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Conceptual Design of a Natural Gas Processing Plant in Western Niger Delta Area

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Abstract

Nigeria has approximately 200.4 trillion cubic feet (Tcf) of proved natural gas reserves by the end of 2019, not much has been done to increase its economic value. Nigeria has an abundant source of energy in natural gas, which can drive and sustain development for a very long period if these assets are effectively processed into the various useful components. Availability of electrical power is a key component in the development of a nation, Nigeria's transformation from a developing nation to a developed nation has largely been stalled by epileptic power supply. This challenge can be resolved by providing infrastructures to process and transform natural gas energy into electrical energy. An indigenous E & P company wishes to undertake the development of a 30MMscf/d natural gas processing plant. This study was therefore initiated to design the gas plant that will process the produced natural gas to meet the specification of a nearby electric power generating plant which will utilized the processed natural gas for electric power generation. A process simulator (ASPEN HYSIS) was used to model the natural gas flow from the feed receiving section down to the sales point to determine natural gas processing plant requirements. Fluid samples were acquired and detailed PVT analysis was carried out to determine the gas composition. Results of the process simulation shows that, to process the 30MMScf/d flow of natural gas, the natural gas plant will require five coolers, three separators (One three phase separator, one two phase separator and a stock tank), four compressors, a pump and a TEG dehydrating unit. The outlet gas has a pressure of 690 psia, water content of 0.257 lbm of H2O/ MMscf of gas, and gross heating value of 1219.72 btu/scf which meets the customer's requirement.

1. Introduction

Natural gas is a fossil energy source that formed deep beneath the earth's surface EIA [1]. According to EIA [2], Nigeria has approximately 200.4 trillion cubic feet (Tcf) of proved natural gas reserves by the end of 2019, not much has been done to monetize this gas. Thus, Nigeria has an abundant source of energy in natural gas, which can drive and sustain development for a very long period if these assets are effectively processed into the various useful components. Nigeria with an average daily gas production of approximately 7.97 bscf/d with 39 percent (2.9 bscf/d) Liquified Natural Gas (LNG), 31 percent (2.3bscf/d) reinjection / other operation usage, Gas flaring at 15 percent (1.1 bscf/d) and domestic gas consumption at 16 percent (1.2 bscf/d) is clear indication that meeting the domestic gas obligation is still a challenge in Nigeria, as a result of lack of gas infrastructures to support the demand [3].

Availability of electrical power is a key component in the development of a nation, Nigeria's transformation from a developing nation to a developed nation has largely been stalled by epileptic power supply. One of the ways this challenge can be resolved is by providing infrastructure to process and transform natural gas energy into electrical energy.

2. Methodology

This section outlines the various inputs and processes undertaken to develop a conceptual design of a natural gas processing plant in western Niger Delta to handle a gas flow rate of 30MMScf/day. The processing plant is expected to process natural gas to meet customer requirements (sales gas). Sales gas from this processing plant is to be utilized by an electric power generation company situated nearby, sales gas specification is: (a) Water content not more than 6 lbm H_2O/MMscf of gas (b) Hydrogen sulfide content not exceeding 0.23 g/100 Scf (c) Gross heating value between 1000 and 1250 Btu/Scf (d) Carbon dioxide content not more than 2mol% (d) Oxygen content 0.01 mol% (max) (e) Nitrogen content not more than 4mol% (f) Total inert content (N_2 and CO_2) not more than 5 mol%. The design process for the natural gas processing plant is shown in Figure 1.

