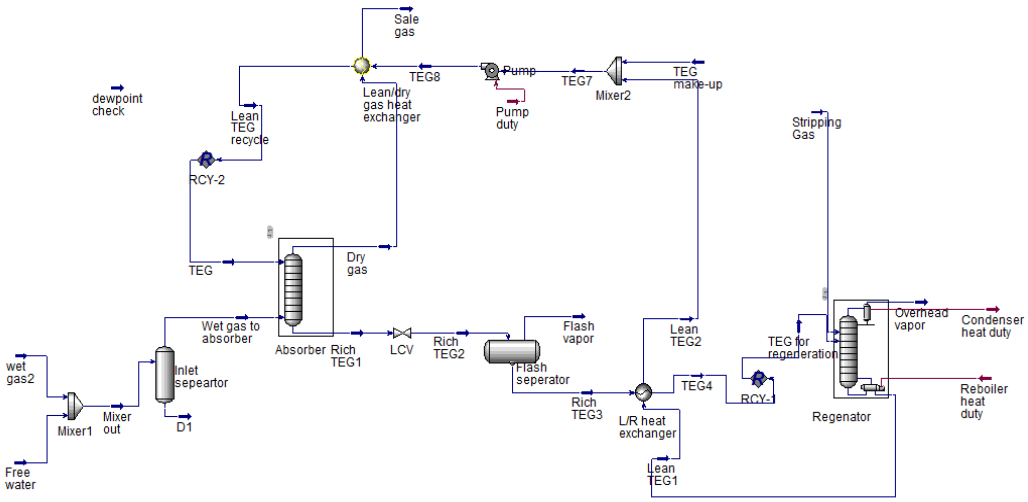
TEG regeneration in Natural gas dehydration process



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Acknowledgement

This project report was done for the 8th semester at the Department of Chemical Engineering, Aalborg University, Esbjerg between February to May in 2021. The project was carried out under the supervision of Professor Rudy P. Nielsen from the section of Chemical Engineering at Aalborg University, Esbjerg. The project deals with TEG regeneration of Natural gas dehydration process using Aspen HYSYS a simulator software.

It was a huge experience of learning in chemical engineering at Aalborg University, Esbjerg.

I would like to express my sincere gratitude and special thanks to my supervisors for sharing their knowledge, energy and time for answering my infinite questions, giving necessary guidance and support as their student.

The project report is a collection of scientific papers. The first part of the report is an introduction describing the background for this project. This includes the extent of how big the issue is and hence why this project work is important. The section ended with an objective section and describing goal, I set for myself from the beginning of the project.

I sincerely hope that you as readers will find my results and the project interesting- enjoy your reading.

Sincerely,

Suborna Rani Nath

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31 May 2021

Abstract

The exploration and production of natural gas are usually contains large amount of water vapor during production operation. In order to protect the gas system from hydrate formation and to meet sale gas specifications it is necessary to remove water vapor from the natural gas stream; a process called dehydration. Glycol dehydration is the most frequent and cost-effective method of removing water from natural gas streams, which employs triethylene glycol (TEG) as the dehydrating agent, were simulated using Aspen HYSYS software. The primary goal of this study is to performing a sensitivity analysis over the obtained results from the simulation and to study the possibility of optimizing the process to predict the optimum parameters in natural gas dehydration system. Three different TEG flow rates, stripping gas flow rate and reboiler temperature were used for the simulation. Result shows that, the simulation process succeeds in reducing the water content to 0.623lb/MMSCF from an initial value of 13.80lb/MMSCF and found out the most effective parameter to remove the water vapor and estimating the TEG purity for 3750kg/h of TEG flow rate at reboiler temperature 204℃ with 1900kg/h stripping gas flow rate. Finally it appears that, using stripping gas is a more effective technique to improve the TEG purity and the overall performance of the dehydration plant.

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1. Introduction

Natural gas is an important source of energy and usually considered as the non-renewable gaseous fuel. Many scientists believed that, about two billion years ago, the natural gas was formed from marine organisms like algae, microscopic animals and plants that died to the bottom of the ocean floor. They buried and formed fossils under a layer of sediment that turned into rock. The layers of sedimentary rock grew thousands of feet thick over time without oxygen under high temperature and pressure, which transformed the energy-rich dead organisms into petroleum and natural gas. Over the years, the natural gas gradually became trapped under the rock layers, as substance and form reservoirs like vast sponges filled with oil and gas.

There has been remarkable increase in the global demand since last 45 years for natural gas which resulted in a diverse primary uses of this fuel as petrochemical feedstock, fuels for power generation and transportation, space heating and a host for other domestic uses (Okafor & Evwierhurhoma, 2020)(Atiqueuzzaman, 2012). Found in much of the worlds offshore fields that, (Okafor & Evwierhurhoma, 2020) the principal market for natural gas is reached by transmission lines that transfers it to various consuming centers, such as industrial, commercial, and domestic sector. This development has been recorded in just few years with the increased availability of the gas supplies from various countries (Atiqueuzzaman, 2012). It is a key feedstock to produce ammonia, via the Haber process for the use of fertilizer production (Suckling et al., 2009). By the statistical review of world energy report 2020, natural gas consumption rose by 78 billion cubic meters (bcm), or 2%, which is well below the strong growth have seen in 2018 [5.3%]. Growth was perhaps driven by the USA (27 bcm) compared to China, Russia, and Japan. Eventually, gas production grew by 132 bcm (3.4%) with the USA accounting for almost two thirds of this increase number (85 bcm) (BP, 2020). Natural gas may appear to be an uninteresting gas in its pure form, as it is colorless, odorless, and shapeless.

The raw natural gas is extracted from three types of well respectively: a) oil wells, b) gas wells, and c) condensate wells primarily. Natural gas, which is produced from the crude oil wells, is generally entitled as ‘Associated gas’ (Anyadiegwu et al., 2014). This gas can exist individually from crude oil in the underground formation as free gas and dissolved in the crude oil as entitled as 'dissolved gas'. Besides, natural gas extracted from gas and condensate well, in which there is little or no crude oil, is typically entitled as non-associated gas. However, gas well normally produces raw natural gas by itself, while condensate well generates raw natural gas, besides a very low-density hydrocarbon condensate called natural gasoline (Suckling et al., 2009). Whatever the source of the natural gas, when it is isolated from crude oil, it generally exists in raw natural gas or in sour gas (Anyadiegwu et al., 2014).

The raw natural gas contains many contaminants such as Hydrogen sulfide (H_2S), water vapor, Carbon-di-oxide (CO_2), Nitrogen and other compounds (Roy & Amin, 2012). In particular, water that is associated with natural gases is in vapor form, which is the most common unenviable 'impurities' to remove from the gas. Generally, the gas must go through several stages of processing to meet the criteria for a clean, dry, and entirely gaseous fuel acceptable for transmission via pipelines and to distribute for burning by end users, including the removal of entrained liquids from the gas, followed by drying to decrease the water vapor (Anyadiegwu et al., 2014) (Kong et al., 2018). The produced gas must be exported and recompressed to onshore facilities. However, on offshore facilities water is eliminated from the natural gas stream by absorbing it from the gas into a polar solvent, usually a glycol liquid (Vizi et al., 2017). The liquid is then regenerated and recycled to reduce the amount of make-up needed. Therefore, the removal of water vapor from the natural gas dehydration system is to meet sales gas specifications or other downstream gas processes, just like gas-liquid recovery (Anyadiegwu et al., 2014) (Gandhidasan, 2003). Basically, water removal is essential as the presence of water in natural gas leads to several problems like producing solid gas hydrates under different temperature and pressure.

