25th World Gas Conference, Kuala Lumpur 2012
4-8 June 2012
Kuala Lumpur, Malaysia

IMPROVE ENERGY EFFICIENCY IN LNG PRODUCTION FOR BASELOAD LNG PLANTS

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ABSTRACT

LNG production is an energy intensive process. In baseload LNG plants, three major areas can be considered for increasing energy efficiency. One is the proprietary areas of acid gas removal and natural gas pretreatment. The second area is the process driver and compressor area. The third area is the heat exchanger and liquefaction area. Increasing efficiency in LNG production will also contribute to the reduction of Greenhouse Gas emissions from baseload LNG plants. Acid gas removal units commonly use proprietary solvents and processes from technology suppliers. Also, the heat exchanger area and liquefaction process are dependent on the liquefaction technology supplier, with technologies and integrations being quite well established. For these reasons, baseload LNG plant owners have often focused on optimization of the driver and compressor area, which will be discussed in more detail in this paper.

Larger train sizes in baseload LNG plants demand the use of larger, single shaft gas turbines, such as Frame-7EA, for compressor drivers. Optimization of driver and compressor sizes and costs may lead to a split mixed refrigerant arrangement whereby the propane compressor and the last stage of mixed refrigerant compressor operate on the same shaft. For example, in the C_3MR/SplitMR™ process two Frame-7EA gas turbine drivers are used to provide greater operating flexibility over a range of ambient temperatures: one for the propane compressor and the last stage of mixed refrigerant compressor, and the other for the first stage mixed refrigerant compressor and middle stage mixed refrigerant compressor. Single shaft turbines can also be used in a cascade LNG process, with different compressor arrangements for increasing efficiency of large LNG production facilities.

Another trend in compressor drivers is to utilize highly efficient aeroderivative gas turbines. For example, the LM2500 aeroderivative gas turbine is being utilized as the mechanical driver for the refrigeration compressor circuits at the Darwin LNG facility. A recent newcomer however is the LM6000 gas turbine. The LM6000 gas turbine is primarily utilized in power generation service but is now the driver of choice for the Wheatstone LNG project. For example, precooling gas turbine inlet air can be used to increase power delivered to compressors. This has been used in the power generation industry and has started to gain acceptance in the LNG industry. It is also possible to use a Combined Cycle Gas Turbine (CCGT) driver system to increase LNG production efficiency. An example of a recent CCGT is the Tangguh LNG plant. The use of CCGT was primarily utilized to gain higher efficiency for liquefaction.

Various types of cryogenic liquid expanders have been used or proposed for use in LNG facilities. For example, cryogenic liquid expanders have been used in C_3MR processes to improve efficiency and increase LNG production. Two-phase cryogenic liquid expanders are being proposed for future LNG plants. Lastly, integrations of Natural Gas Liquids (NGL) recovery processes with the liquefaction section of the LNG facility can significantly reduce the specific power required to produce LNG, while maximizing NGL recovery. With an integrated concept applied to NGL recovery, LNG production can be increased while using the same process horsepower. This paper briefly mentions a number of process design and equipment alternatives that are available to LNG facility owners and designers for increasing LNG production energy efficiency. The selection and arrangement of gas turbines, compressors, expanders and other equipment is often made on a case by case basis, with consideration of many project-specific factors. These factors include ambient conditions, environmental factors, gas supply profiles, reliability, technical risk, and economics.

INTRODUCTION

LNG production is an energy intensive process. Improvements in energy efficiency translate into reduced fuel consumption, or in situations where feed gas supply is limited, into increased LNG production. Increasing efficiency in LNG production will also contribute to reducing Greenhouse Gas emissions. Liquefaction process, heat exchanger and acid gas removal technology suppliers continue to develop designs and equipment to help improve efficiency. As part of overall technology selection and plant design, baseload LNG plant owners have also focused on optimization of the driver and compressor area. This paper, will discuss this area along with several other areas for improving LNG production energy efficiency:

- Driver and compressor configuration
- Aero-derivative gas turbine drivers
- Waste heat recovery and combined cycle gas turbine arrangements
- Cryogenic liquid expanders
- Integration of natural gas liquids recovery with LNG production

DRIVER AND COMPRESSOR CONFIGURATION

In early LNG plants, steam turbines were preferred because of their prevalence in the petroleum refining industry. Steam turbines were applied at Bontang LNG plant (Indonesia) and the Das Island LNG plant (UAE). Another advantage of steam turbines was that they could be sized to fit the required refrigeration compressor service (e.g., Marsa el-Brega, Libya). Later projects determined that gas turbine drivers were a more efficient and less costly option for driving refrigeration compressors.

