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LNG Liquefaction Technology Selection

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Introduction

Technology selection starts at an early stage in a base-load LNG project life and is typically addressed at the feasibility study and pre-FEED definition stages. Process routes have to be chosen for the process, utilities and offsite units of the plant, which include proprietary and non-proprietary technologies. This also applies to the upstream part of the chain, which supplies the gas to the plant.

Potential options have to be identified and evaluation criteria established. The selection could be between alternative processing technologies for the operating units, type of major equipment, or utilities schemes.

This paper presents an overview of the LNG process and an introduction to the main processes available for the liquefaction section of a baseload LNG plant, and discusses some of the main related technology selection issues that affect LNG plant configuration.

The LNG Process

An example of a LNG plant overall flow scheme, and the main process units and supporting utilities, is shown in Fig.1. The process and utility requirement depend, amongst other things, on the site conditions, feed gas quality and product specification.

In a typical scheme the feed gas will be delivered at high pressure (e.g. up to 90 bara) from upstream gas fields via trunk lines and any associated condensate will be removed. The gas is metered and its pressure controlled to the design pressure of the plant.

The gas is first pre-treated to remove any impurities that interfere with processing or are not desired in the final products. These include acid gases and sulphur compounds (e.g. CO_2, H_2S and mercaptans), water and mercury.

The dry sweet gas is then cooled by refrigerant streams to separate heavier hydrocarbons. The remaining gas is made up mainly of methane and contains less than 0.1 mol% of pentane and heavier hydrocarbons. It is further cooled in the cryogenic section to approximately –160 ºC and is completely liquefied. The resulting LNG is stored in atmospheric tanks ready for export by ship.

The heavier hydrocarbons separated during cooling are fractionated to recover the ethane which is normally re-injected in the gas stream to be liquefied, the LPG (propane and butane) which can either be re-injected or exported as products and the pentane and heavier compounds which make a gasoline product for export.

The utilities required to support the processing units include fuel gas (derived from the process streams) to generate electric power, cooling medium (water or air), heating medium (steam or hot oil system), and other services such as instrument air and nitrogen.

Liquefaction Technology

The refrigeration and liquefaction section is the key element of the LNG plant. There are several licensed processes available with varying degrees of application and experience. There are others proposed or under development but these will not be considered here.

The basic principles for cooling and liquefying the gas using refrigerants involve matching as closely as possible the cooling/heating curves of the process gas and the refrigerant, as this results in a more efficient thermodynamic process requiring less power per unit of LNG produced. This applies to all liquefaction processes. Typical cooling curves are shown in Fig.2.

However the way this is achieved and the equipment used play a major part in the overall efficiency, operability, reliability and cost of the plant. The liquefaction section typically accounts for 30% – 40% of the capital cost of the overall plant.

Key equipment items include the compressors used to circulate the refrigerants, the compressor drivers and the heat exchangers used to cool and liquefy the gas and exchange heat between refrigerants. For recent base-load LNG plants this equipment is among the biggest of its type and at the leading edge of technology.

The natural gas, being a mixture of compounds, liquefies over a wide temperature range. Matching of heat curves by minimising the temperature difference between the cooling process gas and refrigerant streams can be achieved by using more than one refrigerant to cover the temperature range and using the refrigerant at different pressure levels to further split the temperature ranges to closely matching ones. The process gas side is normally operated at high pressure (e.g. 40 –50 bara) to reduce equipment size and provide more efficient refrigeration.

The composition of the refrigerant gives an added control parameter as it can be made either from pure or mixed components. With a mixed refrigerant the composition can be adjusted to suit the process conditions.

The heat exchangers used, e.g. the spiral/coil wound heat exchangers (CWHE) or the plate fin heat exchangers (PFHE), have very large surface areas and a large number of passes, to enable close temperature approaches.

The main available liquefaction processes are described below. The MCR™ process will be described in greatest detail. Many of the principles apply to other processes. The main differences will be highlighted.

APCI Propane Pre-Cooled Mixed Refrigerant Process (MCR™)

This process accounts for a very significant proportion of the world's baseload LNG production capacity. Train capacities of up to 4.7 million tonnes per annum (mtpa) have been built or are under construction. It is illustrated in Fig.3 as part of an overall LNG plant flow scheme.

There are two main refrigerant cycles. The precooling cycle uses a pure component, propane, as for a cascade process. The liquefaction and sub-cooling cycle uses a mixed refrigerant (MR) made up of nitrogen, methane, ethane and propane.

The precooling cycle uses propane at three or four pressure levels and can cool the process gas down to –40 ºC. It is also used to cool and partially liquefy the MR. The cooling is achieved in kettle-type exchangers with propane refrigerant boiling and evaporating in a pool on the shell side, and with the process streams flowing in immersed tube passes.

A centrifugal compressor with side streams recovers the evaporated C3 streams and compresses the vapour to 15 – 25 bara to be condensed against water or air and recycled to the propane kettles.

