

US equipment-maker Air Products employs proven technology for larger plants now being proposed

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Among the large volume LNG production facilities that have been proposed recently, some owners favor multiple mid-scale trains, while others lean toward the more traditional large-scale trains to meet similar production requirements.

The logic for selecting multiple mid-scale trains over single larger trains has been that such plants require less initial capital outlay and can be built over time to match the timing of off-take contracts and are therefore easier to finance and generate cash more quickly.

Key driver

While these economic factors may seem different, project developers are all still quick to claim lowest cost per ton of LNG, since that remains the key driver for most large-scale projects. Despite the shift in focus to multiple mid-scale trains, economy of scale can still apply, allowing large-scale trains to offer the most competitive unit price for LNG production.

Another trend in recent LNG project developments is the consideration of a modularized execution strategy, a strategy that has been employed for decades in other non-LNG related industries.

Depending on the project-specific characteristics for the chosen site location, modularization of the plant design can provide benefits to the overall project economics.

Some owners and project developers assume that to achieve the benefits of modularization, the use of mid-scale designs is required, and that modularization precludes the use of large-scale plant designs which take advantage of the simple concept of “economy of scale” to achieve a lower cost per unit of LNG produced.

Recent projects, such as the Yamal LNG facility with a single LNG train capacity of over 5 tons per annum (MTPA), have successfully demonstrated that a modular approach to plant construction can be applied to large-scale trains.

The LNG technology that was

successfully developed for use in the largest LNG facilities in operation is the AP-X® LNG Process.

Developments

As new developments are being proposed for the monetization of very large gas fields in several different geographies, interest in the economy of scale benefits provided by AP-X technology has returned.

This article will address new developments in the AP X® process, specifically around the introduction of proven machinery arrangements developed originally for the AP C3MRTM LNG Process.

Introduction of large train capability - AP-X® process: AP-X® was introduced in 2001 to address capacity limitations with existing LNG process cycles of the time. AP-X® was developed as a variation on the widely utilized AP-C3MRTM LNG Process, with the intent of addressing the maximum LNG production capability of AP-C3MRTM particularly related to the proven size of the then existing coil wound heat exchangers (CWHE), refrigerant compressors, and refrigerant compressor drivers.

The first projects to utilize AP-X® were those built in Qatar to enable the development of the immense North Field gas reserves. The first six AP-X® trains were successfully commissioned in 2009 and have been operating reliably since initial startup.

AP-X® LNG Overview

The liquefaction of clean, dry natural gas has three main steps: precooling (de-superheating) the gas, liquefaction of the gas, and sub-cooling the liquid natural gas.

The AP-C3MRTM LNG Process uses two separate refrigeration loops, with a propane refrigeration loop providing precooling to the feed gas and mixed refrigerant (MR), and an MR loop containing hydrocarbons and nitrogen to provide cooling for liquefaction and sub cooling of the natural gas stream. Since the MR is partially condensed by the propane, the heat duty from the MR is

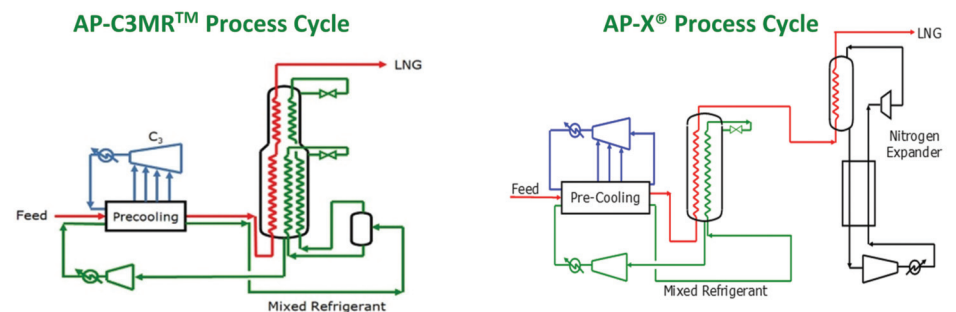


Figure 1 Comparison of the AP-C3MRTM and AP-X® Process Configurations

said to be “cascaded” down to the propane system.

