SSRG International Journal of Recent Engineering Science
ISSN: 2349–7157 / https://doi.org/10.14445/23497157/IJRES-V10I5P105

Volume 10 Issue 5, 39-48, Sep-Oct 2023

Original Article

Design and Performance Analysis of an Industrial Triethylene Glycol Recovery Regenerator of a Dehydration Process

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Received: 01 August 2023 Revised: 03 September 2023 Accepted: 24 September 2023 Published: 11 October 2023

Abstract *- Design models of a regenerator for lean Triethylene Glycol (TEG) recovery in natural gas dehydration plants were developed from the first mass and energy balance principle. The rich TEG was heated in a heat exchanger and fed to the regenerator column. The lean TEG is recovered at the bottom of the column and recycled—the separation between TEG and water results from differences in temperature and densities of both components. The TEG dehydration plant was designed using HYSYS to obtain the design/size specification of the regenerator volume, height, diameter and area of the column as (18.857m3, 6.000m, 2.000m and 3.143m2) respectively, with 0.9250mol% of lean TEG recovery for further absorption. The results obtained show that the natural gas feed condition (temperature, pressure and flow rate) affects the performance efficiency of the regenerator and other units of the TEG dehydration plant.*

Keywords *- Natural gas, Water vapour, Absorber, Aspen HYSYS, Triethylene glycol.*

1. Introduction

Natural gas is one of the most important energy resources used globally. Natural gas reservoirs often contain impurities such as water vapor, carbon dioxide, and hydrogen sulfide that must be removed before transportation and use. Removing water vapor from natural gas is critical because it can cause corrosion, blockages and the formation of hydrates in pipelines. The most commonly used method for removing water vapor from natural gas is through triethylene glycol (TEG) absorption. The TEG dehydration process consists of three primary steps: Absorption, glycol-water separation, and glycol regeneration. In the absorption process, the TEG solution absorbs the water vapor from the natural gas stream. The glycol-water separation process is where the TEG solution is separated from the water. Finally, in the glycol regeneration process, the water is removed from the TEG solution and returned to use in the absorption process. One of the critical aspects of the TEG dehydration process is the design and performance analysis of the industrial TEG recovery regenerator, which is the focus of this research.

An industrial TEG recovery regenerator's design and performance analysis are necessary to efficiently operate the TEG dehydration process. Several design parameters significantly influence the performance of the TEG recovery regenerator. These parameters include TEG composition, regeneration temperature, pressure, and stripping gas flow rate. The regeneration temperature is one of the most critical parameters that affect the performance of the TEG recovery regenerator [1]. The selection of the stripping gas flow rate has also been shown to impact the performance of the TEG recovery regenerator. A study by Zhao et al. [14] investigated the effect of stripping gas flow rate on the performance of the TEG recovery regenerator. The study found that the use of high flow rates resulted in faster regeneration of TEG by stripping off the absorbed water. However, high flow rates increase the regeneration cost, and a balance must be struck to ensure the optimal cost and performance of the system. The efficiency of the TEG recovery regenerator also depends on the type of stripping gas used. Nitrogen is the most commonly used gas in the TEG regeneration process because it is inert and safe to handle.

In the TEG recovery regenerator, the use of a reboiler is necessary to provide the heat required for TEG recovery and regeneration. The reboiler must be designed to allow for efficient heat transfer from the energy source to the TEG solution. Studies have shown that the type of reboiler used, such as a fired or heat exchanger type, can significantly impact the performance of the TEG recovery regenerator [2]. The efficient performance of the TEG dehydration process is critical for the natural gas industry to reduce operational costs while simultaneously improving performance. An industrial TEG recovery regenerator's design and performance analysis

are crucial to achieving these goals. The regeneration temperature, stripping gas flow rate, type of stripping gas, and reboiler are all critical parameters that must be carefully considered and optimized to ensure the optimal efficiency of the TEG recovery regenerator. Further research is needed to investigate the impact of other parameters on the performance of the TEG recovery regenerator.

Several design parameters influence the performance of an industrial TEG recovery regenerator. These parameters include TEG composition, regeneration temperature, pressure, and stripping gas flow rate. The efficiency of the regenerator depends on the type of stripping gas used, with nitrogen being the most commonly used gas. Furthermore, using a reboiler is necessary to provide the heat required for the TEG recovery regenerator to work efficiently [3]. The selection of the stripping gas flow rate has been shown to impact the performance of the TEG recovery regenerator. Studies have revealed that using high flow rates results in faster regeneration of TEG by stripping off the absorbed water but also increases the cost of regeneration [4]. The design and performance analysis of the industrial TEG recovery regenerator is critical to ensuring the efficient and cost-effective operation of the natural gas dehydration process. By optimizing the design parameters and characteristics of the regenerator, the operational costs of the natural gas dehydration process can be reduced while simultaneously increasing its performance.

