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Design and Performance Analysis of an Industrial Absorber for the Dehydration of Natural Gas using Triethylene Glycol

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ABSTRACT

The water content of natural gas is one of the main concerns facing the gas processing industries. This leads to hydrate formation, obstructions, and flow problems, all of which corrode the transmission pipeline and processing plant. This research examined the design and performance analysis of an absorber, a key component of the natural gas triethylene glycol (TEG) dehydration plant, with the regenerator as the other unit. This was done in an effort to lessen or stop the aforementioned problems because natural gas is a cheap and clean energy source that is used both domestically and industrially. In a dehydration plant, the absorber is set up to guarantee that the water content of gas is adequately and successfully eliminated to satisfy the requirements for pipeline transmission. Aspen HYSYS Version 12 was used to model the absorber design or specification under natural gas feed conditions. The absorber design specification was determined to be 7.00 m for column height, 1.50 m for diameter, 1.77 m^2 for area, and 12.38 m^3 for volume, using the conservation law of mass and energy. The absorber design or specification is appropriate for the best dehydration of natural gas with feed pressure, temperature, and flow rate of 6205.28 kPa, 29.440 °C, and 768.63 kg/s, respectively, according to the analysis of the mass or composition and energy balance of the dehydration process. This study found a direct correlation between the size specification, absorber performance efficiency, and natural gas input condition. The developed models provide valuable insights and resources for absorber design and optimization of similar units in gas processing facilities, enhancing their performance and operational efficiency.

Keywords: Natural gas; Petrochemical; Absorber; Aspen HYSYS; Triethylene glycol.

1. Introduction

Natural gas is an essential source of energy that is globally utilized both for domestic and industrial applications. The economic importance of natural gas as a source of energy is the main reason why there is an increasing interest in its production and sustainability in recent years. Natural gas is the cleanest, most environmentally friendly, and most efficient source of energy, an important catalyst for economic advancement (Wosu *et al*., 2023). However, the chemistry of natural gas formation and processes occurring underground for millions of years under the condition of high or intense temperature and pressure in the absence of air usually subject the natural gas to certain impurities such as water vapor, carbon dioxide, and hydrogen sulfide (Abdel-Aal *et al.,* 2003; Wosu *et al.*, 2023a; Nmegbu, 2014). The water content of natural gas has been identified as a major problem due to its high tendency to cause hydrate formation, blockages, flow issues, as well as corrosion during processing and pipeline transmission (Wosu & Ezeh, 2024; Wosu *et al.*, 2024). In a bid to mitigate or remove the water content of natural gas, the natural gas dehydration technologies become highly imperative in order to meet the standard or specification limit recommended by process industries for pipeline transmission and distribution. The standard amount of water content of gas must not exceed 7 Ib/mmscf of NG (Foss, 2004). The absorber column is an important unit in the natural gas dehydration plant, and its design and performance directly affect the quality and efficiency of the overall dehydration process (Dagde & Akpa, 2014).

Natural gas, a hydrocarbon consisting primarily of methane, is hailed as one of the cleanest-burning fossil fuels (Wosu & Ezeh, 2024; Kong *et al.*, 2018). Its utilization in power generation, transportation, and various industrial applications is instrumental in reducing greenhouse gas emissions and fostering energy security. However, the inherent presence of water vapor in raw natural gas poses a significant challenge to its efficient utilization. Water vapor can condense and form gas hydrates under certain temperature and pressure conditions, leading to blockages in pipelines and valves (Brian, 2014). Additionally, water in natural gas streams can induce corrosion in pipelines and equipment, accelerating wear and tear. Moreover, the presence of water vapor can cause intricate flow problems, leading to inefficiencies in gas processing operations (Christensen, 2009). This problem is mitigated in dehydration processes, where water vapor is meticulously removed from natural gas streams. Triethylene glycol (TEG) dehydration plants have emerged as a preferred choice in the industry. TEG, a hygroscopic liquid, possesses a remarkable affinity for water molecules (Francis *et al*., 1991). When brought into contact with wet natural gas, TEG selectively absorbs water vapor, leaving the gas stream dry and ready for transportation and utilization. However, the efficiency of this process is intricately linked to the performance of the industrial absorber within the TEG dehydration unit.