Compressor and gas turbine drivers adapted from the power generation industry were the first on the scene. The Kenai LNG plant (Alaska, US) was the first to use a single-shaft GE Frame 5 gas turbine. Dual-shaft Frame5-B turbines were used at Arun LNG (Indonesia) and Frame 5-D's were used at Atlantic LNG (Trinidad and Tobago). Further advancements in turbine/driver design led to the GE Frame-6, Frame-7 and recently Frame-9 single-shaft gas turbines, with power ranging from 43 to 130 MW. These turbines are driving large axial and centrifugal compressors.

The C_3MR LNG process technology has been employed in the LNG industry for more than 30 years. This process uses a propane refrigerant system to chill the feed gas from ambient temperature to approximately –33°C and a Mixed Refrigerant (MR) to chill the gas to LNG temperatures. Because pure propane is used in the precooling refrigeration cycle, the minimum temperature of this cycle is limited to the boiling temperature of propane near atmospheric pressure. The total duty that can be transferred to the propane refrigerant is thereby naturally limited to heat that can be transferred within this range.

Because of the propane's limited temperature range, one of the characteristics of the C_3MR process arrangement is that the MR refrigeration system requires nearly double the compression power of the propane refrigeration system. The actual difference depends on the number of propane stages, the ambient conditions, the environmental cooling medium, and other process arrangements.

For procurement, maintainability, and sparing purposes, an operating facility would prefer to have each of the compression services driven by the same type and model of gas turbine driver. For the C_3MR process, such an arrangement is typically inconvenient because of the inherent power consumption mismatch between the propane and MR services.

In the C_3MR/SplitMR™ process two gas turbine drivers are used to provide greater operating flexibility over a range of ambient temperatures. The first C_3MR/SplitMR™ process using GE Frame 7 gas turbines is at Ras Gas III & IV (Ras Laffan, Qatar), as shown in Figure 1 [1]. One GE Frame 7 drives a propane compressor and the high pressure stage mixed refrigerant (HP MR) compressor, while another GE Frame 7 drives a low pressure stage mixed refrigerant compressor (LP MR) and a medium pressure stage mixed refrigerant compressor (MP MR).

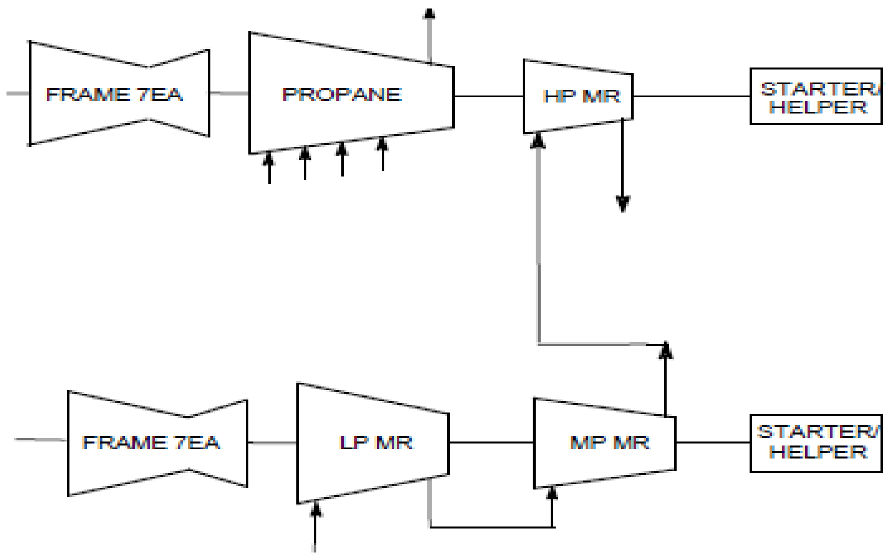

Figure 1. Two Frame 7EA Gas Turbines Used for C_3MR/SplitMR™ Cycle [1]

The Split MR™ configuration shown in Figure 1 allows the power split between propane and MR refrigeration to be optimized while fully utilizing the power available from the two starter/helpers and maximizing LNG production. A similar power split arrangement is also used with Frame 9 turbines in the AP-X LNG process. Single-shaft turbines can also be used in a cascade LNG process, with different compressor arrangements for increasing efficiency of large LNG production facilities.

