New processes for second generation offshore liquefaction processes

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Introduction

In the recent years, Floating LNG (FLNG) technology development has been fuelled to a point that it has currently become a feasible, effective alternative to recover and valorise those gas fields that previously were either inaccessible in stranded fields or destined to be flared or re-injected since as associated gas a by-product of oil production. FLNG can represent the most effective way to monetise a remote and dispersed gas assets without the need for the costly and complex studies and works associated with bringing the gas onshore to be treated and liquefied, such as civil works, gas pipelines etc.
In addition the modular construction an assembly strategy makes the projects less prone to locally difficult contexts.

On the other hand, a Floating LNG unit poses a number of fairly new challenges in terms of safety, energy efficiency, space limitations, and impact of sea motion.

In order to be competitive, an offshore production plant is expected to fulfil a number of requirements:

- All the process units shall have a compact design to reduce the plot space
- The weight shall be controlled to have a feasible and competitive hull design.
- All LPG inventories shall be minimised to limit the safety risks
- As for all high CAPEX projects, FLNG design requires proven technologies to limit the overall risk.
- Maximise operability and thus availability in view of the floating context (sea motions, potential for shut downs etc

Well aware of all these constraints, thanks to the experience built with design and construction of both large LNG trains onshore and large oil FPSO’s, floating platforms and subsea production facilities, Technip has been acting to further develop the LNG industry by proposing technically proven and achievable solutions to the new design challenges in safety, energy efficiency, space limitations and the effects of sea motion.

The three processes presented in this paper have been conceived in the intent of bringing further the emerging FLNG industry and are considered to be of great interest:

In the order the paper is going to present:

- A process for natural gas feedstock preparation for liquefaction schemes where the refrigerant does rely on extracted LPGs , i.e. a refrigerant cycle composed of a gaseous mixture of N_2, CO_2, C_1. The feedstock is split into two streams: a C_{4-} cut that is suitable for liquefaction after removal of CO_2. H_2S and water and a C_{5+} cut that can be sent to condensate storage. In addition to a low equipment count consisting of simple and conventional pieces, this process presents the advantages of avoiding LPG extraction, very low specific and energy consumption, no external refrigeration and minimum flaring during start-up.

- An increased efficiency liquefaction process with respect to conventional N_2 cycle, using a mixture of gases with:
    - Independent refrigerant cycles easy to start and operate
    - Optimisation through the adjustment of refrigerant composition; this optimisation is possible independently for each cycle
    - Overall reduced liquid inventory and potential for cold spills
    - Process operation is not sensitive to motion
    - Ease of operation and start up
- An end flash process maximizing LNG production and allowing production of high purity nitrogen suitable for refrigerant cycle make up in liquid or gaseous form.

Each of these processes boasts simplicity and efficiency and can be applied in many FLNG projects.

For each process this paper is going to review the existing state of the art and provide some critical appreciation of the related advantages and limits; after this reflection, the reasoning behind the research and design of these new processes can be explained and grasped in detail together with the benefits ensuing from their application.

1. Feedstock Preparation

1.1 Requirement for pre-treatment

The raw Natural Gas has to be treated prior to be liquefied to remove impurities that could freeze during the liquefaction:

- Carbon Dioxide (CO_2): its content shall be lower to 50 ppm maximum,
- Water (H_2O): content shall be as low as possible (acceptable below 1 ppm),
- Mercury (Hg) shall be removed due to aluminium heat exchanger in downstream units,
- Heavy hydrocarbons and meanly benzene, its content shall be below 1 ppm,
- Sulphur compounds: Hydrogen Sulphide (H_2S) amount shall be lower than 10 ppm and the content of other sulphur compounds (like mercaptans) shall be lower than 30 ppm.

The removal of acid components, CO_2, H2S and light mercaptans is performed by an amine solution.

The removal of water is performed in molecular sieves and mercury is removed with absorption beds.

The remaining issue is the removal of heavy hydrocarbons. This is usually performed by a cryogenic distillation.

1.2 State of the art

Several schemes are commonly used in the industry to perform the removal of the C5+ components and the benzene. Three of them are described in this chapter, from the simplest to the most complex.

- Dew Pointing

The simple scheme to remove heavy hydrocarbons from a raw feed gas is the Dew Pointing. Feed gas is cooled and then let down in pressure to allow liquid build up in a gas / liquid separator. The vapour stream (“treated gas”) is heated against the feed gas and then compressed to the required pressure. The heavy hydrocarbons at the bottom are pumped to a fractionation unit to produced stabilised condensates.

Although this process is very simple with a limited number of equipment, it will not produce “treated gas” compatible with a downstream liquefaction process if the feed gas is containing more than 1 % mol of C5+.

This scheme does not provide also any means to remove hexane and benzene from the feed gas.

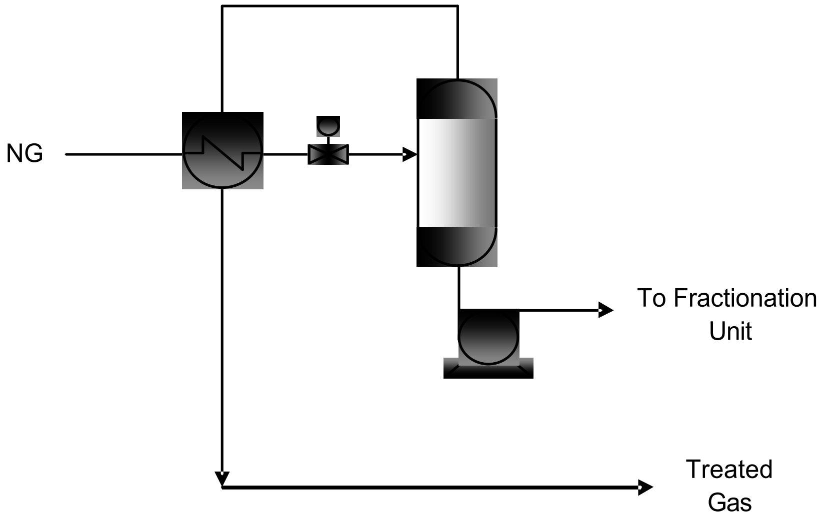

Figure 1: Dew Pointing process

- Scrub Column

This process is a very common scheme in the liquefaction industry. Most of the LNG trains in operation are using this scheme for its ease to achieve the specification of the gas to be liquefied and its integration in the liquefaction process.

The feed gas is cooled against the pre-cooling fluid of the liquefaction unit and introduce to a separation column. The column is reboiled to avoid having too much light hydrocarbon in the bottom product. On the overhead a partial condenser is provided to create a reflux, increasing the quality of the overhead gas. The vapour stream is routed to the Main Cryogenic Heat Exchanger to be liquefied.

The bottom product of the column is routed to a fractionation unit to produce Ethane, Propane, Butane and stabilised condensate. Propane and Butane could be re-injected into the LNG if no commercial production is foreseen.

The main drawback of this scheme is that it is very sensible with very lean gas. Pressure has also to be letdown below the critical pressure of the gas which will limit the liquefaction pressure and increase the power required for the overall process. The other disadvantage for an offshore process is the large inventory in the reflux drum.

