Online ISSN: 2249-4596
Print ISSN: 0975-5861
DOI: 10.17406/GJRE

GLOBAL JOURNAL
OF RESEARCHES IN ENGINEERING: C

Chemical Engineering

Highlights

- Evaluation of the Performance
- Optimal Recovery of Methane Gas
- Recovering Natural Gas Liquids
- Cost-Effective Optimization Process

Discovering Thoughts, Inventing Future

VOLUME 24 ISSUE 1 VERSION 1.0

Global Journal of Researches in Engineering: C

Chemical Engineering

GLOBAL JOURNAL OF RESEARCHES IN ENGINEERING: C

CHEMICAL ENGINEERING

VOLUME 24 ISSUE 1 (VER. 1.0)

OPEN ASSOCIATION OF RESEARCH SOCIETY

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Global Journal of Researches in Engineering: C
Chemical Engineering
Volume 24 Issue 1 Version 1.0 Year 2024
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

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.

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

GJRE-C Classification: LCC: TP692

THEMOSTEFFICIENTANDCOSTEFFECTIVEOPTIMIZATIONPROCESSFORRECOVERINGNATURALGASLIQUIDS

Strictly as per the compliance and regulations of:

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

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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. There have been increasing efforts in the gas industry in recent years. Recently due to the growing demand of natural gas liquids (NGL), there are many processes existing to make a deep NGL recovery from natural gas.

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.

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

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

attention in the Oil & Gas industry. The natural gas plant is shown in fig. 1 and 2 below.

Fig. 1: Natural gas plant

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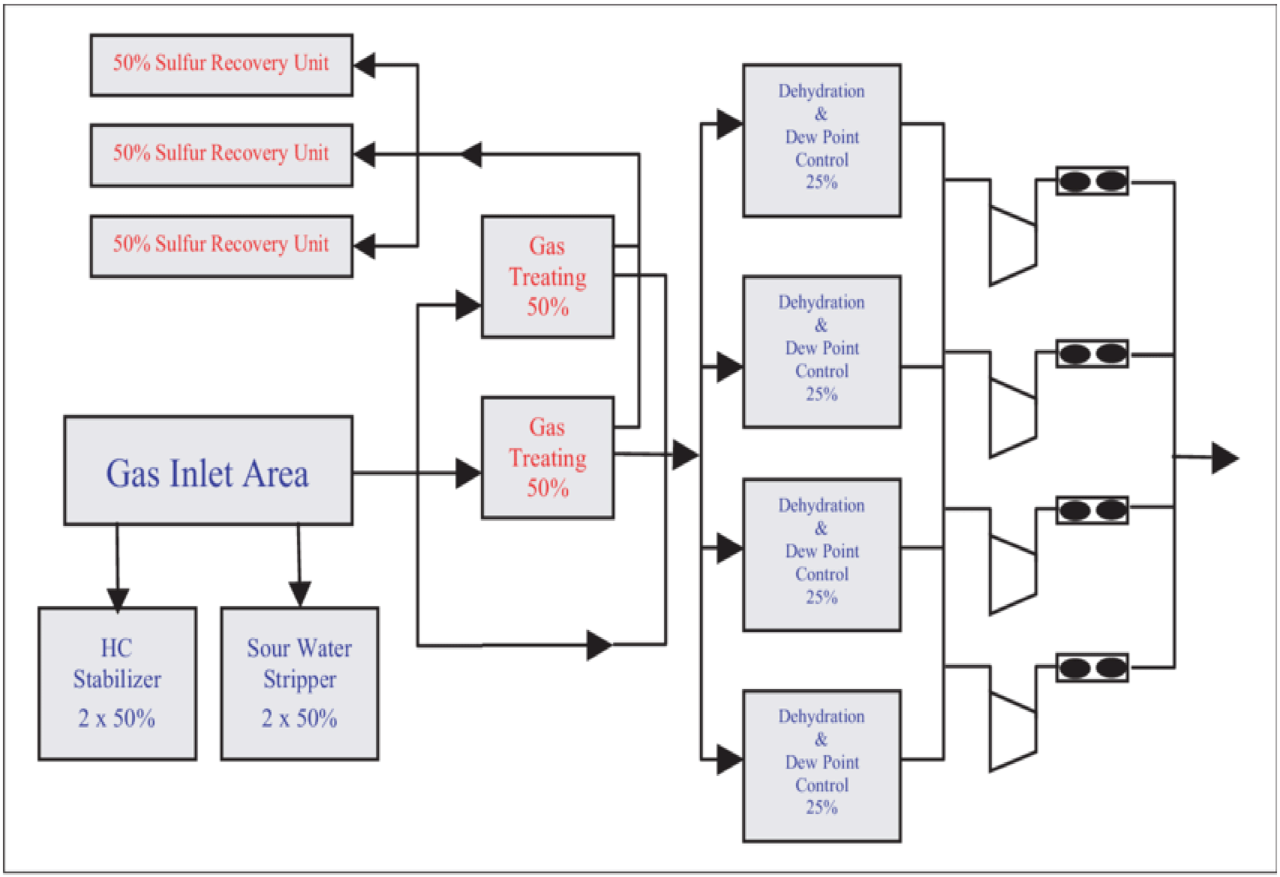


Fig. 2: Diagram of a natural gas processing plant

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.

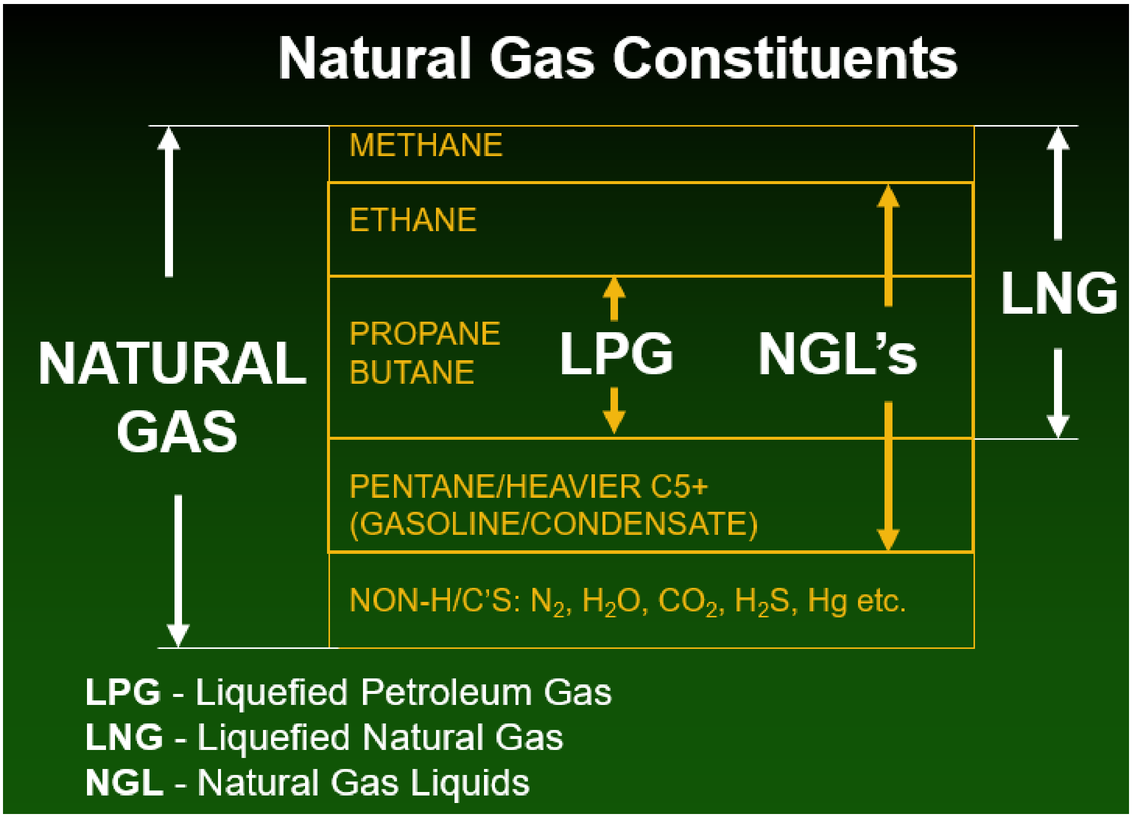
Table 1: Natural Gas Composition

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

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 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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Global Journal of Researches in Engineering: C
Chemical Engineering
Volume 24 Issue 1 Version 1.0 Year 2024
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Variations in the Concentration of CO_2 in Associated Gases: Evaluation of the Performance of a Conditioning Process with Turboexpander

By Leandro Vargas, Andrea Gonzalez & Giovanni Morales

Abstract- Herein we disclose an evaluation of the performance of a Turboexpander unit for the conditioning of associated gasses with different CO2 contents. The performance evaluation was carried out by the comparison of the results from a simulation in Aspen Hysys v10 with the specifications established in the national gas transportation policy for natural gas (RUT). The Turboexpander unit was designed for the conditioning of an associated gas defined by the scenario of medium production for the Valle Medio del Magdalena, according to the prospects of the Mining and Energy Planning Unit (UPME). The conditioning unit considered the sections: stabilization, sweetening, dehydration, and separation by distillation. Similarly, the range for CO2 content variation was defined between 3 - 12% mol, based on enhanced recovery (EOR) pilots of air injection and CO2 injection. The results of the simulations showed an adequate performance of the Turboexpander unit for the conditioning of associated gasses with up to 6% mol of CO2 contents, fulfilling the quality parameters of the RUT.

Keywords: turboexpander, gas transportation policy, associated gas, carbon dioxide, valle medio del magdalena, Aspen Hysys.

GJRE-C Classification: LCC: TP761, TP359

Variations in the Concentration of CO_2 in Associated Gases: Evaluation of the Performance of a Conditioning Process with Turboexpander

Variaciones en la concentración de CO_2 en gases asociados: Evaluación del desempeño de un proceso de acondicionamiento con Turboexpander

Leandro Vargas [α], Andrea Gonzalez [σ] & Giovanni Morales [ρ]

Resumen- Este documento presenta una evaluación de los desempeños de una unidad con Turboexpander, en el acondicionamiento de gases asociados con diferentes contenidos de CO_2. La evaluación de los desempeños fue efectuada por comparación de los resultados de una simulación desarrollada en Aspen Hysys v10 y las especificaciones establecidas en el Reglamento Único de Transporte de Gas Natural (RUT). Para esto, la unidad fue diseñada para el acondicionamiento del gas asociado definido por el escenario medio de producción de la cuenca del Valle Medio del Magdalena, según prospectivas de la Unidad de Planeación Minero-Energética; la unidad de acondicionamiento consideró las secciones: estabilización, endulzamiento, deshidratación y separación por destilación. De igual manera, el intervalo de variación de contenido de CO_2 entre 3 y 12% mol fue establecido, con base en reportes de literatura de pilotos de recobro mejorado (EOR) por inyección de aire e inyección de CO_2. Los resultados de las simulaciones mostraron un desempeño adecuado de la unidad con Turboexpander, en el acondicionamiento de gases asociados con concentraciones de CO_2 de máximo 6% mol, cumpliendo los parámetros de calidad estipulados en el RUT. Asimismo, los resultados de las simulaciones muestran que el perfil de temperatura en la torre de absorción, de la sección de endulzamiento, es alterado cuando se tratan gases con mayor contenido de CO_2. Esta alteración del perfil de temperatura en la torre de absorción conduciría al bajo desempeño en el retiro de CO_2. Lo anterior sugiere rediseños en la sección de endulzamiento o cambio de la respectiva tecnología, con lo cual, los gases tratados puedan cumplir los parámetros de calidad especificados en el RUT.

Palabras claves: turboexpander, RUT, gas asociado, dióxido de carbono, Valle Medio del Magdalena, Aspen Hysys.

Abstract- Herein we disclose an evaluation of the performance of a Turboexpander unit for the conditioning of associated gasses with different CO_2 contents. The performance evaluation was carried out by the comparison of the results from a simulation in Aspen Hysys v10 with the specifications established in the national gas transportation policy for natural gas (RUT). The Turboexpander unit was designed for the conditioning of an associated gas defined by the scenario of medium production for the Valle Medio del Magdalena, according to the prospects of the Mining and Energy Planning Unit (UPME). The conditioning unit considered the sections: stabilization, sweetening, dehydration, and separation by distillation. Similarly, the range for CO_2 content variation was defined between 3 - 12% mol, based on enhanced recovery (EOR) pilots of air injection and CO_2 injection. The results of the simulations showed an adequate performance of the Turboexpander unit for the conditioning of associated gasses with up to 6% mol of CO_2 contents, fulfilling the quality parameters of the RUT. Likewise, the simulation results showed that the temperature profile in the absorption tower (sweetening section) changed when gasses with CO_2 contents greater than 6% mol were treated. This temperature profile change appeared to be responsible for poor CO_2 removal performance. The foregoing would suggest adjustments for the sweetening section or a shift of the respective technology in order to fulfill the quality parameters specified in the RUT.

Keywords: turboexpander, gas transportation policy, associated gas, carbon dioxide, valle medio del magdalena, Aspen Hysys.

I. INTRODUCCIÓN

El gas natural y la gasolina son productos de importancia en la canasta energética nacional, utilizados en diferentes sectores como el residencial, industrial, transporte y electricidad. El gas asociado de los yacimientos de crudo puede ser acondicionado para su uso como gas natural; adicionalmente, un flujo de gasolina natural es derivado como un subproducto. El acondicionamiento del gas asociado permite la disminución de contaminantes y líquidos condensables, a niveles adecuados para su aprovechamiento como fuente de energía térmica. Estos niveles están definidos en el Reglamento Único de Transporte de Gas Natural (Resolución CREG-071 de 1999 y su modificación posterior del año 2019).

Dentro de los contaminantes a retirar del gas asociado se encuentra el CO_2. Este gas es conocido por su participación en el cambio climático. El accionar del CO_2 en el aire impide la salida de calor de las capas

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Author α: e-mail: leandro2165631@correo.uis.edu.co

bajas de la atmósfera (efecto invernadero), lo cual ha generado un aumento progresivo en la temperatura promedio de la superficie del planeta (Osborn *et al.*, 2021). Debido a esta problemática, los gobiernos se han comprometido con la disminución en las emisiones de CO_2. En Colombia, el sector minero energético ha propuesto una meta de disminución en emisiones de 11,2 millones de toneladas de CO_2 equivalentes para el año 2030.

El retiro del contenido de CO_2 en los procesos de acondicionamiento de gas (endulzamiento), es usualmente realizado por absorción con monoetanolamina (MEA) (Elbashir *et al.*, 2019; Mokhatab & Poe, 2012); la MEA gastada es regenerada por calentamiento para su recirculación en el proceso. Posteriormente, el gas endulzado es sometido a un enfriamiento, que puede ser aplicado con un Turboexpander, para una posterior separación de los líquidos condensables, por medio de destilación fraccionada a baja temperatura (Mokhatab & Poe, 2012). Es importante anotar que, Colombia tiene instalada una importante cantidad de unidades de acondicionamiento de gases con Turboexpander (Martínez, 2018). Recientemente, Camacho (2021) desarrolló un análisis técnico-económico para la implementación de una unidad Turboexpander de acondicionamiento del gas asociado generado en el Valle Medio del Magdalena, considerando las proyecciones de producción definidas por la UPME (2018). Los resultados reportados por este autor indican factibilidad técnico-económica en la implementación de la unidad Turboexpander. Lo anterior manifiesta posibilidades futuras en el país, de nuevas unidades de acondicionamiento, basadas en Turboexpander.