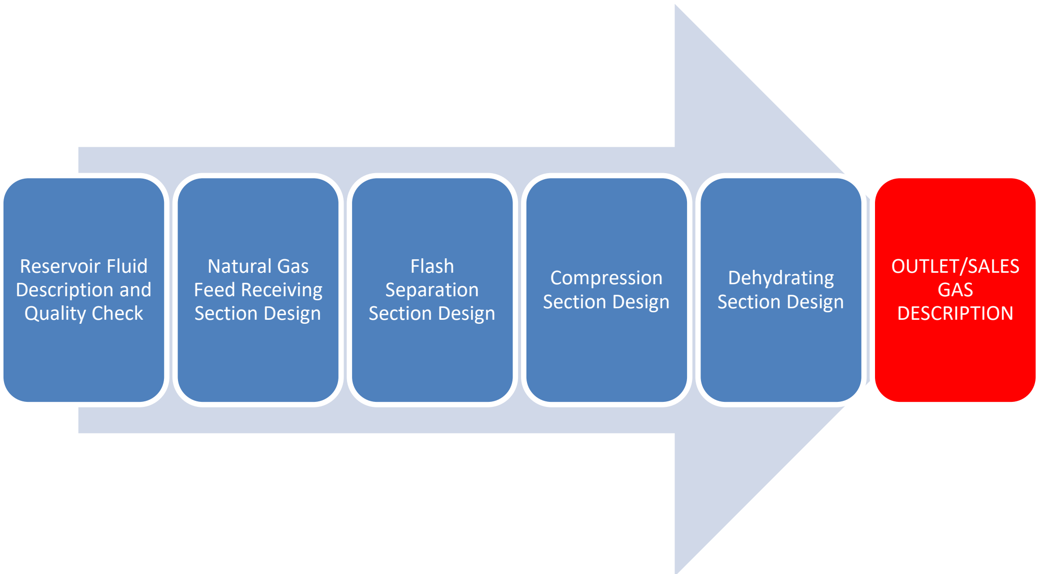

Figure 1: Various Sections in the Conceptual Design Process

Fluid samples were acquired in the field and detailed Pressure-Volume-Temperature (PVT) analysis was carried out in the laboratory; these include compositional analysis, constant composition expansion (CCE) test, constant volume depletion (CVD), maximum gallon per Mscf (GPM) and water content estimation [4]. Furthermore, data acquired from PVT analysis were quality checked using various method [4] (Equilibrium ratio trend, Liquid Drop Out (LDO) plots of CCE and CVD results, Hoffman's plot) to avoid erroneous results and ensure consistency. Natural gas stream have water either existing as free liquid or saturated vapor. Estimation of the water content in a gas stream is very important for a natural gas plant design. Knowing the amount of water is useful as it aids the designer in curbing the side effects (hydrate formation, reduction in heating value of the gas, problem in cryogenic processing of the gas) in an economical way. The water content for the gas stream at the reservoir temperature and pressure was determined using the charts published by Mcketta and Wehe [5] assuming the gas was in contact with 2% brine. The water content was then added to the components of the gas stream and a new composition table generated to aid process flow calculations.

The feed receiving section of a gas plant is expected to receive gas from the wells via three flowlines:

(i) The extra high pressure flowline XHP operating at 1000psia and 20MMScfd
(ii) The high pressure flowline operating at 120psia and 8MMscfd.
(iii)The low pressure flowline operating at 35psia and 2MMScfd.

For an effective and optimal design/construction of a natural gas plant, there are key information that is required e.g. the number of separators required for optimum flash separation, the type of dehydrating unit required to meet sales gas specification, the number and power requirement of compressor required to provided sufficient pressure to deliver the gas to sales point etc. In order to obtain this information, a process simulator (ASPEN HYSIS) was used to model the natural gas flow from the feed receiving section down to the sales point. Using the natural gas composition gotten from PVT analysis and the expected natural gas feed from the three flowlines, a new case was created in HYSIS and Peng-Robinson was used as the preferred equation of state.

3. Results and Discussion

This section shows the results obtained from the process simulator which was used for the conceptual design process of the natural gas processing plant.