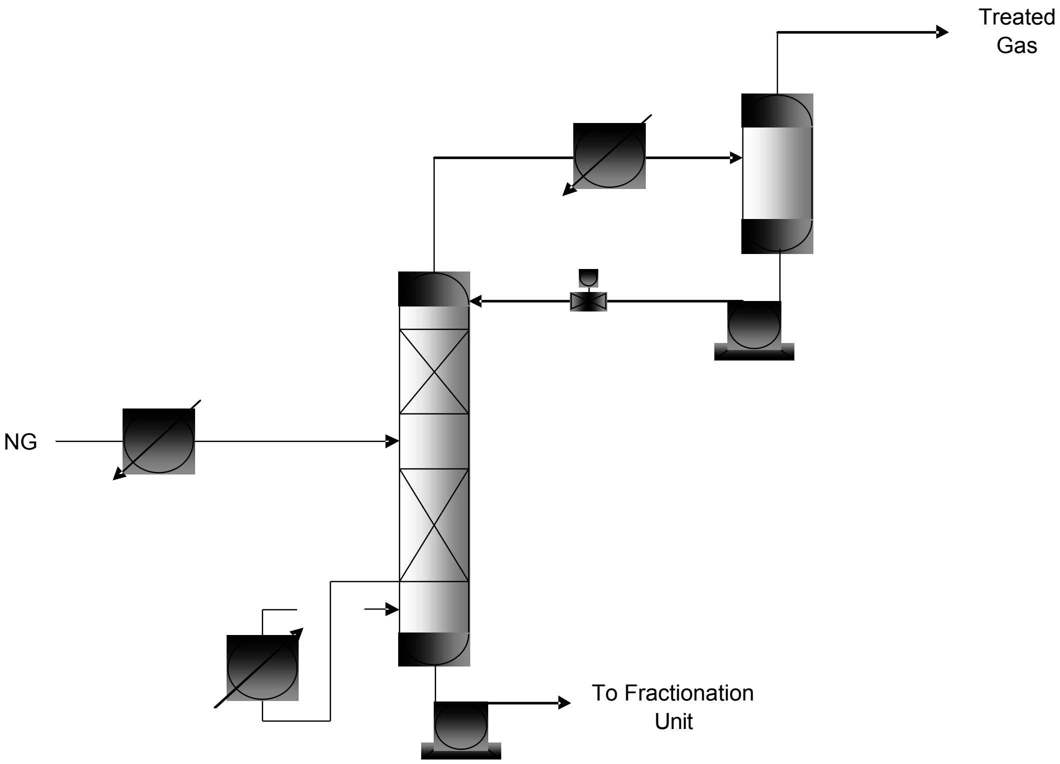

Figure 2: Scrub Column process

- NGL Recovery

NGL Recovery units such as Deep Propane recovery unit (Figure 3) are widely used when Propane and Butane are present in non negligible quantities in the feed gas. Their production increases the revenue of the project despite a slight cost increased compared to the previous scheme.

The feed gas is cooled and partially condensed in a cold box. The vapour is separated from the liquid and routed to a turbo-expander. The pressure is letdown and the flow routed to a fractionation column. The liquid from the separator is sent to the bottom of the same column.

The Treated Gas from the column overhead is heated against the feed gas. It is first compressed in the compressor driven by the expander and then by a booster compressor to allow the liquefaction unit operating at high pressure to improve the efficiency.

The liquid product from the column is pumped to a deethaniser column. The use of a cold box in the process allows a deep heat integration, thus before feeding the deethaniser, the liquid is heated-up to ambient temperature.

The bottom product of the second column is reboiled to produce stabilised C3+. The top vapour is condensed with an external refrigerant (propane cycle for example). It can also be integrated inside the cold box.

The vapour from the deethaniser reflux drum is totally condensed against the cold vapour coming from the first column and routed as reflux to this column.

On an offshore point of view, the use of cold boxes for a deep heat integration is a disadvantage for this process. Operations will be more expose to transient operation, thus could create difficulties to control the heat load from the different sources.

The C3+ product has also to be further processed to produce commercial grade of propane and butane and to produce stabilised C5+.

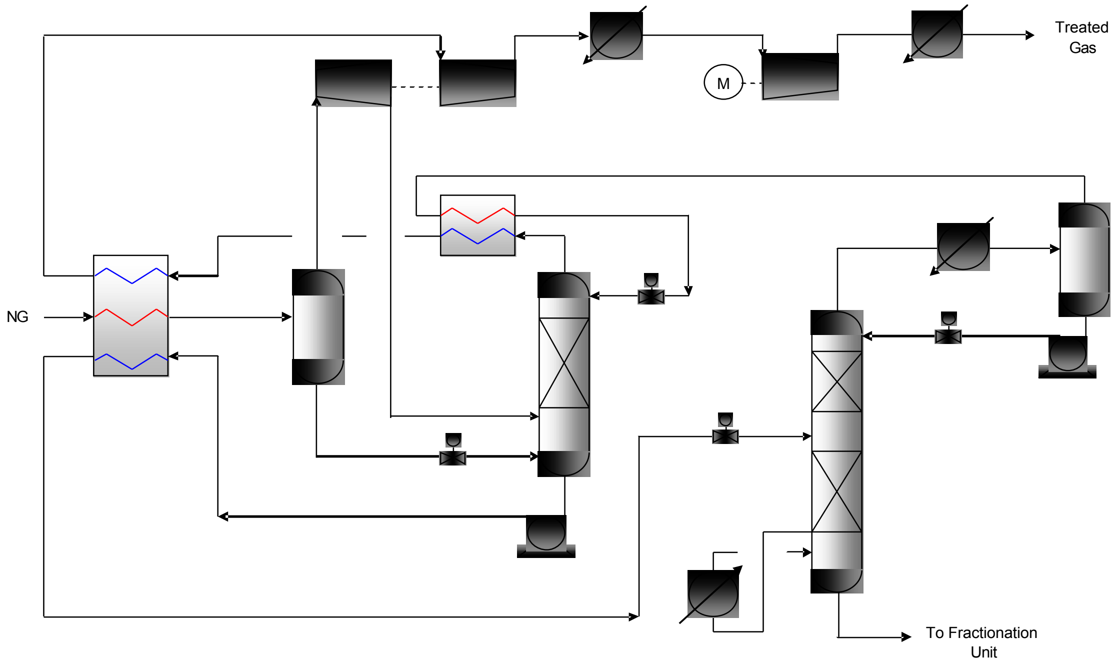

Figure 3: Propane Recovery process

Looking at the three main process used onshore upstream of a liquefaction unit to produce a suitable treated gas, we can see that adaptation to an offshore environment is required to maximize the robustness and the safety and reduce the risk onboard.

1.3 New process description

The new scheme (Figure 4) was developed to cope with environments where the storage and the commercial production of C2+ is not desirable so as to save on space and weight and to improve safety.

It allows the production of both treated gas, which can be liquefied, and a saleable condensate with a low vapour pressure, all with a minimum number of equipment items minimising the required foot print for the process and down time for maintenance.

The feed gas is cooled and partially condensed in a shell & tube heat exchanger. The vapour is separated from the liquid and routed to a turbo-expander. The pressure is letdown to an intermediate pressure and the flow is routed to a fractionation column. The liquid from the separator is sent to the bottom of the same column.

The Treated Gas from the column overhead is heated against the feed gas. It is first compressed in the compressor driven by the expander and then by a booster compressor to allow the liquefaction unit operating at high pressure to improve the efficiency.

