technology choices

Adrian Finn, Costain Oil, Gas & Process Ltd, UK, explores liquefaction technology options for small and mid scale LNG plants.

Increased consumption of natural gas is increasing demand for LNG in many parts of the world. Mid scale LNG projects (up to 1.5 million tpy) are becoming of interest because they enable smaller gas reserves to be exploited and can be easier to finance than large base load facilities (typically 5 million tpy or more). Plants can be expanded to meet market demand as required. However, mid scale LNG plants must provide LNG, and ultimately natural gas, at a competitive price compared with other energy sources, including gas supply by pipeline. The same argument applies to small scale LNG projects (typically 10 000 - 100 000 tpy), where LNG is used for gas storage and to supply gas to remote locations.

For any new plant, selection of the correct liquefaction technology and associated equipment is very influential in reducing cost and increasing project viability. Using a 'standard' design

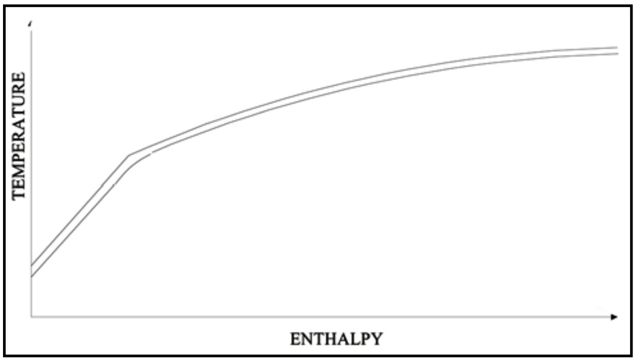

Figure 1. Typical composite cooling and warming curves for mixed refrigerant cycle.

helps reduce capital cost but technology developments should be assessed as to whether they can improve project economics whilst maintaining a robust and reliable overall plant design.

Liquefaction processes

Liquefaction plants have tended to be on either peak shave duty or base load plants, depending on their size and function.

Peak shave

Peak shave facilities usually employ liquefiers of up to 100 000 tpy capacity. They ensure peak gas demands can be met by liquefying and storing gas at times of low demand and vaporising it at times of peak demand. Small capacity LNG plants have also been constructed to supply fuel for vehicular use and for LNG trucking to remote power generation facilities.

Base load

The maximum economic liquefaction train capacity has increased steadily to 5 million tpy with advances in gas turbine drivers for refrigeration compressor duties, improved compressor efficiency, hydraulic turbines for pressure letdown and other technology improvements. New mixed refrigerant/expander hybrid plant designs are now being used for plants of up to nearly 8 million tpy capacity in Qatar.

Mid scale

Mid scale LNG plant capacity ranges from 300 000 tpy to over 1 million tpy. Plant capacities up to 1.5 million tpy are feasible in a single train. To date, few such plants have been constructed, but this is likely to change with the development of smaller gas fields for production durations of 20 years or more.

Liquefaction cycle selection

Liquefaction cycles vary in sophistication and specific power consumption. Choosing the optimum cycle is important to minimise liquefier cost (which also reduces utilities costs). The choice of liquefaction cycle depends on many factors, which differ from project to project. These include:

- Refrigeration compressor configuration and available drivers.
- Specific power requirement (affecting machinery capital cost and operating cost).
- Need for natural gas liquids (NGL) recovery.
- Nitrogen removal to ensure level in LNG is not more than 1.0 mol%.
- Heat exchanger type and surface area optimisation.
- Range of feed gas conditions.
- Ease of operation/startup/shutdown.
- Space requirements.

All these issues should be considered in liquefaction technology selection. Machinery selection is especially important and LNG plant capacity is normally optimised based on the choice of specific refrigeration compressor/driver configuration. For small plants this may not be so important as electric motor drives are more likely to be used.

It is important that the economic appraisal criteria (for process and plant design) are clear, particularly as the best liquefaction technology in terms of capital cost is often not the best in terms of lifecycle cost.

