Evaluation of Chemically Modified Mono-Ethylene Glycol as a Potential Solvent for Enhanced Natural Gas Dehydration Process

By

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

DECEMBER 2014

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.

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WONG YEE JIE

Abstract

Natural gas dehydration using glycol absorption process is one of the gaseous phase water removal technique which is efficient and cost effective. Glycols used for the absorption ranging from mono-ethylene glycol, di-ethylene glycol , tri-ethylene glycol to tetra-ethylene glycol in which tri-ethylene glycol is widely used due to its high dehydration performance. However, many industries in Malaysia that used this approach rarely able to combine high performance, economic energy consumption and low environmental emission. The main problem with the usage of tri-ethylene glycol is BTEX emission, which BTEX are classified as carcinogenic chemicals and are considered as air toxin. Besides, the non-availability of tri-ethylene glycol locally in Malaysia increases the cost of dehydration. Therefore, the locally produced mono-ethylene glycol by OPTIMAL Glycols (M) Sdn. Bhd. with a production of 365000 MTPA make it an attractive candidate. In this study, chemically modified mono-ethylene glycol is used as a new solvent to replace tri-ethylene glycol. The objectives are to simulate different natural gas dehydration processes using mono-ethylene glycol as new solvent, to validate and optimize the simulation besides to investigate enhancement of the dehydration process through chemical modification of mono-ethylene glycol. The scope of study includes comparing the chemically modified mono-ethylene glycol with tri-ethylene glycol in terms of performances; for example, the outlet natural gas water content and BETX emission. The data and results are obtained by process modeling using Aspen HYSYS 8.4 (latest) simulation software.

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Chapter 1

Introduction

1.1 Background of Study

Natural gas is a type of fossil fuel formed when layers of plants, gaseous and animals buried underground, exposed to intense pressure and heating over thousands of years. Natural gas composition mainly comprise of methane and some light hydrocarbons like ethane, propane, butane, pentane, toluene and etcetera. Besides, non-hydrocarbon gaseous like carbon dioxide, hydrogen sulfide and water along with trace amount of organic or inorganic compound may also present. Once brought to the surface, natural gas will be refined through several gas processing processes to remove impurities such as carbon dioxide, hydrogen sulfide, water vapor and volatile organic compound before being transported using pipelines. This is because, natural gas need to meet certain specification before being transported for safety and economical purposes.

Among the impurities, water present can be considered a serious threat. Condensation of water vapor into liquid in pipeline during transmission must be prevented as it can cause pipeline corrosion. Apart from that, the liquid water can reduce the volumetric capacity of the system and interfere with the operation of pressure regulators and filters. Condensed liquids accumulation in pipelines can cause an increase in operating pressures and potential damage to equipment due to liquid carry over (Ryba, A., 2005). Moreover, water vapor condensation may results in potential hydrates formation which can plug the pipelines or other equipments (Luka Polak, 2009). Due to these problems, many transmission companies impose restrictions on the quality of natural gas acceptable for transporting, such as natural gas dew point limits (Rosman, 1973).

To prevent such problems, production and transportation of natural gas installations must be protected from the risk of water condensation. One way to achieve this is through natural gas dehydration to reduce the water vapor content in natural gas along with its dew point, decreasing the tendency of water vapor to condense. Commercial natural gas dehydration technique includes absorption, adsorption, gas permeation and refrigeration (Rojey, A. et al., 1994, Netusil, M. et al., 2011). Among them, dehydration technique by absorption is the most commonly used method to remove water vapor.

1.2 Problem Statement

In practice, glycol dehydration technique is one of the method that is cost effective and efficient. The most commonly used solvent for this process is tri-ethylene glycol (TEG) due to its high thermal stability and low volatility compared to other glycols which make it cost effective. However, the usage of tri-ethylene glycol (TEG) results in two major problems which the first one is BTEX emission. Physically, tri-ethylene glycol (TEG) has high affinity towards volatile organic compounds like benzene, ethylbenzene, toluene and xylene (BTEX) (Triethylene glycol, 2007). Therefore, BTEX along with water vapor will be absorbed by tri-ethylene glycol (TEG) during the absorption process and then vaporized and emitted to the atmosphere together with water vapor during regeneration. However, in gas processing plant, BTEX must be controlled to meet EPA clean air regulation. This because they are classified as a carcinogenic chemical under United States regulations and is considered an air toxin (Kidnay, A.J. et al, 2006).

In addition, to enhance the natural gas dehydration process, tri-ethylene glycol (TEG) used must be of high purity (98.9-99.9% by weight) which required an excellent regeneration process that consume a lot of energy. Many studies had been conducted to optimize the relationship between the output natural gas quality and the energy consumption. However, due the demand of low dew point natural gas, many industries are still spending a lot of money for energy consumption. Moreover, in certain cases, the availability of solvent locally can be a main factor in cost reduction. Due to the unavailability of tri-ethylene glycol (TEG) locally, the production of mono-ethylene

glycol locally in Malaysia is an attractive alternative that can replace the usage of tri-ethylene glycol (TEG). According to OPTIMAL Glycols (M) Sdn. Bhd. that is located in Kerteh, Terengganu, the production of mono-ethylene glycol is 365,000 MTPA. Therefore, for the purpose of cost optimization and emission reduction, chemically modified mono-ethylene glycol is used to replace tri-ethylene glycol in this study.

1.3 Objectives and Scope of Study

The objectives of this study are:

- To simulate different natural gas dehydration processes using mono-ethylene glycol (MEG) as a solvent
- To validate and optimize the simulation of enhanced natural gas dehydration process
- To investigate enhancement of the dehydration process through chemical modification of mono-ethylene glycol (MEG)

The major scope of study is to evaluate the performance of chemically modified mono-ethylene glycol (MEG) as an alternative to tri-ethylene glycol in enhanced natural gas dehydration. The performances to be evaluated include the outlet natural gas water content and BETX emission. All the related data are collected from several trusted and reliable resources that relate with the objectives of this study. These data are used for the purpose of simulation studies using Aspen HYSYS software to simulate the performance of chemically modified mono-ethylene glycol.

Chapter 2
Literature Review

2.1 Natural Gas Dehydration

Natural gas dehydration is a process of removing water content inside natural gas to lower the dew point of the gas. Raw natural gas, upon brought from underground, normally accompanied by sour gaseous, carbon dioxide and water vapor. This study mostly concern about the water vapor as it is an undesired impurity that can problems in transportation of natural gas and downstream processes.

According to Abdel-Aal H.K. et al, there are three main reason to remove water. They are to prevent hydrate formation, to avoid corrosion in natural gas pipelines and for downstream process requirement. Gas hydrates are crystalline molecular complexes formed from mixtures of water and suitably sized gas molecules (Tohidi, B. et al., 1990). Normally, pipelines carry natural gas in high pressure and low temperature. Under high pressure and low temperature condition, high water content in natural gas favors the formation of hydrates. Hydrates can grow as crystals and build up in valves, orifice plates and areas inside the pipelines which are not subjected to full flow. Consequently, the accumulation of hydrates can plug lines and retard the flow of natural gas.

Besides having hydrates formation, low temperature and high pressure in pipelines can also causes the water inside the natural gas to condense. The present of liquid water in pipelines may lead to corrosion. In some cases, natural gas may contain a certain amount of carbon dioxide and sour gas such as hydrogen sulfide. These acidic gaseous may dissolve in liquid water forming an acidic solution which will accelerate the corrosion process.

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Therefore, to prevent such situation, natural gas need to be dehydrated. There are several methods of dehydration available. Among them, three methods which are widely applied in industries are absorption by tri-ethylene glycol, adsorption on solid desiccants and condensation (Netusil, M., 2011) .

2.2 Glycol Dehydration

Absorption of water is the first method of natural gas dehydration invented in human history (Netusil, M., 2011). Absorption dehydration process involves the usage of liquid as a stripping agent to remove water vapor from natural gas. The liquid solvent used for the absorption should have the following properties (Kidnay, A.J. et al., 2006):

- high affinity for water and low affinity for hydrocarbon
- low volatility at absorption temperature to reduce vaporization losses
- low viscosity for ease of pumping and contacting
- good thermal stability to prevent decomposition during regeneration
- low potential for corrosion

In practice, the glycols, mono-ethylene glycol (MEG), di-ethylene glycol (DEG), tri-ethylene glycol (TEG), tetra-ethylene glycol (TREG) and propylene glycol are most commonly used absorbent (Rojey et al., 1994).

Absorption process proceeds in a glycol contactor which is a tray column or packed bed with counter-current flows of wet natural gas and glycol. During the contact, glycol will act as a stripping agent, absorbing most of the water content inside wet natural gas. Glycol, enriched by water will be collected at the bottom of the contactor while dry natural gas will exit from the top. Enriched glycol will then continues to flow into the heat exchanger incorporated on top of the still column before entering the flash drum to flash off paraffinic compounds (Kidnay, A. J., 2006).

After that, glycol will run to the cold side of rich glycol/lean glycol heat exchanger to be heated up. Just afterwards, warm glycol is filtered and sprayed into a still column (Netusil, M. et al, 2011). There, glycol will run into a reboiler to boil out the water. The

reboiler temperature is fixed based on the type of glycol used and should not exceed the decomposition temperature of chosen glycol. Regenerated glycol (lean glycol) is then pumped back to the hot side of rich glycol/lean glycol and dry natural gas/lean glycol heat exchanger to be cooled down before returning into the contactor.

The entire process of glycol dehydration is shown in the figure below:
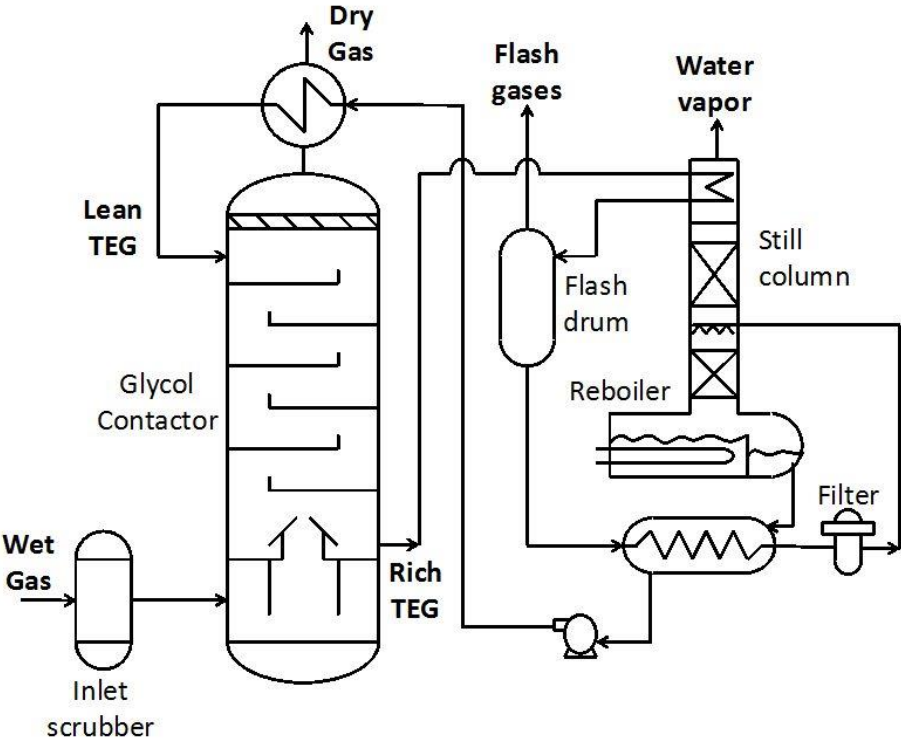
Figure 1: Typical Glycol Dehydration Unit (Netusil, M. et al, 2011)

2.3 Glycol Selection

In practice, the glycols, ethylene glycol (EG), di-ethylene glycol (DEG), tri-ethylene glycol (TEG), tetra-ethylene glycol (TREG) and propylene glycol are the most suitable absorbents for natural gas dehydration (Kidnay, A. J., 2006).
The following tables show the physical properties of glycols.

Table 1: Properties of different glycols (Kidnay, A. J., 2006)

Glycol Name	Formula	Molecular Weight	Boiling Point, 760 mm, °F	Vapor Pressure, 77°F, mm Hg	Relative Density, 77°F	Freezing Point, °F	Pour Point, °F	Viscosity, cp, 77°F	Decomposition Temperature, °F
Ethylene Glycol	HOC₂H₄OH	62.1	387.1	0.12	1.110	8	—	16.5	329
Diethylene Glycol	HOC₂H₄OC₂H₄OH	106.1	472.6	< 0.01	1.113	17	−65	28.2	328
Triethylene Glycol	HO(C₂H₄O)₂H₄OH	150.2	545.9	< 0.01	1.119	19	−73	37.3	404
Tetraethylene Glycol	HO(C₂H₄O)₃C₂H₄OH	194.2	597.2	< 0.01	1.112	22	−42	39.9	428

Table 2: Extended physical properties of different glycol

Glycols	Ethylene glycol	Diethylene glycol	Triethlylene glycol	Tetraethylene glycol	Propylene glycol (1,2 Propanediol)
Formula	$HO - (CH_2)_2 - OH$	$HO - ((CH_2)_2 - O) - (CH_2)_2 - OH$	$HO - ((CH_2)_2 - O)_2 - (CH_2)_2 - OH$	$HO - ((CH_2)_2 - O)_3 - (CH_2)_2 - OH$	$HO - (CH_2)_3 - OH$
Formula	$C_2H_6O_2$	$C_4H_{10}O_3$	$C_6H_{14}O_4$	$C_8H_{18}O_5$	$C_3H_8O_2$
Maximum Recommended Regeneration Temperature	NA	160 C	180 C	200 C	NA
Slow thermal degration temperature	NA	164 C	196 C	NA	NA
Thermal decomposition temperature	240 C	240 C	240 C	NA	NA
Flash point, close cup	126.7 C	154 C	177 C	202 C	104 C
Flash point, open cup	137.8 C	163 C	191 C	204 C	
Autoignition Temperature	427 C	364 C	349 C	358 C	371 C
Boiling Point at 760 mmHg	197.1 C	245.3 C	288 C	329.7 C (decomposed)	187.6 C
Freezing Point	-13 C	-9 C	-4.3 C	-4.4 C	-60 C
Molecular Weight	62.07 g/mol	106.12 g/mol	150.17 g/mol	194.23 g/mol	
Specific gravity at 20 C	1.1153	1.1182	1.1255	1.1247	1.0381
Viscosity at 20 C	N.D.	35.7 mPs	49 mPs	58.3 mPs	48.6 mPs

Among the glycols, mono-ethylene glycol (MEG), di-ethylene glycol (DEG) and tri-ethylene glycol (TEG) are most commonly used glycol in the industry of natural gas dehydration process. However, due to dry natural gas water content requirements and glycols lost during regeneration process, mono-ethylene glycol (MEG) and di-ethylene glycol (DEG) are often not considered. Tetra-ethylene glycol is out of the choice because it has a high boiling point and high molecular weight which make the regeneration cost and pumping cost high. Therefore, tri-ethylene glycol (TEG) is the glycol of choice in most instances due to its lower vapor pressure, higher thermal stability and higher affinity towards water compared to other glycols.

