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PERFORMANCE EVALUATION OF THERMOSYPHON REBOILER FOR THE REGENERATION OF TRIETHYLENE GLYCOL.

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KeyWords
Thermosyphon Reboiler, Triethylene glycol, Material, Energy balance models, *Aspen hysys*, *Mat lab-Simulink*, ***Heat Change (dH)***

ABSTRACT

Natural gas dehydration process with regeneration unit has been the common industrial way of removing water vapour from wet gas using desiccant. The spent desiccant (TEG) required energy for its regeneration. Thermosyphon reboiler in a regeneration column offers optimum amount of energy for the regeneration of TEG without thermal degradation due to its low residence time. The performance evaluation of thermosyphon reboiler for the regeneration of the tri ethylene glycol is presented. The research applied the principles of material and energy balances to develop models with which the reboiler operations were evaluated using process data. The steady state models were developed for the dehydration of the natural gas and subsequent regeneration of the tri ethylene glycol. Fundamentally, process models developed were simulated using Mat lab-Simulink, based on the process **TEG-Yield rate, Heat Change (dH) and the Reboiler operational Time relationship,** aiming at the evaluation for the performance of the reboiler, operating under some process parameters such as $T_o = 105^o$ C (378 K), $T_i = 205^o$C (378 K), K_f = 0.18428 W/m k, U = 3.6 e2 KJ/hr, m_T = 50 Kgmol/hr, as described in Figure 8 which shows a direct proportional increase of the **change in heat rate of the reboiler over the operational time space**, of which at the studied time of **t = 24 hours**, the heat continues to increase from **dH = 0.4691 x 10^9** through **dH = 5.6288x 10^9** correspondently to the increase in TEG generation time, which stands a great chance of increasing the vessel temperature, which is satisfactory to improve yielding rate of the tri ethylene glycol as shown in the profiles plots described at Figure 9, and figure 10.

1. INTRODUCTION

Natural gas dehydration is an important operation in gas processing and treatment industry. This process involves the removal of water vapour from the natural gas streams to enhance in upstream and downstream processing. The level of water vapor in natural gas should have a certain amount below which it is allowed to prevent hydrate formation and also reduces corrosion effect during pipeline transportation on this natural gas. The quality specification process on dehydrating natural gas is done by absorbing water using triethylene glycol. The glycols are effective liquid-desiccants because. of their high hygroscopic property, low vapour pressure, high boiling point, and low solubility in natural gas.

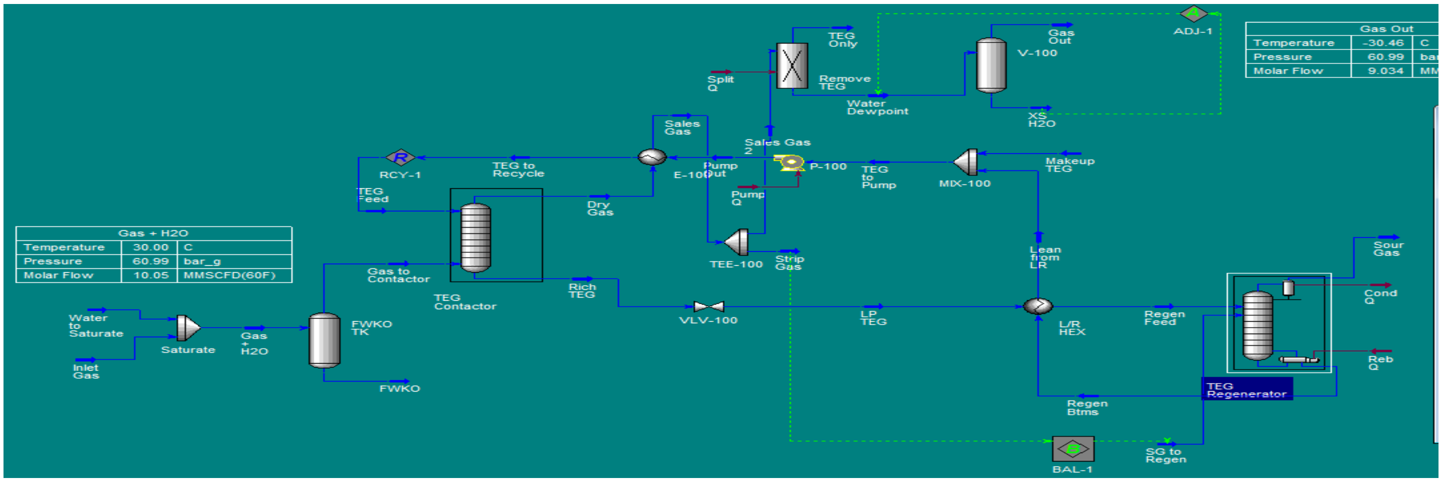
Types of glycols. that have been used for natural gas dehydration are ethylene-glycol (EG), diethylene-glycol (DEG), triethylene. glycol (TEG), and tetra-ethylene glycol (TEG) [9]. The regenerator plays an important role for overall performance of this unit, the regeneration column utilizes the reboiler energy to strip up water as well as dissolved gases in the triethyl glycol. The hydrocarbon increases. the volatility' of water in the solution. of water and TEG. When presented, this type of process, can achieve-compositions of over- 99.99 % with triethylene glycol, resulting in-potential dry gas with the water dew-points range in (-73.3 to -95.5°C). [16]

