Simulation of Typical Natural Gas Dehydration Unit using Glycol Solutions

by

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Dissertation submitted in partial fulfillment of the requirement for the

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(Chemical Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Chemical Engineering Programme
Universiti Teknologi PETRONAS
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Approved by,

____

(AP. Dr. Khashayar Nasrifar)

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Siti Nazira Binti Abdul Ghani

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Last but not least, not to forget to all my colleagues and friends who directly or indirectly involved in this project. Thank you.

ABSTRACT

Natural gas dehydration system used absorption method to remove water vapor in wet gas. Glycol solutions are the commonly used liquid absorbent in dehydration process. There are three types of glycol that are typically used in industries but any of them gives a different water dew point temperature. In this study, a HYSYS model of the plant was developed and used to investigate the important design parameters. Water dew point phase behavior was determined for different types of glycol solutions. The investigation revealed that triethylene glycol (TEG) system is adequate to condition the gas to achieve a lower water dew point. At the other hand, study was done on improving the glycol-water absorption rate by varying the glycol flow rate, number of equilibrium stages, reboiler temperature as well as the inlet gas temperature. Lastly, comparisons between theoretical and simulation results are justified to determine whether it shows a good validation of the result to meet the requirements of current industry practices.

In today’s competitive economy, Engineer must become as productive as possible. One means of increasing this productivity is to use process simulation packages. Hence this paper looks for proffer solution options for optimizing and maintaining the natural gas dehydration plant by using HYSYS simulator software.

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CHAPTER 1: INTRODUCTION

1.1 Project Background

Natural gas is a naturally occurring hydrocarbon gas found in geologic formation beneath the earth's surface. The main composition of natural gas is methane and the minor compositions are ethane, propane, butane, and pentane. Non hydrocarbon gases such as carbon dioxide, hydrogen sulphide, nitrogen, water and various mercaptans also come along with small traces of other organic and inorganic compound.

Natural gas contains water in varying amounts dependent on the upstream conditions. This water is naturally present in the gas form, originating from the reservoir. Water in natural gas can create problems during transmission and processing. The most severe problem is the formation of gas hydrates or ice which may block pipelines, process equipment and instruments. Corrosion of materials in contact with natural gas and condensed water is also a common problem in the gas processing industry (P. Kazemi, R. Hamidi, 2011).

Dehydration of natural gas is removal of water that is mixed with natural gas in vapor form. Dehydration is necessary to ensure smooth operation of gas transmission lines as well as to meet water dew point requirement of a sales gas contract specification which is range from 32.8 to 117 kg/10^6 std m^3 (K. Kolmetz, 2010). Unless gases are dehydrated, liquid water may condense in pipelines and accumulate at low points along the line, reducing its flow capacity.

There are three most common methods for dehydration of natural gas which are absorption using glycol solutions, adsorption on solid (i.e silica gel/molecular sieve) and condensation by combination cooling and chemical injection (ethylene glycol/methanol). Absorption by triethylene glycol (TEG) is the most frequent method used to meet pipelines sales gas specifications. Glycol is a common name for diols and with the two alcohol parts within the bonding these substances have high affinity with water (Perry R. H., 2006). Triethylene glycol (TEG), diethylene glycol (DEG) and ethylene glycol (EG) are the common used glycol in industries. And among these, triethylene glycol (TEG) has gained collective acceptance as the most effective glycol type because:

- TEG is more easily regenerated to a concentration of 98-99% in an atmospheric stripper because of its high boiling point and decomposition temperature.
- Vaporization temperature losses are lower than EG and DEG
- Capital and operating cost are lower

1.2 Problem Statement

Dehydration is important in natural gas processing industry to avoid hydrate formation as well as to minimize the pipelines corrosion. Upon natural gas dehydration process, the dew point of the wet gas decreases with the degree of lowering the water content of the gas. In a gas transmission line a water content of 6-10 lb/mmscf (96-160) kg/m3) giving a gas dew point of -2°C to -9°C is accepted (R. Selamat, 2009). TEG absorbent is chosen among the other type of glycols as it is extremely stable to thermal and chemical decomposition, easy to regenerate and available at moderate cost.

However, glycol absorption rate depends on types of glycol used and variables such as circulation rate, number of stages, amount of carbon dioxide content and regeneration temperature. For instance, as the glycol circulation rate increases the amount of water content in dry gas (sales gas) is decreases. This leads researchers to find alternative methods that are economically justified without compromising on the required sales gas specifications.

One possibility is by performing the analysis on the alternatives glycol and optimizing the natural gas dehydration plant using Aspen HYSYS software. By conducting this simulation study, the most effective types of glycol will be determined and the optimum parameters for natural gas dehydration plant will be investigated.

1.3 Objectives

The objectives of this study are:

- To study the effect of different types of glycol
- To investigate the effect of operating parameters on the efficiency of the process

1.4 Scope of Work

- Investigating and validating the different experimental data from journals
- Modeling the natural gas dehydration plant using Aspen HYSYS
- Investigating the effectiveness of every glycol solutions and analyzing the optimum parameters which gives the minimum water content in sales gas

1.5 Feasibility of Study

Throughout this study there are several phases that will be done during completing the project:

I. Research based on literature review on natural gas dehydration process from multiple types of sources
II. Identifying and collecting all the required data needed before proceed with the plant modeling
III. Comparing and validating of all the collected data. The data were tested in terms of their feasibility and later to be used as input in executing the simulation process.
IV. Conducting the simulation using different types of glycol and optimizing the gas dehydration plant built in order to achieve the minimum water content in sales gas. The best modified data will be reported as the final outcome of this project.

CHAPTER 2: LITERATURE REVIEW

2.1 Gas dehydration unit overview

Basically, there are three reasons of having natural gas dehydration plant. (H. K. Abdel-Aal et al, 2003):

I. To prevent hydrate formation:
   Hydrates are solids formed by the physical combination of water and other small molecules of hydrocarbons. They are icy hydrocarbon compounds of about 10% hydrocarbons and 90% water. Hydrates grow as crystals and can build up in orifice plates, valves and several other downstream equipments. Hydrates formation can plug lines and delayed the flow of gaseous hydrocarbon streams.
II. To avoid corrosion:
   Water vapor that dissolves in hydrogen sulphide in natural gas can form acidic solution. This acidic solution will then reacts with carbon steel in the pipeline to caused corrosion.
III. Downstream process requirement
   In most commercial hydrocarbon processes, the presence of water may cause side reactions, foaming, or catalyst deactivation. As s result, purchasers typically require that gas and liquid petroleum gas (LPG) feedstocks meet certain specifications for maximum water content.

A typical dehydration process in natural gas processing plant can be divided into two major parts, gas dehydration and absorbent regeneration. In dehydration process, water is removed from the gas using glycol and in the regeneration; water is removed from the absorbent (glycol) before it can back to the absorption column. General gas processing plant dehydration unit consists of absorption column, flash tank, heat exchangers, inlet scrubber and regenerator. Typical dehydration unit in gas processing plant is shown in Figure 2.11 below:

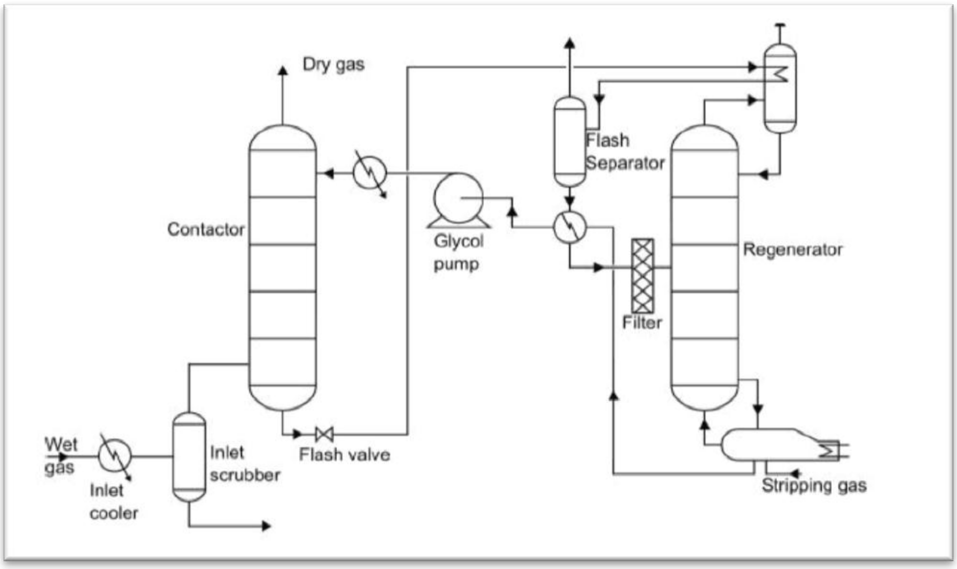

Figure 2.11: Typical gas dehydration unit in gas processing plant (D. L. Christensen, 2011)

