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Retrofitting Recycled Stripping Gas in a Glycol Dehydration Regeneration Unit

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Abstract

Natural gas dehydration is essential in gas processing to avoid serious problems. As a pretreatment in a cryogenic Natural Gas Liquid (NGL) recovery process, it typically uses triethylene glycol (TEG) and followed by a Molecular Sieve dehydration to achieve 1 mg/Sm^3 of water moisture in the dehydrated gas. This work studied the retrofitting of the existing dehydration unit to improve its performance in satisfying the gas moisture qualities. The retrofitted process uses recycled stripping gas schemes to achieve high purity TEG while minimizing the use of fresh stripping gas. The results revealed that the recycled stripping gas has provided sufficiently high purity TEG (>99.99%-wt), significantly reduced the heating and cooling duty by 80%, and reduced the electrical duty by 29% compared to the base case. The TAC was reduced by 38.1% from $ 725,245 /year to $ 448,670 /year. Through this study, the evaluated cases provide similar dehydration results with less equipment, a simpler process, and better economic numbers. Therefore, a more energy-efficient process was obtained.

Keywords: dehydration unit, high purity TEG, recycled stripping gas, retrofitting, total annual cost

1. Introduction

Natural gas is typically saturated with water as it is produced from the wells. The water content has to be removed to meet the sales gas qualities. In gas processing, dehydration is intended to avoid problems associated with the formation of gas hydrate under certain operating conditions. Another reason to dehydrate the gas is to minimize water condensation in the gas transmission pipeline. The dehydration can be accomplished through solvent absorption, solid adsorption (molecular sieve), and gas condensation using refrigeration.

The maximum water content allowed in the natural gas varies depending on few aspects, whether the natural gas is to be transported via pipeline or to be fed to a Natural Gas Liquids (NGL) recovery process. Typical water content specification for sales gas pipeline varies depending on the location, 7 lb/MMscf (112 mg/Sm^3) for US pipeline, 4 lb/MMscf (64 mg/Sm^3) for Canadian pipeline, and even lower 1 lb/MMscf (16 mg/Sm^3) for the pipeline in Alaska. These values are intended to protect the natural gas from water condensation and hydrate formation during winter (1). To achieve the water content specification of 112 mg/Sm^3, the gas can be dehydrated using Tri-ethylene Glycol (TEG) absorption with a conventional regeneration system in which the rich glycol is regenerated at near atmospheric pressure and a reboiler temperature of 204^{o}C. This setup can provide a TEG purity of approximately 98.6%-wt. Higher purity of TEG requires a reduction of the partial pressure of water in the regenerator. This can be achieved by vacuum distillation or using a stripping gas. The stripping gas mechanism can also be employed in which the addition of a dry vapor stream was used to remove a component from a liquid solution, in this case: removing water from the TEG solution. The additional vapor stream will decrease the partial pressure of water in the vapor and therefore lowering the mole fraction of water in the liquid phase, hence increasing the TEG purity. A comprehensive review of the available methods for regenerating TEG to achieve certain TEG purity is elaborated (2). There are some alternative processes such as using stripping gas with or without the Stahl column. The source of stripping gas can be taken from a portion of dried natural gas, using external gas source (e.g. nitrogen), or using pentane, hexane, heptane, or other volatile hydrocarbons such as the DRIZO process. Another method uses a water exhauster principle like Coldfinger technology. Lower water content is required for the NGL recovery using a cryogenic process to avoid hydrate formation problems, sometimes as low as 0.1 mg/Sm^3 may be required. This is typically achieved using molecular sieve adsorption units (3).

Adsorption method for reducing water vapor content in natural gas is a semi-batch process; therefore at least two drier beds are required to accomplish the dehydration process. One bed is in adsorption mode while the other bed is either in regeneration mode or cooling mode (3). The adsorption bed will adsorb water until it reaches its saturation. It needs to be regenerated to refresh its adsorption capacity. Typical regeneration is accomplished through the application of heat. The heated regeneration gas is routed to the regeneration bed via a compressor. The major operating costs of this adsorption dehydration are required for heating and the compression power of the regeneration gas (4). Netusil and Ditl (2011) compared the energy requirements among the absorption dehydration, adsorption dehydration, and the condensation method. The adsorption method typically uses almost two times the energy required by the absorption dehydration method (5). To reduce the size of the mole sieve adsorption unit, a glycol dehydration unit is typically used as bulk water removal. It is followed by a mole sieve unit to achieve the final water moisture target (3). Another aspect in the application of molecular sieve dehydration is that overtime the solid drier bed will lose its capacity due to repetitive heated regeneration cycle. It is common for molecular sieve to have 35% capacity loss over a 3 to 5 year period or approximately 50% loss after 1,600 cycles (4). Therefore, alternative processes for dehydration of natural gas to ppm-level using enhanced TEG dehydration may be considered. This may be achieved through retrofit the existing TEG conventional unit with additional equipment required to achieve higher TEG purity.

A screening method for the retrofit options was developed by Uerdingen et al. (2003) which was organized in three steps: (a) analyze the base case, (b) generate retrofit options, and (c) generate a rough economic evaluation of the retrofit options (6). Further study by Uerdingen et al. (2005) elaborated a systematic method for evaluating retrofit options targeted at improving the cost-efficiency of a continuous process. In addition to the previous three steps, there are two additional steps, namely, generate process optimization without additional investment, and carry out a feasibility study of the retrofit options with additional investment.