Por otra parte, la aplicación de métodos de recobro mejorado (EOR, *enhanced oil recovering*) ha aumentado la producción de crudo (Jiang *et al.*, 2022; Mokheimer et al., 2019), principal contribuyente del mercado energético mundial actual (Baumeister *et al.*, 2020). Uno de estos métodos EOR, basado en inyección de gases, ha conducido al aumento de la concentración de CO_2 en el gas asociado (Barbosa *et al.*, 2012; Escobar, 2006; Jiang *et al.*, 2022). Por consiguiente, se han realizado seguimientos a pilotos EOR de inyección de gases, implementados en diferentes yacimientos del país. Análisis cromatográfico de gases han reportado aumentos en los niveles de CO_2, hasta 12% mol en el gas asociado del campo Chichimene, por aplicación de EOR con inyección de aire (Díaz Molina *et al.*, 2019), y hasta 19% mol en el gas asociado del campo San Fernando, por aplicación de EOR por inyección de CO_2 (Diaz *et al.*, 2018). Este aumento en el contenido de CO_2, en gases asociados de pozos sujetos a EOR, puede ser progresivo en la respectiva ventana de operación (Marinov, 2015).

Este incremento en los contenidos de CO_2 afecta los desempeños resultantes de un proceso de acondicionamiento de gas, especialmente en las etapas de endulzamiento y de recuperación de líquidos (Langé & Pellegrini, 2016; Rufford *et al.*, 2012). En la etapa de endulzamiento, una elevación en el contenido de CO_2 conduciría a un aumento en los requerimientos energéticos de la regeneración del absorbente (Langé & Pellegrini, 2016; Rufford *et al.*, 2012). Por su parte, los contenidos de CO_2 pueden afectar el equilibrio de fases en la etapa de separación de los hidrocarburos líquidos (Rufford *et al.*, 2012). Además, la presencia de CO_2 puede conducir a la formación de hidratos, a ciertas condiciones de presión y temperatura, ocasionando taponamiento en las líneas de flujo (Carroll, 2003).

Ante esta situación de incremento en los contenidos de CO_2, la mayoría de la literatura consultada dirige la atención en la proposición de alternativas de retiro simultáneo de líquidos condensables junto con el CO_2 (Arinelli *et al.*, 2019; Luyben, 2013; Maqsood et al., 2014). Sorpresivamente, un número escaso de documentos reportaron análisis de los desempeños de las plantas con Turboexpander ante aumentos en el contenido de CO_2 en el gas asociado. Getu *et al.* (2013) compararon, por simulación con Aspen Hysys, los desempeños de diferentes procesos de separación de líquidos condensables en gases asociados con concentraciones de CO_2 de hasta 3.65% mol. Los autores mostraron factibilidad técnica en los procesos de retiro de líquidos (incluyendo Turboexpander) para las diferentes concentraciones analizadas, mencionando que las mayores recuperaciones de etano fueron obtenidas en los gases con menores concentraciones de CO_2. De igual manera, El-Husseiny *et al.* (2021) analizaron las variaciones energéticas del acondicionamiento con Turboexpander para gases asociados con concentraciones de CO_2 hasta 3.91% mol. Los autores reportaron factibilidad en el proceso de acondicionamiento para las diferentes concentraciones. Los trabajos de Getu *et al.* (2013) y El-Husseiny *et al.* (2021) presentan la característica de análisis para bajas concentraciones de CO_2; sin embargo, en unidades Turboexpander instaladas, esta condición de bajas concentraciones de CO_2 puede cambiar con los requerimientos de aplicación de EOR por inyección de gases. Asimismo, estos autores omiten los análisis de los perfiles de temperatura en las torres de endulzamiento y de separación de líquido. Estos análisis pueden ayudar en la explicación de los desempeños del proceso de acondicionamiento.

Las variaciones en los contenidos de CO_2 pueden conducir al incumplimiento de los requisitos mínimos para el transporte y la venta del gas, acondicionado en una determinada unidad. Un gas que no cumple con el RUT conlleva a pérdidas económicas y a contaminación ambiental; usualmente este gas es quemado en teas (Elehinafe *et al.*, 2022; Petri *et al.*, 2018). Lo anterior podría ser evitado con la predicción de los desempeños de las unidades de acondicionamiento, previo al tratamiento de los gases asociados. Una predicción de los desempeños de las unidades instaladas conduciría a la selección de la unidad con mayor efectividad, en el acondicionamiento de un gas con determinado contenido de CO_2.

Considerando la problemática planteada, el presente documento expone un análisis sobre el desempeño de una unidad Turboexpander en el acondicionamiento de gases asociados con diferentes contenidos de CO_2. El análisis fue desarrollado considerando las proyecciones de producción de la UPME (2018) y los resultados de una simulación en Aspen Hysys v10.

II. METODOLOGÍA

El flujo de gas asociado correspondió al definido en el escenario medio de producción para la Cuenca del Valle Medio del Magdalena, según las proyecciones de la UPME (2018). Este escenario estableció un flujo promedio de 11,8 MMSCFD al año 2044. Por su parte, la composición de los gases en este escenario fue asumida como la típica de los gases producidos en los campos Bonanza y Lisama de ECOPETROL S.A (Camacho, 2021); una característica de los gases en estos campos es la ausencia de H_2S (Camacho, 2021; Sáchica, 2012), lo cual facilita el respectivo proceso de endulzamiento. La Tabla 1 resume las condiciones de entrada y la composición del gas asociado.

La Tabla 2 compara la composición y las propiedades del gas asociado con los requisitos solicitados por el RUT. Según esta tabla, la composición de agua y de CO_2, así como el contenido de líquidos condensables (definido por el punto *Cricondentherm*) se encuentran fuera de especificación para el transporte y la comercialización del gas asociado; con lo anterior, el gas asociado requiere del respectivo acondicionamiento. Las secciones consideradas en el diseño estándar y en la simulación del proceso de acondicionamiento fueron: estabilización, endulzamiento, deshidratación y enfriamiento con Turboexpander, con una posterior separación por destilación.

Tabla 1: Condiciones y composición del gas asociado (Camacho, 2021)

Flujo, MMSCFD	**11,8**
Temperatura, ºF	**99,8**
Presión, psi	**500**
Metano, % mol	77,06
Etano, % mol	7,20
Propano, % mol	4,87
n-butano, % mol	1,78
i-butano, % mol	1,59
n-Pentano, % mol	0,41
i-Pentano, % mol	0,57
2,2-Mpropano, % mol	0,03
n-Hexano, % mol	0,50
n-Heptano, % mol	0,12
n-Octano, % mol	0,04
n-Nonano, % mol	0,01
n-Decano, % mol	0,01
H_2O, % mol	0,21
Oxígeno, % mol	0,03
Nitrógeno, % mol	1,66
CO_2, % mol	3,91

Tabla 2: Verificación de la composición y las propiedades del gas asociado con los requerimientos del RUT (en paréntesis)

Componente	Gas de entrada (RUT)
H_2O, mg/m^3	58669,5 (<97)
O_2, % vol.	0,03 (<0,1)
N_2, % vol.	1,66 (<3)
Inertes, % vol.	5,60 (<5)
CO_2, % vol.	3,91 (<2)
H_2S, mg/m^3	0,00 (<6)
Poder calorífico, MJ/m^3	41,02 (35,4 – 42,8)
Cricondentherm, ºF	114,0 (<45)

El paquete termodinámico Peng-Robinson fue utilizado para la mayoría de las corrientes y equipos en la simulación; este paquete ha reportado resultados concordantes con diferentes datos de procesamiento de hidrocarburos simples (Poe & Mokhatab, 2017). Por su parte, el paquete termodinámico "Acid Gas – Chemical Solvents" fue seleccionado para la sección de endulzamiento; este paquete aplica cálculos basados en el modelo NRTL en reacciones en fase acuosa, necesarias para el cálculo riguroso del proceso de absorción con MEA (Irina & Watanasiri, 2015). También, el paquete termodinámico "Glycol Package" fue definido para la sección de deshidratación; el "Glycol Package" aplica la ecuación de estado TST (Twu-Sim-Tassone) en la determinación del equilibrio de fases, con resultados consistentes para la mezcla agua-TEG (trietilenglicol) (Hasan *et al.*, 2020).

Por otro lado, los equipos de proceso estándar fueron especificados con base en los trabajos de Benitez *et al.* (2015), Camacho (2021), Elbashir *et al.* (2019), Kherbeck & Chebbi (2015), Mokhatab *et al.* (2019), Mokhatab & Poe (2012) y Tristancho (2017). Para la etapa de estabilización, donde se aplica un tratamiento inicial, los equipos definidos fueron dos separadores *flash*, un compresor y un calentador. La sección de endulzamiento considera una absorción con MEA al 20% molar a 120°F y 847 psi, en una torre de 10 platos y de diámetro de 2,3 ft; es importante mencionar que la temperatura fue definida para una mayor absorción, a partir de pruebas con la simulación. También, la sección de endulzamiento considera una recuperación de MEA gastada, en una torre de destilación de 5 platos y diámetro de 3,9 ft.

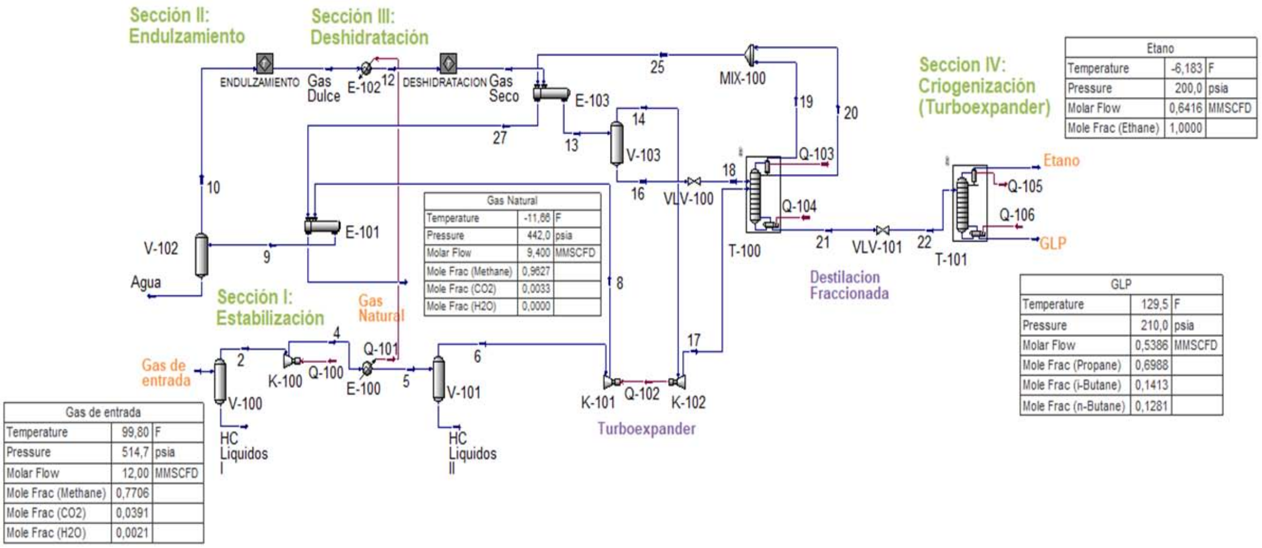
La sección de deshidratación utiliza una solución de TEG al 99% p/p, en una torre de absorción con 20 platos y diámetro de 4,9 ft. El TEG gastado es recuperado en una torre de destilación de 5 platos, operando a presión atmosférica. El gas dulce y seco es enviado a la sección de enfriamiento con Turboexpander (criogenización). En esta sección, el gas es recibido por un enfriador, disminuyendo su temperatura hasta -31°F; el enfriamiento a esta temperatura conduce a una mayor recuperación de etano. Después del enfriador, la sección consideró dos torres de destilación para la generación del gas acondicionado, un flujo de etano y un flujo de GLP. La primera torre es llamada como demetanizadora, la cual es definida a una presión de 450 psia y temperaturas de -139°F en el tope hasta 85°F en el fondo de la torre, con un diseño de 17 platos y un diámetro de 4,9 ft. La segunda torre se denomina desetanizadora y es configurada con 28 platos, diámetro de 4,9 ft y operada a presiones en el rango de 200 a 210 psi y temperaturas desde -11°F en el tope hasta 130°F en el fondo de la torre. El diagrama de proceso (PFD) diseñado en Aspen Hysys es presentado en la Figura 1. En esta figura se definen las propiedades de los flujos principales de entrada y salida de la unidad, así como las secciones codificadas en el PFD.

Con el PFD desarrollado, un total de cinco (5) simulaciones fueron ejecutadas, considerando diferentes concentraciones de CO_2 en el gas asociado. La Tabla 3 presenta las concentraciones del gas asociado para cada simulación; la simulación No 1 corresponde al caso base, con la composición de la Tabla 1. Las concentraciones de metano, del gas asociado del caso base, fueron ajustadas para la consecución de las composiciones mostradas en la Tabla 3. El gas de la simulación No 5 presenta una composición de CO_2 cercana a la máxima del gas asociado del campo Chichimene (EOR por inyección de aire), reportada por Díaz Molina *et al.* (2019). Por otro lado, cada simulación fue ejecutada, considerando las mismas especificaciones y condiciones de operación de los equipos, definidas anteriormente.

Tabla 3: Variación del contenido de CO_2 en el gas de entrada

No. Simulación	1	2	3	4	5
Metano % mol	77,0	75,1	73,3	71,4	69,5
Etano % mol	7,2	7,2	7,2	7,2	7,2
C_3+ % mol	9,9	9,9	9,9	9,9	9,9
H_2O % mol	0,21	0,21	0,21	0,21	0,21
O_2 % mol	0,03	0,03	0,03	0,03	0,03
N_2 % mol	1,66	1,66	1,66	1,66	1,66
CO_2 % mol	3,91	5,79	7,68	9,58	11,4

Nota: La simulación No 1 corresponde al caso base (Tabla 1).



Gas de entrada		
Temperature	99,80	F
Pressure	514,7	psia
Molar Flow	12,00	MMSCFD
Mole Frac (Methane)	0,7706	
Mole Frac (CO2)	0,0391	
Mole Frac (H2O)	0,0021	

Gas Natural		
Temperature	-11,66	F
Pressure	442,0	psia
Molar Flow	9,400	MMSCFD
Mole Frac (Methane)	0,9627	
Mole Frac (CO2)	0,0033	
Mole Frac (H2O)	0,0000	

Etano		
Temperature	-6,183	F
Pressure	200,0	psia
Molar Flow	0,6416	MMSCFD
Mole Frac (Ethane)	1,0000	

GLP		
Temperature	129,5	F
Pressure	210,0	psia
Molar Flow	0,5386	MMSCFD
Mole Frac (Propane)	0,6988	
Mole Frac (i-Butane)	0,1413	
Mole Frac (n-Butane)	0,1281	

Figura 1: Diagrama de flujo en Aspen HYSYS del proceso de tratamiento de gas asociado

III. Resultados y Discusión

a) Validación simulación para el caso base

El PFD de la simulación desarrollada en Aspen Hysys v10 es mostrado en la Figura 1. La simulación reportó convergencia con las composiciones del caso base. La Tabla 4 reporta las características del gas de salida de cada sección de la simulación. Según esta tabla, el proceso diseñado alcanza una disminución en el contenido de CO_2 al valor de 0,28% mol, en el gas de salida de la sección de endulzamiento. Para la sección de deshidratación, la simulación muestra una disminución en la concentración de agua, en el gas de salida, al valor de 53,8 mg/m^3. La Tabla 4 resume las propiedades del gas de salida, reportadas por la simulación, en cada una de las secciones de la unidad. Según esta tabla, los valores obtenidos por la simulación presentan los mismos órdenes de magnitud que los resultados de Camacho (2021). De igual manera, las variables operacionales obtenidas por la simulación, para las diferentes secciones, (Tabla 4) coinciden con diferentes reportes de literatura (ver Chebbi *et al.*, 2010; Getu *et al.*, 2013; Swaidan, 2016; Tristancho, 2017).