A study by Al-Fahmi *et al.* (2018) aimed to optimize and analyze the performance of an absorber tower for TEG dehydration of natural gas. The simulation and optimization of operating parameters such as the TEG concentration, gas temperature, and gas flow rate were found to enhance the absorber's efficiency by minimizing glycol losses and energy requirements. Another study by Wosu & Ezeh (2024) proposed a design optimization method for TEG absorber towers that included the analysis of heat and mass transfer processes, including TEG regeneration and cooling. The study found that the use of a counter-current system for gas and TEG flow improved the heat and mass transfer efficiencies while minimizing the glycol losses. Furthermore, Beckey *et al. (2022)* analyzed the performance of a packed absorber column with structured packing for natural gas dehydration using TEG and identified the key factors that influence the column's efficiency, such as TEG flow rate, gas flow rate, and operating pressure. The study concluded that the use of structured packing enhanced the efficiency of the absorber in comparison to random packing. Wosu *et al.* (2023b) present a design model for the regeneration of lean triethylene glycol (TEG) in natural gas dehydration plants. The model was developed from the first principles of mass and energy balance and employs a heat exchanger to heat the rich TEG before it is introduced to the regenerator column. The lean TEG is recovered from the column bottom and recycled. The design was carried out using HYSYS software, and the resultant specifications of regenerator volume, height, diameter, and column area were obtained as 18.857 m3, 6.000 m, 2.000 m, and 3.143 m2, respectively. The study demonstrated that the natural gas feed conditions, including temperature, pressure, and flow rate, significantly influence the performance efficiency of the regenerator and other units of the TEG dehydration plant. The developed model shows potential for improving the efficiency of TEG dehydration plants.

Wosu *et al*. (2024) researched on design modification and comparative analysis of glycol-based natural gas dehydration plants. In their research, they designed a dehydration plant with a heat exchanger at the TEG inlet to the contactor and compared the design and performance analysis of the plant with the conventional dehydration plant, where a cooler is configured at the TEG inlet to the contactor. Their research showed that the modified plant performed better in terms of the energy efficiency of the process. Usually, the raw natural gas comes from three types of wells: oil wells, gas wells, and condensate wells. When a gas is associated with oil, it is known as associated gas or wet gas, but when it is without oil, it is called non-associated gas or dry gas (Foss, 2004). However, when there is little or no crude oil, it is known as condensate or non-associated gas. Methane forms a major percentage of natural gas with other minor compositions like ethane, propane, butane, pentane, and non-hydrocarbon gases like carbon dioxide, nitrogen, hydrogen sulfide, various mercaptans, and water vapor, along with other inorganic and organic compounds (Undiandeye *et al*., 2015). This natural gas is usually transported through pipelines and must meet certain specifications, which include water content, which is probably the most common unwanted component found in untreated natural gas and can cause problems like hydrate formation, corrosion, plugs that cause slugging flow conditions in the pipeline, etc.

The natural gas dehydration process is an important and essential part of the offshore gas treatment by decreasing the water content of the wet gas using triethylene glycol absorbent technology. This technology is capable of reducing the water content of gas to the acceptable limit or standard for gas transmission (Anyadiegwu *et al*., 2014). But in recent past and present days, very low natural gas dew points are required for gas transmission by pipelines, corresponding to a reduction of water contents to less than 7 Ib/mmscf of NG (Kidnay & Parrish, 2006; Wosu & Ezeh, 2024). Emeka & Anthony (2020) posited that the clean burning characteristics of natural gas make it easier for gas processors in the industry to meet the stringent environmental requirement for processing operations (Elliot *et al*., 2005), and this has contributed remarkably to high global demand for natural gas (Reza, 2009; Jing *et al*., 2018) because of its importance as a primary source of fuel and petrochemical feedstock. The natural gas dehydration by TEG can be used for the removal of water associated with natural gas, and this process can be more efficient and effective by improving the performance of a natural gas dehydration plant using a combination of solvents (Gajduk *et al*., 2018; Onyegbado *et al*., 2016).

