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MASTER OF SCIENCE IN HYDROCARBON PROCESSING ENGINEERING

UNDERSTANDING THE CHALLENGES FACED IN CONTROLLING MOISTURE CONTENT IN THE GAS FLOW LINES

A Dissertation by

Jean Aimable INSHUTITURIKUMWE

Maputo

January, 2024

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Supervisor

António José Cumbane

Maputo,January 2024

DECLARATION OF DOCUMENT ORIGINALITY

"I declare that this dissertation has never been submitted to obtain any degree or in any other context and is the result of my own individual work. This dissertation is presented in partial fulfillment of the requirements for the degree of Master of Science in Hydrocarbon Processing Engineering, from the Universidade Eduardo Mondlane".

Submitted by:

Jean Aimable INSHUTITURIKUMWE

Signature

ABSTRACT

Natural gas, a fossil fuel derived from plants, animals, and microorganisms, is a sustainable and eco-friendly alternative to oil and coal. It accounts for 23.8% of global primary energy consumption and is used in the production of essential chemicals like hydrogen, fertilizers, and plastics. However, natural gas extraction often generates water vapour, which poses challenges for transportation and treatment of raw natural gas. Glycol dehydration is the primary technique used to eliminate water vapour, this research aims to understand these challenges, design a dehydration process using Aspen software, investigate operating parameters, and study the impact of triethylene glycol on the absorption process. The goal is to enhance water removal efficiency in the absorption dehydration unit using TEG glycol, contributing to process design improvement.

Aspen HYSYS was used to simulate the dehydration process and the results are being presented in this report. It has been found a clear relationship between water content in dry gas and inlet gas flow rate. Higher flow rates reduce contact time between gas and glycol in the absorber, resulting in more gas carrying over and higher water content in dry gas. The reboiler temperature, also affects the moisture content in gas. The TEG flow rate is another parameter that was found to affect moisture content in gas, the simulation results also shows that higher TEG flow rates decrease gas moisture content in gas but increase glycol loss and BTEX emissions.

Key words: Natural gas, fossil fuel, dehydration, glycol, Aspen, BTEX emissions

DEDICATION

I dedicate this work to all my family, especially to my parents and brother for their support and for all the help they gave me during the realization of this work

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Above all, I offer my heartfelt gratitude to the Almighty for showering me with boundless blessings, strength, knowledge, and opportunities that have enabled me to successfully conclude my studies and research.

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CHAPTER I

INTRODUCTION

1.1. Introduction

Natural gas is the most important and popular fossil fuel in the current era and future as well (Abdulrahman & Sebastine, 2013), natural gas is classified as a gaseous fossil fuel, which is derived from the remnants of plants, animals, and microorganisms that thrived millions of years in the past. Fossil fuels, including natural gas, are essentially composed of the organic matter that accumulated over extensive periods of time (Teg et al., 2015).The composition of this substance primarily comprises methane, although it also contains substantial amounts of ethane, propane, butane, and pentane. Methane is a compound consisting of a single carbon atom bonded with four hydrogen atoms (Anyadiegwu et al., 2014).

Natural gas, predominantly methane, has been known and utilized since the ancient Greek and Chinese civilizations. Natural gas began playing a significance role in the energy market as early as the 1780s, during the start of the industrial revolution, where it was used in the United Kingdom as a source of lighting for homes and streets. By the mid-1880s, Baltimore became the pioneering city in the United States to adopt natural gas for street lighting purposes (El-halwagi et al., 2019).

Currently, natural gas holds the position as the predominant energy source for both household consumption and as a raw material in the petrochemical sector (Nzeribe & Obah, 2022). Natural gas plays a vital role in our daily lives as it serves as a crucial fuel source and a primary provider of energy for various essential activities and requirements (Anyadiegwu et al., 2014)**.** Natural gas is widely regarded as the most ecologically sustainable fossil fuel, making it a crucial contender in the global energy landscape. Due to its minimal environmental impact, it is anticipated to experience a significant surge in prominence as a primary source of energy worldwide (Neagu & Cursaru, 2017)**.** It is one of the cleanest, safest and most useful of all energy resources, typically, dry natural gas is what is being referred to always as natural gas (Fawehinmi, 2017). Today, natural gas holds a significant share of around 23.8% in the global primary energy consumption. Projections indicate that this proportion is anticipated to experience a steady annual growth rate of 1.6% from 2015 to 2035 (Kong et al., 2018b)**,** The power and industrial sectors are responsible for more than 80% of the increase in global natural gas demand (Faramawy et al., 2016)**.** Since its initial use by Robert Bunsen in 1885, natural gas has found widespread application as a fuel source for cooking, heating, and electricity generation. Over time, advancements in technology and distribution networks have allowed for the utilization of natural gas in various sectors, including residential, commercial, industrial, and electricity power generation. Moreover, natural gas serves as a valuable raw material for the production of essential chemicals like hydrogen, fertilizers, and plastics (Kong et al., 2018b)**.**

There are three main sources of raw natural gas: oil wells, gas wells, and condensate wells. When natural gas is extracted from oil wells, it is referred to as 'associated gas'. This gas either can exist independently from oil in the reservoir (free gas) or be dissolved in the crude oil (dissolved gas). On the other hand, natural gas obtained from gas and condensate wells, where there is minimal or no crude oil present is known as non-associated gas. Gas wells primarily produce raw natural gas on its own, while condensate wells yield both free natural gas and a semi-liquid hydrocarbon condensate (Teg et al., 2015).Whatever the source of the natural gas, once separated from crude oil it commonly exists in raw natural gas or sour gas (Anyadiegwu et al., 2014).

Natural gas plays a crucial role as a primary energy source in human existence. As oil reserves continue to deplete, the significance of natural gas as an alternative fossil fuel grows exponentially. Nevertheless, in order to meet the necessary standards for commercial utilization, it is imperative to remove all acid gas compounds, namely H_2S and CO_2. Additionally, the elimination of hydrocarbon and water, which exist as free liquid in natural gas streams, is equally essential (Affandy et al., 2017). The primary purpose of the natural gas dehydration process is to eliminate the water present in the gas. This is important because water vapor and hydrocarbons can cause the formation of gas hydrates, which can block the gas flow of gas through pipelines and equipment, especially in control systems , the water vapor contributes to the corrosion of pipelines especially in the presence of acidic gases (Kharisma et al., 2020).

There exist multiple techniques for dehydrating natural gas, including liquid desiccant (glycol) dehydration, solid desiccant dehydration, and gas cooling. In the liquid desiccant and solid desiccant methods, the water molecules are transferred into a liquid solvent (glycol solution) or a crystalline structure (dry desiccant) through mass transfer. On the other hand, the gas cooling method involves lowering the temperature of the gas below its initial dew point, causing the water molecules to condense into a liquid phase. To prevent the formation of hydrates, an inhibitor is subsequently injected into the gas (Mokhatab & Poe, 2012).

1.2. Research problem

Natural gas extraction frequently leads to the generation of significant quantities of water vapor, typically reaching saturation levels. The presence of water vapor in a gas stream poses serious problems for the transportation and treatment of natural gas. This includes the formation of gas hydrates, blockages in pipelines, corrosion, reduced capacity of the lines, and decreased efficiency in combustion efficiency (Rouzbahani et al., 2014). The accumulation of liquids in pipelines can cause increased operating pressures and potential equipment damage due to liquid carryover (Taylor, 2010).

Glycol dehydration stands as the predominant technique employed in the industry for eliminating water vapor from natural gas. By extracting a significant portion of the water vapor present in the natural gas, this method relies on various factors including feed composition, glycol purity, glycol flow rate, water content in dry gas, glycol feed temperature and pressure. However, the glycol regeneration process is limited by the maximum allowable reboiler temperature.

1.3 Research objectives

The research objectives have been categorized as general objective and specific Objective.

1.3.1 General objective

The general objective of this work is**:**

- To understand the challenges faced in controlling moisture content in the gas flow lines;

1.3.2. Specific objectives:

- To design and simulate a process of dehydration using Aspen software;
- To investigate the effect of operating parameters on the efficiency of the process;
- To study the effect of quantity triethlylene glycol in the absorption process;
- Compare the plant result and simulation result.

1.4. Motivation, contribution, significance

In the previous section, an overview of the natural gas processing and dehydration processes has been discussed. The process of gas dehydration is essential to meet the necessary gas sale standards because the existence of water and hydrocarbons can cause hydrate formation, leading to problems like line blockages and pipeline corrosion, especially when acid gases are present. This is why it is necessary to dehydrate natural gas before transporting it over long distances through pipelines to prevent liquid water condensation and maintain efficient operation (Taylor, 2010)

This research will be a major step forward in order to make significant progress in exploring ways to enhance the efficiency of water removal from gas in the absorption dehydration unit using TEG glycol. This research aims to identify the operating parameter that yields the best performance, thereby contributing to the improvement of the process design.

1.5. Summary

Natural gas, a type of fossil fuel, is a sustainable and eco-friendly alternative to oil and coal. It currently holds a significant market share of 23.8% in global primary energy consumption and finds application in the manufacturing of crucial chemicals. However, natural gas extraction often generates water vapor, posing challenges for transportation and treatment. To address this issue, the glycol dehydration process is used to remove water vapor, this research aims to understand these challenges faced during the process of removing water in natural gas, design a dehydration process using Aspen software, investigate operating parameters, and study the effect of triethlylene glycol in the absorption process.

CHAPTER II

LITERATURE REVIEW

2.1. Introduction

The purpose of this chapter is to provide a detailed explanation of the origins of natural gas, the gas hydrate, natural gas processing, requirements for water content, and the methods used for removing water from natural gas. This thorough explanation will help in gaining valuable knowledge for the precise simulation process and the subsequent comparison of outcomes.

2.1.1. Natural gas origin and sources

There exist various explanations regarding the genesis of fossil fuels. The most widely accepted theory about the source of natural gas suggests that it comes from organic matter, like the remains of plants, animals, and microorganisms from both land and water. These organic materials are trapped in sediments during their deposition and undergo a long process of transformation, eventually becoming fossil fuels. The breakdown of the original organic material in the sediments is believed to occur through two main mechanisms: biogenic and thermogenic (Mokhatab et al., 2018).Methane is produced through the biogenic process, which occurs when living organisms, specifically methanogenic bacteria, interact with organic materials during sediment deposition and early stages of burial. On the other hand, the thermogenic process involves the gradual decomposition of organic matter in sedimentary basins due to the influence of temperature and pressure, particularly as depth increases. This decomposition reaction is believed to give rise to natural gas, known as thermogenic methane, as well as petroleum (Faramawy et al., 2016).

Hydrocarbons are produced within the "source rock" and frequently migrate towards subsurface formations known as "reservoir rock." The reservoir rock's quality is determined by two primary properties: porosity and permeability. Porosity refers to the empty spaces between the grains, indicating the rock's capacity to hold liquid or gaseous hydrocarbons. On the other hand, permeability measures the rock's ability to transmit oil or gas. The geological characteristics of the reservoir rock vary, leading to differences in natural gas resources. In fact, natural gas can originate from both "conventional" and "unconventional" geological formations (Mokhatab et al., 2018). Conventional gas is trapped in naturally porous reservoir formations that are capped with impermeable rock strata. When intercepted by a well, gas is able to move to the surface without the need to pump while unconventional gas is formed in more complex geological formations which limit the ability of gas to migrate and therefore different methods are required to extract the gas (ZOU et al., 2018). The figure below shows the geological formations of natural gas.

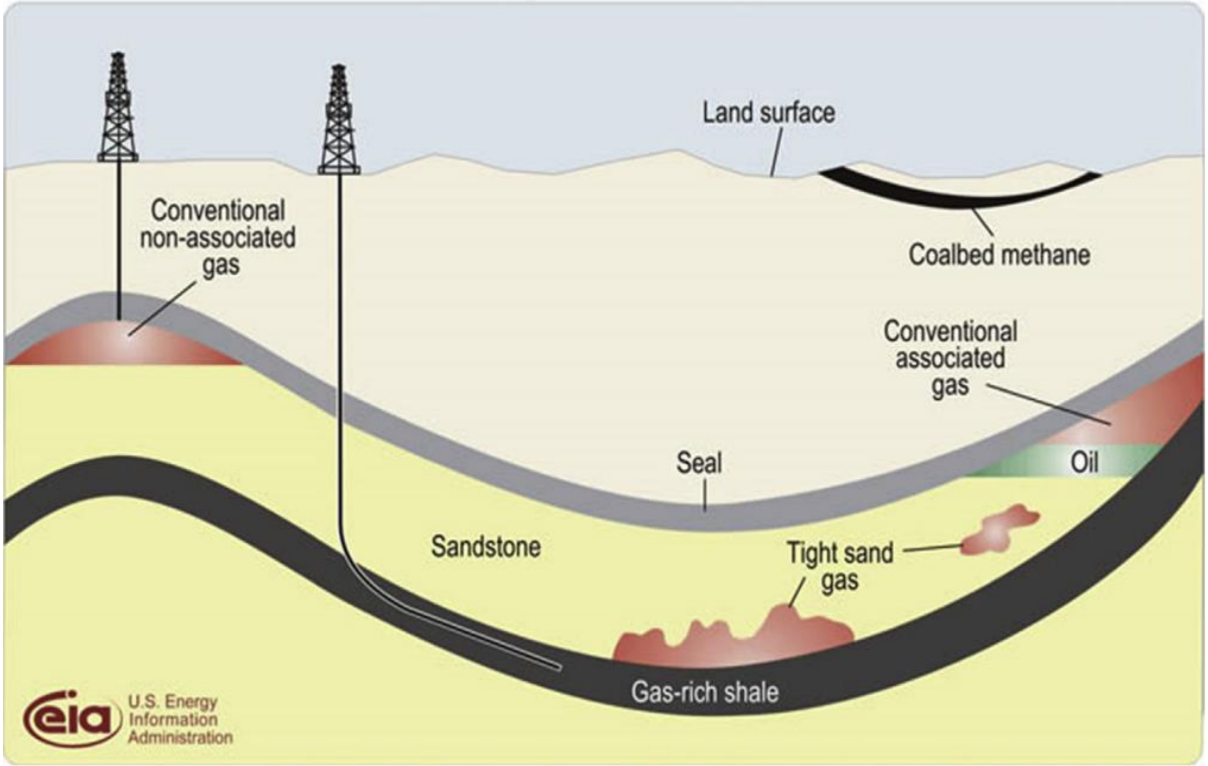

Figure 1: geology of natural gas resources (Mokhatab et al., 2018)

2.1.2. Natural gas composition

Natural gas plays a crucial role in meeting the global energy demand. In its pure form, it is colorless, shapeless, and odorless. It is a combustible gas, and it gives off a significant amount of energy when burned. When compared to other fossil fuels like coal and crude oil, natural gas is widely regarded as an environmentally friendly and clean source of fuel (coal and crude oil) (Faramawy et al., 2016).Natural gas primarily consists of methane (CH_4), but it can also contain significant amounts of ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and pentane (C_5H_{12}), along with traces of hexane (C_6H_{14}) and heavier hydrocarbons (Anyadiegwu et al., 2014).

Additionally, natural gases often contain nitrogen (N_2), carbon dioxide (CO_2), hydrogen sulfide (H_2S), and other sulfur components like mercaptans (R-SH), carbonyl sulfide (COS), and carbon disulfide (CS_2). In addition to these components, there may be trace quantities of argon, hydrogen, and helium. It is crucial to highlight the presence of metallic elements such as arsenic, selenium, mercury, and uranium in natural gases (Mokhatab et al., 2018).

In order to meet the requirements for a pure and fully gaseous fuel that can be transported through pipelines and distributed for combustion by end users, the gas must go through several processing stages. These stages involve the removal of any liquid substances in the gas, followed by a drying process to decrease the water content (Teg et al., 2015).