There are some recent studies on the technical and economic review of enhanced glycol dehydration. Saidi et al. (2014) studied the use of volatile hydrocarbons as the stripping agent in the regeneration process such as DRIZO process. They simulated different solvents (n-heptane, iso-octane, Benzene / Toluene / Ethyl benzene / Xylene (BTEX) compounds, and a mixture of 50% n-heptane / 50% iso-octane) and varied its mass flow to improve the TEG concentration. The performance of the regeneration system was also reviewed in terms of TEG losses. The DRIZO process also compared to the stripping gas configuration using a portion of dried natural gas. The purity of TEG that could be produced with the DRIZO process was 99.63-99.85%-wt. The TEG losses in the DRIZO process were reported less than the one with stripping gas injection process. The study elaborated on the incremental total capital investment required for the modification of the existing process to include the DRIZO process, which was reported to be $2.406 million (7). However, the difference in the operating cost between the stripping gas injection and the DRIZO process was not explored. Kong et al. (2020) conducted the development of a framework to compare the DRIZO based regeneration system to other dehydration processes. They revealed that the DRIZO process in their study was not economically feasible because of the high capital expenditure increment along with its higher electricity cost. They concluded that the stripping gas dehydration process using a portion of dried natural gas can achieve the desired water dew point specification while generating the highest gross profit margin (8). Rahimpour et al. (2013) investigated the performance of the regeneration process using Coldfinger technology. They concluded that by increasing the stripping gas temperature and its flow rate will enhance TEG purity in the regeneration process. A concentration of TEG up to 99.86%-wt could be achieved. They did not review the operating and capital costs associated with the Coldfinger process (9). Gad et al. (2016) compared the use of two different stripping agents, i.e. dry natural gas and nitrogen gas to achieve higher TEG concentration in the regeneration process. Both stripping gas processes could regenerate up to 99.7%-wt TEG. The study revealed that it is more economical to use natural gas. The process configuration used less natural gas for stripping gas, therefore, lowering the utility costs by 1.4%. The capital cost differed by less than 2% (10). However, there were no calculation details on utility costs and capital investment. Neagu and Cursaru (2017) evaluated the performance of regeneration with stripping gas. They compared it to the performance of the conventional dehydration. The various flow rates of stripping gas were studied to increase TEG purity. Their study concluded that higher TEG concentration could be increased to 99.22-99.85%-wt using stripping gas configuration. The water dew point of -24.94^{o}C could be achieved using the 99.22%-wt TEG. The incremental capital investment is only about 2% higher than the conventional unit. The total cost of production (TCOP) of the stripping gas configuration is slightly lower ($3,216,669/year) if compared to the conventional unit ($3,223,975/year) (11). Chebbi et al. (2019) used a parametric optimization analysis to fulfill the water dew point requirement. The glycol circulation rate, the flow rate of stripping gas, as well as the operating pressure and temperature were varied. The TEG purity studied was 98.5, 99.0, and 99.5%-wt. They also evaluated the capital and operating cost of the dehydration process, both the conventional and the stripping gas injection. The incremental capital cost of the stripping gas injection process was less than 1% compared to the conventional process (12).

The annual cost of the stripping gas, however, was approximately 20% higher than the conventional process. Kong et al. (2018) studied the use of two different stripping gas agents, i.e. a portion of dried natural gas and nitrogen to achieve the dehydration target, i.e. water dew point of -25^{o}C. They investigated the comparison of the annual profit margin between the two processes, i.e. gross profit minus the total cost of production (13). It was indicated that higher net profit could be achieved by using the portion of dried sales gas. Affandy et al. (2020) reviewed the study to improve the dehydration unit's performance that uses the flash gas as a source of stripping gas injection to the regenerator. The TEG purity of 98.8%-wt could be achieved by this modification. The proposed modification can meet the sales gas specification and has a 20% reduction in Total Annual Cost (TAC), compared to the base case (14).

Only a few studies were reviewing the use of an enhanced TEG regeneration system to dehydrate the natural gas down to ppm-level. Smith and Humphrey (1995) studied a two-tower TEG absorption configuration to achieve ppm-level of water moisture in natural gas. They used a DRIZO based regeneration system to achieve a high purity of TEG. A simple economic comparison between DRIZO and the Solid Bed dehydration was presented in the study. The DRIZO process has net present value (NPV) approximately 11% lower than the solid bed dehydration (15). Skiff et al. (2002) investigated that a DRIZO based dehydration had a capital cost of approximately 60-70% of comparable solid bed desiccant units (16).

In this work, we develop the simulation of conventional TEG dehydration by using TEG. The Molecular Sieve dehydration was sized according to the method developed by Gandhidasan et al. (2001) (17). The block diagram of the natural gas processing is depicted in Figure 1. The combination of the TEG conventional system and the Molecular Sieve dehydration system is the process intensification target in this study. An enhancement in the TEG dehydration using a regeneration system was developed, mainly using the stripping gas concept to replace the function of the molecular sieve dehydration system. The recycled stripping gas is used to reduce the amount of fresh stripping gas source at the expense of higher capital expense required for the additional equipment in the TEG regeneration system. Higher TEG purity was expected to achieve the ppm-level of water moisture in the dried natural gas. A water dew point of -60^{o}C was also targeted. The TAC of the enhanced process will be calculated, and compared to the conventional unit and molecular sieve dehydration.

2. Process Description

2.1 Absorption Dehydration

A contactor is used to contact the wet gas containing water vapor with a lean TEG solution counter currently. The wet gas enters the column from the bottom part while the lean TEG from the top part of the TEG Absorber. The dehydrated gas comes out from the top of the contactor. The rich glycol that has higher water content is routed to the Regeneration system. Figure 2 depicts the flow diagram used in this work. The gas composition along with the other process operating parameters are described in Appendix A. The maximum water vapor content in the contactor gas outlet is 110 mg/Sm^3 (7 lb/MMSCF). The dehydrated gas is routed to the Molecular Sieve dehydration unit to be dehydrated further down to 1 mg/Sm^3 before entering the NGL Recovery section (3).

The rich glycol coming out from the TEG Contactor is routed to a TEG Flash Drum where the light hydrocarbon flashes out from the rich glycol solution. The flashed gas can be vented, flared, or be used as a stripping gas16. The rich glycol is then routed to the glycol-glycol heat exchangers to improve the heat recovery. After the preheating process, the rich glycol enters a reboiled stripper operated near atmospheric pressure (105 kPa) and operated at 200^{o}C in the reboiler. The overhead vapor products are the water vapor and some amount of TEG. The lean TEG that contains a small amount of water coming out from the bottom of the regenerator. The lean TEG is recirculated back to the TEG Absorber for subsequent dehydration process, via glycol-glycol exchanger and lean TEG cooler.

