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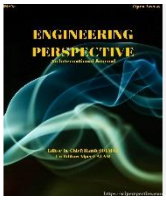

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Techno-Economic Analysis of a Natural Gas Dehydration System: A Case Study of an "X" Processing Plant in the Niger Delta

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ABSTRACT

The presence of water in the natural gas stream could cause pipeline corrosion, limit pipeline flow capacities, pipeline blockages and possible damage to process filters, valves, and compressors. The absorption gas dehydration system with Triethylene Glycol (TEG) as an inhibitor is the most widely used and reliable gas dehydration system for non-cryogenic pipeline operation. TEG losses have been a serious concern to the operation personnel in "X" dehydration Plant in the Niger Delta region of Nigeria.

This study therefore presents the economic analyses of gas dehydration by the introduction of a stripping (sales) gas to the TEG regenerator-reboiler to enhance the vapor separation and scrub off any gaseous impurities that may still exist in the rich TEG. The existing dehydration units were modeled and process parameters were simulated using Aspen HYSYS® software. An instance from the simulation results shows that, for a TEG flow rate of 0.4543 m^3/h, 97% of TEG was recovered. However, with the introduction of a dry natural gas to the reboiler, 99.98% of the TEG was recovered. This significant improvement, which represents 10.2 kg/h of TEG recovery, translates to a cost saving of approximately $89,352 per year.

Keywords: Gas processing plants; Niger Delta; TEG Absorption units; Gas Dehydration

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1. Introduction

Natural gas has residential and industrial uses. It is an energy source often used for heating, cooking, electricity generation and fuel for vehicles. Natural gas is also environmentally friendly. For instance, in electricity generation, natural gas burns cleaner than other fossil fuel such as oil and coal due to the fact that it produces less carbon-dioxide per unit energy released. For an equivalent amount of heat, natural gas produces about 30% less carbon dioxide than burning petroleum and about 45% less than burning coal [1].

Natural gases either from natural production or storage reservoirs contain water, which condense and form solid gas hydrates to block pipeline flow and especially control systems. Natural gas in transit to market should be dehydrated to a controlled water content to avoid hydrate as well as to minimize the corrosion problems. Natural gas processing consists of separating all of the various hydrocarbons and fluids from the pure natural gas [2].

Gas dehydration is one of the most prominent unit operations in natural gas processing facility where water is removed from the natural gas stream. The presence of water in the natural gas stream could cause pipeline corrosion, limit pipeline flow capacities, pipeline blockages and possible damage to process filters, valves, and compressors. This therefore can lead to increased maintenance cost and reduced line capacity [3]. As pointed out by Kidnay and Parish[4], to ensure smooth operation in downstream gas facilities: for example, gas pipeline usually requires 4-7 lb/MMSCF water content (87.2 - 152.6 ppm); for cryogenic unit (to produce Liquefied Natural Gas (LNG)), water content in gas shall be less than 1 ppm; for Compressed Natural Gas (CNG) plant, before entering compressor unit, water content shall be reduced to maximum 3 lb/MMSCF to meet product specification. Some of the methods of dehydration are as follows: direct cooling (refrigeration), adsorption, absorption, membrane processes [5].

The Absorption gas dehydration system with Triethylene Glycol (TEG) as the inhibitor is the most widely used and reliable gas dehydration system in upstream operations. With glycol absorption, it is possible to lower the water contents down to approximately 10 ppmvol, depending on the purity of the lean glycol [6].

Glycol losses are the losses of some glycol content used during dehydration [7]. Glycol losses can occur due to uneven contracting or too high a water content in the glycol mixture composition. The frequent occurrence of glycol losses in the gas dehydration process makes the unit less efficient. The safe limit of glycol losses set by the industry must not exceed is 0.01 – 0.15 gal/mmscf [8].

Several researches on the simulation of TEG dehydration systems considering numerous scenarios have been conducted; for example, the works of Marfo *et al.* [9], Salman *et al.* [10], Kong, *et al.* [11], Anyadiegwu *et al.* [12], Okafor, *et al.* [13], Chidiebere *et al.* [14], Neagu and Cursaru [15].