The design of process equipment generally involves the application of the conservation law of mass and energy in the development of the mathematical model for equipment specification (Gavin & Towler, 2009; Gui & Liu, 2017; Kern, 1950). The developed models can be refined and validated by incorporating the initial feed and operating condition of the process into the advanced process simulation tool HYSYS (Khan *et al*., 2012; Ojong *et al*., 2024). This simulation-based approach not only validates the theoretical models but also offers a platform for detailed analysis, enabling the exploration of a multitude of variables and their impact on the absorber's performance. For efficient and effective dehydration, This research is on developing the performance models of absorbers in the TEG dehydration plant from the first principle of mass and energy balance for determining design/size specifications such as volume, height, diameter, and area of absorbers, as well as using the advanced process simulation software HYSYS to simulate and design the TEG dehydration process plant (Ludwig, 2021; Mohammed *et al*., 2014). The dehydration of natural gas is a crucial step in its processing, as moisture-containing impurities can result in pipeline corrosion, reduced heat transfer efficiency, and the formation of hydrate crystals that can cause blockages in pipelines (NCBD Act, 2004; Sieder & Tate., 1936). The negative impact of corrosion in industrial processes and equipment is a major problem facing process engineers today (Ojong *et al*., 2023). The most commonly used method for natural gas dehydration is the use of triethylene glycol (TEG) as a liquid desiccant in an absorber tower. The fundamental principles that govern the operation of industrial absorbers are crucial for the optimum design and functioning of TEG dehydration plants, while empirical knowledge and industrial experience have shaped the design parameters of these absorbers to a significant extent. This research will therefore delves into the development of performance models for industrial absorbers, rooted in the first principles of mass and energy balance. By employing these fundamental principles, the study aims to unravel the intricate dynamics of absorber operation and its direct correlation with the efficiency and reliability of TEG dehydration processes.

2. Materials and Methods

2.1 Materials

The study investigated a comprehensive array of feed parameters vital to the characterization of natural gas, encompassing temperature, pressure, and flow rate. The natural gas sample analyzed in this research exhibited a diverse composition, consisting of methane (CH_4), ethane (C_2H_6), propane (C_3H_8), i-butane (C_4H_{10}), n-butane (C_4H_{10}), i-pentane (C_5H_{12}), n-pentane (C_5H_{12}), hydrogen sulfide (H_2S), carbon dioxide (CO_2), nitrogen (N_2), water, and triethylene glycol (TEG). A detailed breakdown of the gas composition is presented in Table 1. The experimentation was conducted using a dehydration plant (Figure 1), which comprised several intricately designed units for efficient gas processing. The plant's schematic overview is depicted in Figure 1, where the inlet cooler unit served the purpose of cooling the incoming natural gas, preparing it for further processing, and the inlet scrubber functioned to eliminate impurities and contaminants present in the gas stream, ensuring a cleaner input for subsequent stages. The gas then passed through a contactor/absorber column, where it came into contact with the absorbent, TEG. This phase involved the absorption of moisture and other hydrating agents present in the gas. After absorption, the gas underwent rapid depressurization facilitated by the flash valve and separator, causing the separation of the gas and liquid phases. The separated phases then underwent filtration to remove any remaining particulate matter, guaranteeing the purity of the processed gas. The pre-treated gas was further cooled in the heat exchanger, a critical step to optimize the subsequent absorption process. In the regenerator/distillation column, the absorbed water and other impurities were removed from the TEG, ensuring its continuous efficacy as an absorbent. Stripping Column: The regenerated TEG underwent further treatment in the stripping column, enhancing its reusability and minimizing wastage. A circulation pump was also employed to maintain the flow of TEG within the system, ensuring a consistent and efficient dehydration process. The integration of these units facilitated a meticulous and systematic approach to natural gas dehydration, allowing for the precise control and monitoring of the gas composition.

2.1.1 Natural Gas Composition and HYSYS Simulation Operating Condition

Natural gas is a fossil fuel composed primarily of methane gas, with varying amounts of other gases such as ethane, propane, and butane. The exact composition of natural gas can vary depending on the location of its source and can contain trace amounts of nitrogen, carbon dioxide, and other gases (Table 1). The Aspen HYSYS is process simulation software used to design and optimize natural gas processing facilities. Engineers use HYSYS to model natural gas under different operating conditions, such as pressure, temperature, and chemical composition. These simulations allow engineers to predict the behavior of natural gas and optimize processing facilities to maximize efficiency, yield, and reduce costs. HYSYS simulations have become standard in the oil and gas industry, where effective process modeling can significantly improve the overall operational performance of processing facilities. HYSYS Simulation for the Process Flow Diagram of the Natural Gas Dehydration Unit is shown in Figure 1.