AERO-DERIVATIVE GAS TURBINE DRIVERS

Aero-derivative gas turbines have found application in LNG plants – both as direct drives and for power generation. LM-2500 aero-derivative gas turbines have been used as direct drivers at the Darwin LNG plant (Australia). More recently, LM-6000 aero-derivative gas turbines were selected for use as direct compressor drivers for Wheatstone LNG (Australia). LM-6000 aero-derivative gas turbines have also been used to generate electricity to power electric motors, which in turn drive the refrigerant compressors at the Snohvit LNG plant (Hammerfest, Norway). This has influenced the consideration of all-electric drivers for LNG plants in the future. Table 1 below shows representative gas turbine performance for industrial and aero-derivative gas turbines [2].

Table 1. Representative Gas Turbine Performance [2]

Gas Turbine	Shaft	Power (kW)	Efficiency	Fuel Consumption (indexed)
Frame 5D	Dual	32,580	29.4 %	100
LM 2500	Dual	31,364	41.1 %	72
LM 6000	Dual	44,740	42.6 %	69
Frame 7E	Single	86,225	33.0 %	89
Frame 9E	Single	130,100	34.6 %	85

There are several advantages of using aero-derivative gas turbines. Since they are variable speed drivers they avoid the need for a large starter motor, which is required for single-shaft gas turbines. They can start up under settle out pressures without the need to depressurize the compressor, as is common for single-shaft drivers [3,4]. Other advantages of aero-derivative gas turbines are:

- Much higher efficiency, which leads to reduced fuel consumption and greenhouse gas emissions; and, in situations where feed gas supply is limited, more feed gas available for LNG production;
- Ability to rapidly swap engines and modules, thus improving maintenance flexibility, reducing maintenance downtime and therefore improving the overall plant production efficiency;
- High starting torque capacity; excellent torque-speed characteristics, allowing large trains to start up under settle-out pressure conditions;
- Dry-low-emissions (DLE) technology, available and proven on several engines;
- Relatively easy installation due to low engine weight;
- No starter motors required, resulting in a smaller power generation requirement.

Due to their smaller horsepower output, the application of aero-derivative gas turbines may require parallel refrigeration compressor and driver trains to meet the power requirement of a specified LNG production capacity. However, as operating experience is gained with larger aero-derivatives gas turbines, such as the GE LMS100, this technology could see wider usage in the LNG industry.

One aspect that must be kept in mind in using the aero-derivative gas turbines for mechanical drives, is that their power curves have a steeper decline in high ambient temperatures. In regions with a wide range of ambient conditions, power augmentation, such as pre-cooling the inlet air to the turbines through a humidification (evaporative cooling) package or mechanical chillers, would most likely be required to maintain LNG production. This concept has also been used in the power generation industry to enhance gas turbine power output during the summer season, when electricity demand peaks.

WASTE HEAT RECOVERY AND COMBINED CYCLE GAS TURBINE ARRANGEMENTS

There are also opportunities to increase energy efficiency through the capture of waste heat in the LNG plant. The use of Waste Heat Recovery Units in the gas turbine exhaust stacks have been used in several plants to produce the required heat input to the facility's heating media -- for example hot oil, steam or hot water. Some facilities have also used Waste Heat Recovery coils to heat the dehydration unit regeneration gas. These process improvements result in reducing the number or size of boilers and fired heaters used to generate process heat, and therefore increase plant efficiency by reducing fuel gas auto-consumption.

It is also possible to use a Combined Cycle Gas Turbine (CCGT) driver system to recover waste heat and increase LNG production energy efficiency. An example of a recent CCGT is the Tangguh LNG plant (Indonesia), where Frame 7EA industrial gas turbines are used [5]. There are three areas inside the Tangguh LNG plant to take advantage of the waste heat recovery: acid gas removal unit (AGRU), incremental LNG production, and electrical power generation. The Tangguh LNG project has taken the step to provide each of the gas turbine engines with Heat Recovery Steam Generators (HRSG) in a Combined Cycle application. Recovered energy for each application has been reported as shown in Table 2.