In the recent past and presently, natural dehydration by TEG (glycol-based liquid) has proven to be the best and most popular method for natural gas dehydration because of its capability of reducing the water content of natural gas to less than 0.0112kg H_2O/m^3s of NG as recommended by process industry for pipeline transmission [2][5]. The water associated with natural gas is a pollutant capable of causing the formation of methane hydrate, sludge, cakes, corrosion and other flow problems during processing operation, storage and transmission [6]. The regenerator/distillation column is an important unit of the TEG dehydration plant, thereby making this research highly imperative as it seeks to develop the performance model for sizing the regenerator from the first principle of material and energy balance. That is, determining the volume, height, diameter and area of the regenerator/distillation column.

It will also consider the design of the TEG dehydration plant using advanced process simulation software HYSYS as the design tool. Most researchers and field workers have done considerable work in TEG dehydration plants. A few of them are cited as follows: Muhammad [16] researched enhanced regeneration of TEG to achieve effective dehydration and defined enhanced regeneration as any system or process that improves glycol regeneration to achieve a leaner or more concentrated glycol solution once it has been recycled. He conducted a comparative analysis of the three methods of achieving rich TEG regeneration under low pressure and high temperature in a regeneration process, including Dehydration rate, Stahl column and stripping gas, and Drizo process. Dehydration Rate involves using a typical gas dehydration by TEG and, as such, has little significant impact on the efficiency of the gas dehydration process since the concentration of the regenerated TEG is directly proportional to the amount of water being absorbed in the absorption column. Increasing the reboiler temperature to separate more water from TEG is usually not advisable since it can decompose the TEG itself. The maximum range of reboiler temperature for recovery of TEG concentration of about 97-98% wt is 350^0F (176.7^0C) and 400^0F (204.4^0C) [7].

Stahl Columns and Stripping Gas involves reducing partial water vapour pressure in the distillation column by introducing a stripping gas and adding a Stahl column or by lowering the operating pressure of the distillation column to be below atmosphere pressure (vacuum pressure). By implication, introducing or injecting stripping gas is preferable because of the difficulties or complications and the expensive nature of lowering operating pressure. At the same time, Drizo Process technology enhances rich-glycol regeneration using solvent stripping instead of the conventional gas stripping that uses flash gases. The process is capable of obtaining higher TEG purities of 99.988%, which is more than the gas stripping method and consequently gets a much larger water dew point depression of 100^0C [7] [8]. In this process, the effluent gas in the distillation or regeneration column is recovered as liquid from the top of the column by introducing aromatic gases like n-heptane and benzene as entrainers in the TEG-water system which forms a homogenous azeotropic distillation between benzene and water thereby increasing the concentration of the regenerated TEG so that more water will be absorbed from wet natural gas by TEG leaving very small amount of water vapour of about 0.112kg H_2O/m^3s of dry gas [3]. The above TEG-enhancement methods were simulated by computing the following thermodynamic data and operating conditions using advanced process simulation software called HYSYS.

Mohamed et al. [9] researched the economic comparison between dry natural gas and nitrogen gas for stripping water vapour from glycol in the rich TEG regeneration process during natural gas dehydration. According to the researchers, the natural gas dehydration process is important to prevent problems related to pipeline transportation, corrosion, and water condensation, which causes plugs in pipelines [11]. They utilized the TEG dehydration method in a cost-effective manner by using HYSYS simulation software to compare the efficiency of using part of the dried natural gas obtained from the contactor or absorption column as the striping gas in rich TEG recovery in the regeneration or distillation column to that of using nitrogen gas for stripping water vapour from TEG. They developed material and energy balance models, simulated in HYSYS and applied the following feed

composition/conditions. Gu & Liu [3] researched the design of a natural gas dehydration tower and stated that nature has become a catalyst for economic development in the world [12] [4]. It is the cleanest, most convenient, most economical and most efficient energy compared to crude oil and other sources of energy; however, due to water contained in the natural gas and some other substances (contaminants) which can form hydrate in some special cases/conditions. At certain conditions, natural gas is a solid-state unstable compound capable of causing blockage of the pipe, blockage of the spray nozzle and the separation equipment. They included that TEG dehydration remains the most economical and efficient method of natural gas dehydration; the water in the gas is absorbed in the lean solvent (lean TEG) in the absorption column, producing a rich solvent (rich TEG) in the regeneration/distillation column and a dry gas. Kinigoma & Ani [6] compared gas dehydration methods based on Energy Consumption. The researchers compared the three conventional methods of natural gas dehydration, absorption, adsorption and condensation by developing energy balance models/equations of the three dehydration methods. They considered a natural gas with a given water content, temperature range, and changes or variations in pressure and arrived at the following conclusion. There is a decrease in energy consumption as the pressure increases in the process. At high pressure, the condensation method of dehydration requires the least amount of energy at high pressure and low temperature [13]. TEG dehydration (absorption method) is more suitable. At low dew point temperatures, solid desiccant adsorption is preferable.