Asimismo, una de las variables más importantes dentro del proceso criogénico con un Turboexpander corresponde a la recuperación de etano. El proceso Turboexpander de una sola etapa está diseñado para obtener recuperaciones en el rango 70-80% (Bogoya & Díaz, 2014; Chebbi et al., 2010); el proceso exhibe posibilidades de maximización, según el caso, a valores por encima del 90% (Chebbi et al., 2010; Kherbeck & Chebbi, 2015). Los resultados de la simulación con el caso base, de producción de gas asociado de la cuenca del Valle medio del Magdalena, indican una recuperación de etano del 74,3%, lo cual se encuentra dentro del rango reportado anteriormente.

Con base en la coincidencia entre los valores de la simulación con lo reportado en la literatura y con la recuperación de etano, es posible afirmar que la simulación desarrollada reproduce los valores de operación industrial para el proceso de acondicionamiento de gases asociados, con una unidad Turboexpander.

Tabla 4: Comparación de los resultados de la simulación con la literatura

		Camacho (2021)	Este Trabajo
Sección I: Estabilización	T, °F	120,0	120,0
	P, psi	748,0	762,7
	F, MMSCFD	11,98	11,98
	CO_2, %vol	3,91	3,90
	H_2O,mg/m^3	49611,1	49542,4
	Cricon., °F	103,2	102,5
Sección II: Endulzamiento	T, °F	111,2	85,0
	P, psi	847,0	900
	F, MMSCFD	11,55	11,51
	CO_2, %vol	0,41	0,28
	H_2O,mg/m^3	49000,7	49189,8
	Cricon., °F	105,4	104,6
Sección III: Deshidratación	T, °F	22,1	28,55
	P, psi	590,0	597,8
	F,MMSCFD	11,53	10,58
	CO_2, %vol	0,41	0,29
	H_2O,mg/m^3	65,5	53,8
	Cricon., °F	11,2	6,7
Sección IV: Gas de Salida	T, °F	-13,5	-11,66
	P, psi	445,0	442,0
	F,MMSCFD	10,36	9,40
	CO_2, %vol	0,45	0,33
	H_2O,mg/m^3	73,9	46,3
	Cricon., °F	-80,8	-112,2

b) Simulaciones con los otros casos

La convergencia en las simulaciones con los demás casos fue conseguida por aumento en el flujo de solución acuosa de MEA en un 17%. Este aumento no afecta el diámetro de la torre de endulzamiento; el diámetro se encuentra en función del flujo de gas y la presión de la torre (Elbashir et al., 2019; Kolmetz, 2020; Mitra, 2015). Además, Kolmetz (2020) sugiere que, la relación entre el flujo de gas a flujo de MEA sea fijada entre 0,3 y 0,4 mol/mol, relación cumplida en todos los casos. Las otras secciones de deshidratación y criogenización no reportaron inconvenientes de convergencia con lo especificado para el caso base.

Por otra parte, pruebas en la simulación especificando gases asociados con concentraciones superiores de 11,4% mol de CO_2 reportaron fallas de convergencia en las torres de la sección de endulzamiento. Lo anterior sugiere modificaciones en los diseños de las torres en esta sección, en unidades convencionales, para el tratamiento de gases ácidos con contenidos molares de CO_2 superiores a 11,4%.

c) Perfiles en las torres

La Figura 2 expone los perfiles de temperatura de la torre de absorción, sección de endulzamiento, obtenidos por la simulación para los gases con diferentes contenidos de CO_2. Según esta figura, para los gases con contenidos de 3,91% mol y 5,79% mol, los perfiles de temperatura presentan un máximo en el plato número dos (numeración desde el plato de fondo; el gas ingresa por el fondo, mientras la solución de MEA ingresa por la cima), con valores de 225°F y 223°F, respectivamente. Este máximo se debe al comportamiento exotérmico de la absorción de CO_2 en MEA. Posteriormente, los perfiles muestran una disminución monotónica de la temperatura de los platos superiores, hasta el valor de 112°F (plato 10), debido a la evaporación de agua (Biliyok *et al.*, 2012; Mores *et al.*, 2012; Rashid *et al.*, 2014) y a la temperatura de entrada de la solución de MEA. El comportamiento de estos perfiles de temperatura es consistente con el estudio de Giri *et al.* (2011) y con las mediciones experimentales de Rashid *et al.* (2014).

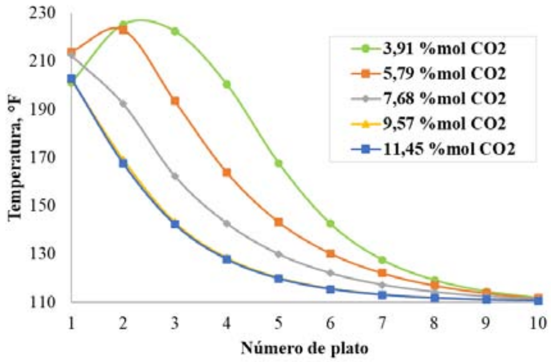


Figura 2: Perfiles de temperatura en la torre de absorción con MEA (20%) para diferentes concentraciones de CO_2

Asimismo, la Figura 2 manifiesta que, a mayores concentraciones de CO_2 en el gas de entrada (*i.e.* 7,68%, 9,57% y 11,54%), el perfil de temperatura presenta un decrecimiento monotónico desde el primer plato. Esta tendencia se debe a la variación del calor de absorción con la carga de CO_2. Reportes experimentales de Kim *et al.* (2014) y Kothandaraman (2010) indican que el calor de absorción disminuye drásticamente en soluciones con cargas superiores a 0,4 mol CO_2/mol MEA. Precisamente, la operación de la torre con gases de contenido 7,68%, 9,57% y 11,54% exhibe una relación mol CO_2/mol MEA superior a 0,4 en la solución de fondo (bajo calor de absorción). De otro lado, la simulación reporta que, en la operación de la torre con gases de contenido 3,91% y 5,79%, la solución acuosa en los platos de fondo muestra una relación mol CO_2/mol MEA inferior a 0,4 (elevado calor de absorción). Con lo anterior, el calor de absorción liberado es menor en la operación con mayores contenidos de CO_2, conduciendo al perfil de temperatura sin punto máximo en los platos de fondo.

Por su parte, la Figura 3 presenta los perfiles de temperatura en la torre deshidratadora; la numeración inicia en el plato de cima. Según esta figura, la temperatura del gas experimenta un aumento en su recorrido, desde el fondo a la cima de la torre, debido a la disminución en su contenido de humedad. El flujo de TEG pobre ingresa en contracorriente a 120°F al plato 1, mientras el flujo de gas ingresa al plato 20, en promedio a 90°F. La condensación del agua contenida en el gas envuelve un enfriamiento en el respectivo plato de contacto, por lo cual, el TEG disminuye su temperatura en su recorrido (de arriba hacia abajo), mientras el gas aumenta su temperatura (de abajo hacia arriba). El incremento de temperatura del plato 19 al plato 2 es de tipo lineal, a razón de 1°F/plato. Del plato 2 al plato de cima, el gas experimenta un calentamiento brusco, con un incremento de 4°F debido a la temperatura del flujo de TEG pobre. Este perfil es característico para las diferentes concentraciones de CO_2. Según la Figura 3, el perfil presenta un desplazamiento vertical hacia abajo (menores valores de temperatura) con el aumento en la concentración de CO_2. Este desplazamiento se debe a la disminución en la capacidad calorífica del gas, con el aumento en el contenido de CO_2 (Cp_{CO2}=0,19 BTU/lb/°F a 35°F; Cp_{CH4}=0,52 BTU/lb/°F a 35°F). Los perfiles de la Figura 3 coinciden con lo reportado por Garmendia (2019), con base en una simulación en PROII/PROVISION de una planta de deshidratación con TEG.

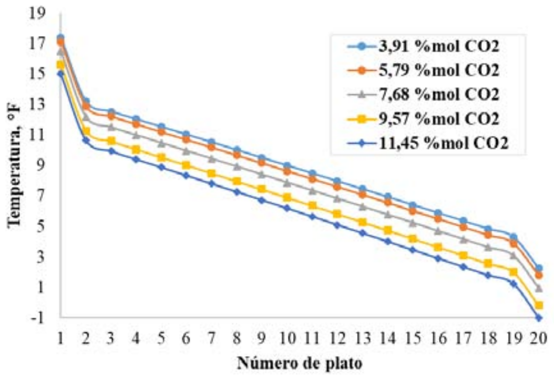


Figura 3: Perfil de temperatura torre deshidratadora con TEG

Por su parte, los perfiles de las Figuras 4 y 5 corresponden a las variaciones en las temperaturas en las torres demetanizadora (Figura 1, T100) y desetanizadora (Figura 1, T101), respectivamente. La numeración en estas torres inicia en el plato de cima; el plato de alimentación en la demetanizadora corresponde al 17, mientras en la desetanizadora, el flujo es alimentado al plato 14. Según las Figuras 4 y 5, la temperatura de cima, como se esperaba, resulta menor en la demetanizadora debido a su mayor presión de operación (450 psia, comparado con 200 psia en la desetanizadora). Asimismo, es posible apreciar que, en cada figura, los perfiles varían en los platos de cima, debido al cambio en el contenido de CO_2 del gas

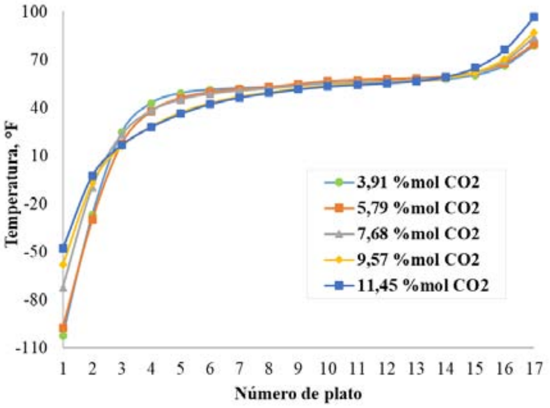


Figura 4: Perfil de temperatura torre demetanizadora

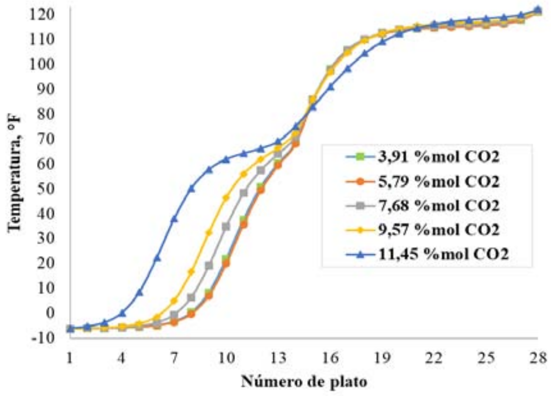


Figura 5: Perfil de temperatura torre desetanizadora

de alimentación. Los perfiles en estas zonas presentan menores temperaturas para menores contenidos de CO_2 (mayores contenidos de CH_4); lo anterior se debe a la diferencia entre las capacidades caloríficas del CO_2 (0,18 BTU/lb/°F a -55°F) y el CH_4 (0,50 BTU/lb/°F a -55°F); a mayor contenido de CO_2 menor requerimiento de flujo calórico para el aumento en las temperaturas de cima. Las tendencias de los perfiles mostrados en la Figura 4 coinciden con lo mostrado por ZareNezhad & Eggeman (2006), autores que analizaron los resultados de la aplicación de la ecuación de estado Peng-Robinson en procesos de recuperación de NGL de mezcla de hidrocarburos. De igual manera, los perfiles presentados en la Figura 5 coinciden con lo obtenido por Binous & Bellagi (2013).

d) Consumos energéticos

Según los resultados de las simulaciones, un aumento en la concentración de CO_2 del gas asociado conduce a una disminución en la potencia generada por el Turboexpander, debido a la respectiva disminución en el flujo de metano (Tabla 3); un menor flujo disminuye la energía disponible en la expansión del gas de entrada. La Figura 6 muestra que la potencia obtenida en la etapa de expansión del Turboexpander es inversamente proporcional con respecto al incremento en la concentración de CO_2. Según esta figura, un aumento en el 1% en el contenido de CO_2 conduce a una disminución de 0,1 hp de potencia generada en el Turboexpander.

Asimismo, y en contraste, la Figura 6 expone también un aumento en el requerimiento calórico del proceso, con el aumento en el contenido de CO_2. Este aumento se debe principalmente a la etapa de regeneración de la MEA, lo cual es consistente con lo reportado por Feng *et al.* (2010).

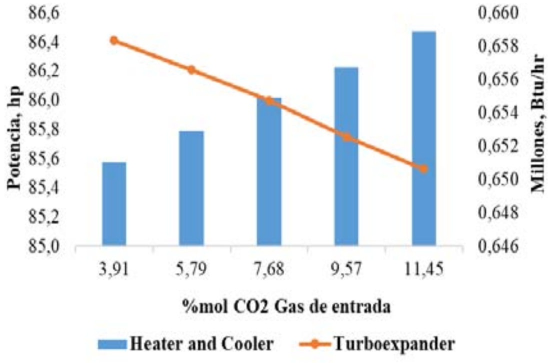


Figura 6: Variación en el requerimiento calórico y de potencia

e) Flujos de salida del proceso

Los flujos de salida del proceso comprenden: el gas asociado acondicionado (Gas Natural), los hidrocarburos condensables (GLP), el etano, el agua de la sección de endulzamiento, el CO_2 de la sección de Endulzamiento y el agua de la

Tabla 5: Calidad del Gas natural obtenido a diferentes concentraciones de CO_2

Componente	% mol CO_2 gas asociado de entrada					RUT*
	3,91	**5,79**	**7,68**	**9,57**	**11,45**	
H_2O, mg/m^3	46,27	44,62	40,73	36,40	33,68	<97
O_2 % vol	0,04	0,04	0,04	0,04	0,04	<0,1
N_2 % vol	2,10	2,12	2,09	2,07	2,05	<3
Inertes % vol	2,47	3,90	6,09	8,77	10,77	<5
CO_2 % vol	0,33	1,74	3,96	6,66	8,68	<2
H_2S, mg/m^3	0,00	0,00	0,00	0,00	0,00	<6
Poder calorífico bruto, MJ/m^3	38,2	37,6	41,6	41,8	40,2	35,4 – 42,8
Cricondentherm, °F	-112,2	-175,0	-98,3	-89,1	-79,5	<45

** Valores límites según el RUT (Resolución CREG-071 de 1999 y su modificación posterior del año 2019).*

sección de Deshidratación. La Tabla 5 compara los parámetros de calidad del Gas Natural predicho por simulación, según el contenido de CO_2 del gas asociado de entrada. De esta tabla es posible mencionar que, el contenido de agua (humedad) disminuye en el Gas Natural, con el aumento en el contenido de CO_2 del gas asociado de entrada. Es decir, un aumento en el CO_2 desplaza favorablemente el equilibrio termodinámico en el proceso de deshidratación del gas asociado. Azmi *et al.* (2011) también reportan un desplazamiento favorable en el equilibrio termodinámico, en su estudio sobre la formación de hidratos en gases con diferentes concentraciones de CO_2. De igual manera, el desplazamiento del equilibrio afecta la propiedad *Cricondentherm* (punto de rocío), aumentando su valor por un incremento en el contenido de CO_2 del gas asociado. El aumento en el contenido de CO_2 desplaza el equilibrio, aumentando los niveles de etano en el Gas Natural, con el consecuente aumento en el *Cricondentherm*. El aumento de etano en el gas natural sintético con contenidos de CO_2 ha sido también reportado por Davalos *et al.* (1976) y Mørch *et al.* (2006); por su parte, el incremento en el *Cricondentherm* ha sido reportado por Brown *et al.* (2009), El-Maghraby *et al.* (2022), Louli *et al.* (2012) y Mørch *et al.* (2006), entre otros.