Three main types of refrigeration cycle have been used, the cascade, mixed refrigerant and expander cycles. There are variants of each cycle, with some common features between them. For example, with both mixed refrigerant and expander technology, feed gas may be precooled by a conventional propane vapour compression cycle. This is also a feature of the cascade cycle.

Cascade refrigerant cycle

Natural gas is cooled, condensed and subcooled in the heat exchanger with evaporating propane, ethylene (or ethane), and finally methane in three discrete stages. Normally each refrigerant circuit has multiple refrigerant expansion and compression stages. After compression, propane is condensed with cooling water or air, ethylene is condensed with evaporating propane, and methane is condensed with evaporating ethylene.

The cascade cycle requires less power than other liquefaction cycles but has a high capital cost for small scale and mid scale plants due to the large number of equipment items. Each refrigeration circuit has a compressor (with associated suction drums and interstage coolers) and refrigerant storage.

The cascade cycle suits very large LNG train capacities where the low heat exchanger area and low power consumption can offset the cost of the multiple refrigeration compressors.

Mixed refrigerant cycle

Mixed refrigerant cycle (MRC) processes for smaller and mid scale plants use a single mixed refrigerant comprising nitrogen and hydrocarbons. Various processes have been used and proposed. Power requirement is usually similar to that of a cascade cycle. The refrigerant composition is specified to evaporate over a temperature range similar to that of the natural gas being liquefied to give close matching of composite cooling and warming curves (Figure 1). A small temperature difference gives high thermodynamic efficiency, reduced power consumption and hence a smaller refrigeration compressor system. MRC designs can be susceptible to changes in feed gas composition, which may necessitate large design margins unless reduced performance can be accepted.

On larger MRC plants it is cost effective to precool the feed gas by a separate propane refrigeration system, absorption refrigeration system, or mixed refrigerant. The cost of the extra refrigeration system must be justified by the overall cost saving due to the reduced power consumption. Clearly such optimisation depends on the project economic appraisal criteria and, in particular, how lifecycle costs are calculated.

Expander cycle

Compression and work expansion of either nitrogen or methane provides refrigeration in a closed cycle (Figure 2). The cycle fluid is cooled by the work expansion to a temperature low enough to produce LNG. The work generated is recovered by boosting the cycle pressure to supplement the cycle compressor. This reduces overall power consumption.

The cold, low pressure gas stream from the expander is rewarmed and its refrigeration is given up to the incoming natural gas and cycle gas. The warmed cycle gas is then recompressed by the main cycle compressor and booster compressor.

Expander cycles are conventional for cryogenic liquefaction (nitrogen, oxygen, etc.) and have several advantages over both cascade and mixed refrigerant cycles. They enable rapid, simple startup and shutdown. As heat exchangers operate with relatively wide temperature differences, changes in feed gas composition are easily tolerated. As the cycle fluid is always gaseous, there are no concerns with non-uniform distribution of vapour and liquid phases into the heat exchanger. The small heat exchangers result in a relatively small cold box[1].

The major disadvantage of the expander cycle is its relatively high power consumption, therefore it normally struggles to compete for larger facilities due to the high capital and operating cost for compression.

The basic single expander cycle can be modified to increase process efficiency and reduce power consumption. For example, power consumption can be reduced by approximately 20% by natural gas precooling with a conventional vapour compression cycle, typically using propane. Increased complexity is cost effective if the cost of additional equipment is offset by the reduction in size and cost of the nitrogen cycle machinery.

Alternatively, two expanders can be used to provide refrigeration, operating over different temperature levels. Figure 3 shows typical composite cooling and warming curves for a double expander cycle. Two expanders allow closer matching of the composite curves, giving higher thermodynamic efficiency. Power consumption is similar to the precooled single expander cycle. The double expander flowsheet avoids the need for feed gas precooling and storage of hydrocarbon refrigerant.

Cycle efficiency comparison

Power consumption is a key parameter due to its effect on both capital and operating cost. The approximate specific power consumption for each cycle (relative to a cascade) is shown in Table 1. The power consumption of the cascade cycle is slightly less than the mixed refrigerant cycles but the relatively large number of equipment items, especially machinery, means it cannot be competitive for mid scale or smaller plant capacities.

