EFFICIENCY VS AVAILABILITY IN FLNG

Tom Haylock, KANFA Aragon, Norway, investigates which is the most important factor in FLNG developments; optimised efficiency or optimised availability.

The floating LNG (FLNG) sector currently has two main types of liquefaction technology proposed: mixed refrigerant cycles and nitrogen cycles. Those proposing mixed refrigerant cycles often do so based on onshore LNG experience and focus on maximising the liquefaction cycle efficiency. Those proposing nitrogen cycles do so based on experience from offshore oil and gas production and are mainly focused on optimising availability and safety.

As a result, there is disagreement over which technology will come to dominate FLNG. It is clear that each will have their own place in the market, but which is best suited for FLNG? To answer this it is important to understand the issues and how they affect project revenue.

Table 1. Comparison of key parameters between a mixed refrigerant cycle and a nitrogen expander cycle (the figures are for the liquefaction train only)[1]

	Propane pre-cooled mixed refrigerant cycle	Dual nitrogen expander cycle
Gas turbine driver	Frame 7 and frame 6	LM6000
Average thermal efficiency of driver	33.2%	41.9%
Production capacity per train	4.35 million tpy	1.11 million tpy
Specific power consumption for liquefaction cycle	0.243 kWh/kg of LNG	0.345 kWh/kg of LNG
Thermal efficiency	94.7%	94.3%

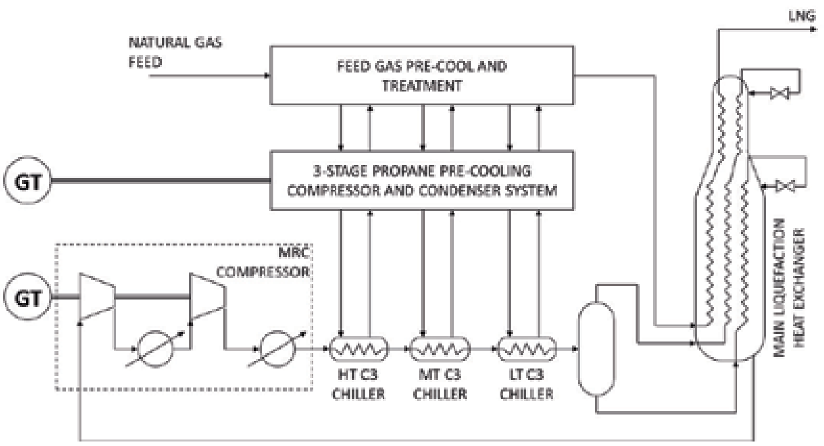

Figure 1. A typical mixed refrigerant cycle.

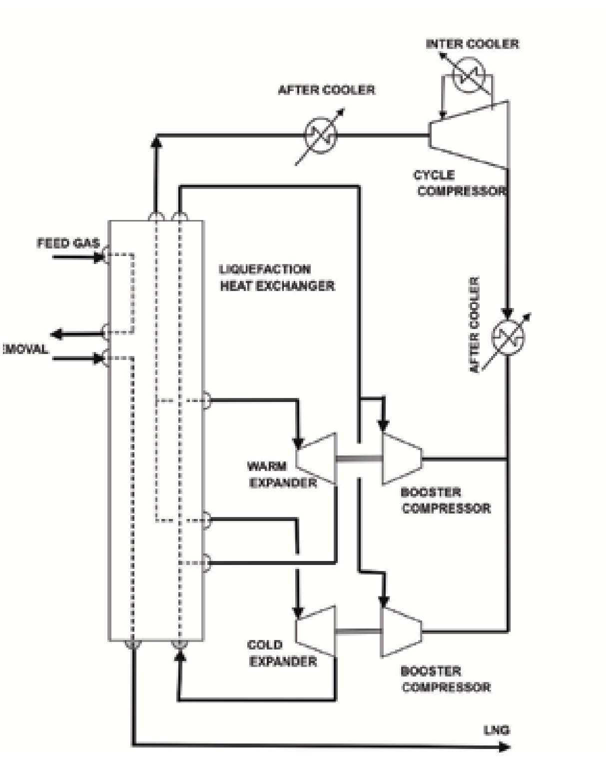

Figure 2. A typical nitrogen expander cycle.

Technical challenges

FLNG plants have different technical and safety challenges to well-established onshore plants. Restrictions concerning space, weight, logistics, operability and potential future re-location are forcing engineers to overcome the technical challenges in plant design.

Experience from the offshore oil and gas sector shows that prioritising safety, availability and flexibility for both changing feed gas composition and more frequent start and stops compared to onshore plants is critical for any offshore process plant's success. Applying this logic to FLNG leads to the use of nitrogen as a refrigerant as it is non-hazardous, single phase and simple to operate.

However, a nitrogen cycle has poorer process efficiency than a mixed refrigerant cycle. But is the improved process efficiency of a mixed refrigerant cycle worth the resulting increased safety risk, higher complexity, lower availability and reduced flexibility when applied offshore?