Asimismo, de la Tabla 5 es posible mencionar que, la disminución en la humedad del Gas Natural corresponde con un aumento en su poder calorífico bruto. Por otro lado, el contenido de O_2 en el Gas Natural resultó constante con la variación de CO_2 en el gas asociado de entrada.

Según la Tabla 5, las propiedades del Gas Natural resultante del tratamiento con la unidad Turboexpander, simulada en Aspen Hysys, cumple con los requisitos del RUT, cuando el gas asociado de entrada presenta concentraciones de CO_2 inferiores del 6% mol. Para contenidos superiores, el Gas Natural resultante se encuentra fuera de especificaciones de contenido de Inertes y contenido de CO_2. Según la Sección 3.3., los perfiles de temperatura en la torre de absorción con MEA (Figura 2) presentan diferencias, según el contenido de CO_2 del gas de entrada. Específicamente, si el contenido supera el valor del 6% mol, el perfil muestra valores bajos de temperatura, lo cual resulta como consecuencia de una relación mol CO_2/mol MEA superior a 0,4 en los platos de fondo. Según esto y la Tabla 5, la relación mol CO_2/mol MEA define el cumplimiento en las especificaciones del Gas Natural tratado.

Con lo anterior, las etapas diseñadas para la unidad Turboexpander estándar (con los parámetros definidos en la Sección 2) permiten el tratamiento de gases asociados con contenidos de CO_2 por debajo del 6% mol, obteniendo un gas con calidad adecuada para su transporte y comercialización. Para contenidos superiores, las limitaciones en el calor de absorción (relación mol CO_2/mol MEA superior a 0,4) restringen la obtención de un gas con cumplimiento del RUT. Un rediseño de la torre y de sus condiciones operativas o un aumento en la concentración de MEA podría conllevar al cumplimiento de una relación mol CO_2/mol MEA inferior a 0,4 para un tratamiento adecuado de gases con contenidos de CO_2 superiores del 6% mol. Asimismo, los avances en el área de captura de CO_2 podrían conllevar a la proposición de un absorbente más eficiente para el endulzamiento, por ejemplo, los fluidos iónicos (Hasib-ur-Rahman *et al.*, 2010).

Por otra parte, los resultados obtenidos con el diseño propuesto en este documento son superiores a los presentados por Tristancho (2017), quien reporta un acondicionamiento adecuado para gases con concentraciones de CO_2 de hasta 4% mol. Por otro lado, las propiedades del flujo de Etano no presentan cambios significativos con la composición de CO_2 en el gas asociado. Según la Tabla 6, para todos los casos, el flujo de Etano cumple las especificaciones de calidad dispuestos por DOF (2016). Sin embargo, el aumento en la concentración de CO_2 en el gas asociado impacta en la producción de Etano, según lo mostrado en la Figura 7. La disminución del flujo se deduce del desplazamiento del equilibrio en la torre demetanizadora. Este resultado coincide con lo documentado por Fernandez *et al.* (1991).

Tabla 6: Condiciones de salida del flujo de Etano, según simulación

Etano	% mol CO_2 en el Gas de entrada				
	3,91	5,79	7,68	9,57	11,45
Temperatura, °F	-6,2	-6,2	-6,2	-6,2	-6,1
Presión, psia	200	200	200	200	200
Flujo, MMSCFD	0,64	0,63	0,51	0,43	0,31
Etano,% mol	100	100	99,99	99,99	99,95
CO_2, % mol	0,00	0,00	0,01	0,01	0,01
Propano, % mol	0,00	0,00	0,00	0,00	0,04

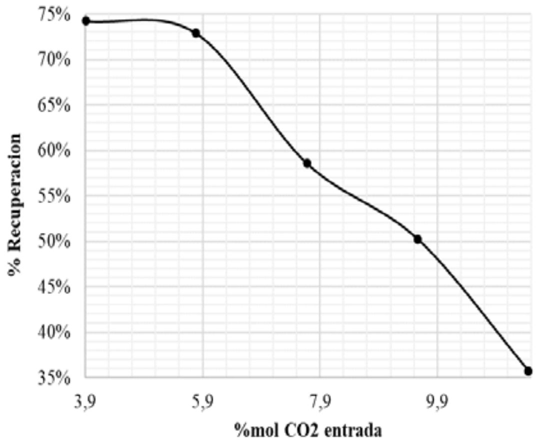


Figura 7: Recuperación de etano en el proceso para diferentes concentraciones de CO_2

Otro subproducto resultante del proceso Turboexpander es el gas licuado del petróleo (GLP). En su mayor proporción, el GLP se compone de propano y butano. La norma técnica colombiana (Ministerio de minas y energía, 2015), establece que las fracciones pesadas (C_{5+}) del GLP presenten un contenido máximo de 2% mol; lo anterior conlleva a un almacenamiento eficiente a altas presiones (UPME, 2013). La Tabla 7 presenta las propiedades para el flujo de GLP resultante del tratamiento del gas asociado, con la unidad Turboexpander.

Tabla 7: Condiciones de salida del GLP obtenido en las cinco simulaciones

GLP	% mol CO_2 en el Gas de entrada				
	3,91	**5,79**	**7,68**	**9,57**	**11,45**
Temperatura, °F	129,5	129,3	129,0	128,7	128,4
Presión, psia	210	210	210	210	210
Flujo, MMSCFD	0,539	0,528	0,515	0,500	0,487
Etano % mol	0,00	0,00	0,00	0,00	0,03
Propano % mol	69,88	70,16	70,48	70,84	71,14
n-Butano % mol	12,81	12,69	12,54	12,36	12,21
i-Butano % mol	14,13	14,06	13,95	13,83	13,73
n-C5 % mol	0,98	0,96	0,94	0,92	0,9
i-C5 % mol	1,65	1,6	1,57	1,55	1,51
2,2-MC3 % mol	0,16	0,15	0,15	0,15	0,14
n-C6 % mol	0,36	0,35	0,34	0,33	0,32
n-C7 % mol	0,02	0,02	0,02	0,02	0,02

Según esta tabla, el contenido de hidrocarburos pesados (C_{5+}) supera el límite de 2% mol, en los cinco casos de simulación. Lo anterior sugiere un tratamiento posterior de la corriente de GLP en una torre de destilación para la síntesis de gasolina natural (Abdel-Aal *et al*., 2003; Ahmad *et al*., 2011). El diseño y el análisis del desempeño de esta torre de purificación de gasolina natural son recomendados para trabajos futuros en el tema.

f) Formación de Hidratos

Para finalizar, unos comentarios finales sobre la formación de hidratos, tema de importancia en el aseguramiento de flujo. La Figura 8 presenta los resultados de la herramienta de detección de formación de hidratos, disponible en Aspen Hysys (Abdulmutalib & Abdulmalik, 2022; Alnaimi *et al*., 2020); la herramienta detalla en rojo aquellas corrientes con un potencial elevado de formación de hidratos. Según esta figura, la formación de hidratos resulta probable en las corrientes del tope de la torre demetanizadora; esto acontece en los cinco escenarios de evaluación de contenido de CO_2. El tipo de hidratos que potencialmente puede ser formado corresponde al tipo II, el cual envuelve el encapsulamiento de nitrógeno y CO_2 a las condiciones de salida del gas (Abdulmutalib & Abdulmalik, 2022; Carroll, 2003).

A pesar de esta detección de hidratos, por parte de Aspen Hysys (Figura 8), las concentraciones de agua son bajas en todos los casos, con lo cual, la formación de hidratos sería indetectable a nivel industrial, sin consecuencias importantes para el proceso. Abdulmutalib & Abdulmalik (2022) reportan una regla heurística de alrededor de 35 mg de agua por m^3 de gas, como contenido ideal para el transporte de gas. La Tabla 5 muestra que la mayoría de los Gases Naturales generados cumplen esta regla heurística. Para el caso de gases con concentraciones un poco más elevadas de 35 mg de agua por m^3 de gas, el contenido bajo de CO_2 evitaría la formación apreciable y detectable de hidratos (Van-Denderen *et al*., 2009). Por otra parte, en caso de una formación importante de hidratos, esta puede ser inhibida por diferente tipo de compuestos como metanol, etanol y glicol (Abdulmutalib & Abdulmalik, 2022; Bharathi *et al*., 2021; Koh *et al*., 2011).

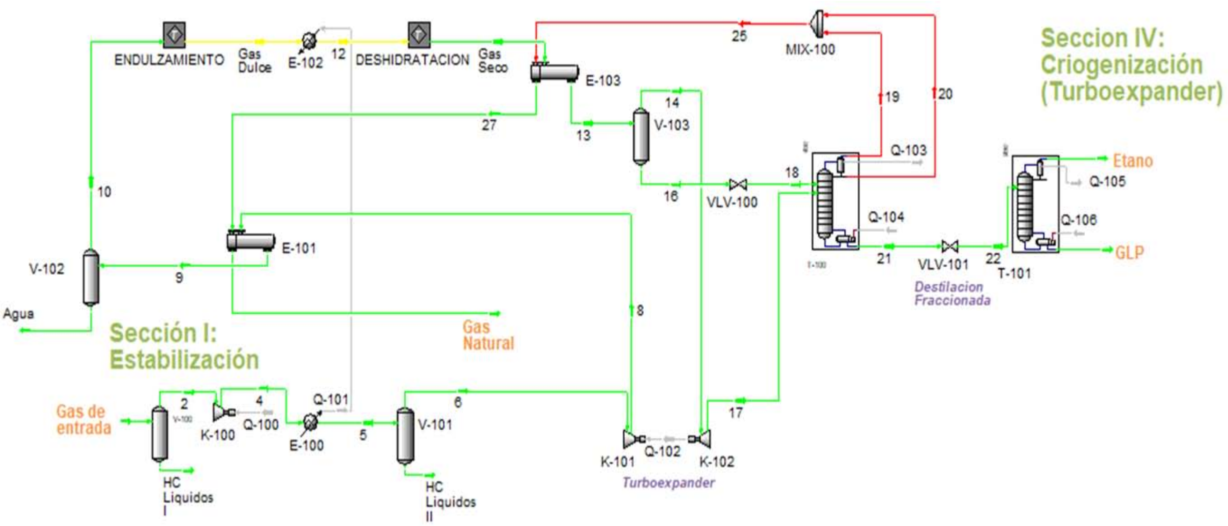


Figura 8: Estado de formación de hidratos a una concentración de 7,68% mol de CO_2 en el gas de entrada. Las corrientes en color verde indican que no hay formación de hidratos. En color rojo advierten que hay formación de hidratos y las corrientes en color amarillo indican que el modelo seleccionado no calculó la formación de hidratos

IV. CONCLUSIONES

El acondicionamiento de gases asociados está condicionado por la normativa del Reglamento Único de Transporte (RUT). Las unidades de acondicionamiento con Turboexpander pueden recibir gases asociados con incrementos en las condiciones de diseño, que superan los respectivos contenidos de CO_2. Estos incrementos pueden conllevar a un acondicionamiento parcial, generando gases por fuera de especificaciones del RUT. Según los resultados del presente documento, una unidad Turboexpander estándar conduciría a un acondicionamiento satisfactorio del gas asociado, supuesto por el escenario medio de proyección para la Cuenca del Valle Medio del Magdalena. Asimismo, los resultados de las simulaciones con Aspen Hysys indican que, la secuencia de etapas de la unidad con Turboexpander podría acondicionar el respectivo gas asociado con contenidos de CO_2 de hasta 6% mol, cumpliendo lo requerido para su comercialización. Un aumento adicional del contenido de CO_2 en el gas asociado afectaría el desempeño del proceso de endulzamiento, generando un gas fuera de especificaciones, en lo referente al contenido de CO_2 e inertes. Por último, la comercialización de los flujos de GLP generados con la unidad requeriría de una torre de destilación adicional, logrando los límites de C_{5+}, según la respectiva norma.

Aportes

Vargas-Reyes, L.: Simulación de la sección de deshidratación y destilación. Escritura del artículo.
González-Martínez, A.: Simulación de la sección de endulzamiento y escritura del artículo.
Morales-Medina, G.: Verificación de resultados, escritura y edición del artículo.

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Global Journal of Researches in Engineering: C
Chemical Engineering
Volume 24 Issue 1 Version 1.0 Year 2024
Type: Double Blind Peer Reviewed International Research Journal
Publisher: Global Journals
Online ISSN: 2249-4596 & Print ISSN: 0975-5861

Optimal Recovery of Methane Gas from Natural Gas Steam using Aspens Hysis Simulator

By Usiabulu, G. I.
University of Port Harcourt

Abstract- In this study, the recovery of natural gas has been carried out using the Aspens Hysis Simulator Version 8.6 for the plant simulation and Technip's feed gas composition was chosen for the process, while testing the effect of products recycles and optimal feed tray position. This work sought to optimize the existing plant framework. The results obtained were analyzed by observing the maximum methane recovery in the column overhead. It was discovered that methane gas recovery was maximum when product recycle was zero, and that increasing no of trays, led to increasing methane recovery in the overhead. A mathematical model was developed for predicting the optimal feed tray position and is given as y=-0.01x2 +x – 3, while the mathematical model for calculating the required number of trays for a desired fraction of methane in the overhead is given as y=2E-06x2 - 3E-05x+0.8931, and the mathematical model for calculating the required number of trays for a desired fraction of NGLs in the overhead was given as y=5E-07x2 - 5E-05x+0.0352.

Keywords: methane, recovery, optimization, recycle, gas plant.

GJRE-C Classification: LCC: TP751

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I. INTRODUCTION

Several environmentalists vision natural gas as a bridge fuel between the prevailing fossil fuel of today and the renewable fuels of tomorrow (Mokhatab, 2006). The fastest growing hydrocarbon is natural gas in the hydrocarbon fuel family and most estimates put the average rate of its growth at 1.5–2.0%. Currently, the demand for Natural Gas is increasing due to its clean burning characteristics and its ability to meet environmental requirements. Increasing the processing and production of all hydrocarbons in an environmentally friendly and cost-effective practice is the current foremost ambition of the industry (Abdel-Aal & Mohamed, 2003). Natural gas is generally separated into two groups, viz: derived from conventional deposits and derived from non-conventional deposits (Peyerl & Figueirôa, 2016). The difference is typically due to a difference in the structure of the deposits, geologically and in their production methods (Ghalambor, 2005). It is projected that by 2030, natural gas will substitute coal as the second most frequently used energy source in the world (Alireza, 2014). Natural Gas from conventional deposits originates mainly from rocks of great permeability. It is mined by means of "traditional" vertical drilling know-how (Salah et al., 2021). The larger part of gas presently produced in the world is derived from conventional deposits, and its method of production is quite economical and simple. (Eggour & Fahim 2003).

Although Natural Gas from non-conventional deposits can originate in rocks with very low permeability, it may not be mined through the same method as gas from conventional deposits. (GPSA, 2004). The weightier hydrocarbon liquids normally referred to as natural gas liquids (NGLs), include ethane, propane, butanes and natural gasoline (condensate). Recovery of NGL constituents in gas not only may be a prerequisite for hydrocarbon dew point control in a natural gas stream (to avoid the unsafe formation of a liquid phase when transporting), but also produces a source of revenue, as NGLs normally have significantly greater value as distinct marketable products than as part of the natural gas stream (Kidnay and Parrish, 2006). Lighter NGL fractions, such as ethane, propane, and butanes, can be sold as fuel or feedstock to petrochemical plants and refineries, whereas the heavier portion can be used as gasoline-blending stock (GPSA, 2004). Natural gas coming directly from a well contains many natural gas liquids that are usually removed (Larson and Carl-Fredrik, 2021). In most instances, natural gas liquids have a higher value as separate products when they are not separated. Thus, it makes economic sense to remove them from the gas stream (EIA, 2012). NGL components products; Ethane, propane, butane, pentane and other heavier products are major markets for the petrochemical and plastic industries as well as the pharmaceuticals industry.

