



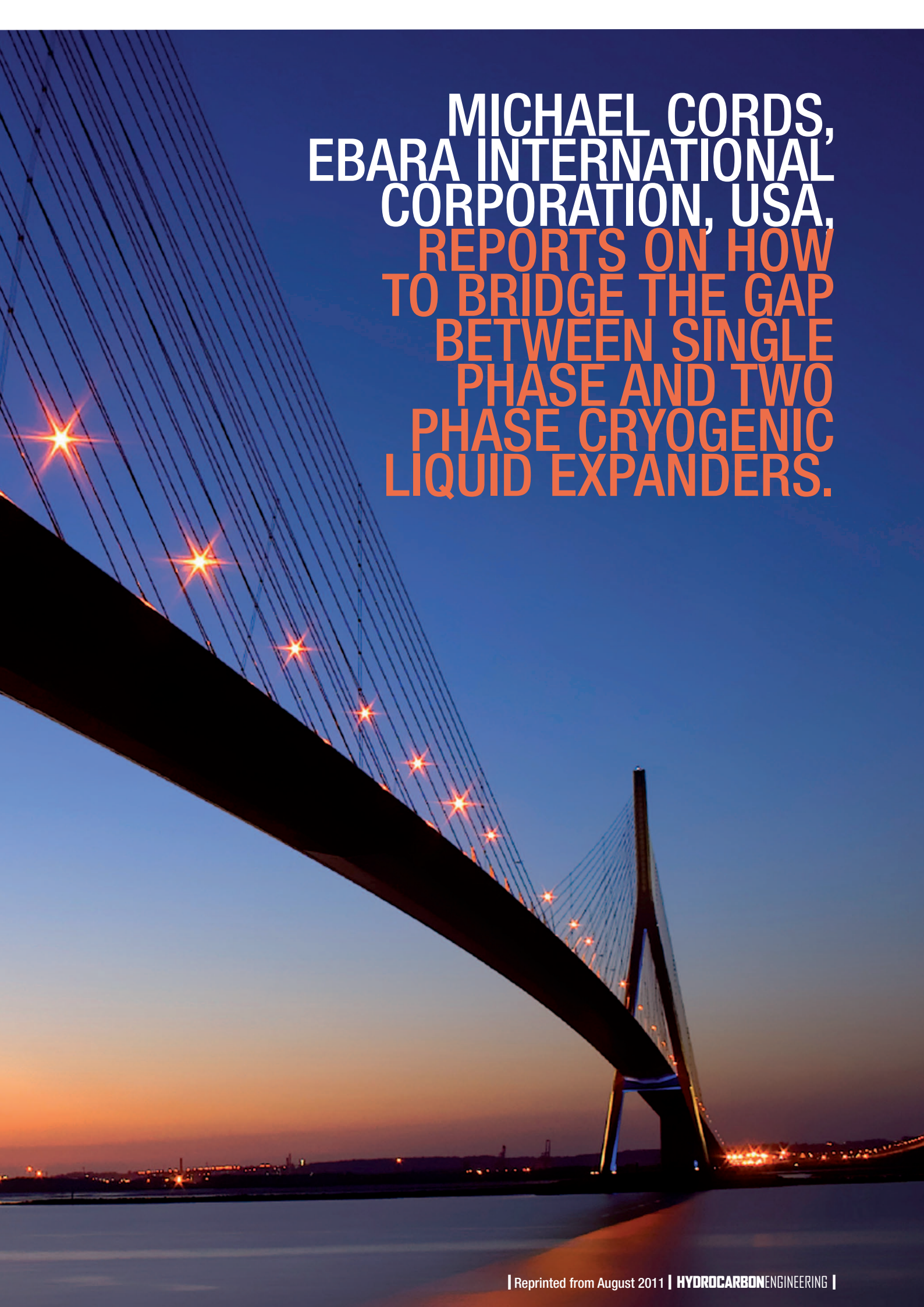
# BRIDGING THE GAP

**C**ryogenic liquid expanders come in a variety of forms. Though relatively small at just over 100 units, the fleet of installed expanders features variable geometry wicket gates, variable speed operation, external air cooled generators, submerged generators, downward flow and two phase operation.