The dehydration process is a critical aspect of the natural gas industry, wherein water is extracted from natural gas to improve its quality and value. Triethylene Glycol (TEG) is a widely used agent in this process, serving as a powerful absorbent of water from natural gas. Upon saturation, the TEG-rich solution requires regeneration to expel the absorbed water. The efficient regeneration of TEG is critical to maintaining operational efficiency, minimize costs and mitigating environmental impacts. In this context, the design and performance analysis of an industrial TEG recovery regenerator is paramount. This research aims to explore the design parameters and performance characteristics of an industrial TEG recovery regenerator, with a particular focus on enhancing its efficiency, operational reliability, and cost-effectiveness. The findings of this study will provide valuable insights that can be used to optimize TEG regeneration in the dehydration process, leading to improved process performance and reduced operational costs.

2. Materials and Methods

2.1. Materials

The material content of this research is: The feed material, i.e. temperature, pressure and flow rate of the characterized natural gas, which is composed of Methane, Ethane, Propane, i-Butane, n-Butane, i-Pentane, n-Pentane, Hydrogen sulphide, carbon dioxide, nitrogen, water and TEG as an absorbent used in the dehydration process. Dehydration plant with the following units: Inlet cooler, Inlet scrubber, contactor/absorber column, flash valve, flash separator, filters, heat exchanger, regenerator/distillation column, stripping column and circulation pump.

2.2. Methods

Design and simulation of TEG natural gas dehydration plant using Aspen HYSYS, development and the performance of models for industrial TEG recovery regenerator in a dehydration plant from the first principle of material and energy balance, and the analysis of stream flow of mass, energy and composition balance in the regenerator/distillation column.

2.3. Natural Gas Composition and HYSYS Simulation Operating Condition

Table 1. Natural gas properties

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 (^{0}C)	29.4444	
Flow rate (kg/s)	768.6343	

Table 2. Equipment and the units of Proposed/Modified plant design

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

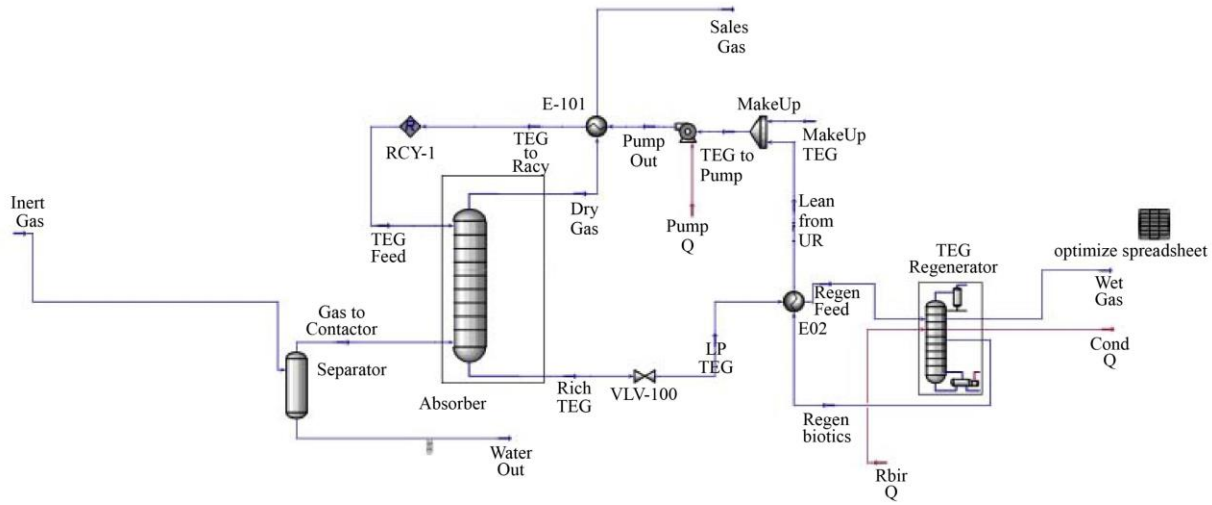

Fig. 1 Process flow diagram of natural gas dehydration unit

Table 3. Streams associated with the Proposed/Modified plant design

Streams	Name
S_1	Inlet gas
S_2	Water our
S_3	Gas to contactor
S_4	TEG feed
S_5	Dry gas
S_6	Sales gas
S_7	Rich TEG
S_8	Low pressure 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

2.4. Development of Performance Models

Consider the schematic of the regenerator/distillation unit of a TEG dehydration plant.

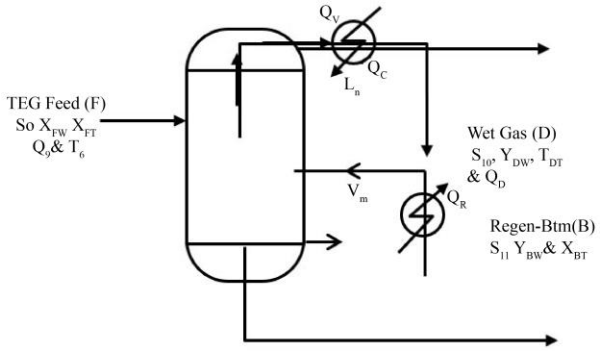

Fig. 2 Schematic of Regenerator/Distillation Column

Consider the schematic representation of a regenerator/distillation column with feed and products as:
The feed stream consists of:

- Lean TEG
- Water

While the product stream consists of the following:

- Rich lean TEG
- Other waste products

The general design model of an industrial regenerator/distillation column is given as follows;

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

- Overall Mass Balance

Since no accumulation and regeneration occurs in a physical process, equation (1) transforms to;

$$S_9 = S_{10} + S_{11} \quad (2)$$

- Component Balance for Water

$$S_9 X_{FW} = S_{10} y_{DW} + S_{11} X_{BW} \quad (3)$$

- Component Balance for TEG

$$S_9 X_{FT} = S_{10} y_{DT} + S_{11} X_{BT} \quad (4)$$

Where X_{FW} = Mole fraction of water in Regen-Feed
X_{FT} = Mole fraction of TEG in Regen-Feed

Y_{DT} = Mole fraction of TEG in wet gas
X_{BT} = Mole fraction of TEG in Regen-Btms

- Regeneration/Distillation Column Energy Balance
Overall Heat Balance

$$Q_R + Q_6 = Q_V + Q_B \quad (5)$$

$$Q_B = S_8 C_{P_{TEG}}(T_9 - T_8) \quad (6)$$

$$Q_V = S_8 C_{P_W}(T_V - T_6) + S_8 \prec_V \quad (7)$$

$$Q_C = S_{10} C_{P_W} T_C \quad (8)$$

$$Q_V = Q_C + Q_D \quad (9)$$

$$Q_D = Q_V - Q_C \quad (10)$$

$$Q_9 = Q_8 - \Delta Q \quad (11)$$

Where $\dot{Q}_R$ = Heat of reboiler (KW)
$\dot{Q}_B$ = Heat of Regen-Btm (KW)
$\dot{Q}_V$ = heat of condenser (KW)
$\succ_V$ = Latent heat of vapourization (kJ/kg)
T_C = Condenser temperature (k)
S_{10} = Mass flow rate of wet gas at the top (kg/S)
$\dot{Q}_D$ = heat of wet gas (KW)

- Operating Lines Determination

This can be obtained by applying the principle of material balance as follows:

For the steady-state physical process, the terms in equation (1) can be defined as follows:

$$\begin{bmatrix} Rate\ of \\ accumulation \\ of\ product \\ within\ the \\ volume \end{bmatrix} = 0 \quad (12)$$

$$\begin{bmatrix} Rate\ of \\ input\ of \\ feed\ into \\ volume \end{bmatrix} = F \quad (13)$$

$$\begin{bmatrix} Rate\ of \\ output\ of \\ feed\ into \\ volume \end{bmatrix} = D + B \quad (14)$$

$$\begin{bmatrix} Rate\ of \\ generation\ of \\ feed\ due\ to\ the \\ process \end{bmatrix} = 0 \quad (15)$$

Combining equation (12) to (15) into equation (1) yields:

$$0 = F - (D + B) + 0$$

$$F = D + B \quad (16)$$

Where
F = Input feed rate (kg/hr)
D = Output rate at distillate (kg/hr)
B = Output rate at bottom (kg/hr)

$$B = F - D \quad (17)$$

$$D = F - B \quad (18)$$

- Component Balance of Water

$$FX_{FW} = DX_{DW} + BX_{BW} \quad (19)$$

For the steady-state physical process, the terms in equation (19) can be defined as follows:
Where,
X_{FW} = Mass/mole fraction of water at the feed
X_{DW} = Mass/mole fraction of water at the distillate
X_{BW} = Mass/mole fraction of water at the bottom
Substituting equation (18) into (19) yields

$$FX_{FW} = DX_{DW} + (F - D)X_{FW}$$

$$FX_{FW} = DX_{DW} + FX_{BW} - DX_{BW}$$

Collecting like terms

$$DX_{BW} - DX_{DW} = FX_{BW} - FX_{FW}$$

Factorizing both sides of the equation yields

$$D(X_{BW} - X_{DW}) = F(X_{BW} - X_{FW})$$

$$D = \frac{F(X_{BW} - X_{FW})}{(X_{BW} - X_{DW})} \quad (20)$$

Substituting equation (18) into (19) yields

$$FX_{FW} = (F - B)X_{DW} + BX_{BW}$$

$$FX_{FW} = FX_{DW} - BX_{DW} + BX_{BW}$$

Collecting like terms

$$BX_{DW} - BX_{BW} = FX_{DW} - FX_{FW}$$

$$B(X_{DW} - X_{BW}) = F(X_{DW} - X_{FW})$$

$$B = \frac{F(X_{DW} - X_{FW})}{X_{DW} - X_{BW}} \quad (21)$$

- Component Balance of TEG

$$FX_{FT} = DX_{DT} + BX_{BT} \quad (22)$$

Where,
X_{FT} = Mass/mole fraction of TEG at the feed
X_{DT} = Mass/mole fraction of TEG at the distillate
X_{BT} = Mass/mole fraction of TEG at the bottom
Similarly, substituting equation (17) into (22) yields

$$D = \frac{F(X_{BT} - X_{FT})}{X_{BT} - X_{DT}} \quad (23)$$

Also,

$$B = \frac{F(X_{DT} - X_{FT})}{X_{DT} - X_{BT}} \quad (24)$$

- Balance at the Top of the Column

$V_n = L_n + D$ (Sinnott & Towler, [12]) (25)

