OSMR®

Liquefaction Process
for
LNG Projects

- Low Cost
- Highly Efficient
- Lower Emissions
- Simple & Reliable

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Optimized Single Mixed Refrigerant (OSMR®) Process for LNG Projects

● INTRODUCTION ●
OSMR® is an innovative, simple, low cost, highly efficient, environmentally friendly, robust and low risk technology that has the potential to benefit future LNG projects. The OSMR® process combines several well-proven, existing technologies into one integrated system. Integration of these proven, primary technologies comprise the core liquefaction process resulting in a plant with a market-leading capital cost, and a considerably more efficient design arrangement that generates lower emissions and improved project economics. The simplicity of OSMR® technology results in a reliable LNG plant that is relatively simple to design, construct, operate and maintain.

The plant capacity of OSMR® currently targets single LNG train capacities of 2 million tonnes per annum (mtpa); however, it is scalable with single LNG train capacities from 0.5 mtpa to 4 mtpa or more. Thus, multiple LNG trains can combine to produce plants of 10+ mtpa capacity. LNG capacity increases with new module train additions as available feed gas grows. The required plot space is less than that needed for traditional LNG plants and the execution strategy, using standard equipment and modular construction, reduces construction cost and schedules.
**CURRENT LIQUEFACTION TECHNOLOGIES**

A number of liquefaction technologies are available for use in LNG projects worldwide:

- **Primary Base Load Technologies**
  - APCI C3-MR Process
  - Conoco Phillips Optimized Cascade Process

- **Other Base Load Technologies**
  - Shell Dual Mixed Refrigerant Process
  - APCI AP-X Process
  - Linde Dual Mixed Refrigerant Process

- **Small Processes (base load, peak shavers, transportation fuels)**
  - Black & Veatch’s PRICO Process
  - Single Mixed Refrigerant (SMR) processes
  - Nitrogen Processes

- **OSMR® by LNG Limited**
  - An optimized approach for a maturing industry

Currently, three LNG projects are proposing to utilize OSMR® technology:

- Magnolia LNG Project, in Lake Charles, Louisiana, USA;
- Bear Head LNG Project, in Nova Scotia, Canada; and
- Gladstone LNG Project - Fisherman’s Landing, in Gladstone, Queensland, Australia.
• **OSMR® EFFICIENCY** •

The above LNG projects utilising OSMR® technology have a train design capacity of approximately 2 mtpa each. The 2 mtpa LNG trains are configured in a 2 in 1 parallel design in which there are two identical cold box exchangers, chilled by an independent closed loop mixed refrigerant (MR). Each MR loop has a dedicated gas turbine drive. The train capacity can vary depending on the type and number of gas turbines.

The two parallel MR circuits within each LNG train provide a turndown capability of approximately 40% of design capacity. This design feature gives tollers and the plant operators maximum flexibility to operate the LNG trains over a wide range of LNG demand. Plant reliability improves as the LNG train can continue to operate at 50% capacity when one MR circuit has tripped or is out for planned maintenance.

Ambient air temperature directly affects LNG production in traditional LNG plants. The higher the ambient conditions, the lower the gas turbine power and therefore the lower the LNG production. Consistent gas turbine power over a range of ambient conditions results from pre-chilling the air to the gas turbines. Inlet air chilling, core to the OSMR® process, is common in gas turbine power stations.

The OSMR® technology aims to maximize the energy efficiency of the LNG trains. Ammonia pre-cooling of the MR ahead of the cold box increases plant capacity further. The impact of ammonia pre-cooling on plant capacity and the fact that it consumes little additional fuel is fundamental to the overall OSMR® energy balance. A combined cycle steam system using the gas turbine waste heat largely powers the ammonia pre-cooling system. Ammonia pre-cooling increases the LNG plant capacity without increasing the size and cost of the major components of the liquefaction plant – the cold box, gas turbine and MR compressor.