Assuming that the challenges for operability and safety can be addressed for mixed refrigerant cycles offshore, the question then becomes: what really is the more important factor for FLNG developments; optimised efficiency or optimised availability?

Efficiency

Although it is common to compare efficiencies of liquefaction processes using specific power consumption (kWh/kg of LNG produced), i.e. the amount of power required per kg of LNG, this method of measuring efficiency is often misleading. Specific power consumption focuses only on the power required for the main cycle compressors and does not take into account important factors such as ambient conditions and driver efficiencies. The calculated efficiency of a liquefaction cycle is highly influenced by where the calculation boundary is set. As such, the boundaries applied in the efficiency calculations should be clearly stated, but unfortunately numbers are often compared on unequal terms.

For accurate comparison it is often best to use the overall plant thermal efficiency to benchmark different liquefaction processes. By assuming natural gas is used as fuel, thermal efficiency expresses how much of the feed is recovered as product and how much is lost during processing, giving a clear picture of the entire liquefaction system efficiency.

As an example, the overall thermal efficiencies using identical and realistic conditions, for both a mixed refrigerant plant and a nitrogen expander plant, have been calculated for comparison.[1]

Table 1 shows that there are significant differences in the specific power consumption between the two technologies. The mixed refrigerant cycle has a lower specific power consumption than the nitrogen cycle. However, because of the fundamental differences of the driver efficiencies, the resulting difference in the liquefaction cycles' thermal efficiency is so small as to be negligible.

This is because mixed refrigerant cycles onshore typically apply heavy duty industrial gas turbines with relatively poor thermal efficiencies. For offshore applications, some mixed refrigerant cycles are being applied with steam turbine drivers, which have even poorer efficiency, as well as no available waste heat. High efficiency aero-derivative gas turbines that are used on nitrogen cycles are rarely applied to MR cycles as their output limits would require duplication of units, which adds more complexity to an MR plant. Aero-derivatives are limited on output, which limits the production possible per train for N_2 cycles. But when looking at the overall plant efficiency, there is little difference between a nitrogen cycle and a mixed refrigerant cycle in reality.

Efficiency's effect on revenue

How does improved efficiency actually affect a project's revenue? If we assume that everything else is equal, improved efficiency will result in reducing the amount of fuel gas required, giving longer production time. So what is the cost of fuel gas and how does it affect net present value calculations? How much extra investment cost would be reasonable to consider for improved efficiency/lower feed gas shrinkage?

For an offshore field developed with a single liquefaction plant for processing all recoverable reserves, the value of the fuel equals LNG sales value at the end of the production time. Assuming that it is possible to apply drivers with the same efficiency and the availability is equal, the most efficient mixed refrigerant cycle will typically give 30% lower fuel consumption than a nitrogen cycle. This difference corresponds to 2 – 3% of the plant total feed gas flow.

Again, for a true picture of the fuel consumption the overall plant efficiency should be used, as this takes into account the total fuel gas consumption for the plant.

The present value data shown in Figure 3 applies a conservative internal rate of return of 15% on a field with reserves of 2.5 trillion ft^3 and a nominal production time of 25 years when producing 2 million tpy of LNG. Initial CAPEX of US$ 1000/tpy (topsides and hull only) was set and should be in the lower range of recently published costs for onshore and offshore LNG projects, together with a fixed amount for subsea CAPEX (US$ 500 million).

A nitrogen expander plant with thermal efficiency of 94.4% will produce for 24 years, giving an overall present value of US$ 4550 million. A development based on a 30% more efficient technology, and identical capacity, availability, and capital cost, would give six months longer production and a present value of US$ 4566 million. So having a cycle that is 30% more efficient gives a revenue increase of only 0.4% over the field lifetime.

Based on the above example there is little incentive to invest more CAPEX in order to boost efficiency, as the effect on net present value is so low.

