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Advances in liquefied natural gas processes

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Abstract

Over the past 30 years, a considerable world trade in LNG has developed. Today, LNG represents a significant component of the energy consumption of many countries and has been profitable to both the exporting host countries and their energy company partners. The attention of LNG producers have now been directed towards improved production. All latest plants have been sized around this number. Some of them have been designed by optimizing existing layout, other brand new and few required the optimization of centrifugal compressors and so the introduction of some novelty to maximize production given a certain driver. Improvements in the aerodynamic design have been necessary to maximize efficiency and increase operating range; advanced rotordynamic design to handle more capacity, new casings to increase design pressure and reduce the number are some of the innovations introduced to advance LNG operations. Novelties have not been limited to main refrigerant compressor but also to auxiliaries such as Boil Off Gas (BOG), CO_2, End Flash. Eventually also new drivers have been qualified for LNG plant operations and other are under study for its high efficiency and possible future application. Extensive application of modular construction techniques will reduce the time and cost of construction in remote areas of the world. This article aims to explain, in layman terms, LNG basic knowledge, exploration, production and advancement. Throughout the article, references have been drawn from a wide range of resources and author's personal industry experience. It is intended to use the article as a vehicle to share oil & gas industry knowledge with a wide range of audience.

Keywords: Liquefied Natural Gas; Compressors; Boil Off Gas; Aerodynamic Design; Refrigerant

1. Introduction

The earth has enormous quantities of natural gas, but much of it is in areas far from where the gas is needed. To move this cleaner-burning fuel across oceans, natural gas must be converted into liquefied natural gas (LNG), a process called liquefaction. LNG production is the process of condensing natural gas into a cryogenic liquid by cooling it to approximately −162 °C or less and removing certain components**.** The process is like that used in domestic refrigerators, but on a massive scale(Saleemet al 2014). The main components of the LNG chain include a gas field, liquefaction plant, LNG carriers, receiving and regasification terminal, and storage. LNG plants can be classified as baseload or peak shaving, depending on their purpose and size. Baseload plants produce LNG for export or long-term storage, while peak shaving plants produce LNG for short-term storage and use by power plants when needed. The LNG plant consists of two main processes: the gas treatment process and the liquefaction process (Bernocchi et al 2003).

Liquefied Natural Gas (LNG) is natural gas, predominantly methane (90%) with some mixture of ethane, propane, butane, some heavier alkaline and nitrogen that has been condensed into a cryogenic liquid through liquefaction process at close to atmospheric pressure by cooling it to approximately −162°C or less for ease of storage or transportation. The liquefaction process involves removal of certain components, such as dust, acid gases, helium, water and heavy hydrocarbons. For transportation to other countries, natural gas is liquefied to reduce it to one six-hundredth of its original volume, and then transported on LNG carriers (Mokhatab et al 2014). As a result, an "LNG Chain" is required,

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by which natural gas that has been extracted from a gas field is refined, liquefied, transported by ships, and then re-gasified in the area where it is to be consumed. Maximum transport pressure is set at around 25kPa. Approximate lower and upper flammable limit is between 5% and 15% by volume in the air. It is odourless, colourless, non-toxic and non-corrosive. Hazards include flammability after vaporization into a gaseous state, freezing and asphyxia (Saleemet al 2014).

2. LNG Commercial Aspects

In the commercial development of an LNG value chain, LNG suppliers first confirm sales to the downstream buyers and then sign long-term contracts (typically >20 years) with strict terms and structures for gas pricing. Only when the customers are confirmed and the development of a Greenfield Project deemed economically feasible, the sponsors of an LNG project invest in their development and operation. Hence, the LNG liquefaction business has been limited to players with strong financial and political resources(Mokhatab et al 2014). Major international oil companies (IOCs) such as ExxonMobil, Royal Dutch Shell, BP, BG Group, Chevron and some national oil companies (NOCs) are active players in the world LNG market. LNG quality is one of the most important issues in the LNG business. LNG is sold based on its heating or calorific value which depends on the source of gas that is used and the process that is used to liquefy the gas. The range of heating value can span +/- 10 to 15 percent. The typical higher and lower heating value of LNG is approximately 50 MJ/kg or 21,500 BTU/lb and 45 MJ/kg or 19,350 BTU/lb (Kumar et al 2011).