During the process, the lean glycol fed to the absorption column through the top side while the rich glycol is collected at the bottom of the column before being sent to the regenerator. Wet gas enters to the absorption column after it passed the scrubber. In the absorption column, the up-flow of wet gas will be in contact with down-flow of lean glycol. During this process, the lean glycol will absorb water from wet natural gas and flow down to the bottom of the absorption column as rich glycol. Rich glycol passes through a coil, which is used as reflux at the top of the absorption column to increase its temperature. A three phase splash tank uses for removal of absorbed acidic gases and hydrocarbons in glycol before the rich solvent is fed to the regenerator. At the end of the process cycle, the regenerated glycol will cool in heat exchanger and will back to the top of absorption column for reuse.

2.2 Glycol Selection as the Absorbent Medium

Glycol used in this process is a thermodynamic inhibitor type or called as hydrate antifreeze where it works by changing the thermodynamic properties of the fluid system, thereby shifting the equilibrium conditions for gas hydrate formation to lower temperatures or higher (James G. Speight, 2006). This glycol selection for natural gas dehydration may be based on number of factors including dehydration capability, glycol losses in the contactor and regenerator and absorption of VOCs

(I.M.T Arui et al., 2008). The basic principle of absorption capability of glycol and other absorbent such as methanol in removing water vapor from gas lies in its chemical structure. Each of these molecules of the absorbents contains hydroxyl groups (OH) whereby they will form hydrogen-bonds with the water molecules (M. A. Huffmaster, 2004). Thus, water vapor molecules contain in wet gas will be easily attracted to the absorbent once a direct contact occurred between them.

The most commonly used glycol in the industry are triethylene glycol (TEG), diethylene glycol (DEG) and ethylene glycol (EG) however, DEG and EG are often not considered due to dry gas requirements. By using EG and DEG instead of TEG, it is an environment concern since it can greatly reduce BTEX emissions, thus reduce emissions from the glycol still vent (Braek et al,. 2001). TEG offers the best cost beneficial compromise, and is the most widely used (Manning and Wood, 1993). Even though it is marginally more expensive than DEG, but it brings much less losses due to lower vapor pressure. It also has higher affinity towards water but lesser than tetraethylene glycol (TREG). Conversely, TEG is easily regenerated since it has a higher decomposition temperature of 204°C and is not too viscous as the temperature is above 4°C (Manning and Thompson, 1991). Thus it is suitable to be used with broad range of temperatures for the process. Table 2.21 below describes the properties of different types of glycol.

Table 2.21: Properties of glycol

	Degradation T (°C)	**Boiling point (°C)**	**Melting point (°C)**	**Molecular wt (kgmole)**	**Viscosity (cP) @10,20,60 (°C)**
EG	165	197.3	-13	62.1	34, 21, 5
DEG	164	244.8	-85	106.1	70, 38, 9
TEG	206	285.5	-7	150.2	93, 48, 10

2.3 Factors affecting gas dehydration process

Gas absorption process using glycol is affected by several factors especially the system design and operating conditions. When optimizing the design of dehydration facilities, the impact of the following parameters should be considered (J. P. Nivargi, 2008):

- Number of trays in glycol contactor
- Glycol circulation rate through absorption column
- Temperature of the reboiler in the regenerator
- Amount of stripping gas used
- Operating pressure of the regenerator
- Carbon dioxide content in the feed gas

In addition to the design parameter listed above, several other factors influence the residual water content of the sales gas. First, the temperature of the inlet gas will impose the total amount fed to the unit. Usually, lower inlet temperature requires less water to be removed by the glycol. Second, the lean glycol (dehydrator) temperature at the top of the absorption column will affect the partial pressure of water at the top stage. However, this temperature is normally no cooler than -12.2˚C above the inlet gas to prevent hydrocarbons in the feed from condensing in the solution.

The amount of water to be removed from the gas depends on the lowest temperature at which the gas will be exposed in the pipeline. This is due to the reason that as the gas temperature reducing, the water vapor in it tends to condense into liquid that later will increase the tendency of hydrate formation in the pipelines. The point where the water vapor starts to condense is known as dew point. This dew point acts as an indicative of the quantity water vapor present in the gas stream.

2.4 Methods of calculating water content based on empirical formula (T. V. Lokken)

Various simple empirical models have been developed for the calculation of water content of natural gas. The simplest model is based on functions fitted to the experimental data for the vapor pressure of pure water. In an ideal gas the water content will be directly given by the vapor pressure of water and the total pressure. However, such models will generally be invalid for pressure higher than typically 10 bar. The maximum pressure will depend on how ideal the gas mixture behaves.

Some empirical models correct for the non-ideality of the gas by fitting the model to high pressure experimental data. Such models can give reasonable results at higher pressures, but will in general be limited to gases with similar composition as what was as experimental basis. The popular method published as a standard for defining the relation between water content and water dew point of natural gas (ASTM D1142-95) was developed by Bukacek. The equation is on the form $W = A/P + B$; where W is the water content, P is the total pressure, A is a constant proportional to the vapor pressure of water and B is a constant depending on temperature and gas composition. The effect of gas composition is indirect corrected for by multiplying the B factor with a term dependent on gas gravity.

Thermodynamic models based on equation of state (EOS) for calculating water dew point and water content in natural gas can be relatively complex and computers have to be utilized in doing efficient calculations. However many of the developed models have been shown to give accurate predictions of water dew point for large number of gas compositions and total pressures. Some of the popular equations of state like Peng-Robinson, Glycol package, and SRK often used in the oil and gas industry.

Most modern equations of state are developed by fitting parameters to experimental data for both pure components and mixture. The advantages of methods based on fundamental thermodynamic models are that they are expected to cover a larger range of gas compositions, temperatures and pressures.

CHAPTER 3: METHODOLOGY

This project is developed in two main phase which are construction of plant simulation and development of gas dehydration performance analysis to obtain the minimum water content.

3.1 Project work

In analyzing gas dehydration system performance, the plant simulation is modeled first by using process simulation software. In this step, Aspen HYSYS is selected as a medium to carry out the simulation process. It is essential to have a model that reliable in representing gas dehydration system because some data is unavailable from the existing plant and only available from the HYSYS package and model. To achieve the objective of this project, the plant simulation used the actual operating parameters, gained from the journals and some literature review works that have been done previously. Plant simulation that is using the plant actual operating parameters will able to represent the real simulation of current plant operations. To obtain the confidence and more accurate results, the estimated operating parameters gained from the simulation will be adjusted and modified. Every changes made will be recorder and the outcome will be analyzed.

Most of the gas processing plants in the entire world are using TEG dehydration to reduce the water content in processed gas. It is important to meet the sales gas specification as it has less water content and favorable to buyers. TEG dehydration is a gas-liquid absorption process. TEG in liquid is passed through wet gas in a contactor and water is removed from wet gas to TEG due to different water content driving force. This dehydration performance is analyzed in several essential areas such as wet gas volume, outlet dry gas water content and lean TEG concentration.

This project will be conducted based on three separate components. Firstly, it will start with the construction of gas processing plant dehydration unit model in HYSYS. Secondly, the integration of model with current operating variables. Last but not least, the project will go on with variables alterations and modifications to obtain the minimum water content in the processed gas. The capability to calculate engineering calculations such as absorption system performance rise from the availability of estimated value from reliable simulation model and current operating value. Figure 3.1 below shows the gas dehydration plant that has been converged in Aspen HYSYS.

