Natural Gas Dehydration Process Simulation and Optimisation - A Case Study of Jubilee Field

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Abstract

Natural gas, a naturally occurring fossil fuel has become a popular energy source in recent years due to its environmental merit over alternate fossil energy sources. However, a challenge associated with produced natural gas is saturated water vapour among other impurities. These must be removed by gas treatment processes to prevent problems such as hydrate formation, corrosion and other threats to process facilities. Employing Triethylene glycol (TEG) as a liquid desiccant, a dehydrating plant for natural gas obtained from Jubilee Field was designed and simulated using Aspen HYSYS software. The model of the plant was used to investigate the effect of varying TEG flow rate, reboiler temperature and number of stages of the packing column in the contactor on dry gas water content. The study revealed that a TEG flow rate of 0.5 m^3/hr was sufficient to dehydrate a 240 MMSCFD from 37.98 lb/MMSCFD water content to 4.84 lb/MMSCF of water in the dry gas stream with 8 contacting stages at reboiler temperature of 204.4 °C.

Keywords: Natural Gas, Jubilee Field, Simulation, Aspen HYSYS, Triethylene glycol (TEG)

1 Introduction

Natural gas is a naturally occurring fossil fuel used as a source of energy for electricity generation, heating and domestic purposes. It has application in the petrochemical, fertilizer and plastic industry as a feedstock, and as a precursor for production of materials such as nylon. Natural gas is touted as the cleanest, safest and most useful fossil fuel (Arubi and Duru, 2008). When natural gas is combusted, its emissions of sulphur dioxide are negligible and the levels of carbon dioxide and nitrous oxide are about 50% less compared to other fossil fuels (Marques *et al*., 2014). These facts and an increasing interest in environmental advocacy have led to an increase in the demand for natural gas worldwide in recent years.

Until the 21st century, a great quantity of natural gas produced at oil and gas fields were flared, especially in areas lacking pipelines and other gas transportation infrastructure (Elvidge *et al*., 2009). Although natural gas is still being flared worldwide due to problems of storage and lack of a ready market, the demand for natural gas has created the need for more facilities for the production, processing and transportation of natural gas.

Ghana discovered oil in the Jubilee Field offshore Cape Three Points in the Western Region in 2007. Over the years, oil and gas exploration have continued with more discoveries of crude oil and natural gas. By the end of 2016, Ghana had begun work on the Sankofa Gas Project which encompasses the development of the Sankofa and Gye Nyame gas fields located 60 km offshore of Western Ghana in water depths ranging from 520 m to 1,014 m in the Tano Basin. These fields are estimated to hold 1.45 Tcf of non-associated gas. It is expected that gas obtained from this project will account for 40% of the nation’s domestic power generation (Kuukyee, 2015). A pipeline network construction is underway to link the offshore fields to the onshore receiving facilities.

In view of these, it is imperative to note that, the produced natural gas has to meet certain quality specifications before being fed into any pipeline transportation system in order for the pipeline grid to operate efficiently (Roy and Amin, 2011). This is because natural gas produced at the well head, as pointed out by Bhran *et al*. (2011), is a mixture of many hydrocarbon gases and some non-hydrocarbon gases, mainly hydrogen sulphide, carbon dioxide, nitrogen, and water vapour. These impurities if not processed can cause corrosion, reduction in heating value of the gas, environmental pollution and several problems to the pipeline during transportation. Water vapour in particular increases natural gas corrosivity especially when acid gases are present (Mawgoud and Khalil, 2014). It also causes hydrate formation at low temperature conditions which may plug the system. Dehydration is therefore vital in gas processing prior to transportation through pipelines. The industrial pipeline specification of water content in a processed natural gas stream is between the range of 4 to 7 lb/MMSCFD (Arubi and Duru, 2008) and therefore natural gas must be dehydrated to meet these specifications.

There are several technologies currently available for gas dehydration. In most cases, natural gas is treated with glycols, which absorbs water efficiently. Triethylene glycol (TEG) is typically used because of its low vapour pressure which results in less glycol loss (Mondal *et al*., 2013). The gas dehydration process, like other engineering processes can be simulated using commercially available process simulators, such as Aspen HYSYS before any equipment is designed. The essence of process simulation in modern times cannot be over emphasised. This is because process simulation enables engineers to develop optimal plant designs and analyse the operations of plants even before they are constructed. Process simulation reduces the operating cost of a plant in the long run especially when much effort is put in the search of the optimal design condition of the process through optimisation studies (Roy and Amin, 2011). This paper presents the simulation of a gas dehydration process offshore using Ghana's Jubilee Field as a case study.