Where,
V_n = Vapour flow rate at the top (kg/hr)
L_n = Liquid flow rate at the top (kg/hr)
n = Top tray

$$R = \frac{L_n}{D} \text{ (Sinnott \& Towler, [12])} \quad (26)$$

$$L_n = RD \quad (27)$$

- Balance at the Bottom of the Column

If the feed enters the boiling point, the ratio of the heat rate of vaporization of 1 mole of feed to the molar average latent heat of the feed (q) is 1[12].

But since the feed enters below the boiling point, Q > 1[12]

$$q = 1 + \frac{\dot{m} Cp_{av}}{\prec_{av}} \quad (28)$$

Where,
$\dot{m}$ = Molecular heat capacity of the mixture (kmol/kg)
Cp_{av} = Specific heat capacity of the mixture (kj/kmolk)
$\prec_{av}$= Average latent heat of vaporization of the mixture (kj/kgk)
T_{FS} = Boiling point temperature of the mixture (k)
T_F = temperature of the feed entering the column (k)
Therefore,

$$L_m = L_n + qF \quad (29)$$

Where,
L_m = Liquid flow rate at the bottom (kg/hr)

$$L_m = V_m + B \quad (30)$$

where,
V_m = Vapour flow rate at the bottom (kg/hr)

- Upper Operating Line Determination (y_n)

$$y_n V_n = L_{n+1} X_{n+1} + DX_W \quad (31)$$

Where,

$$L_n = L_{n+1} = L_{n-1} \quad (32)$$

$$\therefore y_n = \frac{L_n}{V_n} X_{n+1} + \frac{D}{V_n} X_W \quad (33)$$

- Lower Operating Line Determination (y_m)

$$y_m = \frac{L_m}{V_m} X_{m+1} + \frac{B}{V_m} X_T \quad (34)$$

- Plate Efficiency Determination

The number of stages required for separation is given as:

Actual number of stages/plates

$$= \frac{Theoretical\ number\ of\ stages}{Efficiency} \quad (35)$$

Where,
Theoretical number of stages is obtained from McCabe – Thiele Diagram (1925), and an efficiency of 60% can be assumed.

- Pressure Drop Determination (ΔP)

$\Delta P = \rho g h$. Number of stages per plates (36)

Where,
ΔP = Pressure drop (N/m^2)
ρ = Density of water (kg/m^3)
g = Acceleration due to gravity (m/s^2)
h = height of water (m)

$$\Delta P = P_B - P_T \quad (37)$$

Where,
P_B = pressure at the bottom of the column (N/m^2)
P_T = pressure at the top of the column (N/m^2)

- Liquid Vapour Flow Factor (F_{LV}) Determination

This can be determined at the top and bottom of the column. It can be used at a given plate spacing to obtain a correction factor used for determining flooding vapour velocity [12].

- Liquid Vapour Flow Factor at the Bottom (F_{LVb})

$$F_{LVb} = \frac{L_m}{V_m} \sqrt{\frac{\rho_V}{\rho_L}} \quad (38)$$

where,
ρ_V = Density of liquid (TEG)
ρ_L = Density of TEG

- Correction Factor Determination at the Bottom (K_b^1)

$K_b^1 = K_1 \left[\frac{\sigma_T}{0.02}\right]^{0.2}$ (Sinnott & Towler, [12]) (39)

Where,
σ_T = Surface tension of TEG (N/m)
K_1 = Constant value obtained from [12]

- Liquid Vapour Flow Factor at the Top (F_{LVT})

$$F_{LVT} = \frac{L_n}{V_n}\sqrt{\frac{\rho_V}{\rho_L}} \quad (40)$$

- Correction Factor Determination at the Top (K_T^1)

$$K_T^1 = K_1\left[\frac{\sigma_w}{0.02}\right]^{0.2} \text{ (Sinnott \& Towler, [12])} \quad (41)$$

Where,
σ_w = Surface tension of water (N/m)

- Flooding Velocity Determination (μ_f)

The flooding condition determines the nature of the upper limit of vapour velocity. Usually, a high vapour velocity is required for high plate efficiencies, and the velocity is normally between 70 and 90% of that which would cause flooding [12]. In this research, 85% flooding at maximum flow rate is considered.