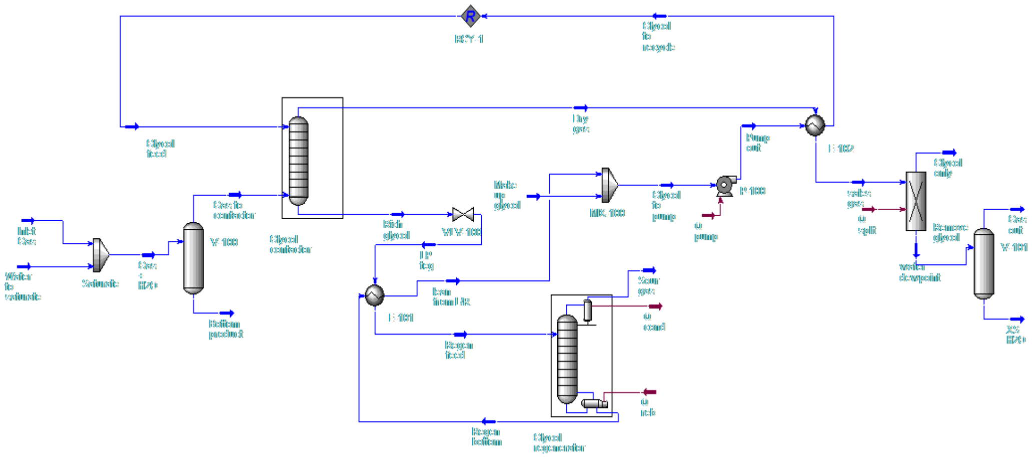

Figure 3.1: Gas dehydration unit modeled in HYSYS

3.2 Project methodology

Project activities will be categorized into two main phases which are the plant simulation and gas dehydration performance analysis. Plant simulation required validation process to ensure its robustness, practicability with current plant operations and accurate simulation. On analysis phase, scope of analysis will be identified based on familiarization of glycol dehydration system and current operations practice. Analysis should be reasonable to engineers as the project objective is to maintain the amount of water content in processed gas at the very minimum value.

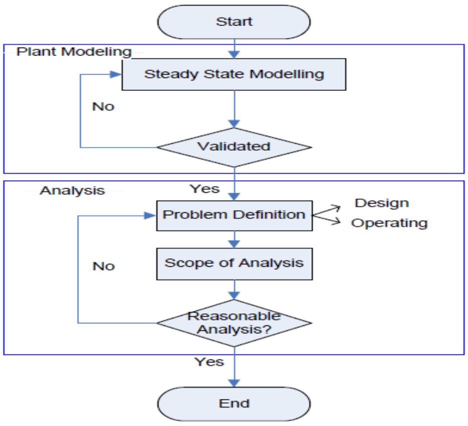

Figure 3.2: Project methodology

3.3 Project activities

Phase 1: Plant simulation

i. Overview of Gas Processing Plant

   Background study on existing plant has been carried out. Several journals, reference books and online articles that are related to plant operations are studied and condensed together in the literature review section. Data has been gathered based on existing plant operations.

ii. Simulation of dehydration unit

   By taking the data from existing plant, simulation of gas dehydration unit were carried out using Aspen HYSYS software.

Phase 2: Gas dehydration performance analysis

i. Based on the input data from existing plant, HYSYS will be able to calculate the real simulation of current plant operations. The operating parameters are varying and their effects on the amount of water content in dry gas are investigated.
ii. In performing any system performance analysis, familiarization is required to understand the key area and calculation in the system. By understanding the system, it is easier to identify analysis area scope and noted the reasonable variables that require attention and calculation. The analysis should be easily understandable and reasonable to all parties in order to identify any problems and opportunities lies within the current operations.

3.4 Project tool

Aspen HYSYS

- Aspen HYSYS is process simulator software that enables plant operations simulation in mostly on process area. The software is a powerful simulation tools especially in material and heat balance, flow estimation and unit operations.

3.5 Key milestone

Table 3.51: Key milestone of the project

Milestones	Planned Timescale	Commentary	Progress
Project work continues	Week 1-2	Meeting with supervisor weekly to update the progress	Done
Plant modeling using Aspen HYSYS	Week 3-4	Constructing and evaluating the experimental data by modeling it in Aspen HYSYS	Done
Data validation	Week 5	Data from 4 journals were run in Aspen HYSYS and the results are compared with the theoretical result	Done
Plant optimization	Week 6-7	The HYSYS model is modified and evaluated based on several variables	Done
Progress report	Week 8	Writing and submitting the progress of the work to the supervisor	Done
Project work continues	Week 9-10	Optimization study on the HYSYS model continued to achieve the minimum water content in sales gas	Done
Pre-EDX	Week 11	Poster presentation	Done
Submission of draft report	Week 12	Submission of report to the supervisor and coordinator	Done
Oral presentation	Week 14	Final year project presentation	

3.6 Proposed Timeline for Activities, and Deadlines

Table 3.61: Gantt chart

Detail/Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14	15
Project Work Continues								**Mid-semester break**								
Submission of Progress Report									●							
Project Work Continues																
Pre-EDX												●				
Submission of Dissertation (soft bound)													●			
Submission of Draft Report														●		
Submission of Technical Paper														●		
Oral Presentation															●	
Submission of Project Dissertation (Hard Bound)																●

CHAPTER 4: RESULTS AND DISCUSSIONS

HYSYS is provided with rigorous property packages, which includes thermodynamic and physical property models, component libraries, oil characterization module, extensive unit operations models, case study tools and excel-like spreadsheet for customized programming. It is user-friendly, vigorous and flexible. With HYSYS, process optimization and modification are easily achievable within a shorter period of time. The first step in building HYSYS simulation model is the fluid package definition.

For the purpose of this simulation, the Peng-Robinson's (PR) equation of state was used. The choice of PR over other property method is because of its high level of accuracy over a wide range of conditions and applications. It is vigorously solves most single, two, or three phase systems with a high degree of efficiency and consistency.

The inlet data used in the simulation are based on the conditions resemble one of the paperwork in Iran Plant (J. P. Nivargi, D. F. Gupta, 2010) as shown in Appendix I. The flow rates, composition and other operating conditions of the streams as well as the process flow diagram (PFD) are presented in Appendix II.

The efficiency of dehydration simulation using the PR thermodynamic package is evaluated by the water content in the dry gas and the purity of glycol regenerated. In the following discussion, the effect of different types of glycol in dry gas water content as well as the impact of operating conditions is gas dehydration unit is address.

4.1 Effect of different types of glycol

The overall outcomes of simulation run for different types of glycol are to be compared with each other. These data are compared in terms of their ability in dehydrating the wet gas at the most minimum level of water contents remained in the dry gas after it leaves the contactor. The most significant comparison was done using the P-T diagram (phase envelope diagram) in order to compare the water dew point of the natural gas. Based on the literature, one can tell that the lower the pressure at constant temperature, the greater the water possible in the gas. Table 4.1 below illustrates the effect of different type of glycol on residual water content in dry gas.

Table 4.1: Residual water content on different types of glycol

Glycol	**Degradation temperature (°C)**	**Water fed (mass fraction)**	**Residual water (mass fraction)**	**Percentage water removed**
Ethylene glycol (EG)	165	0.002	0.0015	25 %
Diethylene glycol (DEG	164	0.002	0.0009	55 %
Triethylene glycol (TEG)	204	0.002	0.0002	90%

The performance of each of these absorbent in gas dehydration unit is investigate in terms of the water dew point and water content remaining in the dry gas after it passed through the contactor. Figure 4.11 shows the P-T diagram (phase envelope diagram) of the EG solution. The initial water dew point for gas dehydration unit was -40°C. After the wet gas is passed through the contactor with EG absorbent, the dew point of water becomes -20°C. At this condition, the water content of natural gas has been reduced significantly while reducing the water dew point temperature as well.