Table 1: Natural Gas Properties (Wosu *et al*., 2023)

Components	Composition	Molar Mass (g/mol)
C_1	0.8939	16.00
C_2	0.0310	30.00
C_3	0.0148	44.10
i-C_4	0.0059	58.12
n-C_4	0.0030	58.12
n-C_5	0.0005	72.15
i-C_5	0.0010	72.15
H_2O	0.0050	18.00
N_2	0.0010	14.00
H_2S	0.0155	34.10
CO_2	0.0284	44.00
TEG	0.0000	150.154
Total	1.0000	610.894
Operating Condition		
Pressure(kPa)	6205.2832	
Temperature (°C)	29.4444	
Flow rate (kg/s)	768.6343	

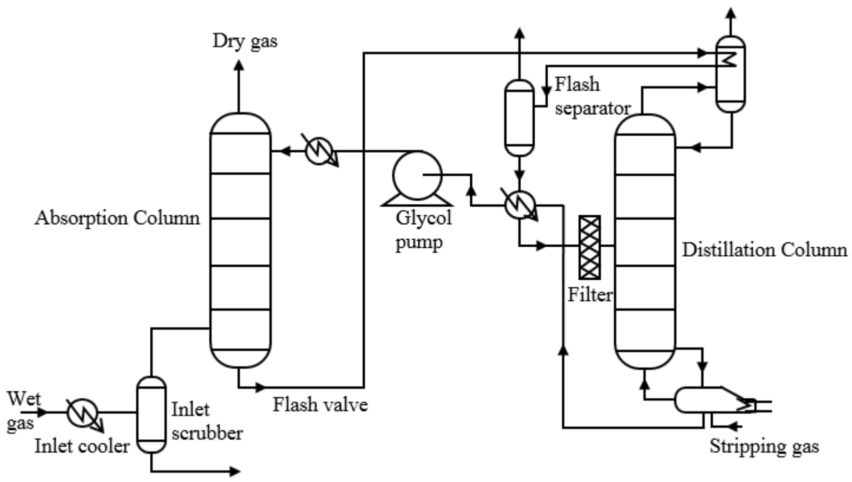

Figure 1: Process Flow Diagram of Natural Gas Dehydration Unit

Table 2. The equipment and units of the dehydration plant is presented in

Table 2: Equipment and the Units of the Plant Design

Design Equipment	Designation/Unit
Inlet cooler	U01
Separator	U02
Absorber	U03
Heat exchanger 1	U04
Regenerator column	U05
Mixer	U06
Pump	U07
Heat exchanger 2	U08

The various streams and nomenclature of the dehydration process is presented in Table 3.

Table 3: Streams Associated with the Plant Design

Streams	Name
S_1	Inlet gas
S_2	Water out
S_3	Gas to contactor
S_4	TEG feed
S_5	Dry gas
S_6	Sales gas
S_7	Rich TEG
S_8	Lowpressure TEG
S_9	Regeneration feed
S_{10}	Wet gas
S_{11}	Regeneration bottom
S_{12}	Lean TEG L/R
S_{13}	Make-up TEG
S_{14}	TEG to pump
S_{15}	Pump out
S_{16}	TEG to recycle

2.2 Methods

The research methodology is both quantitative and analytical; it integrates the design and simulation of a TEG natural gas dehydration plant using Aspen HYSYS Version 12 as the process simulation tool. The sophisticated nature of HYSYS, its program architecture, interactive operation, engineering capabilities, and integrated design make it capable of handling steady-state and unsteady-state simulations. The principle of mass and energy balance was integrated in developing the design/performance model of the industrial absorber, and the column performance in terms of mass, energy, and composition was analyzed. For efficient utilization of the absorber, the size specification in terms of height, diameter, area, and volume of the column was also determined. The performance models of absorbers in the TEG dehydration plant were developed from the first principle of material and energy balance. The performance evaluation of process streams and analysis for mass, energy, and composition of the absorption unit were carried out using the data obtained from the HYSYS simulation.

2.2.1 Development of Mass and Energy Balance of the Absorber Column

Consider the schematic of absorber/contactor column of a TEG dehydration plant shown in Figure 2.

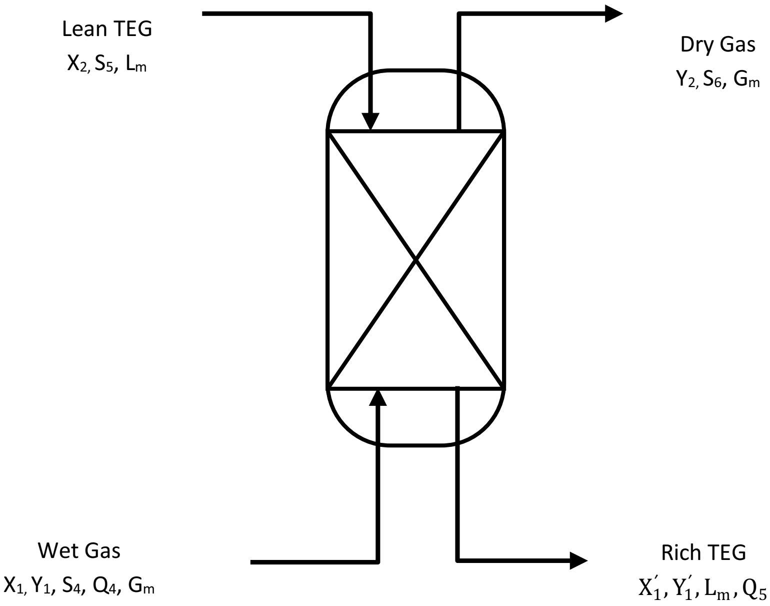

Figure 2: Schematic of an Industrial of Contactor/Absorber

The general mass or energy balance model of an industrial absorber is mathematically given in Equation 1.