1.1 Background of the Study Area

Jubilee oil Field is located in deep-water of about 1100 - 1700 m depth and an approximate distance of 60 km from the nearest coast in the Western Region of Ghana. The field covers an area of 109 265 220 gross sq. m and a total gross resource of 600 MMbbl with upside. The production from the field averaged approximately 102 000 bopd. The field underlies portions of the West Cape Three Point and Deep-water Tano License Blocks. The field start-up occurred on November 28, 2010 and production has continued to ramp up as additional phase one wells has been brought online. The phase 1 development program consists of 17 wells, 9 producers, 6 water injectors, and 2 gas injectors which target the lower and upper Mahogany reservoirs (McLaughlin, 2012). Figure 1 shows the location of the Jubilee Field.

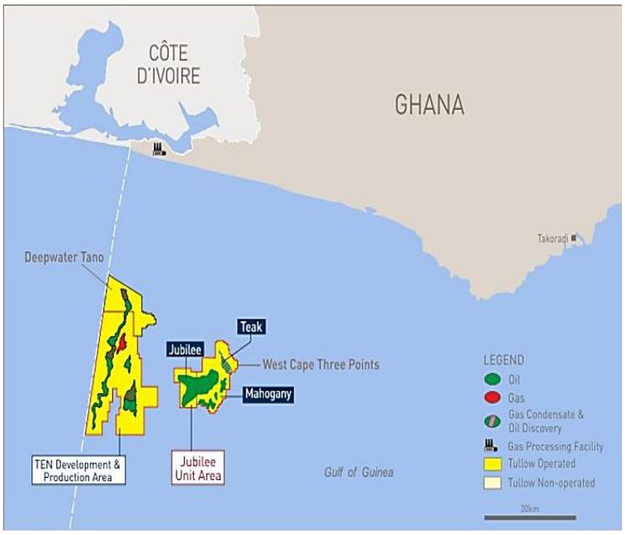

Figure 1 Location of the Jubilee Fields (Source: Anon, 2019)

1.2 TEG Dehydration Process

According to Abdulrahman and Sebastine (2013), the Triethylene Glycol (TEG) dehydration process consists of several operation units such as the glycol contactor tower or absorption column, glycol regenerator and heat exchanger. The glycol absorbers in the contactor tower can either be tray columns or packed columns.

Prior to entering the absorption column, the gas to be dehydrated is passed through an inlet scrubber. The function of the scrubber is to remove any free or condensed liquid droplets from the gas before the gas enters the contactor. The wet gas is then fed through the bottom of the absorption column. While, a water free TEG also known as lean glycol, with a purity of 99% is fed to the topside of the absorption column. As the glycol progresses towards the bottom of the contactor, it comes into contact with and absorbs the water in the wet gas stream. The TEG absorbs water from the gas by physical absorption and exits at the bottom of the contactor when it becomes saturated with water. This saturated glycol stream is known as rich glycol. The dry gas stream exits the top of the contactor tower at the required water dew point and is fed to a pipeline system. The wet, rich glycol then flows from the absorption column to a flash vessel where any entrained hydrocarbons are removed. The rich glycol then enters a cross exchanger where it is pre-heated before it is fed to the glycol regenerator. The glycol regenerator consists of a 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, glycol is heated to near its boiling point enabling it to release virtually all of the absorbed water and any other compounds. Finally, the dry lean glycol is cooled via heat exchange and pumped back to the top of the absorption column for the entire process to be repeated (Anyadiegwu *et al*., 2014; Mondal *et al*., 2013). A typical glycol dehydration process is shown in Figure 2.