2.2 Molecular Sieve Dehydration

The Molecular Sieve dehydration in this study uses three towers for achieving the dehydration targets. Two towers will be in “Adsorption” mode, while the other one will be either in “Regeneration” mode or “Cooling” mode. The process flow diagram is depicted in Figure 3, for 2 (two) towers in Adsorption and 1 (one) tower in Heating/regeneration mode. The other operating mode is depicted in Figure A1 (Appendix A) that resembles the 2 towers in Adsorption and 1 tower in Cooling mode. The time required for each sequence is explained in Figure A2 (Appendix A). The regeneration gas was taken from the dried gas. A small slipstream (about 5% of the incoming gas) is heated in the Regen Gas Heater to 300^{o}C which is then routed to the tower that is in “Regeneration” mode. The regeneration cycle lasts for 12 hours and then followed by the “Cooling” mode for another 12 hours. During the “Cooling” mode, the Regen Gas Heater was shut-off and bypassed, allowing the cool dried gas to the bed after the “Regen” mode.

3. Method

The TEG dehydration units were modeled in the ASPEN HYSYS V10 using the Cubic-Plus-Association (CPA) property package (18). The molecular sieve adsorption units were calculated and sized according to the method developed by Gandhidasan (2001). The results were compared and checked using the sizing method by Campbell (2004) (19).

The main types of equipment involved in both TEG and molecular sieve dehydration units were sized. The results were then used to estimate the capital cost required for each case. The main parameters used in this paper to determine the operating cost were based on the methods developed by Luyben (2011) (20). Table B1 and B2 in Appendix B summarize the formulas used in this work to determine the TAC calculations.

In this work, the total operating cost (TOC) covers the utility cost, chemical/consumables cost, and stripping gas cost. The utility cost consists of heating medium and cooling water costs. The chemical/consumables cost consists of TEG make-up cost and desiccant cost. The total capital cost (TCC) was built from installed costs of the columns (TEG Absorber, Stripping Gas Absorber, and Regenerator column), pressure vessels (flash drum, molecular sieve towers, overhead drum, recycle gas suction/discharge scrubbers), heat exchangers, coolers, heaters, and compressor. The TAC is the sum of TOC and TCC divided by small payback (PB) period (20).

There are few process configurations to enhance the TEG purity in the dehydration units that were evaluated in this work. Figure 4 depicts the configuration where the stripping gas used was recycled using the Recycled Gas Compressor. The stripping gas was also dehydrated using part of the lean TEG (about 0.5 m^3/h) in the Stripping Gas Absorber. The stripping gas source can be taken from dehydrated gas or using an external nitrogen source. The amount of stripping gas recycled was varied from 60-90%. Figure 5 depicts the configuration that very similar to Figure 4 with the exception that the Flash Gas been re-routed to the Stripping Gas recycle system. This configuration uses the dehydrated natural gas as the stripping gas source.

All process configurations were evaluated to provide the gas outlet from TEG Absorber having water vapor moisture quality and the water dew point that are similar to the outlet from the Molecular Sieve dehydration unit. In this work, the targets are to have maximum water vapor moisture of 1 ppmv (or 1 mg/Sm^3) and the maximum water dew point of -60^{o}C.

4. Results and Discussion

The simulation and the economic evaluation results are presented for each case. The high-level summary of the process simulation results was tabulated in Table 1 below. Further detailed results were provided in Appendix A. The reported numbers are describing the case with the inlet gas flow rate of 4.20 x 10^6 Sm^3/d and at operating pressure and temperature of 6000 kPa and 30^oC respectively. The lean TEG flow rate for all cases (base case and evaluated cases) were set at the same rate of 5 m^3/h. Table 1 describes that both water vapor moisture and water dew point targets can be satisfied by the evaluated cases using a similar TEG circulation flow rate (5.0 m^3/h) with relatively high purity of TEG (99.993 %-wt). Therefore, it can be nominated to replace the function of Molecular Sieve dehydration units, provided that it has competitive TAC.

The energy requirements to complete the dehydration process are presented in Table 2. It can be seen that the base case requires 8.513 GJ/h whereas the evaluated case requires much lower energy of 1.658 GJ/h. The large energy consumptions for the base case are the heating and cooling duty of approximately 3.55 and 3.28 GJ/h, respectively. This is due to the requirement of regeneration gas heating from 40^oC to 300^oC and gas cooling from 290^oC to 40^oC.

The regeneration gas compression takes approximately 0.121 GJ/h. The largest heating duty (approximately 0.64-0.69 GJ/h) is used in the reboiler. The important operating parameters in the evaluated case are the overhead vapor cooler outlet and recycled gas compressor after cooler temperatures. The former was set on 75^oC to maximize the condensation of TEG without condensing the heavy hydrocarbons from the overhead vapor stream. The latter was set on 40^oC to maximize water condensation to minimize the water load to the Stripping Gas Absorber. The setup was intended to minimize the TEG losses from the regeneration system. The recycled gas compressor was set to have a discharge pressure of approximately 250 kPa. This pressure ratio of 2.5 will give a discharge temperature not more than 160^oC.

The difference between the two evaluated cases is mainly in the amount of stripping gas required as can be seen in Table 3. It requires approximately 440-520 kg/h of stripping gas for a 5m^3/h lean glycol circulation rate to satisfy the water dew point and the water moisture content in the dried gas. The requirement of fresh stripping gas is decreased by approximately 29% since the flash gas is used to supply the stripping gas. Another aspect is the TEG losses, which can be traced to the losses through the absorber gas outlet, the flash gas, and the regeneration side. Table 4 shows only a small (<5%) difference in glycol losses between the two evaluated cases.

4.1 Base Case: Total Annual Cost Calculation

The Total Annual Cost required by the Base Case, i.e. the TEG conventional unit and Molecular sieve dehydration unit, were tabulated in Table 5. Further details on the TAC calculation were provided in Appendix C.

It can be seen that the molecular sieve has a Total Capital Cost approximately two times of the TEG conventional unit. This mainly caused by the molecular sieve unit that uses 3 towers. It also requires large capital for the Regeneration Gas Heater and Regeneration Gas Compressor. The Total Operating Cost of the mole sieve dehydration is also much larger than the TEG conventional unit, mainly contributed by the heating and cooling costs for the required regeneration gas.

