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Keywords: natural gas, dehydration, triethylene glycol, absorber, regenerator.

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Simulation and Optimization of a Natural Gas Dehydration Plant with Triethylene Glycol

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ABSTRACT

Dehydration of Natural Gas has been a subject of interest for decades due to the effect of wet gas on the system. Specifically, the gas' heating value and its flow assurance are challenged coupled with not meeting markets' specification. Besides these flow assurance and related issues, the hydrate in the gas quickly deactivate catalyst and burn less. This study attempts to economically dehydrate the gas using Triethylene Glycol (TEG) which has to be optimally regenerated and used for further dehydration process. The simulation and optimization of the dehydration process through absorption with TEG was carried out using Aspen HYSYS software and Design-Expert software respectively. The simulation was carried out using Glycol and Peng-Robinson as the thermodynamic fluid package. Effects of parameters such as TEG circulation rate, equilibrium stages of absorption column, operating conditions on the process efficiency were investigated. It was found that, lowering the pressure in the absorption column reduces the amount of hydrocarbons trapped in the wet TEG stream leaving the bottom of the absorber. The optimization of the Recycled TEG was carried out using the numerical optimization of the Design-Expert software, the experimental design was based on the Central Composite Design of the Response Surface Methodology of Design-Expert version 10, this optimization yield a relative increase in TEG recycled stream from 99.59 mole% to 99.89 mole% at an optimum operating parameters of 25°C, 6320 kpa and 1883 kgmole/h of the wet gas stream.

Keywords: natural gas, dehydration, tri- ethylene glycol, absorber, regenerator.

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I. INTRODUCTION

Natural gas provides a great portion of the world growing energy need and the situation is likely to remain so for the next few decades (Appah, 2014). In terms of energy, natural gas consumption represents more than half of the total petroleum consumed and may likely double as natural gas reserved are being discovered at twice the rate of petroleum (Gray *et al.*, 1990; Partho and Ruhul, 2011; Ahmed *et al.*, 2019). This trend indicates the increasingly important role that gas will play in the future world energy (Obonukut *et al.*, 2016). As oil shortage looms in the future, it becomes a concern for scientists and engineers to use natural gas as an alternative source of energy (Patel *et al.*, 2005). This is the way to go as gas reserves with the increasing trend in gas than crude oil and it is anticipated that this trend will extend well into the 21st century (Holmen, 2009; Ahmed *et al.*, 2019).

Over the years, large quantities of natural gas are located in remote areas (isolated from centers of commerce and dense population), where no distribution network exists for its transportation. Transportation cost of remote natural gas is relatively the expensive part of the final delivered price and it is serious as most of the world natural gas reserves are in remote locations (Saeid *et al.*, 2006). In these regions, pipelines are not economical to bring natural gas to the market. Consequently, most natural gas is consumed in the country where it is produced. In some cases, natural gas associated with crude oil is often flared for convenience (Obonukut *et al.*, 2016). The gas needs to be converted to liquid fuels in order to make it easier for transportation to market.

Specifically, Liquefied natural gas (LNG) terminals and vessels can bring remote gas to market. Compressed natural gas (CNG) can be transported from short remote distances using tankers with pressurized containers/vessels. Alternatively, depending on the economic conditions, on-land and subsea pipelines can be constructed to transport the remote gas. However, gas interaction with the aggressive substances within the reservoir influences not only its flow integrity but also its property adversely.

The natural gas, produced from underground reservoir, contains huge quantity of light hydrocarbon mainly methane together with ethane, propane and butane. However, traces of the heavy hydrocarbon compounds (pentane and hexane) and non-hydrocarbon compounds such as: water, nitrogen and hydrogen sulphide are equally found in the gas (Siti and Abdul, 2012; Mokhatab *et al*., 2014). Consequently, natural gas must be treated to enrich its light hydrocarbon content. This could be achieved by dehydration (where water vapour is removed) and separation of the heavy hydrocarbon components (Kong *et al*., 2018; Shoaib *et al*., 2018). The water content in natural gas is a big problem in the oil and gas industry as it can accelerates corrosion in the gas pipe lines and as well reduces the heating value of the natural gas.

The flow integrity of wet gas is challenged as its water content especially at subsea condition becomes 'hydrate' leading to slugging flow conditions thus lowering flow efficiency of the pipelines (Akpabio *et al.,* 2021). Downstream processing of this gas especially in chemical processes involving catalyst would create undesired side reactions, foaming or catalyst deactivation (Obonukut *et al.,* 2016). Therefore, to prevent such problems, natural gas treatment is inevitable. The water in the natural gas contains dissolved aggressive compounds including mineral/inorganic salts (Stewart and Arnold, K. (2011). Thus removing water from the gas implies eliminating these aggressive compounds.

An overview of the gas production activities as well as its formation is necessary. Different offshore processes need to be applied for the gas dehydration, avoiding subsequent problems caused by the wet gas such as corrosion or gas hydrate formation. During offshore oil production, the reservoir fluid coming from the well is typically a mixture of three distinct phases: an aqueous phase (produced water), a liquid hydrocarbon phase (crude oil) and a gas phase with some suspended solids in the mixture. Normally, the three phases must be separated and then further processed in the topside facilities, before being discharged or exported to onshore (Figure 1.1).

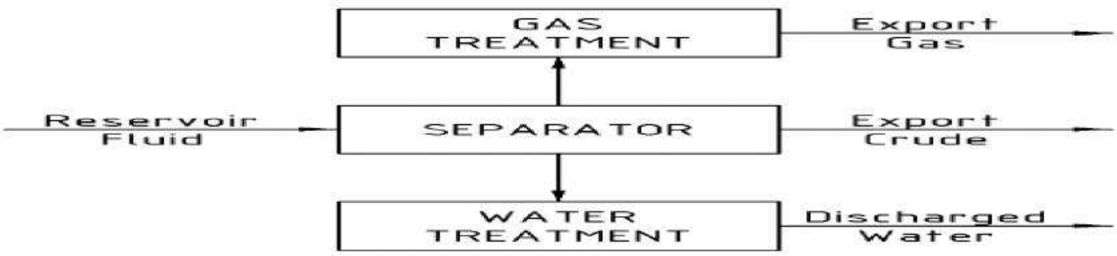

Figure 1.1: Overview of upstream processes in the oil and gas industry

The separation of the three phases is carried out in 3-phase separators. These vessels slow down the reservoir fluid by reducing its momentum. Then, the phases are separated by means of gravitational force. There are normally three separators on offshore facilities, the first being high pressure, the last being low pressure and the pressure of the middle separator is in between. This arrangement serves to stabilize the crude oil by removing volatile components. The produced water is treated in water treatment facilities. The objective is to remove the dispersed hydrocarbons from the water to meet environmental regulations for the produced water discharge quality. The water purification facilities mostly consist of hydrocyclones and skimmers.