However, the usage of tri-ethylene glycol (TEG) lead to various problems like emission of dangerous volatile petro chemicals such as BTEX (benzene, toluene, ethyl benzene, xylene) and paraffinic compounds. This is because those volatile compounds are more soluble inside tri-ethylene glycol compared to other glycols. Hence, in the case of environmental friendliness, tri-ethylene glycol is less favorable.

The following table shows the solubility of different petro chemicals in different glycols

Table 3: Table of solubility of different petro-chemicals in different glycols

	Ethylene glycol	Diethylene glycol	Triethlylene glycol	Tetraethylene glycol	Propylene glycol
Acetone	Completely soluble	Completely soluble	Completely soluble	Completely soluble	N.D.
Benzene	6.0	45.5	Completely soluble	Completely soluble	19.2
Chlorobenzene	6.0	112.0	Completely soluble	N.D.	N.D.
Diethanolamine	Completely soluble	Miscible	Completely soluble	Completely soluble	Completely soluble
Ethyl ether	8.9	19.5	20.4	20.0	Completely soluble
Heptane	Slightly soluble	0.03	Slightly soluble	Slightly soluble	N.D.
Methanol	Completely soluble	Completely soluble	Completely soluble	Completely soluble	N.D.
Paraffin oil	Not soluble	Not soluble	Not soluble	Slightly soluble	N.D.
Phenol	Completely soluble	Miscible	Not soluble	Completely soluble	Completely soluble
Toluene	3.1	20.7	33.0	89.0	12.3

Furthermore, for certain operation condition such as frequent brine carryover into the contactor occurs, mono-ethylene glycol (MEG) is used instead of tri-ethylene glycol (TEG) due its ability of hold more salt. (Kidnay, A. J., 2006).

2.4 Enhanced Natural Gas Dehydration

Instead of choosing or modifying the absorbents in natural gas dehydration, another method used to enhance natural gas dehydration focus on the regeneration of absorbent. Enhanced regeneration can be defined as a system that improves glycol regeneration to produce glycol with higher purity once it has been recycled. It is proven that absorbent or glycol of higher purity has a higher affinity towards water thus producing dry natural gas with lower water content.

For instances, gas stripping can be implemented to enhance glycol regeneration. In this process, a surge tank is installed at the bottom of the reboiler to contain the regenerated glycol. There, a stream of stripping gas is introduced to lower the vapor pressure of water in the regeneration column to enhance the separation between glycol and water. Proprietary design DRIZO, licensed by Poser-NAT, COLDFINFER and Gas Conditioners International, have been patented as an alternative to traditional stripping gas units (Netusil, M. et al, 2011). The DRIZO regeneration system utilized a recoverable iso-octane solvent as the stripping gas. The typical composition of the solvent include about 60% aromatic hydrocarbons, 30% naphthenes and 10% paraffins. In this process, the vaporized solvent together with water vapor will be cooled down and collected in a three phase separator where the solvent is then recovered and recycled back into the surge drum.

Another method of enhanced regeneration system known as Coldfinger regeneration system uses different kind of approach which employs a cooling coil in the vapor phase of the surge tank. The cooling effects will cause the condensation of a huge amount of water vapor together with glycol. The condensate which is the rich glycol mixture is collected and regenerated in further separation process (Netusil, M. et al, 2011).

The figure below shows some examples of enhanced regeneration system.
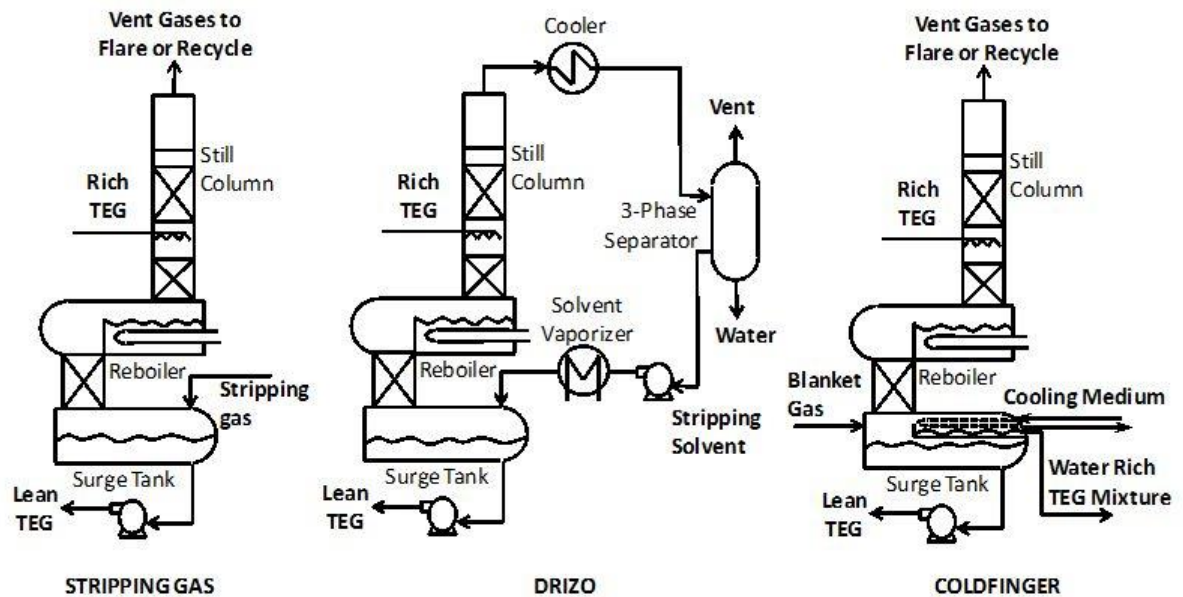
Figure 2: Scheme of enhanced glycol regeneration systems (Netusil, M. et al, 2011)

2.5 Chemical Modification of Glycols to Improve Absorption Capacity

To optimize between the glycol regeneration cost and the output natural gas quality, further modification of glycol is another method which possess a great potential. It is reported by Gavlin, G. et al, 2001 that a glycol solvent selected from a glycol, a salt and a neopentyl alcohol having improved dehydrating capacity and reduced absorbency for aliphatic and aromatic hydrocarbon. In practice, glycol that are suitable for chemical modification is preferably mono-ethylene glycol (MEG), di-ethylene glycol (DEG), tri-ethylene glycol (TEG) and tetra-ethylene glycol (TREG) whereas the salt is a potassium or tetramethylammonium carboxylate selected from the group consisting of potassium formate (KOF), potassium acetate and tetramethylammonium formate (TMAF).

According to Gavlin, G. et al, that the solubility of salt in glycol increases from tri-ethylene glycol (TEG), di-ethylene glycol (DEG) to mono-ethylene glycol (MEG). However, because of tri-ethylene glycol is the glycol of choice in most instances in natural gas dehydration process, salts such as potassium formate (KOF) and

tetramethylammonium formate (TMAF) are salt of choice for most of the research that had been conducted due to their compatibility with tri-ethylene glygol (TEG) (Kidney, A. J. et al, 2006).

The table below shows the solubility of different salt in different glycols based on the research done by Gavlin and Goltskin.

Table 4: Solubility of Salts in Glycols (wt%) at 30 degree Celsius

Salt	MEG	DEG	TEG
Potassium acetate	41.2	33.5	4
Potassium formate	40.4	25	21
Sodium acetate	25.2	15.3	-
Lithium acetate hydrate	-	69	-
Lithium acetate	-	18	-
Tetramethylammonium formate	-	38	32

From the above table, we can observe that the solubility of salt in glycol increases from tri-ethylene glycol (TEG), di-ethylene glycol (DEG) to mono-ethylene glycol (MEG). However, because of tri-ethylene glycol is the glycol of choice in most instances in natural gas dehydration process, salts such as potassium formate (KOF) and tetramethylammonium formate (TMAF) are salt of choice for most of the research that had been conducted (Kidney, A. J. et al, 2006).

Surprisingly, all of the research shows positive results regarding the chemical modification of tri-ethylene. The following table shows the results of the simulation conducted by Isa, M. A. et al, 2012. It was proven that the water content in dry gas is decreasing with the increase of mass flow rate of potassium formate. Besides that, the amount of BTEX in dry gas also increases. This shows that the addition of potassium formate can increase the solubility of water and decrease the solubility of aliphatic and aromatic hydrocarbon in tri-ethylene glycol (TEG).

Table 5: Amount of water vapor and BTEX in dry gas by TEG with addition of potassium formate at DRIZO GDU (Isa, M. A., et al, 2012)

Mass flow rate of makeup benzene (kg/h)	Mass flow rate KOOH (kg/h)	Water content in dry gas (ppm)	BTEX gases (kg/h)			
			Benzene	Toluene	Ethyl benzene	Xyelene
0.0	0.0	45.0				
0.0	162.21	38.0	0.44	0.35	0.20	0.02
0.0	282.77	32.0	0.52	0.43	0.27	0.02
0.0	378.88	30.0	0.62	0.52	0.33	0.03
0.0	518.49	28.0	0.77	0.67	0.43	0.04
0.0	771.74	25.0	1.09	0.97	0.64	0.06
2.0	518.49	18.0	1.45	1.21	0.80	0.07
4.0	518.49	11.0	1.83	1.50	1.00	0.09
6.0	518.49	6.0	2.51	1.88	1.23	0.12
8.0	518.49	3.0	3.02	2.06	1.30	0.12
9.0	518.49	1.0	3.54	2.29	1.45	0.14

Table 3 – Amount of water vapour in dry gas and BTEX by TEG with addition of potassium formate (KOOCH) at DRIZO GDU.

Another research conducted by Gavlin, G. et al, 2001 using tetramethyl-ammonium formate (TMAF) instead of potassium formate, demonstrate the advantage of TMAF as it lowers the viscosity of glycols which has a potential to reduce the pumping cost of the glycols. The table below shows the viscosities of glycols at room and elevated temperatures.

Table 6: Viscosities of chemically modified glycols (cps)

	Dry glycol		2% H20	
Wt%	25 degree Celsius	40 degree Celsius	25 degree Celsius	40 degree Celsius
Potassium formate 20% TEG 80%	260	90	194	66
Potassium formate 25% DEG 75%	275	93	207	71
TMAF 32% TEG 68%	52	22	40	21
TMAF 38% DEG 62%	37	16	27	15

With this, it can be proven that chemical modification of glycol with salt can increase the affinity of glycol towards water and reduce the affinity of glycol towards aliphatic and aromatic hydrocarbon which mainly consist of benzene, toluene, ethylbenzene, and xylene (BTEX). In addition, the present of neopentyl alcohol, such as 1,1,1-

trimethylolpropane also tends to reduce the solvency of hydrocarbons in glycol with the cost of increasing the viscosity of the solvent (Gavlin, G. et al, 2001).

The following table shows the analysis of the research on the chemical modification of glycol done recently.

Table 7: Table of chemical modification of glycol done by researcher recently

System/ Process	Solvent	Output/ Conclusion	Remarks	References
Addition of potassium formate (KOF) to TEG	TEG	Rise the absorption capacity of TEG by 2-3 times	-Reduce BTEX emission -Reduce vapor pressure of TEG	Isa, M. A. et al 2013
Addition of potassium formate (KOF) to MEG	MEG	Absorption capacity of MEG is better than TEG	-Almost zero BTEX emission -Higher glycol loss compare to TEG	Kamarudin, K. 2012
Addition of tetramethyl-ammonium formate (TMAF) to glycol	TEG, DEG	Rise the absorption capacity of TEG and DEG	-Reduce BTEX emission -Lower the viscosity of TEG and DEG	Gavlin, G. et al 2001
Addition of neopentyl alcohol to chemically modified glycol	TEG, DEG	Further rise the absorption capacity of TEG and DEG	-Further reduce BTEX emission -Increase the viscosity of TEG and DEG	Gavlin, G. et al 2001

Chapter 3

Research Methodology

3.1 Introduction

The main purpose of this study is compare the performance of chemically modified mono-ethylene glycol with tri-ethylene glycol in terms of performances including outlet natural gas water content and BTEX emission. The method chosen to be used in this study is through computerized process simulation. Firstly, the overall process route for enhanced natural gas dehydration process will be produced. Next, the overall process will be simulated using simulation software. Certain process parameters such as the composition of chemically modified mono-ethylene glycol will be manipulated. The data obtained from the simulation will be tabulated and plotted on graphs. It will be further analyzed and compared with data from the previous studies. Finally, a report containing all results, discussion, conclusion and future recommendation will be produced.

3.2 Research Tools and Equipments

For this simulation studies on enhance natural gas dehydration process using chemically modified mono-ethylene glycol, the essential tool will be Aspen HYSYS simulation software. Peng and Robinson (1976) and Twu et al. (2005) glycol thermodynamic packages will be necessary for this study. Furthermore, the evaluation of glycol system involves the determination of minimum of glycol concentration required to meet the outlet gas dew point specification (Bahadori, 2009). Therefore, the equilibrium correlations between water dew point (Td) of dry gas with respect to concentration of regenerated glycol (W) developed by Bahadori (2009) will be used. The equilibrium correlations are shown in the following equation:

$$T_d = a + bT + cT^2 + dT^3 \tag{1}$$

where

$$a = A_1 + B_1W + C_1W^2 + D_1W^3 \tag{2}$$

$$b = A_2 + B_2W + C_2W^2 + D_2W^3 \tag{3}$$

$$c = A_3 + B_3W + C_3W^2 + D_3W^3 \tag{4}$$

$$d = A_4 + B_4W + C_4W^2 + D_4W^3 \tag{5}$$

Equation 1: Equilibrium Correlations

3.3 Project Work

3.3.1 Process Flow Chart

Throughout completing this project, the project activities follows the following process flow chart.

Literature Review
- Preliminary study on past researched based on related topic and issue
- Identification of process parameters that are related to the topic

Project Experiment
- Study on the method on how the simulation is conducted
- Familiarize with all the equipments and equations involved

Data Collection and Discussion
- Data are collected after each simulation
- Graphs are plotted based on the data collected to analysed the effect of process parameter to the main subject of the project

Conclusion
- Conclude all the findings from the project

Figure 3: Process Flow Chart

3.3.2 Literature Review

During the initial phase of the project, literature review is conducted to collect useful data and information from several trusted sources such as books, journals, research papers, thesis and etcetera. These data were then analyzed critically and then summarized into a complete literature review format.

3.3.3 Simulation Experiment

Aspen HYSYS 8.4 (newest) software is being employed to simulate all the computational experiment of this project. Initially, the typical model of natural gas dehydration process plant which uses TEG as the solvent is being simulated. All the raw data for wet natural gas input is collected from trusted sources. The following table shows the composition of wet natural gas input for the simulation case.