2.1.3. Natural gas processing

Natural gas, a naturally occurring fossil fuel has become a popular energy source in recent years due to its environmental merit over alternate fossil energy sources (Marfo et al., 2020), during the process of exploring and extracting natural gas, a substantial amount of water vapor is usually produced. However, these impurities need to be eliminated through gas treatment procedures in order to avoid potential problems during transportation to the customers (Nemati `Rouzbahani et al., 2014). Dehydration is a crucial process in the treatment of natural gas where water vapor composition in natural gas is reduced to ensure trouble free operation in the natural gas transmission systems. The presence of water vapor in the gas can lead to the formation of hydrates in the pipelines during transportation, resulting in blockages and corrosion. Additionally, it can diminish the combustion efficiency and volumetric capacity of the system, induce blockage of valve fittings, compression systems, process equipment, and instrumentation, and potentially cause equipment damage due to liquid carryover. This is particularly significant when the natural gas contains high levels of CO_2 and H_2S (Sarker, 2020).

The gas found at the wellhead of a reservoir is referred to as "wet gas" if it contains other hydrocarbons. The composition of this "wet gas" depends on factors such as the type, depth, and location of the underground deposit, along with the geology of the field. On the other hand, natural gas is classified as "dry" gas when it consists mainly of methane (CH4) with the majority of other hydrocarbons removed. The gas processing applied to raw natural gas to achieve pipeline-quality dry natural gas is a complicated process that typically entails several steps like Phase of separation used to separate the wet gas and liquids; gas sweetening unit which is it main function is to remove Hydrogen Sulphide (H_2S) and Carbon Dioxide(CO_2) from the gas to meet sales gas specification; another one is dehydration used in order to removal of water from sweet gas is made by contacting the gas with triethylene glycol solution (Sai & Varma, 2022). Figure 2 below shows a block flow diagram of a typical processing plant for natural gas. It comprises the separation unit, where condensates and produced water are removed, followed by the treatment and sweetening stage, where sulfur and acid are removed. After the sweetening stage, the gas is compressed and then dehydrated. The obtained dry gas could be sold as gas or further processed to LPG.

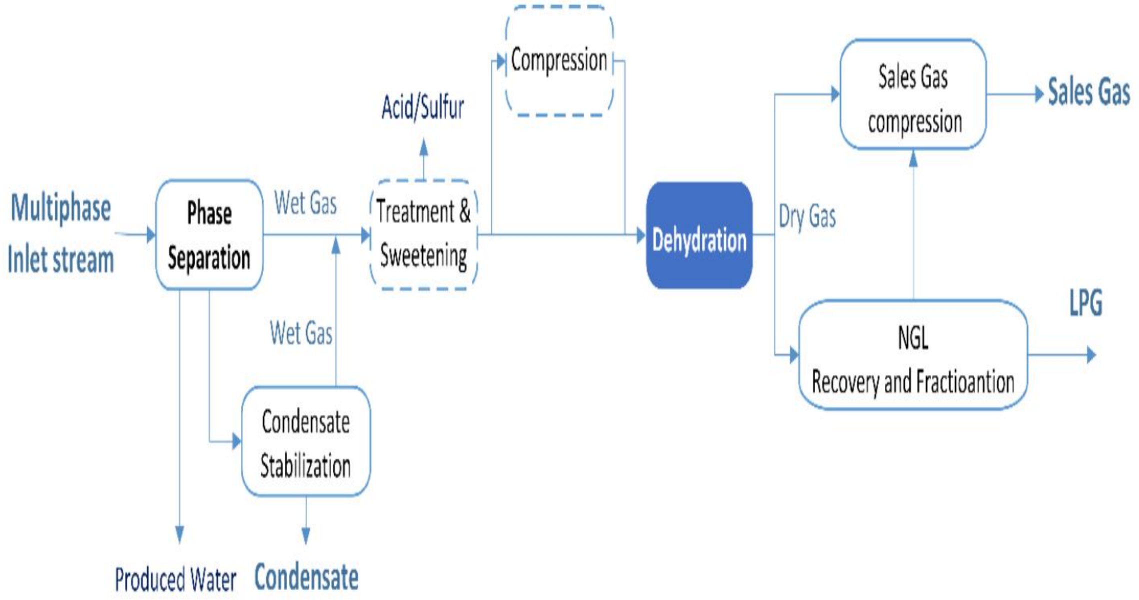

Figure 2: A typical flowsheet of natural gas processing plant (I. Abdulrahman, 2022)

2.1.4. Gas hydrates

Gas hydrates are complex structures made up of water molecules arranged in a crystalline pattern. These structures are similar to dirty ice but have empty spaces that can hold gas molecules. The most common substances found in these empty spaces are water, methane, and propane, or sometimes water, methane, and ethane(Paul M. Muchinsky, 2012). Gas hydrates are a caged structure containing a gas molecule like methane, the cage is formed by water through hydrogen bonding, as illustrated in figure below.

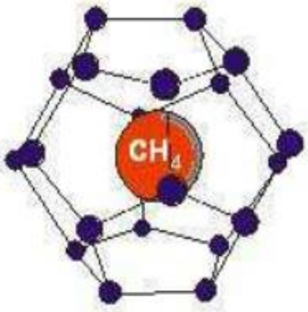

Figure 3: Gas hydrate (Isa, 2009)

In natural gas processing, hydrates are solid formations where water molecules form a lattice structure and encase molecules of CH_4, C_2H_6, CO_2, or H_2S. The water molecules are connected to each other through hydrogen bonds and they are tied to the guest molecules through Van der Waals interactions. These solid structures are a source of erosion and plugging, this latter is particularly troublesome, as decomposition of hydrates during removal can generate large volumes of gas with explosion hazards (Faruque, 2022)**.** The figure below shows the Hydrate formation in natural gas pipeline.

Figure 4: Hydrate formation in natural gas transmission pipeline (Fang et al., 2020).

2.1.5. Water Content Specification

The goal of natural gas dehydration is to reach a particular level of water content, or even lower. The specific value is determined through an agreement between the buyer and seller, as there are no universally accepted standards for natural gas. Different countries may have different limits in place (Kong et al., 2018b).

In the United States, the typical water content requirement for gas is 112mg of water per standard m^3 (7lb/MMCF), while in Canada it is 64 mg/Sm^3 (4 lb/MMCF). It is important to note that these water content requirements may vary between countries and regions. Each country may have its own specific guidelines and regulations regarding the acceptable water content in gas. These guidelines are put in place to ensure the quality and safety of the gas being produced and distributed (Carroll, 2009).

2.2. Natural gas dehydration

Dehydration is the process of removing water from natural gas, commonly used to prevent the formation of hydrates. When there is no water present, hydrates cannot form, it is important to note that even a small amount of water can increase the risk of hydrate formation. Therefore, efficient dehydration systems are essential in maintaining the integrity and reliability of natural gas transportation and processing infrastructure. These systems not only prevent hydrate-related issues but also contribute to the overall safety and efficiency of the natural gas industry (Carroll, 2009).

There are several key justifications for the extraction of water from natural gas. These include the need to prevent potential hazards, to ensure safe gas processing and transmission systems. The major reasons for removing the water from natural gas are:

- Natural gas in the right conditions can combine with liquid or free water to form solid hydrates that can plug valve fittings or even pipelines;
- Water can condense in the pipeline, causing slug flow and possible erosion;
- Water vapor increases the volume and decreases the heating value of the gas;
- Sales gas contracts and/or pipeline specifications often have to meet the maximum water content of 7 lb H2O per MMscf.

Dehydration methods commonly used in the natural gas industry include absorption, adsorption, and refrigeration (cooling) processes. Absorption involves passing the gas through a liquid desiccant, such as glycol, which selectively absorbs the water molecules. Adsorption, on the other hand, utilizes solid desiccants, such as molecular sieves, to adsorb the water vapor. Refrigeration processes involve cooling the gas to temperatures below the hydrate formation point, causing the water to condense and separate from the gas. Several other dehydration methods are less commonly used, and they are not discussed here.

It is important to note that the selection of a specific dehydration technique depends on the desired purity level of the natural gas, the flow rate, the composition of the gas stream, and other factors. Each technique has its advantages and disadvantages in terms of cost, energy consumption, efficiency, and maintenance requirements (Mokhatab & Poe, 2012).

2.2.1. Liquid Desiccants

There are several liquids that have the ability to remove moisture from the gas flow. However, only a few liquids meet the necessary criteria for a suitable commercial application. Some of the criteria of commercial suitability are as follows:

- The absorbing liquid should be highly hygroscopic (i.e., it must have a strong affinity for water);
- The hydrocarbon components of natural gas should have a low solubility in the solvent to minimize the loss of desired product and to reduce hydrocarbon emissions;
- The desiccant should be easily regenerated to higher concentration for reuse, usually by the application of heat, which drives off the absorbed water;
- The desiccant should have a very low vapor pressure to reduce the amount of solvent losses due to vaporization;
- The desiccant should exhibit thermal stability, particularly in the high temperature ranges found in the reboiler;
- Suitable solutions should not solidify in the temperature ranges expected in the process of dehydration;
- All liquids must be noncorrosive to the selected metallurgy of all dehydration equipment, especially the reboiler vapor space, the stripping column of regenerator and the bottom of the contactor;

- The liquid desiccants should not chemically react with any of the natural gas constituents, including carbon dioxide and sulfur compounds (Carroll, 2009).

2.2.2. Glycols

Glycols, which are organic compounds, have properties that make them suitable for commercial applications. The glycols have demonstrated their effectiveness as liquid desiccants in various industrial application due to their remarkable hygroscopicity properties, low vapor pressure, high boiling points and lower solubility in natural gas (Kazemi, 2014) In the industry, there are four different types of glycol dehydration methods that are commonly used: ethylene glycol (EG), diethylene glycol (DEG), triethylene glycol (TEG), and tetraethylene glycol (TREG) (Gandhidasan et al., 2001).

When choosing the glycol for natural gas dehydration, it is important to consider factors such as the lower circulation rate, glycol viscosity, and foaming tendencies. While DEG is cheaper to buy compared to TEG, however DEG has a larger carryover loss, offers less dew point depression, and regeneration to high concentration is more difficult. Considering all these factors, TEG is widely acknowledged as the most economical choice for natural gas dehydration. It offers better performance in terms of dew point depression, lower loss during the process, and easier regeneration to a high concentration. As a result, most glycol dehydrators use TEG as the preferred glycol for natural gas dehydration (Taylor, 2010). TEG, also known as triethylene glycol, is a colorless, odorless, viscous liquid with the chemical formula $C_6H_{14}O_4$ as shown in figure 6 below. It is a type of glycol that is commonly used as a dehydrating agent in natural gas processing and as a component in various industrial applications such as in the production of plastics, resins, and textiles. TEG is also used as a solvent in the pharmaceutical and cosmetic industries. The figure below shows the chemical structure of triethylene glycol (TEG).

Figure 5: Chemical structure of triethylene glycol (TEG) (Aldrich, 2012)

The previous section discussed the four different types of glycol; each type of glycol has its own unique properties that make it suitable for specific applications. The table provided below illustrates the properties of the commonly used glycols in the dehydration process.

Table 1: Properties of common glycols which are used in dehydration process (Kazemi, 2014)

Parameter	EG	DEG	TEG	TREG
Chemical name	Ethylene glycol	Diethylene glycol	Triethylene Glycol	Tetraethylene Glycol
Molecular formula	$C_2H_6O_2$	$C_4H_{10}O_3$	$C_6H_{14}O_4$	$C_6H_{18}O_5$
Molecular weight, g/mol	62.1	106.1	150.2	194.2
Density, g/cm^3	1.110	1.114	1.1255	1.247
Boiling point, ℃	197.1	245.3	288.0	329.7
Degradation Temperature, ℃	163	177	204-206	224
Vapor pressure at 25℃ (Pa)	12.24	0.3	0.05	0.007
Viscosity at 25 ℃ (cp)	17.71	30.21	36.73	42.71
On set of decomposition ℃	-	240	240	240

2.2.3. Glycol dehydration process

The liquid desiccant process consists of two steps. In the first step, the water is absorbed from the feed gas in a staged tower. Then, the solvent is regenerated in a separate column. The regenerated solvent is then returned to the first column to remove water from more gas. Figure 6 shows a simplified diagram of the glycol dehydration process (Carroll, 2009).

Glycol dehydration units are commonly represented by various components such as an absorber (glycol contactor), a flash tank, heat exchangers, a reboiler, a condenser, and circulation pump. The combination of these components in a glycol dehydration unit allows for the efficient removal of water vapor from natural gas streams, ensuring the production of dry gas that meets the required specifications(Kazemi, 2014). The figure below shows the natural gas dehydration process.

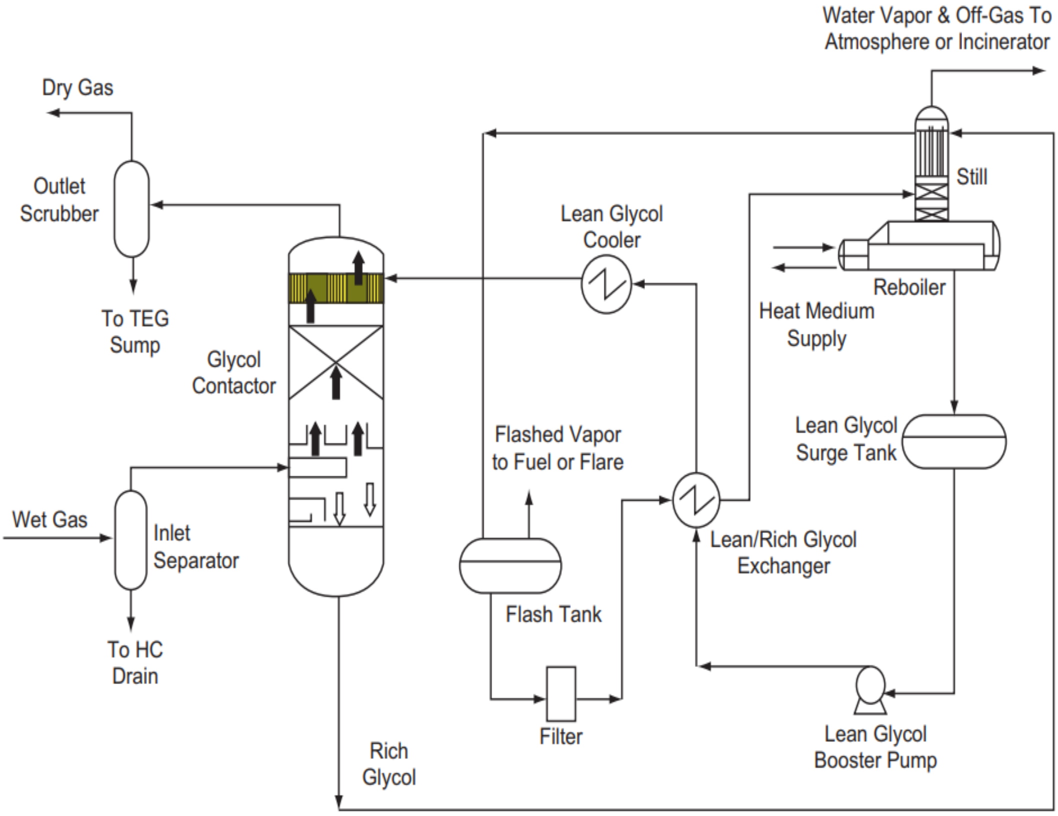

Figure 6: Simple flow diagram of the natural gas dehydration process (Mokhatab & Poe, 2012)

During this process the wet gas enters at the bottom of the absorber and the lean glycol (TEG) enters at the top of the contactor, it absorbs the water contained in the wet gas which is entering from the bottom. The dry gas exits at the top of the contactor at the required water dew point while the rich glycol (TEG) is sent to the regenerator from the bottom for further processing (Anyadiegwu et al., 2014).The rich solvent that leaves the absorber is then treated and regenerated by removing the absorbed water and hydrocarbons (Neagu & Cursaru, 2017), In order to achieve the desired outcome, it is necessary to decrease the pressure of the glycol (TEG) from the absorber to match that of the regenerator (Trueba et al., 2022).