This work therefore presents techno-economic analyses of the impact of introducing a dry natural gas into regenerator reboiler to enhance the vapor separation to reduce TEG losses in "X" gas processing plant located in the Niger-Delta of Nigeria. Note that, TEG losses have been a concern to the operation personnels in "X" gas dehydration Plant, as 1.5 kg of TEG is lost per day. This translates to approximately 11 kg of TEG losses per week, which calls for action. The field covers an area of 365 x 250 gross m^2 and with a gas processing capacity of 125 MMSCFD. The "X" gas processing plant has three major functions: Process, monitor, control and deliver gases at the required specifications at Gas Transfer Point, recover condensate mixed with reservoir water and send to "X" Flow Station for treatment, and generate utilities like electricity and domestic water for others facilities.

Table 1. Operating conditions for the TEG dehydrating unit of "X" gas processing plant

Parameters	units	Value
Molar Flow	MMSCF/D	10.01
Mass Flow	kg/hr	9463
Pressure	bar	66.67
Temperature	^{0}C	30
Liquid Volume	Barrels/D	4317
Composition	CH_4-CH_{6+}, N_2, H_2O	See Table 2
Lean Glycol (TEG)	TEG	-
Lean TEG purity	wt%	≥ 99.5%
Lean TEG temperature	°C	50
Lean TEG pressure	bara	52.05
Contactor pressure	bara	66.07
Contactor gas temperature	°C	30
Glycol Temperature	°C	29.10

2. Data gathering, process description and methodology

2.1 Data description

Oil and gas field in the Niger-Delta in recent years have high water cut in the excesses of 22% [16]. The dataset used for developing the simulation for this study was obtained from the field operating manuals (describing the facilities - location, description, process data, reference documents, e.t.c) of "X" processing plant in the Niger-Delta region of Nigeria. The field covers an area of 365 x 250 gross m^2 and with a gas processing capacity of 125 MMSCFD. Table 1 and 2 show summaries of the operating conditions of the dehydration unit and the feed gas composition of the "X" Processing Plant.

Table 2. Feed Gas Composition

Component	Formulae	Mole Fraction
Methane	CH_4	0.8785
Ethane	C_2H_4	0.0602
Propane	C_3H_6	0.0256
i-butane	i-C_4H_8	0.0065
n-butane	n-C_4H_8	0.0078
i-pentane	i-C_5H_{10}	0.0026
n-pentane	n-C_5H_{10}	0.0019
C^{6+}		0.0018
Water	H_20	0.008
Nitrogen	N_2	0.0002
Carbon-dioxide	CO_2	0.0141
Total		1.000

2.2 Process description and methodology

Figure 1 shows the modelled, using an industrial software Aspen HYSYS [17], existing natural gas dehydration unit of "X" Processing plant located in the Niger-Delta region of Nigeria.

The feed gas was saturated with water through the feed gas saturator to achieve actual wet process conditions as shown in Table 1. The wet gas is sent to the absorber column (TEG contactor) where it's fed through the bottom at 30ºC and 60.67 barg and the lean glycol is fed at 50ºC and 62.02 barg at the top. As the glycol moves towards the bottom of the contactor, it comes into contact with and absorbs the water in the wet gas stream. The dry gas moves to the top of the contactor and leave the system for other processes.

Rich TEG, which has absorbed water from the gas stream, flows out of the dehydrator column at 28.44 °C and 62.05 barg, to the letdown valve (pressure control valve) where the pressure is reduced 1.790 barg before it enters the heat exchanger to avoid any safety concerns.

The glycol heat exchanger pre-heat the rich TEG to 106.0 °C and 1.16 barg before it enters the TEG regenerator. The glycol heat exchanger is a tubular heat exchanger using hot lean glycol from the stripping column as heating medium (shell side). Rich glycol (tube side), enters the heat exchanger at 34.6 °C and leaves the glycol/glycol heat exchanger at 106.0 °C.

The glycol regeneration section consists of the main steel column, an overhead condenser, and a reboiler whose function is to regenerate the glycol to a high purity so that it can be recirculated to the absorber to continue its dehydration function. In the reboiler, the rich glycol is heated 198.9°C to near its boiling point enabling it to release virtually all of the absorbed water and any other compounds. The main steel column is packed with random packing to ensure good contact between vapor and liquid phases. The generated vapours pass up the rich glycol steel column along with any volatile material and are contacted with liquid traveling down the column.

The glycol is sent to the surge drum, the glycol surge drum provides a buffer volume for circulating glycol. The lean glycol is cooled again with a trim cooler before being fed back into the absorber. The condenser cools the vapor leaving the main steel column and condenses any glycol vapours to liquid. The water remains as vapours and exits the column at the top.