Table 8: Composition of wet natural gas

Species	Mass fraction
H20	0.002
CO2	0.084
N2	0.005
C1	0.386
C2	0.129
C3	0.158
n-C4	0.097
i-C4	0.052
n-C5	0.032
i-C5	0.033
n-C6	0.006
c-C6	0.002
i-C6	0.006
n-C7	0.001
c-C7	0.001
i-C7	0.002
i-C8	432ppm
c-C8	807ppm
C6H6, benzene	857ppm
C7H8, toluene	697ppm
C8H10, xylene	402ppm
C8H10, ethyl benzene	40ppm

References: Isa, M. A. et al, 2013; Kamarudin, K., 2012

Besides that, all the operating conditions of all the equipments used in the simulation case is also obtained from trusted sources. The following table shows the operating condition employed in the simulation case.

Table 9: Operating conditions of the base case employed in the simulation for TEG

Stream	Operating conditions
Wet gas	Temperature = 56 C Pressure = 4261 kPa Volume flow = 11MMSCFD
Lean TEG	Temperature = 60 C Pressure = 4261 kPa
Absorber	Number of stages = 3 Pressure = 4261 kPa Simulator input: no reboiler (QN=0), no condenser (QI=0)
Regeneration column	Pressure = 101.3 kPa Temperature = 202 C
Stripping column	Number of stages = 5 Pressure = 101.3 kPa Simulator input: no reboiler (QN=0), no condenser (QI=0)

References: Isa, M. A. et al, 2013; Kamarudin, K., 2012; Kidney, A. J. et al, 2006

3.3.4 Validation of Simulation Case

After the simulation case is complete, it is then validated using the correlation developed by Bahadori (2009) as discussed in the research tools and equipments. The variation of data collected from the simulation experiment compared to the data calculated using Bahadori's correlation should not exceed 5%. The validation is done to make sure that the data collected from the simulation experiment are accurate and can be trusted.

3.3.5 Enhancing Simulation Experiments

Next, the validated simulation experiment is then being enhanced by modifying the typical model of natural gas dehydration simulation to advance model of natural gas dehydration simulation like Stahl column and Drizo system. New solvent such as mono-ethylene glycol (MEG) and chemically modified mono-ethylene glycol (MEG) are being input into the simulation case replacing tri-ethylene glycol (TEG).

3.3.6 Data Analysis, Conclusion and Report Writing

After completing the simulation experiments, all the data collected will be tabulated and analyzed critically. The results will be compared with the results from other simulation research previously done by other researcher. The scope of comparison include output natural gas quality and BTEX emission. Finally, a conclusion is justified after completing this project. The introduction, literature review, methodology, results, discussion and conclusion of this project is summarized into a complete documentation in the final report.
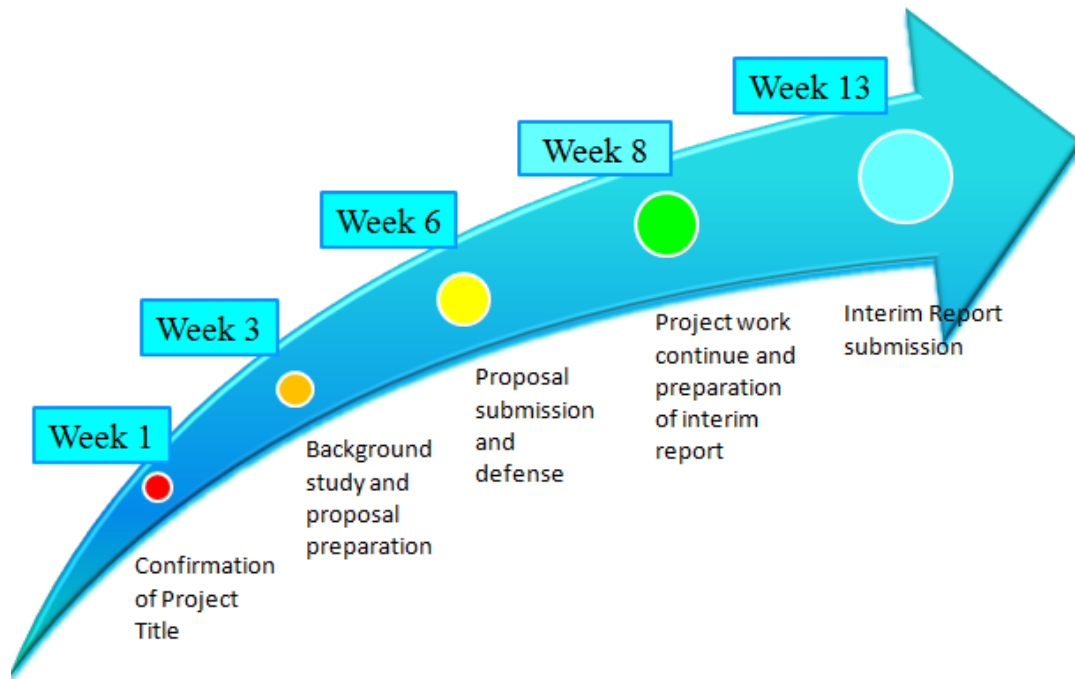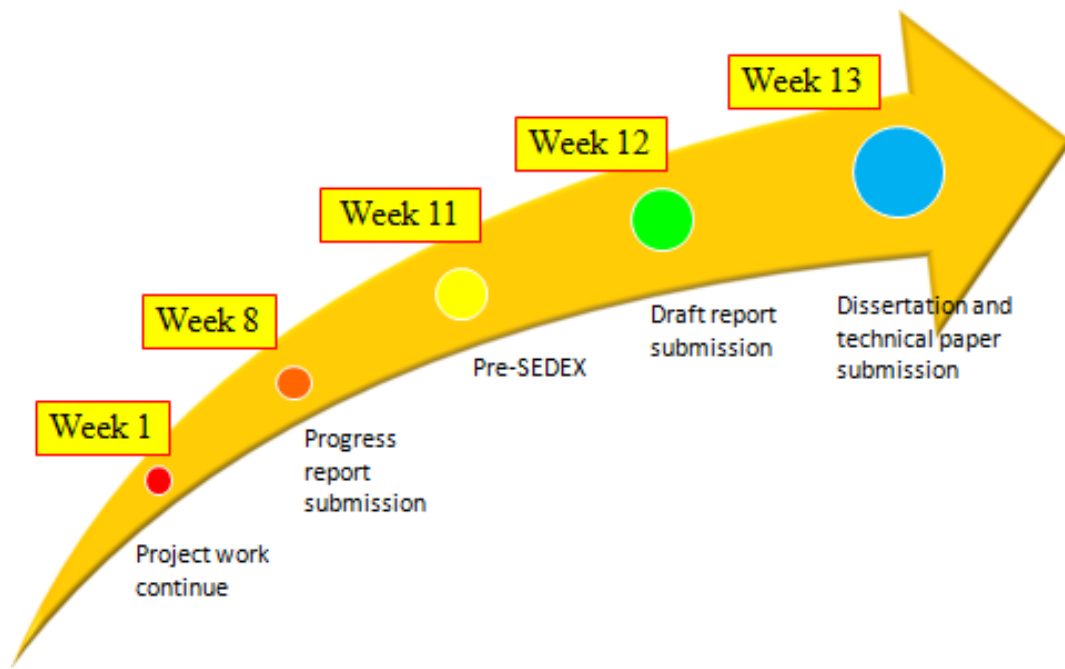
3.4 Key Milestones

Figure 4: Key Milestone FYP 1

Figure 5: Key Milestone FYP 2

3.5 Gantt-chart

Table 10: Gantt-chart

FYP 1	Week													
No	Detail Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of project title	▓	▓												
2	Preliminary research work and proposal preparation			▓	▓	▓									
3	Extended proposal submission						▓								
4	Proposal defense							▓							
5	Project work continue								▓	▓	▓	▓			
6	Submission of interim draft report												▓		
7	Submission of final interim report													▓	▓

FYP 2	Week													
No	Detail Work	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Project work continues	█	█	█	█	█	█	█							
2	Submission of progress report								█						
3	Project work continues								█	█	█	█			
4	Pre-SEDEX											█			
5	Project work continue												█		
6	Submission of draft report												█		
7	Submission dissertation (soft bound)													█	
8	Submission of technical paper													█	
9	Oral Presentation														█
10	Submission of project dissertation (hard bound)														█

Chapter 4

Results and Discussion

4.1 Validation of Simulation Experiment

The validation of simulation experiment is done by comparing the water dew point calculated manually using Bahadori's correlation and the water dew point from HYSYS simulation. The figures below show the result of comparison and their temperature difference.

Table 11: Comparison water dew point (Td) from simulation and theoretical for concentration 90 wt% - 99 wt%

TEG concentration (wt%)	Td calculated (K)	Td HYSYS (K)	Temperature Difference	% Difference
92.99	312	308.1	3.9	1.25
94.99	307	303.3	3.7	1.21
96.99	297	295.3	1.7	0.57
98.99	281	290.3	9.3	3.32

Figure 6: Graph of water dew point (Td) from simulation and theoretical for concentration 90 wt% - 99 wt%

Table 12: Comparison water dew point (Td) from simulation and theoretical for concentration 99 wt% - 99.9 wt%

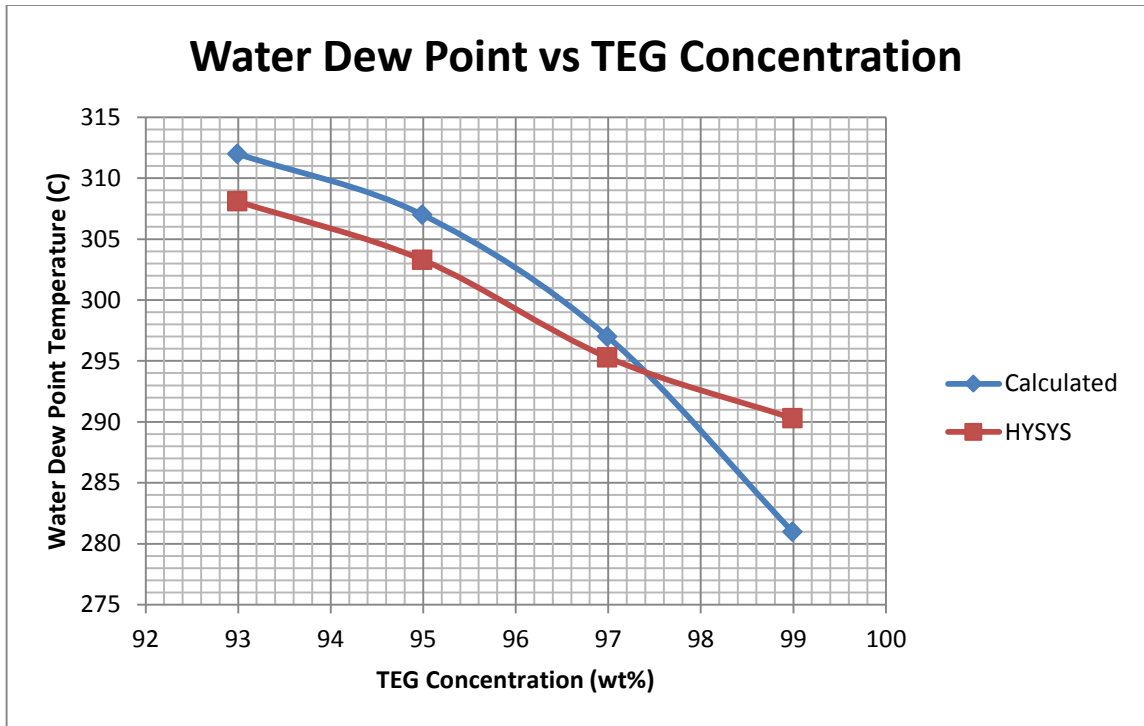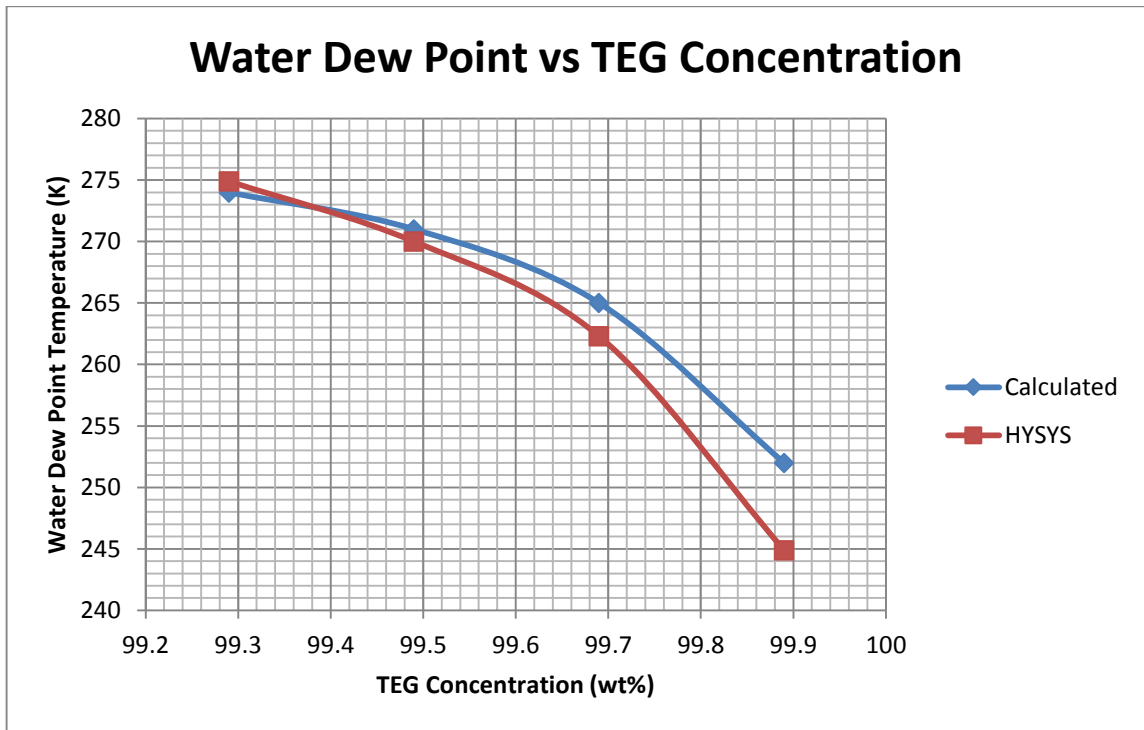| TEG concentration (wt%)	Td calculated (K)	Td HYSYS (K)	Temperature Difference	% Difference
99.29	274	274.9	0.9	0.33
99.49	271	270.0	1.0	0.37
99.69	265	262.3	2.7	1.02
99.89	252	244.9	7.1	2.82

Figure 7: Graph of water dew point (Td) from simulation and theoretical for concentration 99 wt% - 99.9 wt%

Table 13: Comparison water dew point (Td) from simulation and theoretical for concentration 99.9 wt% - 99.99 wt%