These two simple enhancements of cooling gas turbine inlet air and pre-cooling the MR are major contributors towards the reduction in plant cost per unit of LNG produced.

The following charts detail efficiencies of the OSMR® process relative to the baseline SMR process without the optimized features.
**THE USE OF PROVEN TECHNOLOGY IN OSMR®**

An OSMR® liquefaction train uses a low equipment count and a simple configuration. Further, equipment used does not require any significant unique specifications and is therefore readily available in the marketplace from multiple vendors, reducing long-lead times and allowing for healthy competition throughout the procurement process.

The following components, applied and proven in LNG and other industries, comprise the core liquefaction process:

- The single mixed refrigerant (SMR) liquefaction process is at the heart of the OSMR® process, using proven cold box heat exchangers;
- Use of ammonia as a pre-cooling refrigerant, having superior refrigeration properties to propane, allows for smaller condensers, exchangers and general plant size;
- Gas turbine waste heat steam generation (combined cycle process providing motive power to the ammonia refrigeration system);
- A closed loop ammonia refrigeration circuit, driven by steam recovered from waste heat mentioned above, pre-cools the MR and directly cools inlet air to the gas turbines;
- Highly-efficient and reliable aero-derivative gas turbines used for mechanical drive; and
- Inlet air chilling to the turbines to ensure a consistent power output and avoiding significant power loss at high ambient conditions.

Integration of these components in the OSMR® process generates performance improvements.
The OSMR® patent includes an innovative boil-off gas (BOG) handling system, in which the BOG is lightly compressed and then reliquefied by passing it through the cold box and then into the liquid methane separator. Flash gas separation allows liquid methane delivery to the LNG storage tank via the LNG rundown line. The remaining lean vapor phase flash gas from the liquid methane separator, containing a high proportion of nitrogen and some methane, provides lean LP fuel gas in the Waste Heat Recovery & Steam plant’s auxiliary boiler. This overall system enables recovery and re-liquefaction of the low temperature BOG while minimizing compression losses more commonly seen in other designs.

Complementing the OSMR® process design is the use of a modular construction approach (described elsewhere herein), that allows repeatability with respect to the OSMR® liquefaction trains, further improving economics. Use of a modular fabrication approach translates into inherently safer construction sites and reduced on-site labor, providing a high degree of quality and schedule control.

The improved efficiency and simplicity of the OSMR® process optimizes the capital and operating cost of the LNG plant, which is an essential component in enabling development of any LNG project. OSMR® technology aligns with the necessities of LNG production while sustaining targets relating to economics, environment, operation, and safety.

The following chart illustrates the component capital cost savings from applying the OSMR® process design and modular construction approach relative to conventional LNG plant design (~ US$1,000/tonne).
WHY IS AMMONIA USED IN THE OSMR® PROCESS?

The selection of ammonia as the pre-cooling refrigerant is a significant element of the OSMR® process. Ammonia is a commonly used, environmentally friendly, and efficient industrial refrigerant that is naturally occurring. It has a life cycle in the atmosphere of less than one week and, therefore, has a global warming potential (GWP) of zero and an ozone depletion potential (ODP) of zero.

When compared to propane, the use of ammonia in refrigeration cycles demonstrates superior thermodynamic qualities resulting in greater efficiency and therefore reduced emissions from the power generation required for refrigeration. Compared to propane, ammonia is 20% more efficient – that is, the same refrigeration duty can be delivered from 20% less energy.

Ammonia’s superior thermodynamic qualities make it the primary refrigerant across many applications and industries including the International Space Station, cold storage, food and drink processing, wineries, and ice skating rinks.

Early LNG liquefaction plants initially constructed in remote corners of the world where high infrastructure development costs, complex supply logistics, and abundant supply of virtually free natural gas feedstock from dedicated project hydrocarbon resources drove process configurations. Energy efficiency, while certainly considered, was not a primary element in these LNG installations. Propane was universally selected as the pre-cooling refrigerant since, in all of these early facilities, the propane could be readily extracted from the feedstock gas, eliminating the need to rely on challenging logistics chains to support this element of operations. As LNG project development grew worldwide, there was a tendency to reuse familiar liquefaction technologies consistent with those early LNG facilities.