3.1 QC on reservoir composition

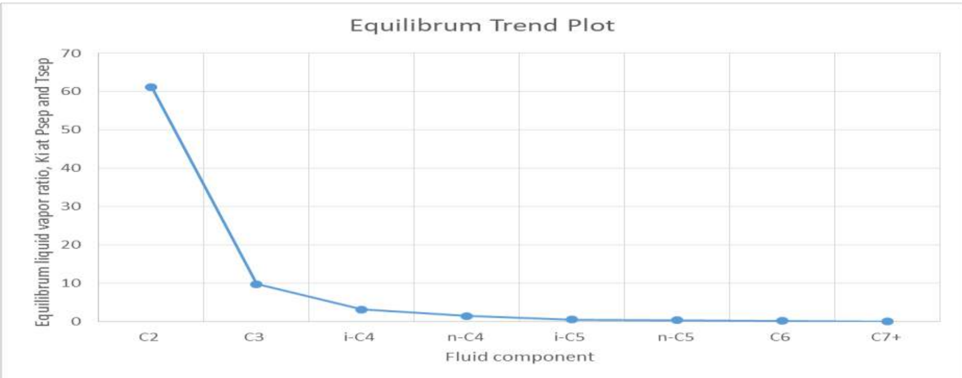

Figure 2: Equilibrium trend plot for reservoir fluid composition

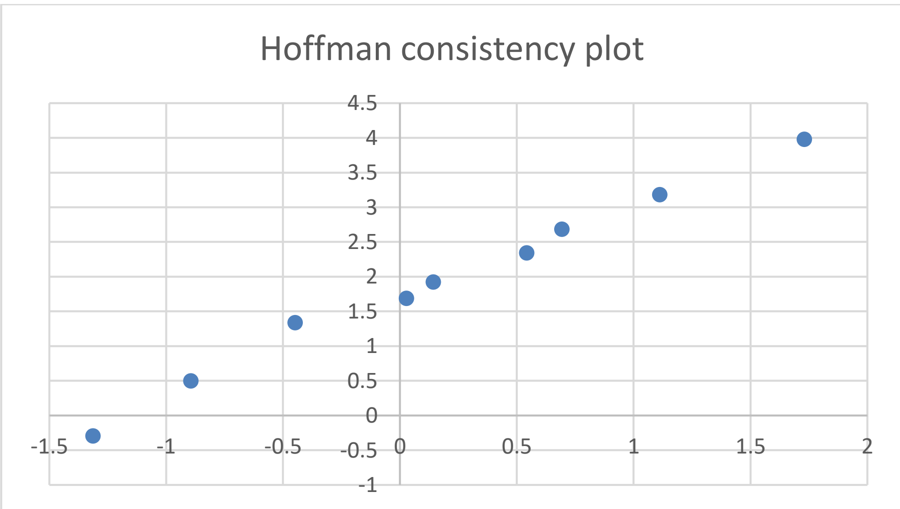

Figure 3: Hoffman consistency plot

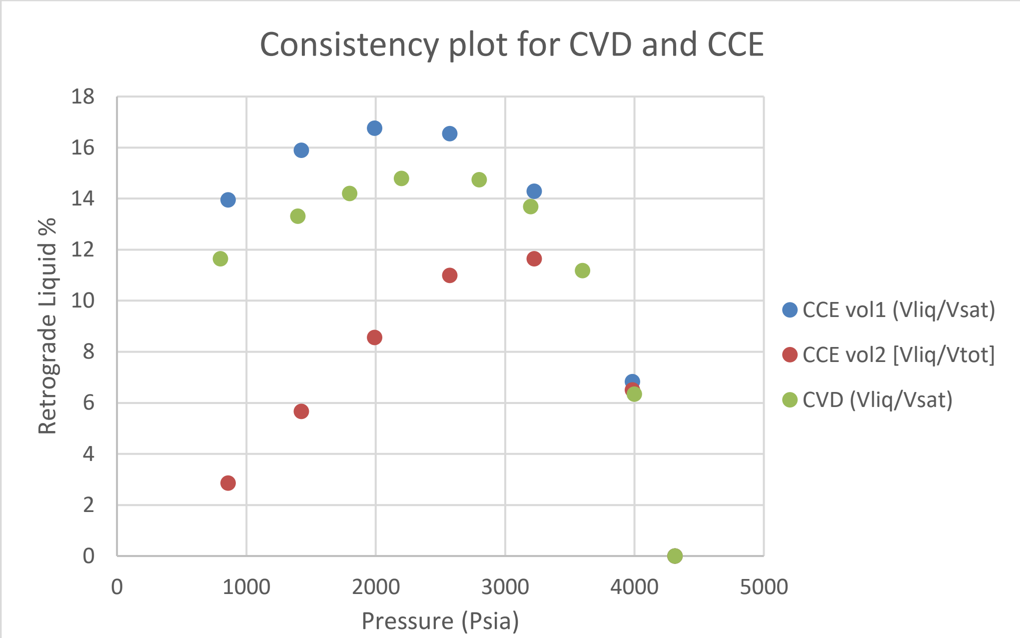

Figure 4: Liquid dropout from CCE and CVD tests

Figure 2 shows the equilibrium trend plot for the reservoir fluid composition. As can be seen from the plot the equilibrium vapor liquid ratio follows the trend of increasing values for increasingly volatile components indicating the validity of the reported reservoir fluid composition. Figure 3 shows the Hoffman's consistency plot, evident from the plot is an approximately linear trend with minute deviations indicating that the reported reservoir composition is valid. Also, it can be seen from Figure 4, that the maximum liquid dropout from the CVD occurs at a lower pressure than the maximum liquid dropout gotten from the CCE and the liquid drop out curve generated from the CVD lies between the liquid drop out values (Vliq/Vsat and Vliq/Vtot) gotten from the CCE, this establishes consistency in the CCE and CVD tests which validates the data from both tests. The fact that both Hoffman plot and equilibrium trend plot agree increases our level of confidence in the reported reservoir fluid composition. Hence the reservoir composition can be used in subsequent analysis.

3.2 Reservoir fluid type

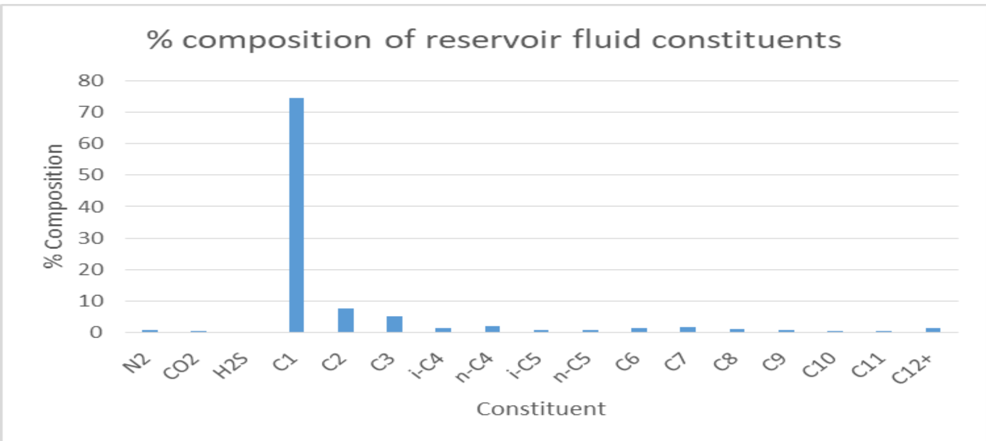

Figure 5: Bar chart showing the % composition of the constituents in the gas stream