4.2 Evaluated Cases: Total Annual Cost Calculation

There are two cases evaluated in this work, which are tabulated in Table 6 below. Again, further details on TAC calculation results were provided in Appendix C. It can be noticed from Table 6, that the evaluated cases have a higher capital cost compared to the TEG conventional unit ($574 326 vs. $403 944). This additional cost ($170 382) can be expected as the evaluated cases use some additional types of equipment to operate the recycled stripping gas such as Recycled Gas Compressor, Scrubbers, Stripping Gas Absorber, as well as coolers and heaters. However, the required TCC is still much lower than the combined TCC of TEG Conventional unit and molecular sieve dehydration unit ($1 245 598).

The required Total Operating Cost of the evaluated case is also lower than the combined TOC of TEG conventional unit and molecular sieve dehydration unit ($257 288 vs. $310 046). Finally, the calculated TAC of the evaluated cases is much lower than the Base Case ($448 670 vs. $725 245).

5. Conclusions

Steady-state simulations of the gas dehydration units have been evaluated in this study. They consist of the conventional TEG dehydration followed with molecular sieve dehydration (Base case), and the enhanced TEG dehydration which employs recycled stripping gas to achieve high purity of TEG (Evaluated case). The Total Annual Cost for both Base and Evaluated Cases were evaluated. The evaluated cases were able to provide the gas outlet quality in terms of water vapor moisture of 0.16 mg/Sm^3 and water dew point of -70.0^{o}C which are very similar to that of the base case using Molecular Sieve unit. The economic evaluation using simple TAC calculation also indicated that the evaluated cases have 38% less TAC than of the base case TAC ($448 670 vs. $725 245). The evaluated cases provide similar dehydration results with less equipment, a simpler process, and better economic numbers. Therefore, a more energy-efficient process was obtained.

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Appendix A

Table A1. Gas composition used in this study

Component	Volume fraction
CO_2	0.0267
N_2	0.0183
methane	0.8319
ethane	0.0530
propane	0.0366
i-butane	0.0100
n-butane	0.0116
i-pentane	0.0042
n-pentane	0.0028
n-hexane	0.0017
n-heptane	0.0007
n-octane	0.0002
n-nonane	0.0001
n-decane	0.0000
C_{11+}	0.0000
H_2O	0.0022
Total	1.0000

Table A2. Operating parameters for the absorption dehydration (conventional)

Input Data	Unit	Min.	Max.
Gas flow rate	10^6 Sm^3/d	1.42	4.20
Absorber pressure	kPa	4500	6000
Absorber temperature	^oC	30.0	40.0
Lean TEG pressure	kPa	4600	6100
Lean TEG temperature	^oC	35.0	45.0
Lean TEG purity	%-wt	98.6	98.6
Lean TEG flow rate	m^3/h	2.0	6.0

Energy consumption	Unit	Value
Reboiler	GJ/h	0.690
Lean TEG Cooler	GJ/h	0.163
Rich Glycol Heater	GJ/h	0.286
Regen Overhead Cooler	GJ/h	0.229
Recycled Gas Comp Cooler	GJ/h	0.000
Stripping Gas Heater	GJ/h	0.000
TEG Circulation Pump	GJ/h	0.044
Recycled Gas Compressor	GJ/h	0.000

TEG losses	Unit	Value
From TEG Absorber	kg/h	0.151
From Flash Drum	kg/h	0.026
From Overhead Regenerator	kg/h	0.099
Recycled Gas Discharge Scrubber	kg/h	0.000

Table A3. Operating parameters for the molecular sieve dehydration

Input Data	Unit	Min.	Max.
Gas flow rate	10^6 Sm^3/d	1.42	4.20
Pressure	kPa	4300	5700
Temperature (Absorption mode)	^{o}C	30.0	40.0
Temperature (Regeneration mode)	^{o}C	280.0	290.0
Regeneration gas flow rate	10^6 Sm^3/d	0.142	
Regeneration gas temperature	^{o}C	300.0	

Energy consumption	Unit	Value
Regeneration Gas Heater	GJ/h	3.550
Regeneration Gas Cooler	GJ/h	3.280
Regeneration Gas Compressor	GJ/h	0.121

Table A4. Operating parameters for the absorption dehydration (enhanced regeneration)

Input Data	Unit	Min.	Max.
Gas flow rate	10^6 Sm^3/d	1.42	4.2
Absorber pressure	kPa	4500	6000
Absorber temperature	^{o}C	30.0	40.0
Lean TEG pressure	kPa	4600	6100
Lean TEG temperature	^{o}C	35.0	45.0
Lean TEG purity	%-wt	99.99	99.995
Lean TEG flow rate	m^3/h	2.0	6.0

Energy consumption	Unit	Value
Reboiler	GJ/h	0.645
Lean TEG Cooler	GJ/h	0.165
Rich Glycol Heater	GJ/h	0.142
Regen Overhead Cooler	GJ/h	0.200
Recycled Gas Comp Cooler	GJ/h	0.278
Stripping Gas Heater	GJ/h	0.111
TEG Circulation Pump	GJ/h	0.044
Recycled Gas Compressor	GJ/h	0.074

