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Technology Review of Natural Gas Liquefaction Processes

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Abstract: Due to the increasing demand for natural gas in the world today, transportation of natural gas from different parts of the world has become a necessity. Liquefying of the natural gas provides a safer and cheaper alternative for its transportation and increases its storage capabilities. However, it has been accounting for the highest operating cost if compared to the other chain of the industry. Hence, liquefaction process has been a key area that constantly in need for development to save cost and increase LNG plant capacity through production. This study reviews for the current development of natural gas Liquefaction (LNG) technologies. The cost items equipments that affect the overall operating cost of the plant and equipments efficiency will be discussed. Studies had been done on several parameters that influence the process efficiency and lead to wide difference in the production of LNG in a plant. These include the tube side design pressure, end flash quantity, temperature approach on main condenser, compressor efficiency, LPG recovery and also liquefaction technologies. Nevertheless, further studies and in depth understanding on the fundamentals of liquefaction process is still required in order to develop innovative methods to further increase the capacity, efficiency and consequently the production of LNG in a LNG plant.

Key words: Natural gas, liquefaction, LNG, transportation

INTRODUCTION

The importance of liquefying natural gas is due to the economics of transporting its bulk liquid form which only occupies 1/600th volume compared to the gaseous form. LNG has a strong market demand worldwide as the source of fuel to generate electricity and the demand is increasing every year. The high demand of LNG fuel is because it emits less harmful gases into atmosphere compare to other fossil fuels as discussed by Shukri and Wheeler (2004), Pillarella *et al.* (2005) and James (2004). Therefore, in order to meet this demand, LNG producers look for better options to maximize their production by optimizing their current plant. However, they need to consider several other factors for this option such that they shouldn't bare extra expenditure for increasing their plant's capacity. An LNG projects represents a chain of capital-intensive investments, consisting five links-field development, pipeline to on-shore, liquefaction facility, tanker transportation and the receipt/regasification terminal.

The liquefaction unit process has been accounting for up to 50% of total project cost of a liquefaction plant as shown in Fig. 1 which reviewed by Finn *et al.* (2000). The train growth on the global scale is shown on Fig. 2. The Evolution of LNG technologies worldwide applied natural gas liquefaction technologies is shown in Fig. 3 and b.

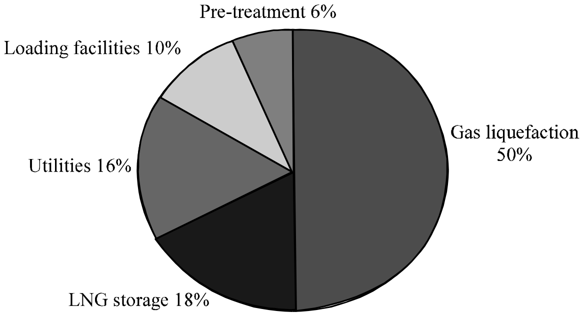

Fig. 1: Typical breakdown of liquefaction plant capital costs

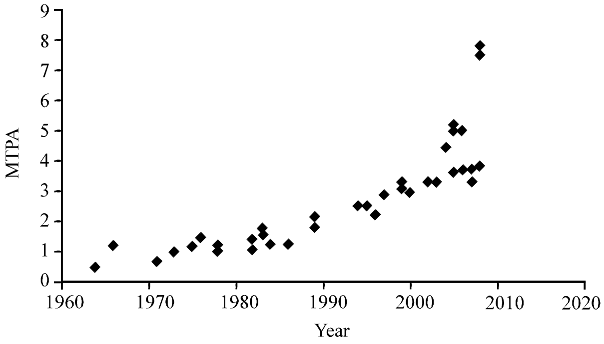

Fig. 2: LNG train size growth

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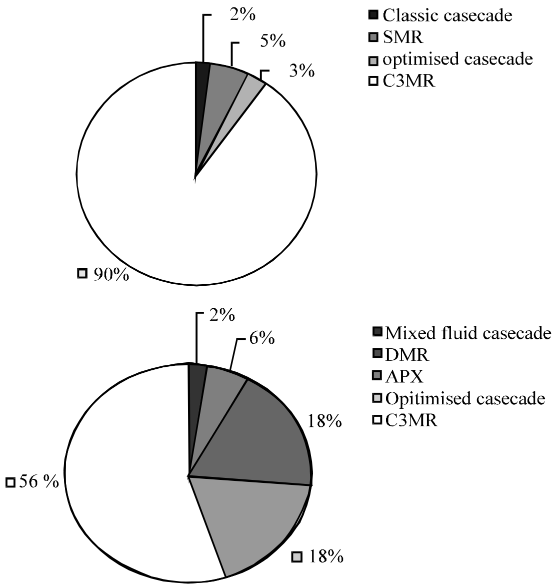