The AP-X® process uses three separate refrigeration loops for precooling, liquefaction, and sub cooling.

Like the AP-C3MRTM process, the AP-X® process uses a propane refrigeration loop to provide precooling to the feed gas and MR to provide cooling for the liquefaction. In both processes, the MR heat duty is cascaded down to the propane system.

The primary difference in the AP-X® process is the introduction of a separate refrigeration loop for sub-cooling the LNG. This third loop is a Brayton gas expansion cycle.

Sub-cooling

The addition of a separate refrigeration loop allows a shift in the refrigeration duty.

Along with the introduction of the sub cooling nitrogen refrigeration loop, the configuration of the CWHE was revised to include a separate CWHE sub-cooler in addition to the traditional single CWHE in the AP-C3MRTM process. The difference in configuration of AP-C3MRTM and AP-X® is shown in Figure 1 above.

The shifting of refrigeration duty from two refrigeration loops and a single MCHE to three refrigeration loops and separate CWHE's for liquefaction and sub cooling within the AP-X® process allowed the benefit of significant capacity increase for a single LNG train (more than 50% higher than the AP-C3MRTM process capability of the time) within existing available technology for the CWHE's, refrigeration compressors, and gas turbines.

Refrigeration and compression arrangements for the AP-X® LNG process:

The first plants utilizing AP-X® used heavy duty industrial gas turbines to drive the compressors for each of the refrigeration loops. The first compression string provided propane precooling using two compressor casings, with a 3-stage low-pressure casing and a single stage high pressure casing.

The second compression string provided MR liquefaction using two compressor casings, with a single stage low-pressure casing and a two stage, vertically split back-to-back high-pressure casing. The third compression string provided nitrogen sub-cooling using two compressor casings, with a single stage low-pressure casing and a single stage high-pressure casing.

The compression strings utilized 45 MW helper motor / generators on each string. In addition to providing for normal startup, the motor / generator configuration allowed for the transfer of power from the propane and nitrogen compressor gas turbines to the MR compressor gas turbines to balance power between the compression loops.

Next generation of large LNG plants

Since the first AP-X® LNG train began operation in 2009, advancing technology and manufacturing improvements for CWHEs, refrigeration compressors, and gas turbine drives now allows for even higher production rates. These advances now allow a single AP-X® LNG train to produce over 10 million tonnes per annum.

Improved compressor aerodynamic

capabilities allow for larger volumetric flow rates within a single compressor casing, facilitating both higher refrigeration flows and the ability to combine process stages into single compressor casings that would have required multiple casing in previous designs, reducing the size and cost of the refrigeration strings. Gas turbine technology has progressed significantly since the development of the original facilities utilizing AP-X®. Mechanical drive heavy duty industrial gas turbines have seen significant increases in ISO power ratings and efficiency.

There has been widespread acceptance and use of Aeroderivative gas turbines in the LNG industry. There have also been advances in new mechanical drive heavy duty industrial gas turbines that offer the advantages of the multi-shaft technology used in Aeroderivative turbines.

In addition to higher capacity machinery, the industry has also seen the development and successful implementation of different refrigeration machinery configurations that allow more flexibility in plant design that were not considered in the first-generation of plants utilizing the AP-X® process.

Refrigeration and compression arrangements for the AP-X® process and - Split MR® machinery configuration – with better utilization of available power:

In the AP-X® process, the split in refrigeration power between precooling, liquefaction, and sub-cooling, which is dependent on liquefaction feed pressure and cooling medium temperature, can vary several percent.

One configuration available for the AP-X®

process that has been widely used in the AP-C3MRTM process is the Split MR® technology configuration for precooling and liquefaction, shown in Figure 2. With

this compressor arrangement, the process can be optimized to fully utilize available power from each gas turbine.