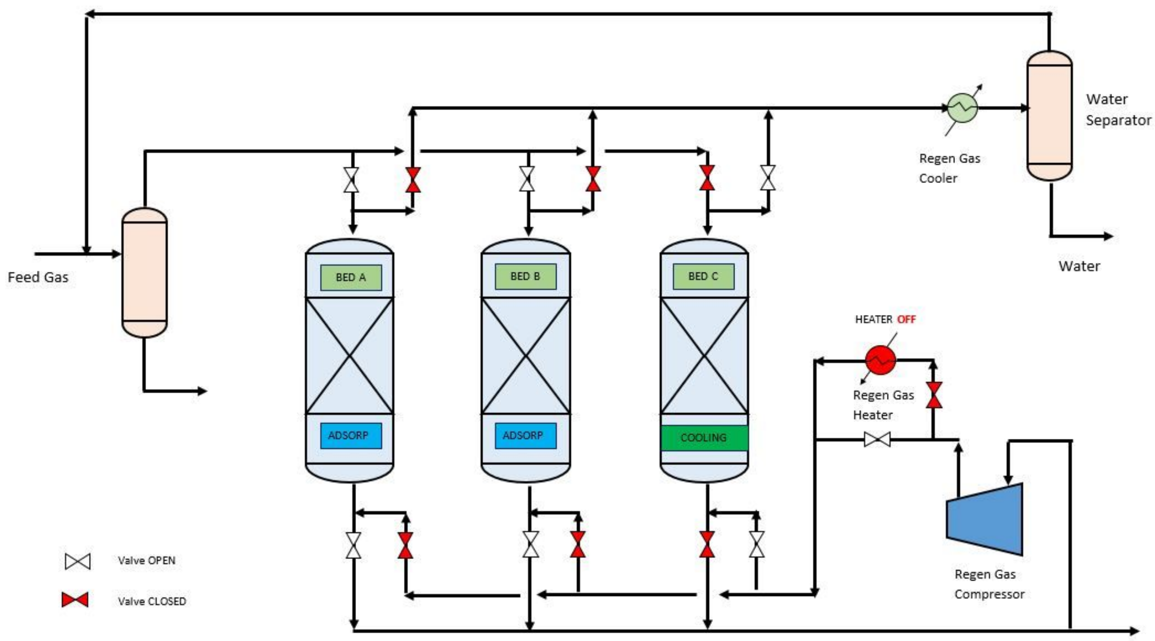

Fig. A1: Molecular sieve dehydration flow diagram – 2 towers in Adsorption and 1 tower in Cooling mode

	Day-1				Day-2				Day-3			
Equipment Name	6	6	6	6	6	6	6	6	6	6	6	6
Tower 1	0	0	0	0	1	2	0	0	0	0	1	2
Tower 2	1	2	0	0	0	0	1	2	0	0	0	0
Tower 3	0	0	1	2	0	0	0	0	1	2	0	0
Regen Gas Compressor	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON	ON
Regen Gas Heater	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF
Regen Gas Cooler	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF	ON	OFF

Operating mode	
Absorpsi	0
Heating	1
Cooling	2

Fig. A2: Typical operating modes in Molecular sieve dehydration

APPENDIX B

Table B1. Utility and chemical cost summary

Utility Cost	**Unit**	**Value**
Heating medium	\$/GJ	9.8
Cooling water	\$/GJ	2.5
Electricity	\$/GJ	16.8

Chemical Cost	**Unit**	**Value**
TEG make-up	\$/kg	2.71
Stripping gas	\$/GJ	3.11

Table B2. Capital cost estimation summary

Equipment type	**Estimated Formula**
Separator/Scrubber/Drum	$17640\ d^{1.066}\ l^{0.802}$
Heat exchanger	$7296\ A^{0.65}$
Centrifugal compressor	$(1293)(517.3)(3.11)(hp)^{0.82}/280$

APPENDIX C

Table C1. Equipment sizing results: Base case (TEG & Mole sieve dehydration)

Equipment Name	Type	Diameter (m)	Length (m)
TEG Contactor	Column	1.6	5.85
TEG Regenerator	Column	0.4	1.00
Flash Drum	Separator	0.9	3.60
Regen Overhead Drum	Separator	0.6	2.10
Equipment Name	**Type**	**Area (m^2)**	
Heat Exchanger-1	Heat Exchanger	22.6	
Heat Exchanger-2	Heat Exchanger	22.6	
Regen Overhead Cooler	Heat Exchanger	0.6	
Reboiler	Heat Exchanger	22.6	
Rich Glycol Heater	Heat Exchanger	5.0	
Equipment Name	**Type**	**Diameter (m)**	**Length (m)**
Mole Sieve Tower 1	Column	1.92	5.5
Mole Sieve Tower 2	Column	1.92	5.5
Mole Sieve Tower 3	Column	1.92	5.5
Water separator	Separator	0.60	2.0
Equipment Name	**Type**	**Area (m^2)**	**Duty (kW)**
Regen Gas Cooler	Heat Exchanger	50	
Regen Gas Heater	Heat Exchanger	50	
Equipment Name	**Type**	**Duty (hp)**	
Regen Gas Compressor	Compressor	45	

Table C2. Equipment sizing results: Evaluated case (Recycled Stripping Gas with natural gas)

Equipment Name	**Type**	**Diameter (m)**	**Length (m)**
TEG Contactor	Column	1.6	5.85
TEG Regenerator	Column	0.5	1.00
TEG Stahl Column	Column	0.5	1.00
Recycle Gas Absorber	Column	0.3	1.00
Equipment Name	**Type**	**Area (m^2)**	
Heat Exchanger-1	Heat Exchanger	22.6	
Heat Exchanger-2	Heat Exchanger	22.6	
Reboiler	Heat Exchanger	22.6	
Lean TEG Cooler	Heat Exchanger	5.0	
Rich Glycol Heater	Heat Exchanger	5.0	
Regen Overhead Cooler	Heat Exchanger	0.6	
Recycled Gas Comp Cooler	Heat Exchanger	0.6	
Stripping Gas Heater	Heat Exchanger	5.0	
Equipment Name	**Type**	**Diameter (m)**	**Length (m)**
Flash Drum	Separator	0.9	3.6
Overhead Drum	Separator	0.5	0.8
Recycle Comp Suction Scrubber	Separator	0.6	2.1
Recycle Comp Disch Scrubber	Separator	0.6	2.1
Equipment Name	**Type**	**Duty (hp)**	
Recycle Compressor	Compressor	27.5	

Table C3. Capital cost estimation for main equipment: base case (TEG dehydration)

Equipment Name	**Type**	**Capital Cost ($)**
TEG Contactor	Column	120 046
TEG Regenerator	Column	8 426
Flash Drum	Separator	44 043
Overhead Drum	Separator	18 554
Heat Exchanger-1	Heat Exchanger	55 368
Heat Exchanger-2	Heat Exchanger	55 368
Overhead Cooler	Heat Exchanger	5 235
Reboiler	Heat Exchanger	55 368
TEG Cooler	Heat Exchanger	20 769
Rich Glycol Heater	Heat Exchanger	20 769
Total		403 944

Table C4. Capital cost estimation for main equipment: base case (mole sieve dehydration)