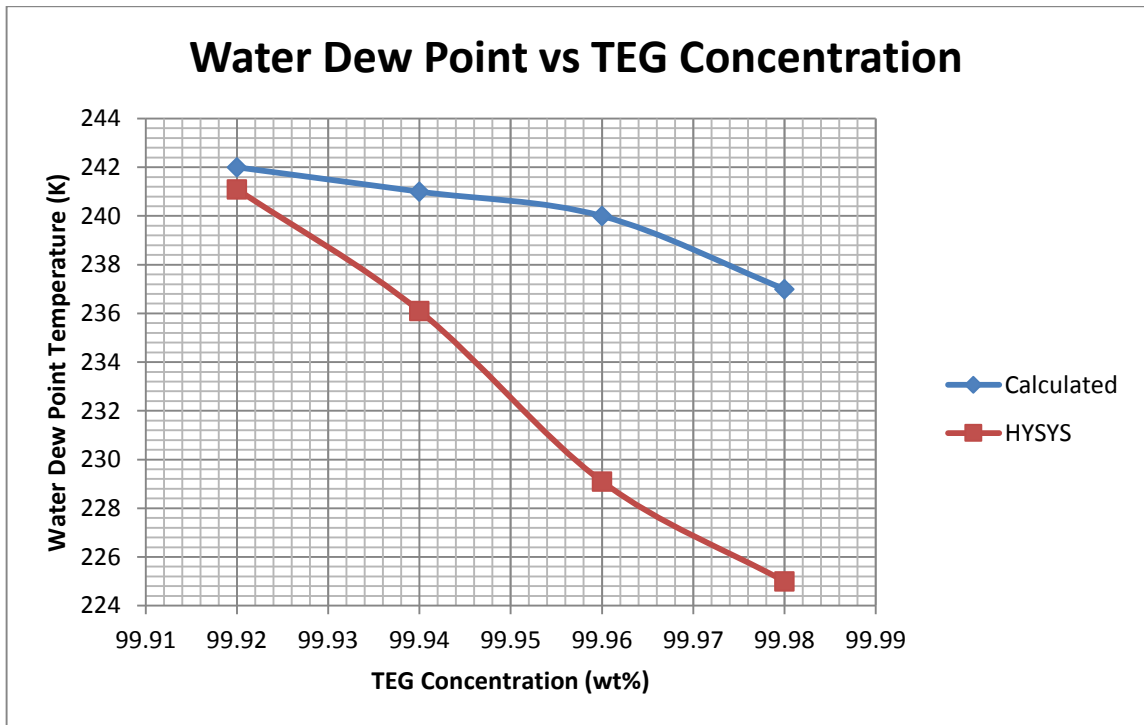| TEG concentration (wt%)	Td calculated (K)	Td HYSYS (K)	Temperature Difference	% Difference
99.92	242	241.1	0.9	0.37
99.94	241	236.1	4.9	2.03
99.96	240	229.1	10.9	4.54
99.98	237	225.0	12	5.06

Figure 8: Graph of water dew point (Td) from simulation and theoretical for concentration 99.9 wt% - 99.99 wt%

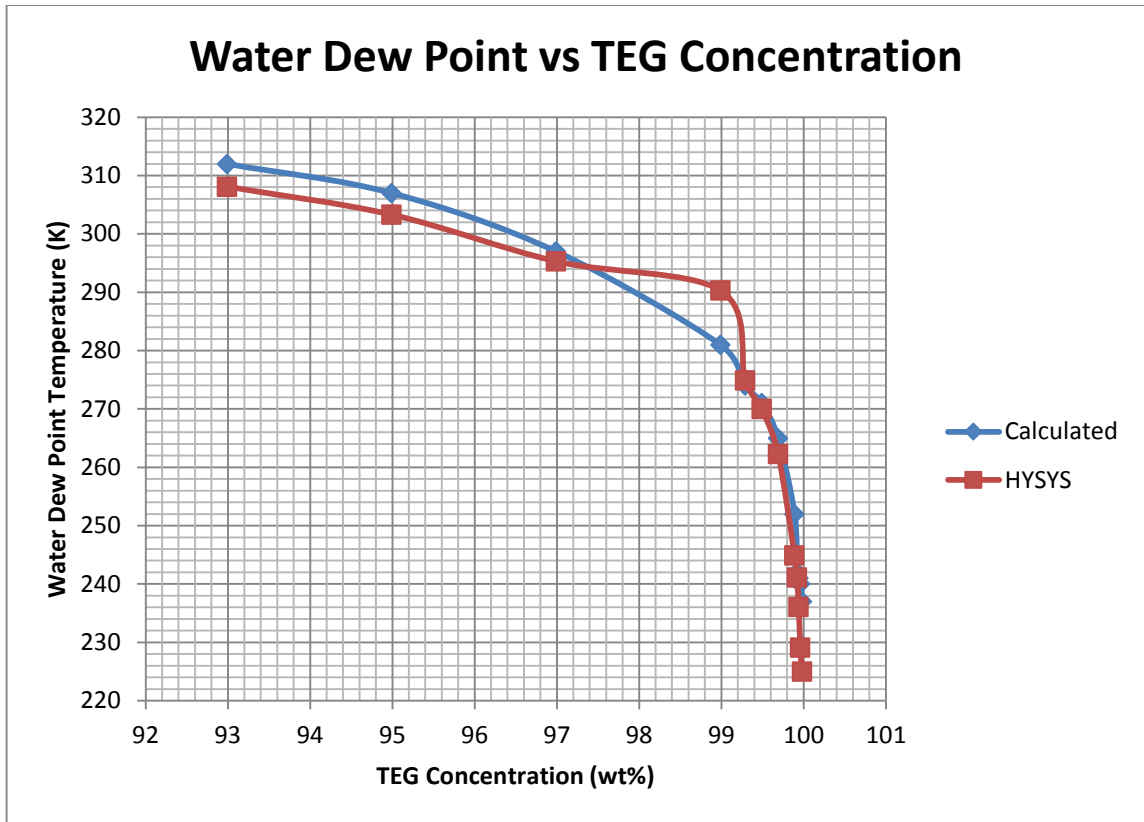Figure 9: Graph of water dew point (Td) from simulation and theoretical for concentration 90 wt% - 99.99 wt%

From the comparison between the simulated and calculated water dew point temperature of output natural gas above, it is observed that the variation between them is small and most of the percentage difference is less than 5%. Thus, it can be said that the data collected from the simulation is valid and can be trusted.

4.2 Optimizing the Natural Gas Dehydration Simulation

The DRIZO natural gas dehydration using tri-ethylene glycol (TEG) is being altered and simulated using Aspen HYSYS 8.4. In the simulation, tri-ethylene glycol (TEG) is being replaced with mono-ethylene glycol (MEG). Due to the different in chemical and physical properties of those two solvent, the operating condition of the process need to be altered and optimized.

4.2.1 Finding the Optimum Reboiler Temperature

Since the boiling point of MEG is 197.1°C which is much more lower compared to TEG (288°C), reboiler temperature of the regenerator plays a very important role in the natural gas dehydration process using MEG. It is very important to first optimize the reboiler temperature before optimizing other parameters.

The following table shows the effect of various reboiler temperature on dry natural gas water content, regenerated MEG mass fraction, regenerated MEG water content and MEG loss. Certain conditions such as the condenser temperature is kept at 100°C and the makeup benzene flow is 0 kg/h.

Table 14: Table of the Effect of Reboiler Temperature on various parameters

| Reboiler Temperature	°C	145	150	155	160	165	170	175	180	185	190
Dry Natural Gas Water Content	ppm	892.15	896.6	900.6	903.9	903.9	872.3	844.5	819.4	797.7	778
	kg/h	4686.1	4709.7	4730.4	4747.8	4747.8	4581.9	4436	4304.2	4189.9	4086.5
Regenerated MEG	mass fraction	0.967	0.9659	0.965	0.9642	0.9642	0.9717	0.9784	0.9843	0.9895	0.9941
Regenerated MEG Water Content	mass fraction	0.033	0.0341	0.035	0.0358	0.0358	0.0283	0.0216	0.0157	0.0105	0.0059
MEG Loss	kg/h	2924.5	2210.3	1631.5	1153.39	784.7	793.6	804	810	820.9	828.7
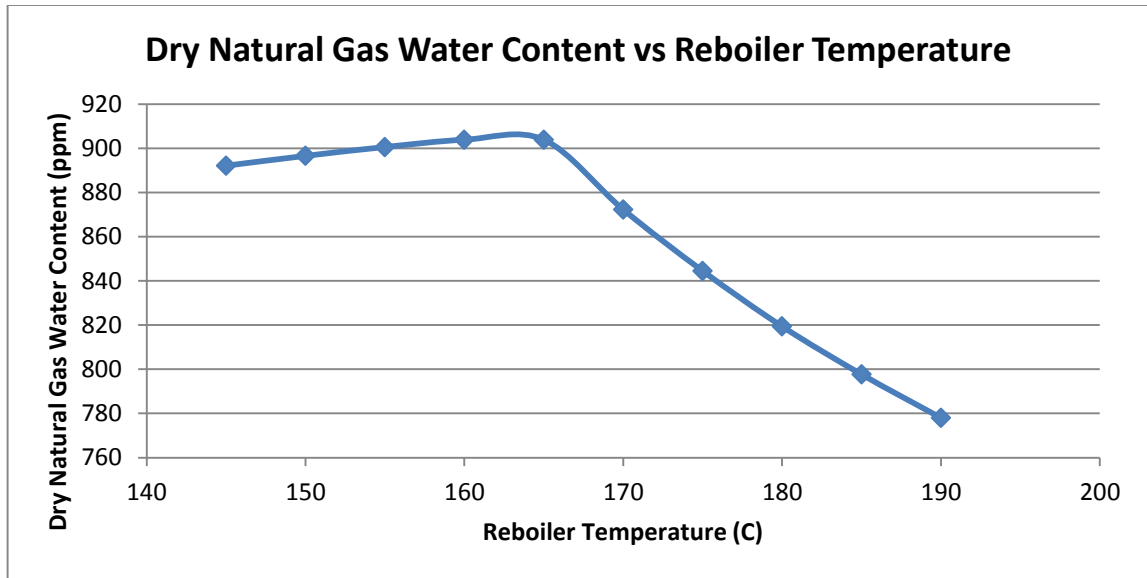
Figure 10: Graph of Dry Natural Gas Water Content vs Reboiler Temperature

The above graph indicates that when the reboiler temperature is increased from 145°C to 165°C, the water content in the dry natural gas also increase slowly from 892.15 ppm to 903.9 ppm. The water content in the dry natural gas peak at around 165°C and then drop drastically from 903.5 ppm to 778 ppm at reboiler temperature around 190°C. This indicates that before 165°C, lower reboiler temperature favors the regeneration but after 165°C, the higher the reboiler temperature, the better the regeneration.

According to the above graph, it is clearly shown that the relationship between the dry gas water content and the reboiler temperature can be divided into two parts. The first part is the part where the reboiler temperature is less than 165°C. In this part, we can see that the higher the reboiler temperature, the higher the dry natural gas water content. This is because, using a reboiler temperature of less than 165°C is not suitable for MEG regeneration. Low reboiler temperature cannot efficiently evaporates the water absorbed by MEG, making the purity of the regenerated MEG to drop; thus, causing the dry natural gas water content to raise.

On the other hand, the second part of the graph (the part where the reboiler temperature is higher than 165°C) shows that the higher the reboiler temperature, the lower the dry

natural gas water content. This is because, using a reboiler temperature which is higher than 165°C can efficiently evaporates the water absorbed by MEG, increasing the purity of the regenerated MEG, which is shown in the graph below. Higher regenerated MEG purity enable it to absorb more water contained in the wet natural gas, thus, this causes the dry natural gas water content to drop. In a nutshell, it can be said that the higher the reboiler temperature, the lower the dry natural gas water content (better gas quality). However, the reboiler temperature cannot be more than 190°C due to the boiling point limitation of MEG.
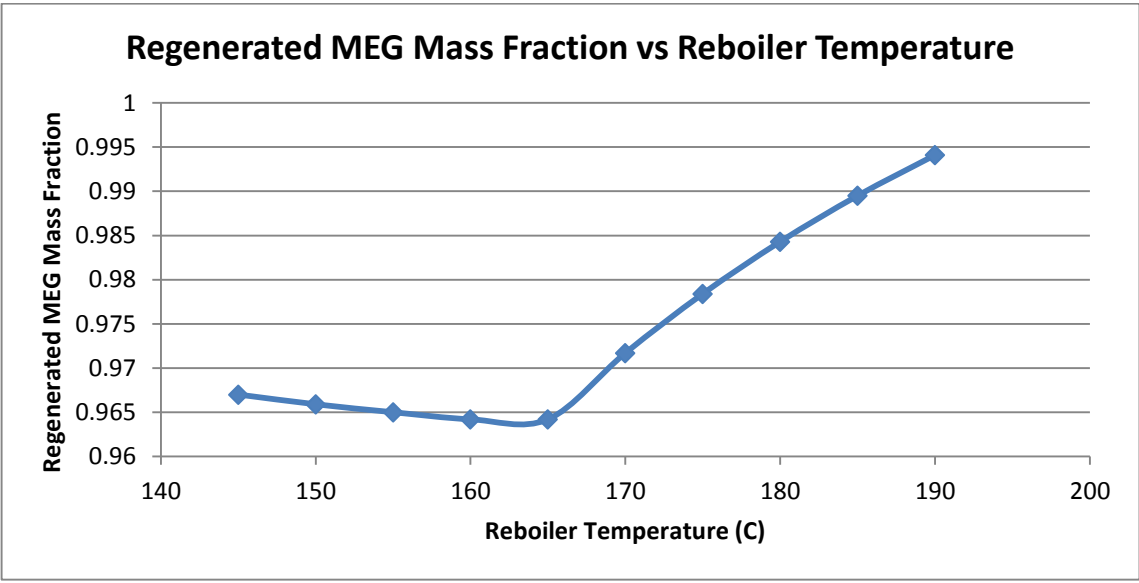

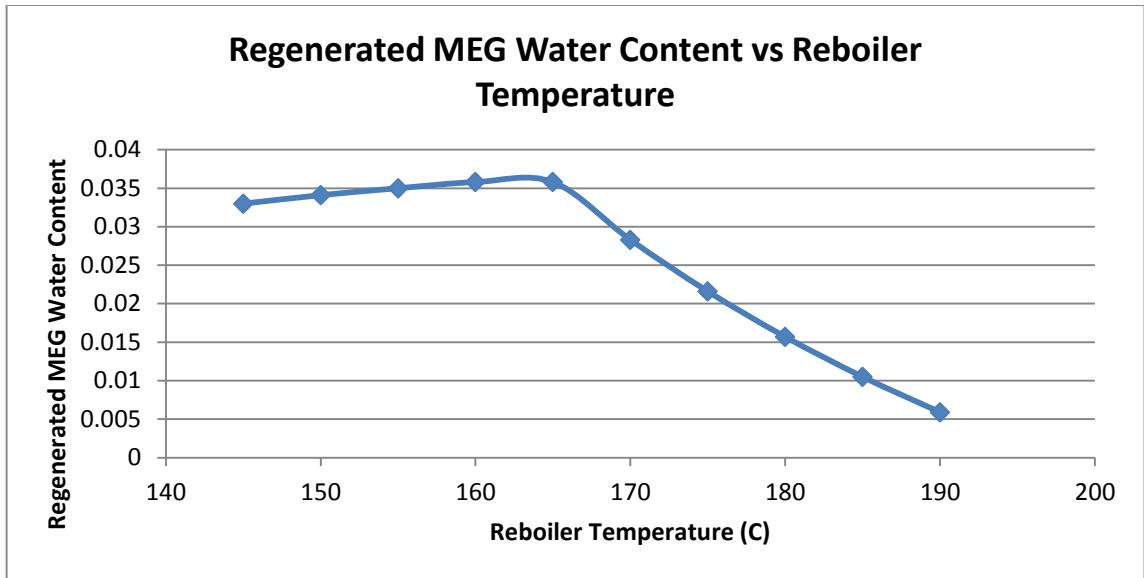Figure 11: Graph of Regenerated MEG Mass Fraction vs Reboiler Temperature

Figure 12: Graph of Regenerated MEG Water Content vs Reboiler Temperature

The figures above show the effect of reboiler temperature on the purity of MEG after regeneration. Figure 10 shows the regenerated MEG mass fraction while figure 11 shows the regenerated MEG water content mass fraction. It is observed that purity of MEG drop from 0.967 to 0.9642 when the reboiler temperature is increased from 145°C to 165°C. However, after 165°C, the purity of MEG increases from 0.9642 to 0.9941 at 190°C.