The produced gas must be recompressed and exported to onshore facilities. The high-pressure (9 - 14 MPa) pipelines (Bothamley, 2004) used for exporting, lay on the seabed where the fluid can cool down to as low as -1°C (Skjoldal, 2007). At this low temperature and high pressure, if there is water in the gas phase it may form solid crystalline hydrates with the light hydrocarbons. The hydrates can cause severe damage to the pipelines. The gas phase in the reservoir fluid is saturated with water because it was previously in contact with the brine and other aggressive substances. Therefore, one of the purposes of the gas treatment is the removal of water from the gas (dehydration).

Dehydration is the main operation employed in the industry to remove the contaminated moisture from the natural gas (Mokhatab *et al,* 2019). This is necessary for hydrocarbon dew point control which is to maintain the water content specification, prevent corrosion, separate the heavy hydrocarbons, prevent the formation of hydrate, avoid side reactions, prevent catalyst deactivation and eliminate condensation of the water and heavy hydrocarbon in the gas transport pipeline (Bahadori, 2014; Abdulla, 2015). There are several ways of removing the water content of the raw natural gas (Rahimpour *et al.*, 2013), one is preferred over the other based on factors such as the composition of the wet natural gas, the condition of the wet natural gas, the operating cost and how effective it is in removing the water content from the wet natural gas, one of such is dehydration of the raw natural gas using the absorption process with glycol as the absorbent.

Industrially, three methods of dehydration are usually adopted, these are: adsorption, absorption by using glycol solvent and condensation by raising the dew point temperature of the hydrocarbon and the water (Netusil and Ditl, 2011). However, there are supersonic method and membrane method for the natural gas dehydration process (Pezman and Roya, 2011). The aim of this paper was to optimize natural gas dehydration process using triethylene glycol (TEG) as the absorbent. This involved simulation of Natural gas dehydration process using Aspen HYSYS. Industry data available in this direction was generously exploited to investigate the effect of operating parameters on the efficiency of the process. Design Expert was used to optimize the solvent regeneration of gas dehydration plant (Luyben, 2011). Thus, optimizing the regeneration of TEG is economical as fewer quantity of the solvent (TEG) and eventually maximize the profitability of natural gas dehydration (Chebbi *et al.*, 2019).

II. MATERIALS AND METHODS

In this study, dehydration process of a typical natural gas from one of the Niger Delta oil field is presented. The plant as simulated using one of the popular commercial software in the oil and gas industry (Aspen HYSYS) explores the real industrial experience of the researcher while in the field.

2.1 Simulation of Natural Gas Dehydration Plant

Basically, a natural gas dehydration plant is divided into two sections. These are mainly the Absorbing/Contacting section where the hydrated gas is contacted with TEG to have a dry gas and the Regeneration/Stripping section where the TEG is recovered and recycled for further absorption operation. Specifically, Triethylene Glycol (TEG) based dehydration process as depicted in absorption unit and the extraction of the solvent (TEG) as presented in regeneration unit singled out the necessary equipment required to model the plant. The gas used is a partially treated natural gas which has bad compositions such as acid gas, mercury and heavy hydrocarbons removed (Sanggyu *et al.*, 2011) as well as its process condition as shown in Table 2.1 and 2.2 respectively.

Table 2.1: Wet Natural Gas Composition

Composition	Mole Fraction
Methane	0.8565
Ethane	0.0614
Propane	0.0494
i-Butane	0.0100
n-Butane	0.0095
i-Pentane	0.0083
n-Pentane	0.0040
Water	0.0010

(Source: Afaiko, 2014)

Table 2.2: Condition of the Wet Gas

Property	Value
Inlet Pressure	7201Kpa
Inlet Temperature	25°C
Flow Rate	1883Kgmole/hr

(Source: Afaiko, 2014)

A combined fluid package (Glycol and Peng-Robinson) was used for the HYSYS simulation as it is commonly used for hydrocarbon systems applications and studies (Elliot and Lira, 1999). It is specifically used for gas phase components that handle the complex thermodynamics that occur during compression, and is useful in both upstream and downstream industries.

The simulation on HYSYS commences with passing wet gas to the flash tank (Separator) at 7201 kpa where some of the water in the mixture is separated. The gas is then fed to the absorber (contactor) through the bottom. The absorber was operated with 9 stages for higher purity (Pezman and Roya, 2011; Affandy *et al.*, 2020). The mixed TEG (fresh and recycled TEG) inlet and Dry gas outlet are located at the top of the column while the TEG outlet (Rich TEG) and Natural gas with hydrate (Hydrated gas) inlet are located at the bottom of the column Figure 2.1.

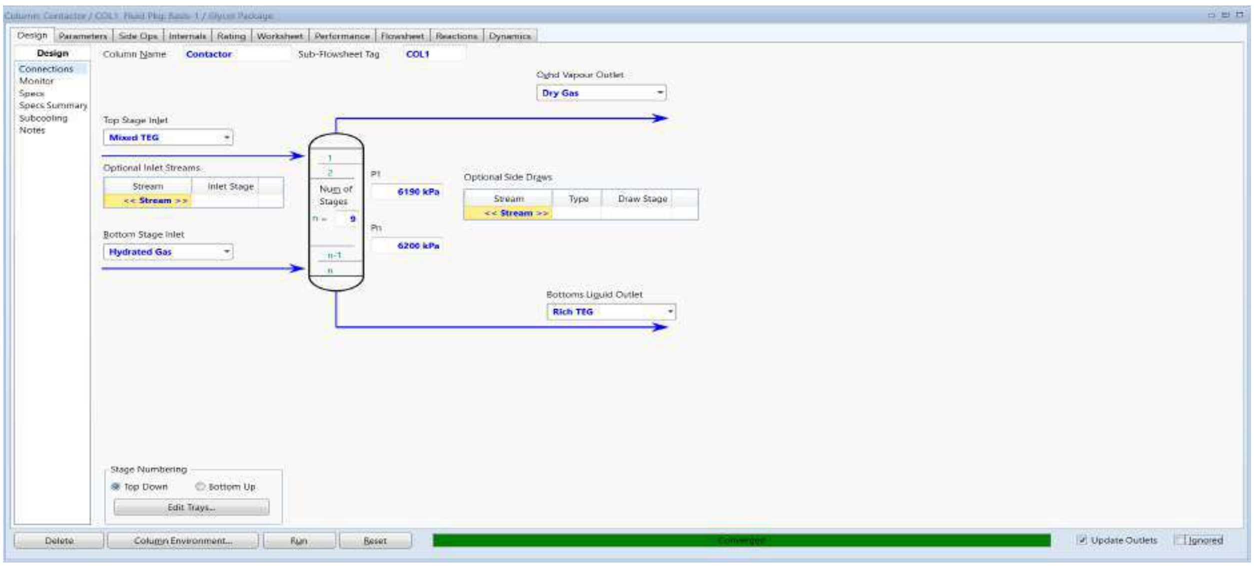

Figure 3.1: The Contactor control screen on HYSYS

The TEG flow is dependent on the water (hydrate) content in the hydrated gas. Rich TEG leaves the bottom by level control and is depressurized by a valve. The rich stream flows through a cartridge filter to remove solid particles coming from corrosion or TEG degradation (Affandy *et al.*, 2017). However, solid particles and degradation are not taken into account in this model. Hence, it is not represented in the simulated plant. Consequently the filtration does not have serious impact on the process. Once filtered, the depressurized TEG stream is subjected to heat exchange with the hot regenerator bottom product (lean TEG) coming out of the TEG regenerator at the Rich/Lean TEG Exchanger before it then becomes feed for the regenerator. The Regenerator is used to strip water from the lean TEG (Figure 2.2).