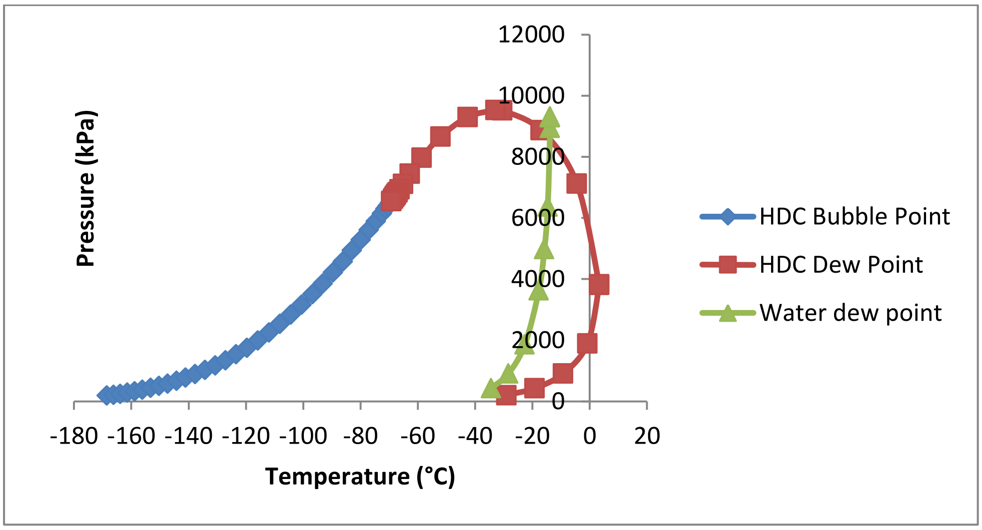

Figure 4.11: P-T diagram of EG solution

As for figure 4.12 and 4.13, it shows the P-T diagram for DEG and TEG solution. Based on the plot, TEG showed the most significant changes of water dew point curve followed by DEG. The water dew point curve in TEG solution has been shifted to the most left side of hydrocarbon dew point resulted in large amount of water dew point depressions. Thus it is proven from the literature review that largest water depression are gained from TEG compared to the other two absorbent solutions. From observations, the dry gas from contactor (absorption column) can operate at lower temperature since the water dew point has been shifted to the lower temperature. This is due to the reason that at higher temperature greater than dew point temperature, the gas is under-saturated with water and will not form in aqueous phase. Under this condition, water vapor will not evolve into free water that later will not promote the formation of gas hydrate.

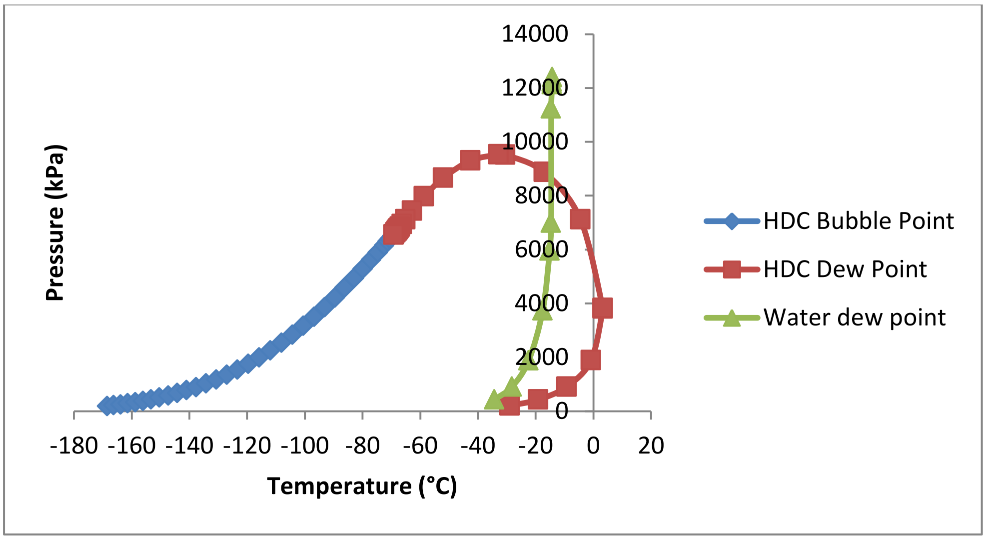

Figure 4.12: P-T diagram of DEG solution

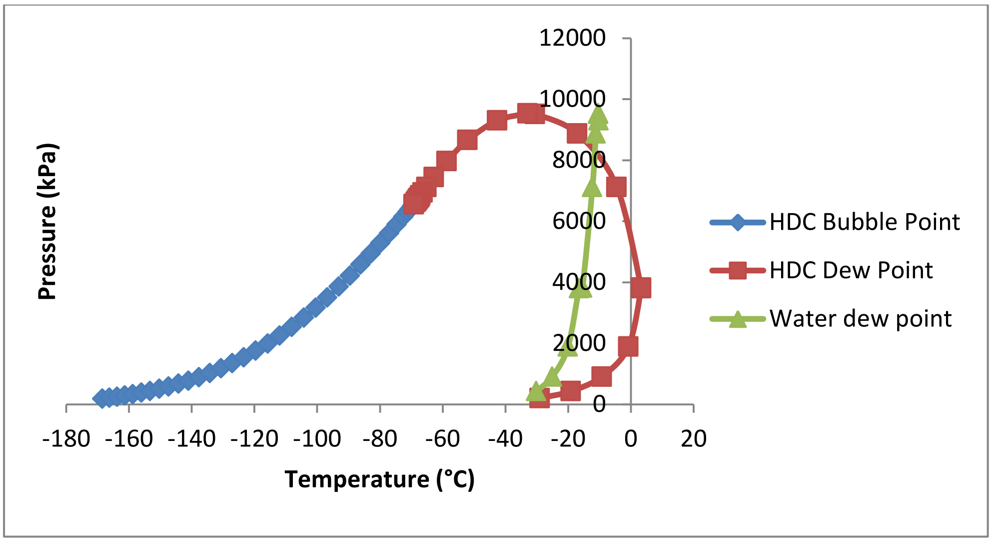

Figure 4.13: P-T diagram of TEG solution

Table 4.12: Summary of water dew point

Glycol	**Dew Point Before Absorption Process (°C)**	**Dew Point After Absorption Process (°C)**	**Percentage Glycol Recovered**
Ethylene glycol (EG)	- 40	- 20	97.92 wt %
Diethylene glycol (DEG	- 40	- 18	98.92 wt %
Triethylene glycol (TEG)	- 40	- 10	99.99 wt %

Based on Table 4.12, the changes between water dew point of three different types of glycol and its percentage recovery are investigated. As shown in the table, the recovery for TEG solution is higher compared to EG and DEG solutions. This showed that TEG used in absorption process meets the criteria needed to be as liquid desiccant as it has high affinity with water, easily to be regenerated and low affinity towards other component in the wet natural gas.

From the simulation run using HYSYS, it showed that there are only small variations of the hydrate formation between these three glycol solutions since the hydrate formation is controlled by lighter components and the major component of natural gas is methane that are not removed in the dehydration process. Meanwhile, the heavy components of the hydrocarbon are still remaining in the dry gas after the dehydration process occurs.

4.2 Effect of Operating Conditions on the Efficiency of Gas Dehydration System

Analyses were done on the effects of the operating conditions toward the efficiency of the gas dehydration process. As stated in the literature review part, natural gas dehydration unit typically represented by a contactor, a flash drum, and a regenerator as shown in Figure 3.1 in previous chapter. The optimization study was done on TEG only because TEG gives a better absorption rate compared to EG and DEG as elaborated in section 4.1 of the report. The outcome data from simulation that is in terms of water content remaining in the gas after it passes through the gas dehydration unit is being manipulated by several parameters. These parameters are number of equilibrium stages in contactor, glycol circulation rate, reboiler temperature, inlet gas temperature and high carbon dioxide, CO_2 content in inlet gas.

4.21 Effect of Number Equilibrium Stages in the Contactor

Figure 4.21 illustrates the effect of number of equilibrium stages on residual water content of the dry gas exiting the contactor using a 202°C reboiler temperature to regenerate the TEG. It can be seen that increase in number of stages of the contactor allows more water to be absorbed from the wet gas therefore reducing the residual water content in dry gas. A lower TEG circulation rate with higher number of stages is required compared to those with lower number stages because higher number of stages allows gas to reach equilibrium with the lean glycol at a lower circulation rate of TEG. Significantly, higher flow rates of TEG would still be required when one ideal stages is used (I.M.T Arui et al., 2008).