The rich triethylene glycol (TEG) flows through a coil, serving as reflux at the uppermost part of the absorption column in order to raise its temperature, the rich TEG is then directed to the flash tank. The flash tank uses high temperature and low pressure to extract light ends components from absorbed gas. Rich TEG is then filtered to remove solid particles (Anyadiegwu et al., 2014). The filtered rich TEG is passed through a plate-type heat exchanger to conserve heat during regeneration (Affandy et al., 2017). Before entering the regenerator column, the rich TEG is preheated in a glycol-glycol heat exchanger to prepare it for the next stages of the process (Affandy et al., 2020).

The reboiler temperature and pressure can be adjusted to control glycol purity in the regenerator. To prevent glycol degradation, it is common to keep the reboiler temperature below 400^{o}F, some operators choose to limit the reboiler temperature to a narrower range of 370^{o}F to 390^{o}F, reducing the temperature of the reboiler helps prevent glycol degradation. Controlling the reboiler temperature and pressure in the glycol regenerator is crucial for maintaining the purity of the glycol and preventing degradation (Mokhatab et al., 2019). The top products of the regenerator column are water vapor, a small amount of glycol, and volatile organic compounds, whereas the bottom product is lean glycol (TEG) which contains a small amount of water. The lean glycol (TEG) is transferred from the regenerator column to the glycol accumulator through heat exchangers to preserve heat energy, before being sent back to the TEG contactor for dehydration (Affandy et al., 2020).

2.2.4. Operational problems

There are several operational challenges that can arise in the functioning of a glycol regeneration unit such as corrosion, glycol contamination, the release of hazardous substances, and the loss of glycol etc., these operational challenges require careful monitoring, maintenance, and proactive measures to ensure the safe and efficient functioning of glycol regeneration units.

2.2.4.1. Corrosion

The primary cause of corrosion issues in glycol systems is typically the thermal degradation of the glycol. This degradation process leads to the creation of organic acids, which in turn lower the pH of the glycol and ultimately contribute to corrosion (Moore et al., 2008).

Another possible source for corrosion is by components entering the system with the rich glycol. CO_2 and H_2S are known to be highly corrosive in combination with free water, and are also soluble in glycol. Dehydration of feed gases with high concentrations of sour gases may therefore require sour gas removal prior to dehydration. To prevent corrosion in the regeneration system different methods can be used. One method is to use corrosion-resistant alloys during manufacturing; another approach is to add corrosion inhibitors to the glycol solution. additionally, optimizing the regeneration process by minimizing temperatures and velocities can also help prevent corrosion (Bråthen, 2008).

2.2.4.2. Emission of hazardous compounds

During the dehydration process, the glycol solvent absorbs different volatile organic compounds (VOCs), including benzene, toluene, ethylbenzene, and various isomers of xylene, which are collectively known as BTEX. However, when the thermal regeneration process of TEG occurs, a considerable amount of BTEX and VOCs are released into the environment, leading to harmful effects on both the environment and human health. As a result, strict regulations have become necessary to tackle these negative consequences (Mukherjee & Diwekar, 2021). A large amount of the BTEX gases are emitted from the top of the regenerator, while a smaller amount is released from the flash vapor stream. The presence of these BTEX gases during the dehydration process has been associated with foaming, flooding, decreased efficiency in dehydration, and higher maintenance costs for the absorber. It is crucial to note that these BTEX gases are known to be irritants or carcinogens, and their direct release into the environment can have significant environmental impacts. It is important to implement efficient control measures for BTEX gases. One effective approach is installing emission control systems, like vapor recovery units, to capture and treat the gases before release. Regular monitoring and maintenance of the regenerator and flash vapor stream can reduce emissions and ensure safe dehydration process (Kong et al., 2018a).

2.2.4.3. Contamination of the glycol

Glycol contamination is a common problem that arises during the operation of glycol regeneration units due to different causes. Corrosion products, together with solid particles brought in by the rich glycol, can lead to fouling of heat exchanger surfaces by deposition and ultimately plugging of heat exchanger pipes. Glycols also absorb salts at low temperatures, which again are desorbed at high temperatures, leading to extensive salt depositions in heat exchangers and on reboiler fire tubes if not handled (Bråthen, 2008).

2.2.4.4. Glycol loss

Glycol loss constitutes one of the most important operating problems of dehydration units. Most of this loss occurs as carry-over of solution with the product gas, although a small amount of glycol is lost by vaporization into the gas stream. An additional small amount is always lost through mechanical leakage, and some may be lost with the vapors leaving the regenerator (L. Kohl, Richard B. Nielsen,1997). To improve dehydration unit efficiency and cost-effectiveness, it's crucial to reduce glycol loss. This can be achieved by addressing leaks, minimizing evaporation, decreasing glycol degradation, and implementing proper maintenance. This reduces glycol loss, resulting in financial savings and optimal unit performance (Carroll, 2009).

2.3. Solid desiccant dehydration

Adsorption, also known as solid bed dehydration, is a widely used technique in various industries to remove water vapor from a gas stream. It involves the use of a solid desiccant material, which has a high affinity for water molecules, to attract and retain the water vapor present in the gas (Farag et al., 2011)**.**

During this process, the water in the gas stream attaches itself to the solid phase, which usually consists of a molecular sieve. As a result, the water is effectively separated from the natural gas. Molecular sieves are frequently used in situations that require an extremely low moisture level, such as in cryogenic processes (Carroll, 2009).

2.3.1. Solid desiccant Selection

Different solid desiccants can be found in the market, each designed for specific applications. While some desiccants are effective only in removing moisture from gases, others have the capability to both dehydrate the gas and eliminate heavy hydrocarbon components. Choosing the appropriate desiccant for a particular application is a challenging task. When it comes to solid desiccants used in gas dehydration, the following properties are desirable:

- High adsorption capacity at equilibrium. This lowers the required adsorbent volume, allowing for the use of smaller vessels with reduced capital expenditures and reduced heat input for regeneration;
- High selectivity. This minimizes the undesirable removal of valuable components and reduces overall operating expenses;
- Easy regeneration. The relatively low regeneration temperature minimizes overall energy requirements and operating expenses;
- Low pressure drop;
- Good mechanical properties (such as high crush strength, low attrition, low dust formation, and high stability against aging). These factors lower overall maintenance requirements by reducing the frequency of adsorbent change out and minimizing downtime-related losses in production;
- Cheap, noncorrosive, nontoxic, chemically inert, high bulk density and no significant volume changes upon adsorption and desorption of water (Mokhatab & Poe, 2012).

There are several types of desiccants that have proven to be effective in removing water from natural gas due to their suitable physical properties, the three basic materials are used most commonly because they possess these characteristics in a satisfactory manner which are: Activated alumina, Silica gel and silica-alumina gel, Molecular sieves (Farag et al., 2011).

A table below shows the comparison of the physical properties of each desiccant:

Table 2: Comparison of the physical properties of desiccants used for dehydration of natural gas (Netušil & Additional, 2012)

Properties	Silica gel	Alumina	Molecular sieves
Specific area (m^2/g)	750-830	210	650-800
Pore Volume (cm^3/g)	0,4-0,45	0,21	0,27
Pore diameter(Å)	22	26	4-5
Design capacity (kg H_20/100kg desiccant)	7-9	4-7	9-12
Density (kg/m^3)	721	800-880	690-720
Heat capacity (J/kg/^oC)	920	240	200
Regeneration temperature (^OC)	230	240	290
Heat of desorption (J)	3256	4183	3717

When it comes to selecting the appropriate desiccant for a particular process, several factors need to be taken into consideration such as equipment expenses, lifespan, and suitability for the specific process requirements. In the majority of adsorption facilities, the proper design and operation play a more crucial role than the actual selection of adsorbents (Gandhidasan et al., 2001).

2.3.2. Adsorption Process Description

The adsorption of water vapor from a gas stream is a semi-batch process. Therefore, at least two beds are required. One bed is in the adsorption phase, and the other is in the regeneration or cooling phase. During the adsorption step, the gas to be processed is sent on the adsorbent bed, which selectively retains the water, as the bed adsorbs water it becomes saturated, and that portion of the bed can no longer adsorb water. When the bed is saturated, hot gas is sent to regenerate the adsorbent. Regeneration is achieved via application of heat. Thus a hot gas stream is passed through the bed to strip the water and regenerate the bed. Following the stripping stage, the bed must be cooled before it can be placed back in service (Carroll, 2009). The figure below show a simplified flow diagram for a solid desiccant dehydration plant

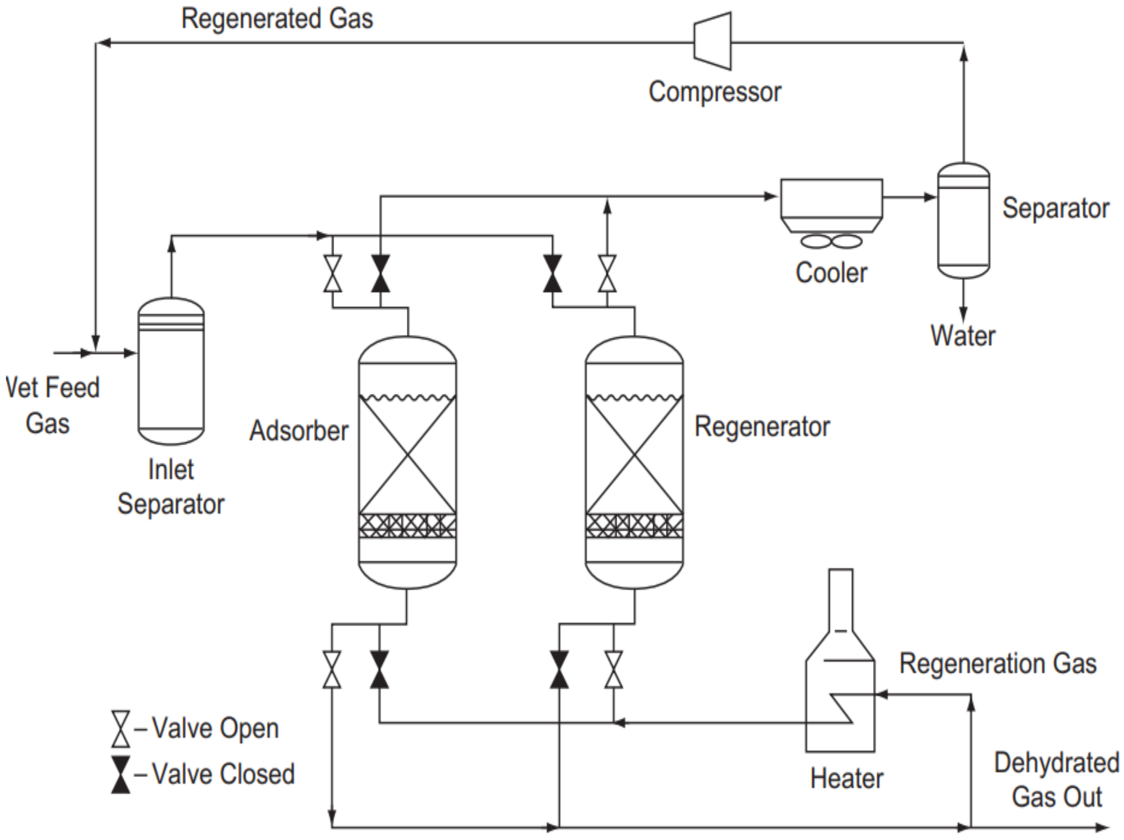

Figure 7: Simplified flow diagram for a solid desiccant dehydration plant (Mokhatab & Poe, 2012)

2.4. Condensation dehydration process

This method employs cooling process of gas to convert the water molecule into liquid and then remove from the stream. The condensation technology uses refrigeration of natural gas and once refrigerated the water condensates and thereafter can be removed from the wet gas (Kinigoma & Ani, 2016).

In this process the wet natural gas is throttled in two steps inside the flash tanks. The lower temperature (due to the Joule-Thompson effect) of the gas stream in the flash tanks leads to partial condensation of the water vapors. The droplets that are created are removed from the gas stream by a demister inside the flashes. Essential part of the system is injection of hydrate inhibitors (methanol or Mono Ethylene Glycol – MEG). This prevents hydrate formation and thus plugging. In cases where cooling by the Joule-Thompson effect is insufficient (the usable pressure difference between the inlet and outlet of the gas is insufficient), the air pre-cooler and the external cooler are turned on. A condensation method is applied when suitable conditions for the Joule-Thompson effect are available (Netušil & Ditl, 2010). The figure below shows the process of dehydration method utilizing the Joule-Thompson effect.

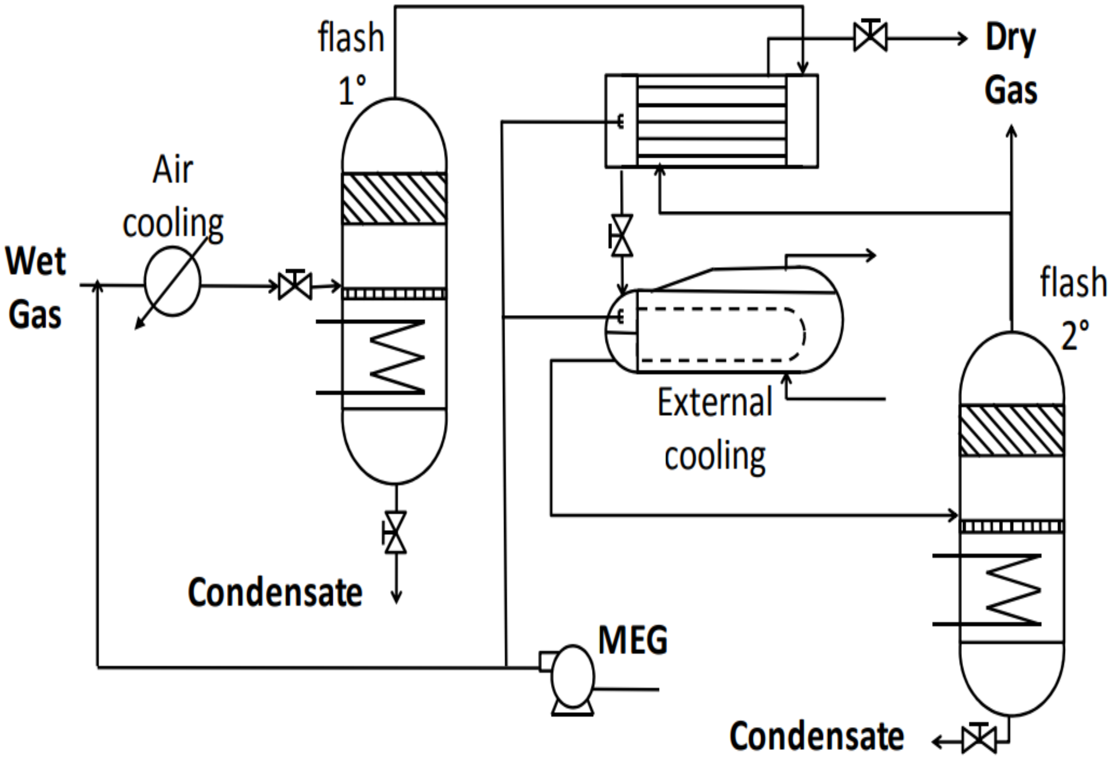

Figure 8: Dehydration method utilizing The JT effect and hydrate inhibition (Kinigoma & Ani, 2016)

Among the various processes that have been discussed, it is generally considered that absorption using liquid desiccant is more economically feasible. This is because it requires less energy comparatively to other methods (Anyadiegwu et al., 2014). Furthermore, the advantage of using liquid desiccant is that it can be continuously changed without requiring a shutdown, unlike the adsorption bed which needs to be replaced. Another benefit of using liquid desiccant, particularly glycols, is the presence of hydroxyl groups that facilitate the formation of hydrogen bonds. These bonds are similar to the ones formed between water molecules, making glycol a highly effective absorber of water (Paymooni et al., 2011). Furthermore, TEG is the preferred choice among glycols due to its regeneration capability, low thermal degradation rates in the regeneration systems and its minimal thermal degradation as explained earlier. As a result, this study will only focus on the typical gas dehydration process based on Absorption by liquid desiccant.