The liquid product from the column is letdown to a low pressure, heated-up to ambient temperature and routed to a fractionation column operating around 5 bara. The bottom product is reboiled to produce stabilised C5+. The top vapour is compressed in an overhead compressor to a pressure slightly higher than the pressure of the first column to allow having only one reflux drum for the two columns.

The compressed overhead is condensed at ambient conditions and liquid is split in two steams. The first one is sent directly as reflux of the low pressure column to ensure the required quality of the C4- vapour. The second one is first subcooled against the bottom product of the first column and then feeds this column as reflux.

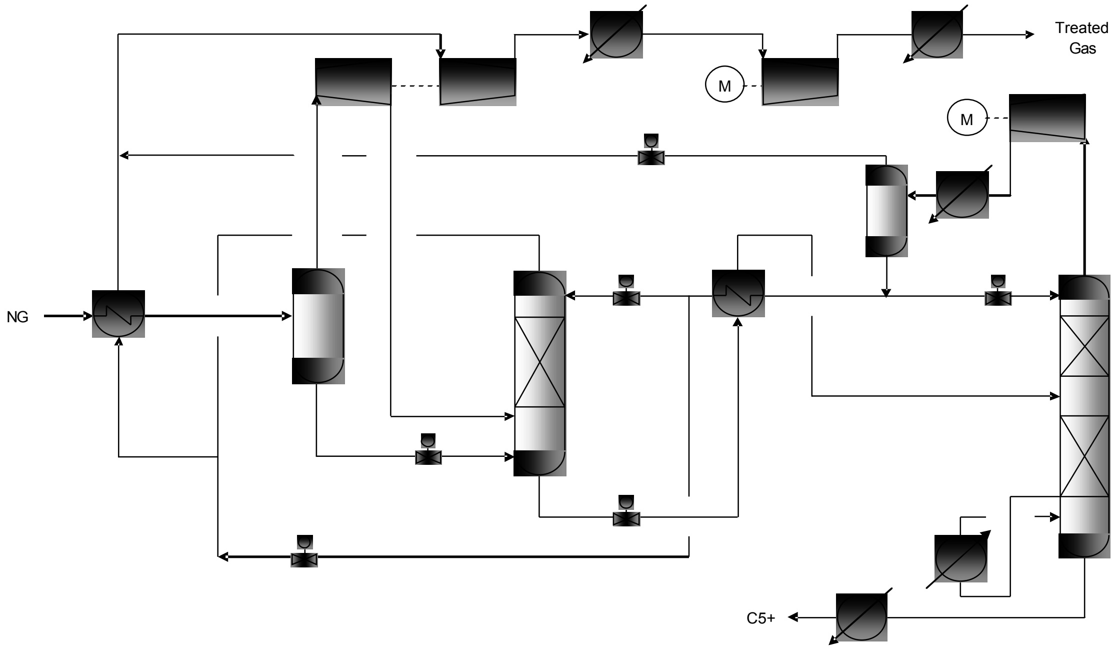

Figure 4: Offshore Dual Column Process

Process can also be adapted to very lean gas composition by increasing the heat integration and thus decreasing the temperature of the two reflux streams (Figure 5).

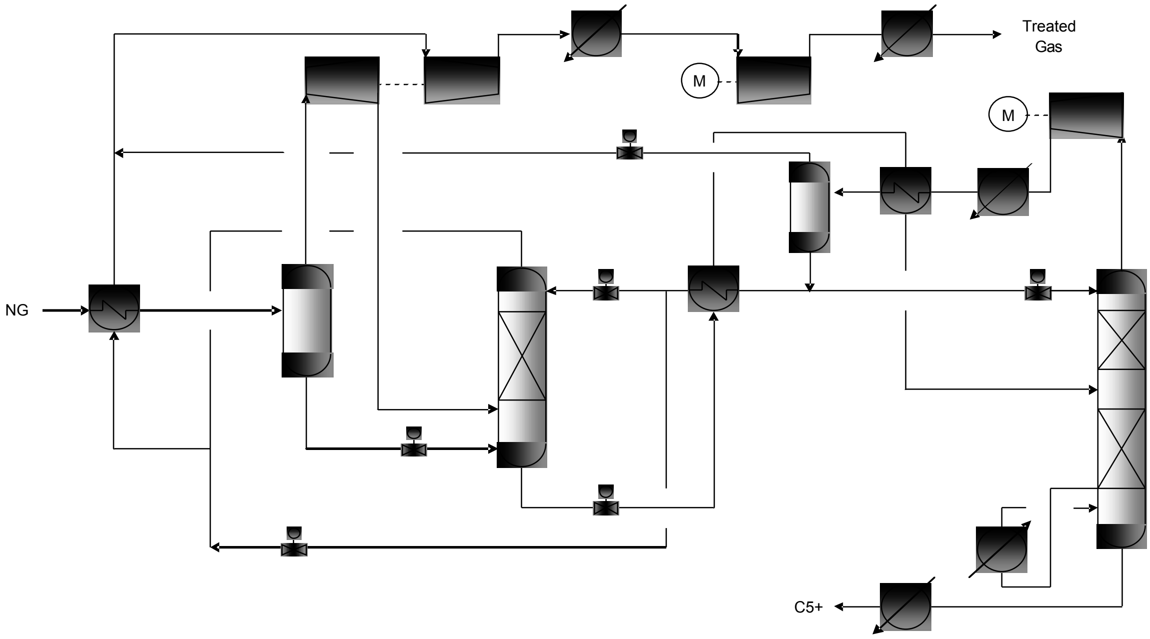

Figure 5: Offshore Dual Column Process for lean gas

This new scheme fulfils the requirements of a Floating LNG facility:

- The low liquid inventory increases safety,
- Fractionation columns allow the use of structured packing, the preferred approach when on a floating support subjected to motion. The liquid will be better distributed inside the column and dead zones will be limited,
- Shell & Tube heat exchangers are used for thermal integration of the process, to simplify the design and limit the CAPEX. They are also more robust,
- All the refrigeration needed to achieve the recovery of the C_{5+} components is provided by a turbo-expander. No additional refrigeration, for example from a mechanical refrigeration cycle, is needed. With such equipment, start-up (and re-start) of the process is smooth and fast,
- During start-up, the treated gas is recycled to the inlet of the plant thus avoiding flaring and any impact on the environment,
- Reduce the overall process footprint due to the fact that no fractionation unit is required to separate C_{2+} into commercial product,
- A booster compressor is used to allow a liquefaction process at very high pressure to improve the efficiency.

The main disadvantage of this process is that the LNG process downstream shall not be based on mixed refrigerant process as LPG are fully re-injected into the treated gas and are not produced. One can see that it is not a blocking point for an offshore liquefaction process.