Next, the effect of reboiler temperature against MEG loss is also being investigated. It is shown in the graph below that the loss of MEG decreases from 2924.5 kg/h to 784.7 kg/h when the temperature of the reboiler increases from 145°C to 165°C. After that, the MEG loss stay almost constant when the reboiler temperature increases from 165°C to 190°C. This is because low reboiler temperature causes the regenerated MEG to be less pure which lowers the its vapor pressure. This will cause more MEG to be evaporated and discharged together with water later in the DRIZO dehydration process, causing a high MEG loss.
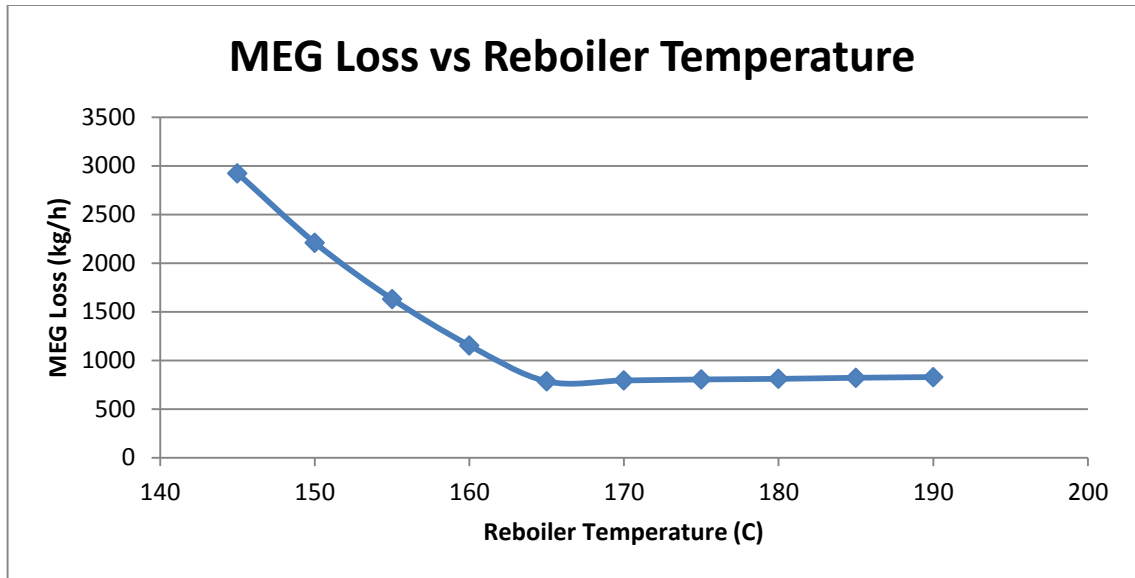
Figure 13: Graph of MEG Loss vs Reboiler Temperature

In the nutshell, it can be said that higher reboiler temperature will results in better regeneration process which can produce purer regenerated MEG. This leads to lower dry natural gas water content, increasing the quality of dry natural gas. However, the boiling of the MEG is around 197.1°C and it may also decompose on high reboiler temperature. Due to the boiling and decomposing temperature constraints, the reboiler temperature cannot be set too high. It is also recommended that the reboiler temperature is around 160°C. Thus, to optimize the process and fulfill all the constraints, 170°C is being chosen as the optimum reboiler temperature.

4.2.2 Finding the Optimum Condenser Temperature

Besides reboiler temperature, condenser temperature also plays an important role on the regeneration column. In order to find the optimum temperature of the condenser column, the experiments on the effect of condenser temperature on various parameters was being carried out.

The following table shows the effect of various condenser temperature on dry natural gas water content, regenerated MEG mass fraction, regenerated MEG water content and MEG loss. Certain conditions such as the reboiler temperature is kept at 170 °C and the makeup benzene flow is 0 kg/h.

Table 15: Table of the Effect of Reboiler Temperature on various parameters

Condenser Temperature	°C	100	102	104	106	108	110
Dry Natural Gas Water Content	ppm	872.3	872.3	872.3	872.3	872.3	872.3
	kg/h	4581.9	4581.9	4581.9	4581.9	4581.9	4581.9
Regenerated MEG	mass fraction	0.9717	0.9717	0.9717	0.9717	0.9717	0.9717
Regenerated MEG Water Content	mass fraction	0.0283	0.0283	0.0283	0.0283	0.0283	0.0283
MEG Loss	kg/h	793.6	835.9	880.5	922.6	976.5	1036.1

Unlike the reboiler temperature, the increasing the condenser temperature does not affect the dry natural gas water content or the regenerated MEG mass fraction. It is shown in the table that when the condenser temperature is increased from 100°C to 110°C, the dry natural gas water content and the regenerated MEG mass fraction stayed constant at 872.3 ppm and 0.9717 respectively. This is because, the purpose of condenser is to condense back the evaporated MEG. As the boiling point of water is 100°C, condenser temperature which is higher than 100°C cannot condense the water vapor that is being evaporated in the column, making the water vapor content in the outlet vapor stream of the distillation column stayed constant. Thus, the regenerated MEG water content is also constant.

However, the MEG loss does not stay constant. This is because, the higher the condenser temperature, the lower amount of evaporated MEG is being condensed back into the column, making the flow rate of MEG in the outlet vapor stream higher. The MEG in the vapor stream is the amount of MEG loss during regeneration process. The below graph shows the relationship between the MEG loss and the condenser temperature.
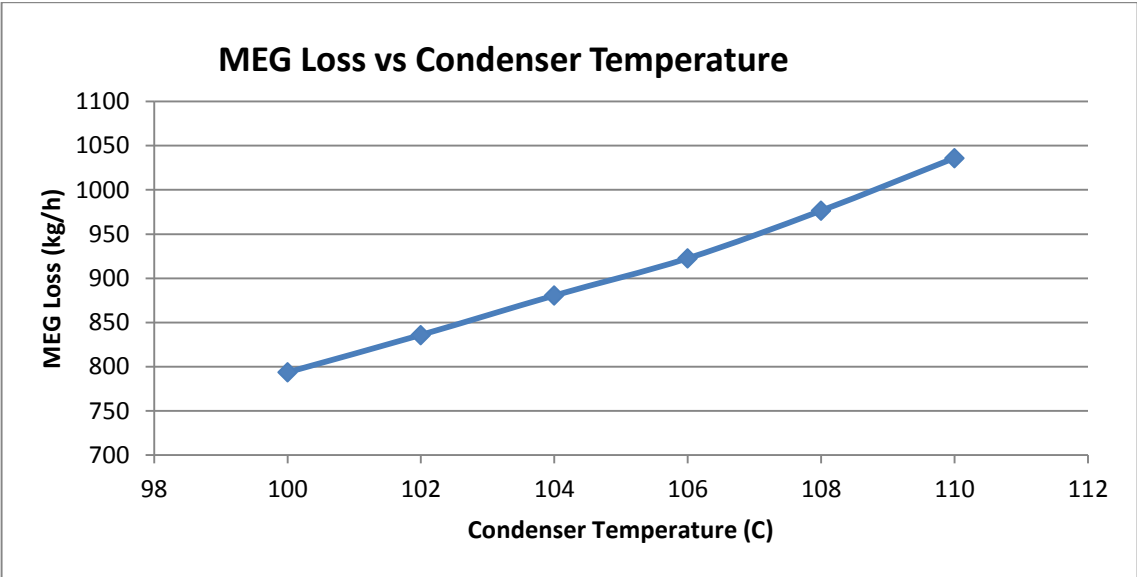

MEG Loss vs Condenser Temperature

Figure 14: Graph of MEG Loss vs Condenser Temperature

It is shown in the graph that, the higher the condenser temperature, the higher the MEG loss. Since the loss of MEG will increase the operating cost, the lower the MEG loss the better the operation. However, the condenser temperature cannot go below 100°C which is the boiling point of the water to avoid water being condensed back into the regeneration column. Thus, in order to minimize the glycol loss, the optimum temperature for the condenser should be 100°C.

4.2.3 Optimizing the Flow rate of Mono-Ethylene Glycol (MEG)

After optimizing the reboiler and condenser temperature, the flow rate of mono-ethylene glycol (MEG), need to be optimized in order to produce the lowest dry natural gas water content. The following table shows the effect of various flow rate of MEG on dry natural gas water content, regenerated MEG mass fraction, regenerated MEG water content and MEG loss. Certain conditions such as the reboiler temperature is kept at 170°C, condenser temperature is kept at 100°C and the makeup benzene flow is 0 kg/h.

Table 16: Table of the Effect of MEG flow rate on various parameters

| Flow rate of MEG	m3/h	20	40	60	80	100	120	140	160	180	200
Dry Natural Gas Water Content	ppmv	373.7	240.9	185.1	158.1	143.8	135.7	130.9	127.8	126.4	125
Regenerated MEG	mass fraction	0.9719	0.9713	0.9711	0.9709	0.9708	0.9708	0.9707	0.9707	0.9705	0.9705
Regenerated MEG Water Content	mass fraction	0.0281	0.0287	0.0289	0.0291	0.0292	0.0292	0.0293	0.0293	0.0295	0.0295
MEG Loss	kg/h	772.7	908.6	970.7	1001.7	1021.1	1033.6	1044	1051.7	1093.5	1098.3
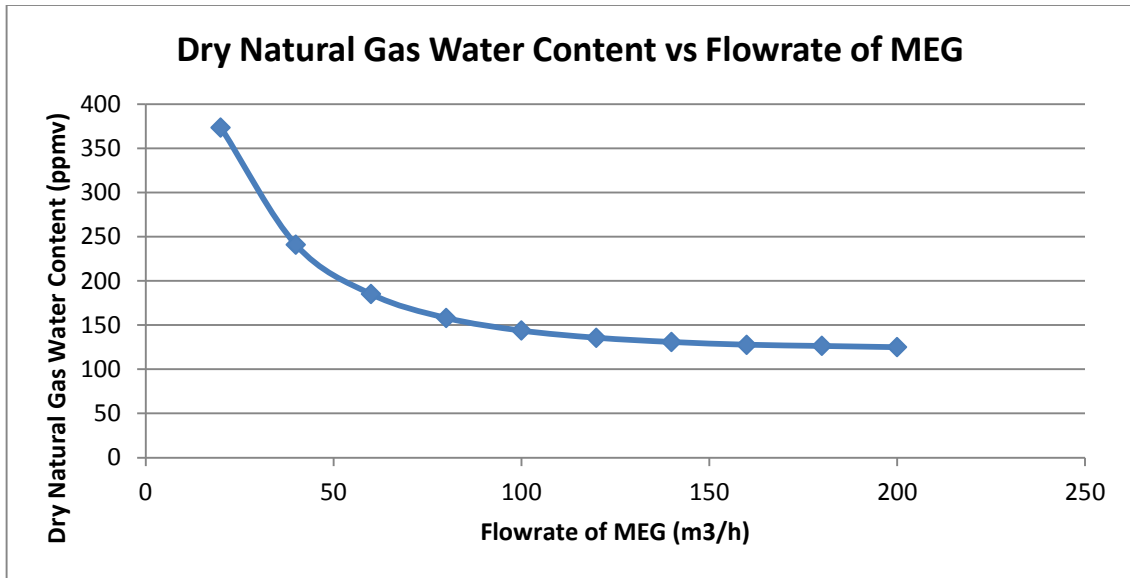
Figure 15: Graph of Dry Natural Gas Water Content vs Flow rate of MEG

From the table, the graph above shows the effect of flow rate of MEG on the dry natural gas water content is being plotted. It is shown in the above graph that the flow rate of MEG is being increased from 20 m3/h to 200m3/h. It is observed that the water content in the dry natural gas drops very steeply at the beginning and slowly come to constant when the flow rate of MEG is reaching 200 m3/h.
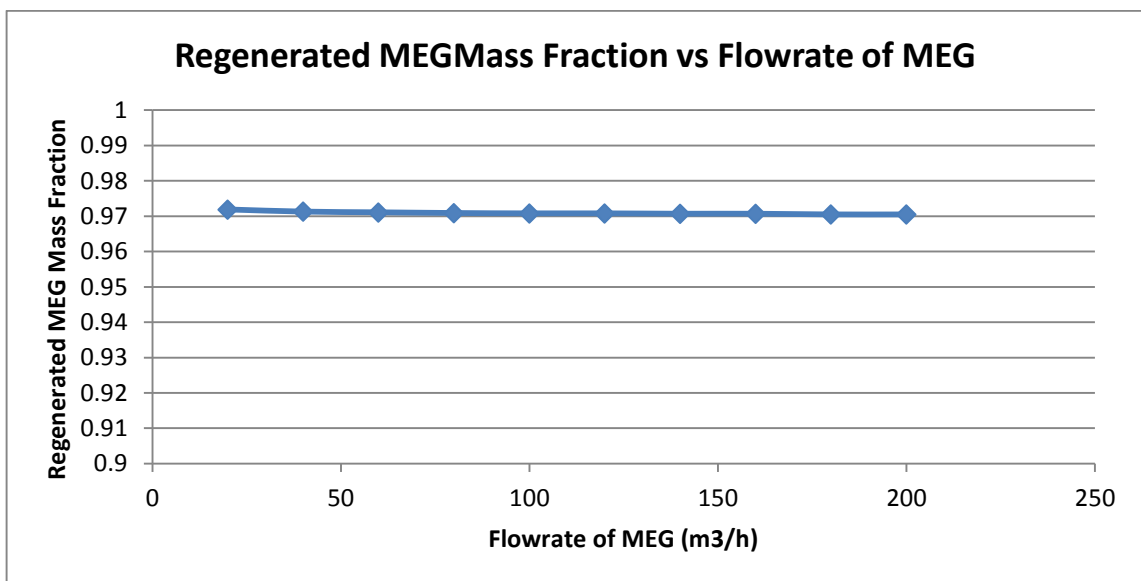

