A NEW LIQUEFACTION PROCESS SUITABLE FOR OFFSHORE

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KEYWORDS: LNG; liquefaction; offshore

ABSTRACT

In recent years, Floating LNG technology has progressed to a point that it has now become a feasible and attractive alternative to recover and monetize offshore natural gas fields. Additionally, the modular construction and assembly strategy in a shipyard makes FLNG projects less prone to onshore constraints such as permitting and a challenging construction environment. However, Floating LNG poses new challenges in terms of safety, energy efficiency, space limitations and motion. Key to this debate is the choice of liquefaction process for which the leading contenders are mixed refrigerant processes, that have light hydrocarbon inventory as principal drawback, and gaseous, reverse Brayton cycles that are handicapped by efficiency. A new liquefaction process in the latter category has been developed to increase overall efficiency among other advantages: With respect to conventional N2 cycles: Independent refrigerant cycles easy to start and operate, Possible on-stream optimization through the adjustment of composition, independently for each cycle and without refrigerant storage. With respect to other mixed refrigerant cycles: Overall reduced liquid inventory and potential for BLEVE and cold spills, Motion insensitive. This paper will: Provide a description of the new process including the thinking behind its development, Compare this process to conventional industry standard liquefaction processes in terms of process efficiency, layout and CapEx, Depict how, thanks to its simplicity and efficiency, it could be applied on many FLNG projects.

1. BACKGROUND

Onshore liquefaction plants use mechanical refrigeration and light hydrocarbons (C2 - C5 depending on the process) among the refrigerant components. Offshore, it is important to minimize the inventory of these components, particularly in the liquid phase, to reduce the risk of explosion and the need for safety gaps between modules. If they can be eliminated entirely the production or the importation of propane and ethane and respective storage facilities can be avoided.

For time being, in the industry most of the plants in production use light hydrocarbon refrigerant cycles. For example, Air Products C3/MR Process (almost 90% of the total LNG installed capacity) requires the storage and the production or the importation of Propane and Ethane.

Nitrogen expansion cycles are another known solution however they suffer from poor efficiency and the heat to be dissipated from the compression loop is significant, increasing the size of the cooling water system, piping and heat exchangers.

The newly developed Tricycle liquefaction process uses three gaseous phase refrigeration cycles with expansion turbines. Unlike the standard nitrogen cycle the efficiency of the Tricycle approaches that of processes using light hydrocarbon refrigerants to within 20%. Each of the three cycles is totally independent from the other two. Gas compositions, pressures and temperatures are optimization parameters.

The gaseous refrigerants of the three expansion cycles are mixtures of natural gas and nitrogen which is produced in all LNG plants for inerting piping and equipment. Refrigerants can be produced rapidly from the process avoiding the problems caused by the first fill of refrigerant, eliminating the hazards from LPG handling and the problems of finding refrigerant with very high purity. There is also no requirement to remove
NGL from the natural gas in order to produce refrigerants make-up and it avoids the requirement to import refrigerant in the case of a very lean gas without NGL.

The fact that all refrigerants stay in the gaseous phase reduces the light hydrocarbon liquid inventory, compared to a traditional refrigeration cycle. There is no need for a large liquid accumulator.

A major advantage on a floating platform is that the process is not sensitive to motion.

2. STATE OF THE ART

- Natural liquefaction can be performed using different types of refrigeration cycles:
  - Cycles using light hydrocarbon liquid refrigerant vaporizing at low pressure. The refrigerant can be either a pure component or a mixture. The low pressure refrigerant after vaporization is then compressed, cooled and condensed. The cooling and the condensation are performed by use of water or air under ambient conditions. The cooling can be completed using another refrigeration cycle in cascade.
  - Cycles using gas dynamic expansion (reverse Brayton cycle) where the gaseous refrigerant at high pressure is expanded in a turbine to obtain a cold refrigerant used in the liquefaction process. Before being expanded the high pressure refrigerant can be pre-cooled.

- The following processes have been used for several years in onshore LNG export plants and are considered for future projects:
  - The C3 / MR process using two refrigerant cycles: one with propane and one with a mixed refrigerant comprising Nitrogen, Methane, Ethane and Propane. The propane cycle is used for the natural gas pre-cooling and for the partial condensation of the mixed refrigerant. The mixed refrigerant cycle allows the natural gas liquefaction and the LNG sub-cooling.
  - The Cascade Process (propane, ethylene, methane) using three pure component refrigeration cycles: the first one using propane, the second one using ethylene, and the third one using methane. The first cycle is used to pre-cool the natural gas and the third cycle methane and to condense the second cycle ethylene. The second cycle allows the natural gas liquefaction and the third cycle methane condensation. The third cycle allows the LNG sub-cooling.
  - The Air Products APX process using three refrigerant cycles: the first one using propane, the second one a mixed refrigerant comprising Methane, Ethane and Propane and the third one containing nitrogen. The first cycle is used to pre-cool the natural gas and the third cycle nitrogen and to condense the second cycle mixed refrigerant. The mixed refrigerant cycle allows the natural gas liquefaction. The third nitrogen refrigerant cycle which is a gaseous expansion cycle allows the LNG sub-cooling.
  - The DMR (dual mixed refrigerant) process using two mixed refrigerant cycles: the first mixed refrigerant containing mainly ethane and propane and the second mixed refrigerant cycle containing nitrogen, methane, ethane and propane. The first cycle is used to pre-cool the natural gas and partially or totally condense the second refrigerant. The second mixed refrigerant cycle allows the natural gas liquefaction and the LNG sub-cooling.
• Gaseous expansion cycles (reverse Brayton cycles)