Thermosyphon reboilers provides a simple but low maintenance design process for condenser-reboiler distillation column systems, this made this equipment to play a huge role in dehydration units. The thermosyphon reboiler, contains the two-endearing qualities of the evaporator, namely mechanical simplicity, and operation in the nucleate boiling- regime with its attractive high fluxes. Thermosyphon reboiler in a regeneration column offers optimum amount of energy without thermal degradation due to its low residence time. Therefore, it is pertinent to utilize this reboiler in TEG regeneration unit for effective dehydration. This present research seeks to apply the principles of chemical engineering materials and energy balances and computer software application in the design and performance study of thermosyphon reboiler for effective regeneration of Triethylene Glycol (TEG). [8]

Thus, the aim of this study is to carry out performance evaluation of thermosyphon reboiler for TEG regeneration. This aim is achieved by developing performance equations for thermosyphon reboiler using the principle of conservation of mass and energy. The performance model equations are ordinary differential equations (ODEs), which are solved with literature data, performance simulated, and sensitivity analysis are carried out to evaluate the influence of the operating parameters on the process performance using ASPEN HYSYS

2 Process Description

The simulation process for the dehydration of natural gas and the regeneration of the TEG glycol follows the method as described in literature by [12] In this process, wet natural gas is first flashed in an inlet separator to remove liquid and solid content. The process condition of the feed stream is; temperature at 30^{o}C, pressure of 6200kpa and a flow rate of 500kgmol/h with all the components of the natural gas used in their various mole fractions. After reducing the liquid content in the separator, the gas stream from the separator is dried in a contactor unit that is designed as an absorber using counter current TEG stream. The rich TEG stream coming out from the bottom of the absorber unit is mixed up with a makeup TEG stream to meet the required flowrate and then feed to shell side of the heat exchanger to raise the temperature through the energy stream coming from the reboiler operation. The heat exchanger thus serves to take heat from where it is not needed to the places where it is needed. The regeneration operation is carried out using a distillation column to recover fully the TEG against wastage. The rich TEG stream from the contactor is passed through a valve to reduce its pressure to that required for the regenerator where it exchanges heat with the regenerated LEAN TEG stream. Further, the LEAN TEG stream as shown in Figure 1 below which contain more of TEG to be recycled is flashed in a mixer operation to ensure material balance of the TEG, because some quantities of TEG has been lost during the dehydration wherein a pump is installed to raise the pressure of the TEG stream before it enters the contactor streams. In addition, another heat exchanger is also added to cool the TEG stream to the regenerator column Furthermore the sales gas is flashed to the component splitter in order to remove completely the TEG in the sales gas because one of the criteria used to determine the efficiency of a dehydration facility is the water dew point of the dry gas. This property can easily be checked by finding the temperature at which water will just begin to condense wherefore all traces of TEG must be removed from the stream to be tested because TEG affects the water dew point. [1, 14].



Gas + H2O		
Temperature	30.00	C
Pressure	60.99	bar_g
Molar Flow	10.05	MMSCFD(60F)

Gas Out		
Temperature	-30.46	C
Pressure	60.99	ba
Molar Flow	9.034	MM

Figure 1: Complete process flow diagram for the dehydration of Natural gas using TEG and the Regeneration process for TEG

3. METHODS

The methods deployed in this study includes development of material and energy balances; simulation of the developed model equations and its validation by comparing with Aspen Hysys process simulation.

3.1 Thermosyphon Reboiler Performance Design

In developing the performance model equations for thermosyphon, the following assumptions are applied.

i. Perfect mixing of vapour in the regenerator sump vapour space and perfect vapour-liquid separation of return material from the thermosyphon, in the column
ii. The process is operated at steady state fluid flow regime and full disengagement of vapour generated inside the liquid in the regenerator sump
iii. No leakage from the thermosyphon reboiler internals and across the sump baffles and the mechanical energy terms of reboiler is negligible
iv. The thermosyphon reboiler is modelled as a shell and tube heat exchanger and the reboiler is well lagged to prevent heat losses
v. Fluid flow regime is counter current and constant heat flux flow across reboiler length
vi. The effects of change in total molar flow rate is ignored by applying assumed average value for total molar flow.

3.2 Model for the Reboiler Performance

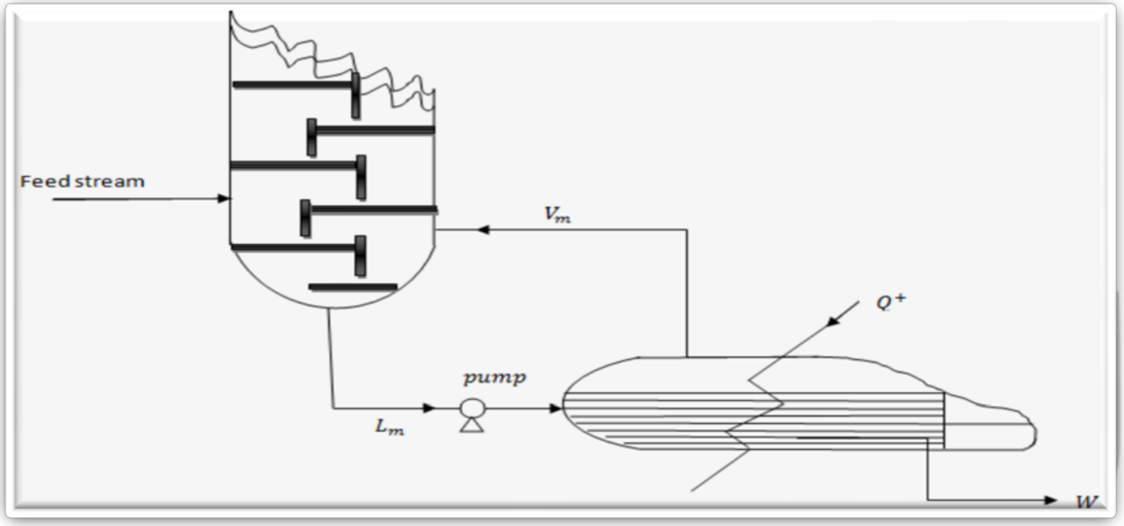


Figure 2. Reboiler Performance Diagram

3.2.1 Material Balance for Thermosyphon Reboiler

The material Balance expression for the Reboiler is stated thus

$$\begin{pmatrix}\text{Rate of accumulation}\\ \text{of matrial specie}\\ \text{wihtin the reboiler}\end{pmatrix} = \begin{pmatrix}\text{Rate of inflow}\\ \text{of material specie into the reboiler}\end{pmatrix} - \begin{pmatrix}\text{Rate of outflow}\\ \text{of material specie out the reboiler}\end{pmatrix} \qquad (2.1)$$