2.5. Summary

Natural gas is a crucial global energy source, primarily composed of methane and other combustible gases. It undergoes several processing stages, including the removal of liquid substances and drying to decrease water content. Dehydration is a crucial process in natural gas transportation and processing infrastructure to prevent the formation of hydrates, which can cause hazards and damage to pipelines and valve fittings. Efficient dehydration systems are essential for maintaining the integrity and reliability of natural gas transportation and processing infrastructure.

Dehydration methods commonly used in the natural gas industry include absorption, adsorption, and refrigeration (cooling) processes. Absorption involves passing the gas through a liquid desiccant, such as glycol, which selectively absorbs the water molecules. Adsorption uses solid desiccants to adsorb the water vapor, while refrigeration processes involve cooling the gas to temperatures below the hydrate formation point, causing the water to condense and separate from the gas. The efficient dehydration systems are essential for the natural gas industry to ensure the safe and reliable transportation and processing of this valuable energy source. By removing water vapor and preventing hydrate formation, these systems help maintain the integrity of pipelines, reduce the risk of equipment failure, and ensure a steady supply of natural gas to meet global energy demands.

CHAPTER III

3. RESEARCH METHODS AND STRATEGIES

3.1. Introduction

The dehydration of natural gas is very important in the gas processing industry. It is necessary to remove water vapor present in a gas stream that may cause hydrate formation at low-temperature conditions that may plug the valves and fittings in gas pipelines. The most effective practice to remove water from natural gas streams is to use TEG in the gas dehydration process (Twu et al., 2005).In order to achieve the established objectives, the gas dehydration process, like other engineering processes can be simulated using commercially available process simulators, such as Aspen Hysys (Marfo et al., 2020). It can handle multiphase flow modeling, gas processing and refinery reactors making it the best choice for modeling and optimization of hydrocarbon processes from wellhead to sales point (Felicia & Evbuomwan, 2015). Process simulation reduces the operating cost of a plant in the long run especially when much effort is put in the search of the optimal design condition of the process through optimisation studies (Marfo et al., 2020).

3.2. Natural Gas composition

The process of natural gas dehydration using TEG was carried out in Aspen HYSYS. Figure 9 illustrates the flow diagram of a standard dehydration and TEG regeneration process, which was further explained by the equipment employed. The gas composition data and feed stream composition data were obtained from the plant which has two reservoir, A and B. Table 3 contains detailed information on the specific gas composition obtained from the plant while the table 4 explain the operating condition of the plant.

Table 3: Natural gas composition plant data

Component names	**mole %**	
	Reservoir A	**Reservoir B**
Methane	0,9179	0,9405
Ethane	0,0295	0,0169
Propane	0,0131	0,0058
i-Butane	0,0021	0,002
n-Butane	0,007	0,0018
i-Pentane	0,0013	0,001
n-Pentane	0,0019	0,0007
n-Hexane	0,0029	0,0011
n-Heptane	0.0013	0,0003
n-Octane	0,0015	0,0006
n-Nonane	0,0005	0,0002
n- Decane	0,0005	0,0002
n- C11	0,0001	0,0001
n-C12	0	0
Methyl cyclopentane	0	0,0002
Cyclohexane	0,0001	0,0004
Methyl cyclohexane	0,0007	0,0003
Carbon Monoxide	0	0,0029
Nitrogen	0,0147	0,0001
Water	0,012	0,0248
Toluene	0,0001	0,0001
E-Benzene	0	0
m-Xylene	0,0001	0
o-Xylene	0	0
n-propyl benzene	0	0

Table 4: Plant operating condition

Plant operating condition	
Inlet gas flow rate	23700 kgmole/h
Inlet gas temperature	30 ^{o}C
Inlet gas pressure	1650 kPa
TEG flow rate	2100 kgmole/h

3.3. Description of the simulated process

The TEG-dehydration process consists of two main stages: gas dehydration and solvent regeneration. In the dehydration stage, TEG is used to remove water from the gas. In the following regeneration stage, water is separated from the solvent. The TEG-dehydration process is an efficient and effective method for removing water from natural gas. It ensures that the gas meets the required specifications for transportation and processing, while also allowing for the recovery and reuse of the TEG solvent (Kazemi, 2014). The TEG natural gas dehydration unit operates at relatively high pressure on the contactor side and low pressure on the regeneration side. The high-pressure side consists of the glycol contactor and the inlet separator. The low-pressure side consists of the regenerator and the flash tank and associated equipment (Carroll, 2009).

Gas extracted from reservoirs A and B is transported to the plant for processing where it passes through the inlet facility to eliminate water content from the gas before proceeding to the production separator for further processing. The process of gas dehydration and TEG regeneration process is shown in figure 9 and the rest of this section discusses the individual components of the dehydration process in some detail.

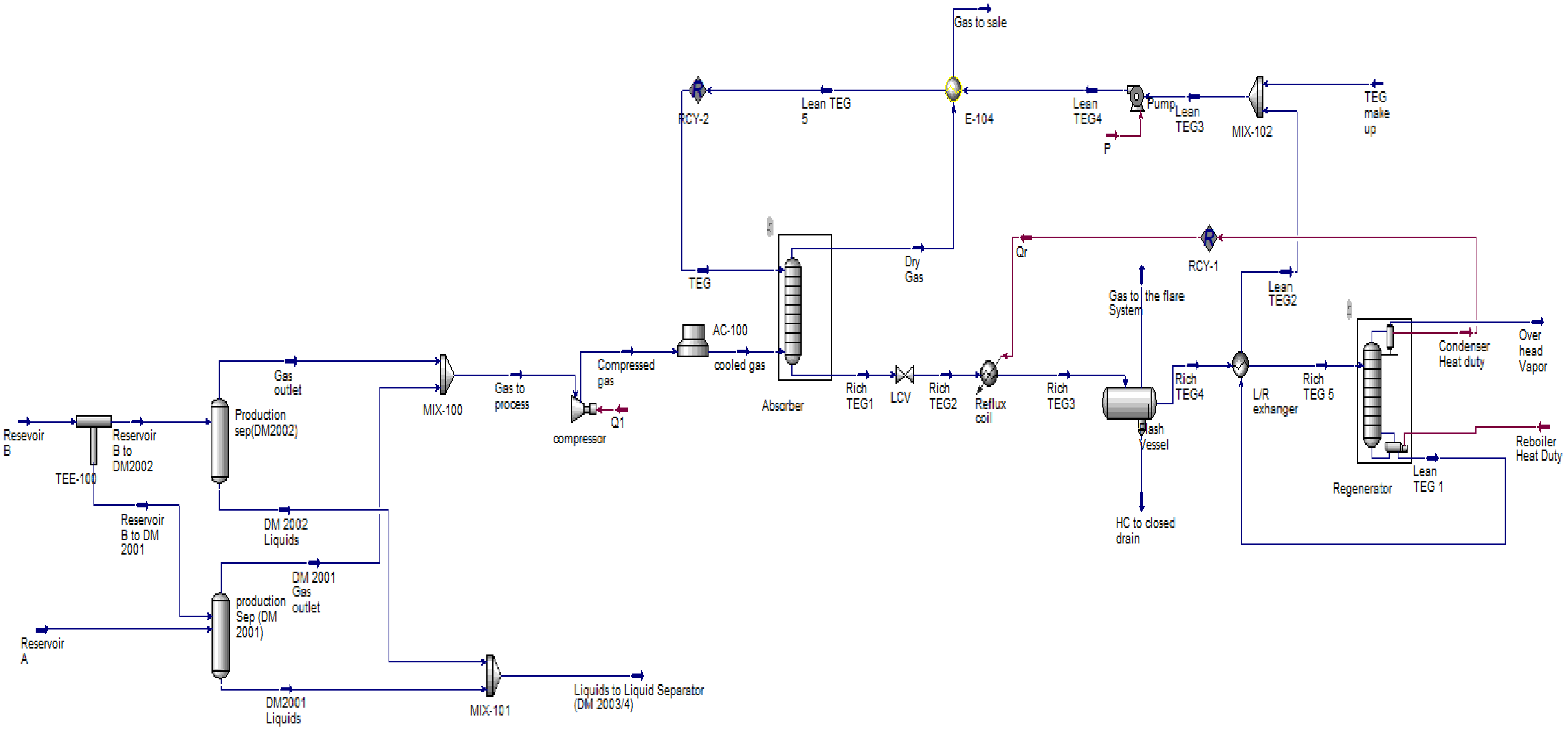

Figure 9: Aspen HYSYS natural gas dehydration and TEG regeneration system

3.3.1. Production Separator

The first step in the natural gas dehydration process is to remove any free liquids in the stream. To do this, a separator is used before the contactor (absorber) to separate any hydrocarbon liquids and free-water. This separator could be a two-phase or three-phase separator depending on the amount of free-water expected (Carroll, 2009). Gas from reservoirs A and B flows through the production separator to remove free liquid, reducing water content and decreasing glycol usage in the absorber. After separating gas and water, the gas is sent to the low-pressure compressor.

3.3.2. The compressor

The gas pressure from the well is not sufficient to meet the operational needs of the plant. As a result, the lower pressure compressor is utilized to increase the gas pressure to the required level for plant operations. This compressor effectively boosts the gas pressure from 1650 kPa to 6300 kPa. However, it is crucial to understand that as the pressure of the gas increases, so does its temperature. This is due to the relationship between pressure and temperature in the ideal gas law. Therefore, after passing through the compressor, the gas is directed through the Air cooler to lower its temperature to approximately 34°C. This is necessary because high pressure can have negative effect on both equipment and operation facility. This cooling process ensures that the gas remains within the desired temperature range for optimal plant operation.

3.3.3. Absorber

The contactor, also known as the absorber, is an essential component in the dehydration unit as it is primarily responsible for removing water in natural gas by using glycol. The absorber is designed in such way that the lean glycol enters at the top of the contactor while the rich glycol is collected at the bottom of the contactor and sent to regeneration. On the other hand, the wet gas enters the contactor at the bottom and after the absorption process take place the dry gas leaves the absorber at the top (Isa, 2009). The wet gas enter at the bottom of the absorber with the pressure of 6300kpa, in this process the lean glycol flowing downwards and effectively absorbs water from wet gas stream, the absorber operate at a pressure of 6200 kPa and lean TEG(triethylene glycol) enter to absorber unit at temperature of 34^{o}C and pressure of 6300kPa.

After absorption is finished, the dry gas leaves from the top of the absorber with temperature of 34^{o}C and pressure of 6200 kPa. On the other hand, the rich TEG (we call rich because it is contain the water absorbed from the natural gas) is discharged from the bottom section of the absorber with the pressure of 6200kpa and 35^o C and send to the regeneration process.

3.3.4. Level Control valve (LCV)

The LCV valve, also known as the level control valve is responsible for effectively lowering the pressure in the contactor column to match the regeneration pressure. The amount of pressure reduction depends on the pressure in the contactor and the losses experienced through the pipes and equipment leading to the regeneration column (Isa, 2009).In this case, the LCV reduces the pressure from 6200 kPa to 700 kPa.

3.3.5. Flash separator

The contactor, which is a crucial component in the glycol dehydration process, plays a vital role in separating the natural gas and water using glycol. The rich glycol, which has absorbed a significant amount of water vapor and other impurities, is typically withdrawn from the bottom of the contactor, after that the glycol is preheated by passing it through tubes in the overhead condenser at the top of the still column. After preheating, the rich glycol enters to a lower pressure flash separator, where most of the volatile components are vaporized. Flash separator pressures are typically in the range of 300 to 700kPa (50 to 100psia). The pressure range is carefully chosen to separate volatile components from glycol and minimize glycol loss (Carroll, 2009).

The flash separator is used to separate gas, rich TEG and hydrocarbon. The gas is sent to the flare system, while the hydrocarbon and TEG, in liquid form, are separated based on their densities. The hydrocarbon, which has a lower density, collects at the top of the flash separator, while the TEG settles at the bottom. The hydrocarbon is then sent to the closed drain, while the rich TEG is transferred to the heat exchanger to increase its temperature before being sent to the regenerator. It is important to note a small amount of TEG is lost during this operation, and this will be taken into account when adjusting the make-up stream in the TEG regeneration process.

3.3.6. Heat exchangers

Heat exchanger ‘simply’ exchanges the heat between those two sides; as a result, it is decreasing the temperature of higher temperature side and increasing the temperature of lower temperature side (Kolmetz, 2020), the basic purpose of the lean-rich exchanger is to conserve energy. In the lean-rich exchanger, hot, lean glycol from regeneration is cooled with rich glycol from the contactor. The lean glycol entering the contactor should be cool, and the rich glycol to regeneration should be warm (Carroll, 2009).The numbers of heat exchangers varies with the design of the process plant because of the large temperature difference between the contactor and regenerator column, rich glycol needs to be heated while lean glycol must be cooled because heating is necessary to remove water from the rich TEG, while cooling is essential to prepare the lean TEG for the next dehydration cycle. With proper design of heat exchangers between the rich and lean glycol most of the energy can be conserved (Isa, 2009). Therefore, in this process of TEG regeneration the heat exchanger plays a vital role in the TEG regeneration process by increasing the temperature of Rich TEG 4 from 36^{o}C to 105^{o}C using lean TEG 1.At the same time, lean TEG 1 is cooled from 195^{o}C to 123^{o}C for Lean TEG 2 and the lean TEG 4 stream entering the absorber unit is cooled by the dry gas stream in the gas glycol heat exchanger.

3.3.7. Regenerator

The TEG regenerator is a crucial component in the TEG dehydration process where TEG and water is separated. The regenerator consists of reboiler and condenser which are strategically positioned at the top of the column. The reboiler temperature must be limited up to 206^{o}C to prevent TEG thermal degradation (Piemonte et al., 2012). The column separates the water from TEG (Regenerator), works at a low pressure of one bar and at reboiler temperature of 195 ^{o}C and condenser temperature of 102 ^{o}C. The rich glycol (Rich TEG5) is preheated in heat exchangers before it is fed to the regenerator column and enters to the column for regeneration with temperature of 105 ^{o}C.

The excess water vapor leaves the total condenser and is vented to the atmosphere after leaving the condenser. The reboiler at the regenerator column provides the energy needed to separate TEG and water, where the recommended maximum temperature is 206°C but in our simulation, we used 195 ^{o}C in order to avoid TEG thermal degradation. The lean TEG is removed from the reboiler pass through the heat exchanger in order to reduce it temperature and increase the temperature of the rich is going to enter in the regenerator, before being recycled the lean TEG passes through the mixer.

3.3.8. Mixer

There are TEG losses that must be accounted for during the gas dehydration and TEG regeneration process. Therefore, a make-up mixer was added to combine the TEG make-up stream with the lean TEG2. Also the mix can be used in order to combine the gas outlet form the production separator before sending to the compressor, and used in combining the liquid outlet from the production separator before sending to the liquid separator.

3.3.9. TEG Pump

A circulation pump raises the pressure of the lean glycol and delivers the glycol to the top tray of the glycol contactor (Carroll, 2009).The TEG Regenerator operates at a low pressure of approximately 1 bar, while the Absorber works at a high pressure. This differentiation is essential because the Absorber requires high pressure to efficiently eliminate water, whereas the Regenerator requires low pressure to effectively extract absorbed water and regenerate TEG. Therefore, a pump is required to increase the pressure of the Lean TEG stream before it enters the Absorber. After make-up mixer, the pump increases the pressure of lean TEG from 103 kPa up to 6300kPa, which is the working pressure of the absorber.