II. METHODOLOGY

a) *Modelling Environment*

The NGL recovery plant with recycling was modelled using the ASPEN HYSYS V8.6 simulation environment. The fluid package PENG-ROBINSON was chosen for the modelled process as recommended by the ASPEN tutorial manual. (Gayubo, 2000)

b) *Unit Operations Needed*

The Unit-operations needed for the complete modelling of the process are given below:

Expander, Valve, reboiled absorber, Tee, Cooler, Compressor, Heater, Recycle, Heat Exchanger (Zaixing, 2018).

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

c) *Inlet Feed Conditions*

The inlet conditions of the natural gas were modelled according to the following conditions listed in Table 1.

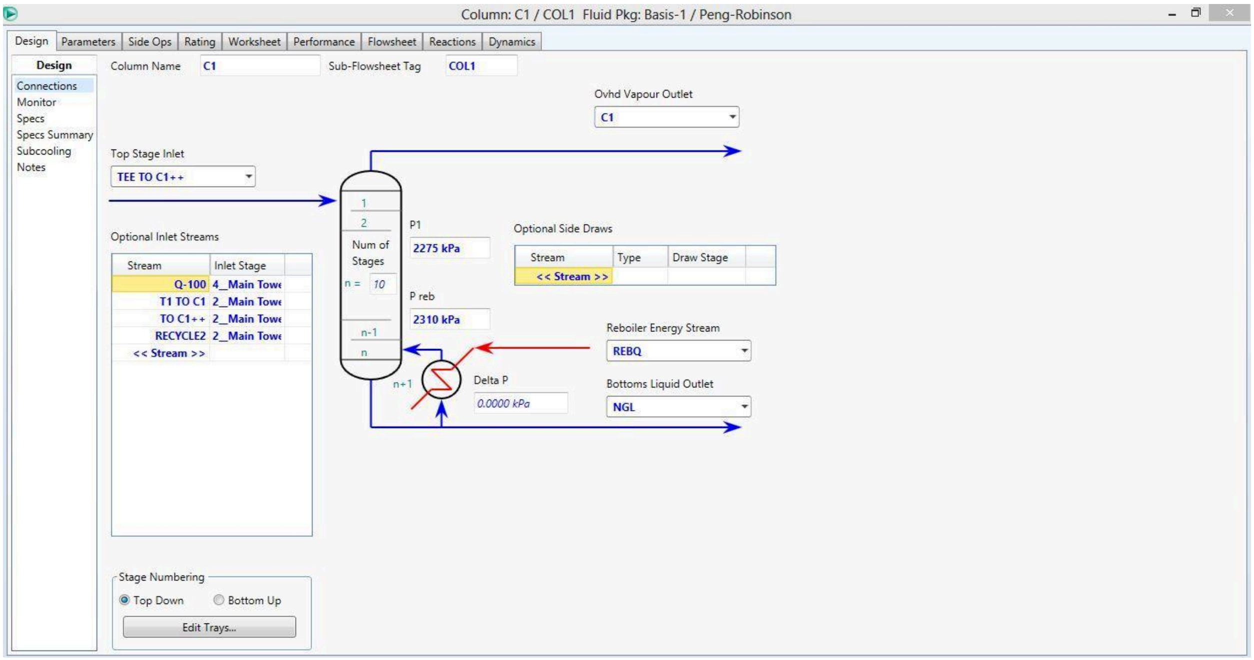
Table 1: Inlet feed conditions

Temperature [C]	-34
Pressure [kPa]	6000
Molar Flow [kgmole/h]	40000

The component fractions are listed below:

d) *Specifications in the Fractionating Column*

The specifications for the fractionating column are listed in Figure 1 and Figure 2 they contain the no. of trays in the column, the inlet stages, the outlet stages and top and bottom operating pressures.



Column: C1 / COL1 Fluid Pkg: Basis-1 / Peng-Robinson

Column Name: C1

Sub-Flowsheet Tag: COL1

Ovhd Vapour Outlet: C1

Top Stage Inlet: TEE TO C1++

Optional Inlet Streams

Stream	Inlet Stage
Q-100	4__Main Towe
T1 TO C1	2__Main Towe
TO C1++	2__Main Towe
RECYCLE2	2__Main Towe
<< Stream >>	

Num of Stages: n = 10

P1: 2275 kPa

P reb: 2310 kPa

Optional Side Draws

Stream	Type	Draw Stage
<< Stream >>		

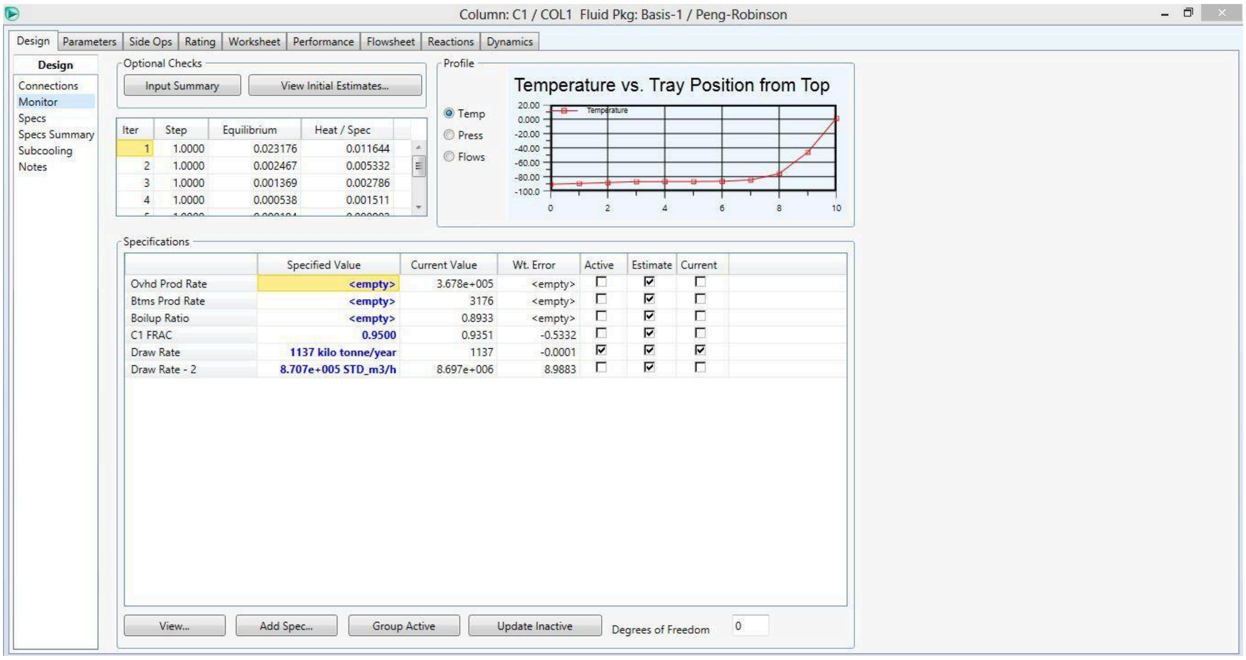
Reboiler Energy Stream: REBQ

Delta P: 0.0000 kPa

Bottoms Liquid Outlet: NGL

Stage Numbering: ● Top Down ○ Bottom Up

Figure 1: Column specifications 1



Column: C1 / COL1 Fluid Pkg: Basis-1 / Peng-Robinson

Iter	Step	Equilibrium	Heat / Spec
1	1.0000	0.023176	0.011644
2	1.0000	0.002467	0.005332
3	1.0000	0.001369	0.002786
4	1.0000	0.000538	0.001511

Profile: ● Temp ○ Press ○ Flows

Specifications

	Specified Value	Current Value	Wt. Error	Active	Estimate	Current
Ovhd Prod Rate	<empty>	3.678e+005	<empty>	☐	☑	☐
Btms Prod Rate	<empty>	3176	<empty>	☐	☑	☐
Boilup Ratio	<empty>	0.8933	<empty>	☐	☑	☐
C1 FRAC	0.9500	0.9351	-0.5332	☐	☑	☐
Draw Rate	1137 kilo tonne/year	1137	-0.0001	☑	☑	☑
Draw Rate - 2	8.707e+005 STD_m3/h	8.697e+006	8.9883	☐	☑	☐

Degrees of Freedom: 0

Figure 2: Column specifications 2

e) Sales Gas Compressor

The sales gas compressor was modeled as a one stage compressor for simplicity, under the conditions of different Adiabatic efficiencies ranging from 20%-75%, with the aim of observing the energy demand on the compressor with different recycling options (EIA, 2012.). The specifications of the sales gas are 6000kPa and 34^{o}C.

f) Products Recycle

The overhead product of the column was sent to a Tee where it was split in two parts of the same composition; with splits starting at 5%-95% recycled back into the column.

g) Feed Inlet Trays

The inlet tray of the incoming natural gas was varied for a column with 10 trays, 20 trays and 30 trays. It would be determined by observing the inlet tray that gives us the maximum methane in the column overhead, minimum NGL in the column overhead, and Lower sales gas compressor power rating (Xinghe et al., 2018). The results from this analysis would be used in developing a model for easy prediction of the best feed tray position for this specific natural composition (Ghalambor, 2005).

III. Results and Discussion

a) Results

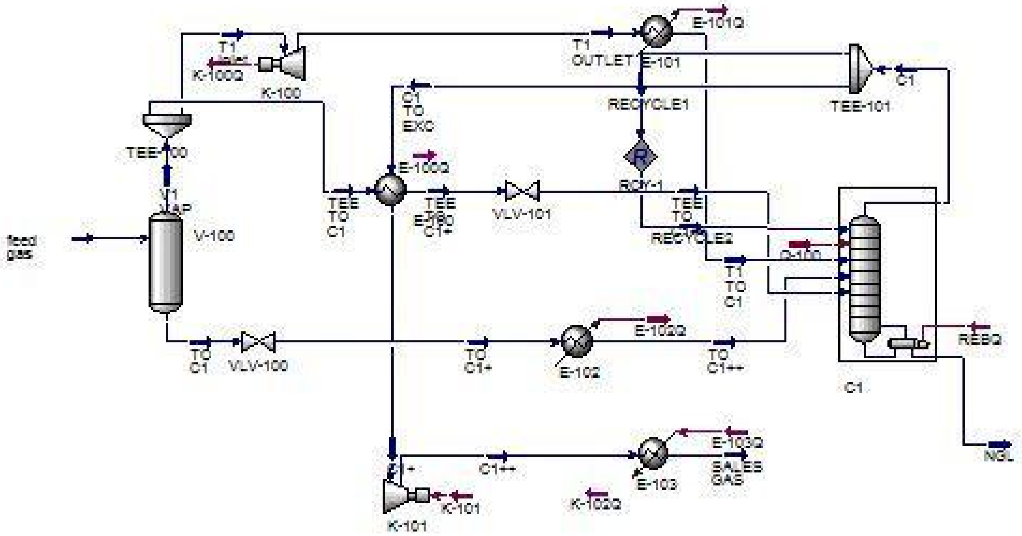


Figure 3: Complete NGL recovery plant

The incoming feed gas goes to a flash drum v-100, and the overhead vapour from the drum is then sent to a Tee feed splitter which split in equal proportions. one stream line from the feed splitter was sent to an expander to drop the pressure rapidly to achieve a corresponding drop in temperature and then sent to a cooler for further refrigeration and then sent to a column, and the other stream from the feed splitter is sent to a heat exchanger where the overhead product from the column is used for sub cooling it, and then sent to the separation column. The Bottom products of the flash drum is sent to a cooler and valve for further refrigeration and pressure drop and sent directly to the separation column. A stream containing mainly methane comes out of the column overhead.

b) Effect of Product Recycle

The product recycle versus methane in overhead is shown in table 2 below.

Table 2: Product recycle vs. Methane in overhead

PRODUCTS RECYCLE	METHANE IN OVHEAD
0.0000	0.8887
0.0500	0.8883
0.1000	0.8880
0.2000	0.8872
0.3000	0.8865
0.4000	0.8858
0.5000	0.8851
0.6000	0.8849
0.7000	0.8841
0.8000	0.8845
0.9000	0.8854
0.9500	0.8852

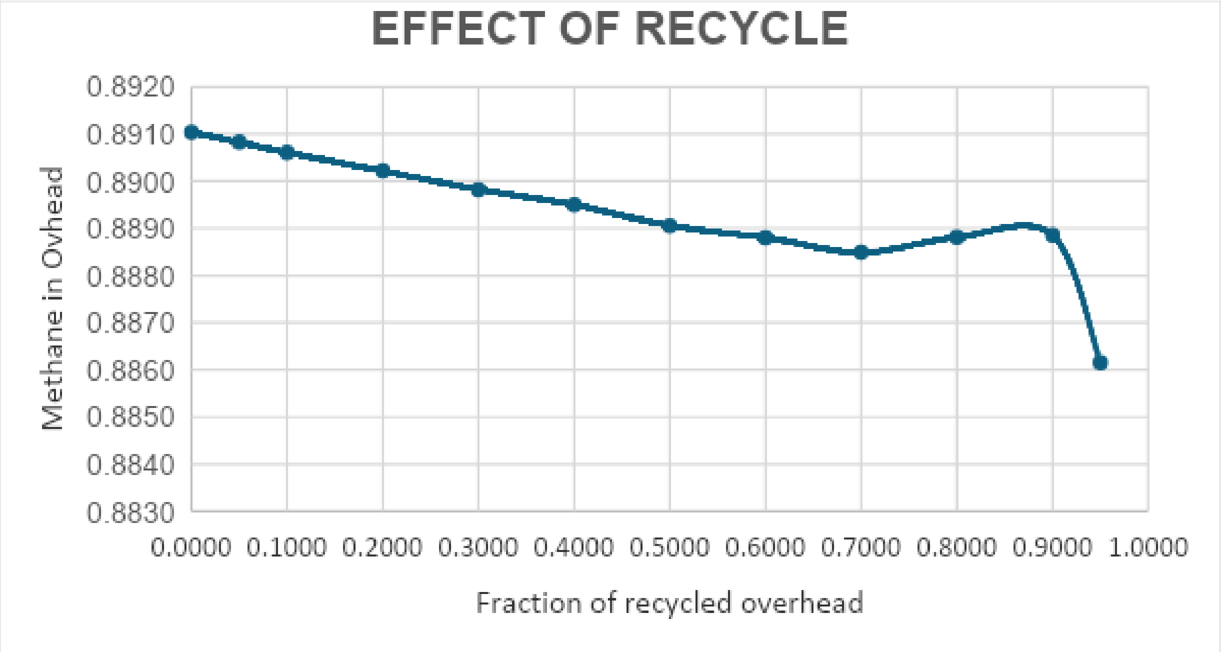


Figure 4: Graph showing the effect of recycling on methane fraction in a column overhead

FEED INLET POSITION

Column with 10 Trays

Table 3: Effect of tray position on methane fraction in column overhead and sales gas compressor power requirement for column with 10 tray

TRAY	METHANE IN OVERHEAD	POWER REQUIREMENT OF SG COMP
2.0000	0.8910	23261.2474
3	0.8921	23179.5078
4	0.8927	23152.3384
5	0.8930	23141.5127
6	0.8930	23139.9554
7	0.8927	23151.0407
8	0.8915	23193.7471
9	0.8887	23291.7624
10	0.8826	23489.5450

