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The Most Efficient and Cost-Effective Optimization Process for Recovering Natural Gas Liquids

By Usiabulu, G. I.
University of Port Harcourt

Abstract- The oil and gas industry has been around for nearly a century and a half, producing the lifeblood of the modern world economy. The natural gas portion of this industry, however, is just beginning to show high progress in capitalising and marketing this resource. In the past, natural gas has been an unwanted byproduct of crude oil production and has been vented or flared. As technology progresses, the ability to find, capture, process, transport and utilize this invisible resource to its full potential can be accomplished effectively and economically. Major ongoing problems found in the natural gas industry are the ability to safely process, store, and transport natural gas while maximising output. Natural gas is a vital component of the world's energy supply and an important source of many bulk and speciality chemicals. It is one of the cleanest, safest, and most useful of all energy sources, and helps to meet the world's rising demand for cleaner energy into the future. However, exploring, producing and bringing gas to the user or converting gas into desired chemicals is a systematic engineering project, and every step requires a thorough understanding of gas and the surrounding environment. Any advances in the process link could make a step change in gas industry.

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Keywords: due points, flashpoints, natural gas liquids, molecular weight, specific gravity.

I. Introduction

Today the main drive of oil and gas industry is to increase the production of all hydrocarbons in an economical and environmentally friendly practice, and reducing the hydrocarbon dew point of natural gas has been an issue for pipeline transportation since large intrastate, interstate, and international pipelines were developed. The problems surrounding the processing and transportation of large quantities of natural gas are many and interconnected. This research provides a review of major natural gas liquids recovery methods including refrigeration methods, chemical methods, physical methods, and combined heat and power (CHP) systems. The advantages and disadvantages of each method will be discussed.

Author: World Bank Africa Centre of Excellence, Centre for Oilfield Chemicals, University of Port Harcourt, Rivers State, Nigeria.
e-mail: godsdayusiabulu@gmail.com

The produced natural gas from wells is saturated with heavy hydrocarbons (HCs) and water vapour. Natural gas liquids (NGLs) are a group of light hydrocarbons existing as liquids at surface conditions after separation from natural gas (Ma *et al*., 2010) These are primarily composed of ethane, propane, butane, and pentanes, with boiling points higher than methane, the main constituent of natural gas (Song *et al.,* 2014). The process of separation of heavy HCs from the natural gas stream is called natural gas liquid (NGL) recovery. Separation of NGLs typically occurs through condensation or absorption processes at natural gas processing plants (Rahbari *et al.,* 2013). While chemically similar to crude oil, NGLs boast a lower boiling point range, making them easier to separate and utilize.

The cryogenic processes are the most common method of NGL recovery in the natural gas industry (Getu *et al.,* 2018). The number of NGL recovery plants has been growing in the last few years due to the increasing demand for this product (Alabdulkarem *et al.,* 2011). Due to the high price of natural gas condensate as well as the necessity of correcting the natural gas dew point, the NGL recovery is set up. The NGL recovery can be conducted in numerous methods such as using cryogenic refrigeration, Joule–Thomson (JT) process, turbo-expander, vortex tube and supersonic separator (3S) (Shoghl *et al.,* 2019). The conventional separation methods like the JT process require large equipment, high operating and capital cost, large pressure drop for a specific separation and negative influence on the environment due to the injection of chemical inhibitors. The novel 3S overcomes these deficiencies. (Oliveira *et al.,* 2017). The compact design and simple configuration of the 3S make it suitable for off-shore plant and unmanned operation. One of the questions that is always raised is, what are the advantages and disadvantages of using 3S instead of conventional processes such as the JT process in a gas plant. It was observed that, the 3S has a good cooling performance compared to the other self-cooling systems like turbo-expander and JT process (Shoghl *et al.,* 2019). The first engineering team focused on this technology was a group from Twister BV10. Another Russian engineering team also worked on this separator. This technology has attracted considerable attention in the Oil & Gas industry. The natural gas plant is shown in fig. 1 and 2 below.