Fig. 3: Worldwide Natural Gas Liquefaction Technologies liquefaction capacity within (a) 1964-2000 and (b) 2001-2012

One of the criterions for the selection of liquefaction process is the capacity requirements. Designing a large plant and running it far below the capacity rates is a waste of investments and potentially could result in greater maintenance issues. Economy of scale means maximising profit based on fixed capital investment as reported by Charles *et al.* (2005). Hence in order to fully take advantage of their economy of scale, production must be maintained near capacity. Since production level is based on what the market will support, if the demand goes down, so would production. Likewise, if production of LNG is greater than demand, the sale price will weaken and production rates must be decreased which leads to further waste of capital investments as discussed by Martin and Fischer (2003). Therefore, the selection of process technology is not only concerned with capacity and stability but also with maximising profit based on market demand.

Refrigeration for liquefaction: The refrigeration and liquefaction section Is the key element of an LNG plant where it typically accounts for 30-40% of the capital cost of the overall plant. Liquefaction of natural gas involves the transfer of energy from hot stream of natural gas to cold stream of the refrigerant via LNG heat exchangers. During this process, the phase of natural gas changes from vapour to liquid. The basic principle of using refrigerant to liquefy the gas to cryogenic temperature of approximately (-160°C) is to match the cooling/heating curves of the process gas and refrigerant as closely as possible. Results in a more efficient thermodynamic process requiring less power per unit of LNG produced. After the liquefaction process takes place, LNG is pumped into cryogenic storage tanks, until a tanker is available to transport LNG to the market as reported by Doug (2002) and Bosma and Nagelvoort (2009). These tanks are typically double-walled, with an outer wall of reinforced concrete lined with carbon steel and an inner wall of nickel steel as mentioned by Bosma and Nagelvoort (2009). There is insulation between the two walls to prevent ambient air from warming the LNG. After an empty tanker docks at the berth, LNG is loaded into the tanker through insulated pipes that are attached to the tanker by rigid loading arms as discussed by DOE/EIA-0484 (2009), APX Energy Viewpoints (2005) and Ross *et al.* (2008). Once the tanker is filled, the pipes are disconnected, the loading arm will swing away from the ship and the tanker is ready to sail. Figure 4 shows an example of a typical temperature-heat diagram or cooling curve for the cooling of natural gas using both pure and mixed refrigerants as reported by Pillarella *et al.* (2005) and Eaton *et al.* (2004).

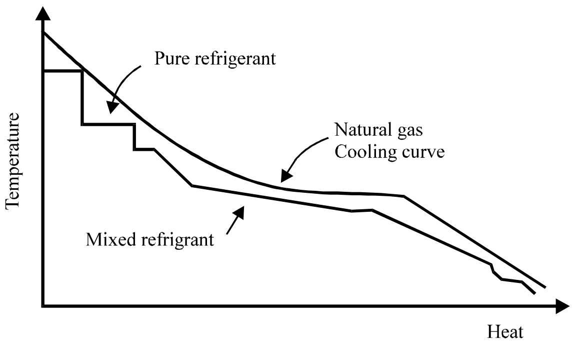

Fig. 4: Natural gas refrigerant cooling curve

The closer the line depicting the refrigerants is to the curve of the natural gas, the more efficient is the cycle. Reducing the amount of work done on the refrigerant can increase the efficiency of the heat exchange in the natural gas liquefaction process. Higher efficiency is indicated by the closeness of space between the refrigerant and the natural gas curves as reported by Rivera *et al.* (2008) and Shuhaimi and Razik (2008).