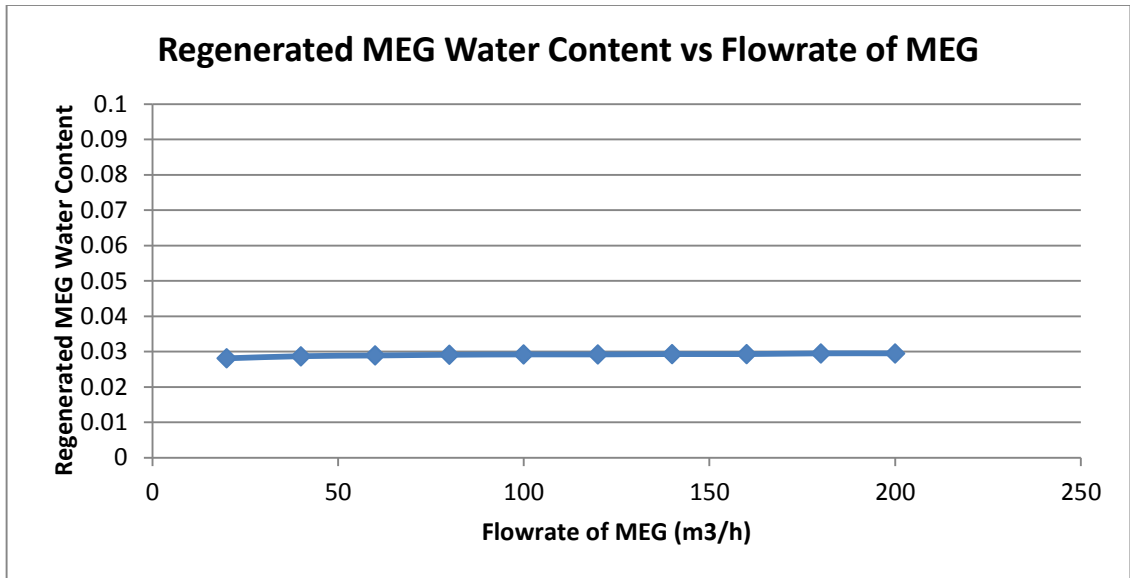Figure 16: Graph of Regenerated MEG Mass Fraction vs Flow rate of MEG

Figure 17: Graph of Regenerated MEG Water Content vs Flow rate of MEG

Besides that, the effect of flow rate of MEG against regenerated MEG mass fraction is also being investigated. From the observation on the above figures, higher flow rate of MEG reduces the purity of MEG. However, the magnitude of reduction is very small and it does not really give a big effect to the operation.
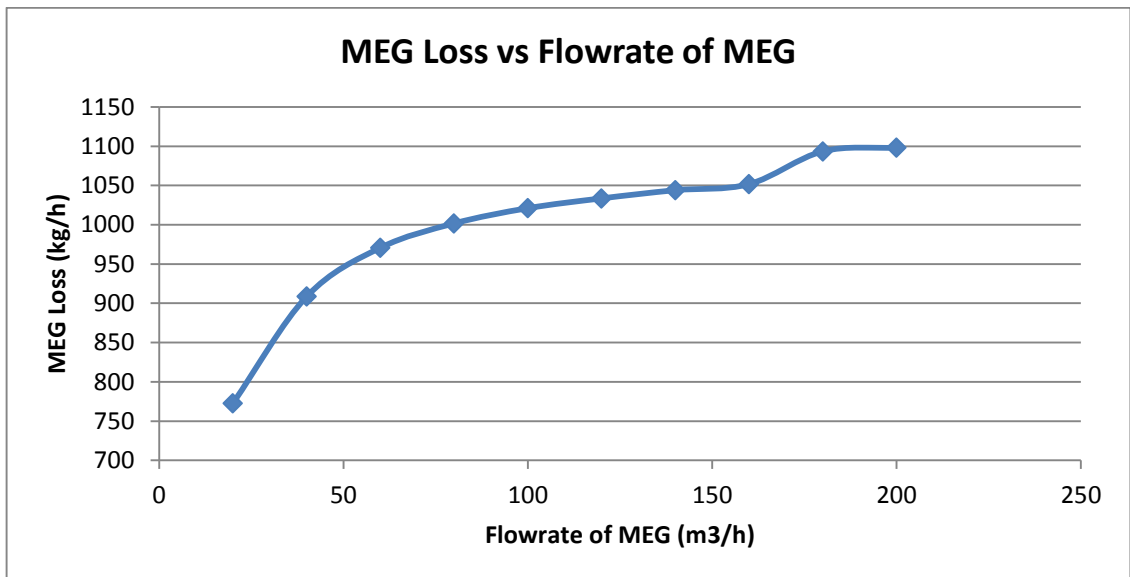

Figure 18: Graph of MEG Loss vs Flowrate of MEG

Next, the effect of the flow rate of MEG on MEG loss is also being investigated. The above figure shows that the higher the flow rate of MEG the higher the MEG loss. It is observed that the MEG loss increases very fast with the increase in the MEG flow rate at the beginning. After that, MEG loss stabilized and stayed almost constant when the flowrate of MEG reaches 150 m3/h. However, there is a sudden increase in the MEG loss when the flowrate of the MEG is increased from 160 m3/h to 180 m3/h.

To further interpret the relationship between the dry natural gas water content and the flow rate of MEG, changes in dry natural gas water content is being calculated. The figures below shows the graph of changes in dry natural gas water content vs MEG flow rate.
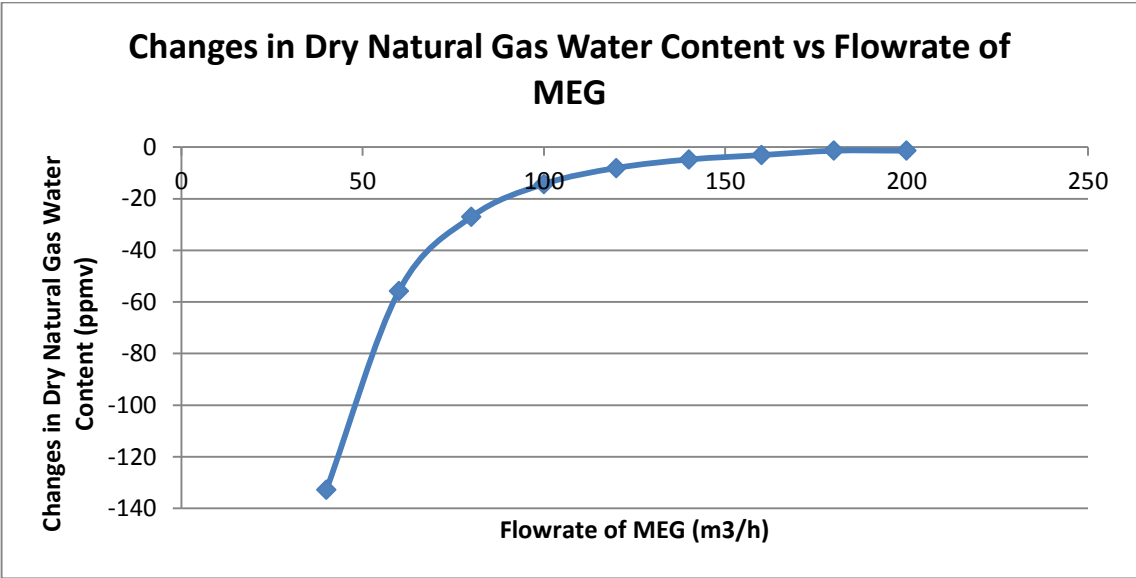

Figure 19: Graph of Changes in Dry Gas Water Content vs Flow rate of MEG

As shown in the above graph, there are very large changes in dry natural gas water content when the flow rate of MEG is being increased from 20m3/h to around 100 m3/h. However, the changes in dry natural gas water content slows down and eventually come to constant when MEG flow rate reaches 180 m3/h. This graph indicates that the optimum flow rates of the MEG should be around 160 m3/h. This is because, further

addition of MEG flow rate does not really increase the dry natural gas quality but also leads to higher MEG loss.

4.2.4 Optimizing the Flow rate of Makeup Benzene

The flow rate of makeup benzene plays a very important role in DRIZO natural gas dehydration process. The following table shows the effect of various flow rate of makeup benzene on dry natural gas water content, regenerated MEG mass fraction, regenerated MEG water content and MEG loss. Certain conditions such as the reboiler temperature is kept at 170°C, condenser temperature is kept at 100°C and the MEG flow rate is kept at 100m3/h.

Table 17: Table of the Effect of makeup benzene flow rate on various parameters

| Make Up Benzene Flow	m3/h	0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Dry Natural Gas Water Content	ppmv	143.8	108.5	75.11	65.8	56.2	52.6	48.9	47.2	44.7	42.1	42.07
Regenerated MEG	mass fraction	0.9708	0.9809	0.9903	0.9928	0.9954	0.9964	0.9974	0.9979	0.9985	0.9992	0.9992
Regenerated MEG Water Content	mass fraction	0.0292	0.0190	0.0096	0.0071	0.0044	0.0035	0.0025	0.0020	0.0013	0.0006	0.0006
MEG Loss	kg/h	1021.1	1139.8	1330.1	1458.0	1699.2	1794.1	1924.1	2006.1	2139.4	2362.4	2396.0
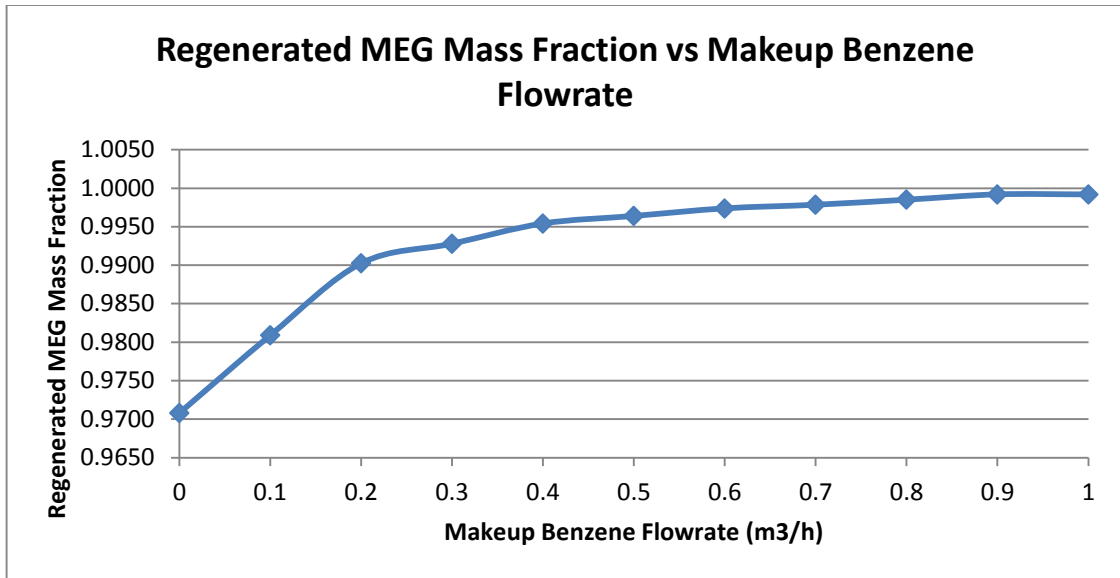
Figure 20: Graph of Regenerated MEG Mass Fraction vs Makeup Benzene Flowrate
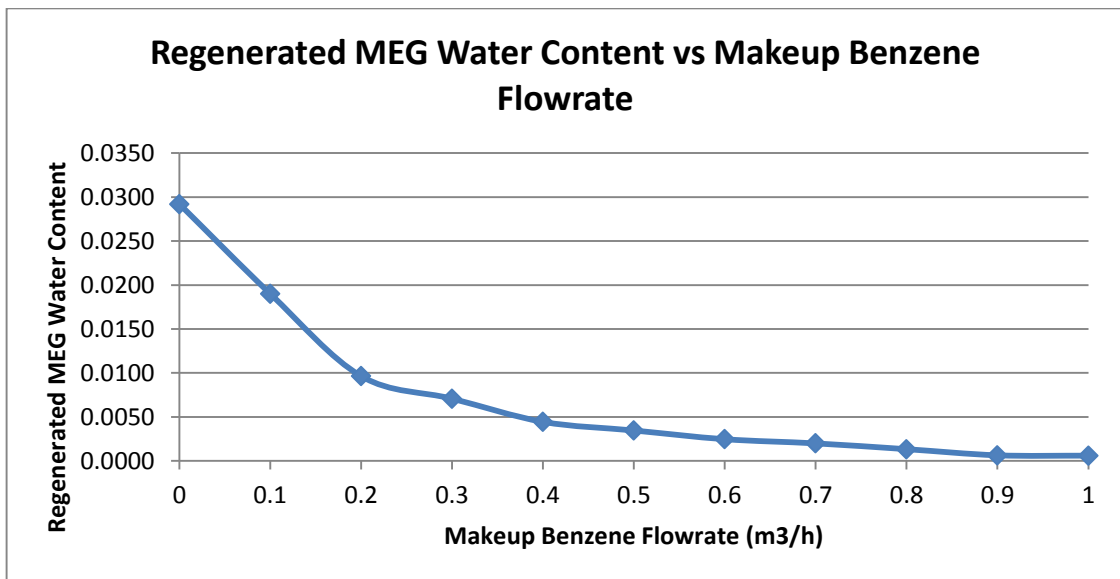

Figure 21: Graph of Regenerated MEG Water Content vs Makeup Benzene Flow rate

Two of the above graphs shows the effect of makeup benzene flow rate against the purity of MEG. It is observed that the higher the makeup benzene flow rate, the higher the purity of the regenerated MEG. This is because introduction of benzene into the stream will make the vapor pressure of the rich MEG lower. This will make the regeneration of rich MEG easier as water can evaporates more efficiently; making the purity of regenerated MEG higher.