Fig. 1: Natural gas plant

Stadler/Bwag fotos (2021)

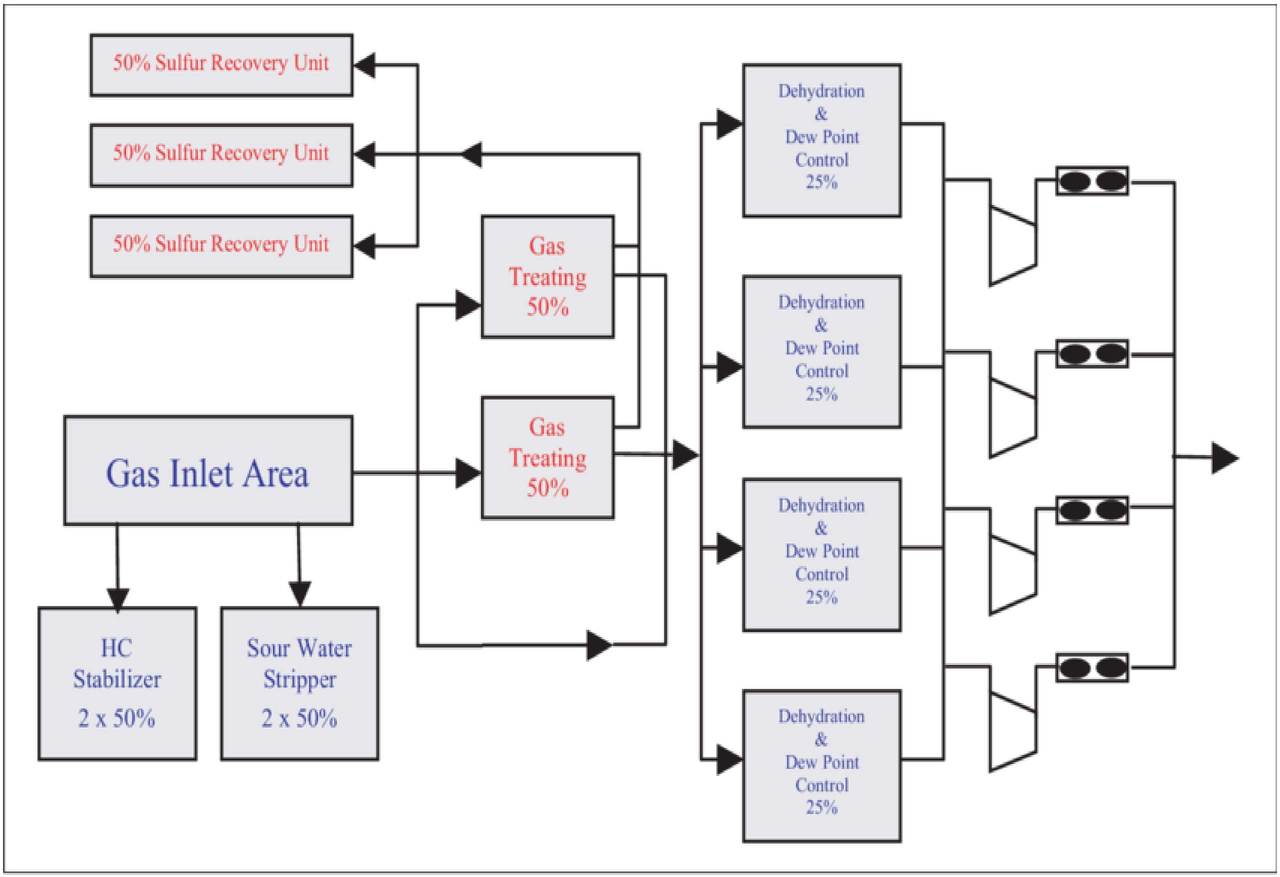


Fig. 2: Diagram of a natural gas processing plant

To replace the 3S with conventional separation processes, the structure of it should be optimized first. These optimizations can include the optimization of the profile of the wall, swirler structures and the dimensions of a 3S (Yang *et al*., 2017). In the last decade, some researchers focused on the optimization of the structure and the separation performance of the 3S. For example, Jiang and Bian et al. employed the discrete particle method and the field experiment for the optimization of the 3S. They increased the length of the expanding section and decreased the expanding angle to improve the separation performance. (Wen *et al*., 2012) optimized the structure of swirler and diffuser. Liu et al. optimized the separation performance of the 3S using the few properties and the relationship between the shockwave position and pressure effect. (Jassim *et al*. 2008) evaluated the influence of several parameters including vorticity, nozzle structure and real gas properties on the performance of the 3S using the computational fluid dynamics (CFD) modelling. They observed that the shockwave location varied considerably when the natural gas state assumed real rather than perfect. (Wen et al., 2011) investigated the 3S both numerically and experimentally and reported that installing the inner body maintained the conservation of angular momentum. (Yang *et al*., 2021) studied the effect of a primary nozzle on the performance of steam ejector taking into account the phase change process. They reported that the first non-equilibrium condensation occurred within the primary nozzle, while second nucleation condensation occurred in the steam ejector. (Yang *et al.,* 2017) developed a wet steam model using CFD analysis to investigate the intricate feature of the steam condensation in the supersonic ejector. They reported the expansion feature of the primary nozzle was exaggerated by the dry gas model