A COMPARATIVE STUDY OF PHILLIPS OPTIMIZED CASCADE AND APCI PROPANE PRE-COOLED MIXED REFRIGERANT LNG LIQUEFACTION PROCESSES

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LIQUEFACTION TECHNOLOGY

The refrigeration and liquefaction section is the key element of the LNG plant. There are a lot of licensed processes available with varying degrees of application and experience. 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. This results in a more efficient thermodynamic process requiring less power per unit of LNG produced. This applies to all liquefaction processes.

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 baseload 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. Heat curves can be matched by minimizing the temperature difference between the cooling process gas and refrigerant streams. This is 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 temperatures 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, for example, the spiral/coil wound heat exchangers or the plate fin heat exchangers, have very large surface areas and a large number of passes, enabling close temperature approaches.

THE LNG PROCESS

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

In a typical scheme the feed gas is delivered at high pressure 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 operating pressure of the plant.

The gas is first preheated to remove any impurities that interfere with processing or are undesirable in the final products. These include acid gases and sulphur compounds (for example, 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 then 0.1mol% of pentane and heavier hydrocarbons. It is further cooled in the cryogenic section to approximately -160°C 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 ethane, propane and butane. Ethane is normally reinjected into the gas stream to be liquefied. The propane and butane can either be reinjected or exported as LPG products. The remaining hydrocarbons (pentane and heavier components) are exported as gasoline product.

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.

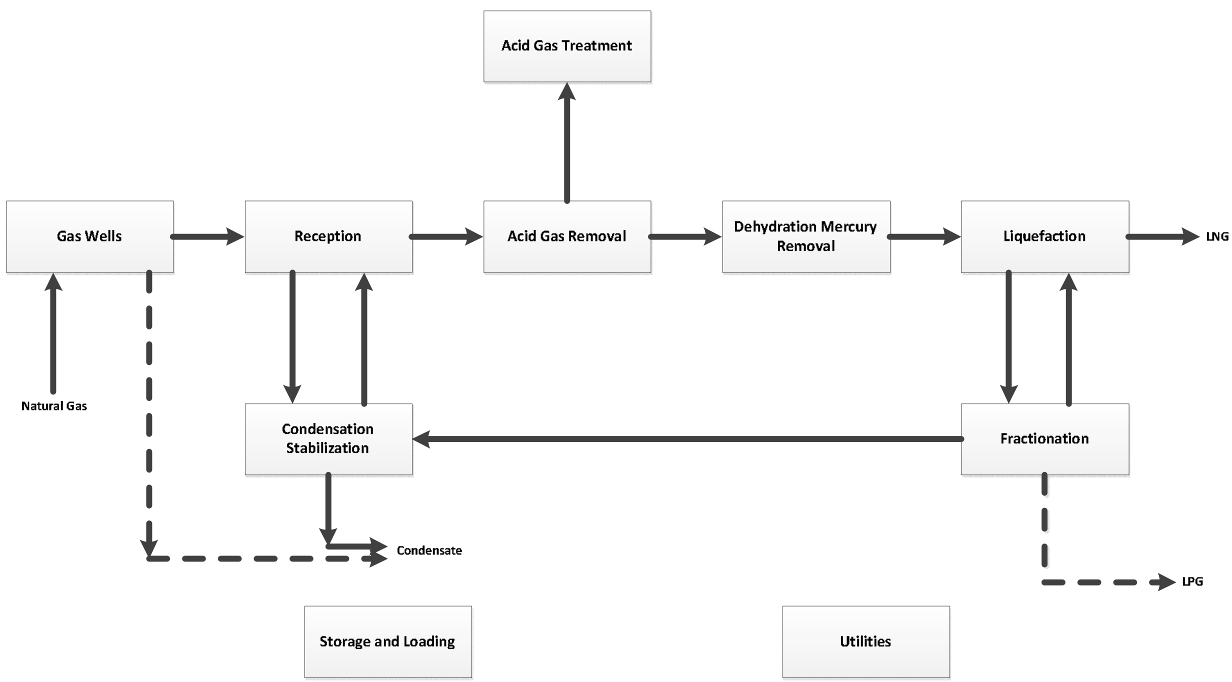

Figure 1. *LNG block flow diagram*

PHILLIPS OPTIMISED CASCADE PROCESS

The original Optimized Cascade LNG process was developed by Phillips Petroleum Company in the 1960's. The objective of this development was to devise a refrigeration cycle that could be utilized in the liquefaction of natural gas that would permit easy startups and smooth operations for a wide range of gas feed volumes and compositions.