2.1. Exploration and Production Process

Oil and gas developments are evolving from conventional to unconventional resources for onshore, and from shallow to deep water for offshore. Offshore developments are shifting from shallow water areas such as Middle East, the North Sea, South East Asia, North America and Australia to deep waters in Africa, Brazil, the Gulf of Mexico and the Artic (Kumar et al 2011). Oil major companies use highly advanced multi-dimension seismic acquisition and processing technologies such as ocean bottom nodes and full waveform inversion modeling as well as interpretive and interactive seismic modeling and imaging algorithms. According to Liang et al (2012), these technologies improve their understanding of complex subsurface conditions throughout the life of their assets from exploration stage to ongoing reservoir management. LNG production process is in two (2) distinct divisions (Offshore/Upstream Production Process and Onshore/Downstream Production Process).

2.2. Offshore/Upstream Production Process

Offshore developments require a long period of time (5 to 15 years) from exploration to the start of production. A typical development process consists of four stages (*Exploration, Development,* Construction and asset operations). *Exploration* is the first stage that involves the discovery of oil or gas prospects through geophysical and geological study and exploration. *Development*" is the second stage that assesses the recoverable reserves by drilling some appraisal wells and analysing the data obtained from the appraisal well. At this time, the operator will determine a development plan detailing key development milestones(Liang et al 2012). Through conducting sequential feasibility and concept studies, and 'Front-End Engineering and Design' (FEED) to produce quality process and engineering documentation of sufficient depth, defining the project requirements for engineering, procurement, fabrication and construction of facilities and supporting a ±10% project cost estimate, the operator then considers to continue with the project at a stage called 'final investment decision' (FID). Following approval of FID, "*Execution*" the third stage of the project is conducted to execute the detailed Engineering, Procurement, Construction and Installation (EPCI). Upon completion of construction and production start-up of the development the operator will move into "*Life of field*" the 4th stage of the development concerned with ongoing asset operations and integrity management. Offshore oil and gas fields are developed through aspects including reservoir geology, drilling, well completion, environmental assessments, facility design, installation and operations (Kavalov et al 2009).

2.3. Downstream Production Process

At downstream, a liquefied natural gas plant (commonly known as LNG Train) is constructed and roughly divided into five processes (Pre-treatment, acid gas removal, dehydration, liquefaction heavy oil separation). In the pre-treatment process (Figure 1), undesired substances are removed from the gas taken from a gas field. Then the gas is separated using a slug catcher into oil and water which are then weighed (Kavalov et al 2009). Natural gas taken from a gas field contains environmental pollutants like hydrogen sulfide (H_2S) and carbon dioxide (CO_2). These impure substances are absorbed and removed from natural gas with an amine absorber acid gas removal or (AGR). With the use of a sulfur removal unit (SRU), sulfur is extracted from the hydrogen sulfide in the removed pollutant. An adsorbent is used to remove water from the natural gas from which impure substances have been removed so that ice will not form during the subsequent liquefaction process. Traces of harmful mercury are removed before liquefaction. The heavy compounds separation process is the core of an LNG plant in which natural gas is cooled and liquefied to –160°C or less using the principle of refrigeration (Yuan et al 2014).