3.4. The Glycol Package and the Twu-Sim-Tassone Cubic Equation of State

The process simulation results are calculated according to the thermodynamic models selected in the Aspen HYSYS properties environment. Aspen HYSYS simulation software provides numerous different thermodynamic models in the properties environment. Choosing a suitable property package is the key to produce accurate simulations (Hasan et al., 2020). The fluid package selected in this case is the Glycol Package because it is applicable over the range of temperatures, pressures and component concentrations encountered in a typical TEG dehydration system. The Glycol Package is based on the Twu-Sim Tasson (TST) equation of state and according to Aspen Technologies, the TST equation of state is suitable for TEG dehydration systems (Marfo et al., 2020).

3.5.1. The TST Cubic Equation of State

The TST cubic equation of state is represented by the following equation:

$$P = \frac{RT}{V-b} - \frac{\boldsymbol{a}}{(\boldsymbol{v}+\boldsymbol{3a})(\boldsymbol{v}-\boldsymbol{0.5})} \qquad (1)$$

The values of a and b at the critical temperature are found by setting the first and second derivatives of pressure with respect to volume to zero at the critical point resulting in:

$$\mathrm{a_c} = 0.470507\,\frac{\mathrm{R^2\,T^2}}{\mathrm{PC}} \qquad (2)$$

$$b_c = 0.0740740\,\frac{RT_c}{Pc} \qquad (3)$$

$$\mathrm{Zc} = 0.296296 \qquad (4)$$

The values of Zc for the Soave Redlich Kwong (SRK) (Zc = 0.333) and for Peng Robinson (PR) (Zc = 0.3074) are larger than the TST value, which is under 0.3, being closer to the real value of most substances. Since a is a function of the temperature, it can be calculated from

$$a(T) = \alpha(T)a_c \qquad (5)$$

Where the alpha function, (T), is a function of reduced temperature and the Twu alpha function is represented as:

$$\alpha = T_r^{N(M-1)} e^{L(1-T_r^{NM})} \qquad (6)$$

The alpha function parameters L, M and N used to correlate the vapor pressure of a component are unique for each component and can be calculated from the regression vapor pressure data of the pure component (Twu et al., 2005).

3.5.2. The TST mixing rules

The ability of a cubic equation of state to predict phase equilibrium of mixtures is related to the mixing rule applied. For the parameters a and b, the TST zero-pressure mixing rule can be defined as (Twu et al., 2005)

$$a^* = b^*\left[\frac{a^*vdw}{b^*\,vdw} + \frac{1}{Cr}\left(\frac{A_0^E}{RT} - \frac{A_{0vdw}^E}{RT}\right)\right] \qquad (7)$$

$$b = b_{vdw} \qquad (8)$$

The parameters a* and b* in Eq. (7) are defined as

$$a^* = \frac{Pa}{R^2T^2} \qquad (9)$$

$$b^* = \frac{Pb}{RT} \qquad (10)$$

The zero-pressure mixing rule assumes that the reduced liquid volume can be either constant or suffer no variation as the one calculated from a cubic equation of state using the van der Waals mixing rule for its a and b parameters.

$A_0{}^E$ is the excess Helmholtz energy of Van der Waals fluid at zero pressure and $A_0vdw\ E$ indicates that it is calculated using Van der Waals mixing rules from the cubic equation of state (Twu et al., 2005). Cr is a function of r, meaning the reduced liquid volume at zero pressure and can be expressed as:

$$C_r = \frac{1}{w-u} \ln\left(\frac{r+w}{r+u}\right) \qquad (11)$$

Where u and w are constants that depend on the equation of state. For the TST cubic equation of state u is 3 and w is -0.5.

The a and b parameters evaluated using van der Waals mixing rules, respectively $avdw$ and $bvdw$ are calculate by the following mixing rule equations:

$$a_{vdw} = \sum_i \sum_j xixj\sqrt{aiaj}\left(1 - k_{ij}\right) \qquad (12)$$

$$b_{vdw} = \sum_i \sum_j xixj\left[\frac{1}{2}\left(b_i + b_j\right)\right] \qquad (13)$$

3.6. Summary

In the gas processing industry, the dehydration of natural gas is crucial to prevent the formation of hydrates and potential leakage in pipelines. To achieve this, the natural gas dehydration process was simulated using Aspen HYSYS, a widely used software for process simulation.

To this end, the Glycol Package was selected because it is applicable over the range of temperatures, pressures and component concentrations encountered in a typical TEG dehydration system. The Glycol Package is based on the Twu-Sim Tasson (TST) equation of state and according to Aspen Technologies; the TST equation of state is suitable for TEG dehydration systems.

CHAPTER IV:

RESULTS AND DISCUSSIONS

The purpose of this chapter is to provide a detailed and extensive analysis of the process by conducting a parametric study. The study aims to evaluate the effects of different operational parameters on the overall process. The key factors that are focused on in this study include temperature, gas flow rate, TEG flow rate, and pressure. The simulation data, which represents the water content in the dry gas after passing through the gas dehydration unit, was manipulated using different parameters including TEG circulation rate, TEG temperature, TEG pressure, reboiler temperature, inlet gas pressure, inlet gas temperature, and inlet gas flow rate. The results and findings of this study are discussed in detail in this chapter**.**

4.1. Effect of TEG flow rate on moisture content in gas

The presence of water in natural gas is an undesirable impurity that must be avoided at all costs. One of the key factor that affect the water content present in dry natural gas is the TEG flow rate. The flow rate of lean triethylene glycol in the absorber has purpose of removing water in the gas, the gas enters in the contactor (absorber) from at the bottom while the lean glycol entering to the top of absorber.

The TEG flow rate was varied within the range of 1800 to 3000 kg mole/h, as shown in Figure 10. The analysis results indicate that as the circulation rate of triethylene glycol increases, the amount of water in the dry gas decreases. To be more specific, when the flow rate was set at 1800 kgmole/h, the water content in the gas was measured at 4.543 lb/MMSCF. However, when the TEG flow rate was increased to 3000 kgmole/h, the water content in the dry gas decreased to 4.502 lb/MMSCF. This phenomenon can be attributed to the fact that a higher volume flow rate of TEG in the absorber allows for increasing the contact between the wet gas and TEG. In simpler terms, this process allows for a greater amount of TEG to form a bonds with molecules of water which facilitating the absorption of water. As a result, the moisture level in the dry gas is decreased.

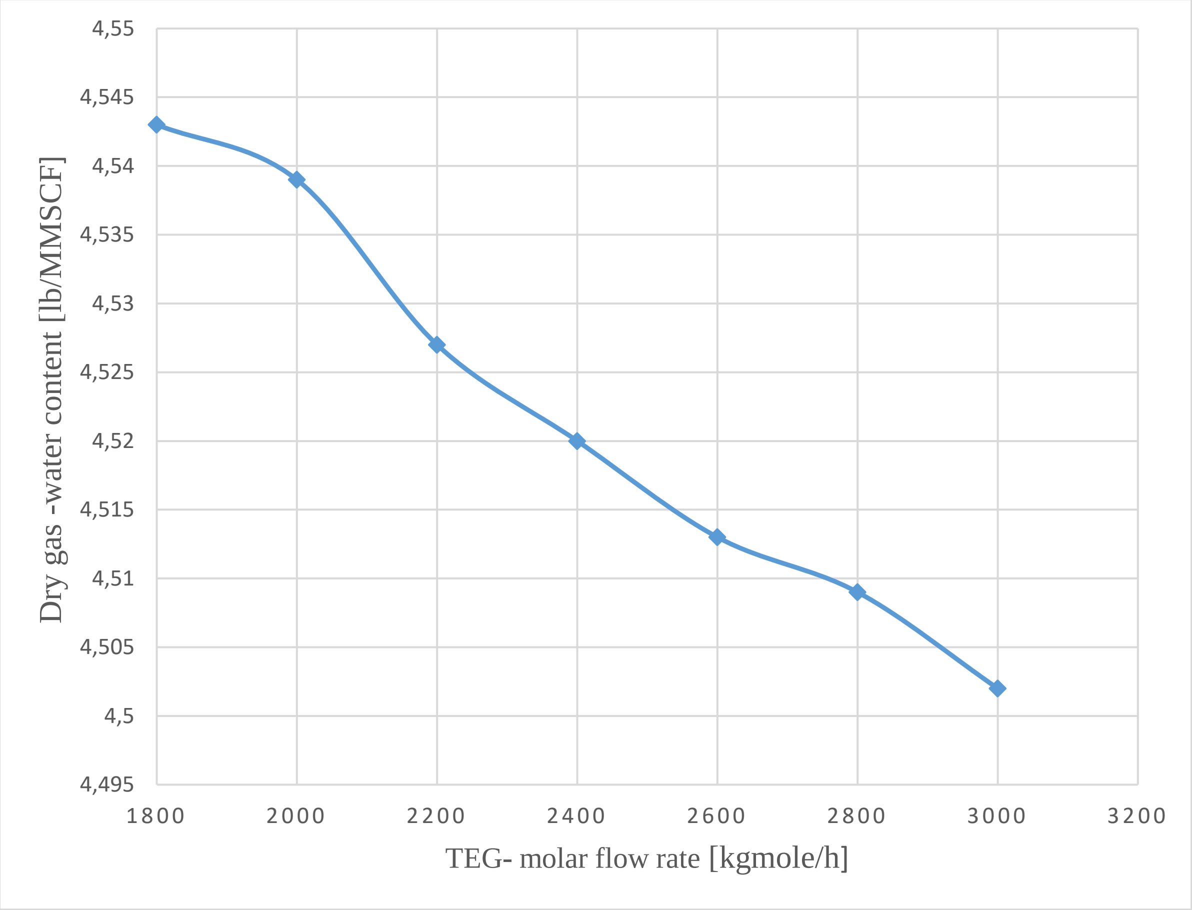

Figure 10: effect of TEG flow rate on moisture content in gas.

4.2. Effect of TEG flow rate on BTEX emission

BTEX gases, which include Benzene, Toluene, Ethylbenzene, and Xylene, can be obtained directly from the dehydration process. These gases are primarily emitted from the regenerator overhead, with a smaller amount being released through the flash vapor stream. However, the presence of BTEX gases in the dehydration process can lead to various significant issues such as severe foaming, increased glycol loss rate, reduced dehydration efficiency, and elevated maintenance costs for the absorber. This not only increases operational expenses but also leads to more downtime for the system.

In this particular case, the TEG flow rate was varied within the range of 2000 kg mole/h to 5000 kg mole/h, with the step size of 400 kg mole/h. This was done in order to assess the influence of TEG flow on BTEX emission. The analysis revealed that as the TEG flow rate increased, the BTEX emission also increased as shown in figure 11. Therefore, it is recommended to keep the TEG flow rate lower rate to a lower level in order to give precedence to emission control and ensure adherence to environmental regulations.

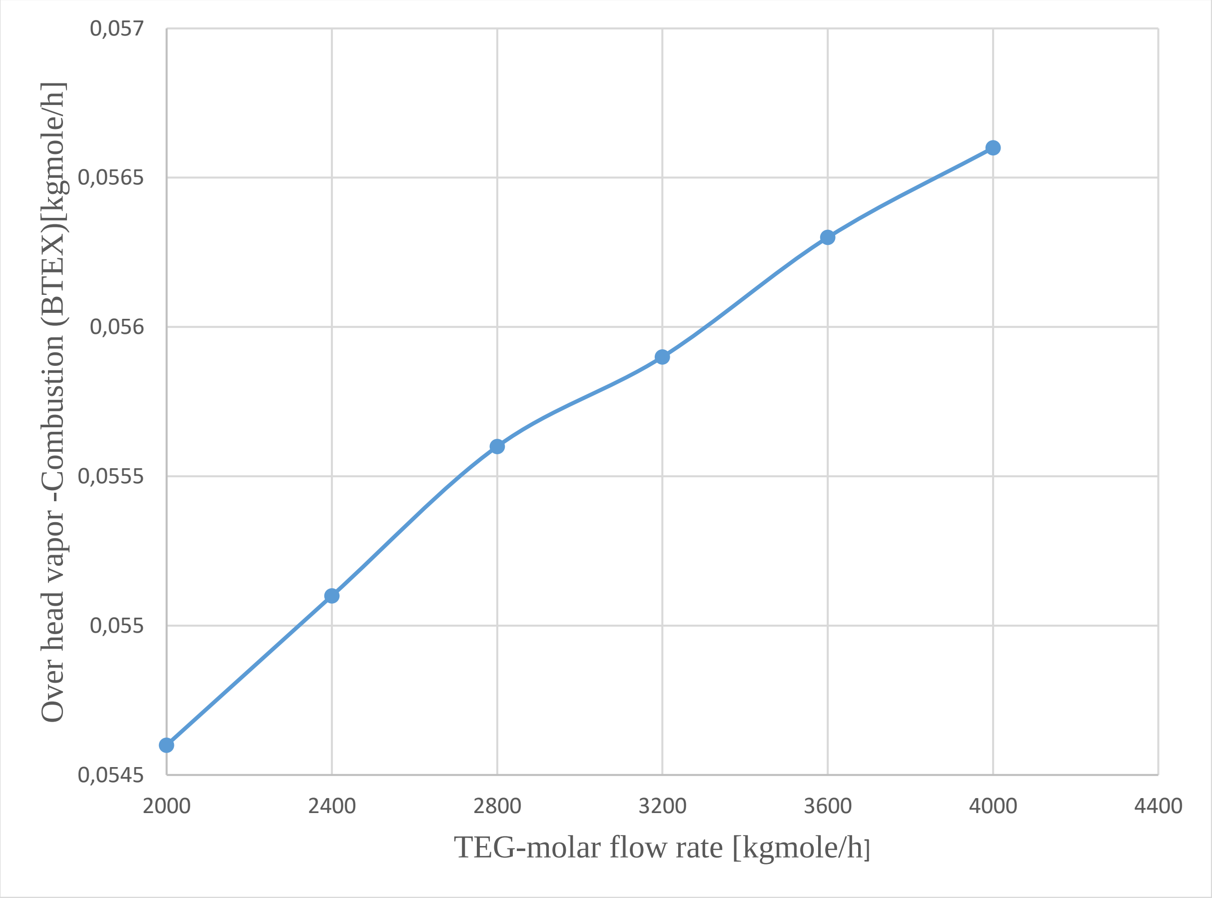

Figure 11: Effect of TEG flow rate on BTEX emission

4.3. Effect of Inlet gas temperature on moisture content in gas

The wet feed gas temperature is another factor that can influence the water content of the sale gas, therefore the operating temperature of the contactor (Absorber) is actually defined by wet gas temperature. In our case study, we conducted simulations with inlet gas temperatures ranging from 20°C to 60°C, with a step size of 5°C.

The analysis conducted on the graph as shown in figure 12 reveals that at 20°C, the water content in the dry gas was measured to be 3.414 lb/MMSCF. As the temperature increased to 60°C, the water content in the gas also increased to 7.809 lb/MMSCF. This is due to the fact that the lower temperature of the inlet gas increases the capacity of absorbent (TEG), allowing them to absorb more water contained in the gas; therefore lower temperature, lower equilibrium moisture capacity and then lower water content in dry gas, on the other hand, if the temperature of inlet gas increases will lead to the degradation of the absorbent (TEG), resulting in a decrease in its effectiveness in removing water from the gas. Consequently, the gas will not be sufficiently dehydrated, resulting in a higher water content in the gas.