$$\begin{bmatrix} \text{Rate of} \\ \text{Accumulation} \\ \text{of product} \\ \text{within the} \\ \text{volume} \end{bmatrix} = \begin{bmatrix} \text{Rate of} \\ \text{input of} \\ \text{feed into} \\ \text{volume} \end{bmatrix} - \begin{bmatrix} \text{Rate of} \\ \text{output of} \\ \text{feed from} \\ \text{volume} \end{bmatrix} + \begin{bmatrix} \text{Rate of} \\ \text{generation} \\ \text{due to the} \\ \text{process} \end{bmatrix} \quad (1)$$

For overall mass or material balance of an absorber column in equation (1) can be presented in terms of process streams as given in Equation 2.
For overall mass or material balance of an absorber column in equation (1) can be presented in terms of process streams as given in Equation 2.

$$S_4+S_5=S_6+S_7 \quad (2)$$

The component balance of water in TEG is given in Equation 3.

$$S_4 Y_1 + S_5 X_2 = S_6 Y_2 + S_7 X_1 \quad (3)$$

Since $X_2 = 0$, Equation 3 transforms to:

$$S_4 Y_1 = S_6 X_2 + S_7 X_1 \quad (4)$$

There is no energy balance taking place in the absorber or contactor since it is usually considered an isothermal process thus;

$$Q_4 = Q_5 \quad (5)$$

2.2.2 Absorber Column Design

Consider the schematic representation of an absorption column with feeds and product streams, as in Figure 2.
The feed streams consist of:
(i) Methane Hydrate (Inlet Wet Gas)
(ii) Lean TEG
The product stream consists of:
(i) Methane (Dry Natural Gas)
(ii) Rich TEG
For the steady-state physical process, the terms in Equation 1 can be defined as follows:

$$\begin{bmatrix} \text{Rate of accumulation} \\ \text{of product within} \\ \text{the volume} \end{bmatrix} = 0 \quad (6)$$

$$\begin{bmatrix} \text{Rate of input} \\ \text{of feed into the} \\ \text{volume} \end{bmatrix} = G_m Y_1 + L_m X_2 \quad (7)$$

$$\begin{bmatrix} \text{Rate of output} \\ \text{of feed from} \\ \text{volume} \end{bmatrix} = G_m Y_2 + L_m X_1 \quad (8)$$

$$\begin{bmatrix} \text{Rate of} \\ \text{generation} \\ \text{due to the} \\ \text{process} \end{bmatrix} = 0 \quad (9)$$

Combining Equations 6-9 into Equation 1 yields:

$$G_m Y_1 + L_m X_2 = G_m Y_2 + L_m X_1 \quad (10)$$

Assuming that the solvent is pure i.e. the Rich TEG, it therefore implies that

$$X_1 = 0 \quad (11)$$

Equation 10 becomes;

$$G_m \; Y_1 + L_m X_2 = G_m Y\_2$$

$$L_m X_2 = G_m Y_2 - G_m Y_1) \quad (12)$$

$$L_m X_2 = G_m (Y_2 - Y_1)$$

$$X_2 = \quad (Y_2 - Y_1) \quad (13)$$

$$L_m = G_m \frac{(Y_2 - Y_1)}{X_2} \quad (14)$$

$$G_m = \frac{L_m X_2}{Y_2 - Y_1} \quad (15)$$

The molar flow rate of gas (G_m) and liquid (L_m) are expressed mathematically as;

$$L_m = \frac{G_t}{3600s/jhrM_G} \quad (16)$$

$$G_m = \frac{L_t}{3600s/jhrM_w} \quad (17)$$

The slope of equilibrium line (m) can be determined by considering a straight-line graph of the equilibrium data,