From the compositional analysis data (Figure 5) it can be seen that the C_1 fraction has the highest composition of about 75%, C_2 fraction has a composition of about 7% while C_{7+} fractions have minimal compositions. This composition corresponds to a non-associated gas from a retrograde-condensate gas reservoir. The data from the CCE and CVD shows that the liquid dropout increases to a maximum value then decreases indicating that the gas is a retrograde condensate. From the compositional analysis the gas is sweet (H_2S<0.5%), non-acidic (CO_2 <0.5%) and contains minimal amounts of N_2. Hence the gas doesn't need to be treated to reduce the amounts of these components in the stream thereby reducing processing cost.

3.3 Gallon per MScf (GPM) analysis

Results from the GPM analysis is presented in Table 1. As can be seen from the table the gas is a rich gas as it has a GPM and GPMC_{3+} of about 6. This indicates that the upper bound to the volume of liquid that can be gotten from the C_{2+} components of 1MMScf of the gas is about 6gallons. This indicates that this gas stream has a high content of natural gas liquids (NGL), which would require significant liquid handling facility.

Table 1: GPM analysis for the reservoir fluid composition

No	**Component**	**Reservoir Fluid**	**Mi**	**S.Gi**	**GPMi**	**Efficiency, Ep**	**GPMi*Ep**
		[mol %]					
1	N2	0.76	28.02	0.8094	0	0	0
2	CO2	0.44	44.01	0.81802	0	0	0
3	H2S	0	34.08	0.07107	0	0	0
4	C1	74.72	16.04	0.3	0	0	0
5	C2	7.5	30.07	0.35619	1.999834	0.05	0.099992
6	C3	5.16	44.1	0.50699	1.417652	0.8	1.134122
7	i-C4	1.29	58.12	0.56287	0.420715	0.95	0.399679
8	n-C4	1.84	58.12	0.58401	0.578368	0.95	0.549449
9	i-C5	0.77	72.15	0.6247	0.28089	1	0.28089
10	n-C5	0.67	72.15	0.63112	0.241925	1	0.241925
11	C6	1.23	86.18	0.66383	0.504354	1	0.504354
12	C7+	5.62	141.62	0.8003	3.141152	1	3.141152
TOTAL		100				**GPM=**	**6.351563**
						GPMC3+ =	**6.251572**