To further analyze the relationship between the regenerated MEG mass fraction and the makeup benzene flow rate, the changes in the regenerated MEG mass fraction is being calculated and the graph of changes in MEG mass fraction vs makeup benzene flow rate is being plotted.
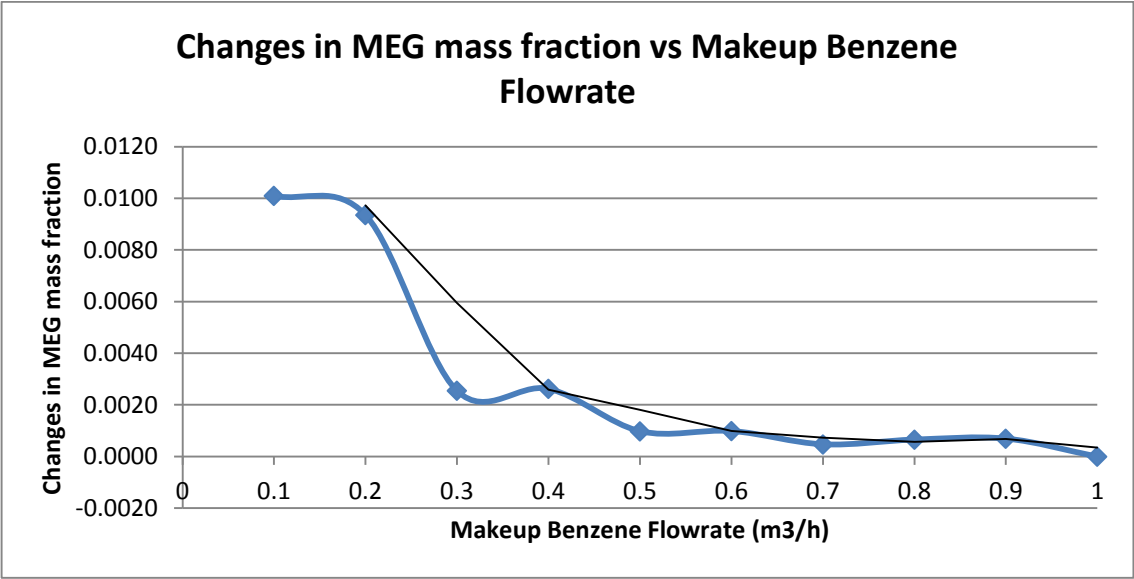

Figure 22: Graph of Changes in MEG mass fraction vs makeup benzene flow rate

As shown in the above figures, the changes in MEG mass fraction reduces with the increase in makeup benzene flow rate. This phenomena indicates that although the introduction of makeup benzene into the stream improve the MEG mass fraction, large amount of makeup benzene flow rate does not really differs much from low makeup benzene flow rate. Thus, to prevent benzene loss, the optimum amount of benzene flow rate is needed to be identified. It is observed that the changes in MEG mass fraction slows down and come to constant around 0.6 m3/h of makeup benzene flow.

As the regenerated MEG mass fraction affects the dry natural gas water content directly, to study how the makeup benzene flow rate affects the dry gas water content, the graph of dry natural gas water content vs makeup benzene flow rate is being plotted.
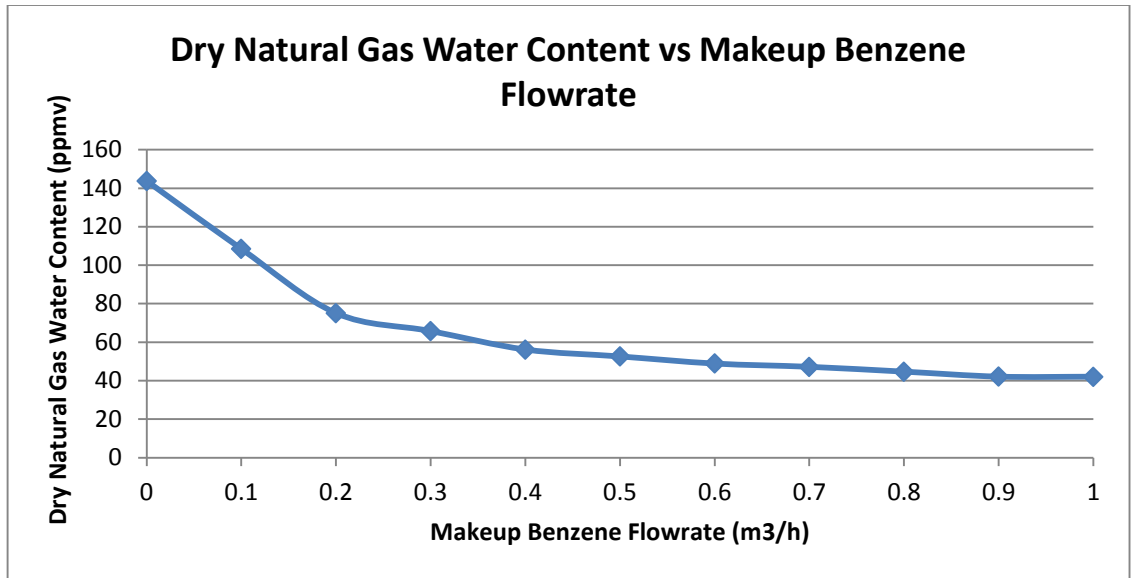
Figure 23: Graph of Dry Gas Water Content vs Makeup Benzene Flowrate

The above figure shows the effect of makeup benzene flow rate on dry natural gas water content. It can be observed that the higher the makeup benzene flow rate, the lower the dry natural gas water content. Initially, the water content in the dry natural gas dropped very fast with the increase in makeup benzene flow rate. However, the drop in dry natural gas water content gradually decreases and become constant at around 40 ppmv, when the makeup benzene flow rate reaches around 0.6 m3/h.

Next, the loss of MEG in the glycol dehydration process is also affected greatly by the flow rate of makeup benzene. As the benzene reduces the vapor pressure of rich MEG, during the regeneration process, higher benzene flow will make more MEG to be evaporated and loss through the system. The graph below shows the relationship between MEG loss and makeup benzene flow rate.

Figure 24: Graph of Glycol Loss vs Makeup Benzene Flowrate
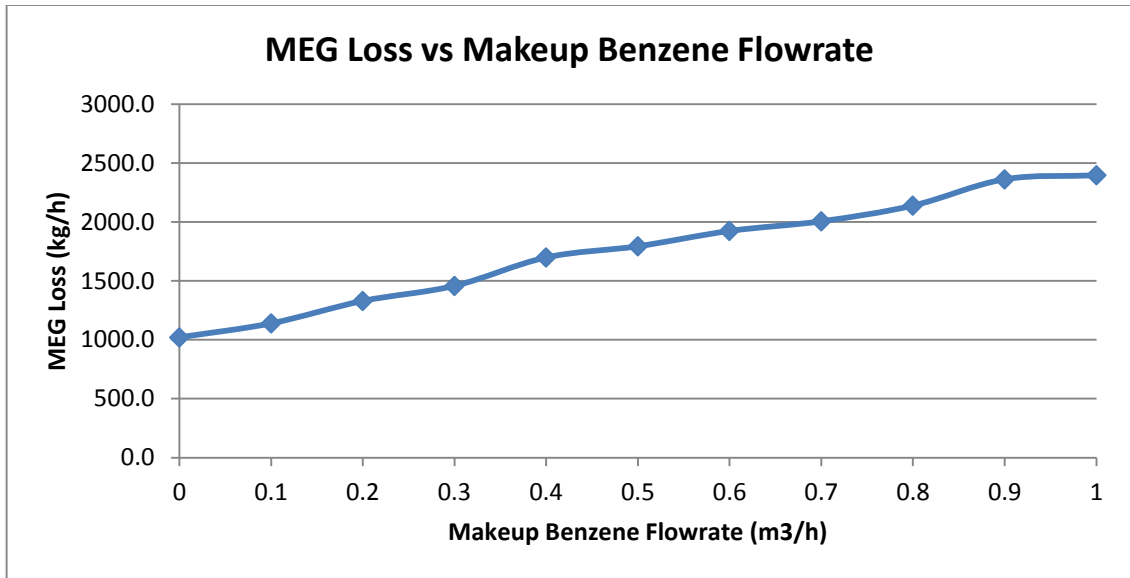
It is observed that the higher the makeup benzene flow rate, the higher the MEG loss and their relationship is linear. Thus, to monitor the changes in MEG loss due to makeup benzene flow, the different in MEG loss is calculated and the graph of changes in MEG loss vs makeup benzene flow is plotted.
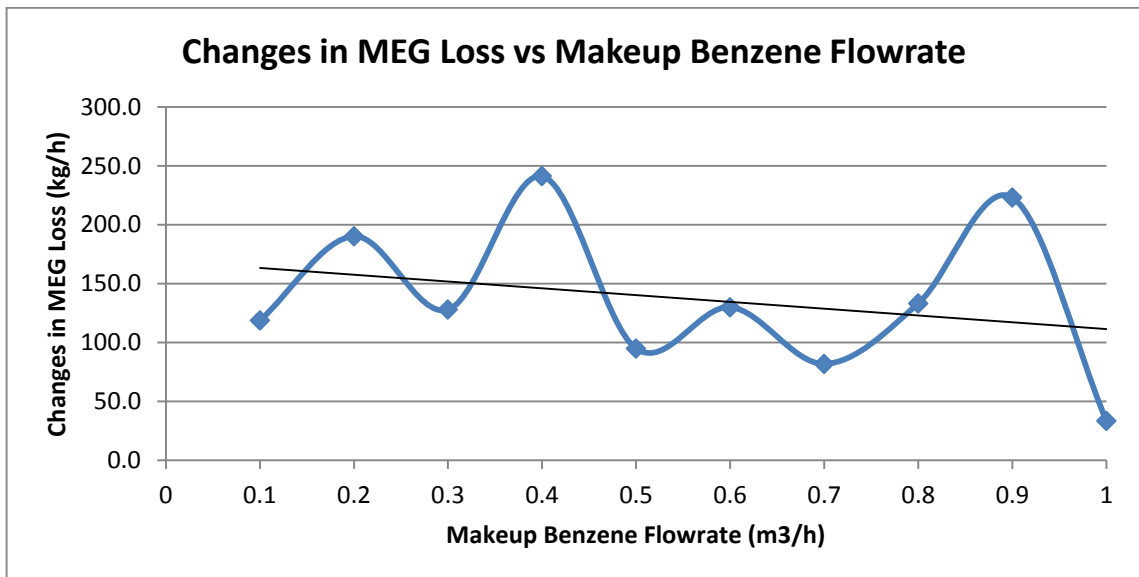

Figure 25: Graph of Changes in MEG Loss vs Makeup Benzene Flow rate

The above graph shows that there are fluctuation in changes of MEG loss in respect to makeup benzene flow rate. From the scattered points in the above graphs, a line of best fit was drawn and it is observed that the loss of MEG is actually fluctuating around a linear line. As the gradient of the line of best fit is almost horizontal, we can said that the relationship between the MEG loss and the makeup benzene flow rate is linear. Thus, from the experiment of optimization of makeup benzene flow rate, it can be concluded that higher benzene flow rate will result in better dry natural gas quality due to higher regenerated glycol purity but it leads to higher glycol loss which may increase the cost. In order to reduce the MEG loss but maintaining a good dry natural gas quality, benzene flow rate which is 0.6 m3/h is chosen as the optimized value.

4.3 Chemical Modification of MEG

After optimizing the simulation of DRIZO dehydration process which uses MEG instead of TEG, chemical modification of MEG is done by mixing MEG with a neopentyl alcohol known as pentaerythritol and being tested using Aspen HYSYS 8.4 software. The table below shows the effects on the dry natural gas quality, MEG loss and BTEX emission over the flow rate of additive.

Table 18: Table of effect of flow rate of additive on various parameter

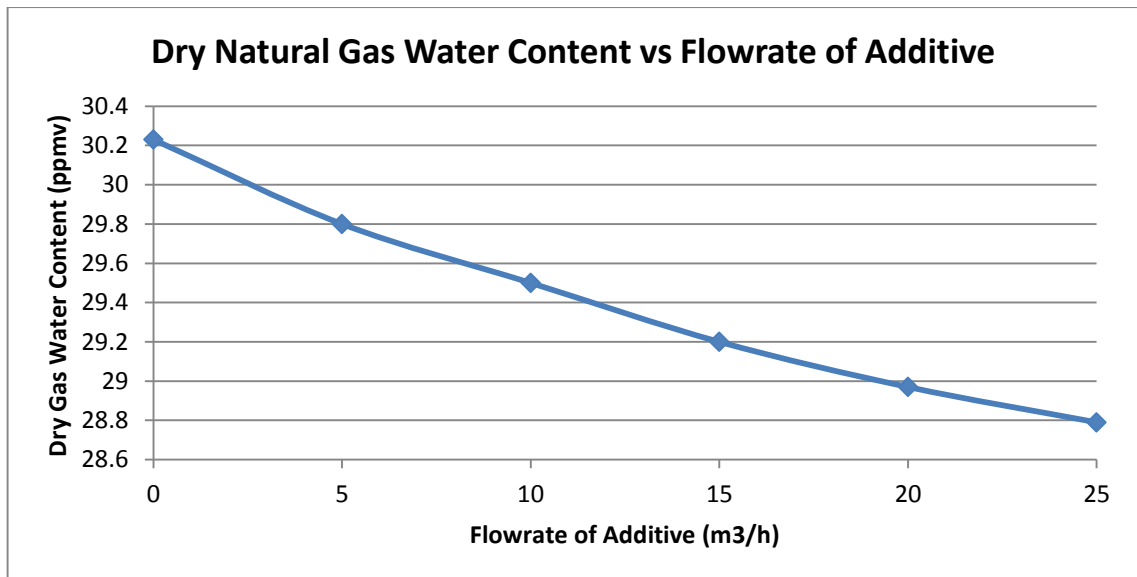| Flowrate of Additive	m3/h	0	5	10	15	20	25
Dry Natural Gas Water Content	ppmv	30.23	29.8	29.5	29.2	28.97	28.79
MEG Loss	kg/h	2087.35	2042.26	2033.25	2024.24	2016.40	2008.94
Benzene	kg/h	58.898	58.082	56.044	54.392	52.563	50.534
Toluene	kg/h	0.0021	0.0023	0.0025	0.0027	0.0030	0.0033
p-xylene	kg/h	0.0002	0.0000	0.0000	0.0000	0.0000	0.0000
e-benzene	kg/h	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000

Figure 26: Graph of Dry Gas Water Content vs Flow rate of Additive

The above figure shows the relationship between the dry natural gas water content and the flow rate of additive. It is observed that the higher the flow rate of additive, the lower the dry natural gas water content and their relationship is linear. However, due to the solubility limit of MEG, the maximum amount of additive added is 25 m3/h, producing a dry gas water content of 28.79 ppmv.
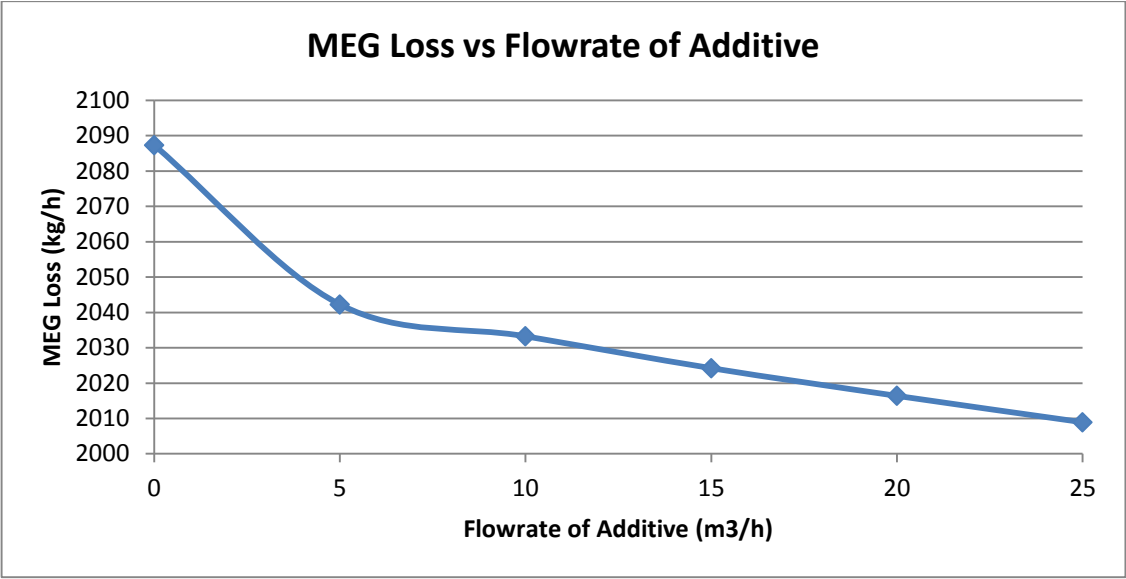