Hence, the materials balance for the thermosyphon reboiler performance at steady state yielded

$$V_m = L_m - W \qquad (2.2)$$
$$L_m = V_m + W \qquad (2.3)$$

Where:
Vm is the vapour flowrate from the reboiler, Lm is the liquid flowrate to the reboiler
W is the lean TEG flowrate from regenerator bottoms.
F_T is temperature correction factor which is determinable using the model described as.

3.2.2 Energy Balance for Thermosyphon Reboiler

The energy balance equation expression for the thermosyphon reboiler is sated thus.

$$\begin{pmatrix}\text{Rate of accumulation}\\ \text{of heat}\\ \text{wihtin the reboiler}\end{pmatrix} = \begin{pmatrix}\text{Rate of inflow}\\ \text{of heat into the reboiler}\end{pmatrix} - \begin{pmatrix}\text{Rate of outflow}\\ \text{of heat out the reboiler}\end{pmatrix} \pm \begin{pmatrix}\text{Rate of heat transfer from hot}\\ \text{utility to the reboiler}\end{pmatrix} \tag{2.4}$$

Substituting into Equation 2.4 and algebraic analysis yields

$$\frac{dH}{\mathrm{dt}} = \mathrm{\rho C}_{Po}\mathrm{L}_M\mathrm{T}_O - \mathrm{\rho C}_p\mathrm{L}_M T_i + UA(T_s - T_i) \tag{2.5}$$

At steady state, equation (2.5) becomes expressed with the primary models (V_m and L_m) for reboiler perfect performance design. Hence, substituting the primary models (equations 2.2 and 2.3) into the model equation (2.5) and upon algebraic analysis yields

$$W = \frac{dH}{dt}\frac{1}{\{\rho C_{p,o}T_o - \rho C_p T_i\}} - \frac{UA(T_s - T_i)}{\{\rho C_{p,o}T_o - \rho C_p T_i\}} - V_m \tag{2.6}$$

Equation (2.6) is used to obtain the estimated TEG yield with respect to the rate of heat change dH in the reboiler per time.
For a counter current thermosyphon reboiler, the logarithmic mean temperature difference is expressed as

$$LMTD = \Delta T_{LM} = \frac{(T_{hi} - T_{ho}) - (T_{ci} - T_{co})}{\ln\left\{{(T_{hi} - T_{ho})}\Big/{(T_{ci} - T_{co})}\right\}}$$

Hence, the mean temperature difference will yield

$$\Delta T_m = F_T \times \frac{(T_{hi} - T_{ho}) - (T_{ci} - T_{co})}{\ln\left\{{(T_{hi} - T_{ho})}\Big/{(T_{ci} - T_{co})}\right\}} \tag{2.7}$$

$$F_T = \frac{\sqrt{R^2+1} \times \ln\left\{\frac{(1-\mathrm{S})}{(1-\mathrm{RS})}\right\}}{(1-\mathrm{R})\ln\left\{\frac{2-\mathrm{S}\left(\mathrm{R}+1-\sqrt{R^2+1}\right)}{2-\mathrm{S}\left(\mathrm{R}+1+\sqrt{R^2+1}\right)}\right\}} \tag{2.8}$$

$$\mathrm{R} = \frac{\mathrm{T}_1 - \mathrm{t}_2}{\mathrm{T}_2 - \mathrm{t}_1} = \frac{T_{ho} - T_{ci}}{T_{hi} - T_{co}} \qquad \mathrm{S} = \frac{\mathrm{t}_2 - \mathrm{t}_1}{\mathrm{T}_1 - \mathrm{t}_1} = \frac{T_{ci} - T_{co}}{T_{ho} - T_{co}}$$

3.3 Thermosyphon Reboiler Operating Condition

The temperature required for regeneration process is expressed as

$$T_i = \frac{\rho C_P \mathrm{L}_M \mathrm{T}_O + UAT_s}{\rho C_P + UA} \tag{2.9}$$

3.3.1 Heat Transfer

The heat transfer within the system is deduced as

$$Q = UA\Delta T_M \tag{2.10}$$

Therefore, the heat transfer area is evaluated from equation (2.10) as

$$A = \frac{Q}{U * \Delta T_M} \tag{2.11}$$

3.3.2 Required Number of Tubes

The required number of tubes is estimated as

$$\mathrm{N_T} = \frac{\mathrm{A}}{\pi \mathrm{d}_T \mathrm{L}} \tag{2.12}$$

3.3.3 Shell Diameter

The shell diameter can be expressed as shown

D_S = bundle diameter + bundle diametrical clearance

$$D_b = 20({}^{N_T}/_{K_1})^{\frac{1}{N_1}} \qquad (2.13)$$

3.3.4 Tube Side Coefficient

The heat transfer coefficient on the tube side can be expressed as

$$h_i = j_h \frac{k_f}{d_i} Re. Pr^{0.33} \left(\frac{\mu}{\mu_w}\right)^{0.14} \qquad (2.14)$$