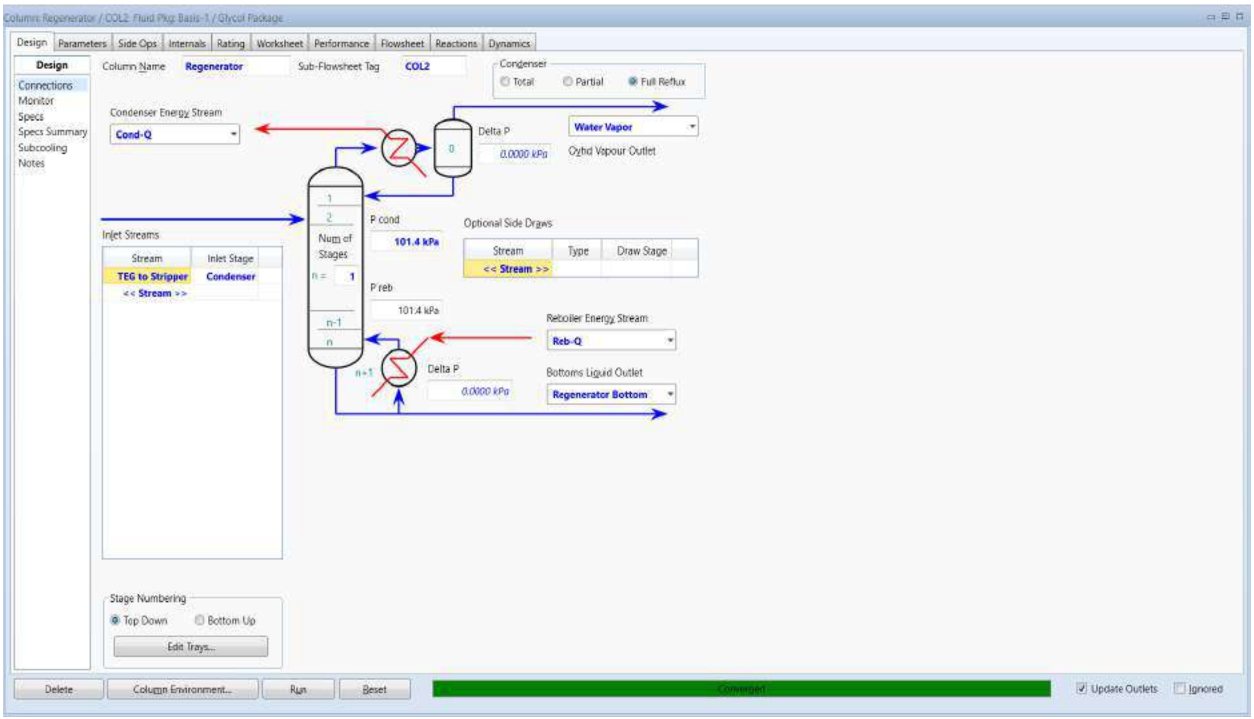

Figure 2.2: The Regenerator control screen on HYSYS

The temperatures given for the reboiler and condenser are 205°C and 102°C respectively. After leaving the regenerator, the lean TEG is once again cooled and stored in a surge drum. At this point there will also be some kind of TEG makeup system to replace the TEG lost to the gas phases in the dehydration plant before it is finally recycled to the start point. Figure 2.3 shows the composition of the rich glycol stream leaving the absorber.

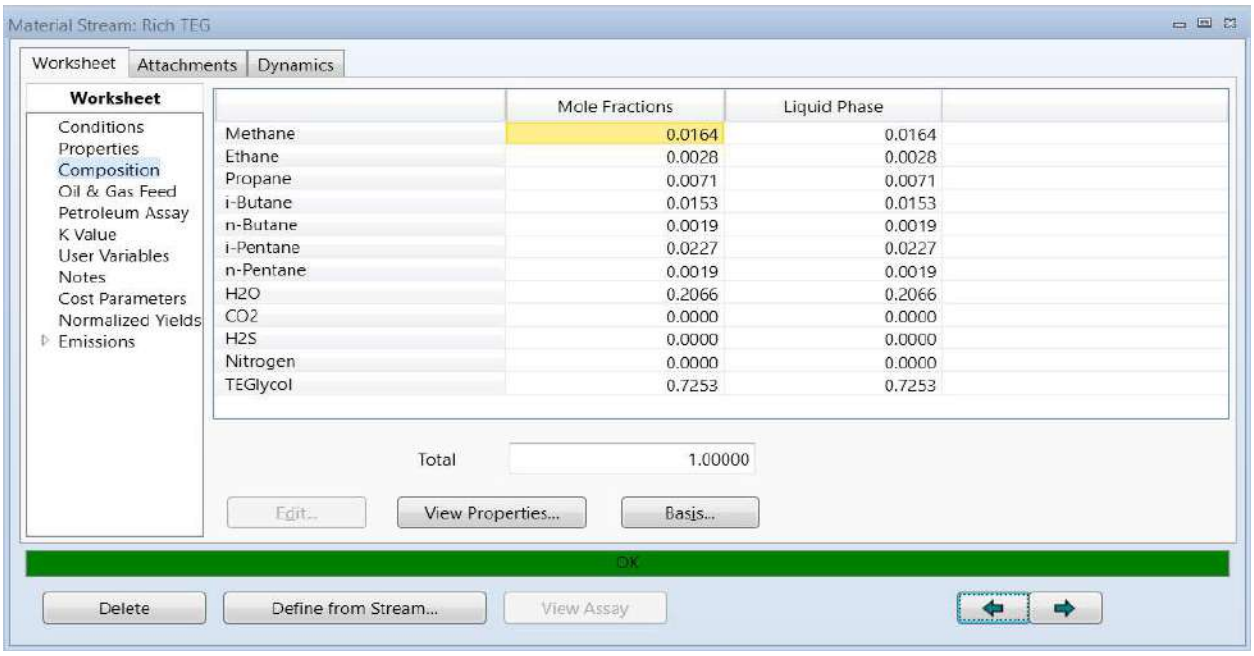

Figure 2.3: Composition of Rich TEG control screen on HYSYS

The Process achieved high water removal and is reflected in zero water composition in the natural gas outlet stream (Sale Gas) shown in Figure 2.4.