In the MR cycle the partially liquefied refrigerant is separated into vapour and liquid streams, which are used to liquefy and sub-cool the process stream by cooling from typically -35ºC to between -150ºC to -160ºC. This is carried out in a proprietary spiral wound exchanger, the main cryogenic heat exchanger (MCHE).
The MCHE consists of two or three tube bundles arranged in a vertical shell, with the process gas and refrigerants entering the tubes at the bottom and flow upward under pressure.

The process gas passes through all the bundles to emerge liquefied at the top. The liquid MR stream is extracted after the warm or middle bundle and is flashed across a Joule Thomson valve or hydraulic expander on to the shell side. It flows downwards and evaporates to provide the bulk of cooling for the lower bundles. The vapour MR stream passes to the top (cold bundle) and is liquefied and sub-cooled, and is flashed across a JT valve or expander into the shell side over the top of the cold bundle. It flows downwards to provide the cooling duty for the top bundle and, after mixing with liquid MR, part of the duty for the lower bundles.

The overall vaporised MR stream from the bottom of the MCHE is recovered and compressed by the MR compressor to 45 – 48 bara. It is cooled and partially liquefied first by water or air and then by the propane refrigerant, and recycled to the MCHE. In earlier plant all stages of the MR compression have normally been centrifugal, however, in some recent plants axial compressors have been used for the LP stage and centrifugal for the HP stage. Recent plants use frame 6 and or frame 7 gas turbine drivers. Earlier plants used steam turbine drivers.

<u>Phillips Optimized Cascade Process</u>

This process, a modified version of a process used in an earlier plant in Alaska in the 1960s, has been used for the Atlantic LNG plant in Trinidad and for a baseload plant under construction in Egypt. Train capacities of up to 3.3 mtpa have been constructed with larger trains in development. This process is illustrated in Fig.4

Refrigeration and liquefaction of the process gas is achieved in a cascade process using three pure component refrigerants; propane, ethylene and methane, each at two or three pressure levels.

This is carried out in a series of brazed aluminium plate fin heat exchangers (PFHE) arranged in vertical cold boxes. Precooling could be carried out in a core–in-kettle type exchanger.

The refrigerants are circulated using centrifugal compressors. Each refrigerant has parallel compression trains. Frame 5 gas turbine drivers have been used.

Black & Veatch PRICO® Process

This is a single mixed refrigerant process, which has been used on an earlier base load plant in Algeria. Train capacity has been uprated to 1.3 mtpa per train. It is illustrated in Fig.5.

The mixed refrigerant is made up of nitrogen, methane, ethane, propane and iso-pentane. The cooling and liquefaction is carried out at several pressure levels, in plate fin heat exchangers (PFHE) in cold boxes. The refrigerant is compressed and circulated using a single compression train. In the Algerian plant axial compressors driven by steam turbines were used.

Statoil / Linde Mixed Fluid Cascade Process (MFCP)

In this process three mixed refrigerants are used to provides the cooling and liquefaction duty. It has been selected for the Snøhvit LNG project (Ekofisk, Norway) which is under design/construction. This is a single train 4 mtpa LNG plant. The process is illustrated in Fig. 6.

Pre-cooling is carried out in PFHE by the first mixed refrigerant, and the liquefaction and subcooling are carried out in spiral wound heat exchanger (SWHE) by the other two refrigerants. The SWHE is a proprietary exchanger made by Linde. It may also be used for the pre-cooling stage. The refrigerants are made up of components selected from methane, ethane, propane and nitrogen.

The 3 refrigerant compression systems can have separate drivers or integrated to have 2 strings of compression. Frame 6 and Frame 7 gas turbine drivers have been proposed for large LNG trains (> 4 mtpa). A novel feature of the Snøhvit project is that all motor drivers will be used for the main refrigerant compressors, with sizes up to 60 MW.

The SWHE itself is being installed with other liquefaction processes, in new and expansion projects or as replacement for old cryogenic exchangers.

Axens Liquefin™ Process

This is a two-mixed refrigerant process, which is being proposed for some new LNG base load projects of train sizes up to 6 mtpa. It is illustrated in Fig 7.

Detailed studies have been made including input from main equipment vendors. All cooling and liquefaction is conducted in PFHE arranged in cold boxes. The refrigerants are made up of components from methane, ethane, propane, butane and nitrogen. The first mixed refrigerant is used at three different pressure levels to precool the process gas and precool and liquefy the second mixed refrigerant. The second mixed refrigerant is used to liquefy and subcool the process gas.

Using a mixed refrigerant for the precooling stage allows a lower temperature to be achieved, e.g. -60ºC depending on refrigerant composition.

The PFHEs are non-proprietary and can be supplied by independent vendors. Two large drivers can drive the refrigerant compression systems. Frame 7 gas turbines are being proposed for the large LNG trains.

Shell Double Mixed Refrigerant Process (DMR)

This is a dual mixed refrigerant process, which is being applied in the Sakhalin Island Project with a capacity of 4.8 mtpa per train.