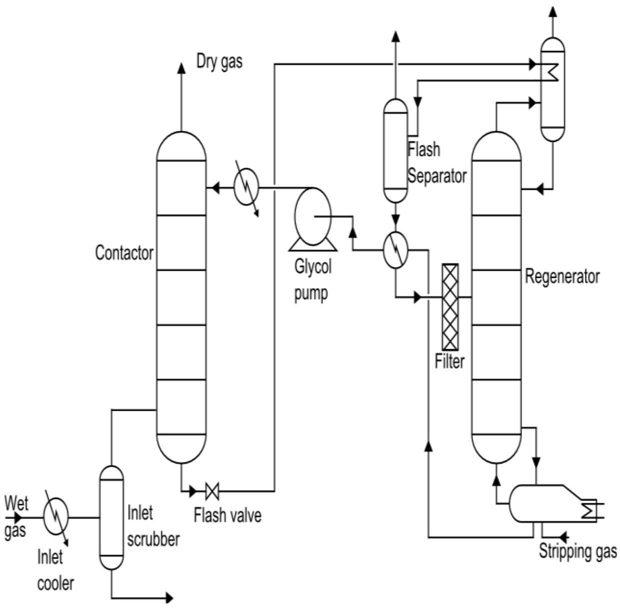

Figure 2 Typical Glycol Dehydration Process (Source: Christensen, 2009)

2 Resources and Methods Used

2.1 Data Acquisition

The basic parameters required for simulation of TEG dehydration of natural gas in Aspen HYSYS are:

- Composition and feed stream conditions of raw natural gas coming from the well;
- Required purity and operating conditions of lean TEG; and
- Design and operating conditions of the plant.

Secondary data on these parameters were obtained from different sources for the purposes of this study. Data on gas composition and feed stream composition from the Jubilee Field were obtained from the Tullow Ghana Limited website. Data on glycol purity is a general standard which must be equal to or higher than 99.5 wt%, and was obtained from literature. Tables 1 and 2 show data on gas composition and operating conditions from the Jubilee Field.

Table 1 Jubilee Field Gas Composition

COMPONENT	MOLE %
Methane	73.565
Ethane	9.325
Propane	9.270
Isobutane	1.463
n-Butane	2.941
Isopentane	0.645
n-Pentane	0.589
Hexane	0.087
Nitrogen	0.770
Carbon Dioxide	1.151
Benzene	0.019
Water	0.080
Toluene	0.006
Ethylbenzene	0.0001
P-Xylene	0.0005
O-Xylene	0.0002
Methylcyclopentane	0.059
Methylcyclohexane	0.019
3-methylhexane	0.007
Total	**100.00**

(Source: Acquah, 2017)

Table 2 Jubilee Field Gas Operating Conditions

OPERATING CONDITIONS	
Pressure	3000 kPa
Temperature	30 ºC
Flow Rate	240 MMSCFD

(Source: Acquah, 2017)

2.2 Resources Used

The Aspen HYSYS software was utilised in the simulation of the TEG dehydration process. Aspen HYSYS is a user friendly, industry-standard simulation program used by researchers, process engineers and engineering companies. Version 8.8 of the software was used for the simulation.

2.3 Methods Used

2.3.1 Process Simulation of the Gas Dehydration Plant

Process simulation is a model-based representation of technical processes and unit operations in software and it can be used for the design, development, analysis and optimisation of processes such as the TEG dehydration plant. Process simulation software describes processes in flow diagrams and solves mass and energy balance equations to find optimal conditions for processes.

2.3.2 Gas Compositional Model

For the purposes of this study, a steady state simulation of the dehydration plant was carried out. The software requires the input of the pure gas components. Therefore, in the first step of the simulation process, the main components of the gas were defined by adding the data on gas stream compositions of this case study.

2.3.3 Selection of fluid package

Following the selection of gas components, a fluid package was selected. The fluid package is the equation of state used by the software to calculate gas stream properties and it is carefully selected depending on the process type and its pressure and temperature range. The fluid package selected in this case is the Glycol Package because it is applicable over the range of temperatures, pressures and component concentrations encountered in a typical TEG dehydration system. The Glycol Package is based on the Twu-Sim-Tasson (TST) equation of state and according to Aspen Technologies, the TST equation of state is suitable for TEG dehydration systems and can accurately predict;

- Activity coefficients of the TEG-water solutions within the absolute deviation of 2%.
- Dew point temperatures within an average error of positive or negative 1 °C.
- Water content of gas within the average absolute deviation of 1%.