Using these criteria as design parameters, computer programs were developed to calculate the total process requirements for a cascade cycle system utilizing propane, ethylene, and methane as the refrigerants. Propane was chosen because it is available in quantity world-wide, ethylene because it would condense methane at a refrigerant pressure above atmospheric pressure and could in turn be condensed by propane and methane because it is available in the natural gas stream.

Applying the computer programs, models were created to optimize the cycle. These models determined the optimal liquefaction train configuration to maximize production yields of LNG.

The optimized Phillips cascade process was also used for the Atlantic LNG plant in Trinidad and for a baseload plant under construction in Egypt. Train capacities of up to 3.3 million tpy (tonnes/year) have been constructed with larger trains in development. This process is illustrated in figure 2.

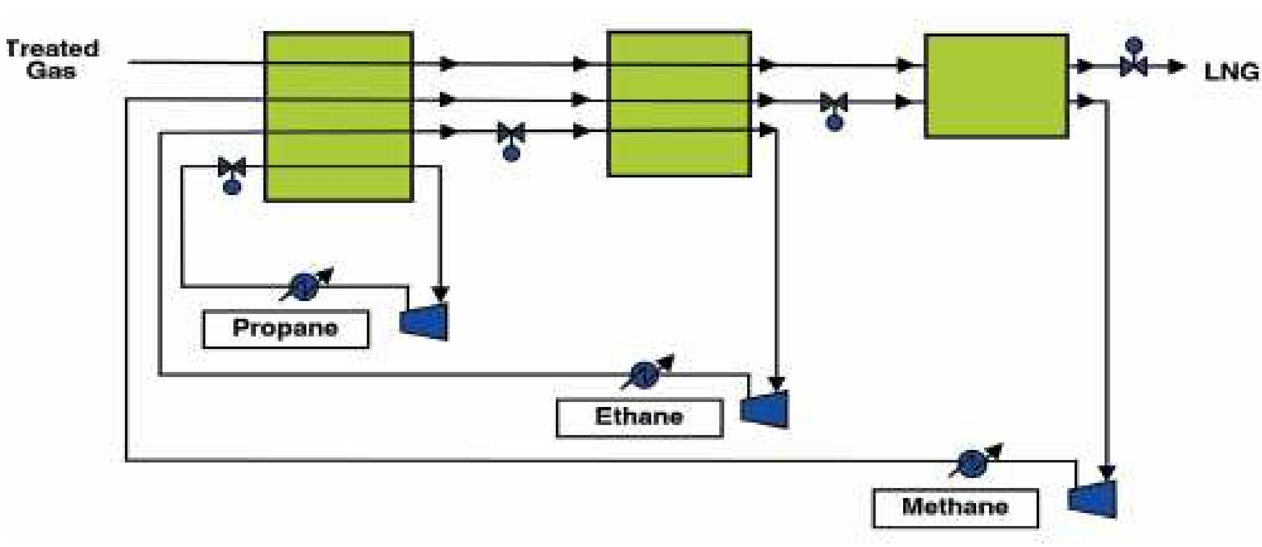

Figure 2: *Phillips optimized cascade process*

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 PFHEs (Plate-Fin Heat Exchangers) 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 turbines were used.

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 tpy (tonnes/year) were built or are under construction. It is illustrated in Figure 3 as part of an overall LNG plant flow scheme.

There are two main refrigerant cycles. The precooling cycle uses a pure component, propane. 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°C. 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 C_3 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 that are used to liquefy and sub-cool the process stream form typically -35°C to between -150°C-160°C. 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 which then 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 Thompson valve or hydraulic expander onto the shell side. It flows downwards and evaporates, providing the bulk of cooling for the lower bundles. The vapour R stream passes to the top (cold bundle) and is liquefied and sub-cooled, and is flashed across a JT valve into the shell side over the top of the cold bundle. It flows downwards to provide the cooling duty for the lower bundles.

The overall vapourised 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 plants all stages of the MR compression were normally 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.

A recent modification of the process, which is being considered for large LNG capacity plants (> 6 million tpy), is the APX-process, which adds a third refrigerant cycle (nitrogen expander) to conduct LNG subcooling duties outside the MCHE.