3.4 Water content estimation

Table 2: Water content estimation for inlet feed

Gravity correction, Cg	0.95
Salinity correction, Cs	0.955
Water content $\gamma = 0.6$, $W\,(\frac{lbm}{MMscf})$	85
$W_{sweet}\,(\frac{lbm}{MMscf})$	77.11625
Standard gas volume, $V_{sc}\,(\frac{MMscf}{lb.mole})$	0.0003794
$W_{sweet}\,(\frac{lb.mole}{MMscf})$	4.284236111
$W_{sweet}\,(\frac{lb.mole}{lb.mole})$	0.001625439

Table 3: Adjusted reservoir composition table with water composition added

No	**Component**	**Reservoir Fluid**	**Adjusted Reservoir Fluid**
		[mol %]	[mol %]
1	N2	0.76	0.758766671
2	CO2	0.44	0.439285967
3	H2S	0	0
4	C1	74.72	74.59874428
5	C2	7.5	7.487828989
6	C3	5.16	5.151626345
7	i-C4	1.29	1.287906586
8	n-C4	1.84	1.837014045
9	i-C5	0.77	0.768750443
10	n-C5	0.67	0.668912723

11	C6	1.23	1.228003954
12	C7	1.77	1.767127641
13	C8	0.95	0.948458339
14	C9	0.69	0.688880267
15	C10	0.43	0.429302195
16	C11	0.32	0.319480704
17	C12+	1.46	1.45763071
18	H20	-	0.162280142
TOTAL		**100**	**100**

Water content estimation is a critical aspect of natural gas plant design. Table 2 shows the water content estimated for the inlet feed. The estimated water content was then added to the list of components in the gas stream and a modified composition table generated as shown in Table 3. This modified composition is more representative of the gas stream produced from the reservoir.

3.5 Flash Calculations and Separator design

Table 4: Thermodynamic and flow parameters of the material streams for the various separators

	Unit	**Vap Out**	**HC Out**	**Water**	**HC_Vap Out**	**HC_Liq Out**	**Tank_Vap Out**	**Condensate**
Vapour Fraction		1	0	0	1	0	1	0
Temperature	*F*	88.3492	88.34925	88.349	73.21198	73.21198	52.72681	52.72681
Pressure	*Psia*	700	700	700	123	123	14.8	14.8
Molar Flow	*lbmole/hr*	19721.9	3324.219	12.84	833.0653	2491.153	412.8822	2078.271
Mass Flow	*lb/hr*	390341	284929.6	231.33	20617.46	264312.1	17404.19	246907.8

Fluid Volume Flow	*barrel/day*	79076.9	29624.3	15.873	3740.714	25883.58	2438.81	23444.77
Heat Flow	*Btu/hr*	-6.8E+08	-2.9E+08	-2E+06	-3.1E+07	-2.6E+08	-19076953	-2386202