Table 2. Tangguh LNG Plant Combined Cycle Application [5]

Item	Recovered Energy (MW)	% of Total Plant Energy Demand
AGRU Reboilers and Heaters	259.1	21.7
Frame 7EA Steam Helper Turbines	50.3	4.3
Power Generation	11.0	0.9
Total	320.4	26.9

CCGT are often recommended for power generation due to their high thermal efficiency. However, they require more complex systems, including boiler feedwater supply and steam condensers resulting in higher installation cost and increased operational complexity and operability risk in a remote, stand-alone application. For example, the shutdown of any single gas turbine could cause voltage or frequency fluctuations in the power system, resulting in a possible loss of power supply to the LNG Plant.

APPLICATION OF CRYOGENIC LIQUID EXPANDERS

Cryogenic liquid expanders have been used in the C_3MR process to improve energy efficiency and increase LNG production. Liquefied gases are expanded from high pressure to low pressure, converting pressure energy into electrical energy while reducing the enthalpy of the liquefied gas. In baseload LNG plants, liquid expanders are applied to the mixed refrigerant circuit and the LNG product circuit as shown in Figure 2 [6]. For LNG expanders installed between the Main Cryogenic Heat Exchanger (MCHE) and the LNG storage tank, a variable speed liquid expander can be used also as a control valve to increase the process efficiency.