Equipment Name	Type	Capital Cost ($)
Mole Sieve Tower 1	Column	138 761
Mole Sieve Tower 2	Column	138 761
Mole Sieve Tower 3	Column	138 761
Regen Gas Cooler	Heat Exchanger	92 772
Regen Gas Heater	Heat Exchanger	142 265
Water separator	Separator	17 842
Regen Gas Compressor	Compressor	168 491
Total		841 654

Table C5. Operating cost estimation for main equipment: base case (TEG dehydration)

	Running hours (h)	Consumption (GJ/h)	Energy Unit Cost ($/GJ)	Utility Cost ($)
Heater duty	8 640	0.975	9.8	82 606
Cooler duty	8 640	0.392	2.5	8 465
Electrical duty	8 640	0.044	16.8	6 436
	Running hours (h)	**Consumption (kg/h)**	**Chemical Unit Cost ($/kg)**	**Chemical Cost ($)**
TEG make-up	8 640	0.2755	2.71	6 541

Table C6. Operating cost estimation for main equipment: base case (mole sieve dehydration)

	Running hours (h)	Consumption (GJ/h)	Energy Unit Cost ($/GJ)	Utility Cost ($)
Heater duty	4380	3.55	9.8	152 380
Cooler duty	4380	3.28	2.5	35 916
Electrical duty	8760	0.121	16.8	17 792

Table C7. Capital Cost estimation for main equipment: Evaluated case (Recycled Stripping Gas with natural gas)

Equipment Name	Type	Capital Cost ($)
TEG Contactor	Column	120 046
TEG Regenerator	Column	8 426
TEG Stahl Column	Column	8 426
Recycle Gas Absorber	Column	4 888
Heat Exchanger-1	Heat Exchanger	53 368
Heat Exchanger-2	Heat Exchanger	53 368
Reboiler	Heat Exchanger	55 368
Lean TEG Cooler	Heat Exchanger	20 769
Rich Glycol Heater	Heat Exchanger	20 769
Regen Overhead Cooler	Heat Exchanger	5 235
Recycled Gas Comp Cooler	Heat Exchanger	5 235
Stripping Gas Heater	Heat Exchanger	20 769
Flash Drum	Separator	44 043
Recycle Comp Suction Scrubber	Separator	18 554
Recycle Comp Discharge Scrubber	Separator	18 554
Recycle Compressor	Compressor	112 511
Total		574 326

Table C8. Operating Cost estimation for main equipment: Evaluated case (Recycled Stripping Gas with natural gas)

	Running hours (h)	**Consumption (GJ/h)**	***Energy Unit Cost* ($/GJ)**	***Utility Cost* ($)**
Heater duty	8 640	0.898	9.8	76 035
Cooler duty	8 640	0.6425	2.5	13 878
Electrical duty	8 640	0.1179	16.8	17 118
	Running hours (h)	**Consumption (kg/h)**	**Chemical Unit Cost ($/kg)**	**Chemical Cost ($)**
TEG make-up	8 640	0.2017	2.71	4 723
	Running hours (h)	**Stripping Gas consumption (Sm^3/h)**	**Stripping Gas Unit Cost ($/GJ)**	**Stripping Gas Cost ($)**
Stripping Gas[a]	8 640	131.8	3.11	145 475

[a] Gas heating value: 40.96 MJ/Sm^3

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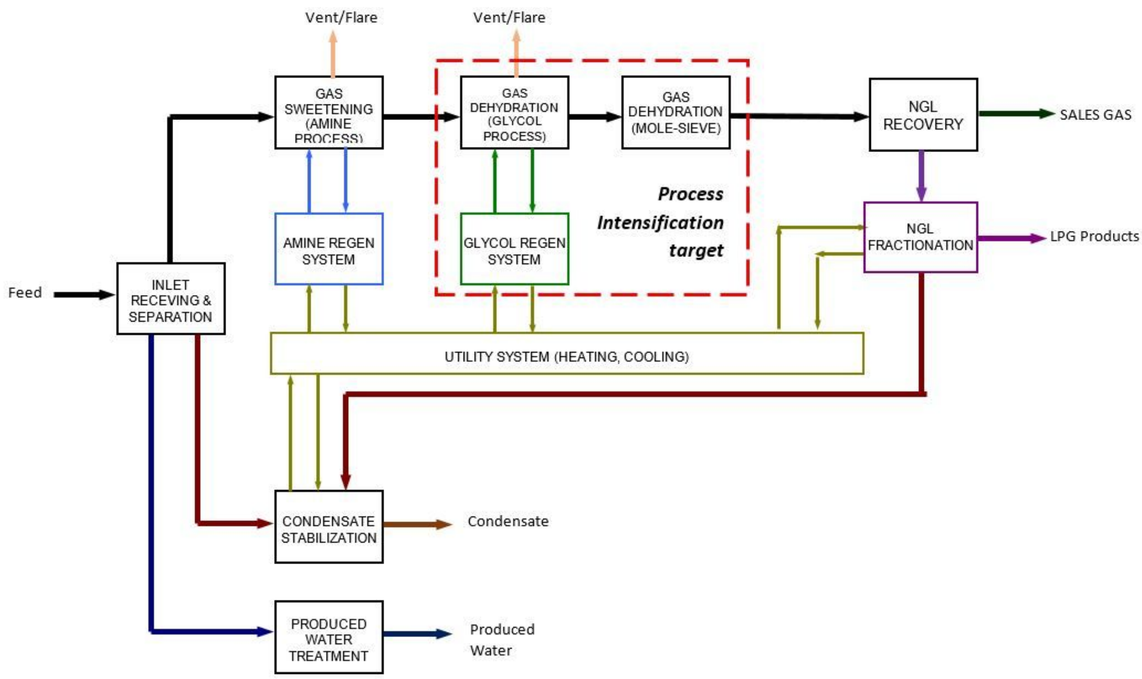

Figure 1: Typical block diagram in a natural gas plant in which gas was sweetened, and dehydrated before being processed in a cryogenic NGL recovery process