1.1 Hydrate Formation

The presence of water vapor in natural gas that condenses in transmission pipelines and forms gas hydrates, whether they come from natural production or storage reservoirs.

Figure 1. Hydrate formation in transmission line (Sajjad, 2018).

Natural gas hydrate (NGH) is a solid crystalline compound showing in Figure 1, which is formed due to low temperature and high pressure by natural gas molecules such as methane, ethane, propane, butane, carbon-di-oxide, H2S and water molecules that may look like ice. However, gases larger than butane do not form hydrates (Farag et al., 2011), where the other compounds stabilize the crystal. Thus, it poses serious problems for the transportation and treatment process which results in line plugging, pipeline

corrosion in the presence of acid gases i.e., H_2S and CO_2 (Nemati Rouzbahani et al., 2014). This issue was first described by Hammerschmidtin in 1934 following which considerable resources were then allocated by natural gas industry to better understanding and predicting hydrate formation (Kong et al., 2018). These abovementioned reasons highlighted the importance of dehydration in gas processing.

The lifetime of a pipeline is directly related to the amount of water contained in the gas, which causes the corrosion, multiphase flow that can limit the pipeline flow capacities, also governing to blockages, and possible damage to process filters, valves, and compressors (C. et al., 2015) (Mokhatab et al., 2019). Therefore, dehydration of natural gas has become a necessity in the gas processing industry, an appropriate dehydration process should be chosen and designed to remove water vapor present in the natural gas (Anyadiegwu et al., 2014). The design criteria depend on a) the amount of water present in the natural gas b) the presence of acid gases effluence the water content treatment (it will also influence the process design and the overall process). The most common method of natural gas dehydration process is absorption by liquid desiccant to remove the water vapor. This process has been used on a large scale in industry for several years. This project focuses on the absorption process and will discuss briefly about other dehydration processes for knowledge purposes.

The efficacy of the gas removal, which is, depends on the water content of the regenerated liquid and that is determined by the effectiveness of regeneration. Below a certain limit of allowed water content traditional dehydration process are ineffective and that necessitates a modification to the solvent regeneration process (Vizi et al., 2017). TEG cannot be regenerated to levels higher than 99.8-99.9% by weight if water rich TEG is distilled in a simple atmospheric column. This is due to the reboilers operating temperature, which cannot be set above 204℃. In fact, typically this temperature must be considered an upper limit for degradation of TEG at higher values (Piemonte et al., 2012).

1.2 Problem formulation

In the previous section an overview of the natural gas processing and dehydration processes has been discussed where we found that gas dehydration is important to meet the sale gas specifications because water and hydrocarbons can form hydrates, which results in line plugging, pipeline corrosion in the presence of acid gases. Therefore, requires increased maintenance cost and reduced line capacity due to free water forming in the pipeline. Glycol dehydration is the most effective way to remove the water vapor from the natural gas. Reduced water vapor content lowers the saturation temperature (or dew point) of natural gas, lowering the risk of free water forming in the pipeline. Removing most of the water vapor contained in the lean glycol, which is related to several factors such as, feed composition, glycol purity, glycol flow rate, amount of water content in dry gas, number of stages, glycol feed temperature and pressure and stripping gas flow rate. However, in the traditional regeneration process, this is also limited by the maximum allowable reboiler temperature.

To investigate how the process design of the absorption dehydration unit with TEG glycol can be more efficient at removing water from the gas and which operating parameter is most efficient to get better performance, the resulting problem statement is the following question.

Which operating parameters affects the most for natural gas dehydration?

The question is answered by determining the effects of different operating conditions during the Glycol dehydration process and then optimizing the entire process with those optimized parameters using a commercial software named Aspen HYSYS as a process simulator.

To achieve the desired level of the operating parameters selected factors were analyzed on the performance of the gas dehydration unit, to find out the optimum operating conditions to minimize the reboiler duty, glycol flow rate, glycol purity and most importantly water content of the dehydrated gas. However, keeping all other operating parameters fixed, such as feed gas temperature and pressure, number of trays of absorption and distillation column, feed gas composition.

Chapter 2

Literature review

2.1 Natural Gas

2.1.1 Composition of natural gas

The properties of natural gas depend on gas-specific gravity, pseudo-critical pressure and temperature, viscosity, gas density, compressibility factor and gas compressibility. Hence, in designing and investigating natural gas production and processing systems which requires the knowledge on these property values. The amount of water that is present in the natural gas basically depends on the composition of the natural gas also. Nevertheless, natural gas stream is a complex mixture of hydrocarbon gases contains 70-90% methane (CH_4) in most cases. The remaining hydrocarbons have a higher molecular weight, such as ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}). There may also be water vapor, hydro sulphide, carbon dioxide (CO_2), nitrogen (N_2), and helium (He). In Table 1 represented the chemical composition of raw natural gas.

Table 1. Chemical composition of raw natural gas (Suckling et al., 2009).

Compound	**Symbol**	**Wt. % in natural gas**
Methane	CH_4	60-90
Ethane	C_2H_4	0-20
Propane	C_3H_8	0-20
Butane	C_4H_{10}	0-20
Carbon Dioxide	CO_2	0-8
Oxygen	O_2	0-0.2
Nitrogen	N_2	0-5
Hydrogen Sulfide	H_2S	0-5
Noble gases	Ar, He, Ne, Xe	0-2

2.1.2 Natural gas processing

Natural gas that contained at the wellhead of the reservoir, is termed as "wet gas" when other hydrocarbons are present (Anyadiegwu et al., 2014). The "wet gas" obtained from producing wells based on the type, depth, and location of the underground deposit, as well as the geology of the field. However, natural gas is contemplated as "dry" gas when it is almost pure methane (CH_4) and having had most of the other commonly associated hydrocarbons removed. The gas processing applied to raw natural gas to achieve pipeline-quality dry natural gas is a complicated process that typically entails several steps.

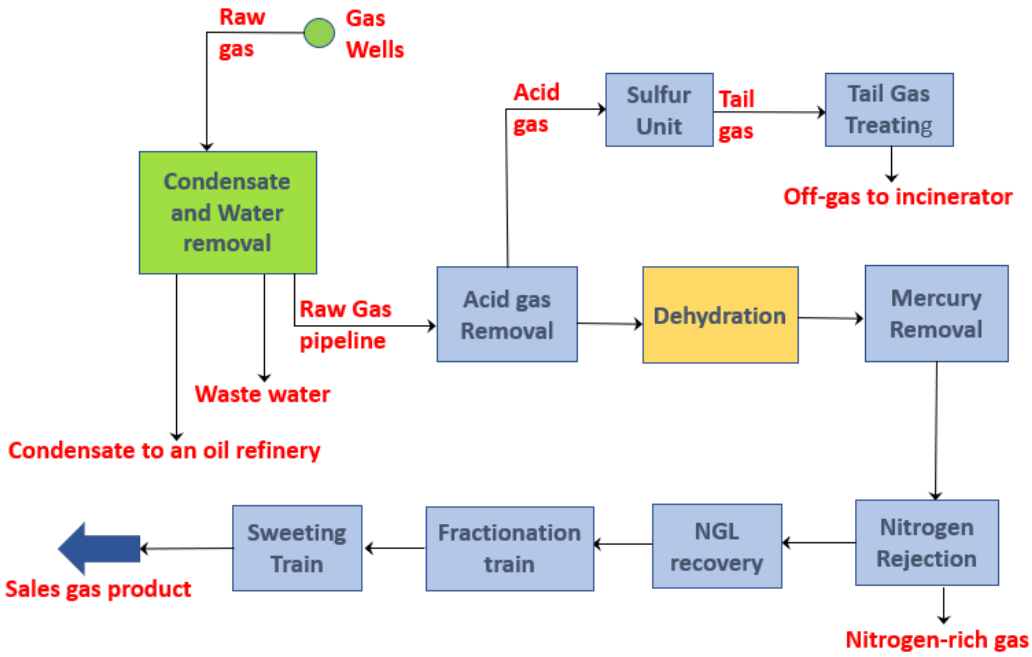

Figure 2. A typical onshore natural gas processing plant (Okafor & Evwierhurhoma, 2020)