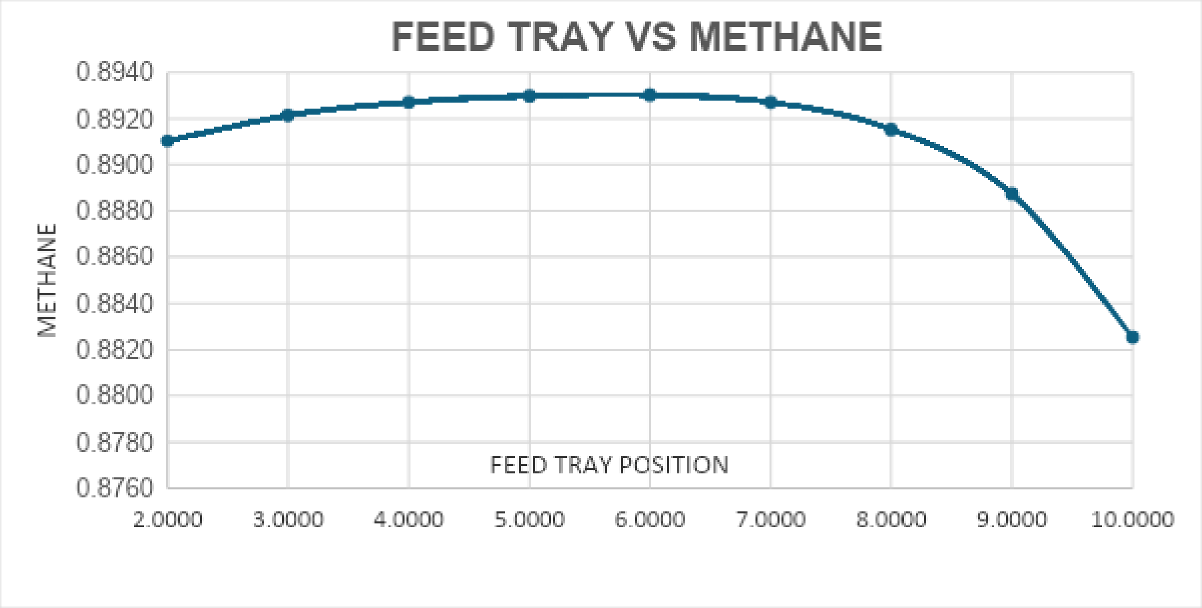


Figure 5: Feed tray vs. Methane in column overhead for column with 10 trays

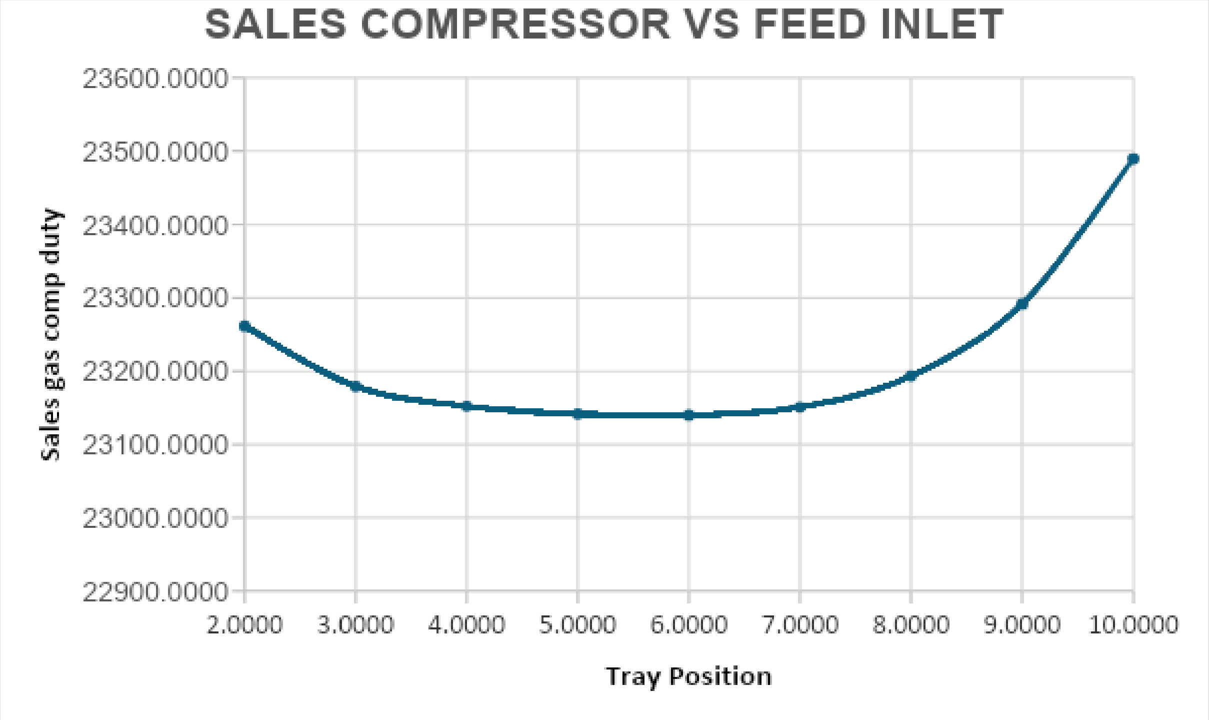


Figure 6: Feed tray vs. Sales gas compressor power requirement for column with 10 trays

Column With 20 Trays

Table 4: Effect of tray position on methane fraction in column overhead, and sale gas compressor power requirement for column with 20 trays

TRAY POSTION	METHANE	POWER
2.0000	0.8910	23383.9375
3.0000	0.8921	23179.3346
4.0000	0.8927	23151.9647
5.0000	0.8930	23140.5291
6.0000	0.8931	23135.4195
7.0000	0.8932	23133.1497
8.0000	0.8932	23132.1299
10.0000	0.8933	23129.3333
12.0000	0.8932	23132.3115
13.0000	0.8933	23128.8161
14.0000	0.8933	23129.9213
15.0000	0.8933	23130.3923
16.0000	0.8932	23133.7765
17.0000	0.8928	23148.2351
18.0000	0.8916	23191.8348
19.0000	0.8887	23291.2662
20.0000	0.8826	23489.6270

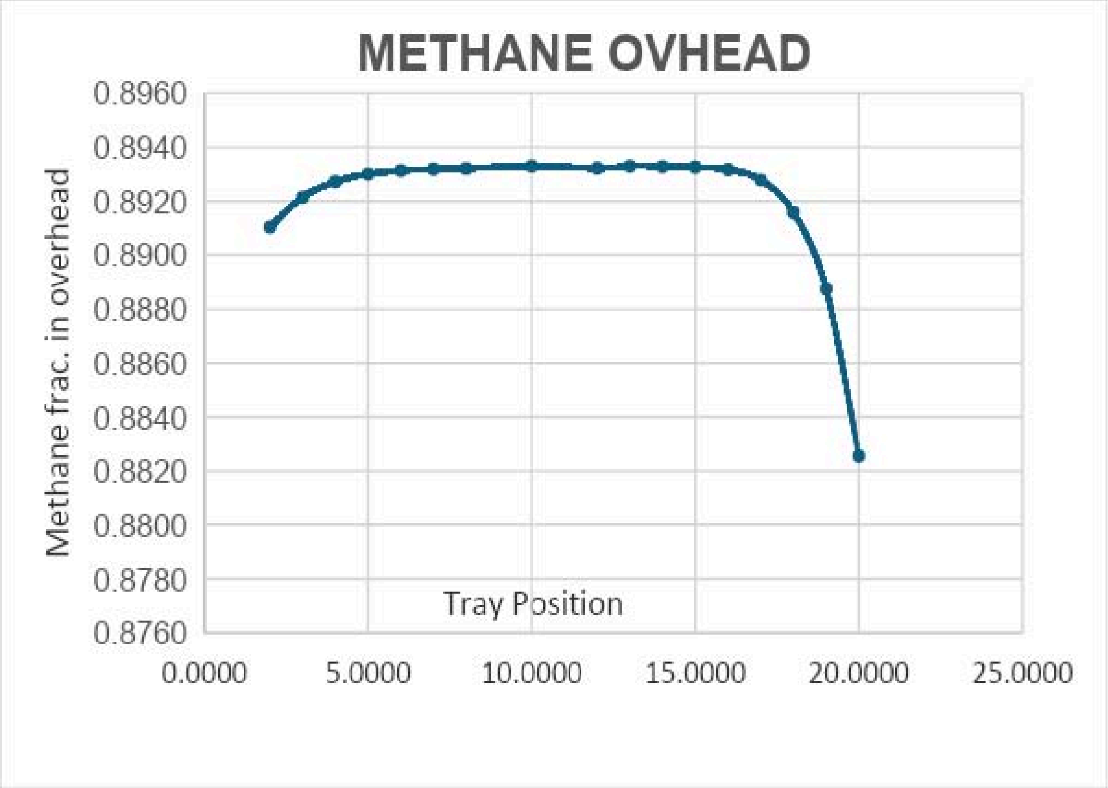


Figure 7: Feed tray vs. methane in column overhead for column with 20 trays

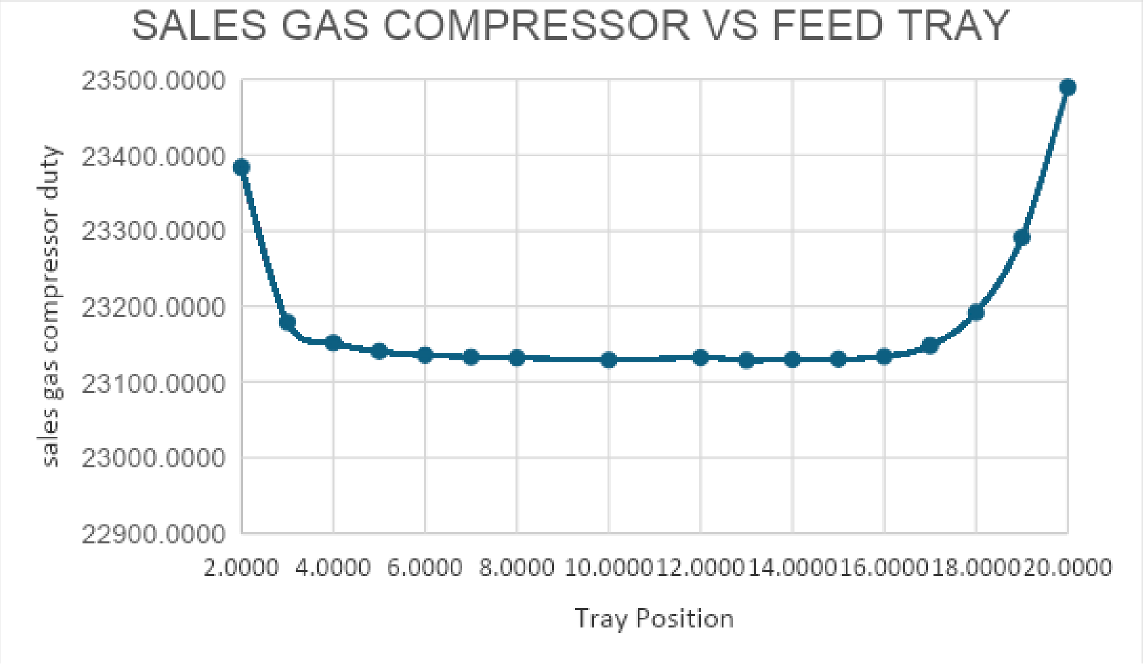


Figure 8: Feed trays vs. sale gas compressor power requirement for column with 20 trays

Column with 30 Trays

Table 5: Effect of tray position on methane fraction, NGL fraction in column overhead, and sales gas compressor power requirement for column with 30 trays

Tray	Methane	Power
3	0.8922	23176.8016
4.0000	0.8928	23149.3691
10.0000	0.8933	23128.0054
15.0000	0.8933	23128.3660
20.0000	0.8933	23129.1485
30.0000	0.8825	23489.8744

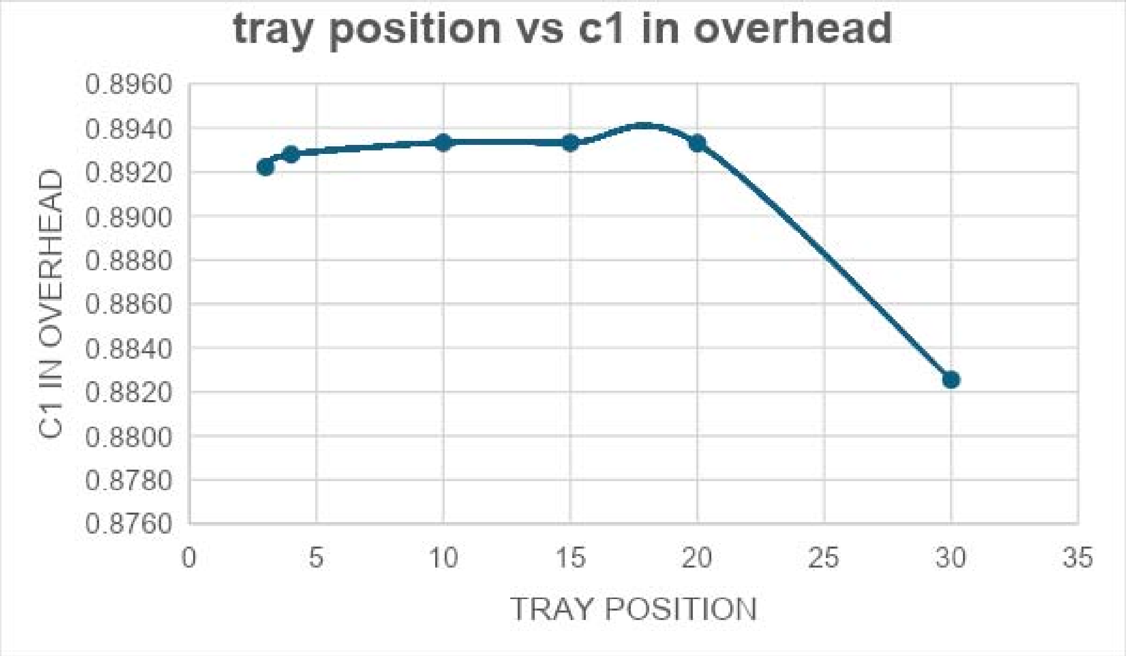


Figure 9: Feed trays vs. methane fraction in column overhead f or column with 30 trays

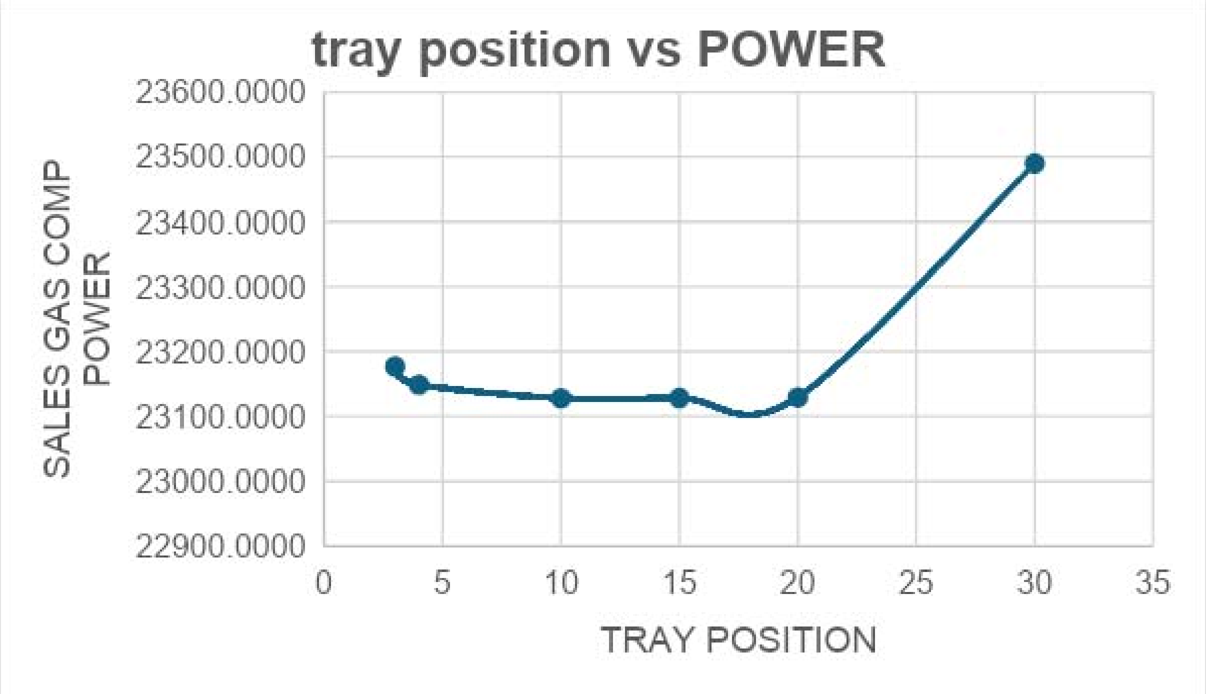


Figure 10: Feed trays vs. Sale gas compressor power requirement for column with 30 trays

c) *Optimum Feed Tray Position for Nth Number of Trays*

Table 6: Optimum feed tray position for different number of trays

No. of Trays	Optimum Feed Tray Position	Methane Fraction in Column Overhead
10	6	0.8930
20	13	0.8933
30	18	0.8940