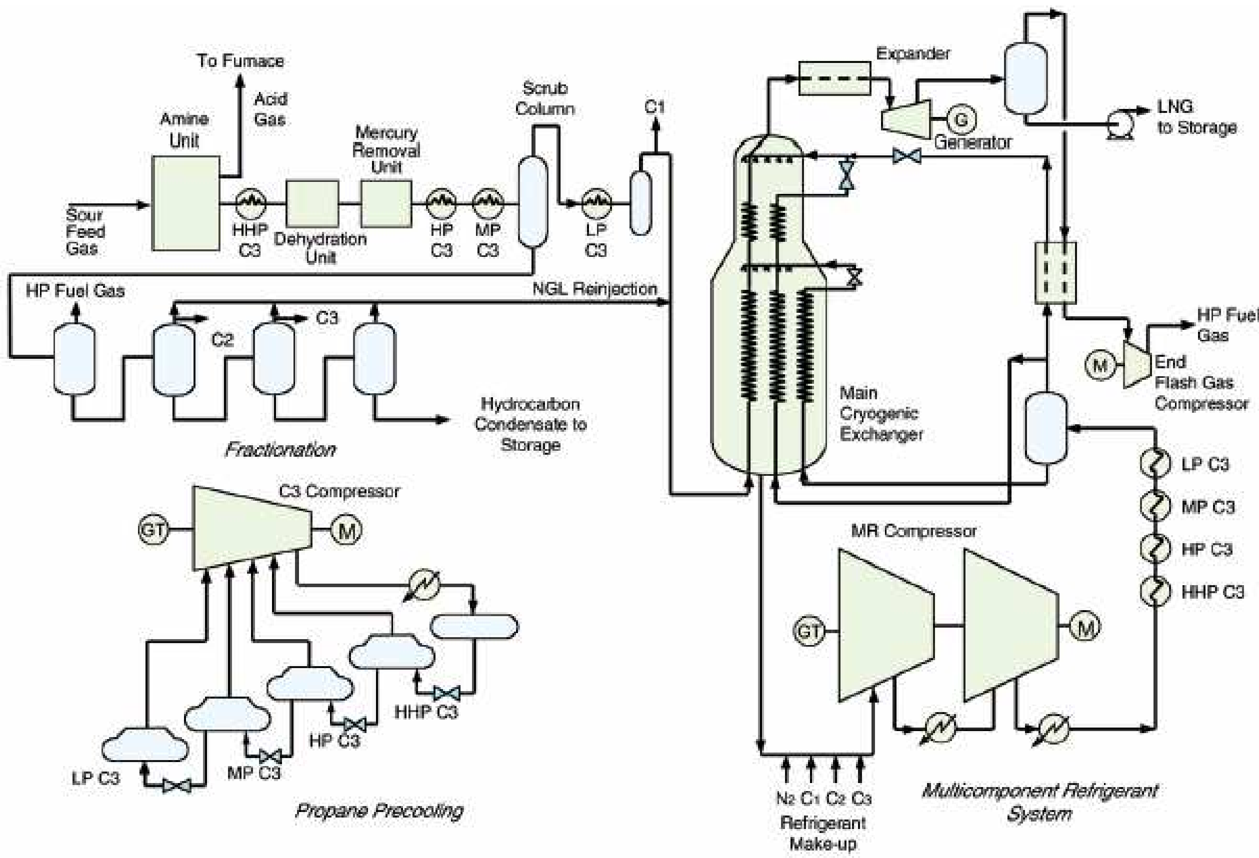

Figure 3: *APCI propane precooled mixed refrigerant process (typical).*

	PHILLIPS OPTIMISED CASCADE PROCESS	APCI PROPANE PRE-COOLED MIXED REFRIGERANT PROCESS (MCR)
Operational Principle	Pure component cascade process	Mixed refrigerant process
Advantage	Potential higher availability with parallel compression	Simpler compression system. Adjusting composition allows process matching
Disadvantage	More equipment and complicated compression system	More complex operation
Refrigerants	Propane, ethylene and methane	Components from methane, ethane, propane, butane and nitrogen
Improvement	This process is a modification of an earlier version used on the Kenai LNG plant	It has been modified to the APX-process which adds a third refrigerant cycle
Capacity	3.3 million tpy	4.7 million tpy
Relative power	167%	100%
Efficiency	20.4kW*day/ton (90%)	12.2kW*day/ton (100%)
Cost	$5 billion	More than $5 billion
Safety	Large flammable refrigerants and high refrigerant circulation rates through process lines makes it less safe	Extensive overpressure potential and flare requirements makes it more dangerous than the cascade process

Table 1: *Comparison of the phillips optimised cascade process and the apci propane pre-cooled mixed refrigerant process (MCR)*

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