3.3.5 Shell Side Coefficient

The heat transfer coefficient of the shell side is given as

$$h_s = j_h \frac{k_f}{d_i} Re. Pr^{0.33} \qquad (2.15)$$

3.3.6 Overall Heat Transfer Coefficient

The overall heat transfer coefficient is deduced as

$$\frac{1}{U_o} = \frac{1}{h_s} + \frac{1}{h_i} + \frac{d_i \ln\left({}^{d_o}/_{d_i}\right)}{2K_w} + \frac{d_i}{d_o h_{do}} + \frac{d_i}{d_o h_o} \qquad (2.16)$$

3.3.7 Tube Side Pressure Drop

The tube side pressure drop is estimated as

$$\Delta P_t = N_p \left[8 j_f \left(\frac{L}{D}\right) \left(\left(\frac{\mu}{\mu_w}\right)^{-m}\right) + 2.5\right] \frac{\rho u^2}{2} \qquad (2.17)$$

3.3.8 Shell Side Pressure Drop

Similarly, the shell side pressure drop is estimated as

$$\Delta P_s = 8 j_f \left(\frac{D_s}{d_e}\right) \left(\frac{L}{l_B}\right) \frac{\rho u^2}{2} \left(\frac{\mu}{\mu_w}\right)^{-0.14} \qquad (2.18)$$

3.4 Process Parameters

The parameters applied in this study are enumerated thus.

3.4.1 Feed characterization: In this study, a natural gas feed was analysed and thus the mixture of multiple components that comprises of the natural gas stream is represented as per source or literature report. Nevertheless, in this study, the needed natural gas composition is given below:

Table 1: Feed Gas Composition Required for simulation.

Components	Composition (mass fraction)
Nitrogen	0.0010
H2S	0.0155
CO2	0.0284
Methane	0.8989
Ethane	0.0310
Propane	0.0148
I-Butane	0.0059
N-Butane	0.0030
I-Pentane	0.0010
N-Pentane	0.0005
H_2O	0.0000

3.4.2 Feed conditions: The feed conditions are the basic physical representation of the feed in real life scenario and are the initial inputs into the model or simulation. The feed input into the simulation is given below

Table 2: Feed Conditions for the natural gas stream

Natural Gas Stream	Process Conditions
Feed charge or total mass flowrate	2.5607kg/s (10.04MMSCFD)
Temperature of the feed	30^oC
Pressure of the feed	60.98 bar_g

The composition of the natural gas stream is saturated with water, prior to entering the contactor. This is to demonstrate the effectiveness of the TEG in the contactor. The gas compositions and conditions are inputted into the software and simulated.

Table 3: Water Composition and Conditions.

Composition (mole fraction)	**1.000**
Mass flowrate	0.025 kg/s.
Temperature	277^oC
Pressure	60.98 bar_g

3.5 Solution Technique

ASPEN HYSYS will be used for the actual simulation of thermosyphon reboiler regeneration unit. ASPEN HYSYS is a computer software used basically for design and simulation of unit operations and processes. The choice of ASPEN HYSYS for this simulation is due to the efficiency and reliability of the software used for design and simulation purposes.

4.0 RESULTS AND DISCUSSION

The result obtained from the Aspen Hysys simulation and designs of a thermosyphon reboiler for the regeneration of Triethylene Glycol (TEG) are presented with rich TEG, make up TEG and regenerated TEG condition. Also, reboiler design performance, influence of temperature on the TEG composition, effect of pressure on TEG compositions, and effect of tray position on TEG composition were also discussed.

4.1 Model HYSYS Simulation Results

Simulated results obtained on the basis of the stated procedure above for solving the model for natural gas dehydration and regeneration is reported. The obtained result is presented in graphical and tabular form with subsequent explanation with complete flowsheet diagram of the intended processes alongside. Nevertheless, the model solution is evaluated under the following sub-headings:

4.2 Natural Gas Dehydration and TEG Regeneration

The foremost objective in a natural gas dehydration and regeneration is to remove the required amount of water in order to meet natural gas pipeline specifications. In addition, the flowrate of TEG for the dehydration of the natural gas stream while taking into consideration of the regenerated TEG stream is also required. Thus, the simulation is checked if it meets this objective wherein before and after treatment of the natural gas stream and the required TEG as well as the makeup TEG is evaluated. The table below gives the before treatment and after treatment of the natural gas stream as well as the required TEG, makeup TEG, and the dry sales gas specification.

Table 4: Natural Gas Stream with Water Content Sent for Treatment

Natural Gas + H_2O	**Condition**
Total molar flowrate	10.05 MMSCFD
Temperature	30^oC
Pressure	60.99 bar_g

Table 5: TEG Feed Conditions.

Composition (mole fraction)	**0.9979**
Total molar flowrate	2.266e-002 MMSCFD
Temperature	50^oC
Pressure	61.04 bar_g

Table 6: Makeup TEG Conditions.

Composition (mole f4raction)	**0.99**
Total molar flowrate	1.381e-002 MMSCFD
Temperature	15^oC
Pressure	0.0033 bar_g

Table 7: Dry Gas Conditions

Composition (mole fraction)	**Components as listed in the feed**
Total molar flowrate	10.04 MMSCFD
Temperature	31.16 ^{o}C
Pressure	60.99 bar_g