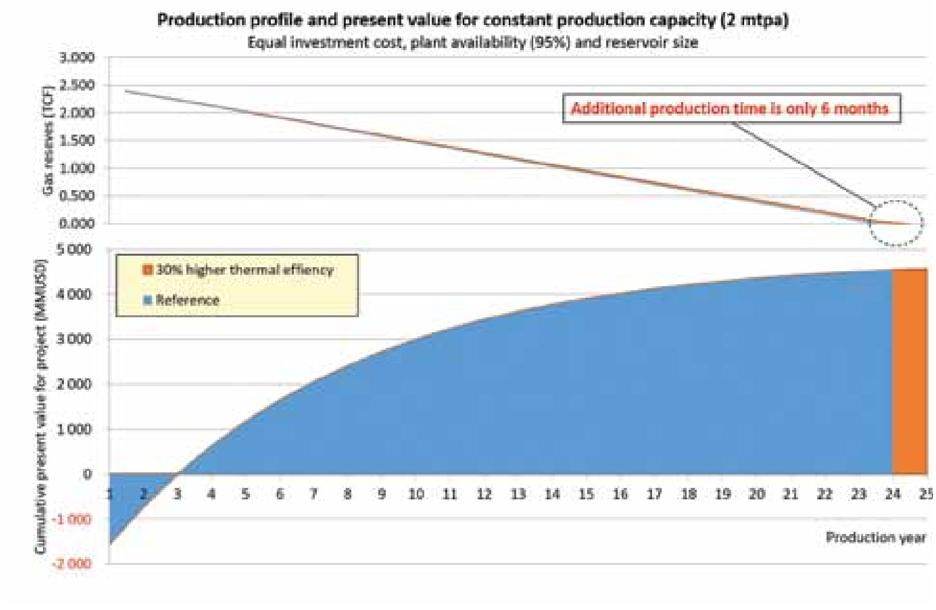

Figure 3. Production profile and present value for constant production capacity while varying thermal efficiency.[1]

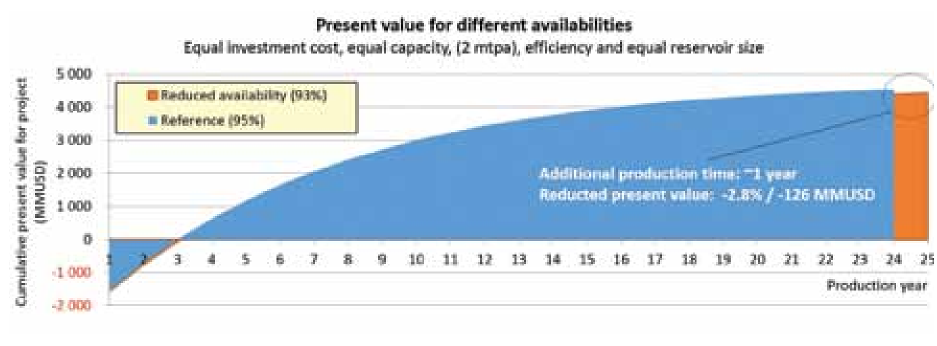

Figure 4. Cumulative present value for different levels of availability.[1]

Availability

Availability is more straight forward than discussing efficiency. Reduced availability results in reduced revenue for each year of production. It also delays part of the production, such that the last part of the reserves will be sold later and generate less present value.

When considering the two main technologies for FLNG, mixed refrigerant is expected to have poorer availability than nitrogen. This is because mixed refrigerant cycles are more complex multiphase processes, which require fine tuning to hit their optimum efficiency for a specific gas composition. Vessel motions will affect the liquid phase and distribution in the cold box, and gas compositions can change quickly in an offshore environment due to wells coming on and off line, all of which will make availability suffer accordingly. Mixed refrigerant cycles are also very complex and require more manpower and a large inventory of hazardous refrigerants, which again affects operability and availability. Nitrogen, on the other hand, is a simple, single phase non-hazardous technology that is well suited to an offshore environment.

Taking the same example of two plants with the same production capacity (2 million tpy), efficiency and investment costs, but with different availability (93% and 95%), the effect on present value is quite pronounced (Figure 4).

The 2% reduction in availability reduces cumulative present value by 3%. According to supplementary calculations,[1] the saving in initial CAPEX (plant and ship) to justify this reduced availability is a minimum of 5%. Alternatively, a maximum of 5% more CAPEX can be invested to recover the availability. Hence, high inherent availability is much more important for the project economy as it has a greater effect on revenue.

Conclusion

In conclusion, considering the examples detailed in this article, it is clear that selecting the liquefaction technology with the optimal availability is the most important consideration.

Overall production levels affect the project economy the most. This is a question of multiple nitrogen cycle trains vs. single mixed refrigerant cycle trains. Due to their lower CAPEX costs and significant advantages offshore, multiple N_2 trains are a strong solution for high production with high availability.

The common claims and assumptions that mixed refrigerant cycles are a better choice than nitrogen cycles for natural gas liquefaction due to their specific power consumption can be misleading.

The examples show that when considering whole plant efficiency, a nitrogen expander cycle utilising a highly efficient aero-derivative gas turbine is as efficient as most of the onshore LNG plants operating today.

So it is highly important that a clear understanding and comparison of key factors such as safety, availability, thermal efficiency and net present value are taken into consideration when selecting technologies for FLNG. Nitrogen gas expander cycles offer a safe, simple, reliable and low cost solution for offshore or at-shore FLNG, with overall efficiency comparable to state-of-the-art mixed refrigerant cycles onshore or offshore, but importantly with optimised availability. **LNG**

Reference

1. Faugstad, S., and Nilsen, I.L., 'Natural gas liquefaction using Nitrogen Expander Cycle - An efficient and attractive alternative to the onshore base load plant', GPAE AGM & Technical Meeting, 29 November 2012.