2.3.4 Design of Process Flow Diagram

After the fluid package selection was successfully done, the simulation environment was entered. The simulation environment consists of a plain flowsheet where the flow diagram can be designed. The design of the dehydration plant flow diagram was completed sequentially using an available model palette on the flowsheet tab. The built-in model palette is used to select blocks of equipment and stream types to add to the flowsheet. There are two stream types available in Aspen HYSYS, the material stream and the energy stream. Material streams are used to show the travelling of material or fluids between different units of operations and the energy streams are used to show the energy travelling between different units of operations.

The design of the process flow diagram was based on the typical TEG dehydration plant described in Figure 2. The various equipment needed for the dehydration process, including the scrubber, absorber, flash separator, heat exchanger, reboiler, regenerator and pump were selected from the palette and connected by their respective material streams. It is important to define the composition and conditions of the feed stream. In this paper, the feed stream is named inlet gas and its molar composition and conditions are based on the data obtained. The input conditions required are the flow rate, temperature and pressure. HYSYS calculates all other conditions using the selected property package.

It is also necessary to specify certain operating conditions of the various equipment. With this information, HYSYS solves all the mass and energy equilibrium equations taking into consideration the specified design parameters for the unit to produce a product stream. The converged sign indicates that the absorber has been simulated successfully. Figure 3 shows the menu for the absorber unit specified with eight contacting stages. The converged sign indicates that the absorber has been simulated successfully. Figure 4 shows the complete process flow diagram.