Since the mid-1850s various forms of processing plants have been used to extract liquids, from the produced crude oil, such as natural gasoline. But natural gas was not a common fuel for many years, since pipeline technology enabled only for short-distance transmission because of until the early twentieth century, most of it was flared or simply vented into the atmosphere (Suckling et al., 2009). However, separation of important components from the raw natural gas can be used as petroleum feedstock products, fuels (i.e., propane), or industrial gases (i.e., ethane, helium) and liquefaction of the natural gas is to be stored or transported (Faramawy et al., 2016). A simplified flow diagram of a typical onshore natural gas processing plant is shown in Figure 2 which depicts different unit processes involved to convert raw natural gas into sales gas for distribution to end users. The process generally followed by water removal, mercury removal, dehydration, and acid gas removal, NGL recovery (Kong et al., 2018). However, the offshore production facility usually carries oil, gas, and condensate via transmission pipelines to the onshore terminal and processing facility and alternatively oil may be

transferred by rail tankers or by pipeline to the onshore terminal. The purpose of this cleaning process is to remove impurities to improve the gas quality, prevent hazards in the process plant or pipeline from corrosion or enable the gas to the required export condition.

Water removal: Free water associated with extracted natural gas is separated at or near the wellhead using gas dehydration [33], which, will be discussed, in the next section.

Acid gas removal: To reduce corrosion it is necessary to remove acid components from the gas which is mainly CO_2 and H_2S that are to be removed even in some cases sulfur components are present that must be removed. Therefore, acid gas removal is designed at the early stages in the gas handling process to keep the acid gas content within the acceptable limit. In addition, the method of removing hydrogen sulfide from sour gas (H_2S rich) is referred to as "sweetening". Since both acid gases (H_2S /CO_2) are removed in the same process, sweeting may commonly refer to as the acid gas removal process in general (Alcheikhhamdon & Hoorfar, 2016).

Dehydration: Dehydration will be discussed in the next section.

Mercury removal: Mercury traces in the gas processing plant could corrode the aluminum heat exchanger, causing the system to fail. Mercury contains sludge from various treatment processes which represents harmful hazardous wastes that are difficult to store or dispose of (Faramawy et al., 2016).

NGL recovery: The process of NGL recovery involves cooling the gas below its dew point temperature, condensing the heavier hydrocarbons in the gas, and afterwards removing the condensed liquid in a separator. NGL separated from the gas to prevent liquid in the pipeline or to market the more costly NGL individually from the gas. To cool down the gas using heat exchangers are the easiest and most effective way at high pressure (Isa, 2009).

In addition, scrubbers, and heaters, are often needed as additional equipment to theses process at or near the wellhead. Scrubbers are used to eliminate impurities such as, sand, and other large particles, while heaters are used to keep the temperature drop to the point where hydrate formation becomes appreciable (Kong et al., 2018). Therefore, before selling to consumer's gas processing is carried out which differs significantly from natural gas that is transported from underground to the wellhead.

2.2 Water content determination

The quantity of water vapor in gas stream strictly controlled where, the efficiency of the gas dehydration is estimated on the amount of water content present in the natural gas. This will help to estimate how much to dehydrate.

The first step is evaluating what is the amount of water the natural gas is carrying to select the gas dehydration unit and designing the process. Second is the presence of acid gases affluence the water content treatment. So, when the process is chosen based on the water content but if acid gases are present along with the water, they will influence not only the water content is measured they also influence the process design and the overall process. That is why it is very essential when designing sour gas dehydration units to evaluate the production of water with sour gas in the inlet separator of the plant. The amount of water present in natural gas depends on the process it will be saturated. Moreover, determining the saturated water content of a gas is a standard but complex problem in thermodynamics. There are varieties of methods for calculating water content of the natural gas. We can use some chart data available in the literature to establish the mathematical processor to perform the calculation. This chart also shows if we change operating temperature and pressure, we can see how much water content can be accommodate by the natural gas or by the pure component when it is a mixture. In general, current methods are adequate for lower acid gas concentrations which is less than about 30% but can lead to serious errors at higher acid gas and methane concentrations greater than 50%, especially at higher pressures (John Carroll, 2020).. At given temperature and pressure this method can evaluate the water vapor content contained in sweet gas by (Mcketta and Wehe, 1958) chart (Figure 3).

1. This can calculate the mole % of H_2S of sour gas by this:

   So (mole %) of H_2S = (mole %) H_2S + 0.7 x (mole% of CO_2).

2. Secondly the ratio of water in sour gas to water in sweet gas can be estimated

- In figure 3. If we locate the point at the little down left corner of the temperature scale and then go to the right to the mole% of H_2S with the given temperature.
- Then after this point, go to the upper chart corner at the given pressure value and move to the left, then get the ratio.

3. Thirdly, can calculate the saturated water content of the sour gas at the given pressure and temperature.

- By multiplying the amount of water vapor content of sweet gas and the ratio of water in sour gas to water in sweet gas.