$$\text{Slope } (m) = \frac{\Delta_y}{\Delta_x} \quad (18)$$

$$(m) = \frac{x_2 - x_1}{y_2 - y_1} \quad (19)$$

The cross-sectional area of the absorption column determines its capacity and the column is normally designed to operate at the highest economical pressure drop, to ensure good liquid and gas distribution. The column cross-sectional area and diameter for the selected pressure drop can be obtained from a correlation of liquid and vapour flow rates, systems' physical properties and packing characteristics, the gas mass flow rate per unit cross-sectional area and lines of constant pressure drop adopted from (Sinnott & Towler, 2009)
The liquid-vapour flow factor (F_{LV}) is mathematically given as;

$$F_{LV} = \frac{L_m}{G_m}\sqrt{\frac{\rho_g}{\rho_L}} \quad (20)$$

The flooding limit determination can be obtained from generalized pressure drop correlation (Sinnott & Towler, 2009) while the percentage flooding and gas flow rate (V_w) per unit cross-sectional area are expressed mathematically as;

$$\%\ \text{flooding} = \sqrt{\frac{K_4^1 \ at\ \Delta p \times 100}{K_4 \ at\ flooding}} \quad (21)$$

$$V_w = \sqrt{\frac{K_4 \rho_v (\rho_v - \rho_L)}{13.1 F_p (\mu_L / \rho_L)^{0.1}}} \quad (22)$$

The old and new areas of the absorber column are given as;

$$Ac_1 = \frac{G}{V_m} \quad (23)$$

$$Ac_2 = \frac{1}{4} \pi D_c^2 \quad (24)$$

The column diameter (D_c) can be obtained from the relationship;

$$D_c = \frac{4Ac_2}{\pi} \quad (25)$$

The diameter to packing size ratio is given as;

$$\text{Ratio} = \frac{D_c}{packing\ size} \quad (26)$$

The percentage flooding due to new diameter is expressed as;

$$\text{New \% flooding} = \frac{Ac_1}{Ac_2} \times 100\ \% \tag{27}$$

The number of gas-phase transfer unit (N_G) can be obtained graphically as a function of slope (m) and $m\frac{G_m}{L_m}$ from (Sinnott & Towler, 2009) as a quick estimate. But if the equilibrium curve and operating lines can be taken as a straight line and the solvent feed is essentially solute-free, the number of transfer units required for a given separation is given as:

$$N_G = \frac{1}{1-\left(\frac{mG_m}{L_m}\right)} \ln\left[\left(1 - \frac{mG_m}{L_m}\right)\frac{y_1}{y_2} + \frac{mG_m}{L_m}\right] \tag{28}$$

While the number of liquid-phase transfer unit (NL) is given as;

$$N_L = \frac{1}{1-\left(\frac{mG_m}{L_m}\right)} \ln\left[\left(\frac{L}{mG}\right) + \left(1 - \frac{L}{mG}\right)\frac{x_1}{x_2}\right] \tag{29}$$

Where, $\frac{L}{mG}$ is known as the stripping factor and $L/G < m$ (scope of equilibrium line)

The height of gas (HG) and liquid (HL) phase transfer unit are obtained from the relationship;

$$H_G = \frac{G_m}{K_G\, a_w\, p} \tag{30}$$

$$H_l = \frac{L_m}{K_L\, a_w\, C_t} \tag{31}$$

Where (a_W) and (C_t) are the effective wetted area of packing and total concentration given as;

$$\frac{a_w}{a} = 1 - \exp\left[-45\left(\frac{\sigma_c}{\sigma_L}\right)^{0.75}\left(\frac{L_w^*}{a\mu_L}\right)^{0.1}\left(\frac{L_w^{*2}a}{\rho_L^2 \cdot g}\right)^{-0.05}\left(\frac{L_w^{*2}}{\rho_L\,\sigma_L\,a}\right)^{0.2}\right] \tag{32}$$

$$Ct = \frac{\rho_L}{(\text{Molecular weight of solvent})} \tag{33}$$

The mass transfer coefficient for the liquid (K_L) and gas (K_G) phase

$$K_L\left(\frac{\rho L}{\mu L g}\right)^{1/3} = 0.0051\left(\frac{L_w^*}{aw\mu_L}\right)^{2/3}\left(\frac{\mu L}{\rho LDL}\right)^{-1/2}(ad_P)^{0.4} \tag{34}$$

$$K_G\left(\frac{RT}{aDv}\right) = K_5\left(\frac{V_w^*}{a\mu V}\right)^{0.7}\left(\frac{\mu V}{\rho V\,Dv}\right)^{1/3}(ad_P)^{-0.2} \tag{35}$$