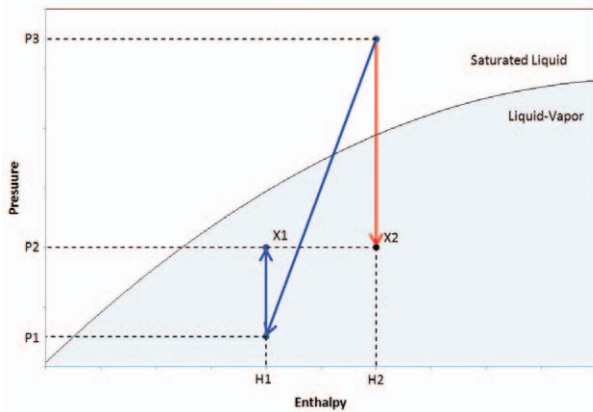
Previously Ebara discussed several of the benefits of the latest configuration; an upward flow liquid expander ('On the Up', *Hydrocarbon Engineering*, July 2010). In part two, the author will take a closer look at the relations between the standard downward flow liquid expander and the two phase expander, along with how the upward flow configuration bridges the gap between the two.

## Review

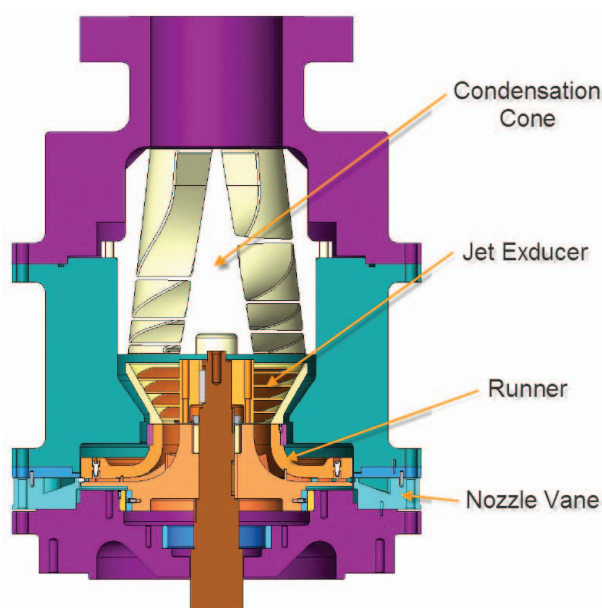
An upward flow cryogenic liquid expander is, in essence, a standard submerged generator liquefied gas expander oriented in the opposite direction. Process liquid through the machine enters from the bottom and expands as it travels upward out the top, rather than the typical downward direction. This upward



**MICHAEL CORDS,  
EBARA INTERNATIONAL  
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REPORTS ON HOW  
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BETWEEN SINGLE  
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PHASE CRYOGENIC  
LIQUID EXPANDERS.**



**Figure 1.** Pressure enthalpy diagram comparing a Joule-Thomson valve (red) to a two phase cryogenic liquid expander (blue).



**Figure 2.** Hydraulic components of a two phase liquid expander.

orientation has many benefits over the standard downward flow expander installed in today's LNG liquefaction plants.

Upward flow allows liquid expansion to occur in its natural direction, not unlike a kettle or a champagne bottle. That is, the natural pressure gradient within the machine is properly aligned with gravity. Any vapour bubbles formed do not collapse under cavitation as the pressure gradient is always decreasing in the flow direction. Upward flow configuration also aids the thrust balance mechanism as the rotating assembly weight acts opposite to the thrust forces. Another benefit is the fact that the expander's containment pressure vessel accepts the incoming flow prior to the expander inlet. This inhibits any debris in the fluid from entering the tight clearance and high velocity areas of the machine, thus protecting it from potential mechanical damage.