compared to the wet stream model. Furthermore, they observed that the dry gas model over-estimated a higher entrainment ratio by 11.71% compared to the wet steam model. (Wen *et al*., 2014) developed the single-phase and two-phase model and analysed the performance of steam ejector. The result of their analysis showed that a single phase few models with pass over the phase change provided an un-physical steam temperature through the supersonic few. (Liu *et al*., 2014) employed the Discrete particle method to predict droplet behaviour inside the 3S. They assumed that the droplet diameter varied from 10 to 50 μm, while the proper droplet diameter in the 3S was about 0.1–2 μm33. Wen et al.19 investigated the influence of different structural parameters of diffuser on the shockwave position and pressure recovery performance. They reported that for natural gas dehydration, the conical diffuser showed the best pressure recovery performance. Wen et al.34 investigated the influence of three delta wings with different sizes on the natural gas swirling few. They reported that for 2 μm droplets, a collection efficiency of 70% can be obtained for the large delta wing.

a) Types of Natural Gas Liquid Products and the Economic Importance

Natural gas liquids (NGLs) are composed of ethane, propane, butane, propane, isobutane, pentane and isopentane that are condensed and recovered *(EIA., 2014*). The uses for those components are illustrated in the Table below. NGL recovery attracts many processing companies due to three reasons. The first reason is to produce a transportable gas stream. This is done to avoid condensation problems during the flow of the two-phase fluid. The second reason is to meet the sales gas specifications. In fact, the main specification for the sales gas is to meet the minimum gross heating value (GHV) while satisfying the hydrocarbon dew point requirement. The third reason is to maximize NGL recovery which is associated with the market trends (*Kherbeck et al., 2014*.). Table 1 below gives the composition of natural gas.