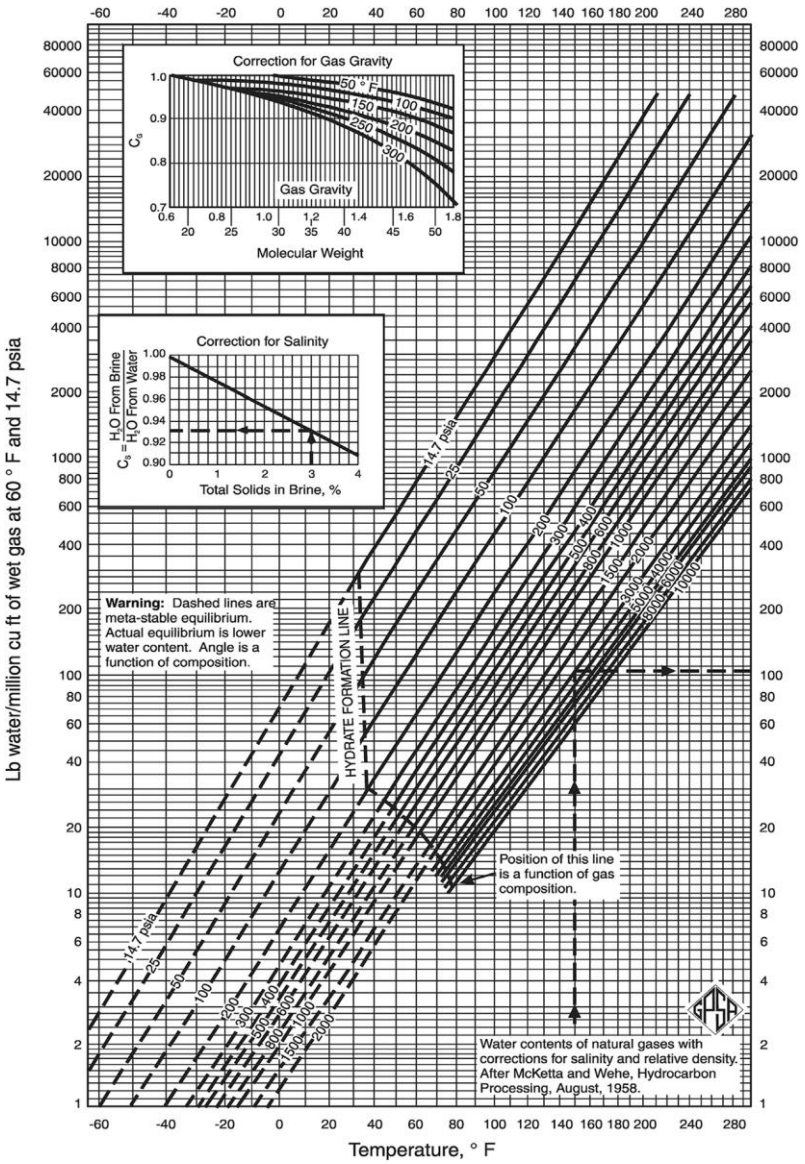

Figure 3. (Mcketta and Wehe, 1958) chart (GPSA, 2004).

There is another procedure, which is the most common way to estimate the amount of vapor in water content. It includes estimating water dew point. In general, a lower water dew point indicates lower water content (Alireza Bahadori, 2014). Water dew point is typically defined in sales gas contracts for transport, storage, or processing. For example, in Europe, the water dew point specification for natural gas transported through pipelines is usually -8℃ at 70bar. Particularly, compliance with these prescribed values through dew point adjustment used protects against the hydrate formation in transmission pipelines during the winter (Jokar et al., 2014)(Kong et al., 2018).

Chapter 3

Gas dehydration

3.1 Gas dehydration

Dehydration of natural gas is one of the most popular process operations in the gas industry. It is very essential to perform a smooth operation of gas transmission lines. Dehydration prevents hydrate formation and mitigates corrosion in transmission pipeline.

3.1.1 Dehydration Methods

Currently several dehydration processes are available including:

- Absorption by liquid solvent
- Adsorption by solid desiccant
- Condensation (Refrigeration along with the addition of hydrate inhibitors)
- Gas permeation with membrane

Usually at lower temperature and high pressure, absorption and adsorption physically provide the better removal of water vapor from the natural gas before it is going to the pipeline or the transmission line (Okafor & Evwierhurhoma, 2020) and both processes can reach the required dew point (Anyadiegwu et al., 2014). Absorption process uses liquid desiccants, which loaded into trays or packed towers while adsorption process uses solid desiccants in dry-bed dehydration (Kong et al., 2018). On contrary, condensation uses gas cooling to transform water vapor into liquid and then remove it from the natural gas stream. All process will be discussed in section 3.3.

3.1.2 Gas dehydration by liquid desiccant

Gas dehydration process utilized glycol liquid desiccant as a chemical solvent to remove water content from the natural gas stream (Abdulrahman & Sebastine, 2013). It is the most commonly used and cost-effective means of removing water from the gas stream (Anyadiegwu et al., 2014).. It has been used for dehydration since the beginning of the twentieth century (Mak et al., 2003)(Jokar et al., 2014), but only a few studies have been done to increase absorber trays yields and examine the equations of state to predict thermodynamic behavior of water-glycol system (Scauzillo, 1961)(Øi, 2003)(Jokar et al., 2014),. Moreover, glycol liquid has a high affinity towards water content, and it absorbs the water content in the

natural gas. This means that, when liquid glycol comes into contact with a stream of natural gas containing water, it will 'absorb' the water from the natural gas stream that is why the operation is called the absorption dehydration process. In absorption dehydration, water vapor is removed from the gas by the associated with a liquid desiccant, which has a special affinity of water. In most cases, contact is made in packed or trayed towers. The glycols are efficient liquid desiccants that are commonly used as absorbents in the dehydration method. The following criteria will explain the liquid that is most preferable to use in dehydration process unit (Isa, 2009)

- Strong empathy to water to lowering the required amount of absorbent.
- Low volatility to reduce the vaporization losses at the absorption temperature.
- Low solubility in hydrocarbons to minimize losses during absorption.
- Non-corrosive and non-toxic
- High boiling points and easy regeneration
- Low tendency to foam and emulsify to avoid a decline in gas handling capacity and minimize losses during absorption and regeneration process.
- Low viscosity, which allows for ease of pumping and optimum gas-liquid phases contact.
- Good thermal stability to prevent decomposition in regeneration process.
- No operational problems when used in high concentrations.
- Available (inexpensive, or it can be regenerated)
- No interaction with the hydrocarbon part of the gas, and no acid gas contamination to minimize hydrocarbon loss during dehydration.

The liquid that meets these criteria are the glycols in the case of gas dehydration. There are various types of glycol that are used for dehydrating natural gas.

3.2.2 Types of glycol

For the natural gas dehydration process Monoethylene glycol, Diethylene glycol, Triethylene glycol, and Tetraethylene glycol used. Usually, in a dehydrator, a pure glycol is used, but a glycol mixes sometimes more cost effective in some cases. Among these triethylene glycol has got universal approval as the most convenient glycols for its superior dew point depression, operation reliability and cost. Furthermore it has strong affinity of water and with it ease of regeneration can be performed and, minimum losses of drying agent during operation can be gained. It has high hygroscopicity, high boiling point, and low vapor pressure (Anyadiegwu et al., 2014). Around 95% of glycol dehydration units for natural gas streams use TEG (Kong et al., 2018). TEG is unscented, uncolored, and stable liquid with a high viscosity in its physical form. However, other glycols might be considered when the process temperature is low (Vizi et al., 2017). Over a wide range of operating circumstances, TEG can be successfully utilized for sweet and sour gas dehydration process.

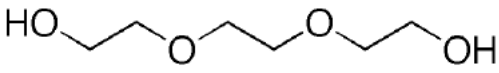

Figure 4. Chemical structure of triethylene glycol (TEG) (Vizi et al., 2017).

Table 2. Physical and chemical properties of different types of glycol (Anyadiegwu et al., 2014).

Parameter	MEG	DEG	TEG	TREG
Chemical name	Monoethylene glycol	Diethylene glycol	Triethylene Glycol	Tetraethylene Glycol
Molecular formula	$C_2H_6O_2$	$(C_2H_5O_2)_2$	$C_6H_{14}O_4$	$HO(C_4H_4O)_3C_2H_4OH$
Molecular weight, g/mol	62.1	106	150.174	194.28
Density, g/cm^3	1.110	1.114	1.1255	1247
Freezing point, ℃	-13	-6.5	-7.1	-6.12
Boiling point, ℃	197	245	286	328
Degradation Temperature, ℃	163	162	202-206	228
Vapor pressure at 25℃	12.1	0.3	0.05	0.007
Viscosity at 20 ℃	20.7	34.8	47.88	60

Over a wide range of operating conditions, triethylene glycol has been successfully used to dehydrate sweet and sour gas.

3.3. Process available for natural gas dehydration

3.3.1 TEG Absorption dehydration process

Figure 5 shows a typical process flow diagram for absorption dehydration process using TEG (Øi, 2003). The overall process is divided into two main units: water absorption in the absorber and TEG regeneration in the regenerator. TEG regeneration influences the water content of regenerated TEG and ultimately, the standard of the dry product gas (sale gas) (Alireza Bahadori, 2014).

