

Evolution of Liquefaction Technology for today's LNG business

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Abstract –For more than thirty five years, Air Products and Chemicals, Inc. has been the leading supplier of natural gas liquefaction technology and main cryogenic heat exchangers. The majority of LNG produced today comes from plants utilizing Air Products' propane pre-cooled, mixed refrigerant LNG process (C3MR) and MCR[®] Wound Coil heat exchangers. New LNG plants face a broader range of requirements than ever before. Growth in LNG demand is faster than ever before, larger process train size is often desirable, new geographical locations for liquefaction plants and new customers for LNG with different LNG specifications are emerging, as well as FPSO applications.

This paper discusses the application of Air Products LNG technologies to these new market conditions. The influence of liquefaction technology on process train capacity will be discussed in the light of ongoing projects using both C3-MR, SplitMR[™], and AP-X[™] process technologies. Recent developments in the capability to build larger main cryogenic heat exchangers for C3-MR liquefaction plants and the implementation of large capacity AP-X[™] process cycles in Qatar have resulted in significantly larger train sizes with a single main cryogenic heat exchanger. Optimization between the liquefaction process and the owner selected compressor/driver combinations continues to be as important as ever before. The Frame 9 gas turbine driver has now become an accepted choice for some of today's largest liquefaction projects.

Integration of LPG extraction with liquefaction processes has become more important than ever to serve present and future markets such as those developing in the USA and the UK. There are many options available from which to select a

preferred scheme for today's large liquefaction trains.

Keywords: LNG Liquefaction

1. Introduction

Mixed refrigerant processes, and specifically the propane pre-cooled, mixed refrigerant process, have taken a commanding position in the liquefaction of natural gas because they are flexible, efficient, and low cost. The C3MR process is operating efficiently in arid and tropical climates, with rich and lean natural gas feed, with and without LPG (C3 and C4) extraction, over a broad range of ambient temperatures. LNG train capacity has continued to increase substantially as shown in Figure 1. This has been due

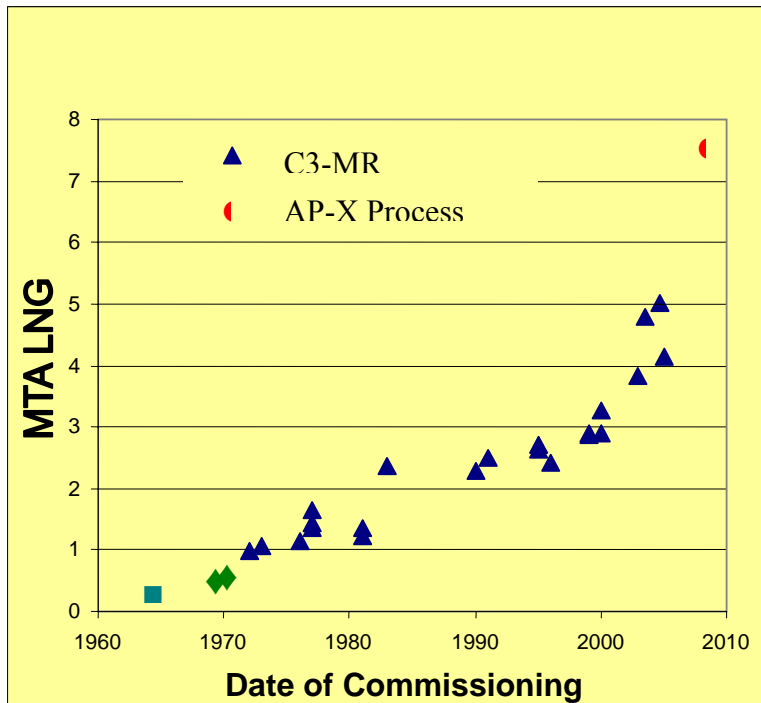


Figure 1 Evolution of LNG train size

to advancements in both process equipment and cycle design. For train capacities up to 5 MTA, the C3-MR process has been the dominant technology. Recent advances in main exchanger manufacturing capabilities have made it possible to extend the range of the C3-

MR process to over 6 MTA. In addition, the industry is poised to make a significant increase in train size capacity to 7.8 MTA with the introduction of the Air Products AP-X™ process in Qatar for which six process trains have been ordered. Studies have shown that single train capacities up to 10 MTA are feasible with the AP-X™ process.