The Split MR® technology machinery

configuration allows the shifting of power between propane and MR compression.

For example, in cold ambient



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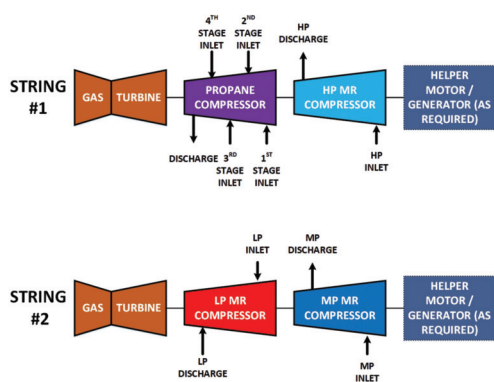
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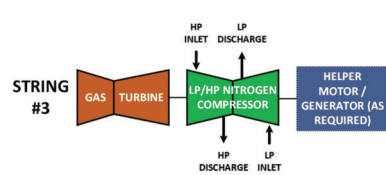
PRECOOLING / LIQUEFACTION REFRIGERATION



SPLIT MR® FOR PROPANE / MIXED REFRIGERANT SERVICES

Figure 2 Refrigeration Compression Arrangement Utilizing AP-X® and Split-MR® Configuration with Heavy Duty Industrial Gas Turbines

SUBCOOLING REFRIGERATION



conditions where less precooling refrigeration is needed, the MR compressor can use available power not being utilized by the propane loop to circulate additional MR, allowing a higher production rate.

Parallel compression improves availability

Another refrigerant compressor arrangement for the AP-X® process that has been used in the AP-C3MRTM process is the parallel AP-C3MRTM process, which reconfigures the compressor casings across the gas turbines to allow the use of parallel compression for precooling and liquefaction. This configuration is shown in Figure 3.

Parallel compression can provide more operational flexibility in an LNG facility operation:

If any one of the three compression strings trips, the train can continue to operate at a reduced rate, instead of forcing a complete train shutdown.

The restart time for the string that trips offline is faster because the liquefaction process continues to run, maintaining operating temperatures in the train.

Scheduled gas turbine maintenance can be performed with the train operating

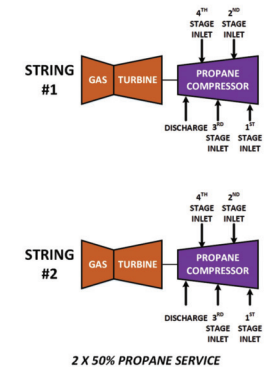
at a reduced rate during gas turbine outages instead of a complete train shutdown.

Like Split MR® technology, the parallel AP-C3MRTM process configuration offers more efficient plant operation at high and low ambient temperature conditions by allowing refrigeration load to be shifted between the precooling and liquefaction refrigeration systems to allow optimization of the process.

An additional benefit of the parallel AP-C3MRTM process configuration is that it can offer more efficient plant turndown options. If a significant production turndown is required for long periods of time, power consumption can be significantly reduced by shutting down one of the parallel propane / MR compression strings, rather than allowing compressor strings to run in recycle.

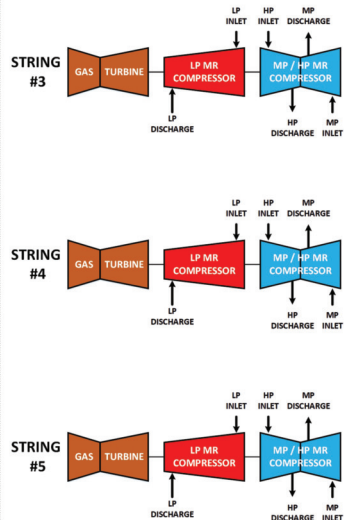
Aeroderivative turbines – additional gas turbine selection flexibility: In addition to configurations that utilize heavy duty industrial gas turbines, AP-X® can be designed using smaller Aeroderivative gas turbines. This configuration allows additional flexibility to select multiple smaller gas turbine drives in place of larger industrial gas turbines. An example of this configuration is shown in Figure 4.