Table 8: Rich TEG Conditions

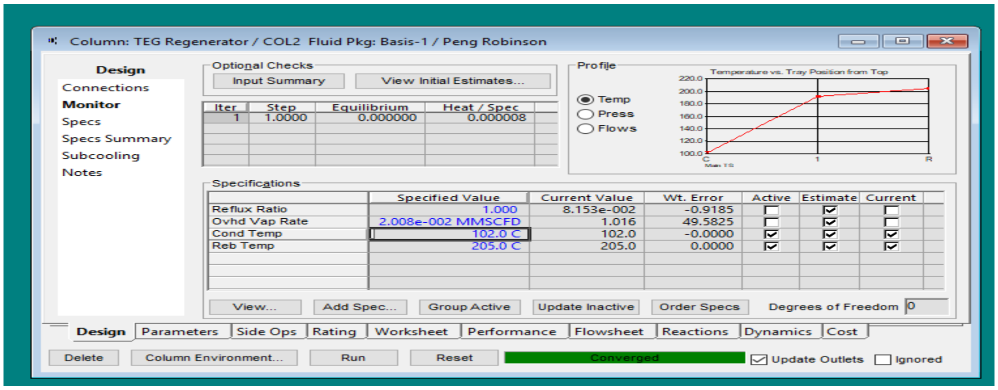
Composition (mole fraction)	**0.6858**
Total molar flowrate	3.297e-002 MMSCFD
Temperature	30.65 ^{o}C
Pressure	60.99 bar_g

Table 9: Regenerated TEG Conditions

Composition (mole fraction)	**0.9985**
Total molar flowrate	0.0213 MMSCFD
Temperature	205 ^{o}C
Pressure	0.0103 bar_g

4.3 Discussions

From the obtained results, a cross examination of result is undertaken to see if it meets design objectives. The amount of water in the dehydrated natural gas stream (dry gas) is checked to see if it meets industrial and literature standards. It can be observed from Table 7 and Table 10 that the amount of water present in dry gas is reduced to the minimum as per required for pipeline quality sales gas and conforms to the result obtained by [6, 8, 12]. In addition, the composition amount of TEG after it has been used to treat the natural gas stream is examined and with due observations and comparison of the TEG feed stream (Table 5) and rich TEG Outlet stream (Table 8), it could be observed that the composition fraction of the TEG feed (0.9979,) is greater than that of the rich TEG stream (0.6858) which is persistent to literature and practice as the TEG stream have absorbed the water that was present in the natural gas stream defined in terms of its composition fraction decrease [6]; [12]. Further, an increase in the flowrate of the rich TEG stream (0.033 MMSCFD) in comparison to the TEG feed stream (0.027 MMSCFD) also demonstrate this fact as the increase in flowrate can be attributed to the absorbed water during the treatment process. Furthermore, the relative amount of regenerated TEG is also checked for consistency with literature and thus with reference to Table 9, it is observed that the flowrate of the regenerated TEG (0.0213 MMSCFD) is less than that required for the feed TEG stream (0.027 MMSCFD) and therefore a make-up TEG stream (0.0138 MMSCFD) is needed in order to meet the required feed flowrate. This phenomenon is quite explainable as during the regeneration process, a small amount of the TEG is lost and a makeup stream is needed as per literature standards process of TEG in Aspen Hysys



Iter	Step	Equilibrium	Heat / Spec
1	1.0000	0.000000	0.000008

	Specified Value	Current Value	Wt. Error	Active	Estimate	Current
Reflux Ratio	1.000	8.153e-002	-0.9185	☐	☑	☐
Ovhd Vap Rate	2.008e-002 MMSCFD	1.016	49.5825	☐	☑	☐
Cond Temp	102.0 C	102.0	-0.0000	☑	☑	☑
Reb Temp	205.0 C	205.0	0.0000	☑	☑	☑

Degrees of Freedom 0

Figure 3: Converged solution for the Regeneration

4.3.1 Reboiler Design

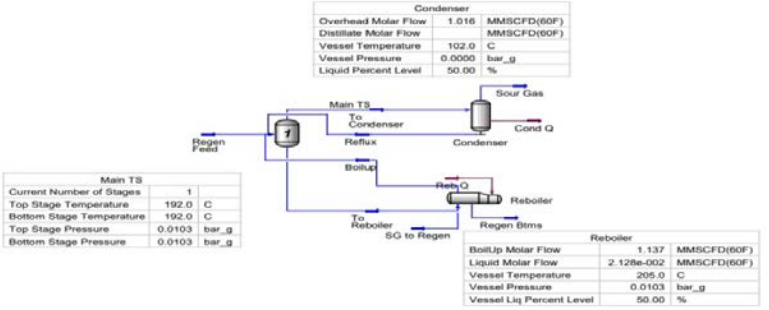
Having simulated the complete process for the treatment of a natural gas stream and the regeneration of TEG stream, it is thus imperative to meet a specific objective of this study which is the performance evaluation of the reboiler for the regeneration of the TEG stream. Notwithstanding, the performance evaluation of the reboiler is defined in terms of the required heat duty, the boil up molar flowrate taking into consideration the reboiler temperature, the liquid volume percent and the pressure of the vessel. The table below shows the numerical value of all the properties listed above.

Table 10: Reboiler Properties from the regeneration of TEG

Reboiler Properties	
Boilup molar flowrate	1.137 MMSCFD
Vessel Liquid Volume Percent	50%
Temperature	205^oC
Pressure	0.0103 bar_g
Total Heat Duty	48 KW
Overall UA	3.6E05 KJ/C-hr.
Heat Flow	1.716E5 KJ/hr.
Utility Type	Medium Pressure (MP) Steam
Utility Flowrate	86.61 kg/hr
Diameter	1.193m
Height	1.789m
Volume	2.00 m^3
Level Calculator	Horizontal Cylinder

4.3.2 Reboiler Performance Analysis

In the reboiler performance, there is need to relate the simulated results with practical essence. In this regard and referencing Table 10 and Figure 5, it is observed that the boilup molar flowrate of the reboiler (1.137 MMSCFD) is greater than the flowrate of the liquid molar flowrate (0.0213 MMSCFD) in Table 9 which is expected as the boilup ratio is usually greater in order to achieve the purpose of regenerating the rich TEG stream to the required lean TEG