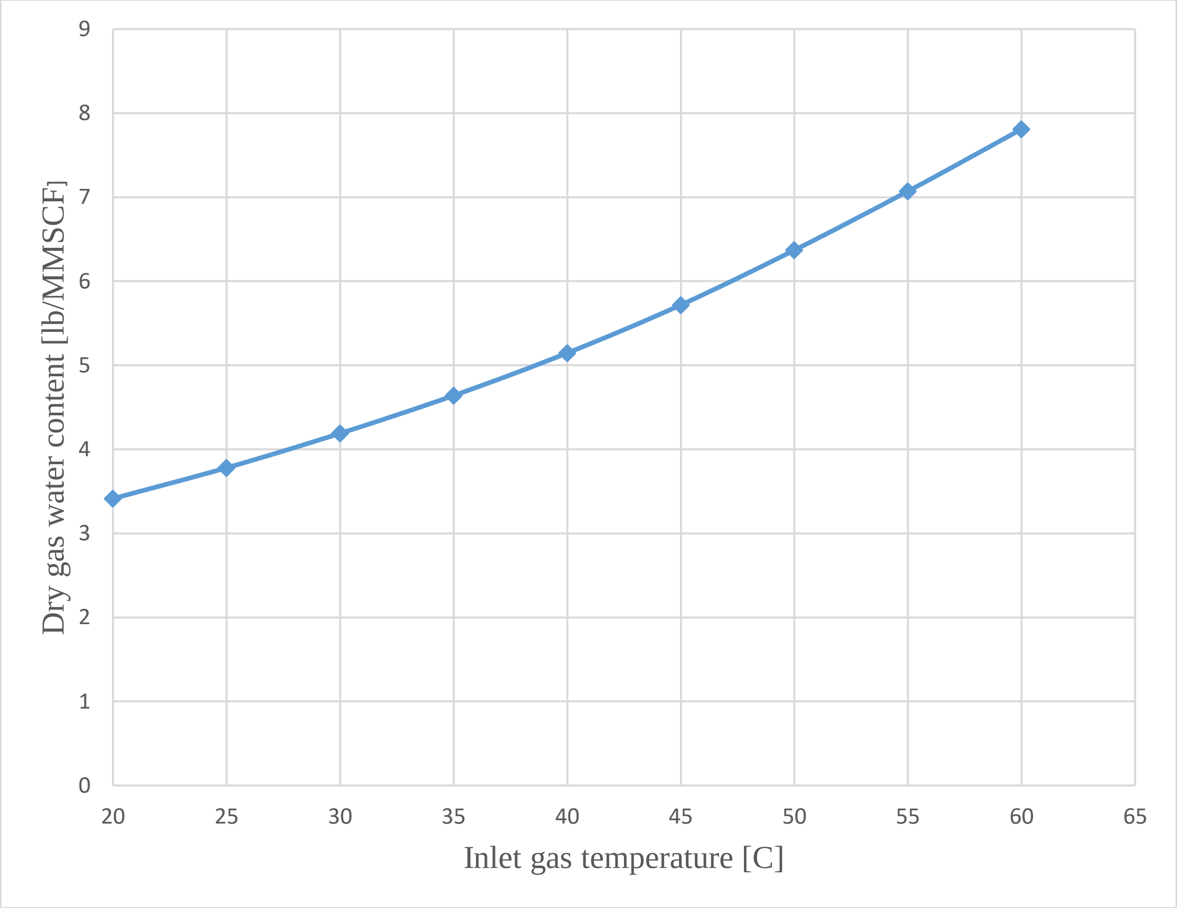

Figure 12: Effect of inlet gas temperature on moisture content in gas

4.4. Effect of inlet gas pressure on moisture content in gas

The dehydration process refers to the removal of water from a gas stream, typically done to meet certain specifications or requirements for the gas to be used in various applications. One of the factors that can affect the efficiency of the dehydration process is the inlet gas pressure. In this specific situation, the absorber pressure is varied from 4000 kPa to 8000 kPa, with step size of 500 kPa, this variation in absorber pressure allowed for a comprehensive analysis of how changes in inlet pressure affect the water content of the dehydrated gas.

The graph in plot 13 demonstrates how the water content of dehydrated natural gas changes with variations in the inlet gas pressure. It is clear that at an inlet gas pressure of 4000 kPa, the water content in the dry gas is 5.583 lb/MMSCF. However, when the inlet gas pressure increases to 8000 kPa, the water content decreases to 3.945 lb/MMSCF. This indicates that an increase in inlet gas pressure facilitates the condensation of water vapor as free water inside the production separator, where the water and gas are separated. As a result, the gas is not overloaded with excessive amounts of water in the absorber, leading to a reduction in both the water content in the dry gas and the amount of TEG used in the absorber.

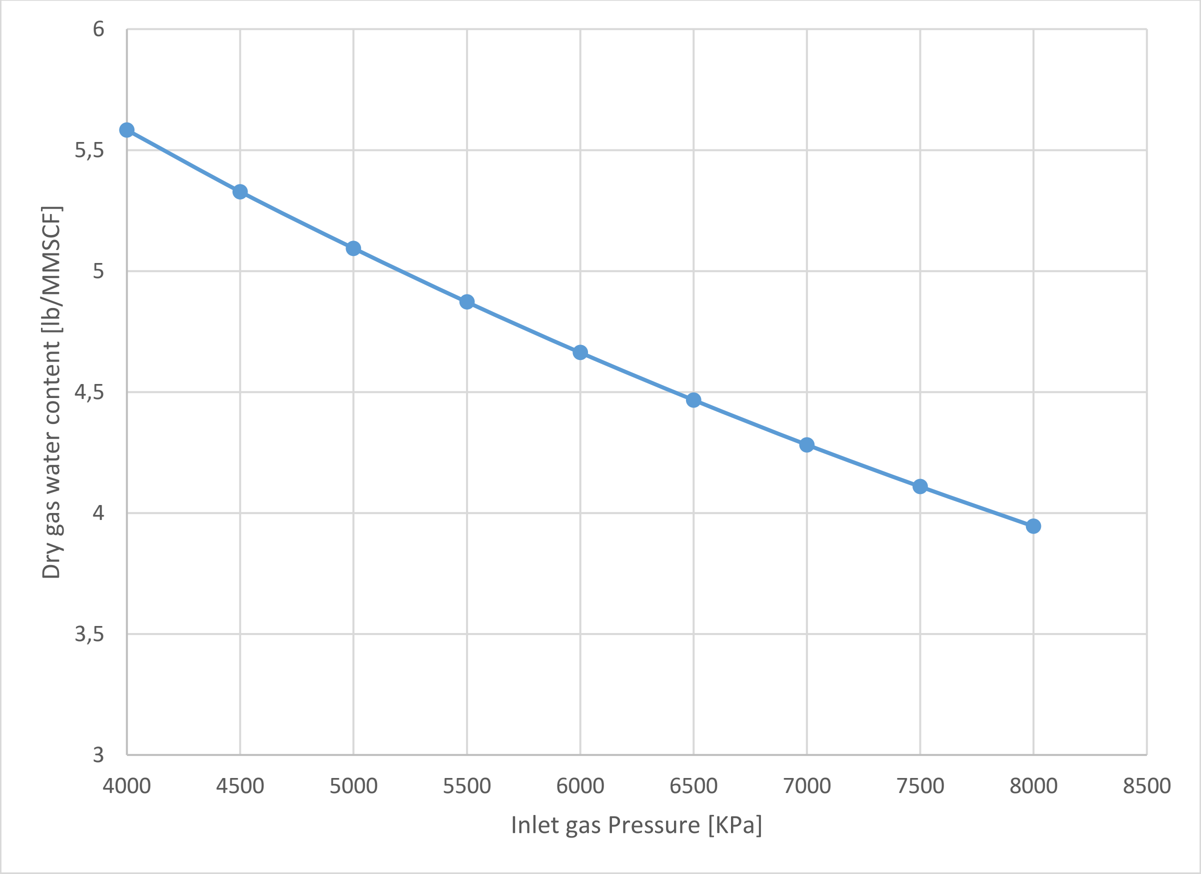

Figure 13: effect of inlet gas pressure on moisture content in gas

4.5. Effect of gas flow rate on moisture content in gas

The wet gas flow rate plays a crucial role in the efficiency of the dehydration process, particularly in TEG regeneration processes, in order to determine how the inlet gas flow rate affects the amount of water in the dry gas; a study was conducted where the gas flow rate in the contactor (absorber) was adjusted. The range of gas flow rates tested was from 40000 Nm^3/h

to240000Nm^3/h, with step size of 20000Nm^3/h. This analysis allows for the optimization of the dehydration process and ensures the production of dry gas with the desired level of dryness.

The analysis results indicate that there was a clear relationship between the water content in the dry gas and the inlet gas flow rate. As the gas flow rate increases, also the water content in the dry gas also increases. From the graph 14, shows that the inlet gas flow rate is initially set at 40000 Nm^3/h and the water content in the dry gas is measured to be 4.523 lb/MMSCF. However, when the inlet gas flow rate is increased to 240000Nm^3/h, the water content in the dry gas also increases to 4.545 lb/MMSCF. This can be attributed to the fact that as the gas flow rate rises in the absorber, the contact time between the gas and glycol decreases. As a result, more gas is carried over in the absorber, leading to a higher water content in the dry gas.

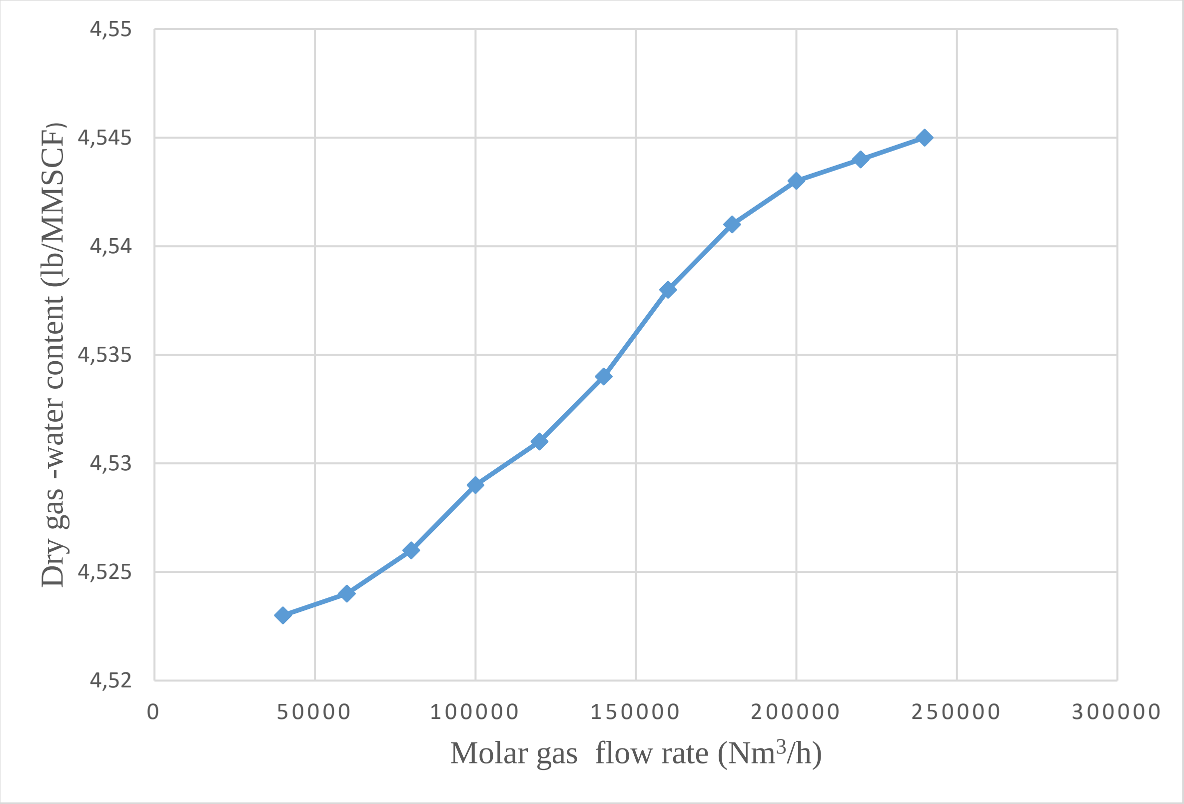

Figure 14: effect of the inlet gas flow rate on the moisture content in the dry gas

4.6. Effect of the gas flow rate in the absorber on moisture content in the plant

The gas flow rate is a crucial factor that can significantly impact the efficiency of the dehydration process. In order to investigate the influence of gas flow rate on the moisture content in the gas, data from the plant covered from April 2022 to June 2023 was analyzed. The results of this investigation are presented in Figure 15, which provides valuable insights into how the gas flow rate affects the moisture content in the gas. The graph clearly shows the relationship between these two variables and illustrates how changes in the gas flow rate can affect the moisture content in the gas.

The data demonstrates that an increase in gas flow rate within the absorber leads to a corresponding increase in moisture content within the gas. This phenomenon can be attributed to the fact that a higher gas flow rate reduces the contact time between the gas and TEG (Triethylene Glycol) in the absorber. Which decreases the absorption efficiency of the TEG and disrupts the equilibrium between the gas and TEG. Consequently, the decrease in residence time of the gas in the absorber further contributes to the higher moisture content in the gas exiting the absorber.

Figure 15: The effect of gas flow rate in the absorber on the moisture content in the pant.

4.7. Effect of Reboiler Temperature on moisture content in gas

The water content in gas can be influenced by the temperature in the reboiler, which is an important factor to consider. However, it is crucial to make sure that the temperature does not go beyond the thermal decomposition temperature of TEG, which is 206 ^{0}C.Typically, the reboiler and condenser are combined into one piece of equipment, and the reboiler is responsible for supplying heat to regenerate the rich glycol in the still through simple distillation. The separation process is relatively easy because water and glycol have significantly different boiling points, to analyze the impact of reboiler temperature on moisture content in dry gas, a temperature range of 180^{o}C to 204^{o}C was selected for the regenerator, with a step size of 4^{o}C. This temperature range was chosen for our specific case study.

The graph in Figure 16 presents the relationship between the water content in dry gas and the temperature of the regenerator's reboiler, which is used to regenerate the rich TEG. It is evident that the water content in the gas starts at 6.013 lb/MMSCF when the temperature is 180°C. As the reboiler temperature increases to 204°C, the water content decreases to 3.829 lb/MMSCF. This decrease can be attributed to the high reboiler temperature, which enhances the purity of the lean TEG. As the result the water content in the gas reduce, it is important to note that the reboiler temperature should not exceed 206°C, as temperatures beyond this point can lead to thermal degradation of the TEG.

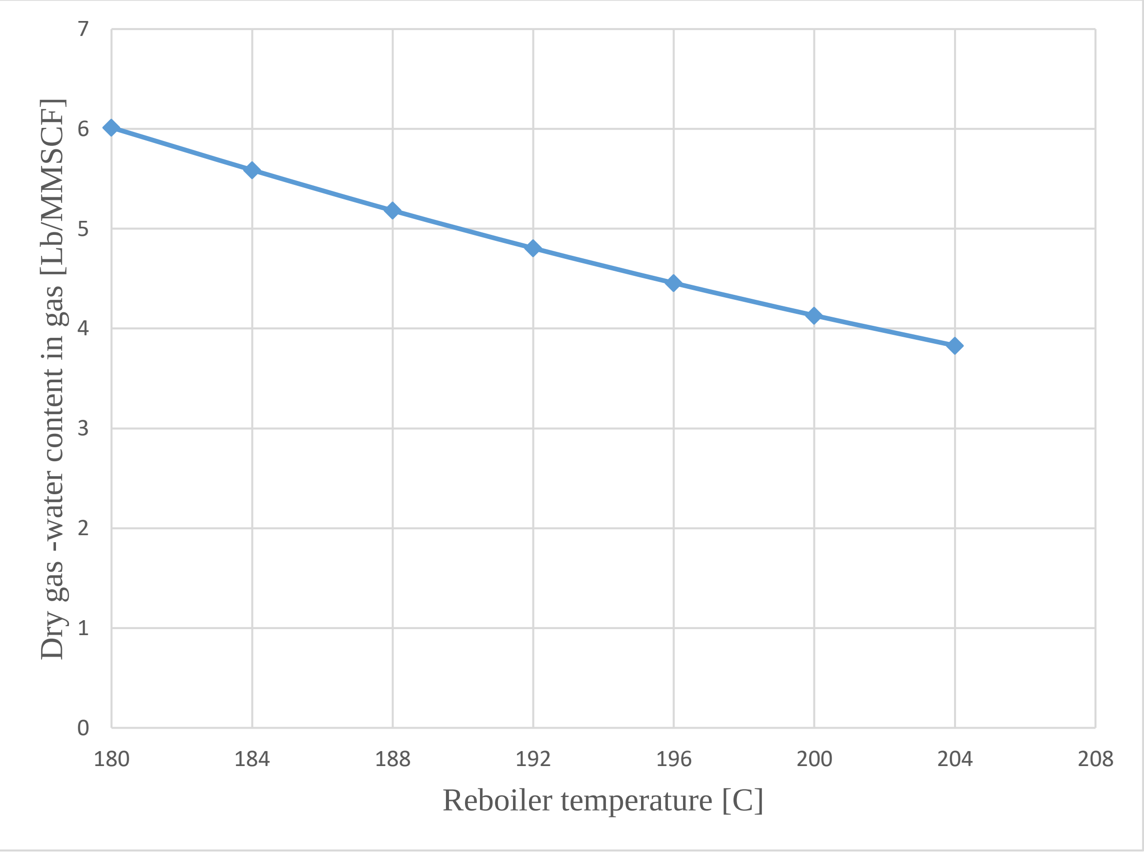

Figure 16: Effect of reboiler temperature on moisture content in gas

4.8. Effect of reboiler temperature on moisture content in the plant

In the reboiler, the rich TEG and water are separated based on their differing boiling points. The rich TEG is heated to a temperature of 190ºC, in this process, the water reaches its boiling point of 100ºC and transforms into vapor.

