OTC OTC-22850-PP

Latest Developments in Floating LNG Liquefaction Technologies: How We Are Combining Proven and Innovative Technologies for the Future

I. B. Waldmann and K. Utkilen, KANFA Aragon AS

This paper was prepared for presentation at the Offshore Technology Conference Brasil held in Rio de Janeiro, Brazil, 4–6 October 2011.

Abstract

As demand for natural gas continues to grow, offshore liquefaction of natural gas (LNG) by floating production, liquefaction, storage and offloading (FPSO) vessels is becoming increasingly attractive. LNG FPSO solutions offer an economic and environmentally sound solution to exploiting the attractive stranded offshore gas fields and commercialising oil associated gas, reducing the need for flaring and giving an extended potential for oil production. For offshore applications different design criteria apply than for onshore plants and the Nitrogen Expander Cycle is meeting all these requirements. The “Aragon’s Optimised Expander Cycle” has additional features that makes it highly applicable for offshore liquefaction.

Introduction

The history of the development of large scale natural gas liquefaction plant started in 1960’s with technologies based on either the classic cascade cycle (by Marathon/Phillips) or simple mixed refrigerant cycles.

At the beginning of this century, several new large scale processes have been demonstrated or proposed. These includes Air Products’ AP-X process, Shell’s propane pre-cooled Parallel Mixed Refrigerant process (PMR), Statoil/Linde‘s Mixed Fluid Cascade (MFC) and Conoco-Phillips’ Optimised Cascade. Common for all these base load technologies are:

- Ultra-large train size
- High process efficiencies but variable overall thermodynamic efficiency
- Large and heavy equipment
- Requirement for large construction areas
- HC Refrigerants

These are features that are not advantageous for offshore applications. Through the last decades the industry has studied to find the most appropriate liquefaction technology for the offshore environment.

The paper gives an overview of the evaluations related to the engineering and design of an LNG FPSO topside. It discusses the different selection criteria that apply for selecting offshore liquefaction systems and gives an introduction to the Nitrogen Expander liquefaction technology and in particular the “Aragon’s Optimised Expander Technology”.

Where is offshore LNG attractive?

There is a wide range of applications where offshore LNG production is attractive:

Stranded Gas Field - These fields are typically located at significant distance from existing offshore or onshore production facilities or pipeline networks. Floating production units is a highly competitive choice compared to new build offshore production platforms and long distance pipeline tie-backs to onshore facilities.

Associated Gas Field Applications - As environmental regulation are getting stricter the presence of oil associated gas in locations remote from existing infrastructure is an increased challenge to Governments and the Oil and Gas Industry Economic development of many of these resources is difficult, particularly for the offshore fields. The result is that 110 billion standard cubic meter of natural gas is being flared annually in the world[5]. Production of this gas in form of exported LNG adds economic value to an existing project, and provides an additional benefit to the environment by reduced emissions.

Early Production System and Staged Development Applications - Floating liquefaction offers a fast-track project compared to an onshore plant. Current LNG FPSO projects show that the development time from project definition until first LNG is up to 50% of the time required for a traditional onshore LNG development. Hence the LNG FPSOs are capable of providing a viable alternative for an early production scheme generating revenues and creating value while the standard facilities are being approved and built.

Pipeline Gas – With current shale gas discoveries and other developments where there is already an existing domestic pipeline grid with surplus gas, an LNG FPSO can be located in a near shore location and produce LNG for export.

Onshore remote gas fields – LNG FPSO atshore solutions can be a highly attractive solution for onshore fields where infrastructure for onshore plant construction is limited. The atshore solution comprises the LNG FPSO to be hooked up to a jetty. Gas feed from shore is liquefied to LNG onboard the FPSO and exported. In addition to the schedule and investment cost benefits, many of the local legislation and political issues can be avoided.

Offshore design criteria

Due to the fundamental differences between the onshore and the offshore environments, offshore oil and gas processing facilities are likely to have different technology selection criteria than onshore facilities.

Offshore facilities must be more compact and have a lower weight to be fitted on the limited available deck space. Being offshore the plant must also offer a high inherent process safety. Other important constraints are the vessel motion, the need for modularisation and the availability for maintenance.

On an offshore facility there are limitations both on logistics and accommodation facilities. The technology selection should also take into consideration the process robustness, the sensitivity to variable feed gas compositions and conditions, and start-up and shutdown times. The number of operators required and their skills, required education and training are also of highest importance.