The height of overall gas-phase(H_{OG}) and liquid-phase (H_{OL}) transfer units are given as;

$$H_{OG} = H_G + \frac{mG_m}{L_m}H_L \tag{36}$$

$$H_{OL} = H_L + \frac{mL_m}{G_m}H_G \tag{37}$$

The height of packing required for gas and liquid phase transfer unit (Z_G and Z_L) and the total height of packing required for gas and liquid phase transfer unit (Z_{GT} and Z_{LT}) are given in Equations 38-41.

$$Z_G = N_{OG}\,H_{OG} \tag{38}$$

$$Z_{GT} = Z + 30\%\ Z \tag{39}$$

$$Z_L = N_{OG}\,H_{OL} \tag{40}$$

$$Z_{LT} = Z_L + 30\%\ Z_L \tag{41}$$

The volume of packed column (V_c) is given as;

$$V_c = \pi r^2 h \tag{42}$$

Table 4: Material Balance Results of Process Streams for Absorber/Contactor Unit

Streams	Inflow 1 Gas to contactor	Inflow 2 TEG Feed	Outflow 1 Dry Gas	Outflow 2 Rich TEG
Molar Flow (kgmol/S)	41.488	0.0010	41.4778	0.0118
Mass Flow (kg/S)	765.4211	0.1422	765.2267	0.3366
Volume Flow (m^3/S)	2.29676	0.00001	2.29660	0.00032

From Table 4, the absorber unit is a two inputs and a two output system configuration which is characterized by the principle of conservation of material where input streams are equal to output streams. For instance, in the process flow diagram, $S_3 + S_4 = S_5 + S_6$. In this unit where dehydration occurs, the inflow of mass in the gas to the contactor unit was reduced from 41.4885kgmol/s to 41.4778 kgmol/s in the dry gas unit and the initial TEG feed of 0.0010kgmole/s was increased to 0.0118 kgmol/s in the rich TEG which signifies that absorption has taken place.

Table 5: Energy Balance Results of Process Streams Absorber/Packed Column Unit

Streams	Inflow 1 Gas to contactor	Inflow 2 TEG Feed	Outflow 1 Dry Gas	Outflow 2 Rich TEG
Temperature (°C)	29.4444	48.8889	29.6828	29.5188
Pressure (kPa)	6205.2832	6205.2832	6205.2832	6205.2832
Heat Flow (KJ/S)	-3.56×10^6	-7.80×10^2	-3.56×10^6	-3.86×10^3

From Table 5, the absorber unit operates as a two-input, two-output system. In this unit, no variation of pressure and heat flow occurs in the gas to the contactor and dry gas streams but there is a light temperature difference between the gas to the contactor and dry gas unit because of the heat exchanger at the TEG inlet to the contactor. The dry gas temperature of 29.68^{0}C is within the recommended range or specification for pipeline transmission of 20^{0}C to 35^{0}C(Kidnay & Parrish, 2006). This validates the objectives of this paper.

Table 6: : Composition Balance of Natural Gas Component in Absorber (Unit 02)

	Composition (Mole Fraction)			
Components	Inlet Stream (S_3) Gas to Contactor	Inlet Stream (S_4) TEG Feed	Outlet Stream (S_5) Dry Gas	Outlet Stream (S_7) Rich TEG
N_2	0.0010	0.0000	0.0010	0.0000
CO_2	0.0285	0.0000	0.0285	0.0008
H_2S	0.0156	0.0000	0.0156	0.0017
C_1	0.8977	0.0000	0.8980	0.0009
C_2	0.0311	0.0000	0.0311	0.0000
C_3	0.0149	0.0000	0.0149	0.0000
$i-C_4$	0.0059	0.0000	0.0059	0.0000
$n-C_4$	0.0030	0.0000	0.0030	0.0000
$i-C_5$	0.0010	0.0000	0.0010	0.0000
$n-C_5$	0.0005	0.0000	0.0005	0.0000
TEG	0.0000	0.9250	0.0000	0.0793
H_2O	0.0007	0.0750	0.0005	0.9172

Table 6, shows the component balance of natural gas composition in the absorber (Unit 03) which operates as a double input and double output system where the natural gas absorption by TEG takes place. The methane component i.e. S_3 = 0.8977 was increased after absorption as shown in the dry gas composition S_5 = 0.8980 whereas, the TEG feed S_4 = 0.9250 is used up and reduced in the rich TEG to S_7 = 0.0793. Also, more water is absorbed by TEG which results in to increase in the composition of water in the TEG feed from S_4 = 0.0750 to S_7 = 0.9172 in the rich TEG. The significance of this is that the water content of the natural gas has been absorbed by the lean TEG which results to an increase in methane (dry gas) at the top exit of the contactor and an increase in the rich TEG (mixture of TEG and water) at the bottom exit of the contactor which will be separated in the regenerator or distillation column of the dehydration plant for lean TEG recovery.