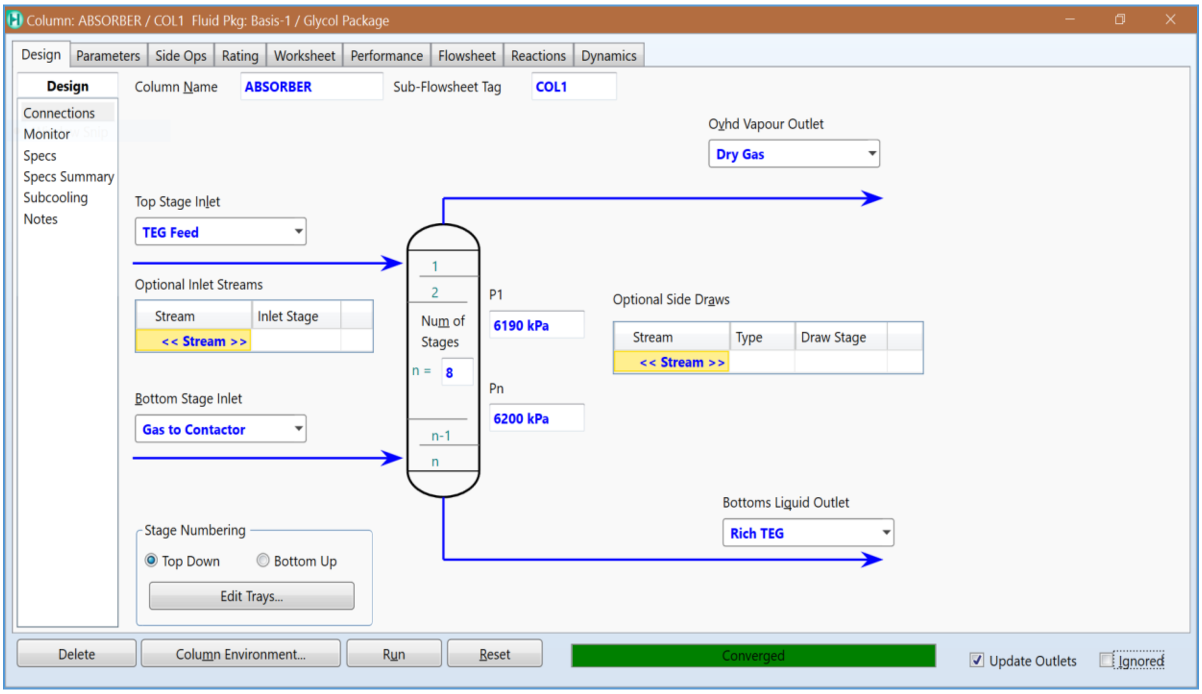

Figure 3 Glycol Contactor Menu

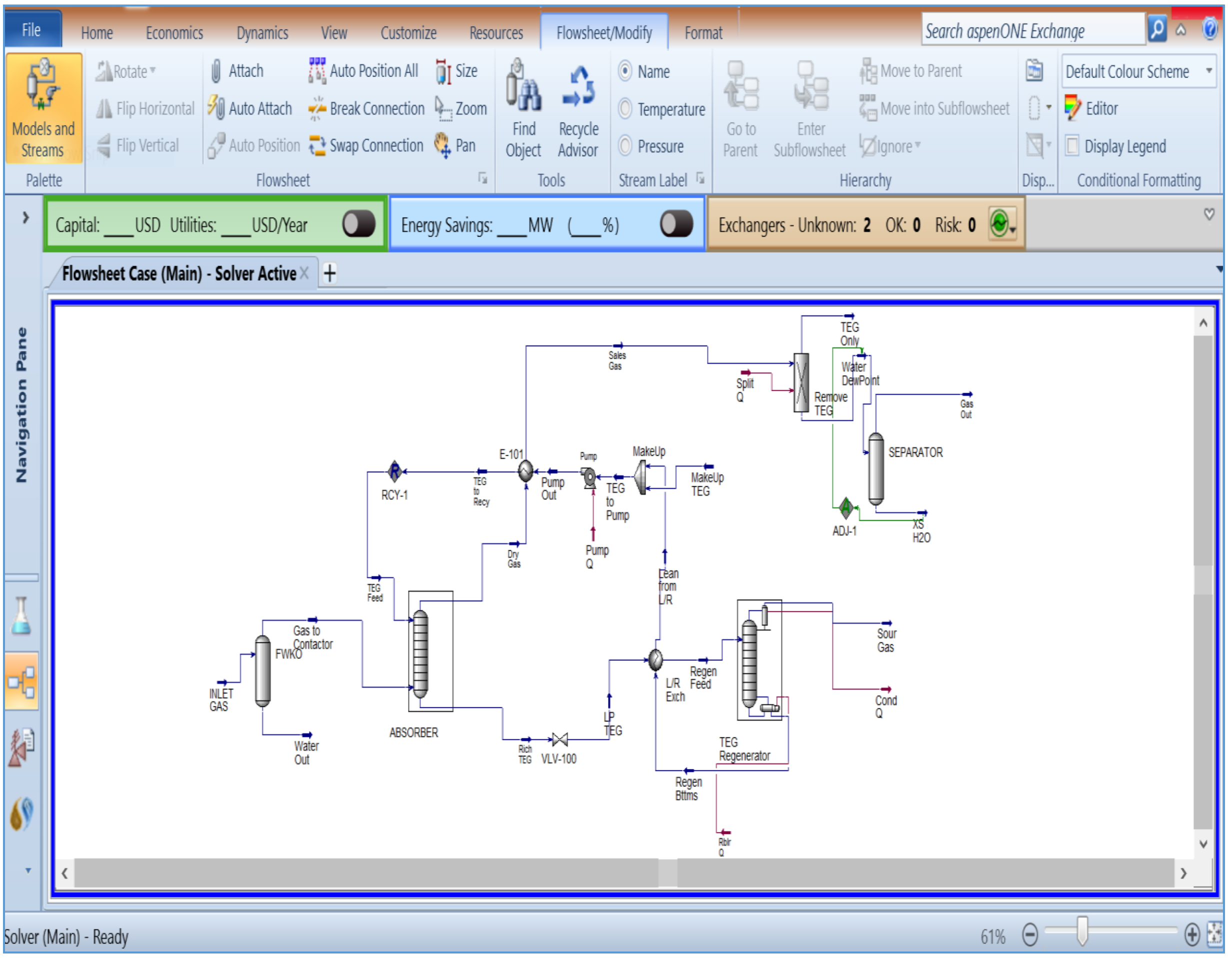

Figure 4 Complete Process Flow Diagram

2.3.5 Simulation Procedure

After the design of the process flow diagram, a simulation process was carried out in which the inlet gas was first passed through a separator to remove any liquid water from the gas stream. The gas was then routed into an absorption column with eight theoretical equilibrium stages. Lean TEG was injected into the contactor at 0.5 m³/hr and 30 °C to flow counter current to the inlet gas and absorb water from the gas. After the dehydration of the gas and further removal of any entrained TEG in a splitter column, the dry gas stream was found to be composed of 4.840 lb/MMSCFD of water at a gas flow rate of 236 MMSCFD. Although this value is within the range of specifications for pipeline quality natural gas and indicates that the processed gas can be transported through pipeline without hydrate forming in the line, it is necessary to investigate the most effective and economical parameters on gas dehydration. Consequently, design and operational variables that affect the gas dehydration process are of utmost importance.