With the migration of the LNG industry to more developed locations, the situation has evolved. The nearby presence of industrial and petrochemical industry brings multiple refrigerant options into play.
Logistics issues and the remote nature of facilities are no longer necessarily major design challenges. Plant efficiencies become more important, both economically (feedstock gas purchases from national supply grids rather than supplied from dedicated hydrocarbon resources) and environmentally, with an increased focus on the continued impact of greenhouse gas emissions on the global environment. Optimizing LNG plant design and efficiency can now take account of competing refrigerant options. In doing so, ammonia, with its superior thermodynamic qualities, becomes the preferred refrigerant for pre-cooling within the OSMR® liquefaction process.

In comparison to propane, anhydrous ammonia vapor is toxic in relatively low concentrations. Despite this important consideration, ammonia has the following superior characteristics:

- Ammonia is not readily flammable – in most situations, ammonia can be considered effectively non-flammable;
- Ammonia is not readily explosive;
- Ammonia has a molecular weight of 17.0, it is generally lighter than air, so it tends to rise and naturally dissipate. High volumetric air flow from the air coolers within OSMR® trains assists in the dissipation of any ammonia vapor;
- Ammonia releases can be readily detectable at relatively low concentrations; and
- Importantly, mitigation of ammonia release exposure is reliable and effective through simple application of automated detection systems, automatically isolatable sections, and water sprays due to ammonia’s high affinity to, and solubility in, water.
The simplistic OSMR® design and configuration allows each LNG train to be broken down into five main process modules. Offsite fabrication of the modules in a fabrication yard, with transport to the project site via ocean-going barge or other transportation method, represents the construction base case approach. A fabrication yard approach is inherently safer and reduces on-site labor whilst providing a high degree of quality and schedule control during module construction. The modular construction approach allows repeatability with respect to the OSMR® liquefaction trains further improving economics.

Delivery of the process modules to the site in a pre-determined sequence allows sequenced assembly of the LNG train. A Material Offloading Facility (MOF) and a heavy haul road enable transfer of the modules from the barge to final position, using self-propelled modular transporters (SPMT’s).
**OSMR® LIQUEFACTION PROCESS DESCRIPTION**

**Pre-treatment:** Feed gas routes from the Gas Gate Station to each LNG train and initially passes through an inlet filter coalescer to separate any liquids/solids to prevent foaming in the acid gas removal unit. Removal of acid gases (CO₂ and H₂S) using a proprietary amine solution occurs in an absorber column. Removal of CO₂ to approximately 50ppm avoids freezing in the downstream liquefaction unit. An ammonia refrigeration system pre-cools the water saturated sweet gas, which passes through a knockout separator to remove bulk water from the gas. The condensed water, along with trace amounts of amine, are recycled to the amine system as make-up water.

The dehydration plant dries inlet gas to remove water down to < 0.1ppm. The dehydration plant includes three molecular sieve vessels. Two vessels are in adsorption mode while the third vessel regenerates at full system pressure using a side stream of dry gas. High-pressure (HP) steam or fuel gas heats the regeneration gas, representing a primary source of HP fuel gas.

Depending upon the design of the dehydration unit, the gas recycled back to the process will be minimized or even eliminated. The dry gas stream makes-up any shortfall in fuel gas.
A mercury removal unit, provided after the molecular sieve dust filters, ensures removal of any trace mercury in the gas prior to entering the liquefaction unit. A treated gas filter downstream of the mercury removal unit is also in place to capture any loose dust particles from the mercury removal unit.