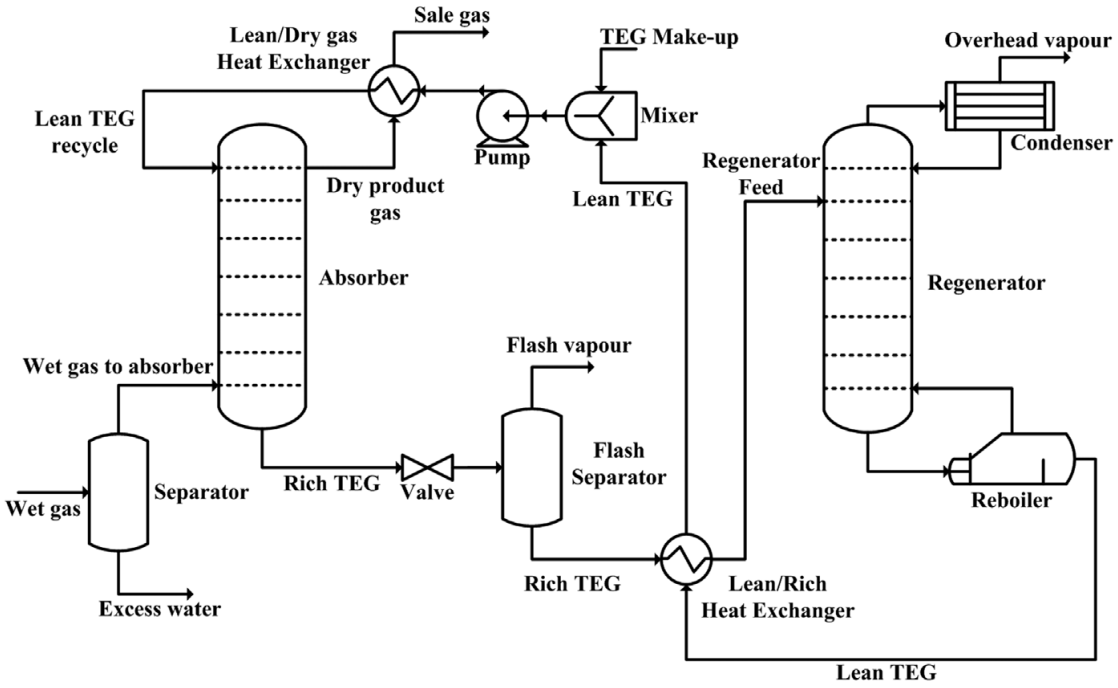

Figure 5. A typical process flow diagram for absorption dehydration process (Øi, 2003).

At the beginning, any other liquid content, or impurities like liquid hydrocarbon solid particles within the wet natural gas should be removed before entering the absorption column unit. This is normally done through installing a two or three phase separator before the absorption column. It is considered more cost-effective because eliminating the liquid content of the gas before transferring it into the column reduces the contamination of the absorption fluid. This helps to reduce the absorption column size and the amount of TEG required. In addition to, an inlet cooler often added before the three-phase separator to reduce the wet gas temperature to the optimal temperature and also to condense liquids out that saves desiccant (Øi, 2003) [not shown in figure 5].

After that, the high pressure wet natural gas enters the absorption column from bottom to top and goes up in a counter-current manner against the water lean (pure) TEG stream which enters from the top of the column. Usually, dehydration process is carried out in multiple contact trayed columns in figure 5,

which allows water-lean TEG to travel from a certain section of the absorption tower. In absorption process, the best performance can be achieved by packing techniques with low-pressure drop, good mass transfer efficiency and the high capacity (Jokar et al., 2014) at a minimal possible cost.

Figure 6. An example of distillation column tray (Indiamart 2020, n.d.)

So, during the process, due to the tray arrangement the contact time can be adjusted depending on the flow rate to have more efficiency of the process. During the contact between wet natural gas and the water-lean TEG, the water-lean TEG absorbs the water vapor of wet gas. Afterwards the dehydrated dry product gas exists at the top of the column, while the water-rich TEG, which normally contains 3-7% of water leaves from the bottom (Kong et al., 2018).

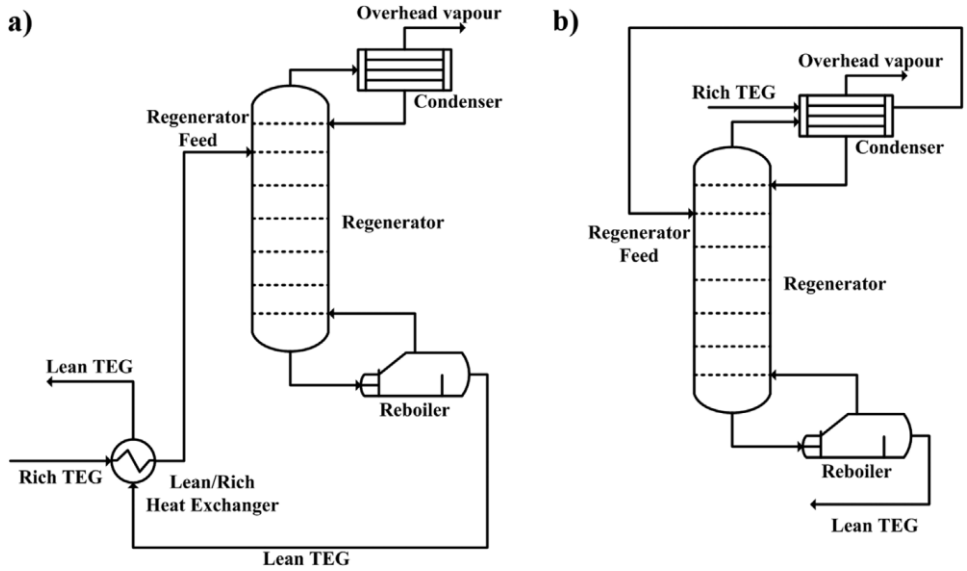

Figure 7. The two different heating configurations for water-rich TEG for regeneration a) Heating by an overhead condenser b) Heating by a glycol-to-glycol heat exchanger [reproduced from (Rahimpour et al., 2013)(Netusil & Ditl, 2011).

Rich TEG passes through an expansion valve, which is used to reduce the stream pressure to its desired level. Rich TEG means it is having more water. However, then water-rich TEG directed into a vertical

two-phase separator (flash separator) where helps to remove light and soluble gas components including CO2 and BTEX gases, those are transferred from gas to TEG that is why it filtered through a vertical two-phase separator shown in Figure 5 (Braek et al., 2001). These gases are then recovered and used as reboiler fuel or as petroleum feedstock or for other purposes. After flashing, the water-rich TEG then directed through a cartridge filter (not shown in Figure 5). It is used to filtered solid particles to avoid (or reduce) corrosion, plugging and deposits problems in the reboiler unit (Díaz Rincón et al., 2016). But in larger systems, activated charcoal and a sock filter are often used for filtering (Gandhidasan, 2001).

In next, the water-rich TEG is preheated to another heat exchanger before it is fed to the regeneration column. The two different heating configurations is used to do the regeneration part has shown in figure 8 (a) & (b). In figure 8 (a) the water-rich TEG is passed through the tubes in the overhead condenser at the top of the regeneration column, which is the most widely mentioned configuration (Øi, 2003)(Rahimpour et al., 2013)(Netusil & Ditl, 2011). In figure 8 (b) used an alternative configuration, which is based on the use of glycol-to-glycol heat exchanger, where the water-rich TEG is passed through a lean-rich heat exchanger, which exchange heat with the water-lean TEG that leaves out from the regeneration column unit.