2. The Tricycle Process

2.1 Background

A liquefaction process adapted to offshore shall have a minimum inventory of refrigerant volume to limit the plot space reserved for storage and to increase the safety of the plant. If the proportion of C_{2+} refrigerants can be limited, particularly in the liquid phase, it reduces the risk of explosion and the need for safety gaps on the deck between modules.
For time being, in the industry most of the plants in production use C_{2+} refrigeration cycles. For example, Air Products C_3/MR Process (almost 90% of the industry) requires the storage and the production or the importation of Propane and Ethane.
In the natural gas liquefaction industry, we find also process schemes with nitrogen expansion cycles. These cycles have a poor efficiency and the heat to be dissipated by the compression loop is significant, increasing the size of the cooling water system, piping and heat exchangers. This leads to a less-economic liquefaction plant.
The new process described in this chapter allows the production of LNG using three gas expansion refrigeration cycles with expansion turbines. Unlike standard nitrogen expansion cycles the efficiency approaches that of processes using liquid refrigerants. Each of the three cycles is totally independent from the others and is adjusted to work with the optimal conditions of gas composition, pressure and temperature.
This new liquefaction scheme doesn’t require the storage of liquid refrigerants. There is also no requirement to remove NGL from the natural gas in order to produce refrigerants and it avoids the requirement to import refrigerant in the case of a very lean gas without NGL. 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.
The fact that all refrigerants stay in the gaseous phase reduces the hydrocarbon inventory, compared to a traditional refrigeration cycle. There is no need for a liquid accumulator that can have a huge volume.
A major advantage is that the process is not sensitive to the motion of a floating platform.

2.2 State of the art

- Natural liquefaction can be performed using different types of refrigeration cycles:

    - The cycles using liquid refrigerant vaporising at low pressure. The liquid 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.
    - The cycles using pure liquid refrigerant (e.g. ammonia) vaporising at low pressure. The refrigerant after vaporization is then condensed using a low pressure absorption process followed by a high pressure distillation process.
    - The cycles using gas dynamic expansion (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.

- Within the LNG industries the following five following processes are commonly used for several years in the LNG export plants:

- 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 DMR (dual mixed refrigerant) Process using two refrigeration 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.

- The TMR (three mixed refrigerant) using three refrigerant cycles: the first mixed refrigerant containing mainly ethane and propane, the second mixed refrigerant containing methane, ethane and propane and the third mixed refrigerant cycle containing nitrogen and methane. The first cycle is used to pre-cool the natural gas and the third mixed refrigerant and to condense the second refrigerant. The second mixed refrigerant cycle allows the natural gas liquefaction and the third mixed refrigerant allows the LNG sub-cooling.

- The C3 / MR / N2 Process (Air Products APX) 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 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.

- Gaseous expansion cycles (Brayton cycles)

The principle of Brayton cycle, such as the nitrogen cycle, is based on the letdown of a high pressure refrigerant at ambient or below ambient temperature through an expansion turbine producing work. This dynamic letdown to a lower pressure gives a lower temperature than initial one. 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.

When broadly analysing the aforementioned schemes, one can notice that C_3/MR, DMR and Cascade cycles are all based on refrigeration provided via the latent heat of vaporization of the refrigerant; therefore, all these schemes inherently require the presence of a liquid LPG phase in the cycle. This type of scheme may be therefore affected by sea motions on a floating unit. In addition all this family of processes requires to store liquid LPG inventories to provide the cycles 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 classical nitrogen expansion cycle suffers from a poorer efficiency when compared to the liquid refrigerant cycles; 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 hereafter.

2.3 New process description

The Tricycle process fills the gap between the liquid refrigerant cycles, that boast a high efficiency but require a liquid refrigerant inventory onboard, and the nitrogen expansion cycle that, though decreasing significantly the safety risk in the installation, presents a low efficiency and therefore have usually been applied in smaller capacity trains.

The proposed scheme consists of three gas expansion cycles, each of which is based on the reverse Brayton cycle principle. The refrigerant used in a reverse Brayton cycle shall remain under gaseous phase during expansion in the turbine to obtain a maximum refrigeration duty. Depending on the temperature to be obtained the refrigerant selection is limited.

Pure nitrogen can be easily used for a refrigeration range from ambient down to -160°C.

Methane can also be used for a temperature range from ambient down to -110°C.

Of course methane-nitrogen mixtures can be used. These refrigerant mixtures can also contain other components either hydrocarbons from ethane to pentane or even carbon dioxide provided that fractions are such that the refrigerant remains gaseous.

In the process described hereafter the mixture used contains nitrogen, natural gas and components from this natural gas so any external import is deemed necessary.

Figure 6 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 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.

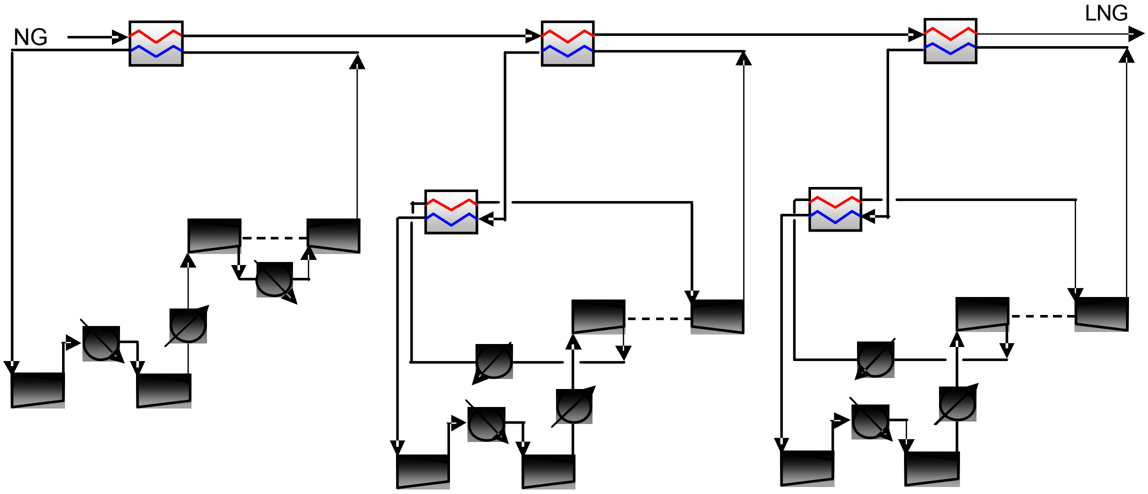

Figure 6: Tricycle liquefaction process

This scheme allows adjusting the three cycles to the specific gas thus obtaining a fairly high efficiency for an expansion gas cycle; in addition it offers a certain ease of operation and start-up, since the three cycles are totally independent.

Being this a gas expansion cycle, the heat integration is designed so as to take full advantage of the cold sensible heat provided by the refrigerant letdown.

The intrinsic flexibility and adaptability of the three cycle scheme have permitted via an extensive simulation study to develop different alternate configurations to enhance efficiency by adapting to the specific case.

The composition of the three refrigerant cycles can also be selected to meet the best efficiency: in the alternate configuration presented in figure 7, a gas mixture fairly close to the natural gas quality can be used for the precooling cycle, while a light natural gas quality can be used for the liquefaction cycle, instead of the usual nitrogen.