The following parameters were therefore varied to observe their effect on outlet gas water content:

- TEG flow rate;
- Number of equilibrium stages of contactor; and
- Reboiler temperature.

3 Results and Discussion

Pipeline specifications indicate that water content in a processed natural gas stream should be below 7 lb/MMSCFD. The raw unprocessed natural gas stream obtained from the Jubilee Fields contained 0.08 mole percentage of water and at a gas flow rate of 240 MMSCFD and pressure of 3000 kPa, water content translates to 37.988 lb/MMSCF. This is far above the pipeline specification of water in natural gas and therefore necessitated dehydration of the gas stream. Thus, a simulation process was carried out in Aspen HYSYS to dehydrate the natural gas stream. The resulting outlet dry gas stream composed of 4.840 lb/MMSCFD of water at a gas flow rate of 236 MMSCFD. However, TEG flow rate, number of equilibrium stages of contactor and reboiler temperature were varied to investigate their effect on the water content of the outlet dry gas stream.

TEG was flowed at different rates to determine the effect of different flow rates on water content in the processed natural gas stream as shown in Table 3.

With the reboiler temperature fixed at 204 °C, gas pressure at 3000 kPa and TEG temperature of 30 °C, the number of equilibrium stages in the absorption column were varied along with TEG flow rates to observe their effects on outlet gas water content. Table 4 indicates the resulting values for water content with varying number of contractor stages and varying TEG circulation rates.

Based on the research conducted by Arubi and Duru (2008), it has been established that increasing reboiler temperature above 204 °C would result in the thermal decomposition of TEG. Reboiler temperature was therefore simulated between 180 to 204 °C as shown in Figure 5 and 6. Keeping all other operating parameters constant, a simulation was carried out to determine the effect of stripping gas rate on lean TEG purity. Figure 7 shows the relationship between stripping gas flow rate and glycol purity. A stream analysis was therefore conducted to ascertain the possibility of hydrate formation in the stream. Figure 8 indicates the results obtained.

Table 3 Obtained Values for Water Content Using 8 Contactor Stages and Varying TEG Circulation Rates

TEG Flow Rate (m³/hr)	Outlet Gas Water Content (lb/MMSCFD)
0.2	10.156
0.5	4.849
1.0	3.644
3.0	3.618
5.0	3.659
10.0	3.764
15.0	3.871

Table 4 Resulting Values for Water Content with Varying Number of Contactor Stages and Varying TEG Circulation Rates

Number of Contacting Stages	TEG Flow Rate (m^3/hr)	Outlet Gas Water Content (lb/MMSCFD)
4	0.2	12.168
	0.5	6.655
	1.0	4.351
	3.0	3.645
	5.0	3.664
10	0.2	9.778
	0.5	4.521
	1.0	3.599
	3.0	3.617
	5.0	3.659
12	0.2	9.537
	0.5	4.324
	1.0	3.584
	3.0	3.617
	5.0	3.659

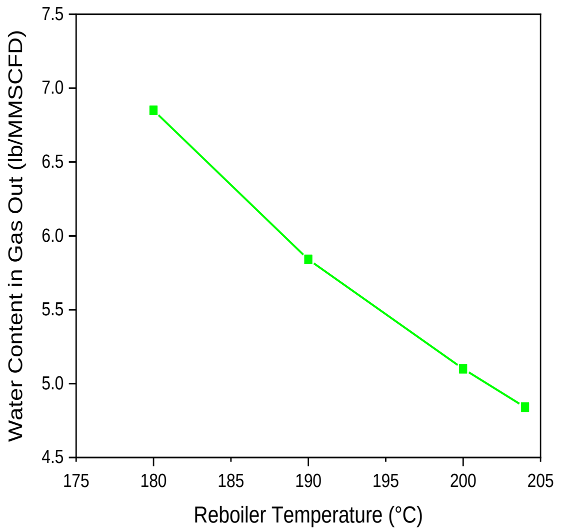

Figure 5 Outlet Gas Water Content against Reboiler Temperature at 8 Contactor Stages and TEG Flow Rate of 0.5 m^3/hr