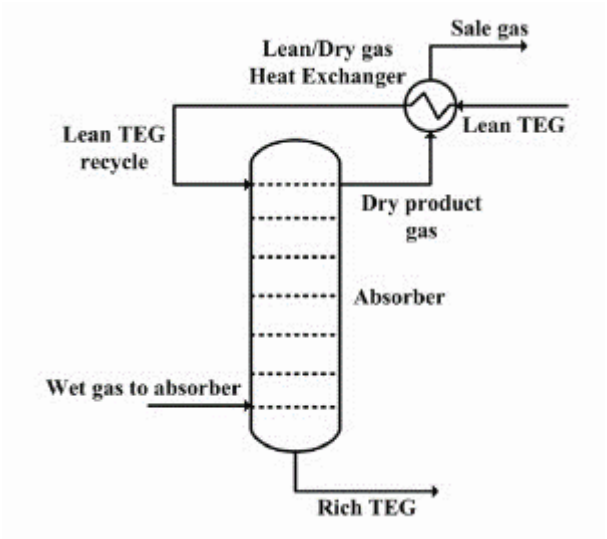

Figure 8. The water-lean TEG before entering to absorber unit cooling by heat exchange with dry gas product gas (Díaz Rincón et al., 2016) (Rahimpour et al., 2013)(Netusil & Ditl, 2011).

The enriched TEG then finally enters in the distillation column from the top of the column and then flows downward, while water vapor, hydrocarbon, and traces of TEG are separated from the regenerator overhead. By using the circulation pump, the regenerated TEG (water-lean TEG) leaving the regeneration column is then send to the top of the absorption column unit. In addition to, an extra make-

up flow compensated for the TEG component, which is lost during the absorption, flash, and regeneration part. After that, the water-lean TEG cooled down by heat exchange with the dry gas coming out from the absorber unit (shown in Figure 8) (Díaz Rincón et al., 2016) (Rahimpour et al., 2013)(Netusil & Ditl, 2011).

3.3.2 Adsorption dehydration

Adsorption is a process in which gas flows through a bed of granular solids that have an affinity for water, most often by mole sieve, silica gel or alumina. Two-bed system is used, as a minimum. Specifically, one bed is for drying gas and the other bed is being regenerated. In this process before natural gas goes to dehydration operation it passes through a separator depending on the composition of the natural gas, to remove the solid or liquid compound before going to adsorption tower. At first the wet gas pass from the top of the tower, due to the reason of high velocity of the gas to not disturb the solids in the tower. The wet gas usually passes through the solid packing and the dry gas comes out from the bottom part of the tower, which can remove most of the water present in the natural gas. Then the dry gas moves to regeneration process, where the solid get free generated so the tower can be used for the next cycle. To make the arrangement, a part of the gas goes through heating process and the heated natural gas pass through the regeneration tower from bottom to be able to remove all the impurities and regenerate the bed for the uses. Then it must go through a cooler before it sent to the separation process. In this case, one regeneration gas scrubber needed to get the water from the separator and collect at the end. This will be the water to dispose (Engineering & Harcourt, 2016). Again, if some liquid content is present in the natural gas that also separates during the process.

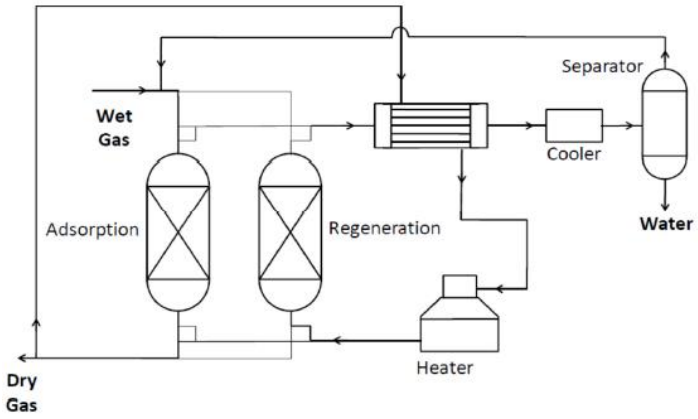

Figure 9. A typical process flow diagram for adsorption dehydration process [Reproduced from (Engineering & Harcourt, 2016).

3.3.3 Condensation dehydration

This method employs cooling process of gas to convert the water molecule into liquid and then remove from the stream. The condensation technology uses refrigeration of natural gas and once refrigerate the gas the water condensates which can be remove that from the wet gas. Therefore, the condensation method is applied for simultaneous dehydration and NGL recovery without forming hydrates by injecting methanol or Monoethylene glycol (MEG) to inhibits hydrate inhibitors before each cooling (Engineering & Harcourt, 2016).

However, among all discussed processes, absorption with liquid desiccant is typically more economically feasible. It requires less energy than adsorption by solid desiccant (Anyadiegwu et al., 2014) and liquid desiccant can be changed continuously while changing an adsorption bed requires a shutdown. In addition, the existence of hydroxyl groups in glycols causes hydrogen bonds to form, which are basically the bonds that exist between water molecules, making glycol a strong absorber for water (Paymooni et al., 2011). Moreover, TEG is the most widely used glycol given its regeneration capability, low thermal degradation rates in the regeneration systems which already been mentioned in section 3.2.2. So, this study will only focus on the typical gas dehydration process based on Absorption by liquid desiccant.

Chapter 4

Glycol regeneration

4. Processes to improve glycol regeneration

This section discusses the different regeneration methods available to achieve lower water content in the glycol. These methods are applicable to all glycol dehydration application for the sake of less operational costs and maximizing the profit.

4 .1 Stripping gas processes

The addition of stripping gas process regarded as the simplest and the popular method for enhancing the TEG regeneration efficiency. It also lowers the partial pressure of the stream, resulting in an increase in the final purity on the regenerated TEG (Vizi et al., 2017). The addition of inert gas allows the original TEG purity limit of 98.8% in the default process (Figure 6) to rise to 99.2-99.99% to achieve a complete water removal (Kong et al., 2018), depending on the types of stripping gas used, which resulting in lower water content in the regenerated TEG. The inert gas such as methane, added externally not from default process itself, that is introduced as a portion of dry product gas (sale gas). DRIZO uses its own internally generated stripping column and a mixture of volatile hydrocarbons of the C5+ shown in figure 12. There are two different methods are available for stripping gas implementation into the dehydration process. The first method involves injecting the stripping gas into the reboiler of regeneration column. The second, alternative method, entails direct injection of stripping gas into the separate packed column where the lean TEG is further stripped from water by dry product gas (Vizi et al., 2017)(Kong et al., 2018). This modification is called the Stahl-column.