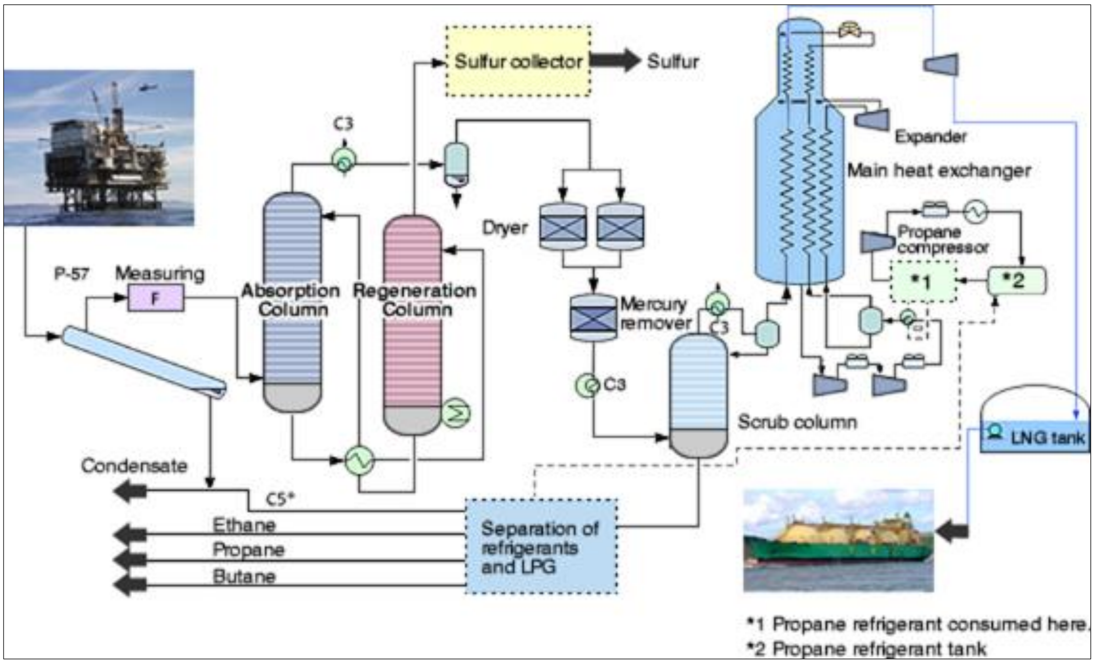

Figure 1 LNG Process Flow Diagram

2.4. LNG Refrigeration Process

As gas is cooled and liquefied to an extremely low temperature during the process, an enormous amount of energy is consumed. Reduced consumption of this energy is very important, so various ingenious processes have been proposed and commercialised. The C3-MR method is currently the main method. Propane and mixed coolants (nitrogen, methane, ethane and propane) are used as the coolant (APCI), and an improvement on this method called the AP-X method is also used for large LNG plants (Yuan et al 2014). All of these methods require enormous refrigeration compressors. Gas turbines are used for giant power plants to drive them, so elaborate engineering based on experience and high-level knowledge is required to design, produce and assemble the compressors and gas turbines. Hydrate inhibitors are used to prevent hydrate formation in subsea pipelines. It is injected at the wellhead and follows the gas and liquid flow to the gas processing facility. MEG is separated at the LNG processing plant along with LNG condensate (Song et al 2017).

2.5. Natural-gas Condensate (Condensate)

This is a by-product of the LNG process is a low-density mixture of hydrocarbon liquids that are present as gaseous components in the raw natural gas produced from many natural gas fields. Some gas species within the raw natural gas will condense to a liquid state if the temperature is reduced to below the hydrocarbon dew point temperature at a set pressure (Song et al 2017). In general, gas condensate has a specific gravity ranging from 0.5 to 0.8, and is composed of hydrocarbons such as propane, butane, pentane etc. Condensates are stored in specially built storage tanks to export via condensate tankers (Bernocchi et al 2003).