**Heavy Hydrocarbon Removal Plant:** The final pre-treatment unit involves removal of heavy hydrocarbons such as pentanes and benzene. Benzene must be removed down to <1ppmV to avoid freezing in the liquefaction plant. The heavy hydrocarbon removal plant design is very dependent upon a detailed analysis of the range of components in the feed gas. Coal seam gas feeds contain no heavy hydrocarbons and therefore no unit is required. Careful consideration of the range of possible heavy hydrocarbon contaminants occurs for locations using pipeline specification gas. The design may include turbo expander as well as a scrub column. The auxiliary steam boiler burns any resultant liquids, which alternately may be exported.

**Ammonia Refrigeration Plant:** The ammonia refrigeration is used to pre-cool the dry feed gas to approximately 18°F (-8°C) prior to entering the liquefaction plant. The ammonia system is a one or two stage closed loop refrigeration cycle, utilizing two parallel steam turbine driven compressors powered by steam from the waste heat recovery plant (described later). The ammonia refrigeration improves the output and efficiency of the SMR process. It also provides stable operation of the plant since it dampens the impact of variations in ambient air temperatures, which would otherwise more greatly affect plant operation and capacity. Optimizing the temperature of the ammonia refrigerant tunes overall performance of the plant.

The ammonia refrigerant cools a number of units around the LNG train:

- Pre-cool the dry feed gas prior to entering the liquefaction unit;
- Mixed refrigerant in the ammonia/MR pre-cooler;
- Inlet air for the gas turbines;
- Wet gas exiting the amine contactor; and
- Cooling requirements, when necessary, within the heavy hydrocarbon liquid (HHL) removal system.

**Liquefaction Plant:** The liquefaction plant cools and liquefies the feed gas from approximately 18°F to minus 260°F (-162°C). The OSMR® liquefaction plant, based on an SMR process, comprises a simple vapor compression cycle using a mix of refrigerants providing a close fit of cooling curves in the main plate fin heat exchanger (cold box). The main liquefaction exchanger is a multi-core brazed aluminium plate fin exchanger using a minimal number of exchanger streams. Enhancement of main exchanger performance results from the ammonia pre-cooling refrigerant, which cools the mixed refrigerant in the Ammonia/MR Pre-Cooler. This allows cool low pressure mixed refrigerant (LPMR) to exit the cold box. The cool LPMR feeding the MR compressor improves its performance.

Within each train, two separate independent parallel refrigeration circuits each include a MR compressor, MR air cooler, Ammonia/MR Pre-Cooler, cold box, and suction scrubber. The dual parallel
rerefrigeration/liquefaction circuits provide added reliability and availability, while allowing use of common equipment sizes. Dry feed gas splits into two feed lines cooling in a cold box. A liquid knockout separator is used to provide consistent remixing of the two-phase refrigerant stream. The combined stream returns to the cold box and continues cooling and liquefies at approximately \(-260^\circ F \ (-162^\circ C)\) then exits the cold box. The liquefied gas is flashed to low pressure and flows to the storage tanks.

The MR for each cold box is compressed by a single stage centrifugal compressor directly driven by a highly fuel efficient, low emissions aero-derivative gas turbine. Air coolers remove the heat of compression causing a very small quantity (< 2% volume) of MR to condense. Any potential mal-distribution of this small quantity of liquid in the Ammonia/MR Pre-Cooler cores will not affect exchanger performance.

The high-pressure mixed refrigerant (HPMR) partially condenses in the Ammonia/MR Pre-Cooler using ammonia refrigerant. The HPMR is then fully liquefied in the cold box and expanded (partially flashed), using Joule-Thomson expansion, providing refrigeration for the system. The flashed LPMR provides the refrigeration in the cold box and cool MR vapor returns to the compressor via the suction scrubber. MR make-up is provided from the process gas (methane), BOG (nitrogen), with remaining refrigerants of ethane (high-pressure cylinders) and n-butane (ISO container) sourced externally.

Each of the two MR compressor packages consist of an aero-derivative gas turbine directly coupled to a single stage multi-wheel centrifugal compressor. Inlet air is cooled to approximately 44\(^\circ F\) (7\(^\circ C\)) using an ammonia-to-air exchanger, to increase the power output and efficiency of the gas turbine, particularly at high ambient temperature conditions.