2. C3MR

The current generation of 5 MTA Propane Pre-cooled Mixed Refrigerant liquefaction plans have

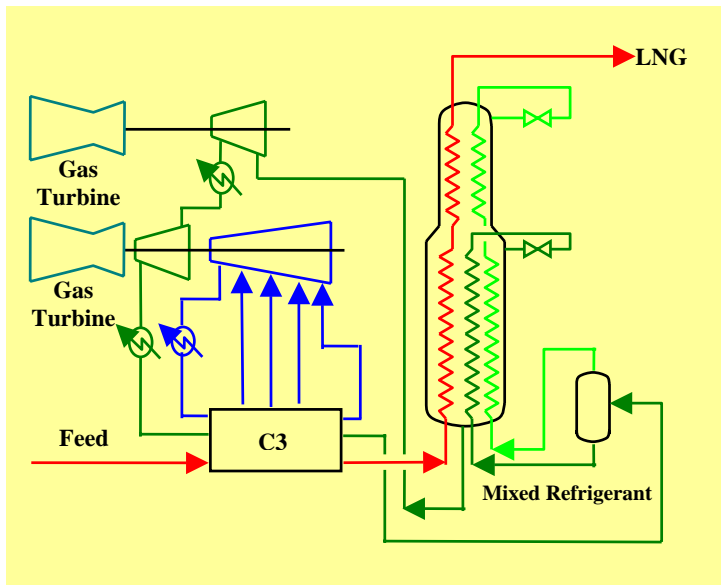


Figure 2. The C3MR process

particular features of equipment selection. These plants typically utilise two frame 7 gas turbine drivers with starter/helper motors capable of continuous operation. Fuel for the gas turbines is partly provided from end flash with the balance being provided in part from storage tank boil off gas. This plant size employs Air Products Split MR™ compressor/driver arrangement as shown in figure 2. In this arrangement the power of each gas turbine plus its helper motor is fully utilised by having mixed refrigerant compression services on both gas turbines and the propane compression service on one of the gas turbines. A single propane compressor casing is used in figure 2. These plants require only a single Air Products MCR® Wound Coil Heat Exchanger for liquefying natural gas. In the C3MR process this heat exchanger both liquefies and subcools the natural gas. A typical installed helper motor size for these 5 MTA LNG trains is less than 20 MW.

C3MR process capacities greater than 5 MTA can be achieved by adding a second propane compressor casing. This can be done at lowest capital cost by using one casing to provide compression for two of the propane pressure levels and a second compressor casing for compression of the other two. This arrangement is shown diagrammatically in figure 4. This arrangement enables the piping to remain simple without the increase in piping associated with using two 50% parallel compressors. Flow balancing between the two compressors is also avoided with this arrangement. Both compressor casings can be mounted

on the same gas turbine shaft along with the HP mixed refrigerant compressor casing. This increase in compression capacity can be matched with more power input from increased helper motor size. As helper motor size increases beyond 20MW one generally must add another power generation turbine to the plant.

Once the highest reasonable helper size has been reached further capacity increment requires a change in compressor driver philosophy. The lowest cost increment is to replace the two frame 7 gas turbine drivers with two frame 9 gas turbine

drivers. The first use of frame 9 gas turbines as drivers for LNG liquefaction compressors will occur through the new projects underway in Qatar. The starter/helper motor, which had become large in the two frame 7 case, now needs only to be sized for the starting load of the machinery strings. The arrangement of compressor casings on gas turbine shafts remains the same as the frame 7 case. The result of such a change can raise the available C3MR plant capacity to approximately 6 MTA. Air Products is able to manufacture its MCR® Wound Coil Heat Exchangers of sufficient size to carry out this liquefaction duty in a single unit.