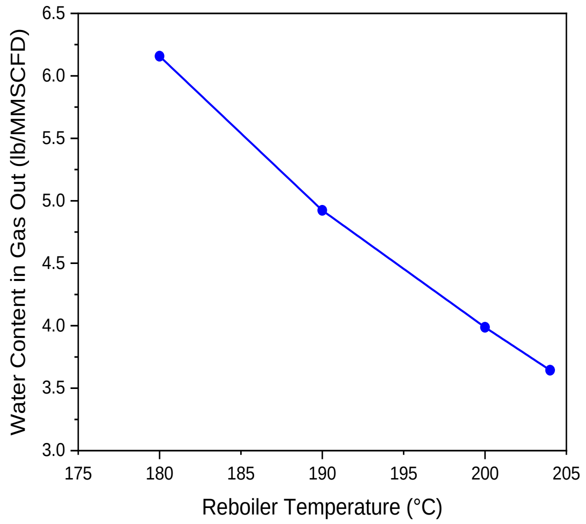

Figure 6 Outlet Gas Water Content against Reboiler Temperature at 8 Contactor Stages and TEG Flow Rate of 1m^3/hr

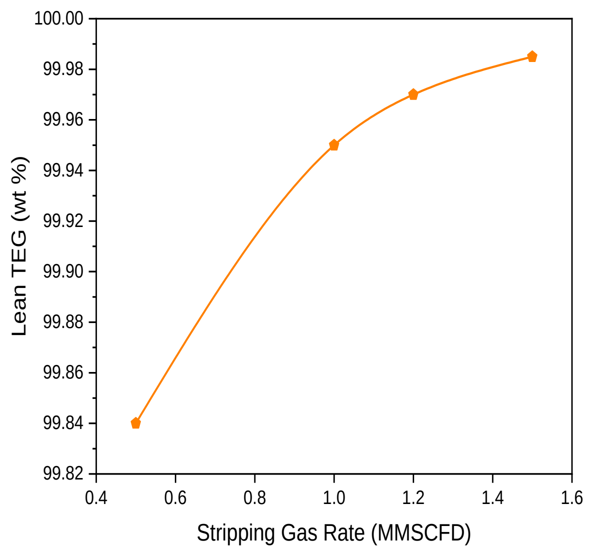

Figure 7 Lean TEG against Stripping Gas Flow Rate

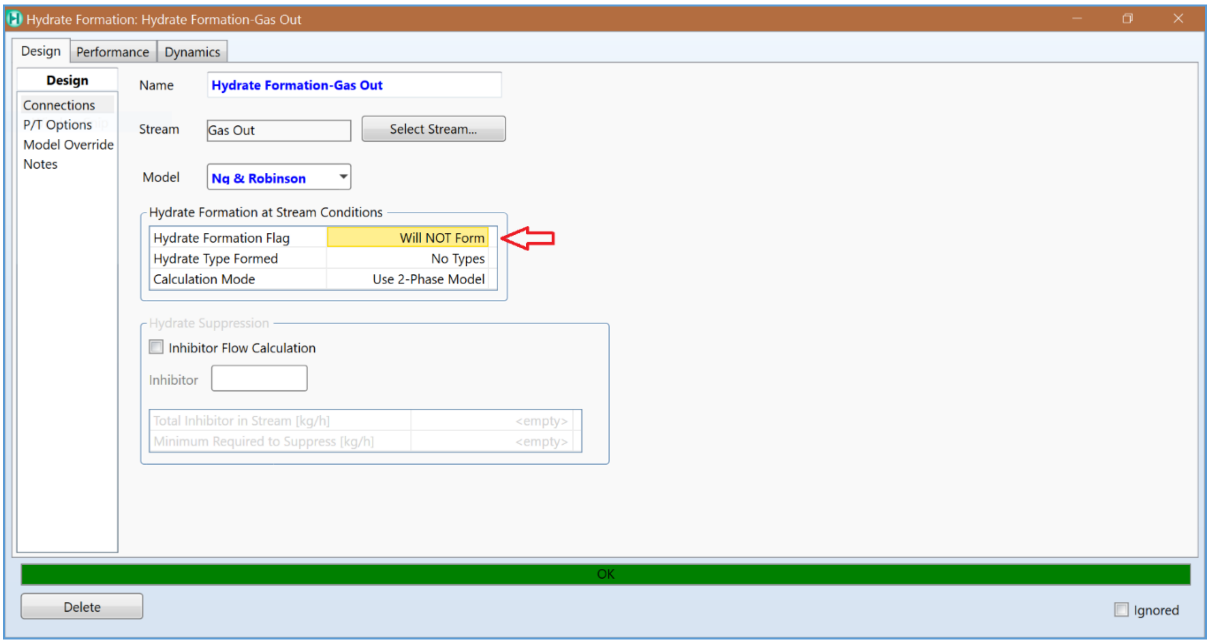

Figure 8 Hydrate Formation Possibility of Gas Outlet Stream

From Table 3, it can be observed that outlet gas water content reduces with high TEG flow rate and increases with low flow rates. However, between a TEG flow rate of 0.5 m³/hr and 3 m³/hr, water content is well within pipeline specifications. It can also be recognised that high TEG flow rates of 5 m³/hr and above do not further decrease water content in the outlet gas stream significantly. Anyadiegwu *et al.* (2014) reported that flooding the contactor with such high amounts of TEG could rather result in a phenomenon called liquid carryover where the excess TEG becomes entrained in the gas stream causing an increase in the hydrate formation temperature. It would therefore not be economical to flow TEG beyond 1 m³/hr given the processing conditions obtained from the Jubilee Field. Similarly, a low TEG flow rate of 0.2 m³/hr would result in water content which do not fall within the range for pipeline quality natural gas and therefore cannot be used.

Table 4 indicates that, increasing numbers of theoretical equilibrium stages of the contactor results in reduced water content of outlet gas regardless of the TEG flow rate. A TEG flow rate of 1 m³/hr for example, results in 4.351 lb/MMSCFD of water in the outlet gas stream at 4 contacting stages, 3.644 lb/MMSCFD at 8 contacting stages (Table 3), 3.599 lb/MMSCFD and 3.584 lb/MMSCFD at 10 and 12 stages respectively. Thus, as expected, a greater number of contactor stages indicates a larger surface area for effective transfer of water from the gas to the glycol. Also, a greater number of trays indicates that the gas would have a higher contacting time in the vessel and would as such lead to more effective dehydration. These results are corroborated by researches conducted by other authors (Anyadiegwu *et al.*, 2014; Arubi and Duru, 2008). It can also be noticed that a TEG flow rate of above 3 m³/hr is uneconomical and leads to liquid loading in the gas because of excessive TEG in the contactor.