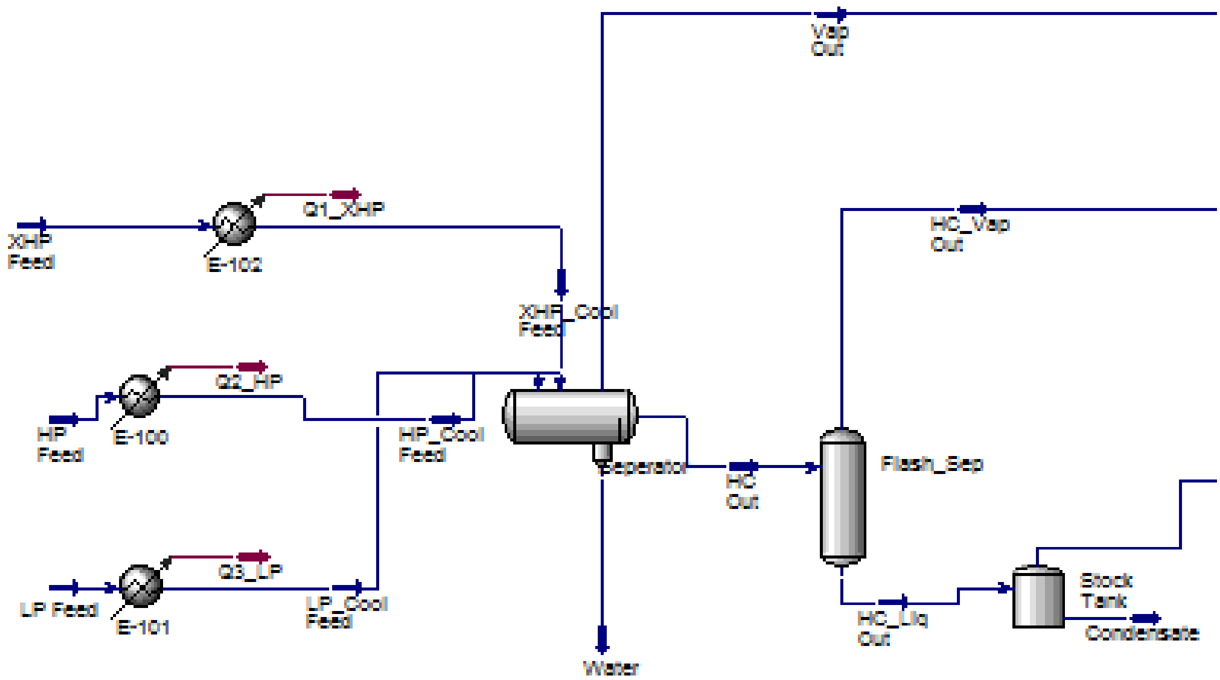

Figure 6: Process flow diagram showing coolers and separators and condensate tank

Results from the process simulation on Asphen HYSIS is shown in Table 4 and Figure 6. The Vap Out, HC_Vap out and Tank_Vap Out streams are the vapors from the high pressure three phase , two phase separator and condensate tank respectively while the HC Out, HC_Vap Out and Condensate streams are the liquid streams from the High pressure three phase. From multiple simulation runs, the set up shown in Figure 6 gave the best results in terms of fluid volume; about 85 Mbbl of vapor phase (gas) and 23 Mbbl of liquid phase. Figure 6 shows the combination of equipment required for optimal reservoir fluid separation to maximize gas (vapor phase) output. The reservoir fluid enters the plant at inlet feeds XHP (extra high pressure), HP (high pressure) and LP (low pressure). These feeds where then cooled to a temperature of 100 ^{0}F and pressure of 1000 psia. At these conditions hydrate doesn't form in the flow lines. The cooled streams were then passed into a high pressure three phase separator operating at a pressure of 1000psia where the streams are separated into gas (Vap Out), oil (HC Out) and water as shown in Figure 6. The Hydrocarbon liquid (HC Out) goes to a low pressure two phase flash separator operating at 123 psia and temperature of the inlet stream, which flashes the liquid to produce vapor (HC Vap) and liquid (HC_Liq Out). The liquid (HC_Liq out) then goes to the condensate tank operating at 15 psia.