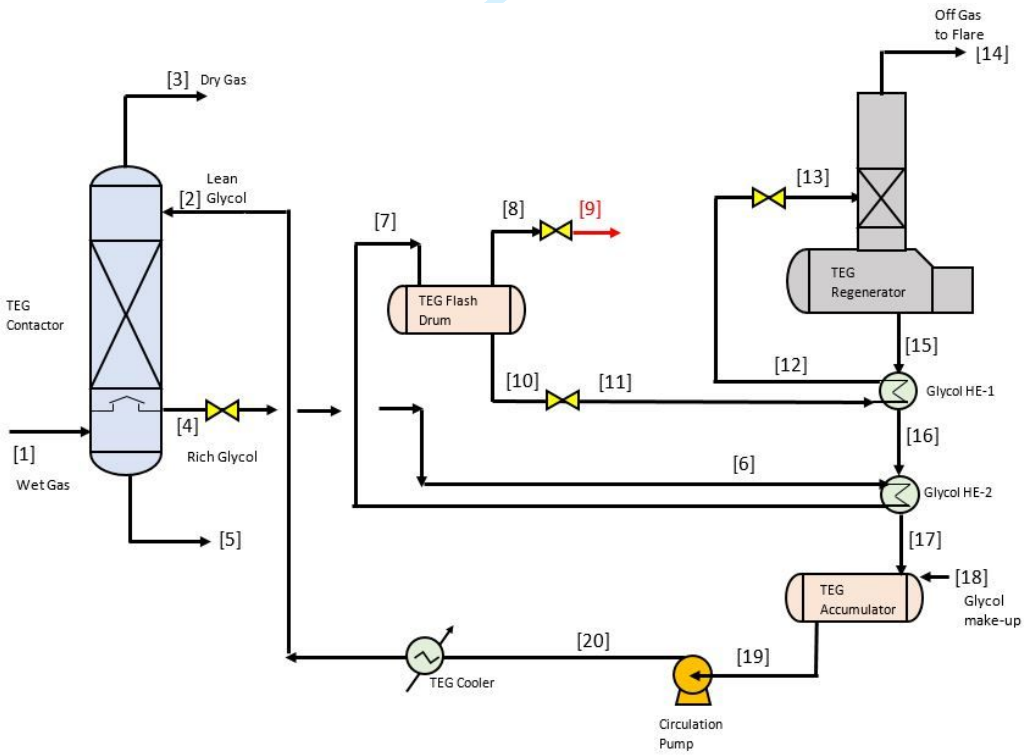

Figure 2: Conventional TEG dehydration unit for removing the bulk of water vapor

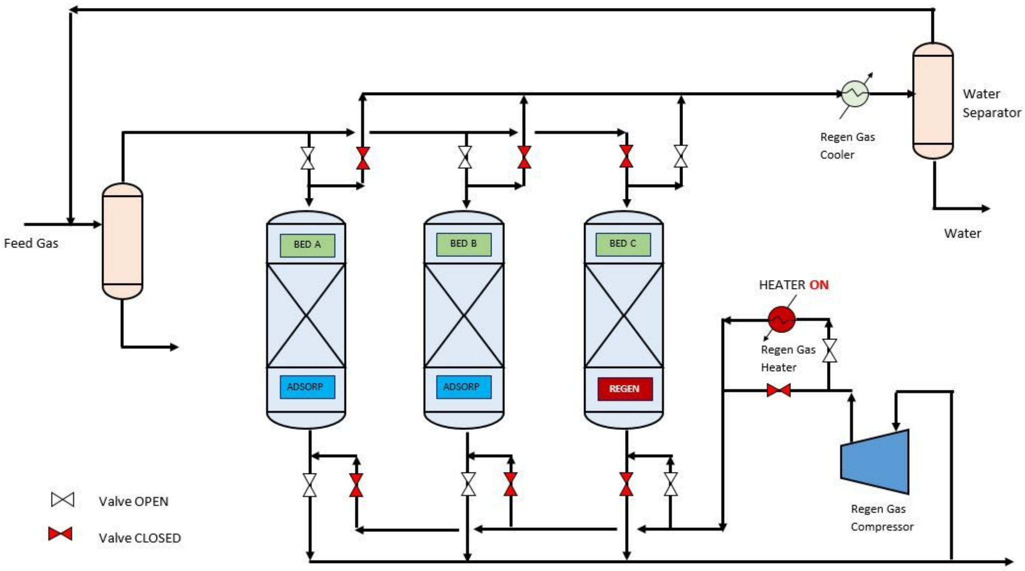

Figure 3: Molecular sieve dehydration flow diagram – 2 towers in Adsorption and 1 tower in Heating/regeneration mode