**Boil-off Gas System:** The BOG system for a 4 x 2 mtpa LNG plant would typically comprise three to five low-pressure compressors to recover flash gas, BOG and ship vapor from the LNG tank, and a simple re-liquefaction and nitrogen rejection system to ensure meeting the required LNG composition. The compressed BOG vapor is re-liquefied in the cold box and sent to the liquid methane separator, where it is separated with the liquid methane stream returning to the LNG storage tank. The lean vapor flash gas from the liquid methane separator, containing a high proportion of nitrogen and some methane, is used as lean LP fuel gas in the Waste Heat Recovery & Steam plant’s auxiliary boiler.

This system also rejects nitrogen from the LNG and BOG in order to meet the required nitrogen content in the LNG. Normally only one BOG compressor is used to handle BOG from one LNG train; however, during ship loading, additional BOG compressor(s) are used to recover the additional BOG generated.

**Waste Heat Recovery (WHR) and Steam Plant:** The Waste Heat Recovery & Steam Plant is comprised of:

- Waste heat recovery from the two gas turbines using once through steam generators (OTSG’s);
- Two steam turbines for the auxiliary refrigeration plant compressor drives;
- An auxiliary boiler for start-up and supplemental steam;
- Process and utility steam heating system;
- Air cooled condensers; and
• All associated systems required for a Waste Heat Recovery & Steam plant.

A schematic diagram of the Waste Heat Recovery & Steam Plant follows:

Compression power and heat for the plant is provided by waste heat from the gas turbine exhausts as well as from the auxiliary boiler, which is fuelled by three sources: (1) feed gas in the plant, (2) lean flash gas from the methane separator in the BOG system, and (3) heavy hydrocarbon waste stream. The HP steam powers the two ammonia refrigeration steam turbines. A portion of the HP steam is attemperated and used as LP process heat for the amine reboiler, regeneration gas heater, and fuel gas heater.

The auxiliary refrigeration plant is sized to consume all available power that can be generated from the waste heat and lean flash gas. During ship-loading, generation of additional BOG occurs, thereby producing additional LP fuel gas, which reduces the use of feed gas used in the auxiliary boiler. This alleviates the need for flaring of BOG during ship loading.
OSMR® liquefaction technology has been subject to numerous independent reviews since design inception. Below is a list of some of the reviews and reports:

- CH·IV – Evaluation of OSMR® LNG Process, October 2008;
- Foster Wheeler – Gladstone LNG - OSMR® Study Report, June 2009;
- SKE&C – Evaluation of the OSMR® Process for Gladstone, June 2009;
- LNG Industry Article in March 2010;
- HQCEC and WorleyParsons – OSMR® Technical Evaluation, November 2010;

Beneficial suggestions from these reports were implemented; however, the general outcome of the reviews was favourable and highlighted the simplicity and innovative design of OSMR®.
● OSMR® PATENT OVERVIEW ●

LNG Technology Pty Ltd, a wholly owned subsidiary of LNG Limited, owns OSMR®.

LNG Limited has filed domestic patent applications in approximately 20 countries and regions around the world as part of its international patent program.


Patent 1 is titled “A method and system for production of liquid natural gas” and Patent 2 is titled “Boil-off gas treatment process and system”.

The following map outlines where patents have either been granted or the patent process undertaken and decisions pending.

● SUMMARY ●

The simplicity and high efficiency of OSMR® results from integrating proven highly efficient gas turbine drives for the main refrigerant compressors together with combined cycle heat and power technology, and efficient ammonia refrigeration. Gas turbine inlet air-cooling and low-pressure BOG re-liquefaction are employed. The combination of these proven simple technologies results in a plant cost that is very competitive compared to competing technologies. It is highly efficient resulting in lower emissions and offers improved project economics in a reliable design package.

For more information, refer to the website of LNG Limited: www.LNGlimited.com.au
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