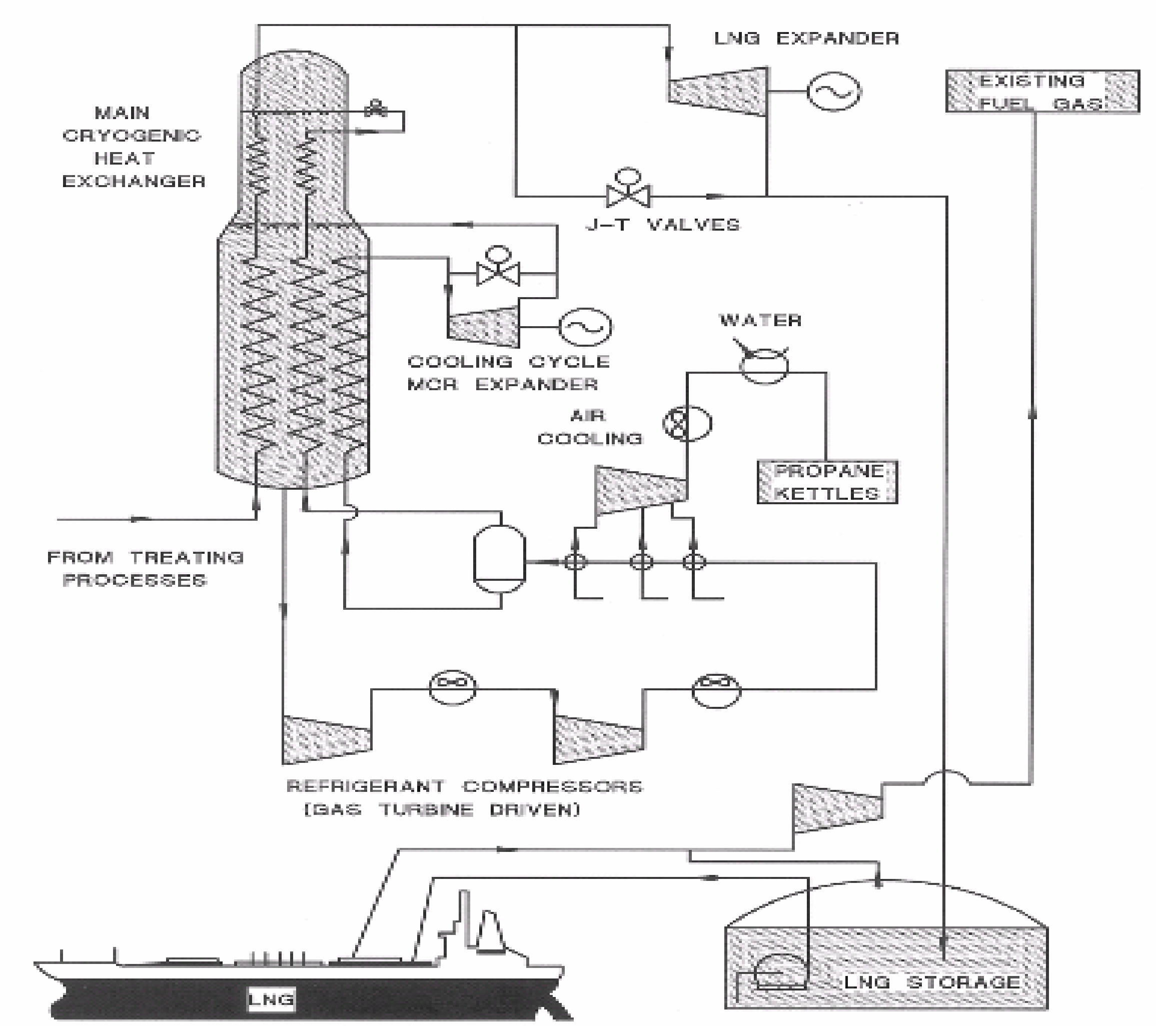

Figure 2. Liquid Expanders for C_3MR Cycle LNG Plant [6]

Since 1996 many LNG plants have replaced the Joule-Thomson (JT) valve with a cryogenic liquid expander to expand the condensed natural gas from high pressure to low pressure, and substantially improved the thermodynamic efficiency of the existing refrigeration process – contributing to an increase in total LNG output by about 6% and a reduction in greenhouse gas emissions. Liquid expanders are typically applied to the heavy mixed refrigerant stream and the LNG stream from the cryogenic heat exchanger in the C_3MR process.

More applications are anticipated in the future for other LNG processes, such as the cascade processes. The first generation of basic liquid expander generator was used in LNG plants at Bintulu, Malaysia and in Nigeria. Cryogenic liquid expanders of the second generation use variable speed, constant frequency converters and offer significant advantages over basic fixed speed designs. Several variable speed cryogenic liquid expanders in the power range of 1 MW are already in successful LNG plant operation. Currently available sizes range between 1.5 to 2 MW.

The installation of variable speed LNG expanders enables the direct interaction between the liquefaction process and the LNG expander with the potential to optimize the liquefaction process over a wide range of LNG output. The third generation of LNG expanders is in development. The target is to expand cryogenic liquid partially into the vapor phase, while operating the expander in the two-phase region, to improve process thermodynamic efficiency.

INTEGRATION OF NATURAL GAS LIQUIDS RECOVERY WITH LNG PROCESS

Lastly, integration of Natural Gas Liquids (NGL) recovery processes with the liquefaction section of the LNG facility can significantly reduce the specific power required to produce LNG, while maximizing NGL recovery. For example, a turbo-expander LPG recovery system can be integrated with a liquefaction process to increase LNG production while maintaining the same process horsepower [7,8].

A front-end expander plant minimizes impact to the liquefaction unit from variation in the feed composition. Figure 3 [7] shows the schematic of an integrated expander plant within an LNG plant. In this process, feed gas is pre-cooled by a propane refrigerant and partially condensed against the lean gas from the scrub column overhead. The vapor is expanded through a turbo-expander before entering the scrub column. The scrub column overhead stream provides the feed cooler duty before going to recompression and then on to the Main Cryogenic Heat Exchanger for producing LNG. If ethane extraction is desired, a portion of this high pressure gas is fully condensed against the column overhead stream and is used as reflux to the column.

The NGL section is similar to a front-end expander gas plant, except that the upstream propane precooling decreases the load on the recompression resulting in a higher efficiency for the extraction process. However, the propane refrigeration system load is increased. It should be noted that the introduction of the feed gas compressor and expander in series with the liquefaction process could have some impacts on overall plant availability.