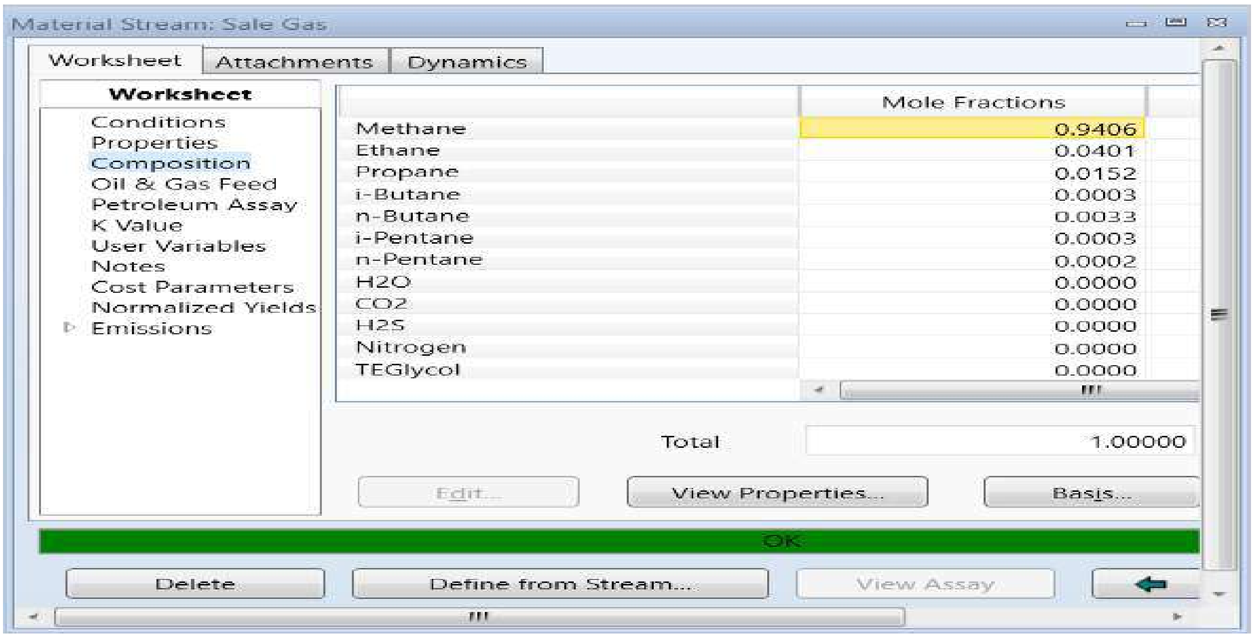

Figure 2.4: Composition of the Dehydrated (Sale Gas) control screen on HYSYS

Waste gases consisting of water and the hydrocarbons dissolved in the TEG leave the regenerator at the top. The lean TEG then enters a Surge drum in which gaseous hydrocarbons that were absorbed along with the water in the separator is vaporized as flash out. The Lean TEG is then cooled, pumped (Glycol Circulation Pump) and recycled back to the contactor as it mixes with fresh lean TEG in a mixer (TEG Mixer) and fed to the contactor. Figure 2.5 shows Process Flow Diagram (PFD) of the HYSYS simulation of the Natural gas Dehydration process.

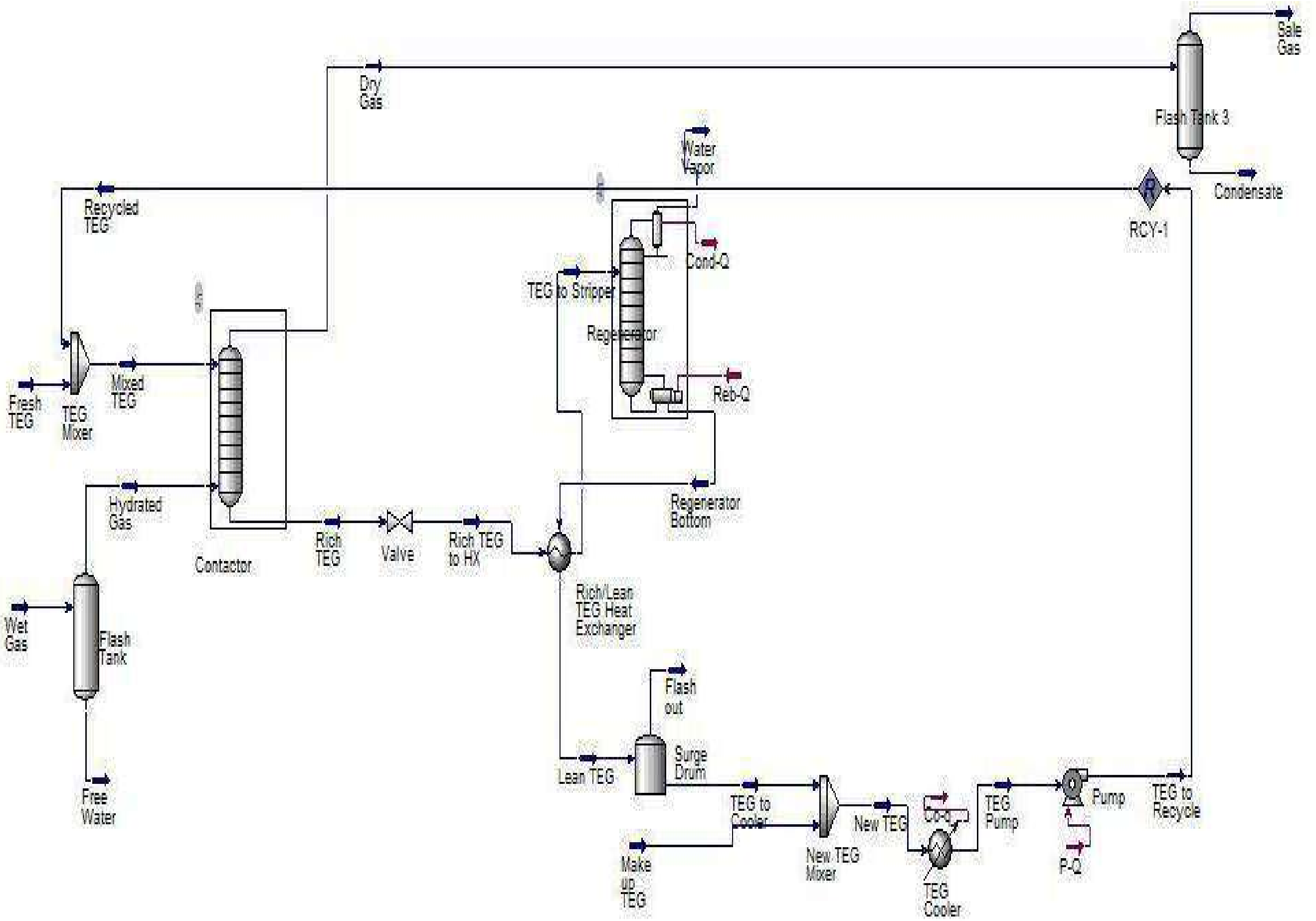

Figure 2.5: Process Flow Diagram of Natural Gas Dehydration Plant in Aspen HYSYS

2.2 Optimization of the Natural Gas Dehydration Plant

Optimization of the natural gas dehydration plant was carried out using Design Expert version. 10 to maximize the yield of recycled TEG that will be used for further dehydration process. The Response Surface methodology (RSM) using the Central Composite Design (CCD) of design expert was adopted for the optimization process, the process variables of the wet natural gas stream were used to evaluate the optimum operating condition at which maximum recycled TEG yield could be achieved. By using design expert version 10, low and high values of the process variables (temperature, pressure and flow rate) were specified and the response set to be Recycled TEG. A total of 15 runs were generated from the specified low and high values of the process variables to generated different ranges of the process variables at which one should give the maximum yield of the regenerated TEG. This generated process variables were then taken to Aspen HYSYS to simulate the dehydration plant, the values of Recycled TEG using the new process variables were used as response variable to analyze the maximum Recycled TEG yield using Design Expert numerical optimization method.