LIQUEFACTION TECHNOLOGY

APCI propane pre-cooled mixed refrigerant process (C3MR): In this technology, there are two main refrigerant cycles. The precooling cycle which uses a pure component propane and the liquefaction and sub-cooling cycle useing 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. Figure 5, shows C3MR process flow sheet. A centrifugal compressor with side streams recovers the evaporated C3 streams and compresses the vapour to 15-25 bar 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. The refrigerant is used to liquefy and sub-cool the process stream from typically -35°C to the temperature range -150 to -160°C. This is carried out in a proprietary spiral wound exchanger commonly known as the Main Cryogenic Heat Exchanger (MCHE) as addressed by Finn *et al.* (2000). 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-Thomson (JT) valve or a hydraulic expander onto the shell side. It flows downwards and evaporates, providing the bulk of cooling for the lower bundles. The vapour MR stream passes to the top cold bundle, liquefied and sub-cooled. It is then 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 top bundle and, after mixing with liquid MR, part of the duty for 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 as mentioned by Finn *et al.* (2000)

Dual mixed refrigerant process (DMR): The dual mixed refrigerant process or DMR is very similar to the APCI liquefaction process. Figure 6 shows the DMR process flow sheet as discussed by Ross *et al.* (2008). It is designed to overcome the inherent limitations of using a single component refrigerant in pre-cooling in the C3MR design; the additional degree of freedom resulting from the use of two mixed refrigerant cycles allows full utilization of power in a design with two mechanically driven compressors. Furthermore it allows keeping the compressors at their best efficiency point over a very wide range of ambient temperature variations and changes in feed gas composition. The natural gas stream is cooled via two stages. The first stage cools natural gas to -50°C while the second column cools natural gas to LNG at -160°C.

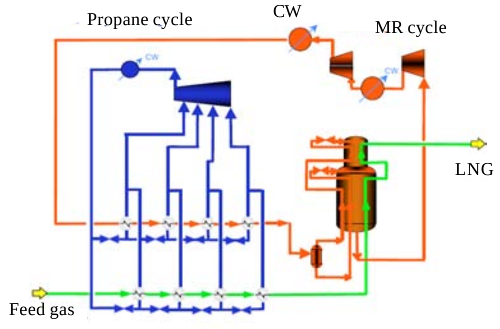

Fig. 5: C3MR process flow sheet

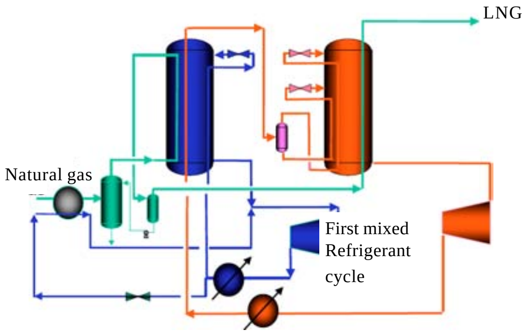

Fig. 6: DMR process flow sheet

The composition of the pre-coolant cycle is 50/50 of ethane/propane on molar basis and the coolant composition of the cooling cycle is similar to the composition of APCI. In this process the heat exchanger tower is divided into two sections and this concept allows the choosing of load on each refrigeration cycle through controlling the two compressors work before each column.

DISCUSSION

There are many aspects, that have been addressed to have influence on the efficiency of liquefaction process and affecting the quantity of LNG produced.

Tube side design pressure: The tube side design pressure in MCHE is increased from 76 to 83 barg using a feed compressor. Higher tube side design pressure allows for higher operating pressures which results in higher LNG production and lower specific power.