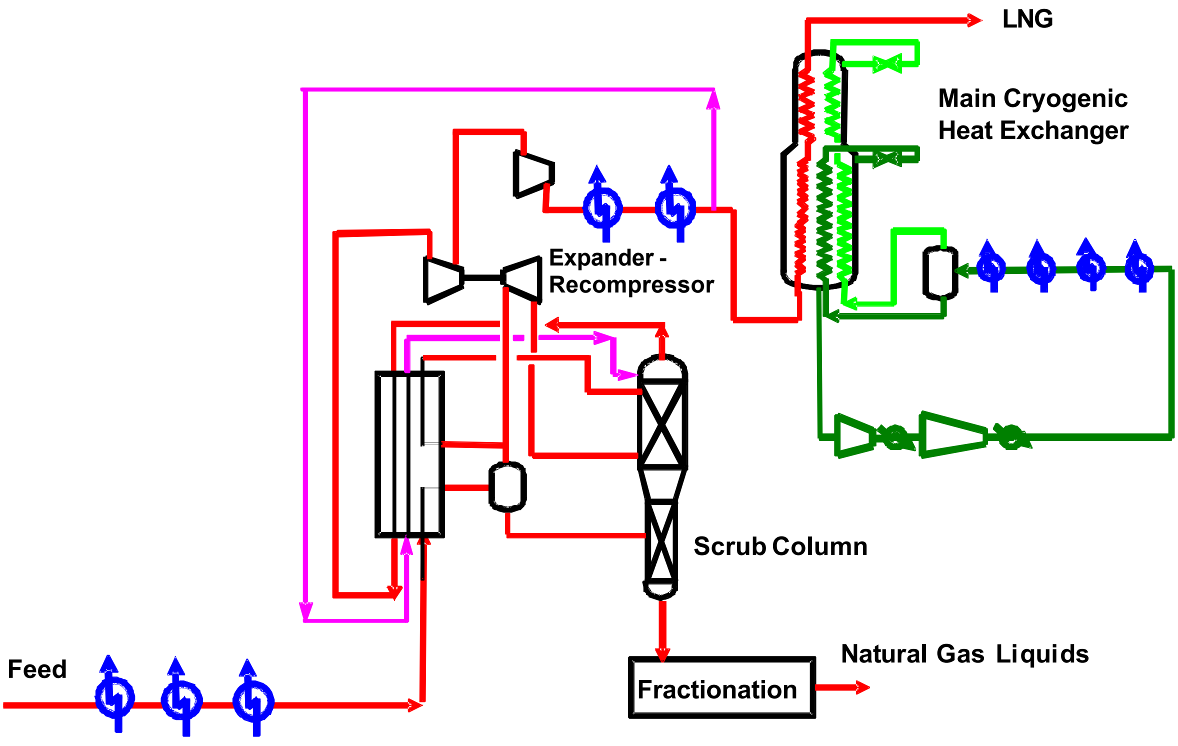

Figure 3. Expander-Recompressor LPG Recovery Process for C_3MR LNG Process [7]

CONCLUSIONS

This paper briefly mentions a number of process design and equipment alternatives that are available to LNG facility designers and owners for increasing LNG production energy efficiency:

- Driver and compressor configuration
- Aero-derivative gas turbine drivers
- Waste heat recovery and combined cycle gas turbine arrangements
- Cryogenic liquid expanders
- Integration of NGL recovery with LNG production

Lastly, it may be beneficial to compare the range of these potential efficiency improvements to a C3MR base process.

Table 3. Efficiency Improvement Opportunities

Arrangement	Efficiency Improvement	Potential for Further Improvement
C_3MR/SplitMR Arrangement	High	Modest
Aero-derivative Turbine Drivers	Moderate	Extend applications and experience
Waste heat recovery and Combined Cycle Gas Turbines	Moderate to High	Extend applications and experience
Cryogenic Liquid Expanders	Low to Moderate	Use of 2-phase expanders
Integration of NGL Recovery	Moderate	Application and feed specific

The comparisons shown in Table 3 are based on some subjective observations. Lost work analysis or a complete heat and material balance could be used to obtain a more quantitative comparison.

The selection and arrangement of gas turbines, compressors, expanders and other equipment is often made on a case by case basis, with consideration of many project-specific factors. These factors include ambient conditions, environmental factors, gas supply profiles, reliability, technical risk, and economics. As plant designers and owners gain experience with implementation and operation of advanced technologies, future LNG production plants will strive to reach higher energy efficiencies and lower greenhouse gas emissions.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to Bobby Martinez for his assistance and suggestions.

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