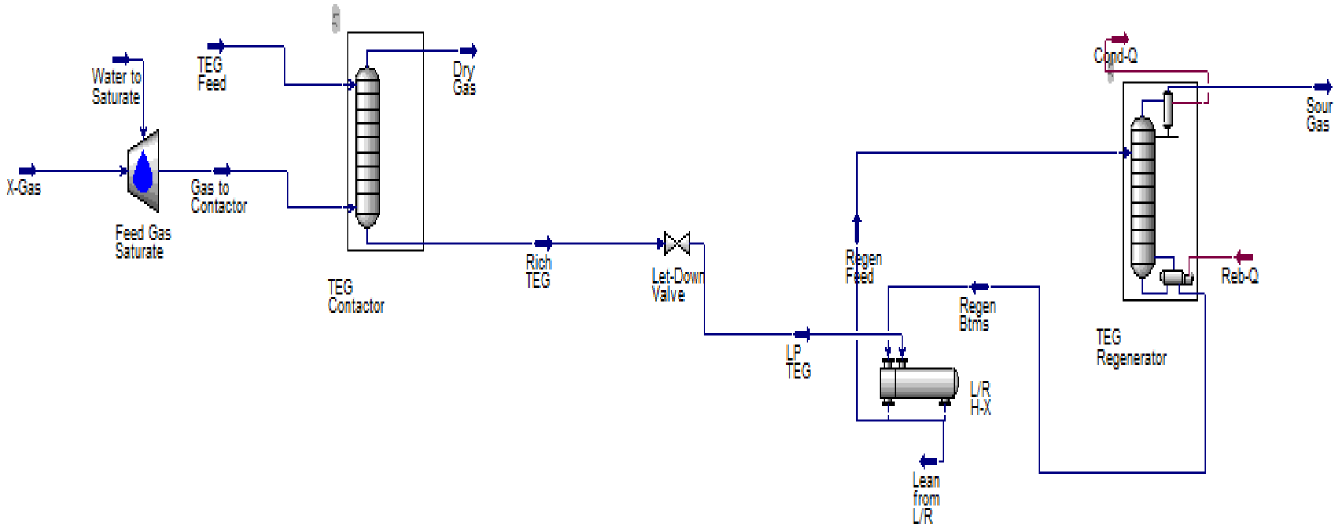

Figure 1. Model of the existing TEG dehydration unit of the “X” gas processing plant.