For offshore applications one should select a technology which gives the highest availability as this give the highest turnover and best economics. High process efficiency is also an important criteria but care should be taken not to increase the investment significantly for the purpose of enhancing the process efficiency and at the same time sacrificing by increased complexity, lower availability and reduced inherent safety.

Based on the above, liquefaction technology based on the Nitrogen turbo expansion is by many acknowledged as being the most suitable technology for offshore medium-scale LNG production [1].

Nitrogen expander technology

All expansion cycle processes are based on the Reverse Brayton-Claude Cycle where high-pressure Nitrogen stream is pre-cooled to an intermediate temperature and then expanded over turbo expanders to approximately minus 160ºC. Because the expansion is near isentropic, the turbo expanders lowers the gas temperature significantly more than expansion across a J-T valve. After the expansion, cold, low-pressure gas streams are returned to the cryogenic heat exchanger (cold box) providing refrigeration to the incoming process gas stream and to the precooling of the incoming Nitrogen gas stream.

The cold boxes for Nitrogen expander cycles are generally a combination of brazed aluminium plate-fin heat exchangers (BAHX). The work generated in the expansion turbine, which is loaded by a compressor, will be used to boost up the Nitrogen before it is further compressed in the main cycle compressor (Figure 1).

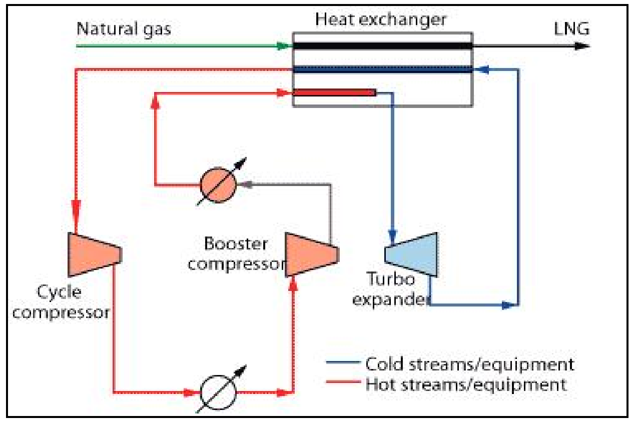

Figure 1 – The Nitrogen Expander Cycle

Larger systems usually utilises some kind of improvements to the basic single expander cycle in order to improve the efficiency, and in particulars the conventional Dual Nitrogen expander cycle. In a dual Nitrogen expander cycle the use of two expanders at two different temperature levels allow for a closer temperature match of the warm and cold streams, giving reduced temperature differences and thereby reducing the thermodynamic loss. Power consumption is reduced by approximately 30% compared to a single expander cycle. In general the Dual Nitrogen expander cycle offers:

- High inherent safety level due to non-flammable refrigerant.
- Low complexity weight and investment costs
- High robustness for changes in feed gas composition and condition.
- High availability

Train capacity. There are limitations in train size capacity for Nitrogen expander cycles, both related to cold box sizes and potential available direct drivers if this is preferred. With the latest innovation on Nitrogen turbo-expansion technology approximately 1.2 mtpa can be produced per train[2]. With the low equipment number per train numbers presented indicate that up to three trains are competitive in terms of CAPEX compared to Mixed Refrigerant cycle one train solutions[3]. Two trains can easily fit on a ship-sized 170,000 m3 LNG carrier tank, while three trains could be fitted if the required field specific systems are limited.

Large scale reference. The Dual Nitrogen expander cycle has a large scale reference with the Nitrogen part of the AP-XTM system being equivalent to a 1.5-2 mtpa stand-alone system. The system uses four cold expanders and one warm expander and a BAHX is used as Nitrogen cold box (Figure 2).

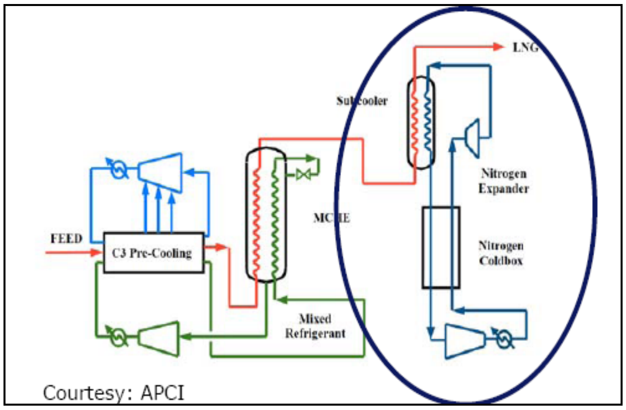

Figure 2 – Large scale reference for the Nitrogen Expander Cycle

Efficiency versus availability

For an onshore large scale base load plan with production above 4 mtpa and with relatively unlimited available plot space, it is maybe naturally to select a technology with high train capacity and high process efficiency. The efficiency is normally given as the power consumption of the refrigerant cycle compressors upon kg produced LNG. The focus on driver selections was traditionally never selecting the highest efficiency resulting in a rather limited overall plant efficiency at the existing main base load onshore plants.