3.6 Compressor design

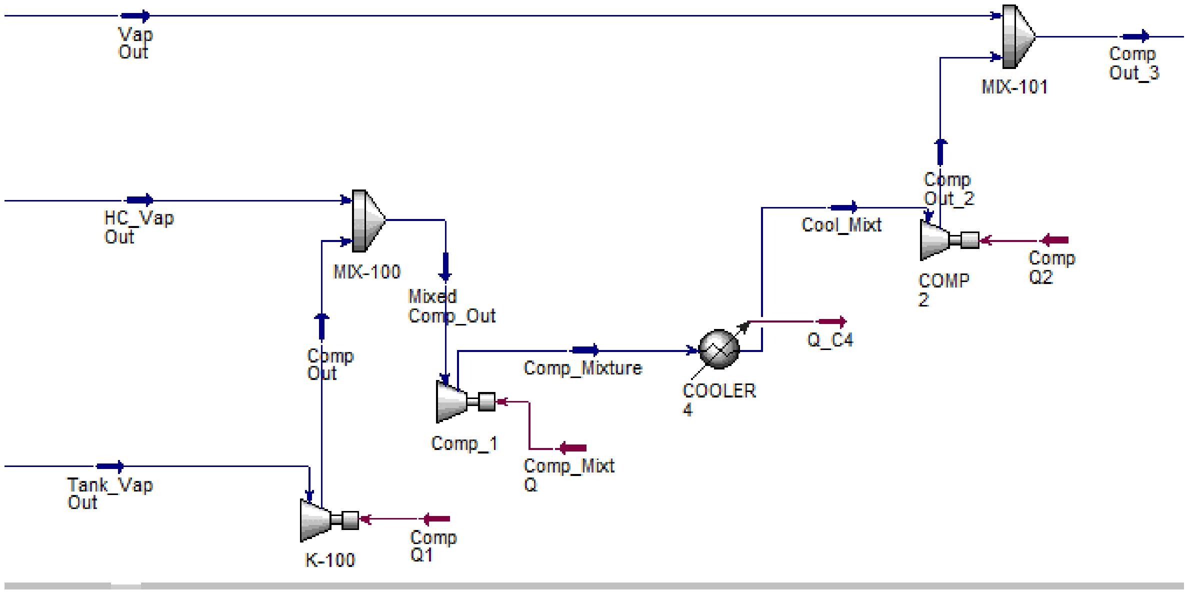

Figure 7: Process flow diagram for gas compression

Table 4: Thermodynamic and flow parameters of the material streams at the outlet of each compressor

	Unit	**Comp Out**	**Comp_Mixture**	**Comp Out_2**	**Comp Out_3**
Vapour Fraction		1	1	1	1
Temperature	*F*	229.3373	245.4592	251.0389	101.9121
Pressure	*Psia*	123	293.428	700	700
Molar Flow	*lbmole/hr*	412.8822	1245.947	1245.947	20967.87
Mass Flow	*lb/hr*	17404.19	38021.65	38021.65	428362.4
Liquid Volume Flow	*barrel/day*	2438.81	6179.523	6179.523	85256.45
Heat Flow	*Btu/hr*	-1.8E+07	-4.7E+07	-4.8E+07	-7.3E+08

Table 5: Compressor power requirements, duty and temperature and pressure changes

	Compressor		
Name	K-100	COMP 2	Comp_1
Power [hp]	507.339468	627.9281145	681.6572573
Adiabatic Efficiency	75	75	75
Polytropic Efficiency	77.66547304	76.63336083	76.46359401
Delta T [F]	176.6104449	106.9389071	101.3768249
Delta P [psi]	108.2	406.572	170.428
Duty [Btu/hr]	1290891.749	1597721.591	1734431.844

The vapor streams from the separators and condensate tanks were compressed as shown in the Figure 7 above. The lowest pressure vapor (Tank_Vap Out) goes into the first compressor (K-100) which compresses the gas to the pressure of the medium pressure gas stream (HC_Vap). These streams are then mixed in a mixer (mix-100) to give Mixed Comp_Out which is at the same pressure as the inlet to the mixer. Mixed Comp_Out is compressed in two stages with an inter-cooler in-between to give Comp Out_2 which has the same pressure as the high pressure stream (Vap_Out). Vap_Out is then mixed with Comp_2 Out in mix-101 to give Comp Out_3 which has the same pressure as the two streams. The inlet and outlet temperatures of each compressor were all above the dew point temperatures.

Table 4 shows thermodynamic and flow parameters of the material streams at the outlet of each compressor. The negative value in the heat flow row shows that heat flow out of the material stream. Table 5 shows the compressor power requirements (Power, hp), Heat Flow(Delta T, Btu/hr) and temperature increase (Delta T, F) of each compressor for given values of Adiabatic Efficiency, Polytropic Efficiency and pressure increase (Delta P, [psia]).