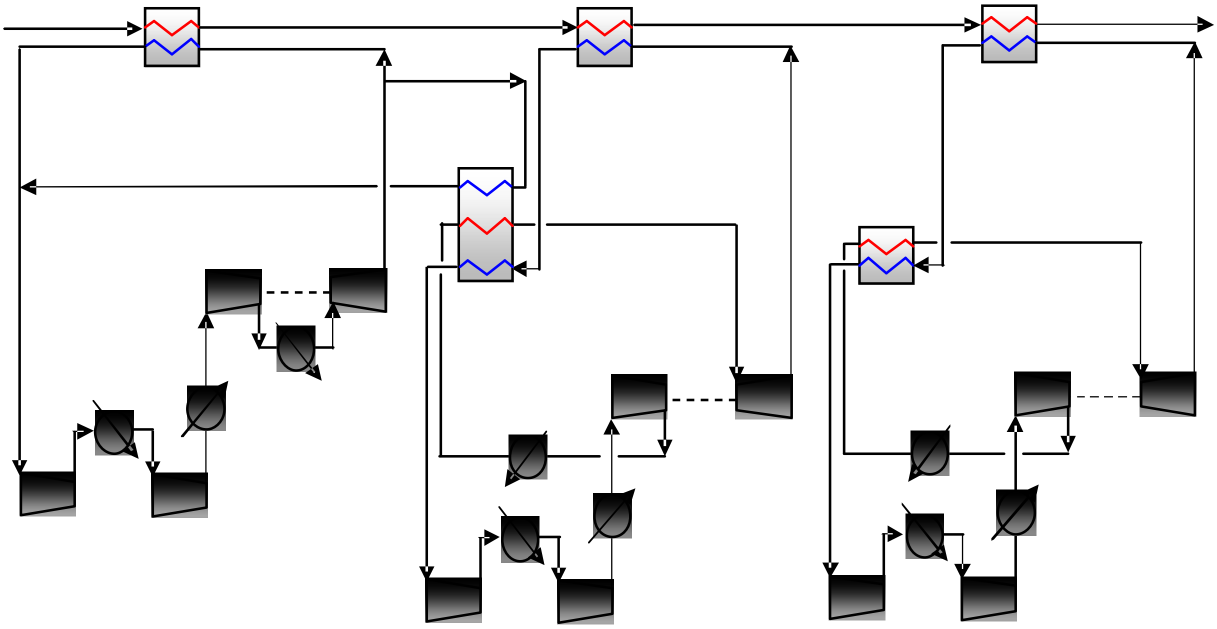

Figure 7: Tricycle liquefaction process with integration between precooling and liquefaction refrigeration cycles

In the configuration from figure 7, the first refrigerant cycle provides cold sensible heat to the refrigerant cycle used for liquefaction, in this way it is possible to improve the overall efficiency, by transferring duty from one cycle to the other.

Likewise, another configuration has been developed by Technip, where the middle refrigerant cycle transfers some duty to the subcooling cycle.

Figure 8 gives an example where the three cycles are all integrated together.

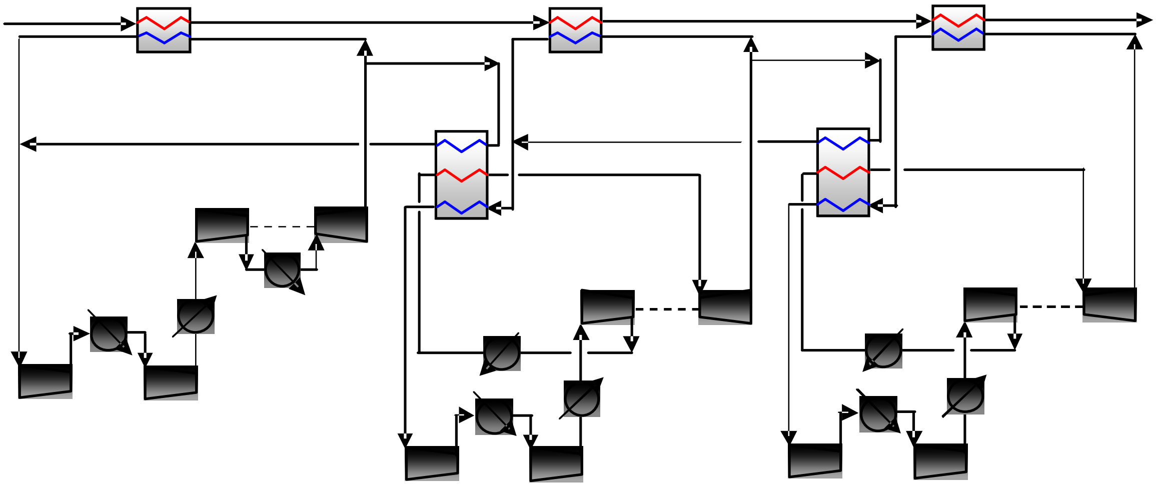

Figure 8 Tricycle scheme with integration between the three refrigerant cycles

Notwithstanding the increased level of heat integration, the scheme remains fairly simple to operate and start-up.

Figure 9 shows another very interesting configuration of this process where in addition to the first two cycles providing natural gas precooling and liquefaction, the LNG subcooling is performed by an indirect Brayton cycle which liquefies and subcools a nitrogen – methane refrigerant. The refrigerant subcools the LNG after being letdown in a liquid turbine providing power to the unit.

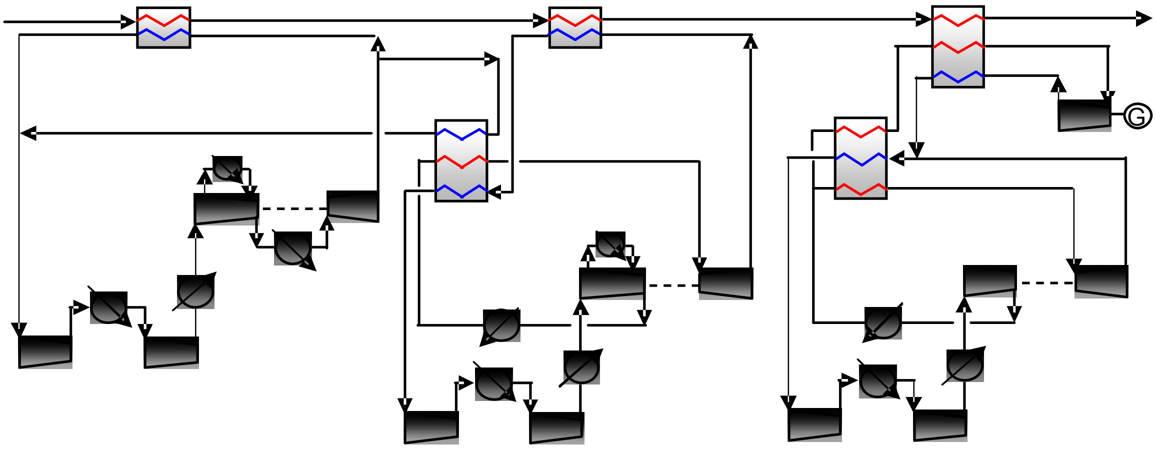

Figure 9: Tricycle with indirect reverse Brayton cycle

Another possible variation patented by Technip offers the production of two pressure level liquefaction. In this case a slipstream of LNG is letdown in an expander after precooling and then liquefied and subcooled with the three cycles.
This can respond to some plants specific demands.

From this insight in the Tricycle concept and variations, it is apparent that this process is a very attractive development for the emerging floating LNG industry, by offering an increased safety thanks to the use of gaseous refrigerant. In addition, the Tricycle efficiency approaches that of a liquid refrigerant as opposed to the traditional gas expansion cycles. Furthermore, from operations point of view, this new process is of high interest because not only working with gaseous refrigerant the Tricycle is not sensitive to motions, but also it is very easy to operate and start-up and therefore mostly suitable to the FPSO environment, where operations and consequent availability are a delicate issue.