Going offshore a highly reliable plant can be even more important than trying to optimise the efficiency and reduce the fuel gas consumption. High availability secures the operator the annual production and the running income. Selecting a technology with slightly lower efficiency does in reality mean that the reservoir will be depleted to a maximum a couple of months earlier.

Easy operation improves availability. Offshore floating facilities are operating on relative marginal fields compared to the large onshore base load plants. The operation is influenced by the reliability of relatively few wells or a nearby FPSO with oil production and oil stabilisation process. Hence the annual LNG production is highly dependent on a robust system which is easy to operate.

The Nitrogen expansion cycles are fast to start and take to stable operation after a shutdown or blow-down. Because of the better robustness for changing flow rate and feed gas composition and faster start-up time period, a Nitrogen gas expansion cycle has very high availability.

A high efficient technology, like the mixed Refrigerant type-processes, requires that the mixture of the hydrocarbons is perfectly adjusted to the feed composition. The result can otherwise be a temperature cross in the main liquefaction heat exchanger with subsequent loss in process efficiency. To ensure that the system is at peak production requires high skilled operators.

Getting highly technical qualified operators offshore might have an additional cost impact. Easy maintained liquefaction systems like expander cycles does not require fine tuning of the process and is efficient over a wide range of feed compositions. In such terms one can expect that the operator gets increased revenue due to higher availability and potentially also higher average efficiency by selecting the expander cycle.

Using two or three trains for Nitrogen expander cycles compared to one train for HC refrigerant cycles results in better overall on stream availability for the unit Also Nitrogen gives the highest availability for rotating equipment.

Driver selection

The overall vessel's fuel gas balance calculation does not only take into account the liquefaction process efficiency but also the efficiency of the refrigerant compressor drivers and the required utility consumption. As an example there has been a game change in the onshore thinking related to technology selection, as e.g. latest development have shifted from using low-efficient large frame size gas turbines to multiple high efficient aero-derivative gas turbines[4]. For offshore applications selecting driver for the cycle compressor is a complex choice as the different types all has its advantages:

Steam turbines. Steam turbines do not have limitation in size within the ranges for LNG FPSO production and are in such terms highly applicable for large one-train liquefaction systems. They have a wide reference from offshore applications and have good track record in term of reliability.

Steam is generated by burning fuel gas in dedicated boilers and uses the heat from the exhaust to produce high pressure steam which drives the turbines. The boilers can accept most fuel gas compositions. Hence steam boilers could have its advantages when producing LNG from reservoir with high Nitrogen content or other gas contaminations.

The disadvantage with the steam drivers is their low thermal efficiency. Further they are not suitable for installation of waste heat recovery units. Investing in a high efficient liquefaction process driven by steam turbines may hence not give an overall fuel efficient plant.

Aero-derivative gas turbines. These types of gas turbines (Figure 2) have the highest efficiency in the marked with up to 42% for the largest available types available for offshore applications (LM6000 PG and RR Trent).

Fuel gas balance calculations shows that the high efficiency of the aero-derivative gas turbines selected for the Nitrogen cycle has a significant impact on the overall feed gas shrinkage. For a 2 mtpa production capacity the feed shrinkage is lower for a two train Nitrogen expander cycle with aero-derivative gas turbines than single train Dual Mixed refrigerant cycle with steam turbines[5], where the latter is selected lately by the industry for the some huge barge solutions. In addition aero-derivative gas turbines give the advantage of the possibility to implement waste heat recovery units which can generate heat for e.g. the heat demanding amine regeneration system required to remove CO_2.

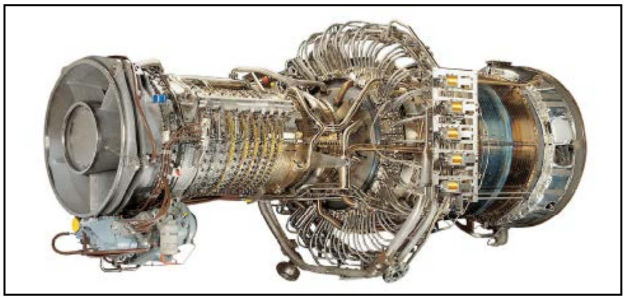

Figure 3 – Illustration of aero-derivative gas turbine

The limitation is in the maximum available output of the drivers which are available for offshore operation. Expander type technologies tend to select aero-derivative gas turbines to compensate for the slightly lower process efficiency compared to e.g. Mixed Refrigerant technologies. Hence the driver is typically the limitation for the train capacity.