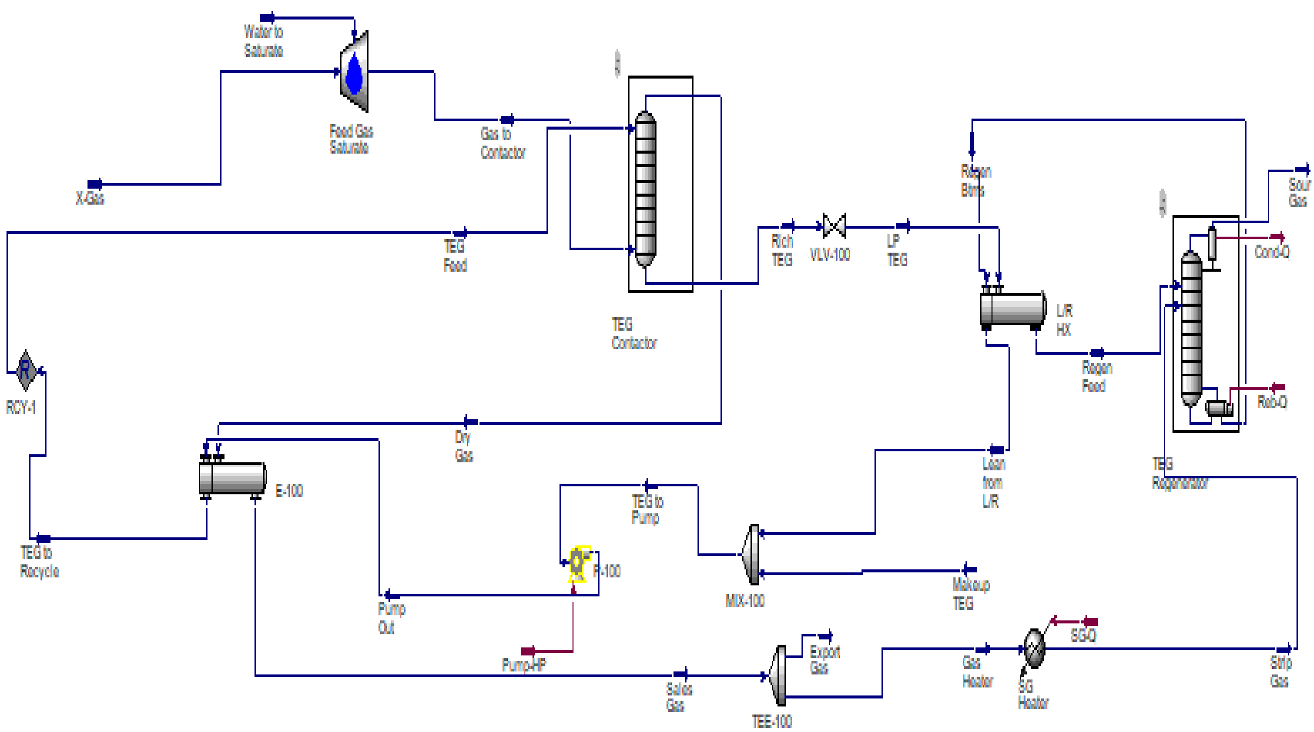

Figure 2. Modified TEG dehydration unit of “X” gas processing plant.

2.2.1 Process modification and analyses

To enhance the performance and maximize the potential benefits of the dehydration unit, the existing (base) model was modified by the introduction of a stripping gas to the TEG regenerator reboiler to enhance the vapor separation and scrub off any gaseous impurities that may still exist in the rich TEG. Figure 2 shows the modified process flow model of the natural gas dehydration unit.

The TEG recovery of both the base and the modified models were then analyzed by comparing the TEG recovery rates. Peter *et al.* [18] maintained that sensitivity analysis can help researchers prioritize research needs and to better understand the tradeoffs associated with achieving higher system efficiencies by increasing operating temperatures or by increasing specific component efficiencies. The effects of some input variables; the feed gas flow rates, TEG flow rates and dry gas flow rates, on the output variable; TEG recovery weight, were therefore analyzed.

2.3 Economic analysis

Natural gas processing facilities are capital projects and would require large commitment of funds. Its impact on the financial wellbeing of an organization extends over a long period. It is therefore necessary that operation and maintenance cost of the dehydration unit does not exceed its value [19]. In this work, break-even analysis (BEA) and the annual cost savings from the glycol recovery to determine the time (years) when the investment decision to modified the process of the dehydration unit of "X" processing plant becomes viable was used.

The costing of the dehydration unit of "X" processing plant considered was primarily the equipment cost, operating cost and installation cost used for the modification of the dehydration unit. The equipment cost comprises: valves, piping, process and instrumentation equipment used for the upgrade of the unit. The prices were verified from Croft Production Systems, a leading company involved in the designing, building and maintenance of dehydration units and oil gas equipment. The installation and operating cost estimates were collected from the Site Manager of "X" processing plant. See Table 3 for the costing summary.

Table 3. Cost summary for the dehydration unit

Cost Item	Amount ($)
Equipment Cost	600,000
Installation Cost	50,000
Operating Cost	10,000
Total	660,000

The economics of the amount of TEG that was recovered yearly from the simulation model of the existing dehydration unit was then compared with the modified model, using Eq. (1) and Eq. (2).

$$SCost = (Vol.\ \ RRTEGwStrippingGas\ \ x\ \ CostTEG) - (Vol.RRTEGwoStrippingGas\ \ x\ \ CostTEG) \quad (1)$$

$$AScost = 365\ \ x\ \ SCost\ \ for\ \ mass\ \ flow\ \ rate \quad (2)$$

3. Results and discussion

3.1 Technical analysis

The simulation results were based on the following variables; hydrate formation temperature, hydrocarbon dew points, water content, TEG losses and TEG recovery.

The dependent parameters/variables i.e. the water content, dew point and hydrate formation temperature of the saturated and dry gas are presented in Table 4. The effectiveness of the model was validated by comparing the dependent parameters of the saturated inlet feed gas and dehydrated dry gas.

According to Marfo, *et al*. [9], the standard water content requirement for natural gas is 6- 7lb/mmscf. This criterion was also used to validate the effectiveness of the simulation model.