From Figures 5 and 6, it can be realised that although the TEG flow rate also determines the extent of dehydration, water content of outlet gas reduces with increasing reboiler temperature. This is because the reboiler temperature largely determines the purity to which the glycol is regenerated. However, reboiler temperature must not be raised beyond 204 °C to prevent breakdown of glycol molecules. This temperature limit also affects the purity of glycol that can be regenerated to less than 98.5%. For this simulation, a glycol temperature of 180 °C resulted in a TEG purity of 96.02%. Operating the reboiler temperature at 190 °C led to a TEG regeneration of 96.96%. Finally, 97.64 and 97.88% of lean TEG were obtained for reboiler temperatures of 200 °C and 204.4 °C respectively.

4 Conclusions

A natural gas dehydration unit was designed with the use of HYSYS software using Jubilee Field gas with compositions and conditions as shown in Tables 1 and 2 to simulate and evaluate the effect of various operating parameters on natural gas dehydration. From the results obtained, it can be concluded that:

a. A natural gas dehydration process has been successfully simulated using Aspen HYSYS and the simulation was efficient as it reduced water content to meet pipeline specifications of 4 – 7 lb/MMSCFD.

b. Different water contents in the final dry gas stream have been obtained for different operating parameters. The TEG flow rate, the number of contacting stages and the reboiler temperature were varied to obtain different dry gas water content that meets pipeline specifications. The ultimate combination to be chosen depends on the most economical option.

c. Based on the simulation conducted, the optimal design is to consider a flow rate of 0.5 m^3/hr of TEG at eight contactor stages and a reboiler temperature of 204 °C. This reduces the water content of the gas stream flowing at 240 MMSCFD from 37.988 lb/MMSCFD to 4.849 lb/MMSCFD, which is within the limit of 4 – 7 lb/MMSCFD.

d. Flow rate of TEG at or below 0.2 m^3/hr will not reduce water content to specified limit and can lead to hydrate formation during pipeline transportation of the gas.

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