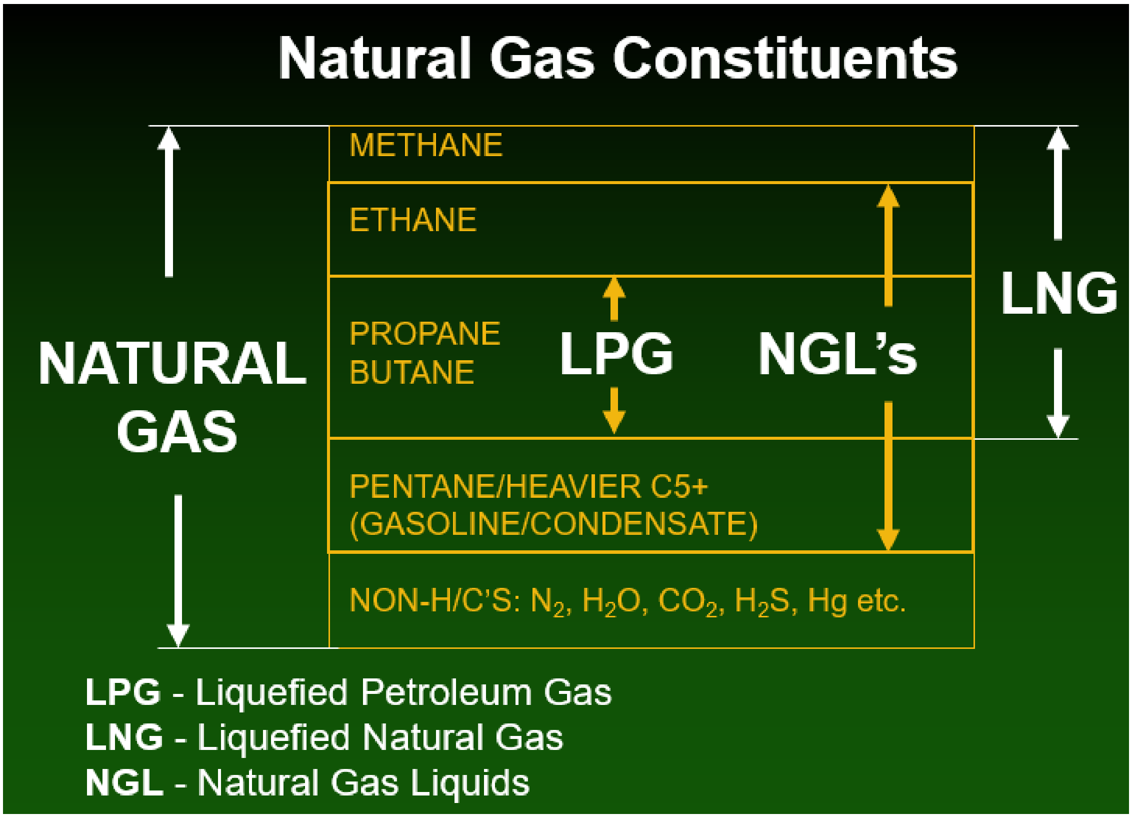
Table 1: Natural Gas Composition

Natural Gas Composition	Molecular Weight	Specific Gravity	Vapour density Air=1	Boiling Point ^{0}C	Ignition Temp. ^{0}C	Flash Point ^{0}C
Methane	16	0.553	0.56	-160	537	-221
Ethane	30	0.572	1.04	-89	515	-135
Propane	44	0.504	1.50	-42	468	-104
Butane	58	0.601	2.11	-1	405	-60
Pentane	72	0.626	2.48	36	260	-40
Hexane	86	0.659	3.00	69	225	-23
Benzene	78	0.879	2.80	80	560	-11
Heptane	100	0.668	3.50	98	215	-4
Octane	114	0.707	3.90	126	220	13
Toluene	92	0.867	3.20	161	533	4
Ethyl benzene	106	0.867	3.70	136	432	15
Xylene	106	0.861	3.70	138	464	17

b) Types of Natural Gas Liquid Product

The NGL product spectrum encompasses various hydrocarbons, each with distinct properties and applications:

- *Ethane (C_2H_6):* A critical feedstock in the petrochemical industry. Ethane undergoes a cracking process to produce ethylene (C_2H_4), a fundamental building block for countless plastic products like polyethylene terephthalate (PET) used in plastic bottles. (Akubuike *et al*., 2010).
- *Propane (C_3H_8):* A clean-burning and versatile fuel commonly employed for cooking, heating homes and buildings, and industrial applications like powering forklifts [z [Singh *et al*., 2010).
- *Butane (C_4H_{10}):* Used as a fuel source for cigarette lighters, camping stoves, and a blending component in gasoline to improve its volatility during cold starts (Yu *et al.,* 2011).
- *Isobutane (C_4H_{10}):* While sharing the same chemical formula as butane, isobutane possesses a branched molecular structure, leading to different properties. It finds applications as a refrigerant due to its low boiling point and as a high-octane gasoline blending component to improve engine performance (Rahmani *et al*., 2013).
- *Pentanes (C_5H_{12}+) and Natural Gasoline:* Heavier NGL fractions grouped under pentanes often include pentane (C_5H_{12}) itself, hexane (C_6H_{14}), and heptane (C_7H_{16}). These components serve as blending components in gasoline to meet specific volatility requirements and as diluents for transporting heavy oil, reducing its viscosity and facilitating pipeline flow. (Han *et al*., 2018).