2.6. LNG Storage Facilities

Modern LNG storage tanks are typically full containment type, which has a pre-stressed concrete outer wall and a high-nickel (9%) steel inner tank, with extremely efficient insulation between the walls. Large tanks are low aspect ratio (height to width) and cylindrical in design with a domed steel or concrete roof. Storage pressure in these tanks is very low, less than 10Kpa. Sometimes more expensive underground tanks are used for storage. LNG must be kept cold to remain a liquid, independent of pressure. Despite efficient insulation, there will inevitably be some heat leakage into the LNG, resulting in vaporization of the LNG. This boil-off gas acts to keep the LNG cold. The boil-off gas is typically compressed and exported as natural gas, or it is re-liquefied and returned to storage tanks. The tanks are fitted with vertical pumps and connected via extensive insulated pipelines from LNG Train, and leading to export marine loading arms. Material Offloading Facility (MOF) is a shallow depth, specially designed and constructed port facility, protected by breakwaters within the plant footprint to facilitate logistical support for the construction of the LNG plant. Large plant equipment and modules are built and fabricated in yards/sites around the world according to design specifications (Yuan et al 2014). Heavy construction equipment and materials, large section of modules are shipped onsite by heavy-lift and semi-submersible project vessels along with a large flotilla of tug and barges. These cargoes are unloaded at the purpose built general and ro-ro berths. Some of these cargo units could weigh over 5000 tonnes, usually rolled-off and driven to site locations by using multi-wheeled heavy haulage SPMTs. On completion of plant construction works this facility usually remains as a support base and tugs shelter for rest of the project life. Marine scope of works during downstream construction phase could be extensive depending on site locations. Many mariners are employed during this construction phase in various capacities (Song et al 2017).

2.7. Loading Facilities and Transportation

Product Loading Facility (PLF) is usually constructed some distances away from the main LNG plant site in a dredged pocket with sufficient depth for the LNG and Condensate vessels to moor and load. It is connected by a jetty from the landside which also houses all piping system. In most cases, PLF is well inshore from open seas, and connected by long dredged channel from the deep water contour line, marked with navigational aids. Vessels are piloted in and out of the port facility by licensed Marine Pilots throughout the life of the facility. These highly experienced mariners, in most cases, act in a dual role as the Pilot Loading Master (PLM), managing vessel loading operations and ship-shore interface. LNG is transported by sea on board specially designed LNG vessels (Kavalov et al 2009). There are predominantly two types of tank construction system currently in use. The Moss LNG tank enables high accuracy of predicted stresses and fatigue life of all parts of the tank structure, eliminating the need for a full secondary barrier. The tanks are generally made from Aluminium and supported around the equatorial ring by a Structural Transition Joint (STJ), which also acts as a thermal break between steel and aluminium. The tanks are then insulated with polyurethane foam which is purged with Nitrogen. A partial barrier in the form of a drip-tray beneath the sphere is fitted. A gas sampling system is fitted to detect any signs of leakage. The complete tank and hold space are protected by weatherproof cover (Bernocchi et al 2003).

2.8. Historical LNG Production

LNG production has started in the sixties with the plants in Algeria and Lybia, then restarted in the 80's and boomed in the last 10years. Since the 80's(Figure 2), there have seen a fast growing of LNG production starting from 3MTPA for QG1 and WOODSIDE 1 to the 7.8MTPY for large QG projects. After that time all the new plant has been designed around 4MTPY. The paper will describe which are the recent novelties introduced in the latest LNG projects (Kavalov et al 2009).