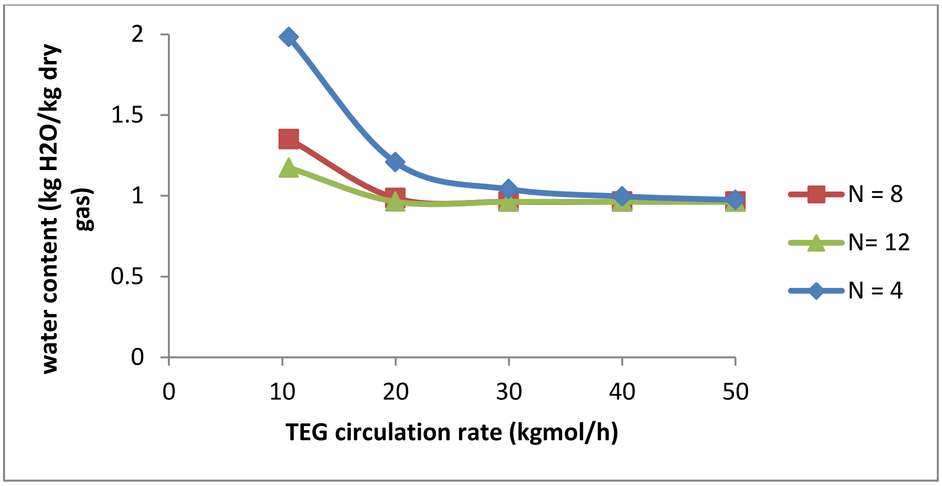

Figure 4.21: Effect of number of equilibrium stages on residual water content

4.22 Effect of Reboiler Temperature

Increasing the reboiler temperature to 204°C will lead to thermal decomposition of TEG. A reboiler temperature of 180, 190 and 200°C were simulated. Figure 4.22 illustrate the residual water content of the dry gas from the contactor outlet with respect to the reboiler temperature of the regenerator used to regenerate the rich TEG. The reboiler temperature influences the overhead water content by changing the purity of the TEG thus improve its absorbent capacity as well. Glycol purities of 97.0 wt %, 98.0 wt % and 99.1 wt % were obtained at 180, 190 and 200°C reboiler temperature respectively. Higher reboiler temperature will produce higher purity of regenerated TEG to absorb more water from the wet gas.

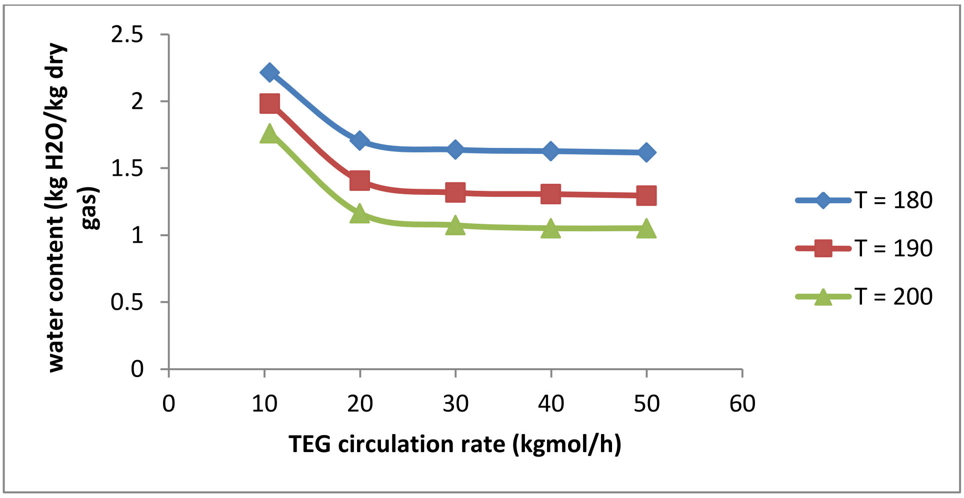

Figure 4.22: Effect of reboiler temperature on residual water content

4.23 Effect of Inlet Gas Temperature

In addition to the parameters listed above several other factors influence the residual water content of the sales gas. However, these factors are usually fixed and cannot be changed when optimizing the unit. Figure 4.23 below dictate the effect of inlet gas temperature to the residual water content. The temperature of inlet gas actually will affect the total amount of water fed to the unit. Based on the plot, it shows that lower inlet gas temperature gives a lesser quantity of water in overhead gas. Lower inlet gas temperature will require less water to be removed by glycol. Likewise, the lean glycol temperature at the top of the contactor will dictate the water partial pressure at the top stage. As a result, high glycol temperatures will cause high water content in the overhead gas. Thus, the temperature of the lean glycol should be at its designed range to avoid high water content in the sales gas.

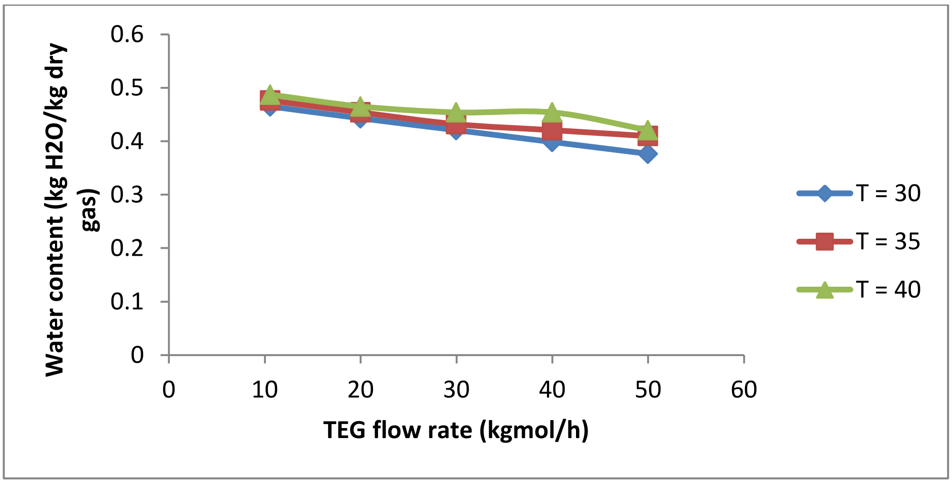

Figure 4.23: Effect of inlet gas temperature on residual water content

4.24 Effect of TEG Flow Rate in the Contactor

Lower water dew point of the gas is needed in pipelines transmission and other downstream process. The amount of residual water content in the dry gas will affects the overall dew point depression. From figure 4.24 below, it can be seen that higher TEG volume flow rate cause higher water dew point depressions. This is due to the reason that that higher TEG volume flow rate will give higher degree of contact between the wet gas and TEG. Hence it enables more TEG to be hydrogen-bonded with water molecules thus absorb them and reduce the dry gas dew point as well.

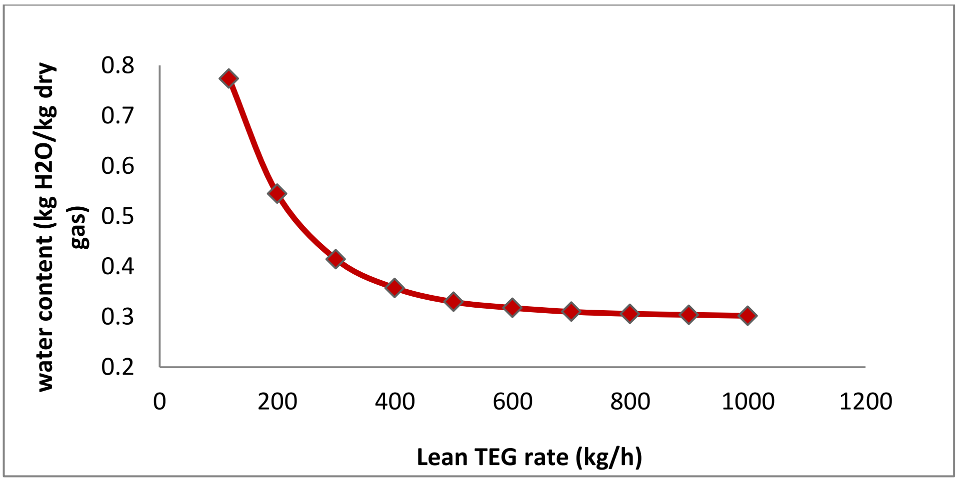

Figure 4.24: Effect of TEG circulation rate on residual water content

4.25 Effect of High Carbon Dioxide, CO_2 Content in Inlet Gas

Theoretically, increasing the CO_2 concentration in feed gas leads to higher amount of residual water content in sales gas. In this study the amount CO_2 concentration fed in the contactor is increased while methane, CH_4 concentration is reduced. Figure 4.25 illustrates the effect of CO_2 concentration on the residual water content. The results indicate that increasing of CO_2 concentration slightly increased the water content in dry gas. This is due to the reason of oxygen molecule in CO_2 being bonded to the water hence increase the water amount. Practically, the sour gas with high CO_2 content should be treated with amine unit first before it passed to the dehydration unit (Vincent N. Hernandez, 2011).