Process configuration is similar to the propane pre-cooled mixed refrigerant process, with the precooling conducted by a mixed refrigerant (made up mainly of ethane and propane) rather than pure propane. Another main difference is that the precooling is carried out in SWHE rather than kettles. The precooling and liquefaction SWHEs will be supplied by Linde.

The refrigerant compressors are driven by two Frame 7 gas turbines. An axial compressor is also used as part of the cold refrigerant compression stages.

Other Processes

The above processes are being used in current LNG plants or applied in LNG projects under progress. There are other processes developed or in development for baseload LNG applications, which can be or are being considered in feasibility studies or for future projects but are not discussed here due to lack of space.

The trend is to extend the capability of existing processes and develop new processes to support large LNG capacities of over 5 mtpa per train. Larger train capacities result in lower specific costs.

Process Selection

Technology selection of process and equipment will be based on technical and economic considerations. Foster Wheeler has carried out selection studies as part of major LNG projects and proposals during the various phases of feasibility, FEED and detailed engineering. In addition to an extensive in-house LNG database, contacts are made with the liquefaction licensors and main equipment vendors to obtain data and develop designs to enable valid comparisons and optimum selections to be made.

Depending on the stage of project development, sufficient process details must be developed to define main equipment and operating parameters to evaluate options using relevant criteria.

Technical considerations include process and equipment experience, reliability, process efficiency, site conditions and environmental impact among others. Economic issues include capital cost, operating cost and life cycle costing. All of these aspects will need to be evaluated arrive at the optimum solution.

Technical risks associated with a process relate to the track record of the process in operation, and any developments required for the project e.g. capacity increase.

Process efficiency, for example, energy required to produce LNG, is not solely related to the thermodynamic efficiency of the liquefaction process but also to the efficiency of the main equipment such as the main refrigerant compressors and drivers.

Site conditions may favour one type of process over other. For example, with very cold ambient temperatures multi-mixed refrigerant processes may offer the optimum solution.

Process requirements and configuration will have an influence on selection. A requirement for greater LPG recovery may suit processes with lower precooling temperatures.

Wider feed gas range will require better process adaptability and may favour mixed refrigerant processes with the added flexibility of changing refrigerant composition.

Refrigerants made up from components that can be produced in the process (in the fractionation unit) will obviate the need for external supply to make up refrigerant losses.

Compressors and Drivers

The rotating equipment selection is affected by the characteristic of the process such as composition and flow rate of the refrigerant and head required. Some will fit available frames and casings whilst others will require some development.
The choice of drivers, compressors and driver arrangements, and their fit with the process and power generation is critical to the selection process.

The larger the drivers and compressors the more efficient and cost-effective they are likely to be. However, if some machinery is limited by available designs, smaller proven equipment may be installed in parallel trains, offsetting increased costs by higher availability.

The choice of drivers for the main compressors is not limited to gas and steam turbines. Studies carried out by Foster Wheeler have shown that the use of large electric motor drivers a feasible option to support high capacity baseload LNG plants. The selection of cooling system will have impact on compressor design, as it would dictate compressor interstage and discharge conditions.

Often the selection of process and drivers, particularly for expansion projects, is dictated by the desire to stay with familiar designs and configurations and to standardise sparing, etc.

Equipment
All the main processes are licensed processes, and some also use proprietary equipment. The main spiral wound heat exchangers used by APCI and Linde are both proprietary. The plate fin heat exchangers (PFHE) used by some processes are non-proprietary and can be offered by different vendors.

Some of the considerations for equipment selection are given in Table 1.

Table 1 Some Technology Selection Parameters

Technology Selection Items	**Pros**	**Cons**
Spiral Wound Exchanger	Robust & flexible	Proprietary / more

	operation	expensive
PFHE	Competitive vendors available. Lower pressure drop and temperature differences	Require careful design / vulnerable to upsets
Axial Compressors	High efficiency	Suitable only at high flow rates
Large Gas Turbines	Proven, efficient & cost effective	Less reliable / strict maintenance cycle / more complicated control / fixed speed
Large Motor Drivers	Efficient, flexible & more available	Untried in LNG at speeds needed / require large power plant
Mixed Refrigerant Process	Simpler compression system Adjusting composition allows process matching	More complex operation
Pure Component Cascade process	Potential higher availability	More equipment and complicated compression system
Air cooling (compared to sea water cooling)	Lower cooling system CAPEX	Less efficient process / higher operating costs
Fluid medium heating (compared to steam)	Eliminates the need for steam generation & water treatment	Higher reboiler costs
Larger train capacity	Lower specific costs (CAPEX per tonne LNG)	Some equipment / processes may require further development

Other Selections

Another important area is deciding the heating and cooling media types as they directly impact process and equipment. Cooling medium is normally a choice between air and water in a direct on indirect system. For the heating medium steam or hot oil systems can be considered. For example a selection of air for cooling, oil for heating and gas turbine drivers will eliminate the need for a steam generation system including water treatment, and a cooling water system which may include a costly seawater intake.

The above issues are typical of the main issues that have to be considered when selecting the technology for an LNG plant.

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