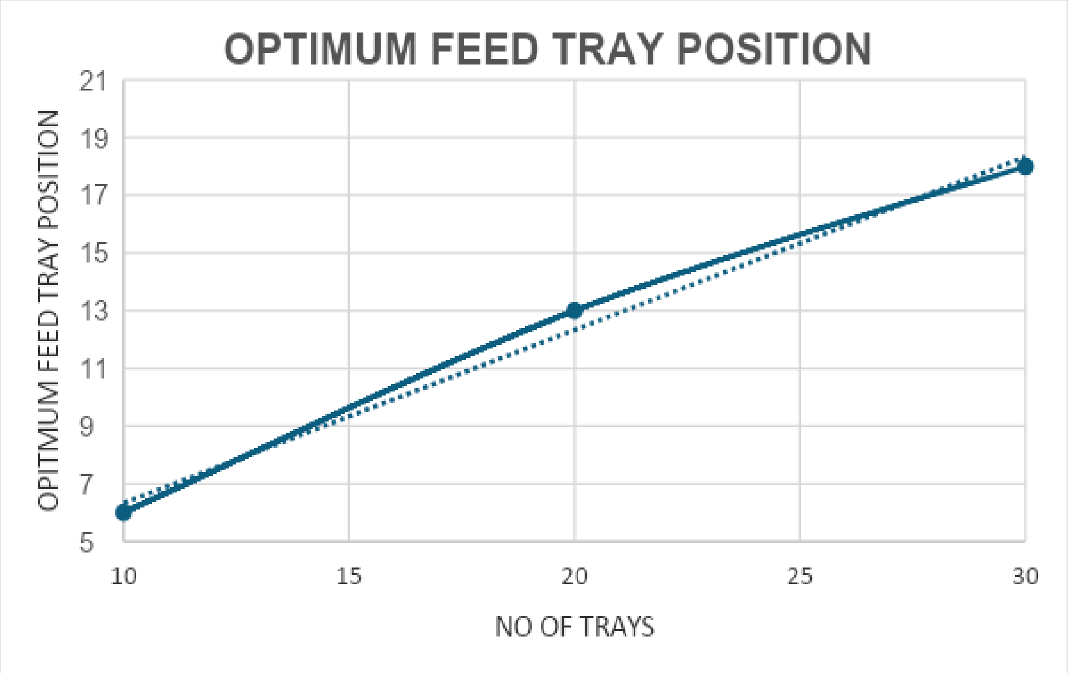


Figure 11: Graph showing optimum feed tray position for different number of trays

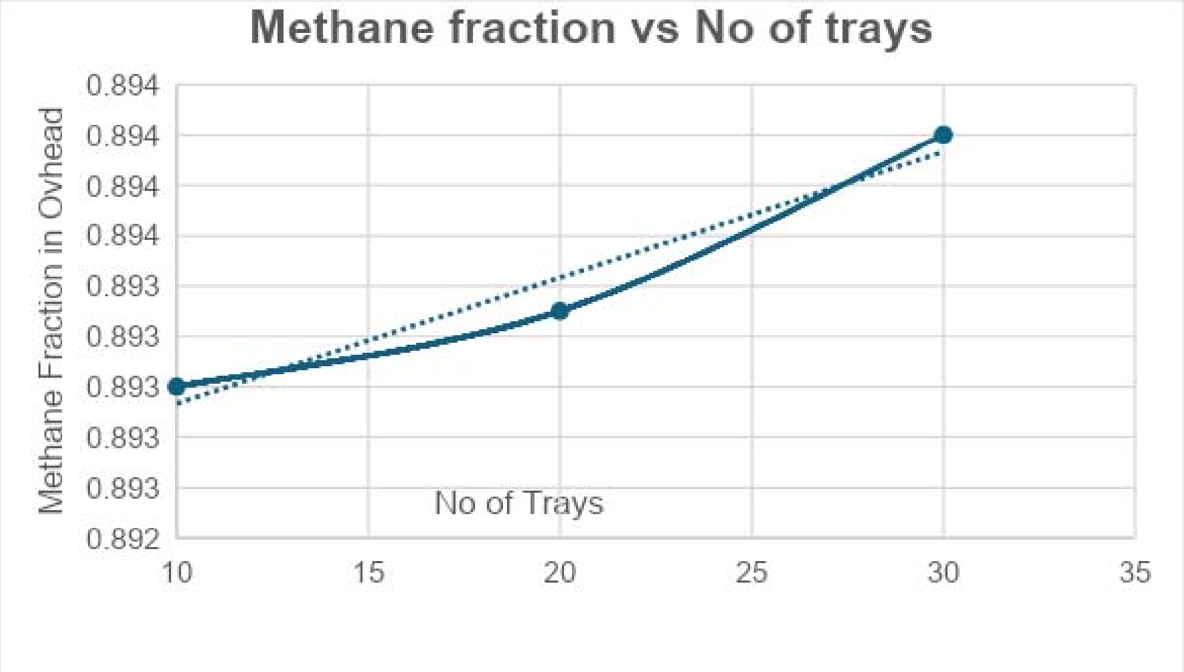


Figure 12: No of trays vs. methane fraction in the overhead

d) Discussion

i. *Effect of Recycle on Methane Recovery*

From figure 4 and table 2, it can be seen that the methane fraction in the overhead is maximum when there is no recycle, and keeps decreasing with increasing fraction of products recycle, and keeps decreasing till it gets to 80% recycle products where and increase is observed until another peak is reached in 90% recycle but not up to the maximum methane recovery as in when no products where recycled.

ii. *Optimum Feed Tray Position*

Column With 10 Trays

From figure 5, 6, 11 it can be seen that the tray that would give the maximum recovery of Methane in the column, overhead and the lowest sales compressor power requirement is the 6th tray. It can be observed in figure 5 that the recovery of methane keep rising until it reaches a peak at tray 6 and then keeps dropping it reaches the final tray. This goes to show that maximum recovery is not inversely proportional to recovery in the column overhead.

Column with 20 Trays

From figure 7, 8 It can be seen that the tray that would give the maximum recovery of Methane in the column, minimum NGL overflow in the column overhead and the lowest sales compressor power requirement is the 13th tray. It can be observed in figure 7 that the recovery of methane keep rising until it reaches a continuous peak at tray 5 and continuous through to tray 16, but reaches its maximum value at tray 13, after tray 16 it keeps dropping until it reaches the final tray. This goes to show that maximum recovery is not inversely proportional to recovery in the column overhead. An observation from this graph shows that this column gives us a wide range of tray number to choose from as they all give us nearly similar values; therefore, an optimum feed tray position can be chosen based on other economic factors apart from recovery alone.

Column with 30 Trays

From figure, 9, 10 it can be seen that the tray that would give the maximum recovery of Methane in the column overhead and the lowest sales compressor power requirement is the 18th tray.

It can be observed in figure 9 that the recovery of methane keep rising until it reaches a peak at tray 18 and then keeps dropping until it reaches the final tray 30.

e) Optimum Feed Tray Position for Nth Number of Trays

From table 8 the fraction of methane in the overhead increases with increasing number of trays, showing that a higher of trays will give higher recovery of methane in the column bottoms.

From figure 11 a 2nd order polynomial mathematical model was developed for determining the optimum feed tray location for a given number of trays.

The Mathematical model developed:

$$y = -0.01x^2 + x - 3 \ (R^2 = 1)$$

Equation 1

Where x = number of trays, y = the optimum feed tray position

A 2nd order polynomial mathematical model was developed for determining the maximum methane recovery in the column overhead for a given no of trays.

The Mathematical Model developed:

$$y = 2E\text{-}06x^2 - 3E\text{-}05x + 0.8931 \; (R^2 = 1)$$

Equation 2

Where X = Number of trays, Y = Fraction of methane overhead

From figure 12 a 2nd order polynomial mathematical model was developed for determining the minimum NGL fraction in the column overhead for a given no of trays.

The Mathematical Model developed:

$$y = 5E\text{-}07x^2 - 5E\text{-}05x + 0.0352 \; (R^2 = 1)$$

Equation 3

Where X = Number of trays, Y= Fraction of NGL overhead.

f) Testing the Model

Assuming our desired methane in the Overhead was 90% mass fraction, let's calculate the number of trays required for the desired separation and the Optimum feed tray position:

Using equation 2, we have 67 trays

Using equation 1 the Optimum Feed Tray Position is the 19th tray.

IV. CONCLUSION

The results from this work, are a framework for predicting the number of trays for a desired separation of methane and the optimum feed tray position for the calculated number of trays, for the specified natural gas composition.

It was discovered that the methane fraction increased with increasing number of trays. Different models were developed for calculating the Optimum feed tray location for any number of trays, and the % of methane in the column overhead. The models were tested for a 90% recovery for methane, and it was calculated to be 67 trays to achieve the desired separation, with tray 19 being the optimum feed tray location.

V. RECOMMENDATIONS

Simulation should be tested for other natural gas compositions to develop other models. Also, economic analysis varying the best feed tray position for a specified column should also be worked on.

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One must be persistent and creative in using keywords. An effective keyword search requires a strategy: planning of a list of possible keywords and phrases to try.

Choice of the main keywords is the first tool of writing a research paper. Research paper writing is an art. Keyword search should be as strategic as possible.

One should start brainstorming lists of potential keywords before even beginning searching. Think about the most important concepts related to research work. Ask, "What words would a source have to include to be truly valuable in a research paper?" Then consider synonyms for the important words.

It may take the discovery of only one important paper to steer in the right keyword direction because, in most databases, the keywords under which a research paper is abstracted are listed with the paper.

Numerical Methods

Numerical methods used should be transparent and, where appropriate, supported by references.

Abbreviations

Authors must list all the abbreviations used in the paper at the end of the paper or in a separate table before using them.

Formulas and equations

Authors are advised to submit any mathematical equation using either MathJax, KaTeX, or LaTeX, or in a very high-quality image.

Tables, Figures, and Figure Legends

Tables: Tables should be cautiously designed, uncrowned, and include only essential data. Each must have an Arabic number, e.g., Table 4, a self-explanatory caption, and be on a separate sheet. Authors must submit tables in an editable format and not as images. References to these tables (if any) must be mentioned accurately.

Figures

Figures are supposed to be submitted as separate files. Always include a citation in the text for each figure using Arabic numbers, e.g., Fig. 4. Artwork must be submitted online in vector electronic form or by emailing it.

PREPARATION OF ELETRONIC FIGURES FOR PUBLICATION

Although low-quality images are sufficient for review purposes, print publication requires high-quality images to prevent the final product being blurred or fuzzy. Submit (possibly by e-mail) EPS (line art) or TIFF (halftone/ photographs) files only. MS PowerPoint and Word Graphics are unsuitable for printed pictures. Avoid using pixel-oriented software. Scans (TIFF only) should have a resolution of at least 350 dpi (halftone) or 700 to 1100 dpi (line drawings). Please give the data for figures in black and white or submit a Color Work Agreement form. EPS files must be saved with fonts embedded (and with a TIFF preview, if possible).

For scanned images, the scanning resolution at final image size ought to be as follows to ensure good reproduction: line art: >650 dpi; halftones (including gel photographs): >350 dpi; figures containing both halftone and line images: >650 dpi.

Color charges: Authors are advised to pay the full cost for the reproduction of their color artwork. Hence, please note that if there is color artwork in your manuscript when it is accepted for publication, we would require you to complete and return a Color Work Agreement form before your paper can be published. Also, you can email your editor to remove the color fee after acceptance of the paper.

TIPS FOR WRITING A GOOD QUALITY ENGINEERING RESEARCH PAPER

Techniques for writing a good quality engineering research paper:

1. Choosing the topic: In most cases, the topic is selected by the interests of the author, but it can also be suggested by the guides. You can have several topics, and then judge which you are most comfortable with. This may be done by asking several questions of yourself, like "Will I be able to carry out a search in this area? Will I find all necessary resources to accomplish the search? Will I be able to find all information in this field area?" If the answer to this type of question is "yes," then you ought to choose that topic. In most cases, you may have to conduct surveys and visit several places. Also, you might have to do a lot of work to find all the rises and falls of the various data on that subject. Sometimes, detailed information plays a vital role, instead of short information. Evaluators are human: The first thing to remember is that evaluators are also human beings. They are not only meant for rejecting a paper. They are here to evaluate your paper. So present your best aspect.

2. Think like evaluators: If you are in confusion or getting demotivated because your paper may not be accepted by the evaluators, then think, and try to evaluate your paper like an evaluator. Try to understand what an evaluator wants in your research paper, and you will automatically have your answer. Make blueprints of paper: The outline is the plan or framework that will help you to arrange your thoughts. It will make your paper logical. But remember that all points of your outline must be related to the topic you have chosen.

3. Ask your guides: If you are having any difficulty with your research, then do not hesitate to share your difficulty with your guide (if you have one). They will surely help you out and resolve your doubts. If you can't clarify what exactly you require for your work, then ask your supervisor to help you with an alternative. He or she might also provide you with a list of essential readings.

4. Use of computer is recommended: As you are doing research in the field of research engineering then this point is quite obvious. Use right software: Always use good quality software packages. If you are not capable of judging good software, then you can lose the quality of your paper unknowingly. There are various programs available to help you which you can get through the internet.

5. Use the internet for help: An excellent start for your paper is using Google. It is a wondrous search engine, where you can have your doubts resolved. You may also read some answers for the frequent question of how to write your research paper or find a model research paper. You can download books from the internet. If you have all the required books, place importance on reading, selecting, and analyzing the specified information. Then sketch out your research paper. Use big pictures: You may use encyclopedias like Wikipedia to get pictures with the best resolution. At Global Journals, you should strictly follow here.

6. Bookmarks are useful: When you read any book or magazine, you generally use bookmarks, right? It is a good habit which helps to not lose your continuity. You should always use bookmarks while searching on the internet also, which will make your search easier.

7. Revise what you wrote: When you write anything, always read it, summarize it, and then finalize it.

8. Make every effort: Make every effort to mention what you are going to write in your paper. That means always have a good start. Try to mention everything in the introduction—what is the need for a particular research paper. Polish your work with good writing skills and always give an evaluator what he wants. Make backups: When you are going to do any important thing like making a research paper, you should always have backup copies of it either on your computer or on paper. This protects you from losing any portion of your important data.

9. Produce good diagrams of your own: Always try to include good charts or diagrams in your paper to improve quality. Using several unnecessary diagrams will degrade the quality of your paper by creating a hodgepodge. So always try to include diagrams which were made by you to improve the readability of your paper. Use of direct quotes: When you do research relevant to literature, history, or current affairs, then use of quotes becomes essential, but if the study is relevant to science, use of quotes is not preferable.