c) *Economic Importance of Natural Gas Liquids*

NGLs hold significant economic value for several reasons table 2 below summarizes them:

- *Value-Added Products:* They represent valuable byproducts from natural gas production, generating additional revenue streams beyond just the methane component.
- *Fuel Sources:* Propane and butane offer clean and efficient fuel alternatives for various applications, contributing to energy security and diversification.
- *Petrochemical Feedstocks:* Ethane is a crucial component for the petrochemical industry, fuelling the production of numerous plastic products and other essential materials.
- *Global Market:* NGLs are traded internationally, with their prices often linked to crude oil prices, influencing the global energy market.

Table 2: Natural gas liquid attribute summary

NGL Attribute summary

Natural gas liquid	Chemical formula	Applications	End use products	Primary sectors
Ethane	C_2H_6	Ethylene for plastic production, petrochemical feed stock	Plastic bags, plastic anti-freeze, detergent	Industrial
Propane	C_3H_8	Residential and commercial heating, cooking fuel, petrochemical feedstock	Home heating, small stoves and barbeques, LPG	Industrial, residential and commercial
Butane	C_4H_{10}	Petrochemical feedstock, blending with propane or gasoline	Synthetic rubber for tires, LPG, lighter fuel	Industrial, transportation
Isobutane	C_4H_{10}	Refinery feedstock, petrochemical feedstock	Alkylate for gasoline, aerosols; refrigerant	Industrial

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Pentane	C_5H_{12}	Natural gasoline, blowing agent for polystyrene foam	Gasoline; polystyrene, solvent	Transportation
Pentanes plus	The mixture of C_5H_{12} and heavier hydrocarbon	Blending with vehicle fuel, exported for bitumen production in oil sands	Gasoline ethanol blend; oil sands production	Transportation

C indicates carbon, H for hydrogen, ethane contains 2 carbons and 6 hydrogen atoms. Pentane plus known as natural gasoline, contains pentane and heavier hydrocarbons.

II. Natural Gas Liquids Recovery Methods

Many NGL and methane recovery systems are available and in use on the market; they work in tandem, and you can recover NGL while extracting methane. Each of these recovery procedures has advantages and downsides that are distinct from one another. NGL recovery methods like turboexpanders, lean oil absorption, and cryogenic refrigeration require a lot of equipment and support facilities, as well as large amounts of chemicals, whereas Joule Thomson and other supersonic devices, as well as ammonia refrigeration techniques combined with CHP, require a lot less (Olsen *et al.,* 2012).

a) *The Refrigeration Recovery Methods*

In the early 1930s, the initial method of processing gas was refrigeration, and ever since it has greatly advanced (Inguscio *et al.,* 2022). The use of a flowing refrigerating liquid/vapor to take heat from a cold location and transmit it to a warm area where it is sent to a thermal sink is the basis of refrigeration. A typical modern system uses propane, lithium, ammonium, Freon, or bromides as the flowing operational liquid. While decreasing the quantity of energy and implements necessary to restore the NGLs, the aim of refrigeration units presently is to expand the restoration levels of NGL. The usage of cold remaining reflux & recycle split steam process is an optimization method, basically using cold liquids in many stages again, giving the necessary advantage to processors of gas to use for refrigeration. Joule-Thompson cryogenics & cooling are the most general methods of refrigeration (Qyyum, et al., 2018).