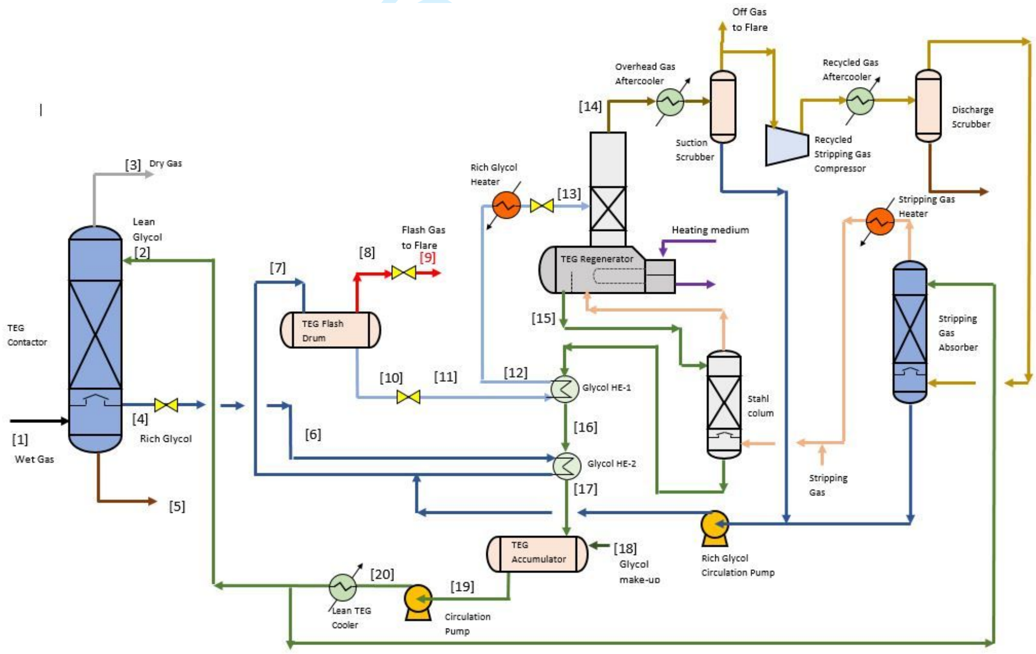

Figure 4: TEG dehydration unit with recycled stripping gas configuration

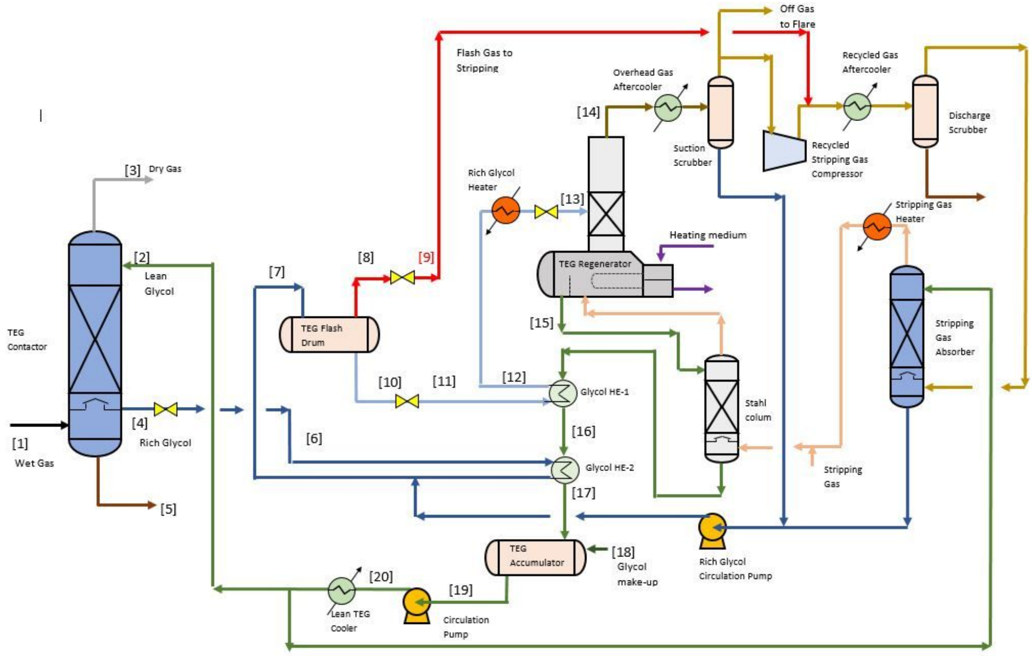

Figure 5: TEG dehydration unit with recycled flash gas and stripping gas configuration.

Table 1: Simulation results - a comparison between the base case (TEG conventional & mole sieve dehydration) and the evaluated case (TEG dehydration with recycled stripping gas)

	Lean TEG flowrate (m^3/h)	Lean TEG purity (%-wt)	Dry Gas Moisture (mg/Sm^3)	Water Dew point (°C)
Base Case				
TEG dehydration	5.0	98.71	110.0	-2.0
Molecular sieve dehydration	-	-	0.16	-70.0
Evaluated Case				
Natural gas stripping + recycle	5.0	99.993	0.16	-70.0
Natural gas, flash gas stripping + recycle	5.0	99.994	0.16	-70.8

Table 2: Comparison of energy consumption between the base case (TEG conventional & mole sieve dehydration) and the evaluated case (TEG dehydration with recycled stripping gas)

	Heating duty (GJ/h)	Cooling duty (GJ/h)	Electrical power duty (GJ/h)
Base Case			
TEG dehydration	0.976	0.392	0.044
Molecular sieve dehydration	3.550	3.280	0.121
Evaluated Case			
Natural gas stripping + recycle	0.898	0.643	0.118
Natural gas, flash gas stripping + recycle	0.909	0.657	0.117

Table 3: Comparison of the amount of stripping gas required in the evaluated case (dehydration with recycled stripping gas vs. the recycled stripping and flash gas)

Evaluated Case	**Unit**	**Recycled Stripping Gas**	**Recycled Stripping Gas + Flash Gas**
Fresh stripping gas	kg/h	113.2	80.8
Overhead % recycle	%	70.0	70.0
Recycled Stripping Gas	kg/h	446.6	512.6

Table 4: Comparison of the glycol losses in the evaluated case (dehydration with recycled stripping gas vs. the recycled stripping and flash gas)

TEG Losses	**Unit**	**Recycled Stripping Gas**	**Recycled Stripping Gas + Flash Gas**
From TEG Absorber	kg/h	0.169	0.169
From Flash Drum	kg/h	0.017	0.000
From Overhead Regenerator	kg/h	0.016	0.015
Recycled Gas Discharge Scrubber	kg/h	0.044	0.053
Total	kg/h	0.246	0.237

Table 5: Total Annual Cost calculation for the Base case (TEG conventional & Mole sieve dehydration)

Base Case	**TCC ($)**	**TCC / PB ($)**	**TOC ($)**	**TAC ($)**
TEG dehydration (conventional regeneration)	403 944	134 648	103 958	238 606
Molecular sieve dehydration	841 654	280 551	206 088	486 640
Total	1 245 958	415 199	310 046	725 245

Table 6: Total Annual Cost calculation for the evaluated cases (TEG dehydration with recycled stripping gas)

Evaluated Case	**TCC ($)**	**TCC / PB ($)**	**TOC ($)**	**TAC ($)**
Recycled Stripping Gas – Natural Gas	**574 326**	**191 442**	**257 228**	**448 670**
TEG dehydration (conventional regeneration)	403 944	134 648	103 958	238 606
Additional equipment	170 382	56 794	153 271	210 065
Recycled Stripping Gas – Natural Gas & Flash Gas	**572 982**	**190 994**	**215 775**	**407 769**
TEG dehydration (conventional regeneration)	403 944	134 648	103 958	238 606
Additional equipment	169 038	56 346	112 817	169 163