3. End Flash Process and Nitrogen Removal

3.1 Background

In the end flash section the liquefied gas exiting cryogenic heat exchanger is let down to the lowest possible pressure, thus separating the final LNG product sent to storage and a residual flash gas. At this final stage of the natural gas liquefaction train, the LNG product has to comply with the commercial Nitrogen content specification below 1% mol, dictated in order to prevent low temperatures, to simplify boil off gas management and to reduce roll over in the LNG carrier storage tanks during transportation.

In case of N2 rich feedstocks, a pure flash unit may prove not sufficient to achieve the desired LNG product specification. Furthermore, the flash gas let down at an almost atmospheric pressure represents an end product, its amount and properties are an inevitable consequence of the mass balance and outlet temperature from the main cryogenic heat exchanger: this end flash gas is then disposed of by recycling at the fuel gas (after compression) and, when deemed profitable, its cold sensible heat can be recovered, for example to increase LNG production. On the other hand, N2 accumulates in the flash gas which in turn may result too rich in inert gas to be suitable as fuel gas (due to a too low HHV), or it may cause control and trip issues in case of flash gas loss and replacement with raw feed gas (due a too abrupt Wobbe index change).

Therefore, the aim of finding a new process replacing the conventional end flash is not only the production of an on spec LNG even for high N2 laden natural gas while maintaining the best efficiency, but also to remove from the picture the end flash gas disposal issue with its consequent impact on fuel gas operation.

In the overall picture of a LNG plant, the Nitrogen requirement and associated quality comes to play another key role, especially if one deals with an offshore installation, where the requirement for compactness, low footprint and weight is paramount. As of today, on floating LNG facility, nitrogen supply is most frequently provided via several banks of membranes analogously to LNG carrier practice; these membranes are frequently oversized to cover for peak demand , that has to be readily available for the offshore operations (offloading purging, tanks maintenance , other types of purging etc). In addition, as opposed to the conventional LNG carrier operations, where Nitrogen users usually require 97% purity, a floating LNG facility may require up to 98-99% Nitrogen purity: such a high degree of purity can still be attained with membranes by adding additional stages of separations (series arrangement of banks), which can result fairly space consuming.

If one thinks further, the question that arises is indeed why not taking advantage of rich Nitrogen flash gas generated by the LNG letdown to supply the Nitrogen plant requirement. The answer to such question lies in the purity achievable in the nitrogen vent.

The process presented in this paper has been conceived to live up to these challenges, i.e. to obtain even for challenging feedstocks an on spec LNG and a high purity nitrogen vent (HC content below 0.1%),which can be reused in the plant or disposed of in an environmentally friendly way. Then since the N2 rich hydrocarbon flash gas would not be the end product of such process, the fuel gas make up could be performed by tapping the (raw) sweet dry feed gas; subsequently, while the fuel gas quality management becomes significantly less troublesome, the feed gas that enters the liquefaction section equates with the final LNG produced, which means that the liquefaction equipment has not to be oversized to account for the fuel gas demand .

This process can also produce other valuable products, such as liquid nitrogen, which can replace the Nitrogen peak demand supply by regularly topping up a liquid Nitrogen storage, and Helium, another highly valuable product, which is concentrated in the Nitrogen vent, and becomes easily recoverable.

3.2 State of the art

Prior to describing the new “Hipur” process, an overview of the typical end flash units is presented, with the intent of giving an insight in the benefits intrinsic in the Hipur process for the offshore LNG units, when dealing with high N2 content feedstocks.

End flash and associated nitrogen rejection type of processes fall into the following families:

- Simple end flash unit: letdown and separation of a LNG product flowing to tanks and a N2 rich flash gas. Separation takes place in a drum,
- End flash unit fitted with reboiled or unreboiled column instead of a drum leading to a LNG product flowing to tanks and a N2 rich flash gas,
- End Flash Gas Nitrogen Rejection via Double or Two-Column scheme,
- End Flash Gas Nitrogen Rejection via Single column scheme.

Simple End Flash

Directly integrated at the end of the LNG train, the simple end flash separates a nitrogen rich LNG stream into a gas stream composed of N2 and methane and a liquid stream containing less than 1% N2, by pressure let down.

The N2/methane stream is recompressed to be used as fuel gas.

The cold flash gas may be used either to re-liquefy part of the recompressed fuel gas or a slip stream of natural gas. This scheme is well suited to feed gases with nitrogen contents below approximately 2 %mol.

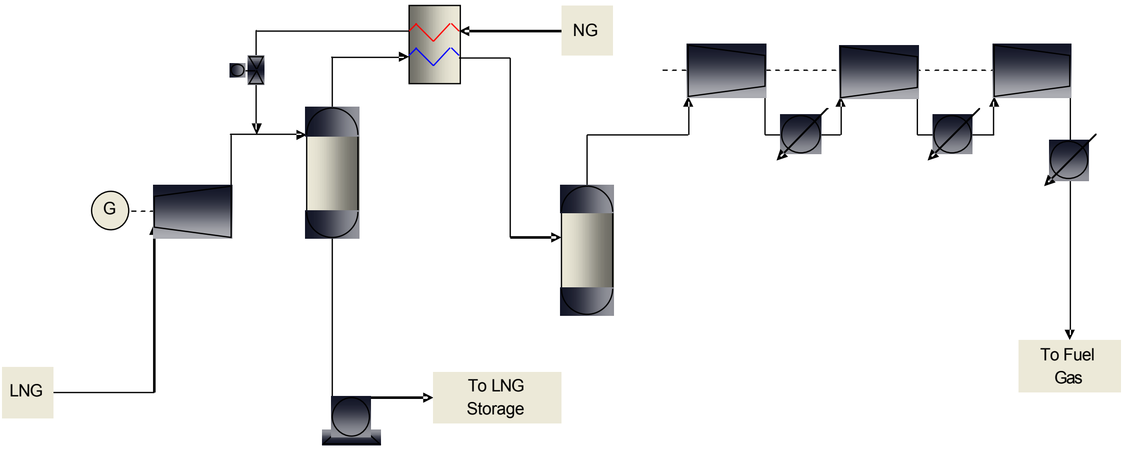

Figure 10: Simple End Flash Drum

Reboiled Column End Flash

The End Flash section can achieve better specification on LNG when the flash drum is replaced by a low pressure nitrogen removal column. The figure 12 provides an example also based on one process also available in Technip portfolio.

This scheme offers a sharper N2 separation from methane for feed gas nitrogen contents greater than 2% mol, and below approximately 5%mol.