Condenser		
Overhead Molar Flow	1.016	MMSCFD(60F)
Distillate Molar Flow		MMSCFD(60F)
Vessel Temperature	102.0	C
Vessel Pressure	0.0000	bar_g
Liquid Percent Level	50.00	%

Main TS		
Current Number of Stages	1	
Top Stage Temperature	192.0	C
Bottom Stage Temperature	192.0	C
Top Stage Pressure	0.0103	bar_g
Bottom Stage Pressure	0.0103	bar_g

Reboiler		
BoilUp Molar Flow	1.137	MMSCFD(60F)
Liquid Molar Flow	2.128e-002	MMSCFD(60F)
Vessel Temperature	205.0	C
Vessel Pressure	0.0103	bar_g
Vessel Liq Percent Level	50.00	%

Figure 4: Process flow diagram for TEG regeneration

It is also observed that the reboiler is designed at 50% liquid volume percent which is attributed to the increase in volume of the reboiler due to the vapor and thus the reboiler must be designed to account for this phenomenon.[21]. Furthermore, with considerations to the above factors, the total heat duty required for the regeneration of the TEG solvent was about 48 Kilo Watts (KW) which will define the design parameters as it relates to the minimum heat requirement for the regeneration of the TEG solvent. Moreover, the overall heat co-efficient for the reboiler obtained using medium pressure steam was 3.6E05 KJ/C-hr. with a heat flow of 1.716E5 KJ/hr. and a total flowrate of the steam utility been 86.61 Kg/hr. this result gives the minimum necessary requirements for the design of the reboiler if medium pressure steam utility is used. The obtained values will thus serve as the design values for the reboiler

4.4 Sensitivity Analysis

Sensitivity analysis is done in order to check variation of some physical properties with respect to another property. This analysis is done in order to observe the effect of some variables with respect to another variable which will enable an optimum solution. Thus, in this study, the effect of varying properties such as TEG concentration with respect to temperature, TEG composition with respect to number of trays and regenerated TEG composition with respect to pressure is considered. The obtained results is cross evaluated to check consistency with literature and industrial standards. The figures and tables below are the obtained results undergone for sensitivity analysis

S/N	TEMPERATURE	COMPOSITION OF TEG
1	130	0.9255

Table 11: Composition of lean TEG variation with Temperature

2	140	0.9289
3	150	0.9311
4	160	0.9378
5	170	0.9491
6	180	0.9626
7	190	0.9626
8	200	0.9799
9	205	0.9921

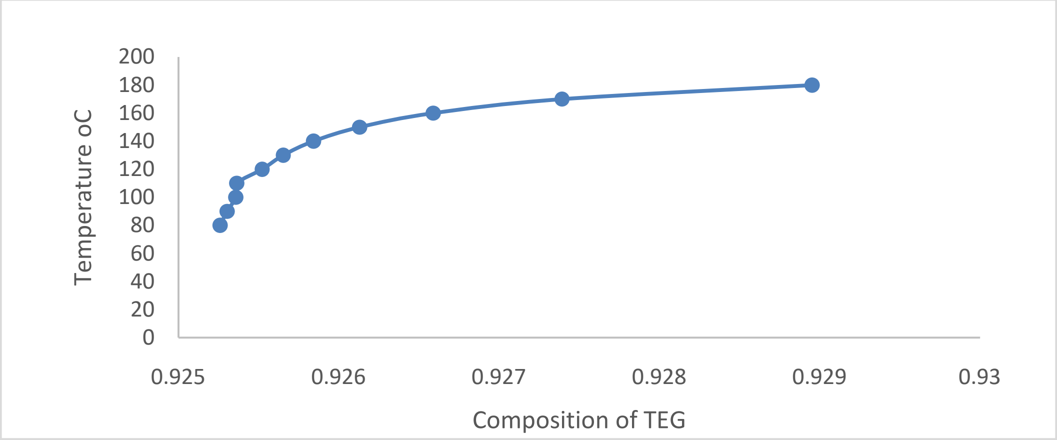


Figure 5: Effect of Temperature composition of lean TEG

4.4.1 Effect of reboiler temperature:

With regards to Table 6 and Figure 6 it is observed that the composition of the regenerated TEG increased as the temperature of the reboiler increased or as more heat was added. This outcome is expected in that the more heat is applied through the reboiler, the more the boil up ratio and the more the TEG is recycled back into the column where there is a better separation effectiveness which translates to a higher mole fraction of the regenerated TEG. [12] .However, care should be taken in order not increase the reboiler temperature beyond the temperature of 205^{0}C where the TEG solvent can thermally decompose and hence the maximum reboiler temperature should be always kept below this limit.

4.4.2 Effect of increase in temperature

Figure 6, reveals that the composition of the TEG increased with increase in temperature which is expected due to the fact that as more of the absorbed water and other components is given off due to the increase in temperature, a more purer TEG composition is obtained. This result conforms to the result obtained by [12] but it should be of note that if the temperature increase is from the feed stream to the regenerator, the reboiler duty also decreases because of reduction in the load and as the feed gas temperature decreases, more adsorbed content is removed in the contactor which leads to an improved performance.