- Flooding Velocity at the Bottom (μ_{fb})

$$U_{fb} = K_b^1\sqrt{\frac{\rho_L-\rho_V}{\rho_V}} \text{ (Fair, 1961)} \quad (42)$$

Where,
U_{fb} = Flooding velocity at the bottom (m/s)
ρ_V = Density of TEG at a given temperature (kg/m^3)

- Actual Flooding Velocity at the Bottom (U_{nb})

$$U_{nb} = 0.85U_{fb} \quad (43)$$

- Flooding Velocity at the Top (U_{ft})

$$U_{ft} = K_T^1\sqrt{\frac{\rho_L-\rho_V}{\rho_V}} \quad (44)$$

Where,
U_{ft} = Flooding velocity at the top (m/s)
ρ_V = Density of water at a given temperature (kg/m^3)

- Actual Flooding Velocity at the Top (U_{nt})

$$U_{nt} = 0.85U_{ft} \quad (45)$$

- Maximum Volumetric Flow Rate at the Bottom (U_b) For liquid flow pattern

$$U_b = \frac{V_m M_T}{\rho_V.3600s/h} \quad (46)$$

- Maximum Volumetric Flow Rate at the Top (U_t) For liquid flow pattern

$$U_t = \frac{V_n M_W}{\rho_V.3600s/h} \quad (47)$$

- Net Area Determination at the Bottom (A_{nb})

$$A_{nb} = \frac{U_b}{U_{nb}} \quad (48)$$

- Net Area Determination at the Top (A_{nt})

$$A_{nb} = \frac{U_t}{U_{nt}} \quad (49)$$

- Weeping Check or Determination

This helps to determine if liquid leakage through the plate holes is excess or not, thereby ensuring that a suitable hole area is chosen.

- Maximum Liquid Flow Rate Determination (ML_1)

$$ML_1 = \frac{L_m.M_W}{3600s/hr} \quad (50)$$

- Minimum Liquid Flow Rate Determination (ML_2)

This is obtained at 70% turndown [16]

$$ML_2 = 0.7ML_2 \quad (51)$$

- Maximum Height of Liquid Crest over Dow Comer (h_{ow})

This can be obtained by applying the Francis Weir Formula.

$$h_{ow} = 750\left[\frac{ML}{\rho_L L_W}\right]^{2/3} \text{ (Sinnott \& Towler, [12])} \quad (52)$$

Where,
h_{ow} = Height of the weir
ML = Maximum/minimum liquid flow rate
ρ_L = Density of liquid (water)
L_W = Weir length

- Maximum Height of Weir Determination (Max. h_{ow})

$$\text{Max. } h_{ow} = 750\left[\frac{ML_2}{\rho_L L_W}\right]^{2/3} \text{ (Sinnott \& Towler, [12])} \quad (53)$$

- Minimum Height of Weir Determination (Min. h_{ow})

$$\text{Min. } h_{ow} = 750\left[\frac{ML_1}{\rho_L L_W}\right]^{2/3} \text{ (Sinnott \& Towler [12])} \quad (54)$$

- Minimum Design Vapour Velocity (U_V)

$$U_V = \frac{K_2 - 0.90(25.4-d_h)}{(\rho_V)^{1/2}} \quad (55)$$

Where,
K_2 = Constant value obtained from weeping point correlation, and it depends on the depth of clear liquid on the plate
d_h = Hole diameter (mm)
ρ_V = Density of vapour at the bottom

- Actual Minimum Vapour Velocity (U_{Va})

$$U_{Va} = \frac{70\%\, U_b}{A_h} \quad (56)$$

If $U_{Va} > U_V$, it is said to be above the weeping point; hence, it is satisfactory.

- Plate Pressure Drop Design

The two main sources of pressure loss are:
(i) Vapour flow through the holes (orifice loss)
(ii) Loss due to the static head of liquid on the plate

- Total Plate Pressure Drop (ΔP_1)

$$\Delta P_1 = 9.8 \times 10^{-3} h_L \rho_L \text{ (Sinnott \& Towler [12])} \quad (57)$$

- Sectorial Area of Column Determination (A_C)

$$A_n = 88\% \text{ of } A_C \quad (58)$$

$$A_C = \frac{A_n}{0.88} \quad (59)$$

- Area of Column at the Bottom (A_{Cb})

$$A_{Cb} = \frac{A_{nb}}{0.88} \quad (60)$$

- Area of Column at the Top (A_{Ct})

$$A_{Ct} = \frac{A_{nt}}{0.88} \quad (61)$$

- Diameter of Column Determination (D_C)
-

$$D_C = \sqrt{\frac{4A_C}{\pi}} \quad (62)$$

Where,
π = Constant

- Diameter of the Column at the Bottom (D_{Cb})

$$D_{Cb} = \sqrt{\frac{4A_{Cb}}{\pi}} \quad (63)$$

- Diameter of the Column at the Top (D_{Ct})

$$D_{Ct} = \sqrt{\frac{4A_{Ct}}{\pi}} \quad (64)$$

- Height of Column Determination (H_C)