3. AP-X™

For very large, single train LNG liquefaction plants, the Air Products AP-X™ LNG process offers an attractive means to significantly reduce

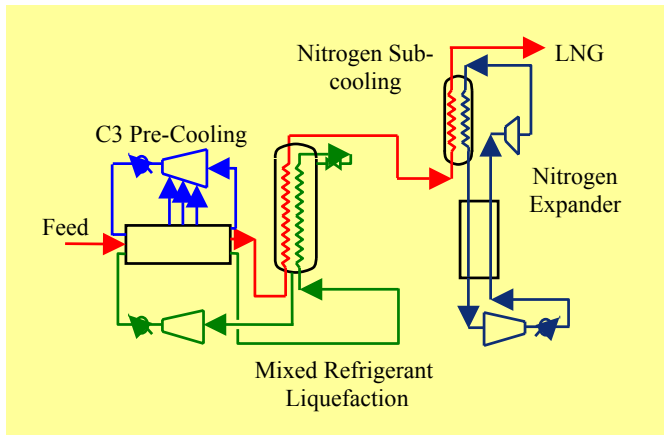


Figure 3 AP-X™ process

the specific capital cost of LNG. The AP-X™ LNG process can be configured with propane or mixed refrigerant pre-cooling as required by ambient conditions and plant location, and it is expected to provide the lowest unit cost of LNG on the market today. The economy of scale is superior to splitting equipment into two process trains or duplicating equipment. The first AP-X™ trains to be built will have a nominal capacity of 7.8 MTA LNG. The AP-X™ concept is depicted in Figure 3. This process retains the concept of single train equipment up to the highest capacity and can employ the Split MR™ compressor configuration. The addition of the sub-cooling cycle using nitrogen as working fluid reduces the propane refrigeration and mixed refrigerant compression duty per tonne of LNG. Plant capacities can be steadily increased from 7.5 to 10 MTA by increasing the amount of driver power consumed using two or three frame 9 gas turbines. It has been shown that natural gas liquefaction capacities of up to 10 MTA and beyond can be achieved with single train compression equipment for mixed refrigerant and nitrogen. Using AP-X™ technology at approximately 7.5 MTA LNG the number of propane compression casings is increased to two in the same arrangement as for the C3MR process. Air Products manufactures and supplies the cryogenic machinery necessary for the

nitrogen expansion required in the AP-X™ process from its manufacturing facility in the United States.

4. LPG extraction

Extraction of heavier (C5+) feed components, aromatics and sufficient ethane and propane for refrigerant make up has always been important in LNG liquefaction design. The emergence of new markets, particularly those in the USA and UK are creating a demand for an LNG traded with lower heating value and Wobbe index than LNG historically traded in the rest of the world. This reduced heating value LNG product is achieved at the export terminal by increasing the amount of LPG components extracted from the feed gas. In many current project developments almost all the propane and butane is being extracted from the feed gas and in some cases some of the ethane too. The requirement to extract large quantities of LPG from the feed gas increases the processing complexity of the liquefaction plant. To achieve high levels of LPG extraction there are two primary process