Table 7: Results of Design/Sizing of Absorber/Contactor column in TEG Dehydration Plant

Absorber/Contactor Column Parameters	Units	Design/Size Specification
Column Height	m	7.00
Column Diameter	m	1.50
Column Area	m^2	1.77
Column Volume	m^3	12.38

Table 7 shows a presentation of the size specification or design of height, diameter, area and volume of an industrial absorber/contactor of a natural gas TEG dehydration process where the TEG absorption takes place. The column size or design specification is what is required for optimum TEG absorption to meet the pipeline transmission standard or specification of sales gas. The absorber design or size specification is the required specification for optimum dehydration of the characterized natural gas with feed rate of 768.63 kg/s at an operating temperature and pressure of 29.44 ^{0}C and 6205.28 kpa.

4. Conclusion

The design and performance analysis of an industrial absorber, also known as the contactor in a natural gas TEG dehydration plant, has been carried out. The absorber column is a key component or unit of the dehydration plant where the natural absorption by TEG takes place. Here, the water content of gas is sufficiently absorbed by TEG to meet the standard recommended for pipeline transmission, distribution, and storage. The natural gas components, composition, and molar mass under standard operating pressure, temperature, and flow rate of 6205.28 kPa, 29.440 °C, and 768.63 kg/s, respectively, were simulated using the advanced process simulation tool Aspen HYSYS Version 12 to give the absorber design or size specification in terms of column height, diameter, area, and volume as 7.00 m, 1.50 m, 1.77 m^2, and 12.38 m^3, respectively. This simulation was governed by the conservation law of mass and energy modeled in the HYSYS, which was also applied in the development of the absorber column design or performance model, which gave an insight for manual design and optimization of the absorber column for future researchers. Based on the analysis of the mass or composition and energy balance of the process, the absorber design or size specification is most economically suitable for optimum dehydration of the characterized natural gas.

Definition of

X_1:	Mass fraction of dry gas in rich TEG	-
X_2:	Mass fraction of dry gas in water	-
Y_1:	Mole fraction of water in dry gas	-
Y_2:	Mole fraction of dry gas out	-
Q_4:	Wet gas heat	kW
Q_5:	Rich TEG heat	kW
G_m:	Molar gas flow rate per unit area	$kmol/m^2s$
L_m:	Molar liquid flow rate per unit area	$kmol/m^2s$
G_i:	Mass flow rate of gas	kg/s
M_G:	Molecular weight of gas	kg/mol
L_i:	Mass flow rate of liquid	kg/s
M_w:	Molecular weight of water	kg/mol
$K^1{}_4$:	Flooding limit at a given pressure	mmH_2O/m
Δp:	Pressure drop	mmH_2O
K_4:	Flooding limit	mmH_2O
V_w:	Gas flow rate per cross-sectional area	kg/mol
ρ_v	Density of vapour	kg/sm^2
ρ_L	Density of liquid	kg/sm^3
F_p:	Packing factor	-
A_c:	Column area	m^2
Dc_1:	Old area	m^2
Dc_2:	New area	m^2
D_c:	Diameter of column	m
N_L:	Number of liquid phase transfer unit	-
H_G:	Height of gas phase	m
K_G:	Mass transfer coefficient of gas	$kmol/m^2s.atm$
a_w:	Effective wetted area of packing	m^2
P:	Column operating pressure	kN/m^2
a:	Actual area of packing per unit volume	m^2/m^3
$L^*{}_W$:	Liquid mass flow rate per unit cross-sectional area	kg/m^2s
σ_c :	Critical surface tension	N/m
σ_L :	Surface tension of liquid	N/m
g:	Acceleration due to gravity	m/s^2
μ_L:	Viscosity of liquid	Ns/m^2
k_L:	Mass transfer coefficient of liquid	$kmol/m^2s.atm$
C_t:	Total concentration	$kmol/m^3$
d_p:	Parking size	m
H_{OG}:	Height of overall gas-phase transfer unit	m
H_{OL}:	Height of overall liquid-phase transfer unit	m
N_{OG}:	Number of gas-phase transfer unit	-
Z_G:	Height of packing for gas phase transfer unit	m
Z_L:	Height of packing for liquid phase transfer unit	m
V_C:	Volume of packed column	m^3
h:	Height of column	m

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