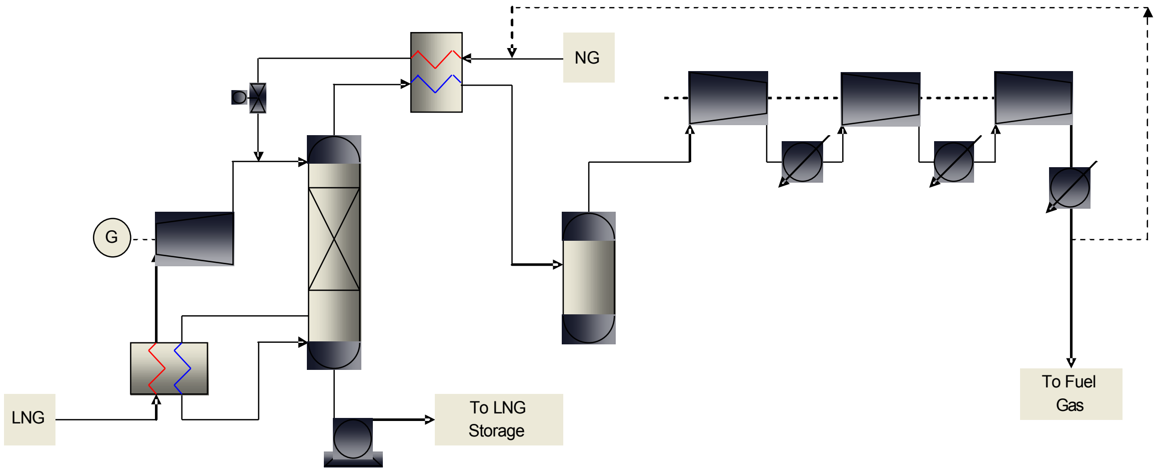

Figure 12 Reboiled Column End Flash

Treating the End Flash Gas: Nitrogen Rejection

As already seen in any of the conventional aforementioned end flash processes, N2 and other inert gases accumulate in the flash gas, therefore to make the latter a suitable fuel gas, namely for gas turbines, a further nitrogen rejection step is required. The typical open art nitrogen rejection processes fall either into the Double or Two-Column processes or into the Single column process. The former processes are both inherited from the air separation units and are based on different pressure level fractionation; one of the main differences between the Double and the Two-column processes lies mainly in the fact that as opposed to the Double Column process, in the Two-Column the condenser of the high pressure column is not thermally linked to the reboiler of the low pressure column, therefore the Two-Column process may prove more flexible in terms of heat integration. The ideal range of application of the Double and Two-Column processes would be for treated gas nitrogen content exceeding 20% mol minimum, so as to have sufficient reflux for the low pressure stripping.

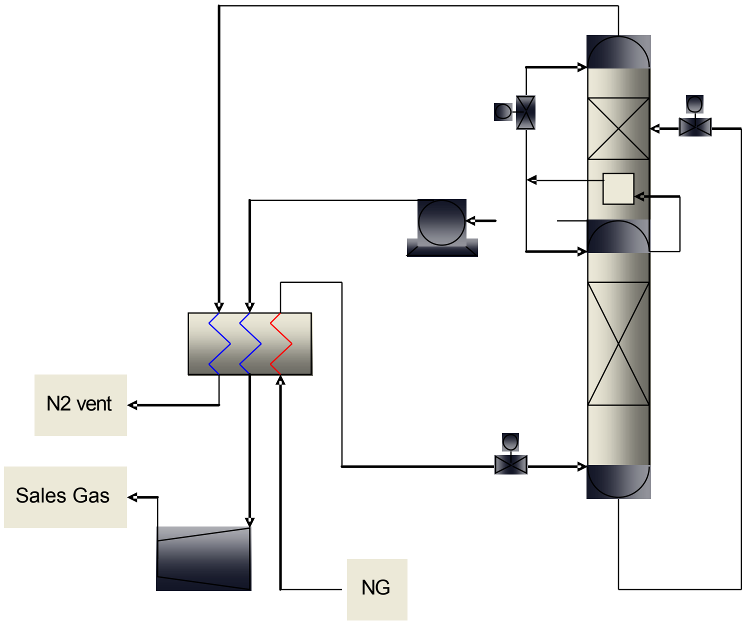

Figure 13: Double Column Process

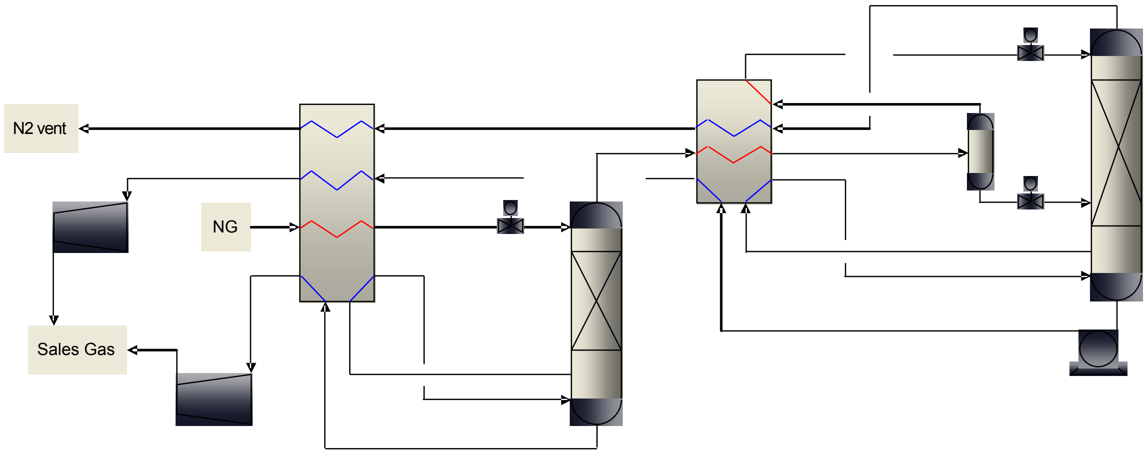

Figure 14: Two Column Process

The single column processes (figure 15) is based on the use of a heat pump, thus allowing the single column to operate at medium / high pressure. This process allows adjusting both the methane recovery and the nitrogen vent purity. Nevertheless, the single column requires higher power consumption due to the use of a compressor to obtain an efficient reflux. In addition, the single column range of application is limited to Nitrogen content in the feed gas below 30% mol, beyond which the methane recovery deteriorates due to the difficulty to condense the overhead stream with a methane loop.