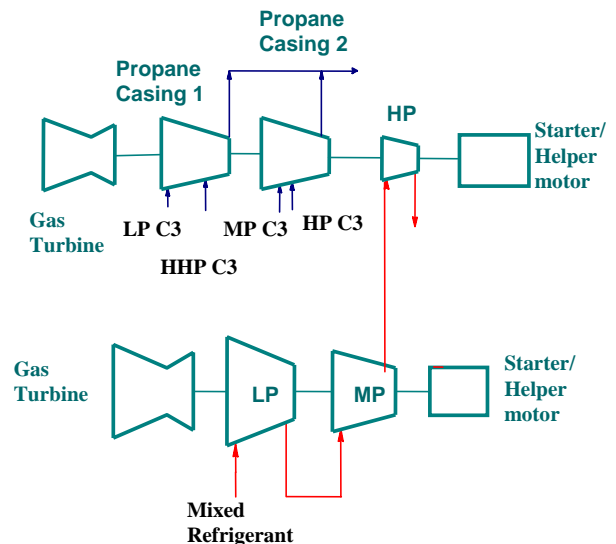


Figure 4 Split MR and two propane compressor casings

options. The first option is generally referred to as an expander plant and may be located immediately upstream of the liquefaction plant or integrated with the precooling section of the liquefaction process. Figure 5 shows a typical schematic of an integrated

expander plant for LPG extraction. Refrigeration for the LPG extraction is produced by expanding the feed gas to a lower pressure. In doing so the separation column operates at a lower pressure which makes the separation by distillation easier. Energy from the turbo-expander is recovered by a compressor linked to the expander (called a compander) which recompresses feed gas downstream of the separation column before liquefaction. The higher the feed pressure the more efficient will be the liquefaction and hence the feed gas to the liquefaction process downstream of the expander process will usually be further compressed. This type of process can recover more than 98% of the propane and butane from the feed gas. Ethane can also be extracted from the feed gas by this process. The addition of a recycle from the feed gas re-compressor cooled against separation column overhead can be added as an option providing a purer reflux to the column enabling any desired quantity of the ethane in the feed gas to be extracted.

A second option for achieving high LPG extraction is a form of the scrub column process which operates at feed pressure to the liquefaction plant. Such a scheme is depicted in figure 6. New studies by Air Products have shown that the scrub column process can be adapted for high propane and butane extraction whilst still retaining high operating pressure for efficient liquefaction. Increased LPG extraction from the scrub column requires lowering the operating temperature of the scrub column top temperature. There is a limit to how low this temperature can be taken as the overhead mixture is getting closer to its critical point. It has been known for some time that recycling some propane and butane from the in plant fractionation system and returning it as reflux to the scrub column increases the amount of butane and heavier extracted from the feed gas. As the top of the column is made colder and as propane and butane extraction is increased the composition at the top of the column becomes leaner. As a natural gas stream gets leaner its critical pressure lowers and normally this would force the operating pressure of the column to be lower leading to less efficient liquefaction operation. Air Products has developed process conditions by which to compensate for the leaning of the mixture in propane and butane. This process recycles ethane to the top stage of the column. This enables a high critical pressure to be retained allowing the column to be operated at an efficient high pressure of greater than 55 bar for liquefaction. If further required by the process a lean oil of C5+ can also be recycled. This being returned to the scrub column at a feed point below the propane/butane recycle stream. By a

combination these means effective scrub column operation extracting more than 95% of the LPG components can be achieved.

Selection of the optimal LPG extraction scheme is very

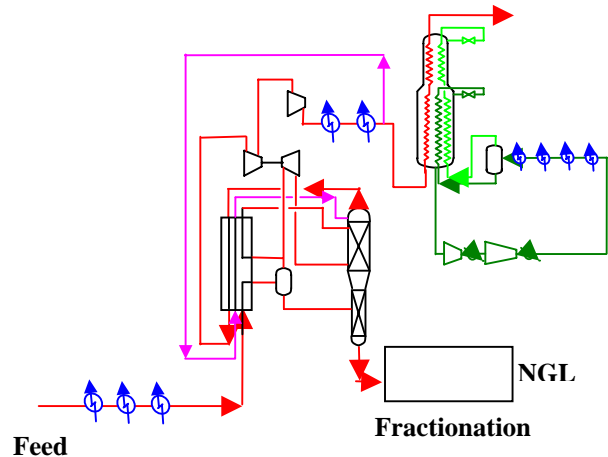


Figure 5. Expander LPG Recovery Process

dependent on the specific circumstances of each project. The expander process is largely self-contained in its provision of refrigeration for the LPG extraction process. This allows the liquefaction machines and liquefaction main cryogenic heat exchanger to be dedicated to producing a maximum amount of LNG. Hence such a scheme may be attractive where high LPG extraction is required and the process is at the limit of available equipment size such as compressors and drivers. On the other hand this process places two additional machines, the compander and the feed gas compressor in series with the liquefaction process which could lower liquefaction plant availability.