III. RESULTS AND DISCUSSION

3.1 Effects of Process Parameters on Natural Gas Dehydration Plant

In the quest to maximize the absorption efficiency of TEG in the contactor, the impacts of the key parameters were evaluated using the simulation model presented in this study. These parameters were:

i. The number of contactor theoretical trays
ii. TEG circulation rate
iii. Temperature of the reboiler in the regenerator

It was found that lowering the pressure in the absorption column reduces the amount of hydrocarbons trapped in the wet TEG stream leaving the bottom of the absorber. The Wet TEG stream also has a low pressure and thus the valve is no more needed. Figure 3.1 shows the composition of the Rich TEG.

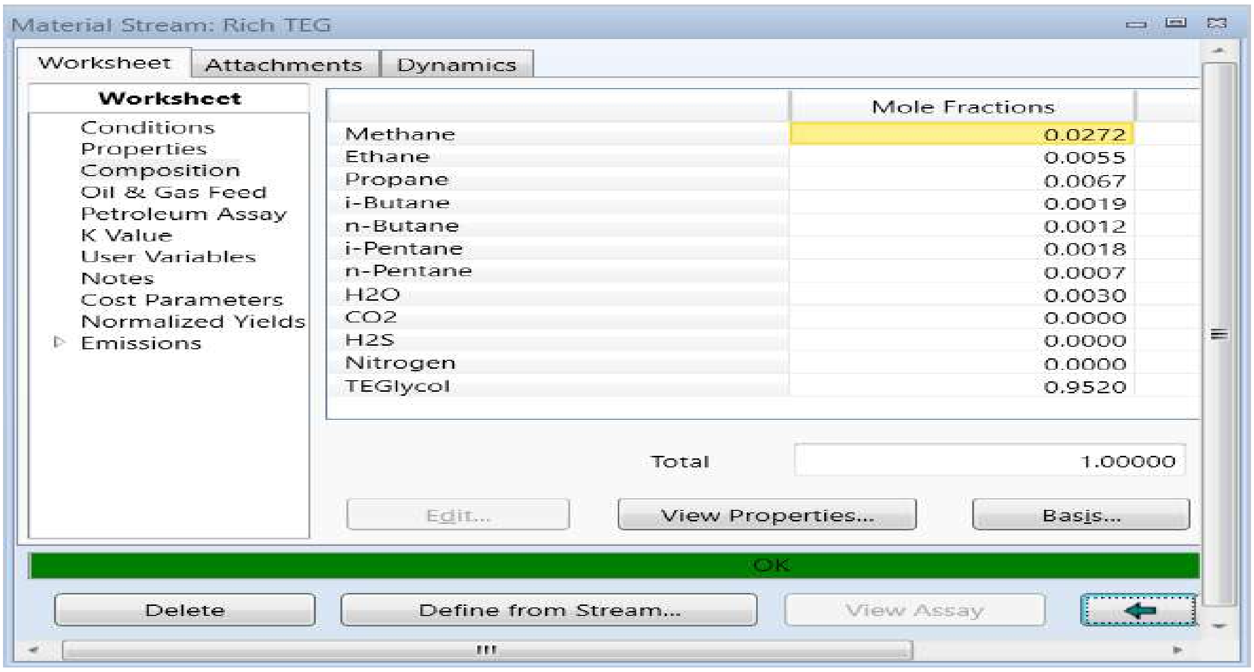

Figure 3.1: Composition of the Rich TEG stream after simulation in HYSYS

However, other parameters may have also a limited impact. It was also observed that increasing the number of trays in the regenerator has no effect on the outlet stream composition. It was observed that increasing the flowrate of the TEG above the minimum requirement is not necessary as maximum separation has already been achieved. TEG is known to decompose at a temperature of 206°C which is far lower than its boiling point of 284°C and this limits the temperature of the TEG regenerator reboiler (Kamin *et al.,* 2017; Neagu and Cursaru, 2017).

3.2 Optimization of TEG Regeneration of the Natural Gas Dehydration Plant

The optimization of TEG regeneration of the natural gas dehydration plant was carried out using Design Expert ver. 10 so as to recover maximum TEG for further dehydration process. This section discusses the Analysis using Response Surface Methodology based on Central Composite Design Model (section 3.2.1), Anova for Response Surface Reduced Quadratic Model (section 3.2.2).

3.2.1 Analysis using Response Surface Methodology (RSM)

After performing the dehydration plant simulation, it was found that recycled TEG yield depends on different parameters of the natural gas dehydration process. So, by controlling these parameters, optimum recycled TEG yield was obtained. Response Surface Methodology (RSM) based on Central Composite Design (CCD) was used to monitor the yield of Recycled TEG with response to the process variables. The variables and their corresponding coded values for the process are analyzed (Table 3.1) and the Response parameter (Table 3.2) as follows:

Table 3.1: Process variables and their corresponding coded values

Factor	Name	Units	Type	Subtype	Minimum	Maximum	Coded	Values	Mean	Std. Dev.
A	Temperature	oC	Numeric	Continuous	20.0522	53.8378	-1.000=25	1.000=48.89	36.945	9.02957
B	Pressure	kPa	Numeric	Continuous	6137.54	7383.46	-1.000=6320	1.000=7201	6760.5	332.987
C	Flow rate	kgmole/h	Numeric	Continuous	92.1477	12320.9	-1.000=1883	1.000=10530	6206.5	3268.26

Table 3.2: Response parameter

Response	Name	Units	Obs	Analysis	Minimum	Maximum	Mean	Std. Dev.	Ratio	Trans	Model
R1	Recycled TEG	mole	15	Polynomial	0.9984	0.9989	0.998593	0.000109978	1.0005	None	RQuadratic

The experimental design using the central composite design consisted of a total of 15 base runs, comprising of 3 factorial points, and 1 response point, Table 3.3 shows the experimental design of TEG regeneration optimization.