Finally, an upward flow expander can take advantage of operating at a lower outlet pressure, thereby providing greater liquid expansion. It is here that the opportunity of two phase liquid expansion exists. Existing two phase liquid expanders utilise the upward flow configuration, and by understanding how they work, a comparison to a single phase upward expander can be viewed.

## Two phase liquid expander

In an LNG liquefaction train, liquid expanders are installed downstream of the main cryogenic heat exchanger (MCHE) to reduce the high pressure liquid gas to near atmospheric pressure for storage. This process is a near isentropic expansion, which produces less residual vapour than a Joule-Thomson valve and also cools the resulting liquid. As opposed to a Joule-Thomson valve, an expander reduces the enthalpy of the liquid; exporting the removed energy as electrical power through a generator.

For the two phase expander, the liquid pressure is allowed to expand to a pressure less than the bubble point; that is, to within the two phase liquid vapour region. By doing so, the greater pressure drop across the machine allows for more energy to be removed from the liquid. Before the liquid exits the machine, the majority of vapour is condensed to result in increased liquid production when compared to an equivalent Joule-Thomson expansion (Figure 1 helps illustrate this concept).

Liquid exits the MCHE at high pressure, P3. For expansion across a Joule-Thomson valve, no work is performed on the liquid and enthalpy remains constant. The pressure is reduced to P2 (red line) within the two phase liquid vapour region under the vapour dome. The quality of the liquid is X2. By comparison, the pressure within the two phase expander is allowed to reduce to pressure P1 (blue line), which is less than the desired outlet pressure P2. Energy is removed from the liquid, the enthalpy reducing from H2 to H1. Before exiting the machine, the liquid is compressed at constant enthalpy to the desired outlet pressure P2. When compared to the Joule-Thomson valve, the two phase expander has produced the same expansion (P3 to P2), but has produced power (H2 to H1) and has condensed more liquid, the liquid quality now being at X1. Two phase expanders produce more liquid condensate for a given mass flow, and generate usable electrical power by recovering the energy in the compressed liquid.

So just how is this accomplished? Two major components unique to the two phase version of the cryogenic liquid expander work in harmony to produce the actions described above; the jet exducer and the condensation cone (Figure 2).

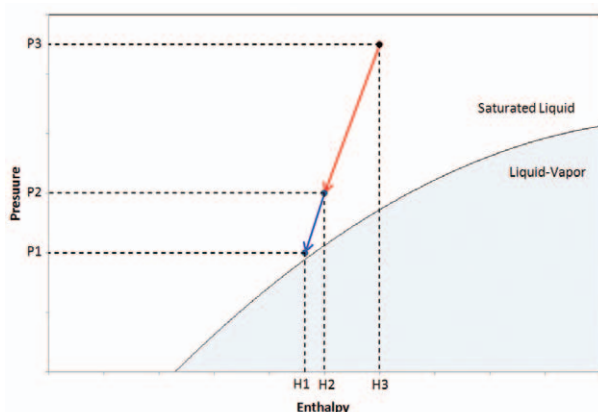
The jet exducer is a rotating radial outflow turbine. The liquid enters the exducer axially (i.e. with no angular momentum) and begins to vaporise at the inlet to the exducer. As the volume of the now two phase liquid increases, the velocity of the fluid increases resulting in a drop in pressure. The two phase liquid exits the exducer at high velocity and at a tangential angle to the shaft thus imparting torque to the shaft. Additionally, the rotating fluid has a large kinetic energy.

This kinetic energy can be converted to static pressure in much the same way as a diffuser converts kinetic energy to pressure energy in a pump. The condensation cone is a static device of gradually increasing area, which straightens the flow and allows diffusion to occur to the desired outlet pressure. In the case of two phase flow, this increase in pressure results in a lower quality fluid closer to the saturated liquid side of the vapour dome.

## Power recovery

The aim of liquid all expanders, be they single or two phase, is to increase the economic benefit of the process train. This is accomplished by increasing the efficiency of the process by means of increasing the LNG production for a given feed gas mass. 15 years of operational history has proven that this efficiency increase is from 3 - 5%.