The integrated scrub column does not affect plant availability and uses less equipment. It can still achieve high LPG extraction. On the other hand it consumes some refrigeration from the liquefaction equipment and has limited potential for ethane extraction if this is desired.

5. New developments for new environments

The recent rapid growth in the LNG business has led to some rapid developments in liquefaction technology such as the AP-X process and the adoption of Frame 9 gas turbine drivers. Until now most new LNG projects have been in geographical locations of warm ambient temperatures. In the future it is expected that there will also be liquefaction plants built in arctic climates and

as floating plants in order to monetize the world's gas reserves. Process design of natural gas liquefaction plants in arctic climates presents some unique challenges. The features of a mixed refrigerant liquefaction process mean they can easily be adapted to this environment. Although arctic conditions have a low average annual temperature close to zero degrees Celsius the temperature variation over a year can be more extreme than warm climates. The cold climate does reduce overall liquefaction power. The power required for the precooling refrigerant such as the propane system is reduced to a greater extent than the liquefaction refrigerant. The wide variation in ambient temperature may

Replacing the pure fluid precooling refrigerant with a mixed refrigerant will also enable large 7-8 MTPA single train capacities.

The AP-X process can easily achieve 10 MTPA LNG production and beyond from a single train.

6. In Conclusion

Air Products natural gas liquefaction processes have been continuously evolving and meeting the needs of an expanding LNG business. Plant sizes have grown and even larger plant sizes can be built in the future if the market demands this.

All today's plants continue to use a single Air Product's Spiral Wound Heat Exchanger for the natural gas liquefaction and are expected to do so in tomorrows even larger plants.

The C3MR process continues to play a significant role in new projects and is expected to continue to do so in the future, complementing the role of the AP-X process for very large process trains.

New approaches to LPG extraction are expected to meet new demands on LNG product quality.

LNG liquefaction technology is ready to evolve further as new projects in new locations place new demands on plant designer and technology licensors.

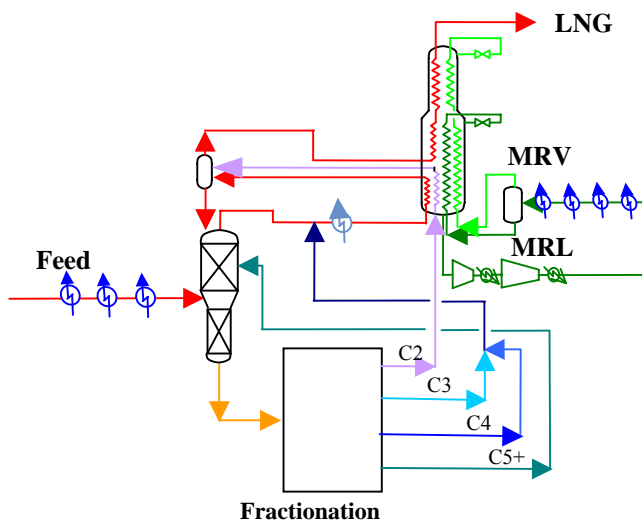


Figure 6. LPG recovery using recycles

significantly vary this precooling load in the case that the plant is air cooled rather than water cooled. All this can enable some new machinery solutions for large liquefaction trains.

A 5 MTPA C3MR liquefaction plant only requires a single frame 9 gas turbine driver driving all liquefaction plant compressors.

Replacing propane refrigerant with propylene enables a C3MR liquefaction train to be designed to have a bigger capacity in the range of 7-8 MTPA LNG. A water cooled liquefaction plant in arctic conditions could even use ethane as precooling refrigerant. Both these choices retain the robust pre-cooling heat exchanger configurations used on today's C3MR processes.