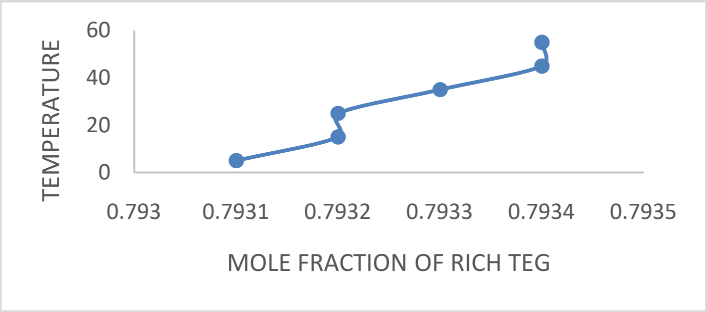


Figure 6: Effect of Temperature on rich TEG composition

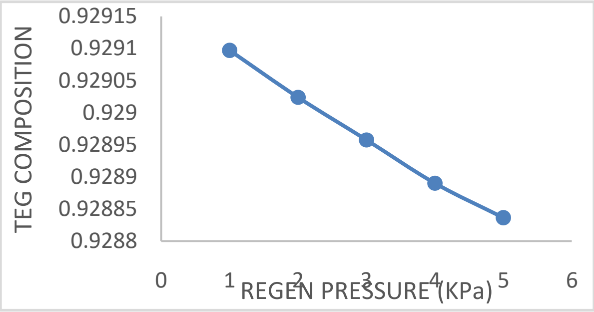


Figure 7: Effect of pressure on regenerated TEG composition

4.4.3 Effect of increase in pressure

In addition, by close review of Figure 7, it is observed that the composition of the regenerated TEG becomes less pure as the pressure is increased. This phenomenon is in consistency with literature wherein it becomes more difficult to treat the rich TEG which have adsorbed components in it due to the increase in pressure which may cause this adsorbed species to exist more in the liquid phase and which means more heat is needed to evaporate them and thus at the design temperature, more of the adsorbed components will be existing in liquid phase, thereby in reducing the purity of the regenerated TEG or its mole composition. In clear terms as reported by [12] , an increase in the absorber pressure leads to higher TEG losses which translates to less pure TEG solvent and implies that a lower pressure is required to strip up water from rich TEG.[6]

4.4.4 Effect of the number of Absorber stages

From Figure 8, it is observed that the composition of the TEG remained steady until the tray location increased beyond twelve (12). This outcome is somewhat defining in that it shows the appropriate range of the number of trays in order to maintain a steady state composition of the TEG. Further, this outcome shows that in order to maintain a high steady state composition of the TEG that will further lead to a better separation, then the number of ideal trays should not be more than twelve (12). This outcome is validated by the findings of [12] wherein as the number of absorber stage (trays) increases, lower water contents can be achieved in the dehydrated stream. However, the water content in the dry gas becomes steady after certain number of stages.

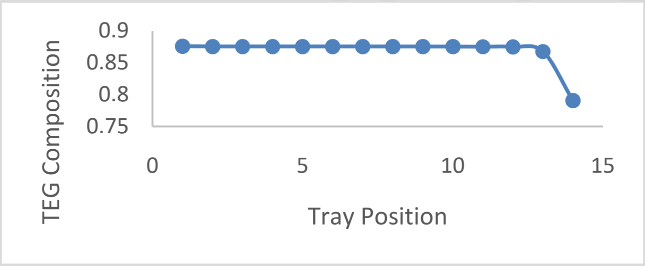


Figure 8: Effect on TEG composition with respect to tray position.

4.5 Deductions from the Sensitivity Results Analysis.

Having obtained the result due to the variation of a physical quantity with respect to another, it is thus necessary to review the results and check for consistency with literature.

In order to cushion this effect or to increase the purity of the regenerated TEG, then the reboiler heat duty needs to be increased which translates to more utility requirements and thus more operating cost. Notwithstanding, the sensitivity analysis reveals the following outcomes

i. The design temperature has effect on the regeneration of the TEG solvent and thus an optimum temperature that is both effective in operability and cost effectiveness is required to be obtained.

ii. The number of trays affect the purity of the TEG across the column during the regeneration process and thus an optimum number of trays needs to be determined in order to have a steady high concentration of the TEG solvent which translates to a more efficient treatment of the natural gas stream with due considerations into the accruable capital cost since the cost of the absorber depends on the number of trays in the column, diameter of the column, vessel thickness and material of construction [12].

iii. The pressure in the regeneration column have tremendous effect on the regenerated Lean TEG in terms of the utility requirements which is directly proportional to the operating cost and thus operating the column at a optimum pressure is not overly overstated.

Data Gathering for Performance Model Testing Using Matlab

From the initially simulated data obtained from the use of HYSYS to determine the effectiveness towards the production of TEG (Triethylene Glycol) using a reboiler – condenser distillation column with multi-functional plates/tray of high tray efficiency related to oil and gas production and technology, the following data were generated from the converged simulation worksheet table;

Table 12: Data obtained from Aspen Hysys simulation of TEG production using a C-R distillation column.

Parameters	Values	Parameters	Values
ρ	1.1 g/cm^3 = 1100kg/m^3	d_i	
T_o	105^{o}C [378 K]	d_o	
T_i	205^{o}C [478 K]	K_f	0.18428 W/Mk
U	3.6 e2 KJ/hr	K_w	
T_{co}	105^{o}C [378 K]	j_h	
T_{ci}	205^{o}C [478 K]	μ_w	
T_{ho}	192^{o}C [465 K]	μ	0.55513 cp
T_{hi}	205^{o}C [478 K]	R_e	
m_s		p_r	
m_T	50 Kgmol/hr	h_{do}	
$C_{p,o}$	333.7 J/molK	K_1	
d_e		N_i	
l_B		Q	1.060 e5 Kgmol/hr
C_p	321.65 J/molK	L_m	7.672 Kgmol/hr
V_m	56.61 Kgmol/hr		

These data are the functional parameters to be used for the accurate determination of the reboiler performance via designed models made satisfactory for reboiler use for TEG regeneration and certain operative conditions, the data will be used in testing for the correctness of the designed models stated in chapter three using MATLAB-Simulink

4.6 MATLAB Simulated Data, Plots and Discussions

Using the models designed above with respect to the data described at Table 4, the following simulated data and plots described below were obtained.