4.1.1 Stripping gas process using a portion of dry product gas

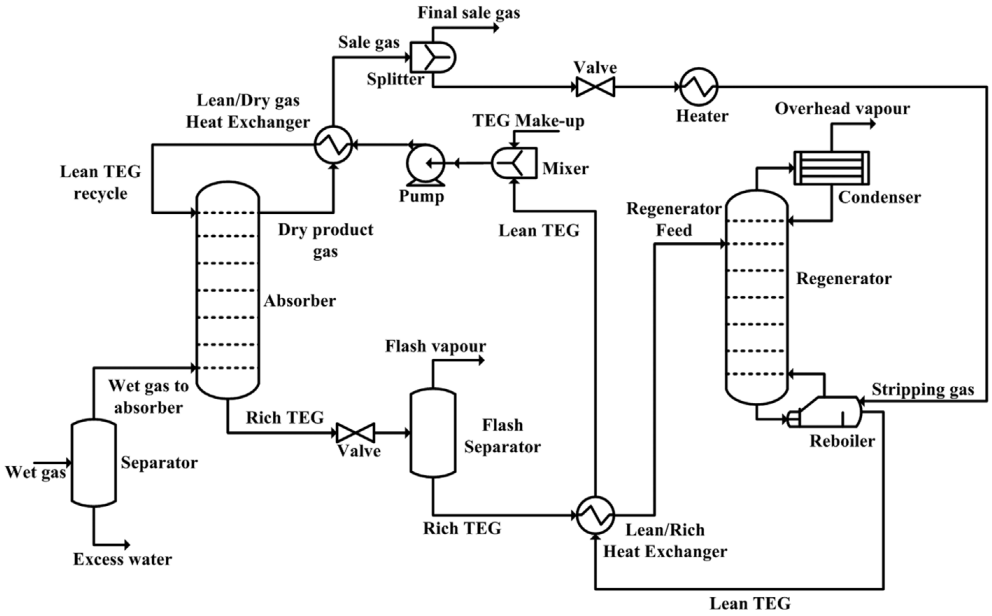

Figure 10. Stripping gas process using the injection of a portion of dry product gas (sale gas) into the regeneration column (Kong et al., 2018).

In addition of a portion of dry product gas can also be used as the stripping gas process as this process is identical to the absorption process (Figure 5) unlike the injection of dry product gas into the regeneration column shown in Figure 10. In this case the stripping gas which is comes from the absorption column unit is additionally directed to the expansion valve, which is then accompanied by a heater to change its operating conditions which is pressure and temperature to match the regeneration column's operating condition has shown in this figure. Stripping gas can be introduced directly into the reboiler. This method also improves the stripping efficiency. It avoids oxidation of glycol by preventing air from coming out into contact with the dry glycol. So far, avoiding glycol losses is the most significant prerequisite for the cost-effective operation of a glycol dehydration process.

4.1.2 Stripping gas process using Stahl column

In this case, the addition of an additional column provides extra removal of water steps from the water rich TEG. Since when a portion of dry product gas is used as stripping gas, the purity of regenerated TEG increases to 99.96%, which results in drier product gas than achieved from in the default system (Figure 5) (C. et al., 2015) (Kong et al., 2018). Unlike the other stripping processes (Figure 10), the stripping gas in this process is injected into the bottom of the Stahl column, where the partially stripped TEG from the reboiler directed into the top of the regeneration column while the lean TEG leaves from the bottom of the Stahl column. To evaporate the water vapor removed from the lean TEG stream, the overhead vapor from the Stahl column can be directed into the bottom of the regeneration column has

shown in Figure 11. It is also a more effective process to evaporate the water vapor with by providing the higher temperature in the reboiler compared to the bottom of the regeneration column (Kong et al., 2018).

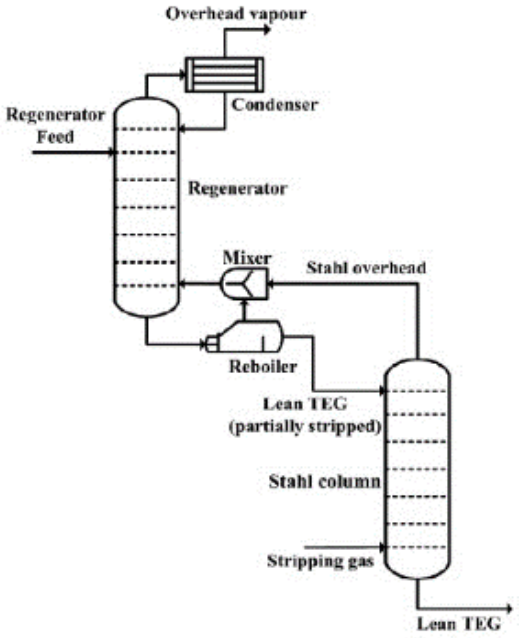

Figure 11. Stahl column (vapor flows directly into the bottom of the regeneration column (Kong et al., 2018).

4.1.3 Stripping gas process using BITEX gases (DRIZO process)

Stripping may be used as heavy hydrocarbons (e.g., BTEX gases) which is supposedly emitted into the atmosphere in the default absorption process in Figure 5, instead of using the inert gas or a portion of dry product gas as in the previously mentioned stripping gas processes. This process is acknowledged as DRIZO process. In this process solvent is usually obtained from C_6^+(BTEX: Benzene, toluene, ethylene, and xylenes) present in natural gas, and process will almost result in some liquid hydrocarbons. This process can be added to the default absorption process (Figure 5) to enhance the purity of the regenerated TEG to up to 99.99%, this leads to a lower TEG flow rate needed for dehydration process (Saeid Mokhatab & William A. Poe, 2012)(C. et al., 2015). This is because BTEX gases provide better water-TEG separation yield compared to using methane alone. Furthermore, the DRIZO process can maximize profit better than the previously discussed two methods, because it prevents the use of invaluable sales gas as stripping gas. In addition to, this process provides the better recovery of heavy hydrocarbons from the regenerator before being sent to the atmospheric distillation, resulting in lower BTEX emissions (Kong et al., 2018). The process flow diagram for DRIZO process has shown in Figure 12.

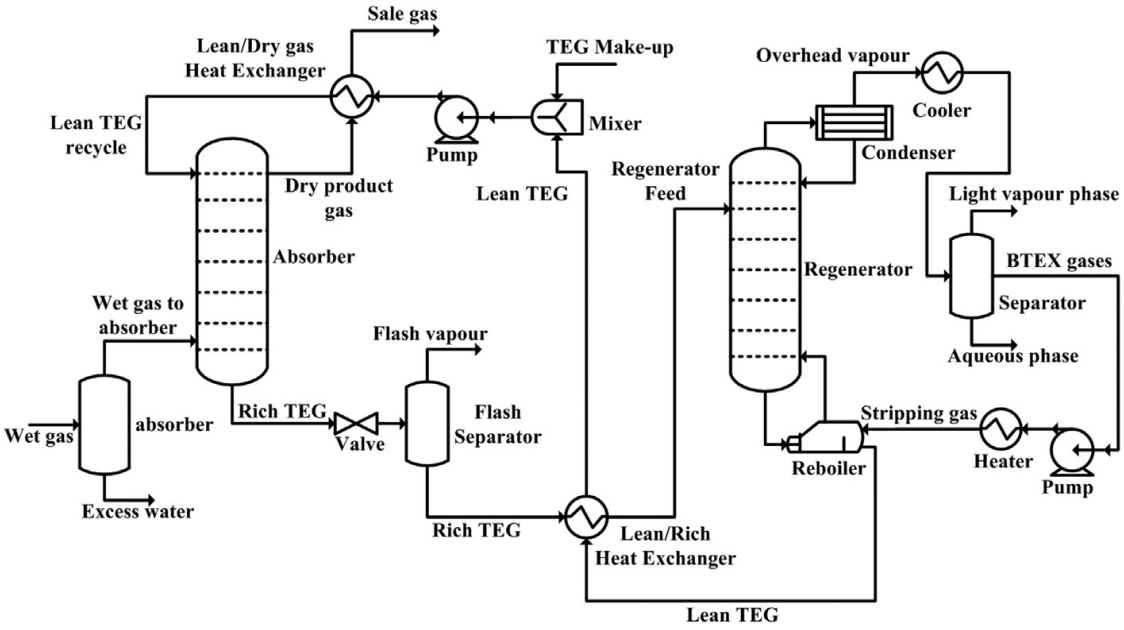

Figure 12. A typical process flow diagram for DRIZO process (Kong et al., 2018).