Electrical motors. Both steam turbines and aero-derivative gas turbines are simple to start and have a good turn-down. Electrical motors are also considered to have an excellent availability record.

The downside is the add-ons required when selecting large motors like soft starters, harmonic filters, solid power generation and transmission system. This will be a significant contribution to the topside installation and to the operation of the FPSO. Electrical motors are equivalent limited in size for offshore applications as the aero-derivative gas turbines.

Using electrical motors could be an advantage for atshore applications where a stable grid exists for the operation of huge electrical motors and where sustainable energy is available from for example hydro power.

Safety

Offshore LNG production introduces other safety concerns than onshore LNG production as escape options are significantly more limited. Special care must be taken in the design phase to ensure an uncongested plant to meet offshore requirements for maximum fire loads and escape routes. Loss off cryogenic containment from e.g. LNG flash tanks and LNG spill is another major risk which is new to the offshore environment. Experience from onshore liquefaction design should be mixed with extensive safety review to mitigate the risk of flammable vapour clouds having a high explosion risk.

The liquefaction system itself takes over approximately half of the size of the LNG FPSO topside. By selecting the Nitrogen as refrigerant the risk factors are significantly reduced as major part of the topside has a non-flammable containment. This is not case the for HC refrigerant type processes. By selecting the Nitrogen expander cycle the requirements to store liquid hydrocarbons is also avoided.

Leakages from seals or flanges are more common for cryogenic systems than ambient, but are non hazardous and easily compensated when selecting the nitrogen expander cycles. The entire refrigerant system is in vapour phase. Hence cryogenic spill protection is limited to the rather minor part of the system which consists of liquefied hydrocarbons.

Marinisation

Cryogenic service is a new design requirement for a floating production unit. All the different liquefaction technologies can be designed for working under maritime conditions, but a comprehensive novel technology review is essential to reduce the risk.

The main equipment in the Nitrogen expander cycle is not novel and has the advantage of having offshore references through reliquefaction plants on LNG carriers.

A further advantage with respect to marinisation of Nitrogen expander cycles is that the refrigerant is vapour throughout the whole cycle. This gives a significant benefit in that:

- The system is not dependent on pipe slope. Independency of slopes gives you an advantage in the detail engineering of large cryogenic piping and to maintain an uncongested plant.
- There are no changes in the compositions or phases so no special care need to be taken to ensure correct distribution in heat exchangers.

Whilst this size of cold box would be considered routine for onshore application and is today in use in the offshore environment, the required size introduces some novel features in its design and construction. Producing a compact design for offshore application presents a challenge to the routing of pipework internal and external of the cold box (Figure 4), whilst ensuring that reaction loads on equipment are maintained within acceptable limits. This is however general offshore engineering practise. The carbon steel cold box structure, enclosing the aluminium heat exchangers, ensures that no new material is exposed to the marine environment.

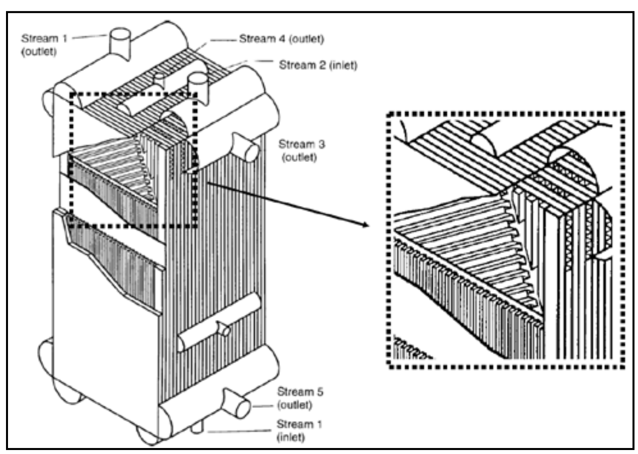

Figure 4 – Illustration of a typical multi-stream brazed aluminium plate-fin heat exchanger

In general specs and requirements are revised and modified for the LNG FPSO and more and more of the legislations are changed to be according to the offshore oil and gas standards.

