full line of two phase liquefied gas expanders. The benefit of these machines has been shown to improve overall liquefaction process efficiencies by over 5% and simplify process controls and equipment, while virtually eliminating the reliability risks normally seen with new machine technologies.