Table 13: Simulated data using MATLAB-Simulink

Time (hr)	dH [1.0e+009 *]	TEG_{yeild} $[W]$
2	0.4691	-33.4434
4	0.9381	-17.9991
6	1.4072	-2.5547
8	1.8763	12.8897
10	2.3453	28.3341
12	2.8144	43.7785
14	3.2834	59.2228
16	3.7525	74.6672
18	4.2216	90.1116
20	4.6906	105.5560
22	5.1597	121.0004

24	5.6288	136.4447

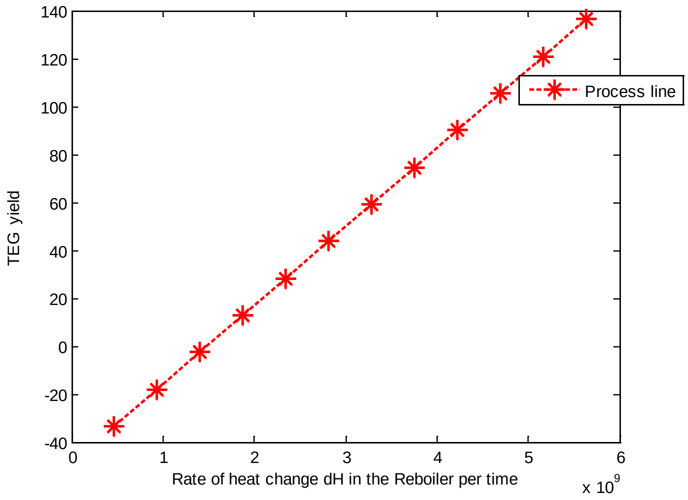
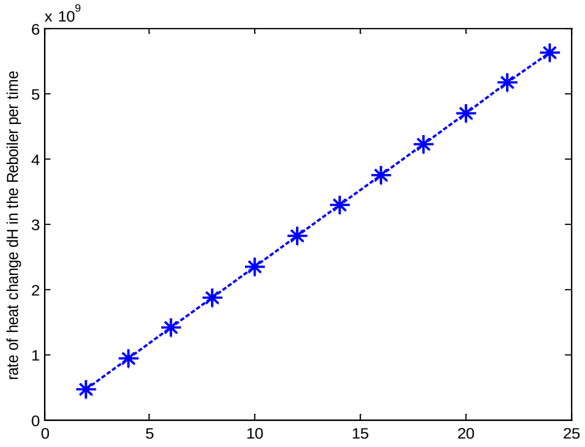


Figure 9: Rate of TEG-yield to rate of heat change dH in the reboiler per time

Figure 9 shows a proportional increase in the yield or produced TEG via the use of the designed models obeying the parametric functions of the designed Reboiler with respect to the algebraic increase in the rate of heat change of the reboiler over operational time. One can say that the change in the working temperature of a reboiler causes a periodic change in the yielding function of TEG. The performance of the designed reboiler can be well accessed from the plot as the heat change over time lies below two hours of the operation time, that is between $dH < 0.4691[1.0\mathrm{e}+009]$ and $dH = 0.4691[1.0\mathrm{e}+009]$ the yielded TEG was undefined but as the dH goes above such level of time and heat, the formation becomes properly defined with favourable yield all through the process. This satisfies the fact that TEG formation from a reboiler needs or requires a reboiler operating at a heating rate not less than $dH = 0.4691[1.0\mathrm{e}+009]$



(kg/mol.hrs)

Figure 10: Rate of heat change dH in the reboiler per time

Figure 10 is a plot of effect of time on the process heat generation, positively we can see that the operational time stands to be an independent variable which the heat change fully depends on. Figure 9 shows a direct proportion increase of the change in heat rate of the reboiler over the operational time space, at the studied time of $t = 24$ hours the heat continue to increase wich stands a great chance of increasing the vessel temperature, of which it will be required the use of a temperature and pressure controllers to avert the risk that could be impacted on the vessel due to overheating of the reboiler.

5. CONCLUSION

The research was able to develop materials and energy on heat balances for a thermosyphon reboiler operation for a liquified natural gas plant. The models were simulated applying process data to check for the reboiler performance over time. From figure 9 shows TEG yield per value of heat change in the reboiler per time is an exponential function of the variables plot. Figure 10 shows the rate of heat change in the reboiler per time against TEG products taken in hours increases to a maximum value. This explains that the model for the study of performance of thermosyphon reboiler predicts adequately the function of the reboiler operation.

NOMENCLATURE

Symbol	Meaning
V_m	Vapour flow rate from reboiler (Kg/hr)
L_m	Liquid flow rate to the reboiler (Kg/hr)
W	TEG flow rate from the regenerator bottom (Kg/hr)
H	Enthalpy of the liquid (kJ/kg)
ℓ	Density of liquid (Kg/m3)
C_p	Specific heat capacity of the liquid (kJ/kg.K)
T	Temperature of liquid (K)
U	Overall Heat transfer area (W/m2.K)
A	Heat transfer area (m2)
M_s	Mass flow rate of steam (Kg/s)
ΔTm	Mean temperature (K)
F_t	Temperature correction factor
L	length of tube. (m)
F	Friction facror
N_T	Number of tubes required
dT	Tube diameter (m)
D_s	Shell diameter (m)
μ	Viscosity of liquid (Nm.s/m2)
U	Velocity of liquid (m/s)
ΔP	Pressure drop (bar)
Pr	Prandtl number
Re	Fluid Reynoid number
K	Thermal conductivity (W/m.K)

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