i. *The Joule-Thompson Cooling Recovery Method*

The process entails a high-pressure gas expanding over a small aperture to increase velocity while lowering pressure. JT cooling is the term for the temperature drop that occurs as a result of this process. Most gases are cool as they expand. Operators avoid the use of JT cooling as an initial base of recovery for NGLs due to rising fuel gas prices and the inefficiency of pressure recovery (Inguscio *et al.,* 2022). JT cooling is notoriously difficult to process and transport. The lost pressure is recovered by chilling with a booster compressor or by being close to the final user because there is no pressure recovery mechanism. However, this does not address the issue of effectively and efficiently transferring moist gas. In transport pipelines, there are few techniques for recovering lost energy as pressure drops, and is mostly seen as an issue (Qyyum, *et al*., 2018). When gas passes through distribution stations, an increase occurs, and in other to prevent a two-phase flow that adversely affects the accuracy of the meters and generates potential destructive liquid slugs, this increase needs to be countered. It is a simple recovery method but inefficient, also, there is an increase in the cost of fuel due to pressure drop, the damaging side effect accompanying transporting and processing stages is an issue, there is a need to install near end-user and the need to heat the gas to prevent drastic cooling.

ii. *The Cryogenics Recovery Method*

Cryogenics is a recovery process that uses both propane and ethane as working fluids in a cascading refrigeration plant to achieve extremely low temperatures and high ethane recovery levels (Badami *et al*., 2018) The cryogenic system is capital costly and hence an essential capital investment due to the controls' complexity and unique materials handling procedures for the extreme cold (Claude *et al.,* 2020). To employ this approach, practically all the impurities in the gas must be eliminated before the NGLs can be recovered. To keep ice and prevent hydrate development, all water must be eliminated. It has the advantage of providing an ultra-low temperature and a high level of ethane recovery (Qyyum, *et al*., 2018). However, Cryogenic plants require significant capital expenditure, the systems require special and care material handling procedures due to the extremely cold operating conditions, it requires complex control systems (Claude *et al.,* 2020). Also, all water must be removed from gas before processing to avoid the formation of ice and hydrates that could damage equipment and its systems are slightly inefficient for NGL recovery above C2 (Carroll *et al*., 2022), (W. Lin *et al*., 2004)

b) *The Physical Methods*

i. *The Membrane Technology Method*

In this method, large molecules of organic compounds are eradicated through membranes from the air. Smaller and even smaller organic molecules can be taken out of gas as technological advancement took

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place in the areas of materials manufacturing, resulting in the production of ever more exotic membranes. Membranes are one of the easiest, most cost-effective of conventional processes (A. Tabe-Mohammadi *et al.,* 2007). In recent times, membrane technology can eradicate NGLs, carbon dioxide, water, nitrogen, and hydrogen sulphide out of the gas streams. However, Membrane fouling frequently occurs at high driving force and there is an occurrence of concentration polarization (L. Handojo *et al*., 2019).

ii. *The Turbo Expander Method*

A high-energy gas is injected into a turbine, and as it expands through the turbine, it exerts a force on the blades and rotates the shaft while lowering the temperature and pressure. The shaft power generated by the natural gas extension is used to power a comparable turbine, rather than compressing gas later in the process. Although turbo expanders have massive equipment to further cool the gas and segregate the NGLs for shipping, they have a substantial cooling impact similar to the JT expansion method, where the gas is cooled as it expands. It was created in the 1960s and is one of the most innovative NGL recovery technologies. However, they require a huge capital investment, a large number of auxiliary equipment to function, and turbines embedded in turboexpanders require extensive and regular preventive maintenance (Qyyum, *et al*., 2018).

iii. *The Supersonic Nozzle Method*

The supersonic nozzle method works by deflecting a high-energy gas over a fixed curved blade, resulting in the formation of a vortex. A supersonic vortex can be created inside static equipment using a nozzle. The vortex tube was developed to improve the separation of natural gas and NGLs while lowering the cost and complexity of the operation (Qyyum, *et al*., 2018). The vortex tube can accomplish this while still retaining most of the the gas's pressure. The pressure drop of this model separation device is only 25-35% of the gas's inlet pressure. The Twister TM is an example of a vortex tube, and it was developed by Shell and uses supersonic flow that has veins at the inlet to create a swirling motion in the gas. The supersonic nozzle method does not require extensive maintenance, gas pressure is sharply maintained hence no need for booster compressor, operations can be unmanned, equipment is competitive in terms of cost, and it is capable of processing both small and medium scale volumes of gas (Qyyum, *et al*., 2018), (X. Cao et al., 2019).