From the dependent parameters presented in Table 4, it can be seen that the water content of the gas was reduced from 39.52 Ib/MMSCF to 4.73 Ib/MMSCF. Based on the simulation results obtained, the composition mass fraction of TEG without stripping gas was 0.9891 compared to 0.9996 obtained when the dry gas was introduced.

Table 4. Results of both the saturated and dry gas of the Model

Dependent variables	Saturated Gas	Dry Gas
Water content (lb/MMSCF)	39.52	4.73
Dew point temperature (^{0}C)	30.00	-66.47
Hydrate formation temperature (^{0}C)	17.4851	-48.6265

The Initial TEG flow rate from the design is 68.56 bbl/d, which translates to 0.4543m^3/h (2 gallons per minutes (GPM)). The density of the TEG is 1100kg/m^3. Therefore, applying Eq. (3), the mass flow rate of TEG is 499.7 kg/h.

$$e = m/v \quad (3)$$

where, e is the density of TEG, m denotes the Mass flow rate, v is the volumetric flow rate.

TEG recovery rate for the existing case= 0.9791 x 499.7 kg/h = 489.3 kg/h.

TEG recovery rate for the modified case= 0.9996 x 499.7 kg/h = 499.5 kg/h.

Therefore, the extent of the improvement in the amount of TEG recovery rate

= 499.5 - 489.3 kg/h = 10.2 kg/h.

The TEG recovery rate of 10.2 kg/h shows the significant improvement in the amount of TEG recovered by introducing a stripping gas to the TEG regenerator reboiler. The physiochemical properties (i.e. hydrate formation temperature, hydrocarbon dew points, water content) of the dry gas were also improved.

Some glycol negligible losses of 0.0004 mass in fraction still exist in the dehydration unit. Therefore, the actual TEG recovery rate for the existing simulation model = 0.0004 x 499.7 kg/h = 0.19988 kg/h = 4.797 kg/d = 1751 kg/Year.

3.1.1 Parametric analysis

This analysis examines the relative importance of the selected process feed (input) parameters to the determination of target (output) variable of TEG recovery. Different case studies were modelled. The summaries of the results are shown in Table 5 and Figure 3, for the effect of TEG rates on TEG recovery; Table 6 and Figure 4, for the effect of stripping gas volume on TEG recovery; Table 7 and Figure 5, for the effect of feed gas rates on TEG recovery.

Table 5. Effect of TEG rates on TEG Recovery

TEG Rate (m^3/h)	TEG Recovery (kg/h)
0.45	0.989070412
0.55	0.989079363
0.65	0.989088029
0.75	0.989088374
0.85	0.989091836
0.95	0.989096694