PRECOOLING REFRIGERATION



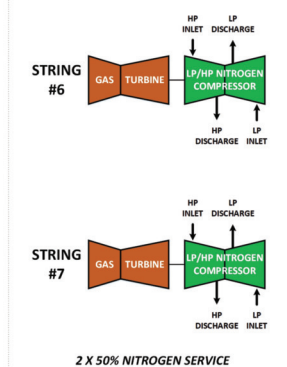
2 X 50% PROPANE SERVICE

LIQUEFACTION REFRIGERATION



3 X 33% MIXED REFRIGERANT SERVICE

SUBCOOLING REFRIGERATION



2 X 50% NITROGEN SERVICE

Figure 4 Refrigeration Compression Arrangement Utilizing AP-X® Process with Parallel Compression and Aeroderivative Gas Turbines

To accommodate the higher production rates desired for a typical AP-X® process design, the required design power available from an Aeroderivative turbine would be approximately 45 - 55 MW.

There are several Aeroderivative turbine models available that can accommodate the required power for typical AP-X® process production rates.

Bringing it all together

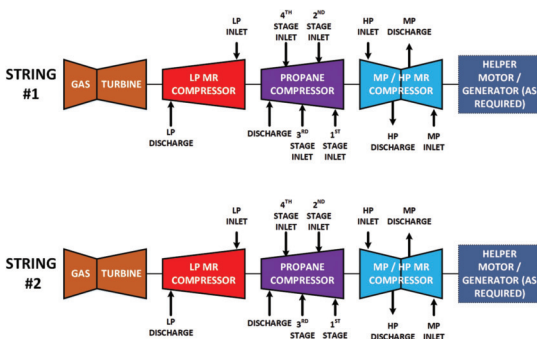
The capabilities of each of the configurations presented in terms of ability to fully utilize power, transfer power between refrigeration loops, and maximize train availability are summarized in the table below.

For more information, please contact Air Products at +1 610-481-4861 or email us at info@airproducts.com

AP-X® Process Compressor Arrangement	Driver Selection	Utilization of Available Power	Power Transfer Between Refrigeration Loops	Availability
1. Separate Single Compressor Strings	Heavy Duty Industrial Turbines	Limited ¹	Limited to None ¹	Reduced rate operation with nitrogen string loss; shutdown with propane or MR string loss
2. Split MR® Configuration	Heavy Duty Industrial Turbines	Full utilization of available driver power	Transfer of available power between propane and MR compressor (HP stage)	Reduced rate operation with nitrogen string loss; shutdown with propane or MR string loss
3. Parallel AP-C3MR™ Configuration	Heavy Duty Industrial Turbines	Full utilization of available driver power	Transfer of available power between propane and MR compressor (all stages)	Operation at reduced rate with loss of any refrigeration string
4. Separate Parallel Compressor Strings	Aeroderivative Turbines	Full utilization of available driver power	None	Operation at reduced rate with loss of any refrigeration string

Notes:
 1. With compressor strings that utilize helper motors that have been configured for combined motor / generator service, limited power transfer can be accomplished by transferring available generated power from under-utilized strings to the helper motor of strings requiring additional power.

PRECOOLING / LIQUEFACTION REFRIGERATION



2 X 50% PROPANE / MIXED REFRIGERANT SERVICES

SUBCOOLING REFRIGERATION

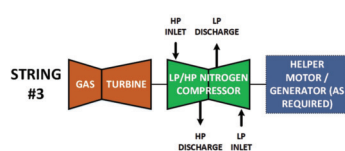


Figure 3 Refrigeration Compression Arrangement Utilizing AP-X® and Parallel C3MR™ Configuration with Heavy Duty Industrial Gas Turbines

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