The effect of reboiler temperature on moisture content in the plant can be observed through the data presented in figure 17, which covers the period from April 2022 to June 2023. The results indicate that the temperature of the reboiler plays a crucial role in determining the moisture content of the gas. The graph clearly demonstrates that whenever the temperature of the reboiler drops below 190 ºC, there is a noticeable increase in the moisture content of the gas. Consequently, this leads to a higher quantity of moisture in the gas. These results provide strong evidence that the temperature of the reboiler significantly influences the moisture content of the gas. The followings graph illustrates the influence of low temperature on moisture content in the gas

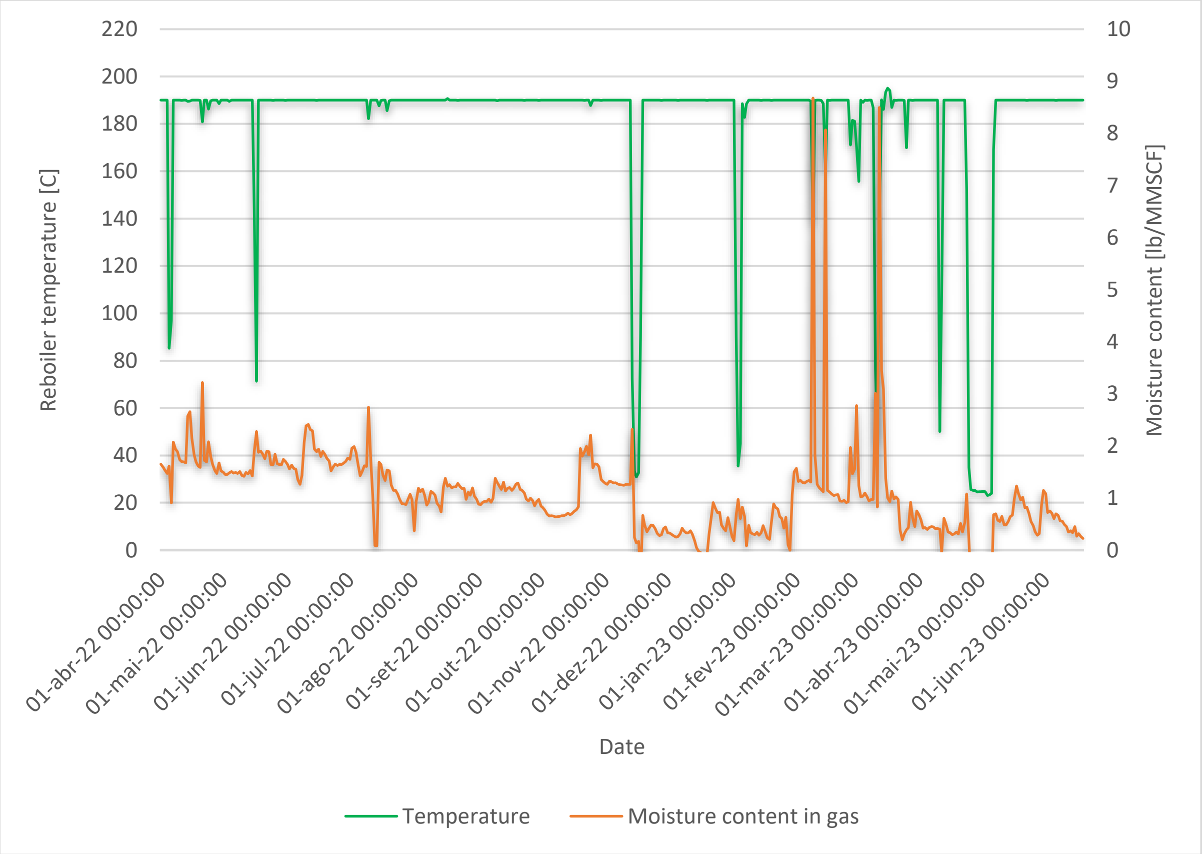

Figure 17: the effect of reboiler temperature on moisture content in the plant

4.9. Glycol loss

Triethylene Glycol (TEG) dehydrators are widely employed in the industrial sector for the purpose of water absorption in natural gas. The process of natural gas dehydration consists of two crucial stages: gas absorption and glycol regeneration. These processes are the primary areas within the dehydration system where a significant portion of glycol loss takes place.

One factor contributing to the loss of glycol is the high gas velocity passing through the glycol contactor, which can result in glycol carryover into the pipeline. Additionally, a poorly functioning mist eliminator at the top of the glycol contactor can allow some glycol to pass through even at normal gas velocity. The majority of glycol loss occurs in the regenerator, and this is mainly due to the flow rate of the glycol. When the flow rate is high, glycol can escape with water vapor in the still column. Another factor that can contribute to glycol loss is the temperature of the reboiler, as high temperatures can cause vaporization or thermal decomposition of the glycol. The impact of TEG circulation rate on glycol loss in the regenerator is visually represented in figure 18, the results show that as the TEG flow rate increases, there is a corresponding increase in TEG loss in the regenerator. This highlights the importance of controlling the flow rate of TEG in natural gas dehydration processes.

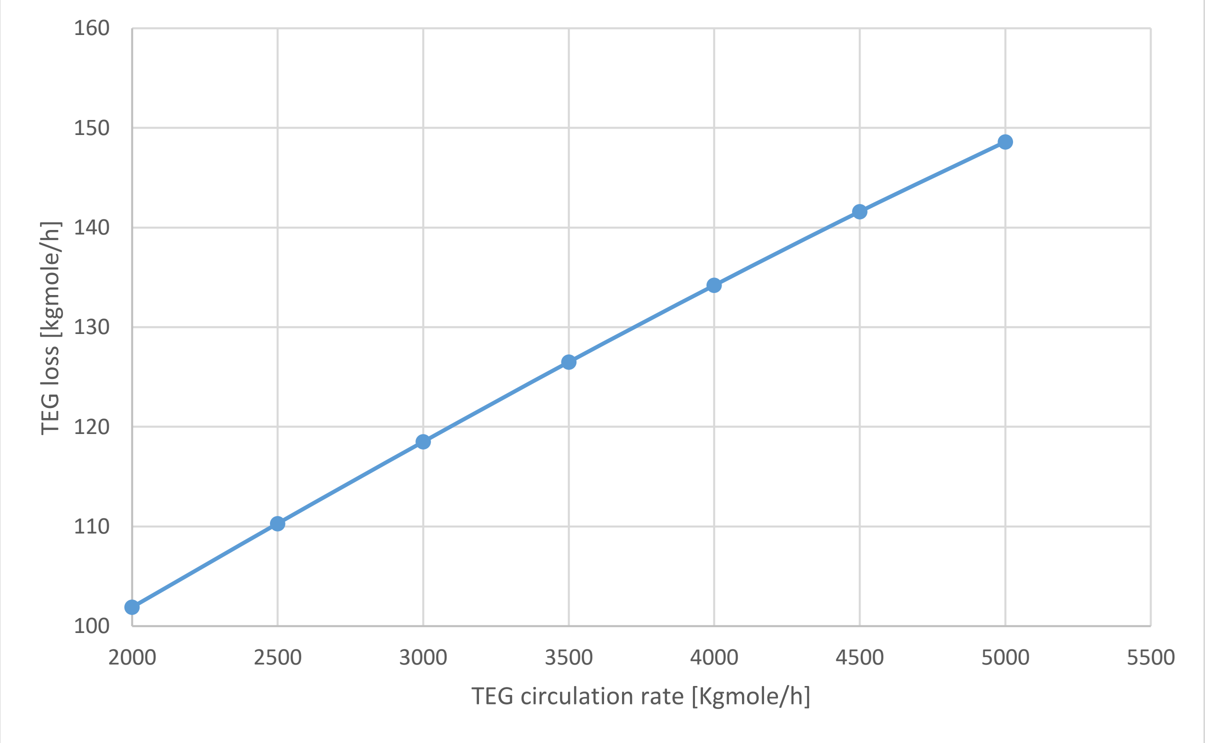

Figure 18: Effect of TEG flow rate on TEG loss

4.10. Summary

Natural gas extraction generates water vapor, which can cause pipeline corrosion, reduced capacity, and decreased combustion efficiency. During the process of elimination of water in natural gas Glycol dehydration is the primary technique to eliminate water vapor from natural gas, however, there are several factors that can affect the moisture content in the gas. A study discovered that increasing the flow rate of TEG in the absorber decreases water content in dry gas, but also leading to higher BTEX emissions. The study also found that the moisture content in the gas is also influenced by the inlet gas temperature and pressure during dehydration.

An experiment was conducted to investigate the impact of inlet gas flow rate on water content in dry gas. Results showed a clear relationship between water content in dry gas and inlet gas flow rate. Higher flow rates reduce contact time between gas and glycol in the absorber, resulting in more gas carrying over and higher water content in dry gas. The reboiler temperature, which should not exceed 206°C, also affects the moisture content in gas. Glycol loss is a significant concern in TEG dehydrators used in the industrial sector for water absorption in natural gas. Factors contributing to glycol loss include high gas velocity, high TEG flow rates, and high reboiler temperatures. Controlling gas velocity, flow rate, and temperature is essential to minimize glycol loss and optimize efficiency.

CHAPTER V:

CONCLUSIONS AND RECOMMENDATIONS

The results discussed in this chapter are related to the study conducted on the extraction of moisture from natural gas using triethylene glycol. The conclusions made are based on the methodology explained in detail in chapter 3, as well as the results discussed in chapter 4.

5.1. Conclusion

Natural gas is usually accompanied by large amounts of water vapor from reservoirs. It is a major task for process engineers to remove the water. Natural gas facilities are designed to remove water from natural gas in order to meet pipeline standards for water content in the processed gas stream. The modeling of the natural gas dehydration and TEG regeneration was successfully completed by HYSYS. The key parameters that influence the TEG dehydration process were TEG flow rate, the temperature of the reboiler, inlet gas pressure and temperature.

Furthermore, the result indicate that a higher flow rate of TEG leads to a decrease in moisture content within the gas. However, this also results in an increase in glycol loss and BTEX emission, which is why it is recommended to operate the TEG system at the minimum flow rate necessary to achieve the desired moisture removal. This helps to minimize glycol loss and BTEX emissions, thereby reducing the overall environmental impact of the process. Additionally, an increase in the inlet gas temperature contributes to a higher moisture content in the gas. Therefore, it is crucial to lower the gas temperature prior to its entry into the absorber. On the other hand, the gas pressure and reboiler temperature have the opposite effect, reducing the moisture content in the gas.

5.2. Recommendation

The recommendations for future work are:

- To study Natural gas dehydration using solid desiccant
- To study natural gas dehydration using condensation process
- To Study the impact of TEG flow rate on BTEX emission and how can reduce it
- To investigate the process of natural dehydration, using other liquid desiccants such as MEG, DEG, or TREG.
- To study different recycling setup for natural gas dehydration

5.3. Summary

Natural gas plants often contain water vapor from reservoirs, making water removal a significant task for engineers. HYSYS successfully completed modeling of natural gas dehydration and TEG regeneration, focusing on key parameters such as TEG flow rate, reboiler temperature, inlet gas pressure, and temperature. The results showed that higher TEG flow rate decreases gas moisture content but increases glycol loss and BTEX emissions. Therefore, it is recommended to operate the TEG system at the minimum flow rate to minimize these effects. Also gas pressure and reboiler temperature reduce gas moisture content. Future work should include studying natural gas dehydration using solid desiccant, examining the impact of TEG flow rate on BTEX emission, investigating natural dehydration using other liquid desiccants, and exploring different recycling setups for natural gas dehydration.

List of abbreviations

Abbreviation	Description
BTEX	Benzene, Toluene, Ethyl benzene and Xylene
DEG	Diethylene glycol
LPG	Liquid Petroleum Gas
LCV	Level Control valve
Lb/MMSCF	Pound per Million standard cubic feet
NG	Natural gas
NGL	Natural gas Liquid 7
MEG	Monoethylene glycol
PH	Potential of Hydrogen
TEG	Triethylene glycol
TREG	Tetraethylene glycol
VOCS	Volatile Organic Compound

KEY WORDS

Natural gas

Dehydration

Glycol

Aspen

BTEX emission

Fossil fuel

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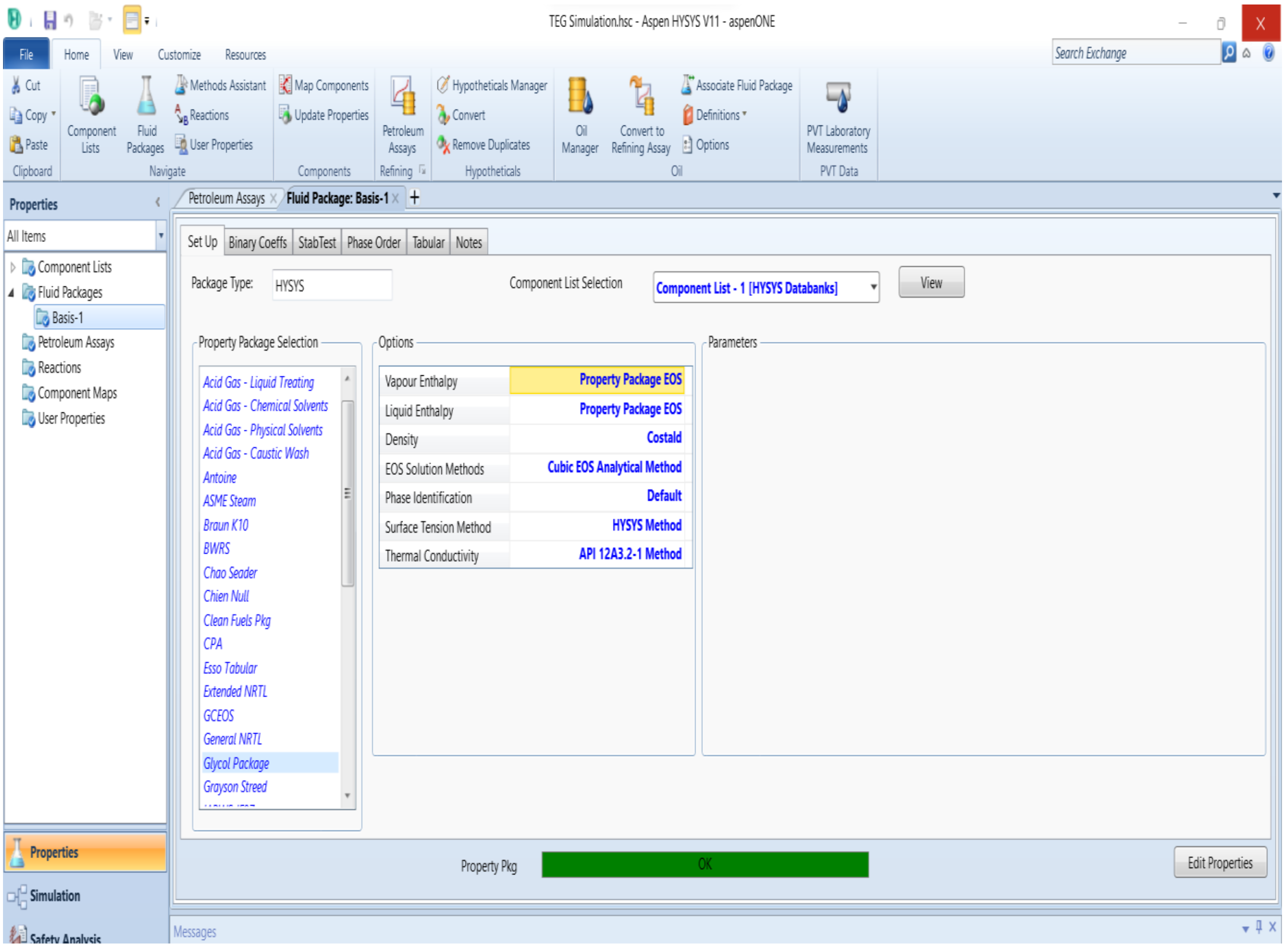
APPENDIX