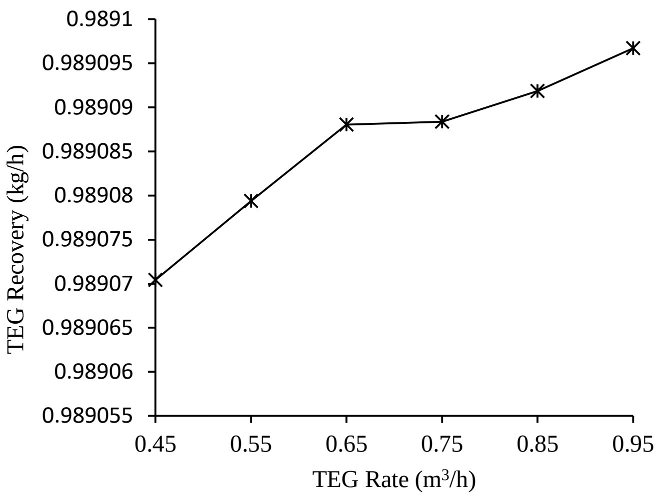

Figure 3. Plot of TEG rates and TEG recovery

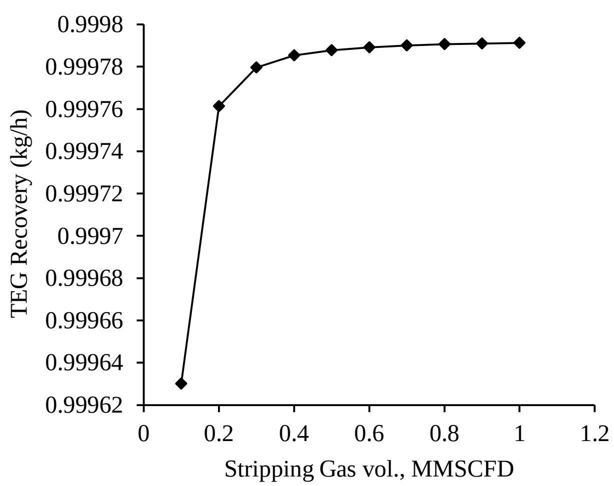

Figure 4. Plot of stripping gas volume and TEG recovery

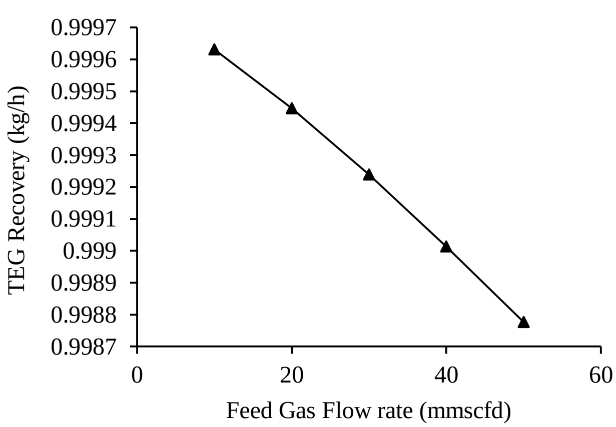

Figure 5. Plot of feed gas rates and TEG recovery

The results of sensitivity analyses indicate that there is a positive relationship between TEG rate and TEG recovery. There is a noticeable increase in the TEG recovery as the TEG rates is increased from 0.45 m^3/h to 0.65 m^3/h and from 0.75m^3/h to 0.95 m^3/h. However, there was a fairly constant TEG recovery between 0.65 m^3/h. and 0.75 m^3/h flow rate, as shown in Figure 3.

Table 6. Effect of stripping volume on TEG Recovery

Stripping Gas Vol. (MMSCFD)	TEG Recovery (kg/h)
0.1	0.999630046
0.2	0.999761265
0.3	0.999779633
0.4	0.999785328
0.5	0.99978785
0.6	0.99978921
0.7	0.999790038
0.8	0.999790586
0.9	0.999790972
1	0.999791256

Looking at the plot of stripping gas volume and TEG recovery in Figure 4, there is a steady increase in TEG recovery as the stripping gas volume is increased from 0.1 to 0.5 MMSCFD with a little or no further TEG recovery was achieved at stripping gas volume between 0.5 and 1 MMSCFD, see Figure 4.

Table 7. Effect of Feed gas rates on TEG Recovery

Feed Gas Rates (MMSCFD)	TEG Recovery (kg/h)
10	0.999631538
20	0.999446588
30	0.99923922
40	0.999013694
50	0.99877634

From the plot of Feed gas rate and TEG recovery in Figure 5, a negative relationship is observed. There is a sharp decrease in the TEG recovery as the feed gas rates is continuously increased between 10 MMSCFD and 50 MMSCFD.

3.2 Economic analysis

According to Adeogun and Iledare [20], various profitability measures have been developed to aid decision makers choose between several investment alternatives; these measures help rank a projects' profitability based on the profitability measures. The economic analysis of the dehydration unit of processing plant was therefore performed using the TEG recovery rate and the annual cost savings. Break-Even Analysis (BEA) was used to determine when viability of the investment decision. The primary concern of the management of "X" processing plant is to reduce the TEG losses and the yearly cost implications. The cost of 1kg of TEG at the international market of approximately $1 has been considered.

Therefore, the cost of TEG recovery rate (489.3 kg/h) of for the existing (base) case = $489.3/hr.

The cost of TEG recovery rate (499.5 kg/h) for the modified case = $499.5/h

Hence, the cost savings = $499.5/hr - $489.3/hr = $10.2/hr =

\$244.8/d = \$89,352/Y

Cost of glycol losses that still exist in the dehydration unit = 0.19988 kg/h = \$0.19988/h = \$4.797/d = \$1751 /Y.

3.2.1 Break-even analysis

The Break-Even Analysis (BEA) was done by comparing the modification cost and the yearly cost savings from TEG glycol recovery of the improved dehydration unit to determine the break-even time (BET). The modification cost is a one-time capital investment, which is added to the yearly acceptable glycol losses that still exist in the gas dehydration unit, as represented in Table 8. The BET is the time (in years) where the savings from glycol recovery equals the modification cost. The investment decision to upgrade the dehydration unit of "X" processing plant becomes viable after the BET.