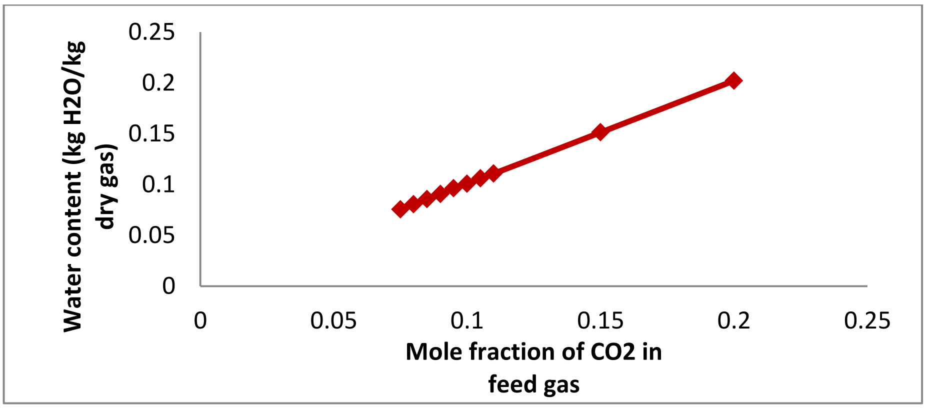

Figure 4.25: Effect of high carbon dioxide, CO_2 content in inlet gas

4.3 Equilibrium Correlations for Predicting Water Dew Point

Comparisons between the theoretical data and simulation data for each of the water dew point temperature with respect to its regenerated TEG are done for several other TEG concentrations. The outcome results from simulation are compared with the theoretical data calculated using the equation and coefficients given relate between the water dew point of the dry gas with respect to the concentration of regenerated TEG. Tables 4.31-4.32 show the difference between the theoretical and simulation data.

Table 4.31: Comparisons of water dew point from simulations and theoretical for concentration 90 wt % - 99 wt % TEG

TEG concentration (wt %)	Temperature dew point theoretical (°C)	Temperature dew point simulation (°C)	Temperature Difference (°C)
93.045	36.60	33.7	-2.88
95.78	30.84	28.48	-2.36
96.95	25.01	23.68	-1.33
97.78	19.89	19.18	-0.71
98.87	12.11	11.03	-1.08
98.89	11.43	11.34	-0.09
98.98	8.08	6.78	-1.3

Table 4.32: Comparisons of water dew point from simulations and theoretical for concentration 99wt % - 99.999 wt % TEG

TEG concentration (wt %)	Temperature dew point theoretical (°C)	Temperature dew point simulation (°C)	Temperature Difference (°C)
99.91	-28.56	-31.40	-2.84
99.968	-33.29	-34.48	-1.19
99.976	-36.57	-40.13	-3.56
99.981	-40.25	-41.11	-0.86
99.99	-48.25	-45.12	3.13
99.995	-48.35	-45.19	3.16
99.9989	-57.28	-50.23	7.05

Based on the tabulated results, these data are comparable with each other and fairly accurate since the deviations between the simulation and theoretical data are satisfying because the percentage difference between these two data are not exceeding 10% difference and thus it is considered as acceptable for industrial practice. Figure 4.31 and 4.32 depicted the difference between the theoretical and simulation data in scatter plot.

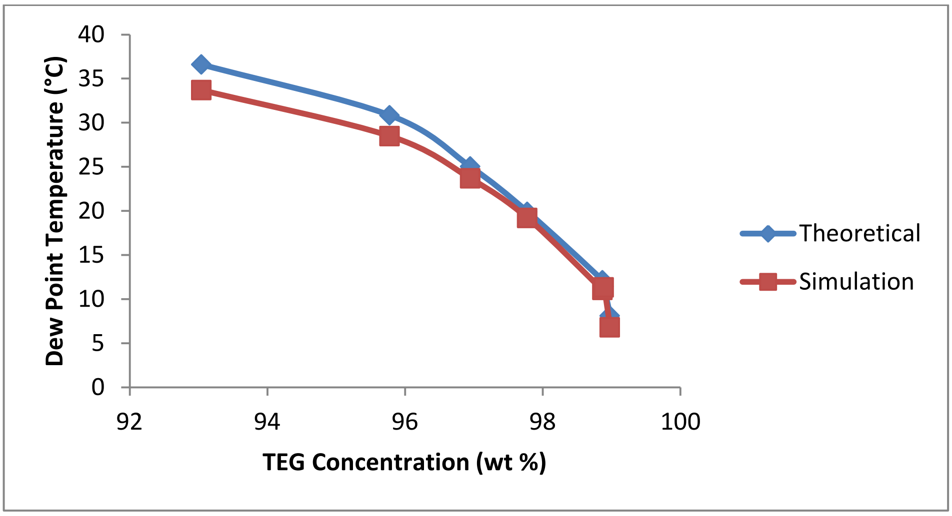

Figure 4.31: Comparison water dew point temperature from simulation and theoretical for concentration TEG 90 wt % - 99 wt %

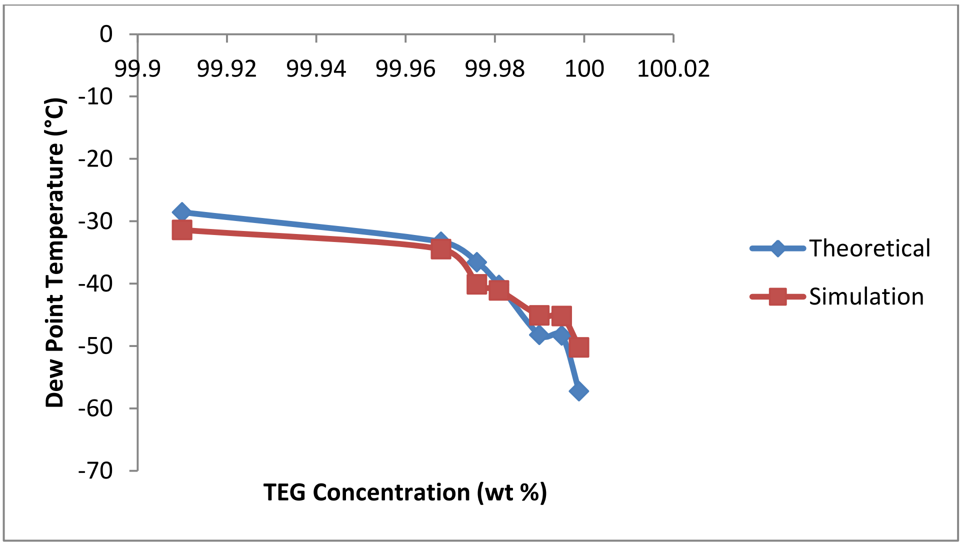

Figure 4.32: Comparison water dew point temperature from simulation and theoretical for concentration TEG 99 wt % - 99.999 wt %

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

Process simulation is a powerful method which can guide to determine the optimum conditions for higher efficiency. It is discovered that Peng-Robinson’s (PR) equation of state gives a fairly accurate result when compared to theoretical results.