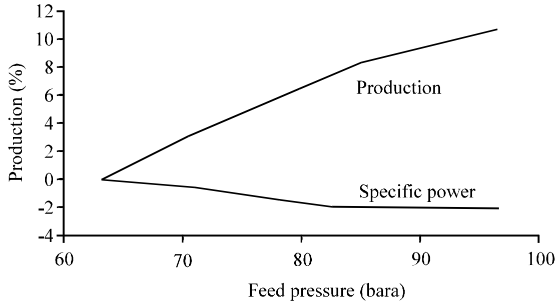

Fig. 7: Effect of feed pressure on production and specific power

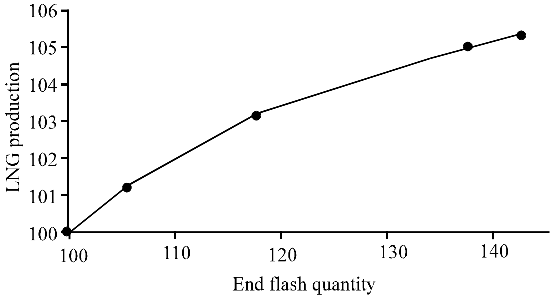

Fig. 8: Effect of end flash quantity on LNG production

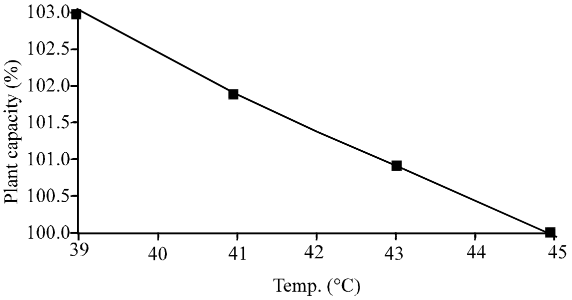

Fig. 9: Effect on LNG production of condenser temperature approach

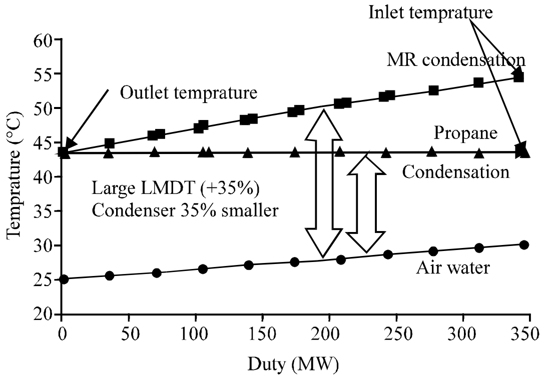

Fig. 10: Effect of using propane or mixed refrigerant on the size of the condenser

Figure 7 shows the percentage increase in production and reduction in specific power as the feed pressure is increased as reported by Pillarella *et al.* (2005). It includes the feed compressor power as well as the propane and mixed refrigerant compressor powers. However, this has to take into consideration of the cost of the required inlet plant equipment or the thermal efficiency options the pressure present for the plant design and also the impact on upstream plant facilities supplying the gas as discussed by Pillarella *et al.* (2005).

End flash quantity: The quantity of end flash usually corresponds to the plant fuel gas consumption. If it is possible to increase the quantity (fuel gas export to other plants and recycle etc) the cold end temperature of the main exchange line will increase and the efficiency of the plant, thus the quantity of LNG produced will also increase. However, the quantity of fuel gas cannot be decreased below a certain quantity due to the nitrogen content of the feed gas. Figure 8 shows the Effect of end flash quantity on LNG production. The power requirement of the fuel gas compressor for the more generated fuel gas also has to be considered. Nitrogen can have significant effect on thermal efficiency, resulting in higher energy consumption and lower thermal efficiency as this gas is cooled to LNG temperature. Hence, the rejection composition of nitrogen should be evaluated by considering the impact on the size of equipment (gas compression) and the piping system (relief valve, vessels and pipe) as discussed by Martin and Fischer (2003).

Temperature approach on the main condenser: A large condenser on the first refrigerant cycle must evacuate the heat produced by the refrigeration compressors. As the outlet of the compressor is at bubble point, to modify the outlet temperature of this condenser will change the discharge pressure of the corresponding compressor.

Figure 9 shows the effect on LNG production of condenser temperature approach. The power of the compressor and overall efficiency will be affected. The closer is the temperature approach, the larger the LNG production. The size of the condenser depends upon whether the refrigerant of the first cycle is a pure component or a mixed refrigerant.

With a pure component, the condensation is done at a fixed temperature (the dew point temperature is the same as the bubble point temperature) whereas with a mixed refrigerant, the temperature varies linearly between the dew point temperature and the bubble point temperature. Either the condenser will be much smaller with a mixed refrigerant in the first cycle, or inversely with the same condenser size, the LNG production will be increased. Figure 10 shows effect of using propane or mixed

Table 1: Comparison between C3MR and DMR

Technology	C3MR	DMR
Similiarity	- Subcooling and liquefaction using mixed refrigerant (nitrogen (1%), methane (27%), ethane (50%), propane (20%) and butane (2%))	
Differences	Precooling-propane One heat exchanger	Precooling-ethane (50%) and propane (50%) Two heat exchangers
Advantages	More efficient than using mixed refrigerant for chilling natural gas prior to liquefaction and cost of compressor can be justified based on overall power propane saving Simpler configuration less amount of equipment	Adjust on seasonal basis as temperature changes High thermal efficiency Higher reliability Optimum selection of compressors and drivers Preferable in floating production storage and offloading (FPSO) facilities to minimize/eliminate propane inventory due to possibility of leak resulting in propane vapor accumulating on or below deck of ship
Disadvantages	- High equipment cost (spiral wound heat exchanger) - High utility cost (propane exchangers) - Lower reliability	- Greater equipment count - Complexity in evaluating composition needed - Multiple refrigerant handling