Table 3.3: Experimental design of TEG regeneration optimization

		Factor 1	Factor 2	Factor 3	Response 1
Std	Run	A: Temperature	B: Pressure	C: Flow rate	Recycled TEG
		oC	kPa	kgmole/h	Mole
8	1	36.945	7383.46	6206.5	0.9987
10	2	36.945	6760.5	12320.9	0.9984
15	3	36.945	6760.5	6206.5	0.9986
5	4	20.0522	6760.5	6206.5	0.9986
3	5	25	7201	10530	0.9985
6	6	53.8378	6760.5	6206.5	0.9986
7	7	36.945	6137.54	6206.5	0.9986
9	8	36.945	6760.5	92.1477	0.9986
14	9	36.945	6760.5	6206.5	0.9986
11	10	36.945	6760.5	6206.5	0.9986
12	11	36.945	6760.5	6206.5	0.9986
13	12	36.945	6760.5	6206.5	0.9986
4	13	25	6320	1883	0.9989
2	14	48.89	6320	10530	0.9985
1	15	48.89	7201	1883	0.9985

3.2.2 Anova for Response Surface Reduced Quadratic Model

Analysis of variance table (Table 3.4), the model F-value of 134.47 implies the model is significant.

There is only a 0.01% chance that an F-value this large could occur due to noise. Values of "Prob > F" less than 0.0500 indicate model terms are significant. In this case B, C, AB, AC, BC, B^2, C^2 are significant model terms. Values greater than 0.1000 indicate the model terms are not significant. The summary of fit of the Factor and Coefficient Estimates are presented in Table 3.5. The best fit model proposed by the software was the quadratic model.

Table 3.5: Fit summary of Factor and Coefficient Estimate

	Coefficient		Standard	95% CI	95% CI	
Factor	Estimate	df	Error	Low	High	VIF
Intercept	1.00	1	5.051E-006	1.00	1.00	
B-Pressure	3.536E-005	1	6.682E-006	1.956E-005	5.115E-005	2.00
C-Flow rate	-7.071E-005	1	6.682E-006	-8.651E-005	-5.491E-005	2.00
AB	2.929E-005	1	9.449E-006	6.946E-006	5.163E-005	2.00
AC	1.354E-004	1	9.449E-006	1.130E-004	1.577E-004	2.00
BC	1.000E-004	1	6.682E-006	8.420E-005	1.158E-004	1.00
B^2	3.125E-005	1	4.808E-006	1.988E-005	4.262E-005	1.00
C^2	-4.375E-005	1	4.808E-006	-5.512E-005	-3.238E-005	1.00

The empirical relationship between response parameter (recycled TEG) and the process variables is represented in Equations 3.1 where A, B, and C are coded terms used for temperature, pressure and flow rate of the wet gas.

$$Y = +1.00 + 3.536E\text{-}005*B - 7.071E\text{-}005*C + 2.929E\text{-}005*AB + 1.354E\text{-}004*AC + 1.000E\text{-}004*BC + 3.125E\text{-}005*B^2 - 4.375E\text{-}005*C^2 \quad (3.1)$$

Where;

Y = Recycled TEG yield

A = Temperature

B = Operating Pressure

C = Flow rate

Intercept = 1.00

The equation in terms of coded factors above can be used to make predictions about the response for given levels of each factor. By default, the high levels of the factors are coded as +1 and the low levels of the factors are coded as -1. The coded equation is useful for identifying the relative impact of the factors by comparing the factor coefficients.

Graphical representation of how the individual process variables affect the yield of recycled TEG as well as a three-dimensional plot (3D plot) and contour plot were generated by the Design-Expert software. The 3D and the contour plots (Figures 3.1 - are used to estimate the effects of the combination of variables (temperature, pressure and flow rate of the wet gas) on the response (recycled TEG yield).

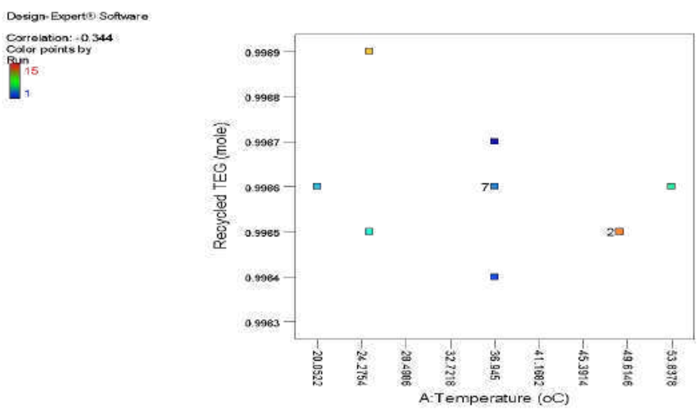

Figure 3.1: Graphical representation of the effect of temperature on Recycled TEG