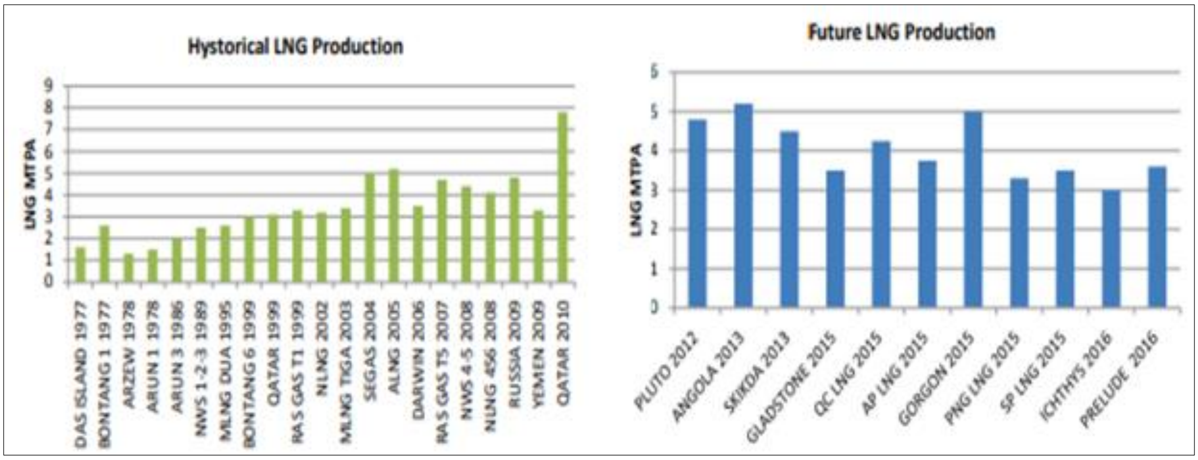

Figure 2 LNG Production

2.9. Previous and Current Train Configuration

Turbomachinery arrangement of latest main refrigerant compressor trains for 3-5 MTPA are recently built around aeroderivative gas turbines such as LM2500 or LM6000 while in the past FRAME 7 was most used. Typical Frame 7 train installed power is around 190MW just for main refrigerant compressor. This type of train is installed in Egypt, Nigeria, Malaysia, and Indonesia. The typical compressor used in the large LNG plant is the beam type centrifugal (Saleem et al 2018). For a specific service (LP MR), a process axial compressor has been also used. The main advantage of the axial compressor is the high efficiency and the large flexibility. Looking to the future new LMS100 is a driver that can be used in the LNG for its high operating flexibility and efficiency. A possible layout of the train to reach 4MTPA could consist of 1 LMS100 and two compressor bodies. Worth to be mentioned is also the longest refrigeration train ever done that is installed in Angola and it's done by Fr7 + 3CC + EM. This plant has also another train with Fr6 + 3CC +EM to complete the refrigeration loop. The entire liquefaction train is done by two trains with Frame 7 and two with Frame 6 for a final production of 5.2 MTPA (Bernocchi et al 2003).

2.10. Compressor and Heat Exchanger Design

Aerodynamic is the building block of the compressors because it's directly connected to the efficiency and so to the LNG production: 1% increase in the compressor efficiency is equal to 1% increase in the LNG production for this kind of plant capacity. Enhanced aerodynamic solutions are under continuous development to increase the overall efficiency. State-of-art tools, tests, and operating experience contribute to the design success.For LNG the most critical stages are within the pre-cooling compressor where the combination of low temperature with high molecular weight and large volume flows leads to Mach number to the extreme. The continuous cost reduction in the Oil and Gas (O&G) market has obliged the Original Engineering Manufacturers (OEMs) to optimize the rotating equipment for example by reducing the dimension (Bernocchi et al 2003). This leads to the reduction of the impeller exit diameter and the increase of the flow coefficient. Compressor efficiency can also be increased by acting on internal leakages, trying to reduce them at minimum. A further option to increase the efficiency is to use vaned parts. Vanes can be introduced upstream the impeller blades (so called IGV or inlet guide vanes) or downstream in the diffuser. Refrigerator compressors are typically equipped with injections between one stage and another to keep all the service within one casing Presence of side stream leads to increased challenges in performance predictability. Proprietary heat exchanger equipment lies at the heart of most natural gas processing systems. In fact, advanced LNG Plants have both coil-wound and plate-fin heat exchangers. Covering the entire LNG value chain, the heat exchangers are equipped with capacity that meets small- to mid-scale performance(Saleem et al 2018).