iv. *Combined Heat and Power Systems*

This is based on the use of a single fuel source to generate two types of power, lowering the system's production losses (S. Murugan *et al*., 2016). Cogenerations are a type of combined heat and power system (N. Jayakumar *et al*., 2016). The waste heat from a compressor engine is used to power a refrigeration unit that cools low-pressure gas. The 'Btus' produced as a by-product of combustion can be utilized instead of being released into the atmosphere by collecting the waste heat from a compressor engine. The attributed heat causes a refrigerant mixture to evaporate, which is subsequently distilled and employed in an evaporator to remove heat from the cold room. The combined heat and power systems use waste heat to provide power to the refrigeration system; they require a small amount of auxiliary equipment and support facilities, have low maintenance costs, can generate distributed power, are a well-established and advanced technology, and can be used in small and medium-scale gas utilization schemes ((S. Murugan *et al*., 2016), (N. Jayakumar *et al*., 2016).

c) The Chemical Methods

i. *The Lean Oil Absorption Method*

It was regarded as a chemical approach when the process was designed in the early 1910s, and it has been in use since then (Qyyum, *et al*., 2018). Its principal role is to allow/permit a moist natural gas stream above it for the oil to absorb the NGLs. After the NGLs are absorbed, lean oil becomes rich oil, which is then delivered to a distillation tower to separate the constituents. To maintain consistency, the NGLs are separated and transferred from the system, while the ethane, methane, and lean oil are recovered and delivered back through the process. This procedure requires large equipment and big physical space/ clearing to function. There are other recovery methods that are effective and efficient, of lower costs and smaller physical sizes. However, the lean oil absorption method can be used to remove both light and heavy NGL, also, other non-hydrocarbon gases like nitrogen can be isolated using the lean oil adsorption method (Hassanean *et al*., 2016), (A. A. Mohammed *et al*., 2016). The re-boiled absorber column is also a unique facility for absorption that contains a number of plates (or trays) that tend to determine the extent of absorption of a particular feed (I. Torres Pineda *et al.,* 2012) Knowing the usefulness of Methane and NGL in the present day and the uniqueness of the absorption method in the removal of both light and heavy NGL, this study capitalizes on the use of plates in the absorption column to optimize the recovery of Methane and NGL in a gas processing plant. Comparison between turbo-expansion processes.

III. Comparisons, Advantages and Disadvantages of each Natural Gas Liquids Recovery Methods

a) The Cryogenics Recovery Method

An external refrigeration process has the advantage of being a simple and a flexible process.

However, this process occupies a large area, and the equipment involved in such systems is heavy with respect to other NGL recovery alternatives such as the turbo expansion process (Barnwell *et al*.,). The energy requirements are also considerable especially for the cascade arrangement where extremely low temperatures are required. In addition, 8 this process involves several pieces of equipment, which requires a high maintenance cost and a high utility requirement. Propane refrigeration becomes inappropriate for feed throughputs of less than 25 million standard cubic feet per day (MMSCFD) (Lokhandwala *et al.,* 2000). For deep-cut recovery purposes, the amount of C02 in the feed must be as low as temperatures of the process can cause freezing of C02• In addition, if the feed gas contains a large number of inert components, the efficiency of process will be reduced due to the interference of the inert.