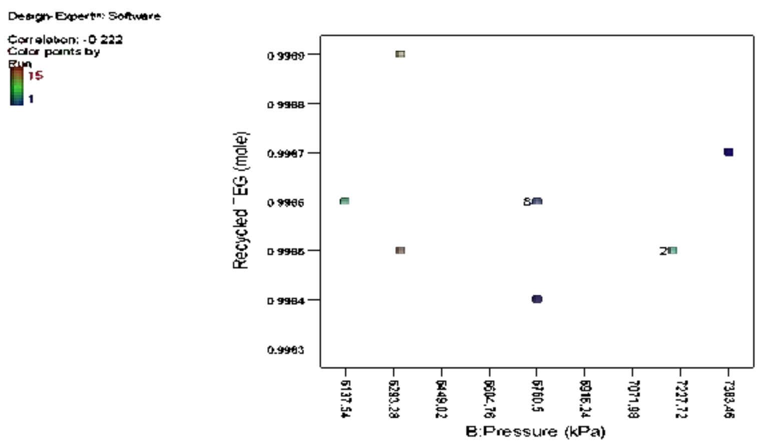

Figure 3.2: Graphical representation of the effect of pressure on Recycled TEG

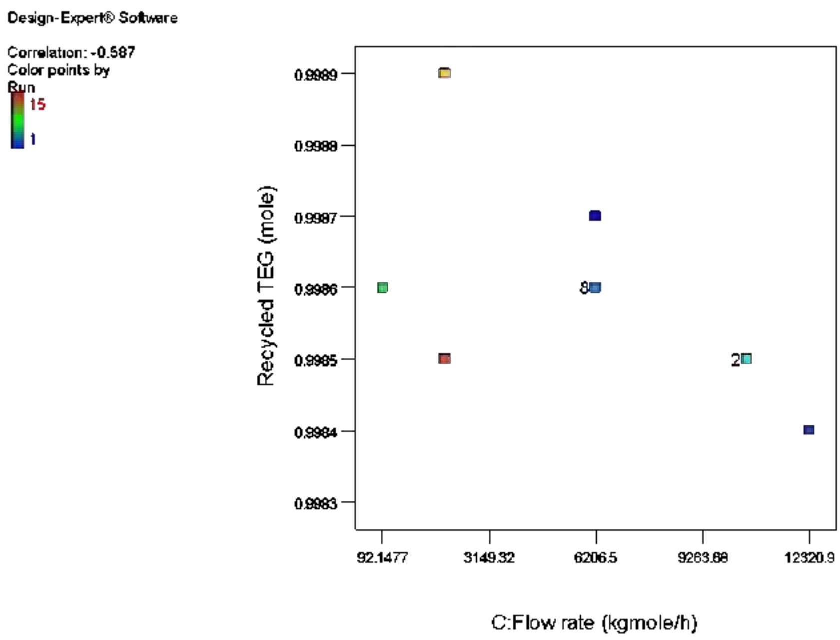

Figure 3.3: Graphical representation of the effect of pressure on Recycled TEG

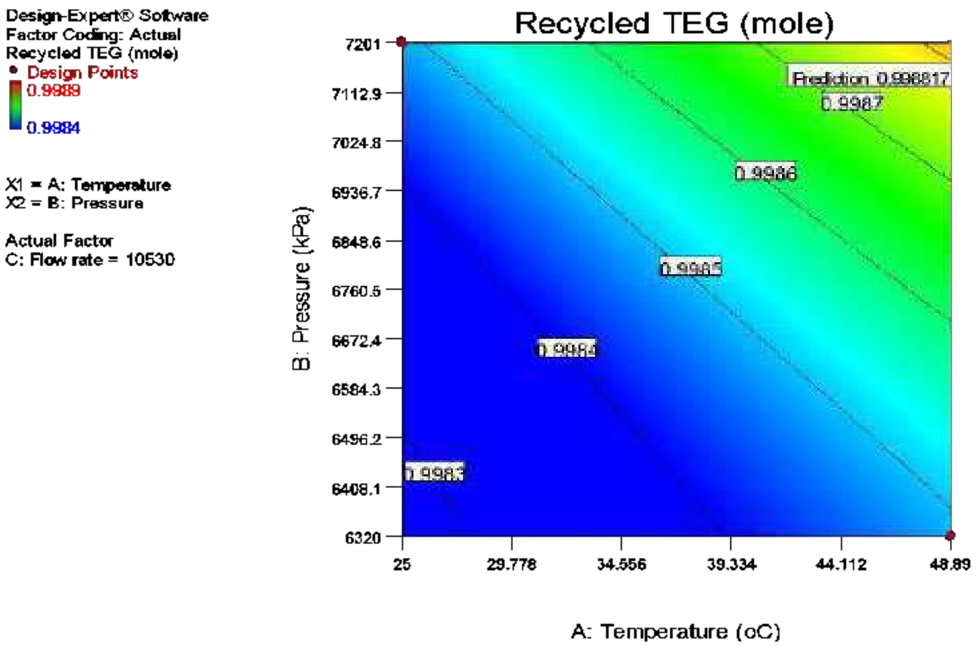

Figure 3.4: Contour Plot showing the effect of temperature and pressure on the Recycled TEG

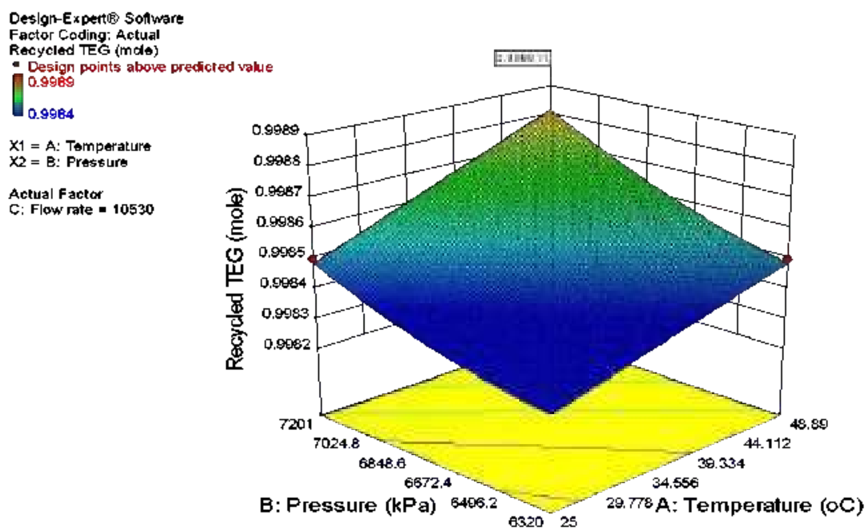

Figure 3.5: 3D Plot showing the effect of wet gas temperature and pressure on recycled TEG response

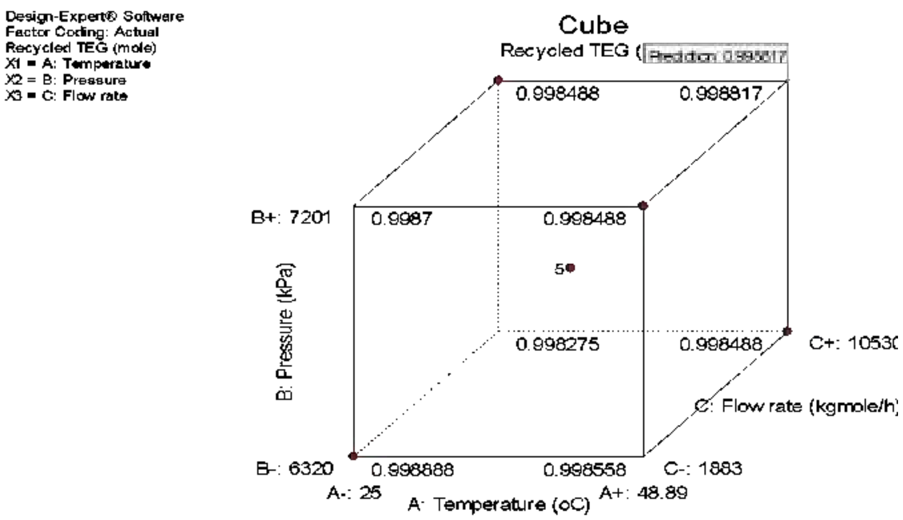

Figure 3.6: A cube showing the effect of wet gas parameters on the response

From the result of the optimization, it was seen that temperature, pressure and flow rate has significant effect on the process, the optimum operating temperature, pressure and flow rates were found to be 25°C, 6320 kpa and 1883 kgmole/h respectively, this process variable values gives an optimum yield of Recycled TEG of 99.89 mol%.

IV. SUMMARY, CONCLUSION AND RECOMMENDATION

4.1 Summary

Dehydration of Natural Gas has been a subject of interest for decades due to the effect of the wet gas on the system, gas' value and market specification. Specifically, dehydration is carried out to prevent formation of hydrates which are known to corrode pipelines and block valves. Besides these flow assurance issues, the hydrate in the gas quickly deactivate catalyst and burn less. Several studies emerged with an attempt to economically dehydrate the gas. In this study, TEG, proven to be the best and less aggressive on the environment has been exploited. This study evaluated the dehydration of Natural gas through absorption with Triethylene glycol and HYSYS simulation of the process was carried out using

Glycol and Peng-Robinson as the thermodynamic fluid package.