10. Use proper verb tense: Use proper verb tenses in your paper. Use past tense to present those events that have happened. Use present tense to indicate events that are going on. Use future tense to indicate events that will happen in the future. Use of wrong tenses will confuse the evaluator. Avoid sentences that are incomplete.

11. Pick a good study spot: Always try to pick a spot for your research which is quiet. Not every spot is good for studying.

12. Know what you know: Always try to know what you know by making objectives, otherwise you will be confused and unable to achieve your target.

13. Use good grammar: Always use good grammar and words that will have a positive impact on the evaluator; use of good vocabulary does not mean using tough words which the evaluator has to find in a dictionary. Do not fragment sentences. Eliminate one-word sentences. Do not ever use a big word when a smaller one would suffice.

Verbs have to be in agreement with their subjects. In a research paper, do not start sentences with conjunctions or finish them with prepositions. When writing formally, it is advisable to never split an infinitive because someone will (wrongly) complain. Avoid clichés like a disease. Always shun irritating alliteration. Use language which is simple and straightforward. Put together a neat summary.

14. Arrangement of information: Each section of the main body should start with an opening sentence, and there should be a changeover at the end of the section. Give only valid and powerful arguments for your topic. You may also maintain your arguments with records.

15. Never start at the last minute: Always allow enough time for research work. Leaving everything to the last minute will degrade your paper and spoil your work.

16. Multitasking in research is not good: Doing several things at the same time is a bad habit in the case of research activity. Research is an area where everything has a particular time slot. Divide your research work into parts, and do a particular part in a particular time slot.

17. Never copy others' work: Never copy others' work and give it your name because if the evaluator has seen it anywhere, you will be in trouble. Take proper rest and food: No matter how many hours you spend on your research activity, if you are not taking care of your health, then all your efforts will have been in vain. For quality research, take proper rest and food.

18. Go to seminars: Attend seminars if the topic is relevant to your research area. Utilize all your resources.

19. Refresh your mind after intervals: Try to give your mind a rest by listening to soft music or sleeping in intervals. This will also improve your memory. Acquire colleagues: Always try to acquire colleagues. No matter how sharp you are, if you acquire colleagues, they can give you ideas which will be helpful to your research.

20. Think technically: Always think technically. If anything happens, search for its reasons, benefits, and demerits. Think and then print: When you go to print your paper, check that tables are not split, headings are not detached from their descriptions, and page sequence is maintained.

21. Adding unnecessary information: Do not add unnecessary information like "I have used MS Excel to draw graphs." Irrelevant and inappropriate material is superfluous. Foreign terminology and phrases are not apropos. One should never take a broad view. Analogy is like feathers on a snake. Use words properly, regardless of how others use them. Remove quotations. Puns are for kids, not grunt readers. Never oversimplify: When adding material to your research paper, never go for oversimplification; this will definitely irritate the evaluator. Be specific. Never use rhythmic redundancies. Contractions shouldn't be used in a research paper. Comparisons are as terrible as clichés. Give up ampersands, abbreviations, and so on. Remove commas that are not necessary. Parenthetical words should be between brackets or commas. Understatement is always the best way to put forward earth-shaking thoughts. Give a detailed literary review.
22. Report concluded results: Use concluded results. From raw data, filter the results, and then conclude your studies based on measurements and observations taken. An appropriate number of decimal places should be used. Parenthetical remarks are prohibited here. Proofread carefully at the final stage. At the end, give an outline to your arguments. Spot perspectives of further study of the subject. Justify your conclusion at the bottom sufficiently, which will probably include examples.
23. Upon conclusion: Once you have concluded your research, the next most important step is to present your findings. Presentation is extremely important as it is the definite medium though which your research is going to be in print for the rest of the crowd. Care should be taken to categorize your thoughts well and present them in a logical and neat manner. A good quality research paper format is essential because it serves to highlight your research paper and bring to light all necessary aspects of your research.

Informal Guidelines of Research Paper Writing

Key points to remember:

- Submit all work in its final form.
- Write your paper in the form which is presented in the guidelines using the template.
- Please note the criteria peer reviewers will use for grading the final paper.

Final points:

One purpose of organizing a research paper is to let people interpret your efforts selectively. The journal requires the following sections, submitted in the order listed, with each section starting on a new page:

The introduction: This will be compiled from reference matter and reflect the design processes or outline of basis that directed you to make a study. As you carry out the process of study, the method and process section will be constructed like that. The results segment will show related statistics in nearly sequential order and direct reviewers to similar intellectual paths throughout the data that you gathered to carry out your study.

The discussion section:

This will provide understanding of the data and projections as to the implications of the results. The use of good quality references throughout the paper will give the effort trustworthiness by representing an alertness to prior workings.

Writing a research paper is not an easy job, no matter how trouble-free the actual research or concept. Practice, excellent preparation, and controlled record-keeping are the only means to make straightforward progression.

General style:

Specific editorial column necessities for compliance of a manuscript will always take over from directions in these general guidelines.

To make a paper clear: Adhere to recommended page limits.

Mistakes to avoid:

- Insertion of a title at the foot of a page with subsequent text on the next page.
- Separating a table, chart, or figure—confine each to a single page.
- Submitting a manuscript with pages out of sequence.
- In every section of your document, use standard writing style, including articles ("a" and "the").
- Keep paying attention to the topic of the paper.

- Use paragraphs to split each significant point (excluding the abstract).
- Align the primary line of each section.
- Present your points in sound order.
- Use present tense to report well-accepted matters.
- Use past tense to describe specific results.
- Do not use familiar wording; don't address the reviewer directly. Don't use slang or superlatives.
- Avoid use of extra pictures—include only those figures essential to presenting results.

Title page:

Choose a revealing title. It should be short and include the name(s) and address(es) of all authors. It should not have acronyms or abbreviations or exceed two printed lines.

Abstract: This summary should be two hundred words or less. It should clearly and briefly explain the key findings reported in the manuscript and must have precise statistics. It should not have acronyms or abbreviations. It should be logical in itself. Do not cite references at this point.

An abstract is a brief, distinct paragraph summary of finished work or work in development. In a minute or less, a reviewer can be taught the foundation behind the study, common approaches to the problem, relevant results, and significant conclusions or new questions.

Write your summary when your paper is completed because how can you write the summary of anything which is not yet written? Wealth of terminology is very essential in abstract. Use comprehensive sentences, and do not sacrifice readability for brevity; you can maintain it succinctly by phrasing sentences so that they provide more than a lone rationale. The author can at this moment go straight to shortening the outcome. Sum up the study with the subsequent elements in any summary. Try to limit the initial two items to no more than one line each.

Reason for writing the article—theory, overall issue, purpose.

- Fundamental goal.
- To-the-point depiction of the research.
- Consequences, including definite statistics—if the consequences are quantitative in nature, account for this; results of any numerical analysis should be reported. Significant conclusions or questions that emerge from the research.

Approach:

- Single section and succinct.
- An outline of the job done is always written in past tense.
- Concentrate on shortening results—limit background information to a verdict or two.
- Exact spelling, clarity of sentences and phrases, and appropriate reporting of quantities (proper units, important statistics) are just as significant in an abstract as they are anywhere else.

Introduction:

The introduction should "introduce" the manuscript. The reviewer should be presented with sufficient background information to be capable of comprehending and calculating the purpose of your study without having to refer to other works. The basis for the study should be offered. Give the most important references, but avoid making a comprehensive appraisal of the topic. Describe the problem visibly. If the problem is not acknowledged in a logical, reasonable way, the reviewer will give no attention to your results. Speak in common terms about techniques used to explain the problem, if needed, but do not present any particulars about the protocols here.

The following approach can create a valuable beginning:

- Explain the value (significance) of the study.
- Defend the model—why did you employ this particular system or method? What is its compensation? Remark upon its appropriateness from an abstract point of view as well as pointing out sensible reasons for using it.
- Present a justification. State your particular theory(-ies) or aim(s), and describe the logic that led you to choose them.
- Briefly explain the study's tentative purpose and how it meets the declared objectives.

Approach:

Use past tense except for when referring to recognized facts. After all, the manuscript will be submitted after the entire job is done. Sort out your thoughts; manufacture one key point for every section. If you make the four points listed above, you will need at least four paragraphs. Present surrounding information only when it is necessary to support a situation. The reviewer does not desire to read everything you know about a topic. Shape the theory specifically—do not take a broad view.

As always, give awareness to spelling, simplicity, and correctness of sentences and phrases.

Procedures (methods and materials):

This part is supposed to be the easiest to carve if you have good skills. A soundly written procedures segment allows a capable scientist to replicate your results. Present precise information about your supplies. The suppliers and clarity of reagents can be helpful bits of information. Present methods in sequential order, but linked methodologies can be grouped as a segment. Be concise when relating the protocols. Attempt to give the least amount of information that would permit another capable scientist to replicate your outcome, but be cautious that vital information is integrated. The use of subheadings is suggested and ought to be synchronized with the results section.

When a technique is used that has been well-described in another section, mention the specific item describing the way, but draw the basic principle while stating the situation. The purpose is to show all particular resources and broad procedures so that another person may use some or all of the methods in one more study or referee the scientific value of your work. It is not to be a step-by-step report of the whole thing you did, nor is a methods section a set of orders.

Materials:

Materials may be reported in part of a section or else they may be recognized along with your measures.

Methods:

- Report the method and not the particulars of each process that engaged the same methodology.
- Describe the method entirely.
- To be succinct, present methods under headings dedicated to specific dealings or groups of measures.
- Simplify—detail how procedures were completed, not how they were performed on a particular day.
- If well-known procedures were used, account for the procedure by name, possibly with a reference, and that's all.

Approach:

It is embarrassing to use vigorous voice when documenting methods without using first person, which would focus the reviewer's interest on the researcher rather than the job. As a result, when writing up the methods, most authors use third person passive voice.

Use standard style in this and every other part of the paper—avoid familiar lists, and use full sentences.

What to keep away from:

- Resources and methods are not a set of information.
- Skip all descriptive information and surroundings—save it for the argument.
- Leave out information that is immaterial to a third party.

Results:

The principle of a results segment is to present and demonstrate your conclusion. Create this part as entirely objective details of the outcome, and save all understanding for the discussion.

The page length of this segment is set by the sum and types of data to be reported. Use statistics and tables, if suitable, to present consequences most efficiently.

You must clearly differentiate material which would usually be incorporated in a study editorial from any unprocessed data or additional appendix matter that would not be available. In fact, such matters should not be submitted at all except if requested by the instructor.

Content:

- Sum up your conclusions in text and demonstrate them, if suitable, with figures and tables.
- In the manuscript, explain each of your consequences, and point the reader to remarks that are most appropriate.
- Present a background, such as by describing the question that was addressed by creation of an exacting study.
- Explain results of control experiments and give remarks that are not accessible in a prescribed figure or table, if appropriate.
- Examine your data, then prepare the analyzed (transformed) data in the form of a figure (graph), table, or manuscript.

What to stay away from:

- Do not discuss or infer your outcome, report surrounding information, or try to explain anything.
- Do not include raw data or intermediate calculations in a research manuscript.
- Do not present similar data more than once.
- A manuscript should complement any figures or tables, not duplicate information.
- Never confuse figures with tables—there is a difference.

Approach:

As always, use past tense when you submit your results, and put the whole thing in a reasonable order.

Put figures and tables, appropriately numbered, in order at the end of the report.

If you desire, you may place your figures and tables properly within the text of your results section.

Figures and tables:

If you put figures and tables at the end of some details, make certain that they are visibly distinguished from any attached appendix materials, such as raw facts. Whatever the position, each table must be titled, numbered one after the other, and include a heading. All figures and tables must be divided from the text.

Discussion:

The discussion is expected to be the trickiest segment to write. A lot of papers submitted to the journal are discarded based on problems with the discussion. There is no rule for how long an argument should be.

Position your understanding of the outcome visibly to lead the reviewer through your conclusions, and then finish the paper with a summing up of the implications of the study. The purpose here is to offer an understanding of your results and support all of your conclusions, using facts from your research and generally accepted information, if suitable. The implication of results should be fully described.

Infer your data in the conversation in suitable depth. This means that when you clarify an observable fact, you must explain mechanisms that may account for the observation. If your results vary from your prospect, make clear why that may have happened. If your results agree, then explain the theory that the proof supported. It is never suitable to just state that the data approved the prospect, and let it drop at that. Make a decision as to whether each premise is supported or discarded or if you cannot make a conclusion with assurance. Do not just dismiss a study or part of a study as "uncertain."

Research papers are not acknowledged if the work is imperfect. Draw what conclusions you can based upon the results that you have, and take care of the study as a finished work.

- You may propose future guidelines, such as how an experiment might be personalized to accomplish a new idea.
- Give details of all of your remarks as much as possible, focusing on mechanisms.
- Make a decision as to whether the tentative design sufficiently addressed the theory and whether or not it was correctly restricted. Try to present substitute explanations if they are sensible alternatives.
- One piece of research will not counter an overall question, so maintain the large picture in mind. Where do you go next? The best studies unlock new avenues of study. What questions remain?
- Recommendations for detailed papers will offer supplementary suggestions.

Approach:

When you refer to information, differentiate data generated by your own studies from other available information. Present work done by specific persons (including you) in past tense.

Describe generally acknowledged facts and main beliefs in present tense.

THE ADMINISTRATION RULES

Administration Rules to Be Strictly Followed before Submitting Your Research Paper to Global Journals Inc.

Please read the following rules and regulations carefully before submitting your research paper to Global Journals Inc. to avoid rejection.

Segment draft and final research paper: You have to strictly follow the template of a research paper, failing which your paper may get rejected. You are expected to write each part of the paper wholly on your own. The peer reviewers need to identify your own perspective of the concepts in your own terms. Please do not extract straight from any other source, and do not rephrase someone else's analysis. Do not allow anyone else to proofread your manuscript.

Written material: You may discuss this with your guides and key sources. Do not copy anyone else's paper, even if this is only imitation, otherwise it will be rejected on the grounds of plagiarism, which is illegal. Various methods to avoid plagiarism are strictly applied by us to every paper, and, if found guilty, you may be blacklisted, which could affect your career adversely. To guard yourself and others from possible illegal use, please do not permit anyone to use or even read your paper and file.

Criterion for Grading a Research Paper (Compilation) by Global Journals

Please note that following table is only a Grading of "Paper Compilation" and not on "Performed/Stated Research" whose grading solely depends on Individual Assigned Peer Reviewer and Editorial Board Member. These can be available only on request and after decision of Paper. This report will be the property of Global Journals.

Topics	Grades		
	A-B	**C-D**	**E-F**
Abstract	Clear and concise with appropriate content, Correct format. 200 words or below	Unclear summary and no specific data, Incorrect form Above 200 words	No specific data with ambiguous information Above 250 words
Introduction	Containing all background details with clear goal and appropriate details, flow specification, no grammar and spelling mistake, well organized sentence and paragraph, reference cited	Unclear and confusing data, appropriate format, grammar and spelling errors with unorganized matter	Out of place depth and content, hazy format
Methods and Procedures	Clear and to the point with well arranged paragraph, precision and accuracy of facts and figures, well organized subheads	Difficult to comprehend with embarrassed text, too much explanation but completed	Incorrect and unorganized structure with hazy meaning
Result	Well organized, Clear and specific, Correct units with precision, correct data, well structuring of paragraph, no grammar and spelling mistake	Complete and embarrassed text, difficult to comprehend	Irregular format with wrong facts and figures
Discussion	Well organized, meaningful specification, sound conclusion, logical and concise explanation, highly structured paragraph reference cited	Wordy, unclear conclusion, spurious	Conclusion is not cited, unorganized, difficult to comprehend
References	Complete and correct format, well organized	Beside the point, Incomplete	Wrong format and structuring

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ISSN 9755861