3.7 Dehydrator design

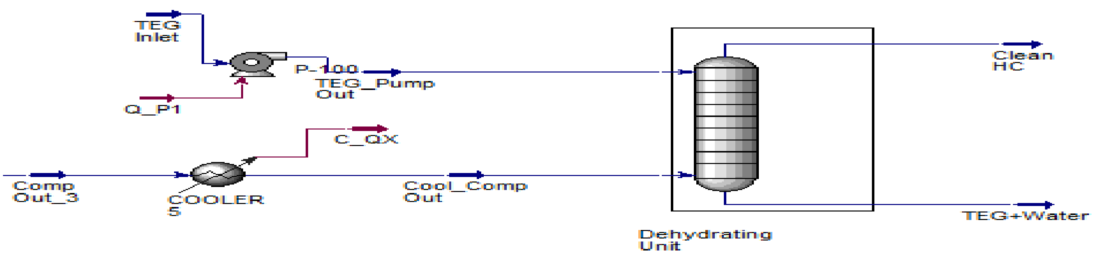

Figure 8: Process flow diagram for gas dehydration

Gas dehydration is essential to meet sales gas specification, from the flow simulation (Figure 8), vapor stream from compressor ‘Comp_3’ is first cooled in the cooler, to lower the temperature of the stream to 95^0 F to yield ‘Cool_Comp Out’. The Cool_Comp Out stream was then passed to the dehydrating unit where the Triethylene gycol (TEG) from TEG_Pump Out stream absorbs water from it to produce natural gas (Clean HC) with lowered water content.

3.8 Outlet gas Description

Table 6: Composition, Gross heating value and water content of sales gas

Component	**Mol fraction, Yi**	**GHVi**	**Yi*GHVi**
N2	0.00835037	8.35E-03	0
CO2	0.00482223	0	0
H2S	0	637.1	0
C1	0.82128875	1010	829.5016
C2	0.08172927	1769.7	144.6363
C3	0.05153445	2516.2	129.671
i-C4	0.01029173	3252	33.4687
n-C4	0.01284035	3262.4	41.89035
i-C5	0.00332908	4000.9	13.31931
n-C5	0.00240725	4008.7	9.649961
n-C6	0.00191753	4756	9.119757
n-C7	0.00113694	5502.5	6.256034
n-C8	0.00024557	6248.9	1.534514
n-C9	7.42E-05	6996.4	0.519254
n-C10	1.98E-05	7743	0.153676
n-C11	6.14E-06	0	0
H20	5.40E-06	0	0
C12+	3.97E-07	0	0
TEG	4.76E-07	0	0

Water Content (lbm H2O/MMscf)	2.57E-01		
Gross heating value	1219.72049		
H_2S content (g/100scf)	0		

Table 7: Comparison between customer's requirement and sales gas output

	unit	**customer requirement**	**sales gas**
Water contents	lbm of H_2O/ MMscf of gas	<= 6	0.257
Hydrogen sulfide content	g/100 scf	0.25-0.3	0
Gross heating value	btu/scf	1000-1250	1219.72
Carbon dioxide content	mol %	<= 2	0.482223
Oxygen content	mol %	<= 0.01	0
Nitrogen content	mol %	<= 4	0.835
Total inert content (N2 and CO2)	mol %	<=5	1.317223
Sand, dust, gums, and free liquid content		none	none
Delivery temperature	F	<=100	96.18604
Delivery pressure	psia	685-700	690

The water content and gross heating value meet the requirements of the customer since the gross heating value (GHV) is between 1000 -1200 Btu/Scf and the water content is less than 6 lbm of H_2O/ MMScf of gas.

4. Conclusion

This paper has presented a process simulation for the design of a natural gas process plant. It was shown that he design of the plant requires five coolers, three separators (One three phase separator, one two phase separator and a stock tank), four compressors, a pump and a TEG dehydrating unit. The reservoir fluid input into the natural gas processing plant is from a non-associated retrograde gas condensate reservoir. The gas is sweet (%H_2S <0.5), non-acidic (%CO_2 >0.5) and have a composition of nitrogen gas within the acceptable range. The reservoir gas is a rich gas having a high GPM of about 6.35gal/MMScf. The maximum flow rate of condensate that can be gotten from the natural gas stream is 23.445Mbbl/d. Sizing of various plant equipment shown in the design has been accomplished. The total compressor power requirement of the gas processing plant is1817 hp. The total pump power requirement of the gas processing plant is 15 hp. The outlet gas has a pressure of 690 psia, water content of 0.257 lbm of H2O/ MMscf of gas, and Gross heating value of 1219.72 btu/scf

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