Optimization of the process was done using the Central Composite Design approach of Response Surface methodology (RSM) of the Design Expert software. The process variables of the wet gas stream were used as design parameters for the experiment based on central composite design. It was found that, at a temperature of 25°C, pressure of 6320 kpa and a flow rate of 1883 kgmol/h, a maximum recycled TEG yield of 99.89 mol% of the recycled stream was obtained.

4.2 Conclusion

Based on the results obtained from the optimization of Natural gas Dehydration plant with TEG, it can be concluded that:

i. The column pressure of the absorption column should be minimized to reduce the amount of hydrocarbons trapped in the wet TEG stream leaving the bottom of the absorber.
ii. The number of theoretical trays of the TEG regenerator has a little impact on lean TEG content; a minimum possible number of trays should be used.

4.3 Recommendation

Based on the findings of this work, it is recommended that the TEG regenerator reboiler temperature should not exceed 206°C as triethylene glycol degrades at this temperature which is far less than its boiling point of 285°C. Also, for Optimum TEG regeneration operation, the temperature, pressure and flow rate of the wet gas stream should be 25°C, 6320 kpa and 1883 kgmole/h respectively as maximum yield of the Recycled TEG is achieved at this operating condition.

REFERENCES

1. Abdulla, S. (2015). Simulation of Pumps by Aspen Plus. *International Journal of Engineering Science,* 4 (3): 2 -45.
2. Afaiko, D. U. (2014). *Maximizing the efficiency of natural gas dehydration process with triethylene glycol using Aspen HYSYS*. B. Eng Project, University of Uyo, Nigeria.
3. Affandy, S., Renanto, J., and Chien, L. (2017). Simulation and optimization of structured packing replacement in absorption column of natural gas dehydration unit using triethylene glycol (TEG). Paper presented at 6th International Symposium on Advance Control of Industrial Processes, AdCONIP 2017.
4. Affandy, S., Kurniawan, A., Handogo R., Sutikno, J., and Chien, I. (2020). Technical and economic evaluation of triethylene glycol regeneration process using flash gas as stripping gas in a domestic natural gas dehydration unit. *Engineering Reports* 2 (4):1-3.
5. Ahmed, S., Nadia, A. and Said, A. (2019) Gas Condensate Stabilization Methods: Optimum Operating Conditions. *International Journal of Recent Technology and Engineering*, 8 (3): 1643-1648.
6. Akpabio, J., Bassey, P., Ajie, O. and Obonukut, M. E. (2021) Development of a Model Predicting Rate of Wax Deposition in Production Tubing: A Flow Assurance Study. *Journal of Petroleum Technology and Alternative Fuels* (in press)
7. Appah, D. (2014). Energy Challenge for Nigerian Industrial Revolution Plan: The Way Forward. Paper presented at the 44th Annual Conference of Nigerian Society of Chemical Engineers, Owerri, Nigeria, 2 - 6 November, 2014.
8. Bahadori A. (2014). *Natural gas processing: Technology and Engineering Design*. Gulf Professional Publishing.
9. Chebbi, R., Qasim, M. and Abdel N. (2019). Optimization of Triethylene Glycol Dehydration of Natural Gas. *Energy Report*. 5: 723-732.
10. Elliot J. R. and Lira C. T. (1999*). Introduction to Chemical Engineering Thermodynamics*. Prentice Hall.
11. Gray, David, Tomlinson, Glen and Shen, John (1990). Direct Methane Conversion: An Assessment. *Hydrocarbon processing,* 432-435.

12. Holmen, A. (2009). Direct Conversion of Methane to Fuels and Chemicals. *Catalysis Today*, 142: 2 – 8.
13. Kamin. Z., Bono, A., and Leong, L. (2017). Simulation and optimization of the utilization of triethylene glycol in a natural gas dehydration process. *Chemical Product and Process Modelling*. 12(4):1-9.
14. Kong, J., Mahmoud, Z., Liu, A. and Sunarso, S. (2018) Revamping existing glycol technologies in natural gas dehydration to improve the purity and absorption efficiency: Available methods and recent developments. *Journal of Natural Gas Science and Engineering*, 56: 486 -503.
15. Luyben W. (2011). *Principles and Case Studies of Simultaneous Design*. Hoboken, NJ: John Wiley & Sons.
16. Mokhatab, S., Mak, J. Y., and Poe, W. A. (2019). *Process Modelling and Simulation of Gas Processing Plants*. Handbook of Natural Gas Transmission and Processing. Gulf Professional Publishing; 4th edition.
17. Neagu, M. and Cursaru, D. (2017). Technical and economic evaluations of the triethylene glycol regeneration processes in natural gas dehydration plants. *Journal of Natural Gas Science and Engineering*. 37:327-340.
18. Netusil, M. and Ditl, P. (2011). Comparison of three methods for natural gas dehydration. *Journal of Natural Gas Chemistry* .20(5): 471-476.
19. Obonukut, M. E., Alabi, S. B. and Bassey, P. G. (2016). Steam Reforming of Natural Gas: Value Addition to Natural Gas Utilization in Nigeria. *Journal of Chemistry and Chemical Engineering* 10 (1): 2841.
20. Partho, S. and Ruhul, A. (2011) Aspen-HYSYS Simulation of Natural Gas Processing Plant. *Journal of Chemical Engineering IEB* 26: 62-65.
21. Patel, M. S., Wong, S. F. and Storm, D. A., (2005). Retrofitting Methanol Plants for Higher Alcohols. 78th American Institute of Chemical Engineer's, National Meeting, New Orleans, LA.
22. Pezman K. and Roya H. (2011). Sensitivity Analysis of a Natural Gas Triethylene Glycol Dehydration Plant in Persian Gulf Region. *Petroleum and Coal* 53(1): 71-77.
23. Rahimpour, M. R., Jokar, S. M., Feyzi P., Asghari, R. (2013). Investigating the performance of dehydration unit with Coldfinger technology in gas processing plant. *Journal of Natural Gas Science and Engineering*. 1:471-476.
24. Saeid, M., William A., Poe J. and Speight, G. (2006). *Handbook of Natural Gas Transmission and Processing*. Gulf Professional Publishing, Oxford, United Kingdom.
25. Sanggyu I., Sung-heechoi, Yeongbeom I., Kyusang C. and Young-myung Y. (2011). The study on a new liquefaction cycle development for LNG plant. International Gas Union Research Conference, Seoul, Korea, October 2011.
26. Shoaib, T., Bhran, A., Awad, A. and El-Sayed, M. (2018). Optimum operating conditions for improving natural gas dew point and condensate throughput. *Journal of Natural Gas Science and Engineering*, 49: 324–330.
27. Siti, N. and Abdul G. (2012). Simulation of Typical Natural Gas Dehydration Unit using Glycol Solutions. *Engineering Reports* 8 (2): 27-31
28. Stewart, M. and Arnold, K. (2011). *Gas Sweetening and Processing Field Manual*. Houston: Gulf Professional Publishing, pp. 51–52.