Usually, a 20% allowance for the entire column is taken (Sinnott & Towler [12])

$$H_C = N_T t \quad (65)$$

Where,
N_T = Number of trays/plates
t = Plate spacing
There, Total Height of the column (H_T) is:

$$H_T = H_C + 20\%\ H_C \text{ (Sinnott \& Towler [12])} \quad (66)$$

- Volume of Column (V_c)

$$V_c = \pi r^2 h \quad (67)$$

3. Results and Discussion

From Table 4, the regeneration or distillation column is a single input, two output system and also obeys the principles of conservation of materials where input stream equals output streams. Mathematically, $S_9 = S_{10} + S_{11}$. In this unit, the rich TEG (mixture of TEG and water) is separated into regeneration from the bottom (Lean TEG) and wet gas (water). The Lean TEG recovered is recycled and reused for further dehydration processes in the absorber unit. The TEG Feed molar flow, mass flow and volume flow of (0.01199kgmol/s, 0.33664kg/s and 0.00032m^3/s) were separated into (0.00101kgmol/s, 0.14190kg/s and 0.00013m^3/s) and (0.01078kgmol/s, 0.19474kg/s and 0.00020m^3/s) in the Regen-Feed and Wet Gas streams respectively which indicate that separation has taken place.

From Table 5, we observed that the regeneration or distillation column is a single input and two output system for lean TEG regeneration. Here, little temperature difference is observed in the Regen-Feed of 80^{0}C, which is within the specified standard of usually not above 98.9^{0}C [8], and the reboiler temperature of 204.4485^{O}C satisfies the maximum recommended temperature in the reboiler required to separate TEG and water is 204^{0}C to yield a lean TEG concentration of 98.9wt% [5]. Hence, the modified design performs better with high purity of lean TEG recovery. The pressure and heat flow changes of (110.3162kPa, 103.4214kPa and 101.3529kPa) and (-3.18 x 10^{3}kj/s, -7.11 x 10^{2}kj/s and 2.57 x 10^{3}kj/s) are observed in the TEG-Feed, Regen-Feed and Wet Gas streams respectively.

From Table 6, we observed that the Regeneration/Distillation column (Unit 04) of the modified plant design is a single input and two output system for lean TEG regeneration. Here, an appreciable temperature rise in the rich-TEG (mixture of TEG and H_2O) in the distillation column gives rise to the separation of TEG and H_2O in the Rich-TEG.

Table 4. Mass balance results of Regenerator/Distillation unit of TEG dehydration process

Streams	Inflow 1 Regen-Feed	Outflow 1 Regen-Btm	Outflow 2 Wet Gas
Molar Flow (kgmol/S)	0.01179	0.00101	0.01078
Mass Flow (kg/S)	0.33664	0.14190	0.19474
Volume Flow (m^3/S)	0.00032	0.00013	0.00020

Table 5. Energy balance results of Regenerator/Distillation column unit of TEG Dehydration Process

Streams	Inflow 1 Regen-Feed	Outflow 1 Regen-Btm	Outflow 2 Wet Gas
Temperature (^{0}C)	80.0000	204.4485	101.6658
Pressure (kPa)	110.3162	103.4214	101.3529
Heat Flow (KJ/S)	-3.81×10^3	-7.11×10^2	-2.57×10^3

Table 6. Composition balance of natural gas component in Distillation Column/Regeneration (Unit 04)

Composition (Mole Fraction)			
Components	**Inlet Stream (S_9) Regen-Feed**	**Outlet Stream (S_{10}) Wet Gas**	**Outlet Stream (S_{11}) Regen-Btm**
N_2	0.0000	0.0000	0.0000
CO_2	0.0008	0.0009	0.0000
H_2S	0.0017	0.0019	0.0000
C_1	0.0009	0.0010	0.0000
C_2	0.0000	0.0000	0.0000
C_3	0.0000	0.0000	0.0000
i – C_4	0.0000	0.0000	0.0000
n – C_4	0.0000	0.0000	0.0000
i – C_5	0.0000	0.0000	0.0000
n – C_5	0.0000	0.0000	0.0000
TEG	0.0793	0.0000	0.9249
H_2O	0.9172	0.9961	0.0752

Table 7. Result of Design/Sizing of Regenerator/Distillation column in TEG dehydration plant

Regenerator/Distillation Column Parameters	Units	Design/Size specification
Column Height	m	6.000
Column Diameter	m	2.000
Column Area	m^2	3.143
Column Volume	m^3	18.857

After separation, the TEG composition in the Rich-TEG increases from S_9 = 0.0793 to S_{11} = 0.9249, while the water composition in the Rich TEG decreases from S_9 = 0.9172 to S_{11}= 0.0752. The distillation column is a lean TEG recovery system or unit for subsequent absorption of water in natural gas.

Table 7 shows the size specification or design of the height, diameter, area and volume of the regenerator/distillation column of the natural gas TEG dehydration plant where the lean-TEG recovery occurs. The column size/design specification is needed for optimum lean-TEG recovery in the regenerator.