2.11. Nitrogen rejection units

LNG plants are designed not contain more than 1% nitrogen to avoid storage problems. Some state-ofthe-art, world-scale LNG plants thus feature a nitrogen rejection unit (NRU) for the safe and economical rejection of nitrogen. This is required, for instance, if surplus nitrogen cannot be sent to gas turbines. Not only does the rejection of nitrogen reduce transportation volumes, it also increases the heating value of LNG (Kavalov et al 2009). Alternatively, an NRU can be used to recover methane from tank return or end-flash gas. Today, nitrogen rejection units are tailored with process technology to ensure the highest levels of cost and operational efficiency. NRU are designed with single columns, single partitioned columns, double columns and double columns with enrichment processes, with configurations tailored to the individual composition of the gas (Bernocchi et al 2003).

2.12. Small- to mid-scale LNG production plants

The time, cost and flexibility advantages of "larger" mid-scale units is fuelling demand for this class of plant. To meet this need, Engineers have developed a concept for a new class of mid-scale LNG production plant with a liquefaction capacity of between 1 and 2 mtpa. This concept offers economies of scale relative to smaller LNG plants while still benefitting from components of well-proven sizes that do not stretch technical limits. Furthermore, it has the potential to reduce construction costs, especially in remote areas or high-cost countries, by applying a fully modularised approach. Engineers are now targeting small-scale LNG liquefaction capacities ranging between 100 and 600 tpd (tonnes per day). Such plants typically consist of natural gas treatment (sour gas removal and dehydration) and liquefaction units, an LNG storage tank and an LNG truck filling station (Saleem et al 2018). The natural gas is cooled, liquefied and sub-cooled in a plate-fin heat exchanger (PFHE) mounted in a coldbox using highly efficient single mixed refrigerant cycle process. This mixed refrigerant cycle uses four refrigerants: nitrogen, methane, ethylene or ethane (depending on availability) and butane. Studies have also shown that small-scale LNG plants offer a well-proven nitrogen double expander cycle process, which offers particular advantages if the mixed refrigerants are not available (Kavalov et al 2009). Based on its mid-scale LNG plants, Engineers have developed a concept for a new class of midscale LNG production plants with 1–2 million mtpa liquefaction capacity. These plants are becoming increasingly attractive for the international LNG market as they combine the strengths of both mid-scale and world-scale plant types and markets. The concept offers economies of scale relative to smaller LNG plants while still benefitting from components of well-proven sizes that do not stretch technical limits. Furthermore, it has the potential to reduce construction costs especially in remote areas or high-cost countries by applying a fully modularised approach (Mokhatab et al 2014).

2.13. Floating Liquified Natural Gas (FLNG) operations

FLNG projects are still quite rare and are clearly outnumbered by the hundred-plus mid- and world-scale onshore LNG trains with at least 1 mtpa capacity. The CAPEX of these floating operations can be reduced by increasing the liquefaction capacity to capitalise on economies of scale. However, not all concepts that are proven on shore translate into optimal

FLNG solutions. In many cases, operability is more important than efficiency. This offers new opportunities for expander-based liquefaction processes. Advance technology is needed for FLNG processes to generate a capacity of up to 2.5 mtpa based on two 1.25 mtpa trains. It thus significantly reduces equipment count and plot requirements relative to competing technologies. The thermodynamic efficiency will match that of a well-designed N_2 expander process(Saleem et al 2018).

3. Conclusion

An overview of LNG processes has been presented. Innovative considerations and solutions have been shown. Today's LNG plants offers extremely robust design and ease of operation. Advanced LNG plants are designed to reduce processing effort for pretreated feed gas. The plants are built with economies of scale relative for reduced construction costs. Recent constructed plants have proven components and dimensioning without stretching technical limits. Newly built LNG plants have multiple sourcing flexibility with no supplier lock-in or cost component qualification problems. They have significant reduction in overall project risk and complexity.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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