1. Aspen hysys Fluid package



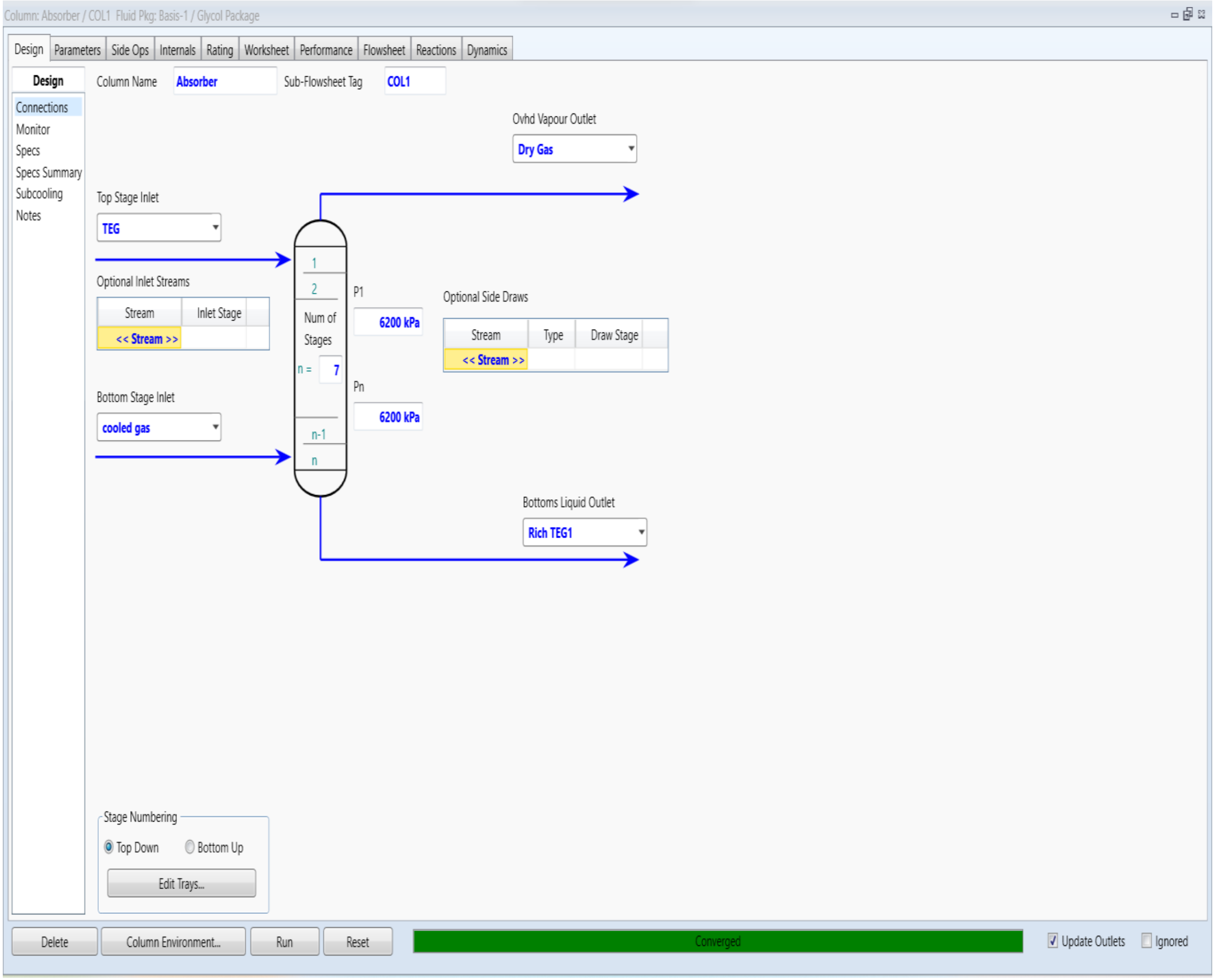
Package Type: HYSYS

Component List Selection: Component List - 1 [HYSYS Databanks]

Vapour Enthalpy	Property Package EOS
Liquid Enthalpy	Property Package EOS
Density	Costald
EOS Solution Methods	Cubic EOS Analytical Method
Phase Identification	Default
Surface Tension Method	HYSYS Method
Thermal Conductivity	API 12A3.2-1 Method

Property Pkg: OK

2. Glycol Contactor (Absorber)


Column: Absorber / COL1 Fluid Pkg: Basis-1 / Glycol Package

Column Name Absorber

Sub-Flowsheet Tag COL1

Ovhd Vapour Outlet Dry Gas

Top Stage Inlet TEG

Bottom Stage Inlet cooled gas

Bottoms Liquid Outlet Rich TEG1

P1 6200 kPa

Pn 6200 kPa

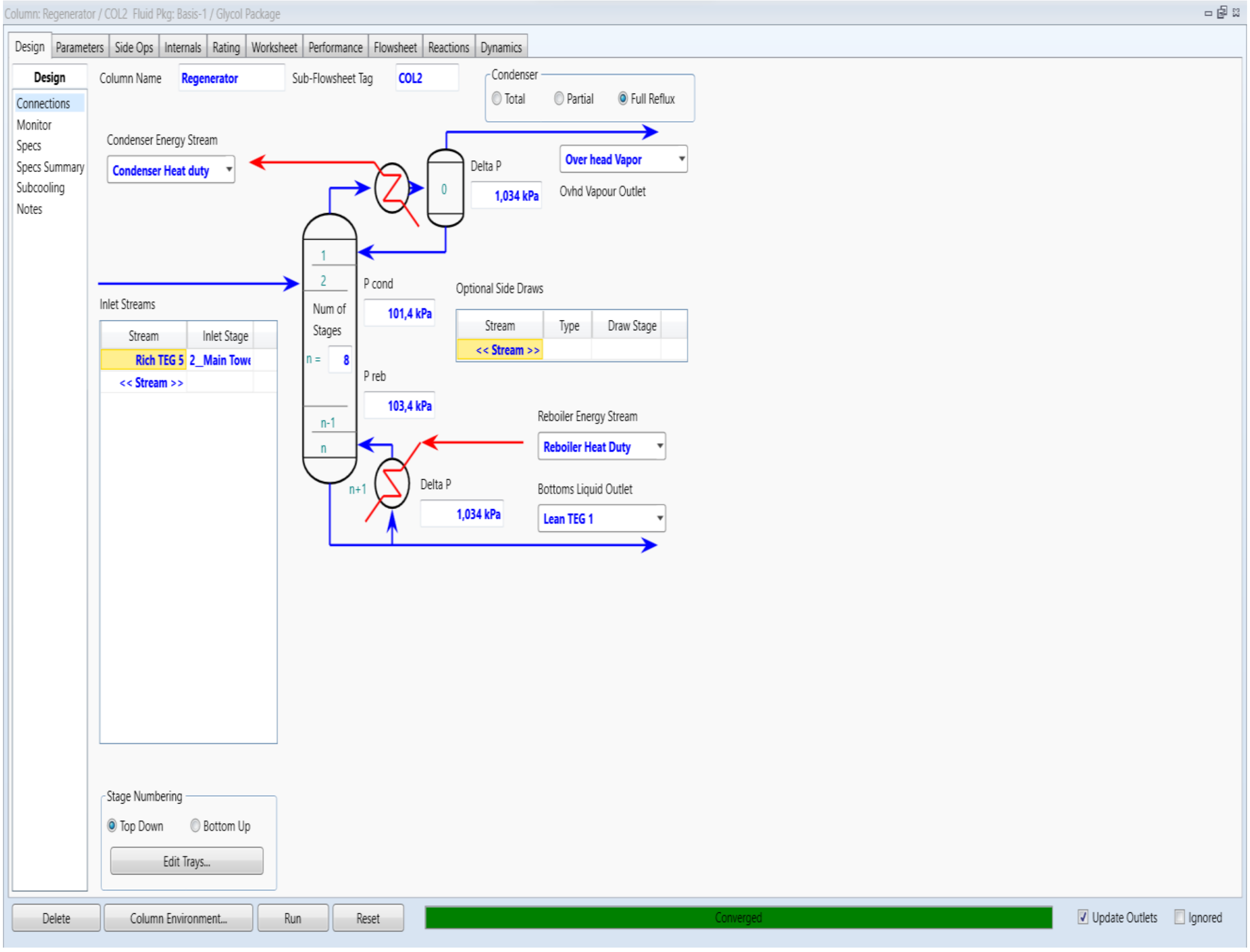
Num of Stages n = 7

Stage Numbering ● Top Down ○ Bottom Up

Converged

☑ Update Outlets ☐ Ignored

3. Regenerator



Column: Regenerator / COL2 Fluid Pkg: Basis-1 / Glycol Package

Column Name: Regenerator

Sub-Flowsheet Tag: COL2

Condenser: ○ Total ○ Partial ● Full Reflux

Condenser Energy Stream: Condenser Heat duty

Delta P: 1,034 kPa

Ovhd Vapour Outlet: Over head Vapor

Inlet Streams

Stream	Inlet Stage
Rich TEG 5	2__Main Towe
<< Stream >>	

P cond: 101,4 kPa

Num of Stages: n = 8

P reb: 103,4 kPa

Optional Side Draws

Stream	Type	Draw Stage
<< Stream >>		

Reboiler Energy Stream: Reboiler Heat Duty

Delta P: 1,034 kPa

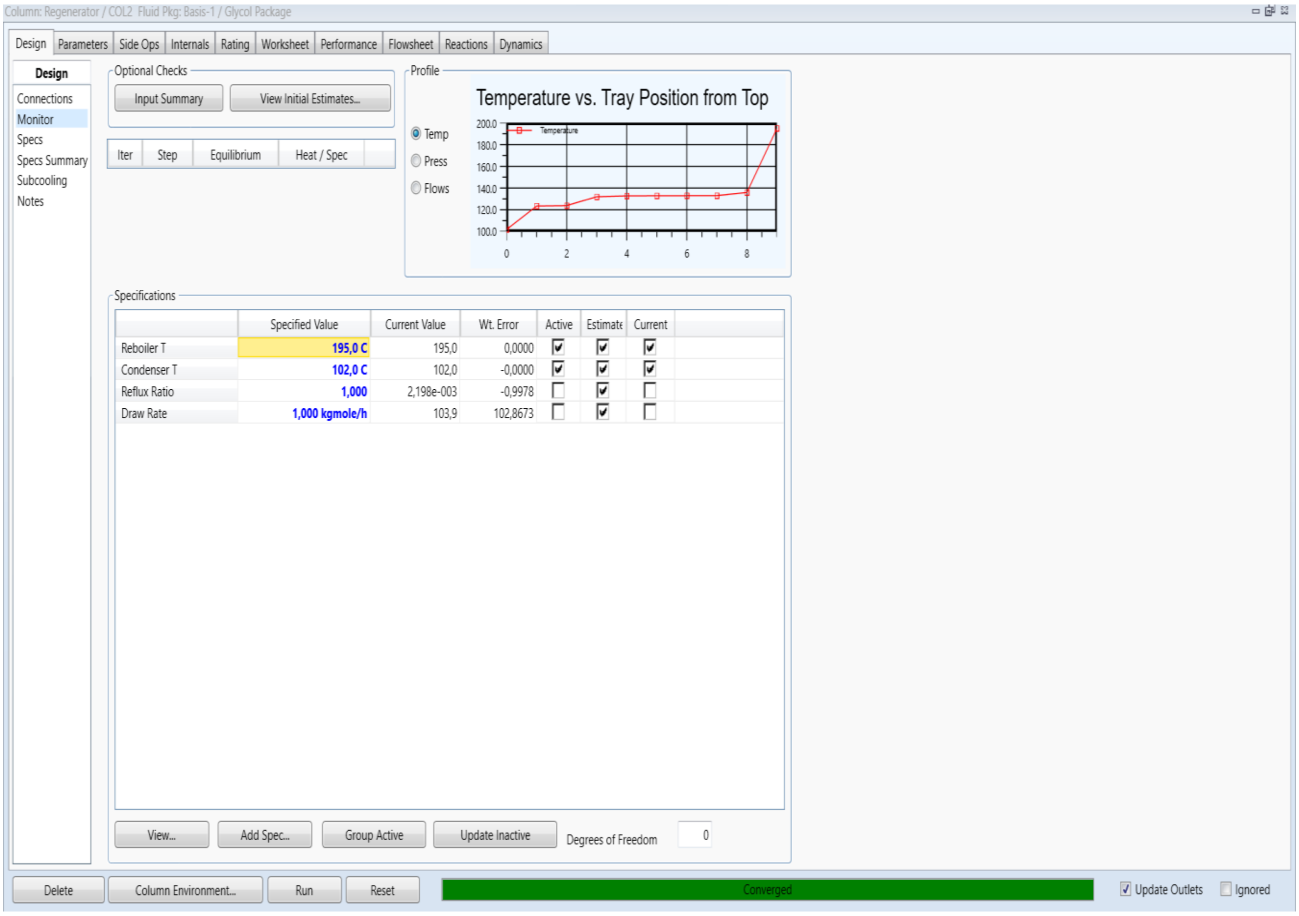
Bottoms Liquid Outlet: Lean TEG 1

Stage Numbering: ● Top Down ○ Bottom Up

Converged

☑ Update Outlets ☐ Ignored

4. Reboiler and condenser Temperature



Column: Regenerator / COL2 Fluid Pkg: Basis-1 / Glycol Package

Specifications

	Specified Value	Current Value	Wt. Error	Active	Estimate	Current
Reboiler T	195,0 C	195,0	0,0000	☑	☑	☑
Condenser T	102,0 C	102,0	-0,0000	☑	☑	☑
Reflux Ratio	1,000	2,198e-003	-0,9978	☐	☑	☐
Draw Rate	1,000 kgmole/h	103,9	102,8673	☐	☑	☐

Degrees of Freedom 0

Converged

CURRICULUM VITAE

Names	Jean Aimable INSHUTITURIKUMWE
Permanent Address:	Kigali , Rwanda
Email Address:	turikumwe17@gmail.com
Education:	Bachelor’s in science in applied chemistry
Affiliation:	Society of Petroleum Engineers