A specific power consumption of approximately 0.33 kWh/kg of LNG is typical for a cascade cycle. Table 1 can therefore be used to identify approximate power consumption for a range of liquefaction technologies. Specific power requirement reduces with increasing feed gas pressure and lower temperature (feed gas and cooling medium) but increases if NGL and/or nitrogen need to be removed.

As the source of power is usually gas, power consumption can be directly related to fuel gas consumption and LNG production. For a cascade plant, 6 - 7% of feed gas would be required to power the refrigeration compressor drivers.

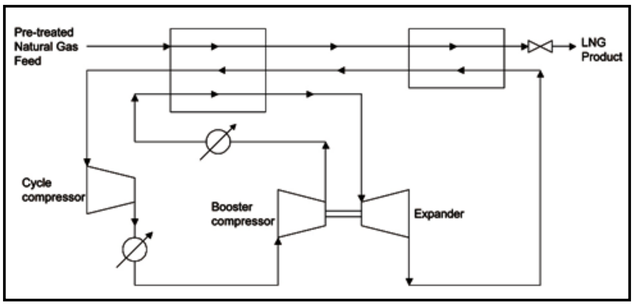

Figure 2. Typical expander cycle (single expander).

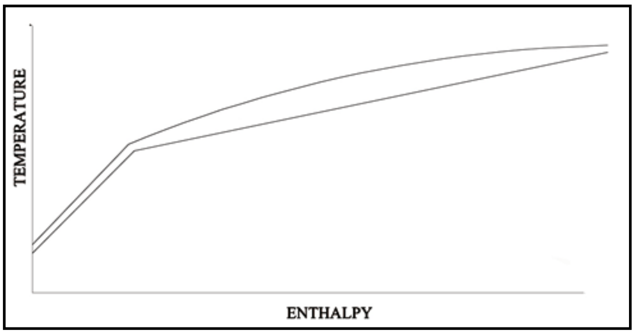

Figure 3. Typical composite cooling and warming curves for double nitrogen expander cycle.

Table 1. Comparison of liquefaction cycle efficiencies

Cycle	Approximate power consumption relative to cascade cycle
Cascade cycle	1.00
Single stage mixed refrigerant cycle	1.25
Mixed refrigerant cycle with propane precooling	1.10 - 1.15
Single expander cycle	2.00
Single expander cycle with propane precooling	1.70
Double expander cycle	1.70

Table 2. Liquefaction cycle evaluation

Criteria	Cascade	MRC	Expander
Efficiency	High	Moderate/high	Low
Complexity	High	Moderate	Low
Heat exchanger type	Plate fin	Plate fin or wound coil	Plate fin
Flexibility	High	Moderate	High

A broad comparison of each liquefaction technology is summarised in Table 2 to assist in cycle selection. Due to the differing attributes of the various cycles, more than one type of cycle can be applicable for a given LNG capacity and the options should be evaluated to determine the best choice for a particular project. Expander plants are favoured on the smallest LNG facilities. Single compressor MRC plants are economical at capacities above 50 000 - 70 000 tpy.

In practice, the refrigeration compressor/driver options, the potential to use waste heat from gas turbines, choice of whether to use hydraulic turbines for LNG or refrigerant pressure reduction and other engineering decisions can influence the LNG plant configuration, cost and utilities consumption, but Tables 1 and 2 enable initial assessments to be made.

Mixed refrigerant technology for mid scale LNG plants

Interest in mid scale LNG plants from prospective project developers initiated a reappraisal of accepted mixed refrigerant technology to reduce LNG production cost. Mixed refrigerant technology that has one main refrigeration cycle and a single compressor is well proven, but it was considered that cycle optimisation based on the latest process design methods, machin-