b) The Turbo Expander Method

The turbo expander is compact with a low weight and low space requirement compared with absorption equipment or external refrigeration systems. The operational as well as capital costs are relatively low (Moins *et al.,).* These features make turbo expanders very attractive for an offshore plant. In addition, gas compression requirements on the plant can be reduced by energy recuperated from the gas expander. 10 Variation in pressure and composition of the gas can significantly affect the operation of the turbo expander (Barnwell *et al*.,). Another disadvantage of this process is the height ' required for the de-methanizer tower. The installation of an elevated tower is extremely difficult on offshore plants and could also present operational problems due to the common strong winds in the sea, especially in the Atlantic Canada. When ethane is not recovered, the height of the tower is reduced. Another drawback is the lack of tolerance to wet gas in the feed since it can damage the mechanical system. Nevertheless, a certain amount of liquid can be managed in the exit of the equipment. Another important limitation of the turbo expander is the elevated maintenance cost. In addition, the operation of this equipment represents a major issue in terms of safety.

c) The Lean Oil Absorption Method

This process is selective to propane, and a low ethane recovery is achieved. The process can be used for feed gases containing C02 since the minimum temperature within the process is above the freezing point of even pure C02• Inert gases in the feed gas do not interfere with the process of the absorption of the hydrocarbon and pre-treatment of the gas is not needed. This is also true for feeding gas with water. For offshore applications, the height of the distillation column must be restricted because the wind in the open sea can cause serious damage. Some areas are extremely windy, and this factor needs to be considered in the equipment design on the platform. In the case of associate gas treatment, this process is rarely used (Moins *et al.,)*. There are also the possible environmental impacts of chemical use including spills, storage of virgin/waste oil, etc. For feed pressures below 2,800 kPa absorption systems operate well, but for higher pressures a dual pressure absorber column with high- and low-pressure sections is 12 required. Above 8,500 kPa the efficiency of the absorption system will be reduced. The efficiency of the absorption process is improved with rich gases. In the cases of lean gases solvent make up is required due to solvent evaporation. The absorption systems also suffer from the high-energy costs needed to run solvent circulating pumps and regeneration of oil.

d) Adsorption Method

An adsorption process requires an enormous amount of energy due to the regeneration process. In addition, the equipment involved is heavy and expensive, which is unattractive for offshore plants. Safety is a considerable issue for this process since the high temperature with the hydrocarbon solids could produce a fire or related accident.

e) The Membrane Technology Method

Membranes require smaller space and are relatively light, which are desired characteristics for offshore applications. In addition, membranes typically have lower installation, operation, and maintenance costs compared with other technologies. For example, the installed cost to treat 10 MMSCFD of lean gas (3.9 GPM, 1185 Btu/SCF) for a membrane system is $1.1 million while for propane refrigeration system is $1.6 million. In addition, the relative processing cost (which includes capital cost) for membranes compared to propane refrigeration is 0.594 (Lokhandwala et al., 2000) Additionally, membranes are operationally simple and do not require additional separation agents. The principal operating cost is the replacement of the polymeric membrane element (Markiewicz *et al*.,).

Another advantage of membrane is the flexibility of its operations. This means production 15 conditions can be modified, and the membrane process can be easily adapted to it. The membranes are arranged in modules, which can be orientated in horizontal or vertical positions. However, the membrane separation technologies are appropriate for small to medium production, around 10 to 100 MSCFD since beyond these values the cost is prohibit.

IV. Conclusion

The market for natural gas has been rapidly increasing and is becoming one of the most important sources of energy in the world. Natural gas is a "cleaner" burning fuel when compared to other fossil fuels and therefore environmental impacts are minimized. Gas produced (associated gas) with oil is largely methane with heavier fractions referred to as NGL (Natural Gas Liquids). NGL is used as feedstock for petrochemical processes or as fuel for industrial and domestic purposes. The recovery of NGL is commonly carried out at onshore oil and gas operations where space and weight are not critical design parameters. The limited space on offshore platforms makes NGL recovery a challenge. Currently, in the Newfoundland and Labrador Offshore, the associated gas is re-injected, and used for power on the platforms, and some is flared but not recovered due to the difficulties in storage and transport in this remote location. This associated gas contains high levels of NGL, making attractive its recovery from the economic and environmental points of view. This research describes in detail the development of a membrane process to recover NGL. Different processes such as turbo-expander, absorption, adsorption, external refrigeration and membranes are reviewed and compared. As a result of this comparison, membranes are proposed as a feasible option for NGL recovery.

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