Table 8. Break-even analysis of modification cost and glycol cost savings

Break-Even Time(Y)	TEG Glycol Losses (in \$)	Modification Cost (in \$)	TEG Glycol Cost Savings (in \$)
1	1,751	660,000	89,352
2	3,502	663,502	178,704
3	5,253	665,253	268,056
4	7,004	667,004	357,408
5	8,755	668,755	446,760
6	10,506	670,506	536,112
7	12,257	672,257	625,464
8	14,008	**674,008**	**714,816**
9	15,759	675,759	804,168
10	17,510	677,510	892,520

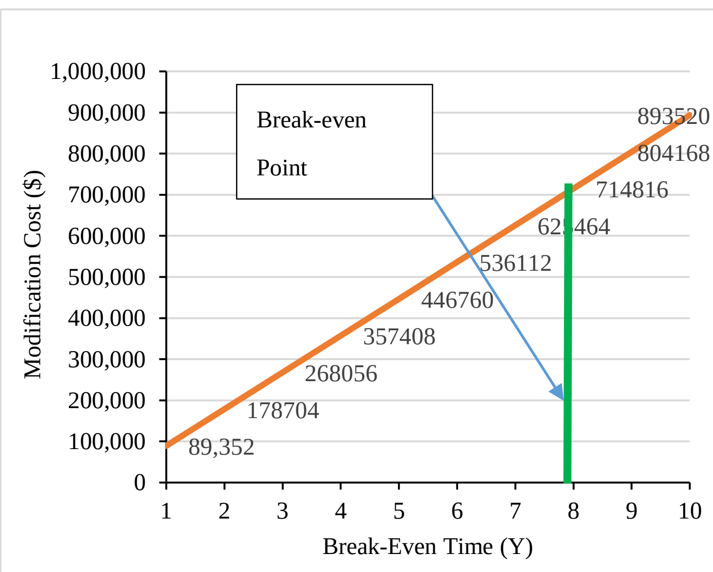

Figure 6. Plot of Modification cost and break-even time

From Figure 6, the break-even point (BEP) is after year 8. This represents the point at which the yearly cost savings from glycol recovery equals the cost of upgrading the dehydration unit by the introduction of a dry gas to the TEG regenerator reboiler to enhance the vapor separation. Beyond the break-even point, the investment decision to upgrade the existing dehydration unit becomes a viable investment decision.

4. Conclusions

A techno-economic analyses of the impact of introducing a dry natural gas into regenerator reboiler to reduce TEG losses in the absorption system of "X" gas processing plant located in the Niger-Delta of Nigeria has been performed. Although, the modification of the existing dehydration unit is capital intensive, the investment decision to upgrade the existing gas dehydration unit becomes viable after the Break-Even Point (BEP). The following conclusion can be drawn from this research;

- the modified model of introducing a dry gas to the reboiler of TEG regenerator has improvement on the glycol recovery of the dehydration unit by 10.2 kg/h, which translate to a cost saving of approximately \$89,352 per year.
- the target parameters of the modified model were all improved, and the water content value of 4.73 lb/MMSCFD of the dry gas is within the standard limit of 6-7 lb/MMSCFD for pipeline transport.
- TEG losses still exist in the gas dehydration unit but it is considered negligible.
- the sensitivity analysis of the stripping gas volume and the TEG recovery rate shows that there was a steady increase in TEG recovery as the stripping gas volume was increased from 0.1 to 0.5 MMSCFD and a constant TEG recovery was achieved at stripping gas volume between 0.5 and 1 MMSCFD.

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Nomenclature

e	TEG density (kg/m^3)
m	TEG mass flow rate (kg/h)
v	TEG volumetric flow rate (m^3/h)
$SCost$	Saved cost (\$)
$AScost$	Annual saved cost (\$)
TEG	Triethylene Glycol
BEP	Break-even point

Conflict of Interest Statement

The authors declare that there is no conflict of interest in the study.

CRediT Author Statement

Musa Shittu: Conceptualization, Data collection, Simulation, Writing-original draft, Writing-revised draft. **Aniefiok Livinus:** Supervision, Writing-revised draft, Editing.

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