The power generated by a liquid expander is proportional to the product of the mass flow and differential pressure across the inlet and outlet of the machine.



**Figure 3.** Pressure enthalpy diagram comparing a traditional downward flow expander (red) to an upward flow expander (blue).

$$P = Q \Delta p \eta$$

Where,

P = power

Q = mass flow

$\Delta p$  = differential pressure

$\eta$  = expander efficiency

Increasing the differential pressure drop across the expander can increase power. An increase in power results in greater energy being extracted from the gas stream, allowing for reduced boil off and increased LNG production.

Single phase cryogenic liquid expanders are limited in their ability to extract energy. This is due to the necessity to maintain a margin between the outlet pressure of the expander and the vapour pressure of the liquid. Typically, this margin is in the range of 4 - 6 bar. Two phase expanders, by definition, do not require this margin as they operate within the two phase region. Thus, they can accommodate a larger pressure drop and extract more energy from the liquid.

## Upward flow expanders

The pressure margin required by standard downward flow liquid expanders is a source of unused available potential energy. If this pressure can be reduced through the expander rather than across a downstream control valve, the energy can be extracted as usable electrical power.

An upward flow expander is able to access this potential pressure energy by means of allowing a lower outlet pressure than an equivalent downward flow expander. The lower outlet pressure is possible due to the fact that the hydraulic components are positioned above the main bearings and generator. As a submerged machine, these components require a portion of the process flow for cooling and lubrication. As the pressure within the machine approaches the vapour pressure, bubble formation is formed above the main bearings and generator and drawn away from them. The natural pressure gradient of the upward flow expander works positively to allow lower outlet pressures.

By doing so, a larger portion of the total desired process expansion occurs within the expander rather than the downstream valve. Since an expander can produce more liquid condensate for a given expansion than a valve, the efficiency of the overall process is increased (Figure 3 illustrates this concept). A standard downward flow expander reduces the

pressure of the process liquid from P3 to P2 (red line). The outlet pressure P2 is some margin above the vapour pressure for the necessary protection of the machine. The total enthalpy reduction is from H3 to H2. An equivalent upward flow expander is able to operate with less margin to the bubble point, so can continue to expand the liquid to pressure P1 (blue line). The enthalpy reduction is greater (H3 to H1).

## Bridging the gap

When considering single phase and two phase liquid expanders, plant process conditions often dictate one type of machine over the other. Cryogenic distillation processes, such as nitrogen rejection, naturally require two phase operation and the associated two phase expander. Conversely, it may be necessary in an LNG process to maintain higher outlet pressures in order to feed storage tanks where run down product pumps are not available. Here, the standard downward flow single phase expander is traditionally used. But where process conditions vary, efficiencies are to be maximised and debottlenecking is required, the upward flow expander offers great flexibility encompassing features of both machines.

Single phase and two phase expanders are not radically different machines. They share most of their mechanical design features. The rotating assembly design, generator, balance mechanism and other details are common. It is in the hydraulic components of the jet exducer and condensation cone at the exit of the machine that differentiate the two phase expander from its single phase cousin.

Mechanically, the upward flow expander is a variation of each machine. It is a traditional expander mounted in an upward configuration; a configuration pioneered in the two phase expander. This provides the opportunity to accommodate the two phase jet exducer and condensation cone, if desired. These components can be retrofitted into the upward flow expander should future process conditions require.

## Conclusion

Both types of machine, the downward flow expander and the two phase expander have several years of successful operating history. Each has found its niche in the industry. But they are not separate and diverse machines; rather they are variations along the same expander evolutionary path. The upward flow expander fits in to this continuum to bridge the gap between the traditional downward flow single phase expander and the two phase expander.

## References

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2. CHIU, C. et al, 'Two-Phase LNG Expanders Replace Two-Phase Joule-Thomson Valves', AIChE Spring National Meeting, 2004.
3. KIMMEL, H., 'Two-Phase Expansion', *Hydrocarbon Engineering*, December 2010.