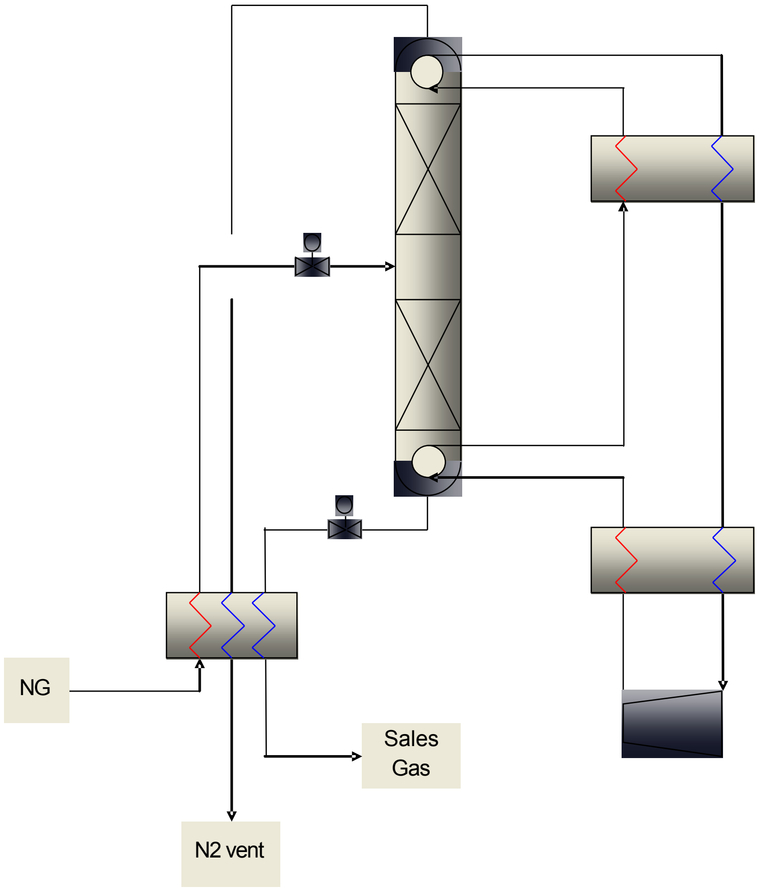

Figure 15: Single Column Process

3.3 HiPur End Flash Process

The new Hipur process developed by Technip aims at finding a more adapted solution than conventional end flash process for high N2 feedstock, combining the increase of LNG production (higher efficiency) with the production of high purity nitrogen vent , rather than a Nitrogen rich flash gas, which could be difficult to recycle as fuel gas. The process consists of a refluxed column resulting in a low methane content Nitrogen vent (below 0.1% HC content) and LNG product from the bottom.

The Hipur main feature is the refrigeration cycle fitted with a gas expander subcooling part of the LNG from the main cryogenic heat exchanger. In addition, an open heat pump is used to produce high purity nitrogen and to reject an eventual helium rich stream.

As the fractionation of methane and nitrogen is performed at cryogenic temperature the process has been designed with extensive thermal integration to minimise power consumption.

The installation of a heat pump makes the fractionation of methane and nitrogen feasible; in fact the heat pump allows condensing the compressed overhead vapour by exchanging with the reboiling bottoms, the latter producing in fine the same vapour used as refrigerant. However this design is effective for the fractionation as long as the column condenser and reboiler have comparable duties. After an extensive simulation study, it has been proven that the fractionation column duties can be balanced by adjusting an adequately low feed inlet temperature. For this purpose a Brayton cycle has been added to ensure that the inlet column feed temperature allows to cope with the required reflux flow. Given the order of temperature reached in this process, the Brayton cycle should use a Nitrogen refrigerant with a purity of 99%; as in the depicted scheme, the Brayton cycle can then be integrated with the heat pump compressor and use the same refrigerant, ie the Nitrogen vent itself.

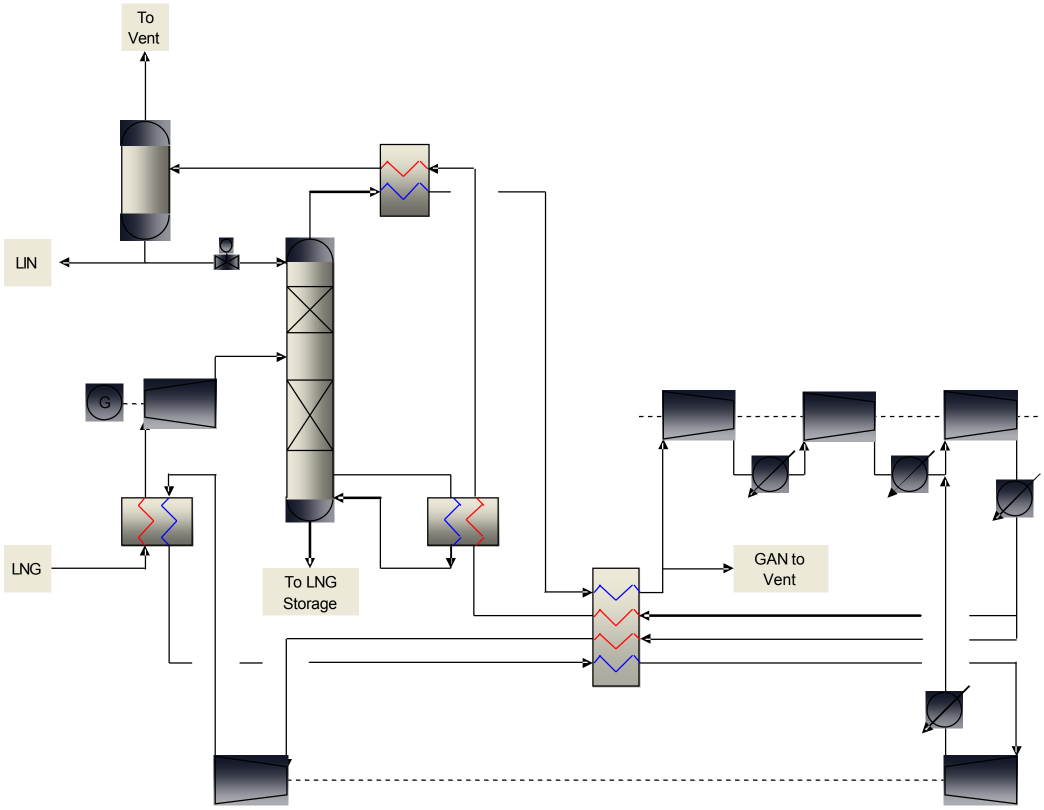

Figure 16: HiPur Process

Therefore, the described Hipur process innovates and improves the conventional end flash scheme in the most adapted way to floating supports: it allows to take full advantage of the installed gas turbine power and cryogenic heat exchanger surface and in addition provides valuable product for the plant such as liquid and gaseous nitrogen to be reused. In case of Helium present in the feedstock, it can easily be recovered and valorised.

Compared to a conventional end flash scheme, one can then recall the main advantages:

- The production of LNG is maximized for a given liquefaction refrigerant compressor power (full recovery of methane)
- Nitrogen does not have to be disposed of with fuel gas, avoiding fuel gas quality variation, increasing gas turbine availability, and simplifying the fuel gas scheme and control. The methane content in the nitrogen can be has low as 0.1% mol, reducing the impact on the environment (if N2 vent is not reused in the plant)
- High purity gaseous nitrogen can be produced and fed directly to the utility network or used as refrigerant make up to the liquefaction cycles described above.
- Fuel gas is drawn from unprocessed feed gas, reducing also the size and power of the liquefaction unit

This new scheme also allows the production of valuable by products:

- Liquid nitrogen can be produced and stored, thus increasing nitrogen availability at peak consumption and limiting the size of the nitrogen plant in utilities. This represents a significant gain for Floating LNG plants where space and weight savings are of the utmost importance
- Helium contained in the feed gas is accumulated in one single nitrogen vent and therefore it can be valorised and result in an additional source of profit for the plant (pending the availability of adequate facilities or transport of this stream)

Conclusion

In the recent years, FLNG technology is steadily gaining more and more acceptance. Technip has acted as a key player in the FLNG advance toward deployment. The experience gained in building large FPSO and large onshore LNG trains has permitted to win a vantage point to move further both in applying the available feedback and in proposing innovative solutions.

Speaking strictly on a process point of view, Technip has been able to examine critically the available processes so as to innovate and propose new processes to meet the constraints of an offshore operation and subsequently to improve the profitability. The three proposed processes patented by Technip respond 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. Technip is able to bring these solutions to realisation and to tailor their implementation for the particular field context.

References

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