As for conclusion, the overall objectives of this project are achieved. By simulation run using HYSYS, TEG showed the most significant change of water dew point curve followed by EG and DEG. In gas dehydration process, water content in wet natural gas has been reduced significantly by the gas dehydration process while reducing the dew point temperature as well. It is also discovered that to increase the absorption efficiency several factors such as number of equilibrium stages, reboiler temperature, and glycol circulation rate need to be converged. Justifications between overall simulation results with respect to theoretical results calculated from given correlations shown a satisfactory results whereby the difference between these two data are mostly not exceeding 10% difference and it is considered acceptable or industry practices.

As for further developments of the project, experimental approach need to be carried out especially in terms of addition of additives such as salts into the glycol solutions. This is important to see the difference in absorption rate between the mixed glycol and glycol solutions alone. Sensitivity analysis and study of the effectiveness parameters such as number of equilibrium stages, glycol circulation rates, and other operating conditions should be investigated in more details to obtain a reliable and maintainable gas dehydration unit with respect to economical factors.

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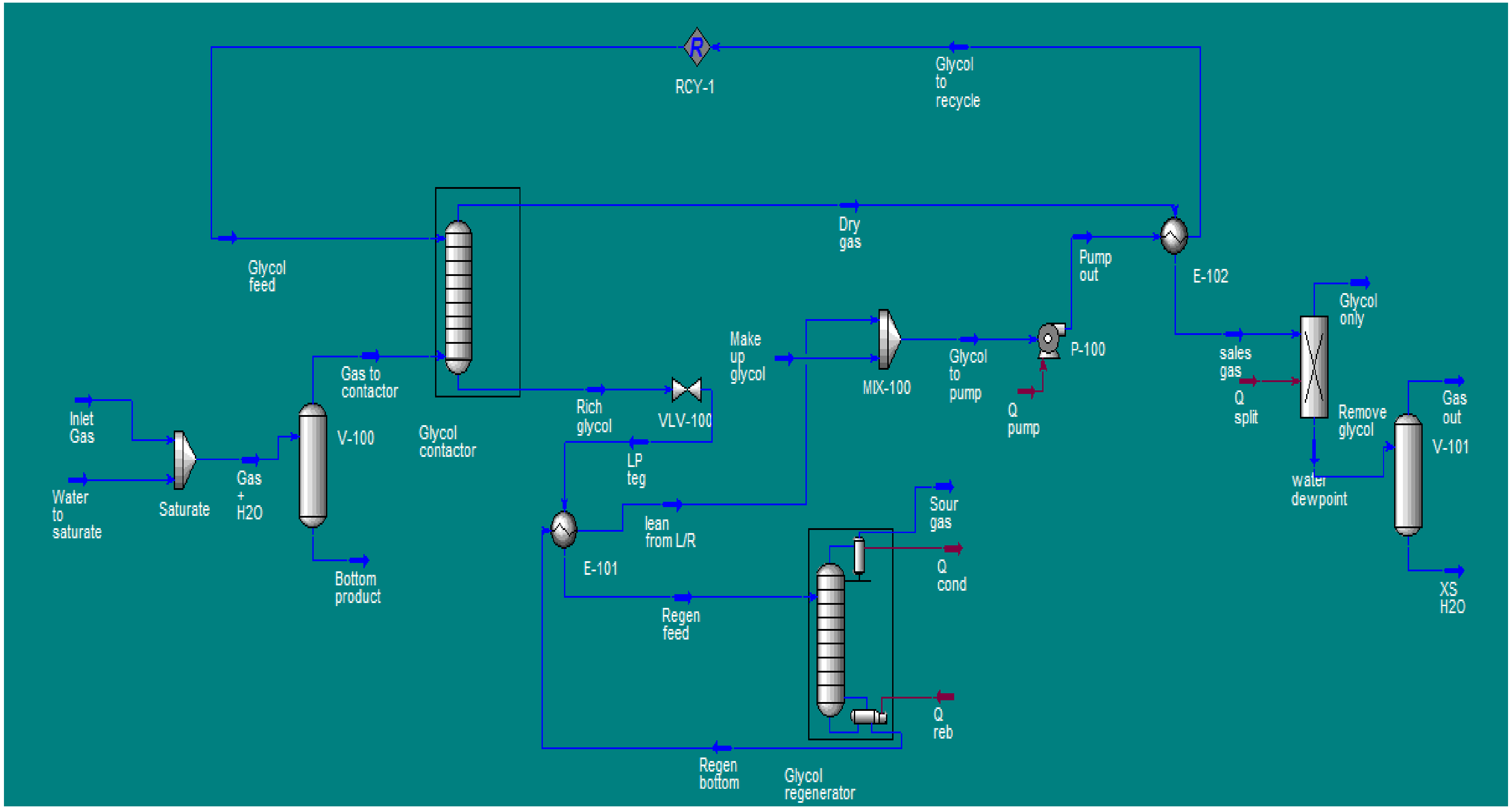
APPENDIX I

INLET GAS SPECIFICATIONS

Stream	Inlet gas
Flow	11065.55 kgmole/h
Temperature	25 °C
Pressure	59.013 bar
Molar composition	
Methane	0.684
Ethane	0.037
Propane	0.021
i-butane	0.006
n-butane	0.009
i-pentane	0.005
n-pentane	0.005
n-hexane	0.007
n-heptane	0.007
n-octane	0
Water	0.002
Nitrogen	0.106
Carbon dioxide	0.0112
Hydrogen sulphide	4 PPM
Stream	Lean Glycol
Type	TEG
Lean TEG purity	0.999
Lean TEG temperature	25 °C
Lean TEG pressure	60 bar
Contactor pressure	70 bar

APPENDIX II

PROCESS FLOW DIAGRAM

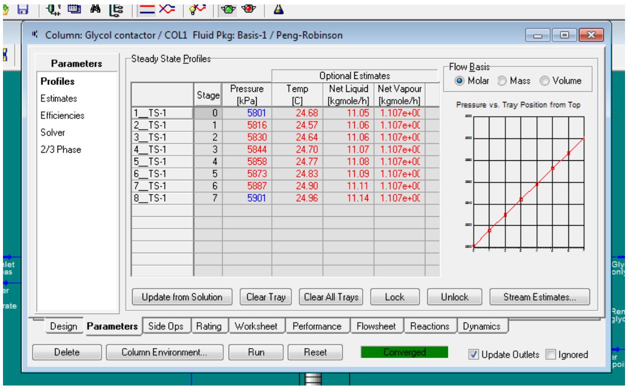


APPENDIX III

TEG System

Stream	**Component**	**Inlet gas**	**Gas to contactor**	**Glycol feed**	**Dry gas**	**Rich glycol**	**Regen bottom**
Mass fraction	Methane	0.684684685	0.832382083	7.06E-07	0.832408249	1.70E-02	6.21E-06
	Ethane	3.70E-02	2.40E-02	5.56E-07	2.40E-02	1.53E-03	2.61E-06
	Propane	2.10E-02	9.30E-03	1.37E-06	9.30E-03	1.04E-03	4.37E-06
	i-Butane	6.01E-03	2.02E-03	9.95E-08	2.02E-03	1.01E-04	2.41E-07
	n-Butane	9.01E-03	3.02E-03	2.00E-07	3.02E-03	1.71E-04	4.86E-07
	i-Pentane	5.01E-03	1.35E-03	9.68E-08	1.35E-03	6.23E-05	1.89E-07
	n-Pentane	5.01E-03	1.35E-03	1.17E-07	1.35E-03	6.77E-05	2.28E-07
	n-Hexane	7.01E-03	1.59E-03	1.60E-07	1.59E-03	6.78E-05	2.62E-07
	n-Heptane	7.01E-03	1.36E-03	1.43E-07	1.36E-03	4.77E-05	2.02E-07
	n-Octane	0	0	0	0	0	0
	n-Nonane	0	0	0	0	0	0
	n-Decane	0	0	0	0	0	0
	CO2	0.112112112	4.97E-02	2.80E-05	4.97E-02	1.52E-02	8.97E-05
	Nitrogen	0.106106106	7.39E-02	3.04E-06	7.39E-02	9.08E-03	1.53E-05
	H2S	0	0	0	0	0	0
	H2O	0	4.52E-05	9.09E-03	3.76E-05	7.49E-02	7.10E-02
	TEGlycol	0	0	0.990876034	1.40E-07	0.880772658	0.928852083
Temperature °C		25	24.95797518	50	24.67875447	24.96087456	202
Pressure (kPa)		5901.3	5901.3	5930	5801.3	5901.3	103