Figure 27: Graph of MEG loss vs Flow rate of Additive

Besides that, the increase in the flow rate of additive also reduces the MEG loss. It is observed that over 25 m3/h of additive added, the amount of MEG loss is reduced by 78.41 kg/h.
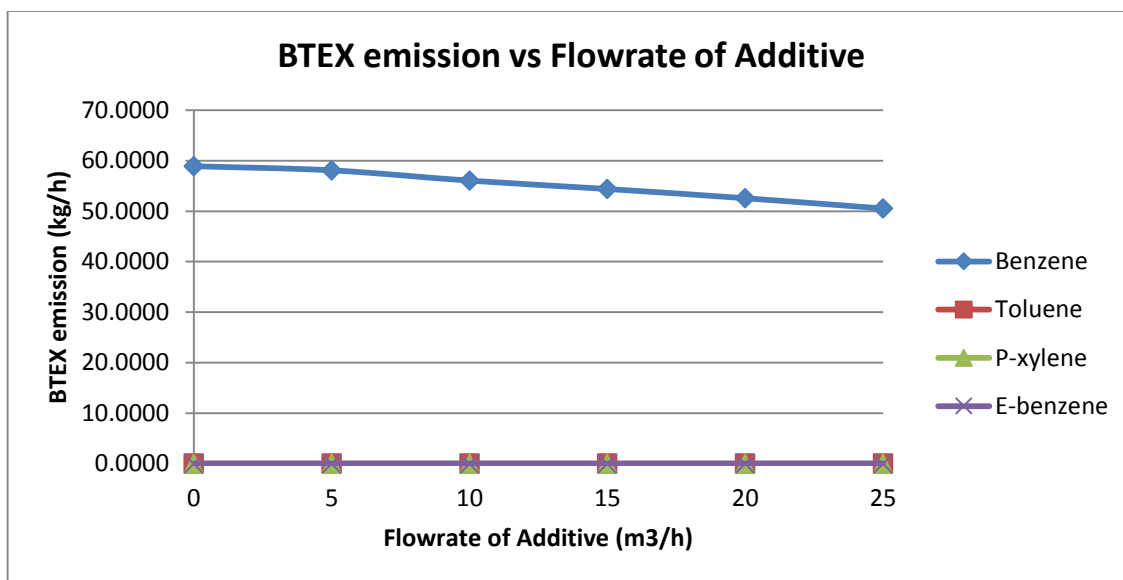
Figure 28: BTEX emission vs Flow rate of Additive

In addition, the chemical modification of MEG also reduce the amount of BTEX emission. It is observed that the amount of toluene, p-xylene and e-benzene stayed zero throughout the increase in the flow of additive. For benzene, it is calculated that over 25m3/h of additive added, the amount of benzene emission is reduced by 8.375 kg/h.

4.4 Comparison between the Performance of TEG and Chemically Modified MEG

4.4.1 BTEX Emission

Table 19: Table of BTEX Emission for TEG, MEG and Chemically Modified MEG

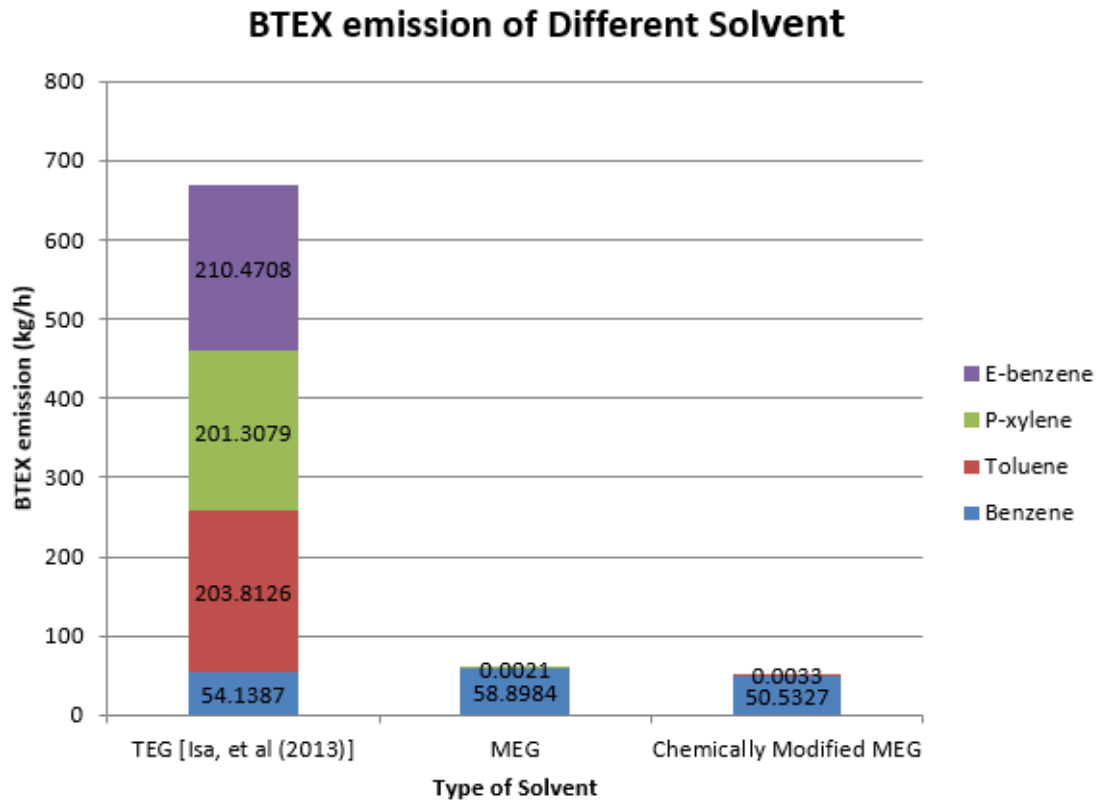| BTEX Gaseous	TEG	MEG	Chemically Modified MEG
Benzene (kg/h)	54.1387	58.8984	50.5327
Toluene (kg/h)	203.8126	0.0021	0.0033
P-xylene (kg/h)	201.3079	0.0002	0.0000
E-benzene (kg/h)	210.4708	0.0000	0.0000
Total (kg/h)	669.7300	58.9005	50.5360

Figure 29: Graph of BTEX emission of Different Solvent

The above table and figure show the amount of BTEX gaseous emitted from the natural gas dehydration process using TEG, MEG and Chemically Modified MEG respectively. It is calculated that the total amount of BTEX emitted by the process using TEG as the

solvent is 669.73 kg/h, MEG is 58.9005 kg/h and chemically modified MEG is 50.536 kg/h. Thus, it can be said that using TEG as a solvent in natural gas dehydration process emit the most amount of BTEX gaseous. On the other hand, using MEG instead of TEG can reduce the total amount of BTEX emitted by using TEG by 91.2% and using chemically modified MEG can reduce that amount by another 1.254%, making a total of 92.454% reduction.

There are a big difference in the reduction of BTEX emission between using TEG and MEG is due to their chemical properties. Referring to the table of solubility of different petro-chemicals in different glycols (Table 3), it is observed that BTEX gaseous especially toluene, xylene and ethyl-benzene are more likely to dissolve in TEG than MEG. Thus, during the dehydration process, the BTEX gaseous present in the natural gas will be absorbed by the TEG. Later in the regeneration process, the dissolved BTEX gaseous in TEG will be emitted to the atmosphere. However, the solubility of BTEX gaseous in MEG is very low. Therefore, MEG will only absorb a very little amount of BTEX gaseous during the dehydration process so there will be very low emission during the regeneration of MEG. Furthermore, chemical modification of MEG can further reduce the solubility of BTEX in MEG making the BTEX emission even lesser than the usage of pure MEG.

4.4.2 Dry Gas Water Content

Table 20: Table of Dry Natural Gas Water Content (ppmv) for TEG, MEG and Chemically Modified MEG

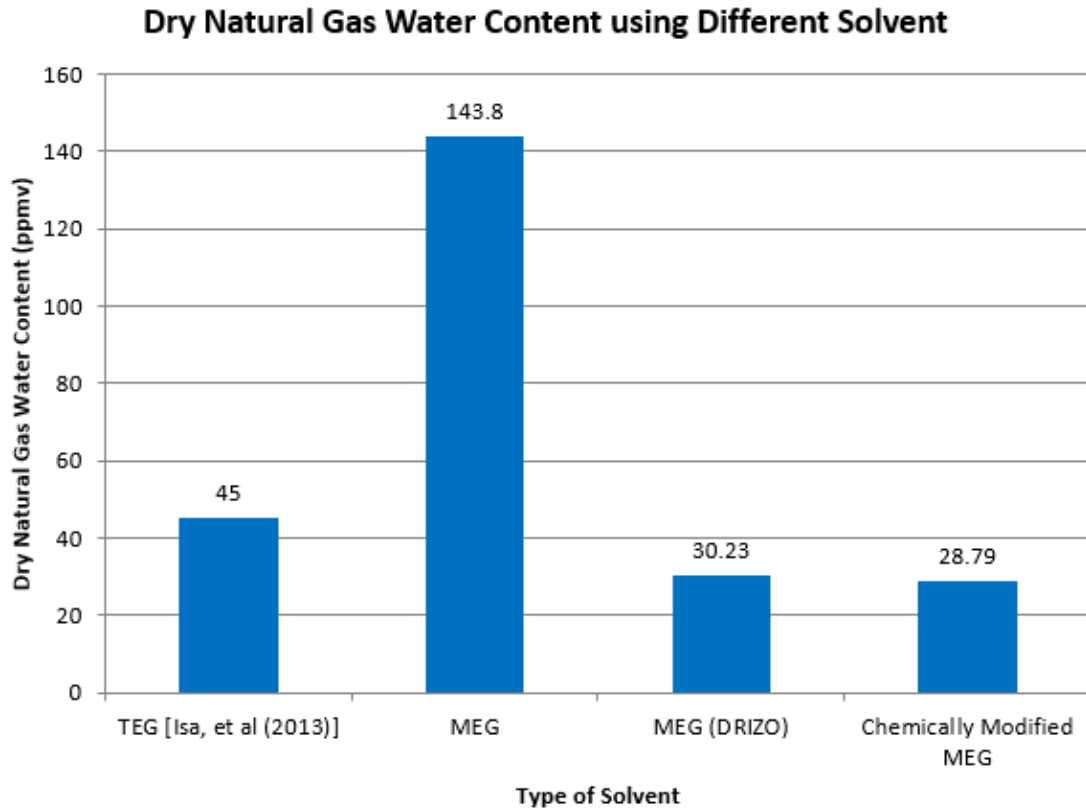|	Dry Natural Gas Water Content (ppmv)	Reference
TEG	45	Isa, M. A. et al 2013
MEG	143.8	-
MEG (DRIZO)	30.23	-
Chemically Modified MEG	28.79	-

Figure 30: Graph of Dry Gas Water Content using Different Solvent

The above table and figure show the amount of water content in dry natural gas after being dehydrated using TEG, MEG and chemically modified MEG respectively. It is calculated that the initial amount of water content in wet natural gas is 812.48 ppmv. From the table, using TEG as the solvent to dehydrate the natural gas in normal natural gas dehydration process produces a dry natural gas with a water content of 45 ppmv. On the other hand, using MEG instead of TEG produces dry natural gas having a water content of 143.8 ppmv. This is because chemically, TEG has more affinity to absorb water compared to MEG, thus TEG has a better performance.

However, by modifying the natural gas dehydration process by introducing a makeup flow of benzene (known as DRIZO process), the amount water content in dry natural gas after dehydration reduces to 30.23 ppmv. This is because, the introduction of benzene into the system can reduce the vapor pressure of water, making the regeneration process

of MEG easier, thus producing a purer MEG which can absorb more water from the wet natural gas. Chemical modification of MEG by mixing a neopentyl alcohol known as pentaerythritol with MEG further improve the absorption capacity of MEG, which produce a dry natural gas water content of 28.79 ppmv.

Chapter 5

Conclusion and Future Recommendation

As conclusion, this project is important as it is designed to come out with a chemically modified mono-ethylene glycol (MEG) which its performances can compete with the current tri-ethylene glycol (TEG) that is commonly used as a solvent in natural gas dehydration industries. All the objectives of this project have been completed successfully within the time limit.

The simulation experiment for typical natural gas dehydration process using tri-ethylene glycol had been completed and the validation of the data had been done. The analysis of the data shows that the simulation experiment is accurate and having a percentage error of less than 5%. This indicates that the simulation is valid and can be trusted.

Next, the optimization of DRIZO natural gas dehydration simulation that uses MEG instead of TEG is also done. The parameters that were optimized includes reboiler temperature, condenser temperature, MEG flow rate, and makeup benzene flow rate. The final optimized DRIZO natural gas dehydration simulation works with a reboiler temperature of 170°C, condenser temperature of 100°C, MEG flow rate of 160 m3/h and makeup benzene flow of 0.6 m3/h. These result in dry gas water content of 30.23 ppmv, MEG loss of 2087.35 kg/h and total BTEX emission of 58.9005 kg/h.

Later the MEG is further enhanced by chemical modification. In the experiment, a maximum amount of 25 m3/h of a neopentyl alcohol known as pentaerythritol is being added to MEG and its effect is being studied. It is observed that chemical modification reduced the dry gas water content to 28.79 ppmv and MEG loss to 2008.94 kg/h. Besides, it also reduces the amount of benzene emission by 8.375 kg/h resulting in a total BTEX emission of 50.536 kg/h.

For future recommendation lab case experiment on the chemically modified glycol solvent should be done in order to get the physical and chemical properties of the solvent to further validate the simulation experiment and to determine the limiting constraints of the solvent. More research on the chemical modification of solvent should also be done in order to produce more efficient solvent.

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Appendices

Appendix 1: MEG manufacturing specification

Component	Specification
MEG	99.91 wtp, minimum
DEG	0.035 wtp, maximum
Water	0.038 wtp, maximum
Acidity	18 ppm, maximum
Iron	0.025 ppm, maximum
Chlorides	0.1 ppm, maximum
Color	4.5 PtCo, maximum
Total carbonyl	8 ppm, maximum
UV 220 nm	82%T, minimum
UV 250 nm	91%T, minimum
UV 275 nm	95%T, minimum
UV 350 nm	98.3%T, minimum

Appendix 2: HYSYS simulation