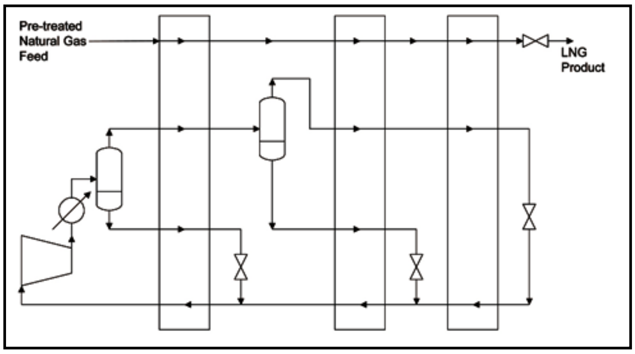

Figure 4. Typical three stage mixed refrigerant cycle.

ery and heat exchanger technology could provide alternative efficient, yet simple, process designs.

The PRICO® cycle[2] uses a single refrigeration compressor and a single mixed refrigerant circuit. The PRICO cycle is simple but has high refrigerant circulation flow that increases both power consumption and heat exchanger area. Economics are improved by using compact aluminium plate fin heat exchangers, which give a low cost per unit area. The PRICO cycle has minimal equipment, is easy to operate and is well established, but the high power consumption and heat exchanger cost are a penalty at larger capacities.

To improve energy efficiency whilst using a single MRC compressor, a number of multistage MRC designs were developed[3]. A typical design is shown in Figure 4. The refrigerant stream is compressed and partially condensed against air or cooling water at approximately ambient temperature and low pressure. The resultant vapour from the separation is partially condensed in the first stage of the main heat exchanger. The liquid is subcooled separately in the heat exchanger and then expanded across a valve, reducing its temperature by the Joule-Thomson effect. This low pressure stream is combined with the equivalent low pressure stream returning from the second (colder) stage, and is rewarmed in the heat exchanger. The refrigeration given up subcools the incoming refrigerant liquid phase, partially condenses the incoming refrigerant vapour phase, and cools/condenses the incoming natural gas.

The incoming refrigerant vapour phase stream is further partially condensed and undergoes a phase separation in a second refrigerant separator. The vapour and liquid phases pass to the second stage of the main heat exchanger, which operates in a similar manner to the first. Vapour is fully condensed and then expanded across a valve to give a sufficiently cold temperature to produce LNG. The liquid is subcooled separately and expanded before it is combined with the low pressure refrigerant returning from the coldest part of the cycle and rewarmed.

This MRC design (and similar processes developed with it) reduce overall refrigerant circulation flowrate without introducing additional machinery. The liquid substreams that are injected into the returning refrigerant stream permit cooling and warming streams to be matched to give small temperature driving forces, thus specific power consumption is comparatively low.

Compact aluminium plate fin heat exchangers are used to reduce power consumption. Multistream plate fin exchangers provide high thermodynamic efficiency, because small temperature driving forces and excellent energy integration can be achieved. Consequently, power consumption is low with a simple machinery configuration.

For any refrigeration system compressor/driver combination, these MRC designs enable LNG production to be maximised so that production cost can be minimised. Assessment at Costain has included evaluation of the largest available aeroderivative gas turbines. Due to their high efficiency, capacities up to 1.5 million tpy are feasible in cool climates with a single refrigeration compressor. This gives excellent specific LNG cost and an outstanding opportunity to monetise gas at a competitive production cost compared with larger and more capital intensive LNG facilities.

Conclusion

Process technology for the liquefaction of natural gas is undergoing continuous improvement so that previously uneconomic natural gas resources can be exploited. Selection of the optimum liquefaction technology for a project depends on plant capacity, location and investment criteria. Questioning conventional design practice can lead to reduced LNG production cost whilst ensuring capital cost is minimised through standardisation in plant design and equipment selection.

Mixed refrigerant cycles that utilise plate fin exchangers and a single refrigeration compressor can be cost effective for both small and mid scale LNG applications. These compete against expander cycles (that are attractive due to process and plant simplicity) for LNG production capacities of 50 000 - 70 000 tpy. At larger capacities, expander cycles are not cost effective.

Acknowledgements

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References

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3. Refrigeration cycle using a mixed refrigerant, European patent No. 0990108, UK patent No. 2326464 and UK patent No. 2326465. ■