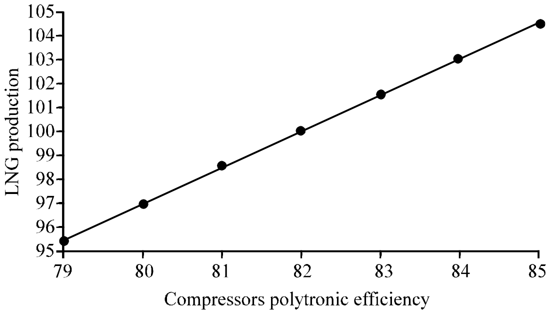

Fig. 11: Effect of compressor polytropic efficiency on LNG production

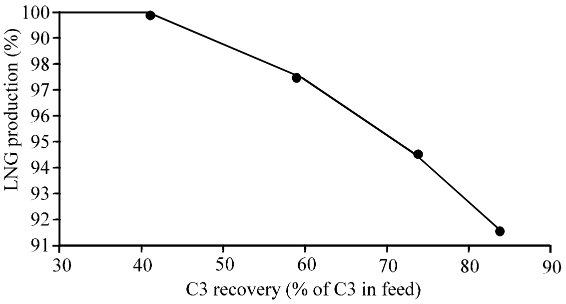

Fig. 12: Effect of LPG recovery on LNG production

refrigerant on the size of the condenser as discussed by Martin and Fischer (2003).

Compressor efficiency: The LNG production can vary tremendously depending upon the compressor efficiency considered. The increase in compressor polytropic efficiency will also increase the LNG production as shown on Fig. 11.

LPG recovery: The recovery of LPG from the gas can make the project economically sound. However, it will increase the power of LNG liquefaction. Hence, with the increase of LPG recovery, it will lead to the decrease in LNG production as shown on Fig. 12 as discussed by Martins and Fischer (2003).

Liquefaction technologies: The significance of Dual Mixed Refrigerant (DMR) is from the modification of propane Pre-cooled Mixed refrigerant (C3MR) to maximize the utilization of power available from compressor drivers while maintaining efficient and efficient refrigerant compressor operation over a wide temperature range. Comparison of both technologies is shown on Table 1.

The selection of liquefaction technologies for an LNG plant depends on the overall economics, the required size train, the volume of natural gas reserves, market demand and equipment reliability. For many years, the propane pre-cooled Mixed Refrigerant (C3MR) process has remained the dominant liquefaction cycle in the LNG industry. This is due to the versatility of this cycle that makes it well-suited to accommodate this ever changing industry. Efficient integration of NGL/LPG recovery with the liquefaction process plays a key role in achieving lower heating value LNG requirements for a variety feed conditions. Though the mixed refrigerant processes rank the highest in equipment cost, it has the lowest operating cost. It consists of one big heat exchanger tower, massive compressors and propane chillers which raise the equipment cost and reduces the operating cost. The operating cost in mixed refrigerant process is lower due to two reasons. Firstly, having large heat exchanger tower which leads to reduction in ambient heat loss since all the heat exchanging process takes place in the tower rather than in separate heat exchangers. Secondly, less work is required due to having one large compressor with a heat exchanging tower which is more efficient than having many compressors running for each loop. The more compressors for each loop results in more frictional and head losses, hence greater compression work.

CONCLUSIONS

Process technology for liquefaction of natural gas is undergoing continuous improvement to meet with the increasing demand of LNG. This has demanded LNG plants to be volume flexible to match with market demand. Thus process evaluation techniques are required to identify process improvements which can be applied on existing plants to lower the operation cost and expand its capacity to increase LNG production. Selection of the optimum process cycle is indeed crucial to ensure the capacity of the plant will be fully utilized and the plant is run in a cost effective manner. The unique characteristic of an LNG plant is to be operating it at an optimum thermal efficiency without neglecting the economics merits and environmental impacts.

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