4. Conclusion

The natural gas TEG dehydration plant was simulated using Aspen HYSYS. The design/performance models of the lean TEG recovery unit were developed from the first principle of mass and energy balance. The performance evaluation results of the mass, energy, composition and design/size specifications are presented in Tables 4 to 7. The analysis of the results agrees with this study's objectives. The design and performance analysis of an industrial Triethylene Glycol (TEG) recovery regenerator is crucial for efficiently operating the dehydration process in the oil and gas industry. This study highlighted the effects of various critical factors, such as regeneration temperature, stripping gas flow rate, type of stripping gas, and reboiler, on the TEG recovery process. The application of modern simulation tools, such as Aspen HYSYS, significantly aided the optimization of these parameters, resulting in cost-effectiveness, optimum performance, and improved natural gas processing efficiency. The successful operation of the TEG dehydration process enables natural gas supply essential in universal development and energy consumption. Further research into new technologies and optimization strategies could bring about significant improvements and innovations in this field, improving the efficiency and sustainability of the oil and gas industry.

Acknowledgments

The authors wish to acknowledge the contributions of the personnel of the Chemical Engineering Simulation laboratory of Federal University Otuoke.

References

[1] C.I.C. Anyadiegwu, Anthony Kerunwa, and Patrick Oviawele, "Natural Gas Dehydration Using Triethylene Glycol (TEG)," *Journal of Petroleum and Coal*, vol. 56, no. 4, pp. 407-417, 2014. [Google Scholar] [Publisher Link]

[2] Michelle Michot Foss, "Interstate Natural Gas Quality Specifications and Interchangeability," *Center for Energy Economics*, pp. 1-52, 2004. [Google Scholar] [Publisher Link]

[3] Qingyue Gu, and Chunjing Liu, "The Design of the Natural Gas Dehydration Tower," *International Journal of Oil, Gas and Coal Engineering*, vol. 4, no. 6, pp. 66-69, 2017. [Google Scholar] [Publisher Link]

[4] Michael A. Huffmaster, "Gas Dehydration Fundamentals," *Proceedings of the Laurance Reid Gas Conditional Conference*, pp. 1-129, 2004. [Google Scholar] [Publisher Link]

[5] Arthur J. Kidnay, and William R. Parrish, *Fundamentals of Natural Gas Processing*, CRC Press, Taylor and Francis Group, pp. 1-49, 2006. [Google Scholar] [Publisher Link]

[6] B.S. Kinigoma, and Goodness Okechukwu Ani, "Comparison of Gas Dehydration Methods Based on Energy Consumption," *Journal of Applied Science and Environmental Management*, vol. 20, no. 2, pp. 253-258, 2016. [CrossRef] [Google Scholar] [Publisher Link]

[7] Laksel EPS Technologies, Drizo Gas Dehydration Package, Laksel, 1995. [Online]. Available: https://www.laksel.com.sg/

[8] Francis S. Manning, and Richard E. Thompson, *Oilfield Processing of Petroleum: Natural Gas*, Pennwell Publishing Company, 1991. [Google Scholar] [Publisher Link]

[9] Mohamed S. Gad et al., "The Economic Comparison between Dry Natural Gas and Nitrogen Gas for Stripping Water Vapour from Glycol in the Gas Dehydration Process," *International Journal of Engineering Science Invention*, vol. 5, no. 8, pp. 8-12, 2016. [Google Scholar] [Publisher Link]

[10] Agu Kingsley Chidozie, and Oduola Mujeeb Koyejo, "Simulation of Improved Design for Ammonia Plant Front End Waste Heat Boilers," *SSRG International Journal of Chemical Engineering Research*, vol. 8, no. 1, pp. 5-14, 2021. [CrossRef] [Google Scholar] [Publisher Link]

[11] M.R. Rahimpour, M. Saidi, and M. Seifi, "Improvement of Natural Gas Dehydration Performance by Optimizing of Operating Conditions: A Case Study in Sarkhun Gas Processing Plant," *Journal of Natural Gas Science and Engineering*, vol. 15, pp. 118-126, 2018. [CrossRef] [Google Scholar] [Publisher Link]

[12] Gavin Towler, and R.K Sinnott, *Chemical Engineering Design*: *Principles, Practice and Economics of Plant and Process Design*, USA: Elsevier Science, vol. 6, pp. 1-167, 2009. [Google Scholar] [Publisher Link]

[13] L. Zhang, *Natural Gas Gathering and Transportation Engineering*, Petroleum Industry Press, 2009.

[14] Weiqiao Zhao et al., "A Disinhibitory Mechanism Biases Drosophila Innate Light Preference," *Nature Communications*, vol. 10, no. 124, pp. 1-11, 2019. [CrossRef] [Google Scholar] [Publisher Link]

[15] Adeloye et al., "Analysis and Classification of Nigerian Crude Oil Types for Modular Refinery Operations," *SSRG International Journal of Chemical Engineering Research*, vol. 9, no. 2, pp. 17-24, 2022. [CrossRef] [Google Scholar] [Publisher Link]

[16] Muhammad Aimen Bin Isa, and Muhammad Aimen, "Natural Gas Dehydration by Absorption Process: A Comparative Simulation Study Towards High Effective Natural Gas Dehydration Using TEG Technology," *Universiti Teknologi Petronas*, pp. 1-58, 2011. [Google Scholar] [Publisher Link]