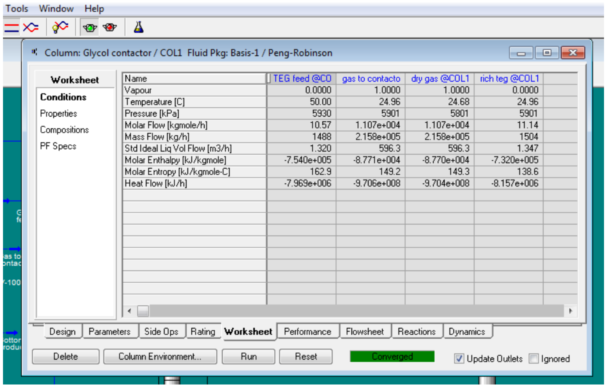
i) TEG contactor and regenerator condition



Flow Basis: ● Molar ○ Mass ○ Volume

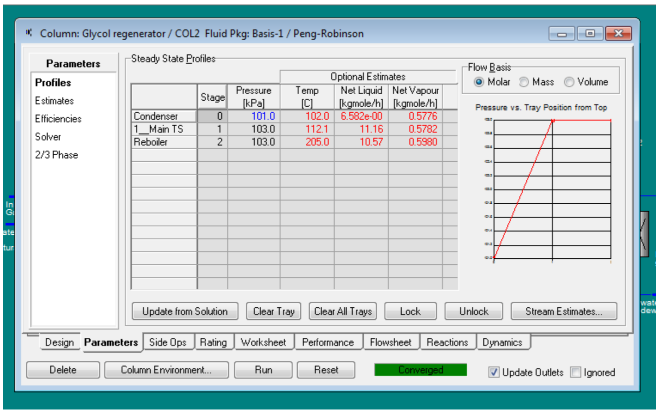
			Optional Estimates		
	Stage	Pressure [kPa]	Temp [C]	Net Liquid [kgmole/h]	Net Vapour [kgmole/h]
1__TS-1	0	5801	24.68	11.05	1.107e+0
2__TS-1	1	5816	24.57	11.06	1.107e+0
3__TS-1	2	5830	24.64	11.06	1.107e+0
4__TS-1	3	5844	24.70	11.07	1.107e+0
5__TS-1	4	5858	24.77	11.08	1.107e+0
6__TS-1	5	5873	24.83	11.09	1.107e+0
7__TS-1	6	5887	24.90	11.11	1.107e+0
8__TS-1	7	5901	24.96	11.14	1.107e+0

☑ Update Outlets ☐ Ignored



Name	TEG feed @CO	gas to contacto	dry gas @COL1	rich teg @COL1
Vapour	0.0000	1.0000	1.0000	0.0000
Temperature [C]	50.00	24.96	24.68	24.96
Pressure [kPa]	5930	5901	5801	5901
Molar Flow [kgmole/h]	10.57	1.107e+004	1.107e+004	11.14
Mass Flow [kg/h]	1488	2.158e+005	2.158e+005	1504
Std Ideal Liq Vol Flow [m3/h]	1.320	596.3	596.3	1.347
Molar Enthalpy [kJ/kgmole]	-7.540e+005	-8.771e+004	-8.770e+004	-7.320e+005
Molar Entropy [kJ/kgmole-C]	162.9	149.2	149.3	138.6
Heat Flow [kJ/h]	-7.969e+006	-9.706e+008	-9.704e+008	-8.157e+006

☑ Update Outlets ☐ Ignored

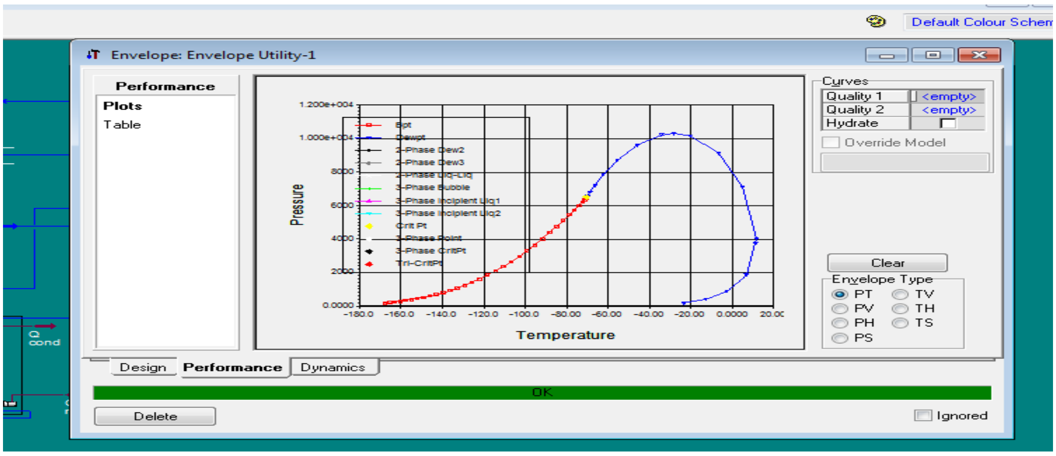


Flow Basis: ● Molar ○ Mass ○ Volume

			Optional Estimates		
	Stage	Pressure [kPa]	Temp [C]	Net Liquid [kgmole/h]	Net Vapour [kgmole/h]
Condenser	0	101.0	102.0	6.582e-00	0.5776
1__Main TS	1	103.0	112.1	11.16	0.5782
Reboiler	2	103.0	205.0	10.57	0.5980

☑ Update Outlets ☐ Ignored

ii) Dry gas stream phase envelope



Quality 1 <empty>
Quality 2 <empty>
Hydrate ☐
☐ Override Model

Envelope Type: ● PT ○ TV ○ PV ○ TH ○ PH ○ TS ○ PS

☐ Ignored

iii) Bubble point and dew point of dry gas stream

Buble Point		Dew Point	
Pressure (kPa)	Temperature °C	Pressure (kPa)	Temperature °C
197.4573585	-167.5080848	202.65	-22.94867569
227.4244015	-165.173021	429.0100534	-12.64417901
262.0756039	-162.7430314	899.3731568	-2.35587506
302.1474051	-160.2145346	1859.32547	6.707291502
348.4822904	-157.584209	3753.065482	11.65548567
402.0383041	-154.8491128	4045.217196	11.71806089
463.8968477	-152.0068273	7122.992869	5.403485582
535.2674741	-149.0556224	9153.627539	-6.520169652
617.4880152	-145.9946468	10166.85876	-20.319574
712.0179794	-142.8241385	10306.8604	-28.09320566
820.4227873	-139.5456539	10233.35971	-33.82917276
944.3461372	-136.1623091	9629.181036	-45.66286636
1085.467704	-132.6790238	8726.892806	-55.02585804
1245.443602	-129.102756	7856.780473	-61.69706749
1425.827706	-125.4427128	7204.995887	-65.9498575
1627.97318	-121.710517	6807.004503	-68.34366383
1852.915395	-117.9203119	6610.423813	-69.48833178
2101.240761	-114.0887797	6540.318326	-69.89551596
2372.946742	-110.2350559	6531.927874	-69.94480395
2667.306857	-106.3805218	6531.927874	-69.94480395
2982.751902	-102.5484673	6533.978596	-69.9325752
3316.786011	-98.76362817	6549.857516	-69.83587179
3665.955344	-95.05162366	6564.570737	-69.74357538
4025.885554	-91.43835701	6567.904836	-69.72210143
4391.397875	-87.94951183	6567.904836	-69.72210144
4756.697054	-84.61041439	6567.031058	-69.727861
5115.587653	-81.44682444	6553.373879	-69.81994915
5461.589587	-78.48783472	6525.126574	-70.01595351
5740.844734	-76.1583206		
6000.191944	-74.0447945		
6231.361485	-72.21389411		
6363.033978	-71.2038753		
6437.114841	-70.65105828		
6478.920835	-70.34577258		
6502.912035	-70.17335773		
6523.487605	-70.02748182		
6525.126574	-70.01595351		