The main step in a reverse Brayton cycle, such as the nitrogen cycle, is the expansion of a high pressure gaseous refrigerant through a turbine producing work. This dynamic letdown to a lower pressure results in a temperature reduction. Ideally the letdown ratio shall be above 2.

The level of refrigeration depends on the refrigerant composition as well as the letdown ratio and the fluid conditions upstream of the turbine.

The commonly used C3/MR, DMR and Cascade cycles are all based on refrigeration provided by the latent heat of vaporization of the refrigerant (reverse Rankin cycles); therefore, all these schemes inherently require the presence of a light hydrocarbon liquid phase in the cycle. This type of scheme may be therefore affected by sea motions on a floating unit. In addition this family of processes requires storage of light hydrocarbon liquid to provide make up, which can increase the safety risk on a FPSO and hence have an impact on the layout (safety gaps, safety walls etc)

On the other hand, a simple nitrogen expansion cycle suffers from poor efficiency compared to the liquid refrigerant cycles; so the heat dissipated by the compression loop is significant and has a direct impact to the size of the cooling water system and equipment involved.

These considerations lie at the heart of the Tricycle process development described below.

3. TRICYCLE PROCESS DESCRIPTION

The Tricycle process fills the gap between the reverse Rankin cycles that boast high efficiency but require a liquid refrigerant inventory onboard, and the reverse Brayton cycles using pure nitrogen that improve safety at the expense of low efficiency and therefore have usually been applied in smaller capacity trains.

The proposed scheme consists of three reverse Brayton cycles in which the refrigerants remain in the gas phase even at the expansion turbine outlet where temperatures are lowest.

The refrigerant selected will depend on the temperature sought. Pure nitrogen can be easily used from ambient down to -170°C with the possibility of subcooling the LNG and having no End Flash. Methane can be used down to -110°C. Mixtures of methane and nitrogen are often the most advantageous. Performance can be optimized through the addition of carbon dioxide or C2 – C5 hydrocarbons, on the condition that the refrigerant remains gaseous.

In the Tricycle process the mixtures used contain nitrogen, natural gas and components from the natural gas so no import (except possibly nitrogen) is necessary.

Figure 1 shows the simplest configuration: in this scheme, which is based on patent by Technip, a typical natural gas is precooled to approximately -40°C by the first reverse Brayton cycle, then natural gas is liquefied at approximately -90°C via another refrigerant cycle and finally it is subcooled to -148°C by the third cycle.
The three totally independent cycles can be adjusted individually to obtain the best thermodynamic efficiency. In addition three cycles are easier to start up and operate.

This intrinsic flexibility has been extensively studied to know how to adapt to the most frequently met cases. For example a gas mixture fairly close to raw natural gas can be used for the precooling cycle, while a lean natural gas can be used for the liquefaction cycle. The subcooling cycle is inevitably high in nitrogen.

The composition of the three refrigerant cycles can be selected to maximize the efficiency. Also the cycles can be integrated to improve further the efficiency.

In the configuration from Figure 2, the first refrigerant cycle provides cold sensible heat to the second refrigerant cycle used for liquefaction, in this way it is possible to improve the overall efficiency, by transferring duty from one cycle to another.

In another configuration depicted in Figure 3, the second refrigerant cycle transfers part of heat load to the third subcooling cycle.
In spite of the increased level of heat integration the scheme remains simple to operate and start-up.

Figure 4 shows another interesting configuration where the first two cycles providing natural gas precooling and liquefaction. LNG subcooling is performed by a third indirect reverse Brayton cycle which liquefies and subcools a nitrogen–methane refrigerant. The refrigerant subcools the LNG after being expanded in a liquid turbine providing power to the unit.

4. CONCLUSION

From this insight on the Tricycle process and its different configurations, it is apparent that this process is potentially attractive for the emerging floating LNG industry, by offering increased safety through the use of gaseous refrigerants. In addition, the Tricycle efficiency approaches that of a light hydrocarbon refrigerant as opposed to the traditional gas expansion cycles.
Furthermore, from an operations point of view, this new process is of high interest because it is not sensitive to motions, but also it is very easy to operate and start-up. It is therefore mostly suitable for the FPSO environment, where operations and consequent availability are critical.

The Tricycle process patented by Technip is one response to the offshore demands of increased safety, flexibility and operability, compactness and reduced sensitivity to motions, while combining equipment which is already well known and proven.

**REFERENCE**

WO2010061102: Method for producing a stream of subcooled liquefied natural gas using a natural gas feedstream, and associated facility