Topside integration and modularisation

For the design of an offshore liquefaction plant navel architecture needs to combine the onshore LNG design criteria with the offshore engineering practice. The plant will be located on a floating vessel on the deck above the cryogenic cargo tanks. To ensure successful integration with the hull it is important to have a close dialog with the topside and hull contractor and establish design and engineering specification.

Experience from both FPSO design and cryogenic engineering is crucial as the plant needs to be designed to handle the motions and accelerations that the vessel be will exposed to in combination with the cryogenic operation.

Modularisation is common in the Oil and Gas FPSO industry as it improves delivery time and reduces cost. The cold boxes and rotating equipment in the Nitrogen expander cycle are modularised and fabricated at the typical Korean ship yards like Samsung Heavy Industries and can be fully piped, instrumented and tested for hook-up and topside integration. In such way the vessel construction can go in parallel with the process plant fabrication. The standard working practise, the simpler logistics and the experienced work force at the yard reduses the overall project schedule and hastens the LNG production start-up.

Process integration. A comprehensive overall process understanding is essential to reach a successful integration and operation of an LNG FPSO. This includes the important incorporation of the dynamic operations.

Both LNG and condensate have strict product requirements. Generally the LNG can absorb the most of middle components as butane and propane. However, at stricter LNG specifications there is not much flexibility to spike the LNG product. This might give a requirement for LPG production and thereby a third product to store and export.

The consequence of high content of pentane which often is typical for associated gas prospects may cause recycles from the liquefaction process back into the upstream process and resulting in significant changes in sizing of piping and equipment.

Equivalent it is important to integrate the overall fuel gas balance and boil of gas balance of the ship in the overall process and also to look into the consequences of the transient conditions of this while starting offloading of LNG.

Aragon’s Optimised Expander Cycle

There has been developed a wide range of different patented expansion technologies which are proposed for the offshore LNG production e.g.:

- Niche® LNG
- LNG Smart® Liquefaction Technologies
- Aragon’s Optimised Dual N2 Expander Cycle

They all have their advantages and have improved the standard expander cycles to meet process efficiencies below 0.4kWh/kg LNG.

The Aragon’s Optimised Expander Cycle has kept the simplicity of the Dual Nitrogen Expander Cycle and improved the process on the hydrocarbon side. In general the process offers:

- Optimised heavy hydrocarbon (HHC) removal and improved efficiency compared to conventional expander cycles.
- Integrated HHC removal without introduction of rotating equipment
- Production of up to 1.2 mtpa per train with the largest available aero derivative gas turbines (LM 6000 PG and RR Trent 60) for the offshore market.
- Opportunity to adjust the LNG specifications according to the project requirements (e.g. the Higher Heating Value).
- Highly flexible to feed gas composition ranges and feed gas pressure changes.
- Possibility of turndown and smooth ramp up from 20% to 100% of production capacity including equivalent energy saving per liquefaction train.

In general the Aragon’s Optimised Expander Cycle maximizes the use of proven marine offshore suitable equipment. This enables competition amongst equipment suppliers, thus minimizing overall project CAPEX and shorten equipment lead time.

Closing remarks

There is a clear tendency that natural gas is becoming more and more attractive as the energy source. The demand has increased significantly in light of the earthquake striking Japan earlier this year, with the domino effect of nuclear power plants being shut down and new projects put to hold.

Brazil has further a significant challenge in that they require immediate handling of the large volumes of associated gas from the Pre-salt developments in order to meet environmental regulations for producing the crude oil. Offshore liquefaction is an alternative because of the deep waters, making pipeline construction to shore highly costly and technically challenging.

Lately several offshore liquefaction projects have moved on towards final investment descision. It is anticipated that several project will commence the coming years. With the high competitiveness and the offshore advantages, there are many reasons to believe that many of these plants will select the Nitrogen Expander Cycle.

References

[1] Kennett, A.J., D. I. Limb and B. A. Czarnecki, “Offshore Liquefaction of Associated gas – A suitable process for the North Sea. “ 13th Annual Offshore Technology Conference, Houston, May 1981

[2] Utkilen, K, “Delivering insight into the FLNG Topside”, 6th FLNG Asia Pacific Summit, June 2011

[3] Jones, N., “Overall FLNG Development Philosphies and Strategies”, FLNG Rio Technical Masterclass, Rio de

Janeiro, September 2010
4 Cyrus Meher-Homji, “The Darwin LNG Plant – Pioneering Aeroderivative Turbines for LNG Refrigeration Service”, GE Oil & Gas Conference, Florence, Italy, January 2007
5 Gerner F., Svensson B., Djumena S., “Gas Flaring and Venting”, Public Policy for the Private Sector, Octtober 2004