4.2 Comparison overview of different regenerative methods

Table 3 depicts a quantitative performance of different enhanced processes available to revamp the glycol purity limit. The performance criteria divided into BTEX emissions, economic estimation, (capital cost, operating cost, and the profit), and TEG purity. Among of these processes, the injection of stripping gas is the easiest and most popular way to improve TEG regeneration performance. In particular, the injection of dry product gas provides lower capital cost; lower utility cost, and less energy consumption than the external stripping gas (e.g., Methane), although both stripping gas processes can achieve equal TEG regeneration performance. However, in comparison to these two-stripping gas process that use inert gas and a portion of dry gas, the DRIZO method emits significantly less BTEX gas while removing larger amount of water or equivalently, generates higher purity on regenerated TEG. This results in a lower TEG flow rate, which reduces the operating cost and energy consumption for the dehydration process. Nonetheless, DRIZO process incurs extra capital cost because it necessitates the presence of additional equipment such as a pump; a three-phase separator and a heat exchanger compared to the other stripping gad processes. On the other hand, injection of the stripping gas into Stahl column providing additional equilibrium stages to purify the partially stripped TEG that comes from the reboiler to a higher purity limit, up to 99.6 %. Lastly, the purity of regenerated TEG can be improved by adopting coldfinger technology close to about 99.96% (Kong et al., 2018).

Table 3. Comparison overview of different enhanced processes for TEG regeneration (Kong et al., 2018).

Methods	**TEG purity, wt%**	**Major characteristics**
Stripping gas process using a portion of dry product gas	99.2 to 99.98	• No additional equipment is required except some minor equipment such as heat exchanger and an expansion valve. • The main source of stripping gas comes internally from the dehydration system itself.
Stripping gas process using heavy hydrocarbon or (e.g., BTEX Gases) that is DRIZO process	99.99+	• The main source of stripping gas comes internally from the dehydration system itself. • Resulting in low environmental emission because BITEX gases recycled back to the regeneration column.
Stripping gas process with Stahl column	99.6	• A few more equipment is needed such as pump, heater and three phase separators. • Adding an additional column resulting in extra water removal steps from the water-rich TEG.
Coldfinger process	99.96	• Requires extra column. • It requires low capital cost because it only needs an additional surge tank with the cooling coil.

Chapter 5

Modeling and Process simulation

5.1 Process description:

The gas dehydration and solvent regeneration itself are the two sections of the dehydration method. The process is quite simple. The main goal of any TEG dehydration process is to remove the water content from the wet gas stream to a particular acceptable level. The rich TEG is then sent to the solvent regeneration unit, where it is stripped of water. A simplified flow diagram of a typical gas dehydration and TEG regeneration process shown in Figure A that can be explained by the equipment used. Table 4 and Table 5 represent the input natural gas composition and the initial operating parameters of the process, respectively.

Table 4. Initial operating parameters.

Stream	Parameter	Value
TEG feed	Temperature/℃	40
	Pressure/bar	40
	Flow rate/kg.h^{-1}	2000
Wet Gas feed	Temperature/℃	30
	Pressure/bar	30
	Flow rate/kg.h^{-1}	1.845E+005
Stripping gas	Flow rate/kg.h^{-1}	700
	Temperature/℃	120

Table 5. The wet gas composition list used for simulation.

Component name	Component/mol%
Methane	87.08
Ethane	1.39
Propane	0.56

i-Butane	0.16
n-Butane	0.13
i-Pentane	0.05
n-Pentane	0.03
n-Hexane	0.07
Nitrogen	7.65
CO2	2.18
Benzene	0.02
E-Benzene	0.11
Toluene	0.05
o-Xylene	0.05
Water	0.03

Absorber

The wet gas inlet saturated with water is first enters to the Absorber at the bottom and the lean TEG feed enters from the top. The solvent flowing downwards absorbs water from the wet gas stream. The wet gas pressure fixes the pressure of absorber, which is 70 bar. So, the absorber operates at a pressure of 70 bar and the lean TEG enters to the absorber unit at a temperature of 70 ℃ and at the same pressure of 70 bar. The number of stages in the absorption column was set as four, since increasing the number of stages in the absorption column does not result in a substantial decrease in the dry gas water content.

After absorption, the dry gas leaves from the top of the absorber and the rich TEG leaves from the bottom and then is sent to the regeneration process, but not before passing through a pressure valve (LCV) to lower the pressure to 8.62 bar. The pressure drop through this valve is determined by the absorber pressure as well as the pressure loss in the pipes and equipment before the regeneration column (Vizi et al., 2017).

Flash separator

There is a Rich TEG separator after the pressure reduction valve for separating the hydrocarbon rich gas from the rich TEG (Rich TEG2 stream). Due to the lower pressure, the hydrocarbons absorbed in the glycol will be released. The hydrocarbon rich gas produced by the flash separator can be used as a

process gas in a plant. There is a minor TEG loss that will be taken into account for the make-up stream later in the TEG regeneration process.

Heat exchangers

The number of the heat exchanger depends on the process plants configuration. Rich glycol must be heated while lean glycol must be cooled due to the significant difference between the absorber and the regeneration column. By properly designing the heat exchangers between the rich and lean glycol the majority of the energy consumption can be saved (Isa, 2009). Therefore, the L/R heat exchanger is needed to heat the rich TEG (Rich TEG 3) stream prior to entry into the distillation column for the TEG regeneration process. In the gas-glycol heat exchanger (Lean/dry gas heat exchanger) the dry gas stream is used for cooling the lean TEG stream that enters the Absorber unit. The glycol-glycol (L/R heat exchanger) heat exchanger have a defined pressure drop on the tube side of 2.98 bar, and shell side of 2 bar while there is no pressure drop was taken into account for the gas-glycol heat exchanger (Lean/dry gas heat exchanger).

Regenerator

The TEG regenerator is a distillation column where TEG and water is separated. It is consisting of reboiler and condenser at the top. The column has a low number of stages (three), since increasing the number of stages does not effect on the increase of TEG purity (Piemonte et al., 2012). In the case studies section, the analysis and reasoning for the chosen number of stages will be explained later. The column separates the water from TEG (Figure 13), which works at a low pressure of 2 bar and at a high reboiler temperature of 204 ℃ and condenser temperature 100℃. The rich TEG inlet enters the column for regeneration has a temperature of 124℃.

The condenser enhances the TEG regeneration process by using a reflux stream. To reduce the TEG losses, the reflux ratio was set to 0.2. In addition, the condenser also reduces TEG loss in the regenerator. The excess water vapor leaves the total condenser and is vented to the atmosphere after leaving from the condenser. The reboiler at the regenerator column provides the energy needed to separate TEG and water, where the recommended maximum temperature is 204℃. Basically, the lean TEG is removed from the reboiler and placed in a mixer before being recycled.

The pressure in the regeneration system is just above ambient pressure, ensuring that no air will reach the system through the atmospheric vent.

The TEG purity is influenced by the operating conditions for the regenerator column. TEG has lean glycol concentrations of 95.6 wt.% at 204℃. If the purity of TEG is insufficient, more advanced regeneration methods can be used to increase it. To increase the TEG purity to 99.8 wt.% a stripping gas

can be added to the regenerator boiler or in a stripping column after the regeneration column. In case of this study Stripping gas added to the regenerator boiler (Isa, 2009). Furthermore, der gas is widely used as a stripping gas for the regeneration process, leaving the absorber.

Moreover, there is a TEG loss at the regenerator exhaust stream during the TEG regenerator process, which is included in the TEG flow make-up stream (Vizi et al., 2017).

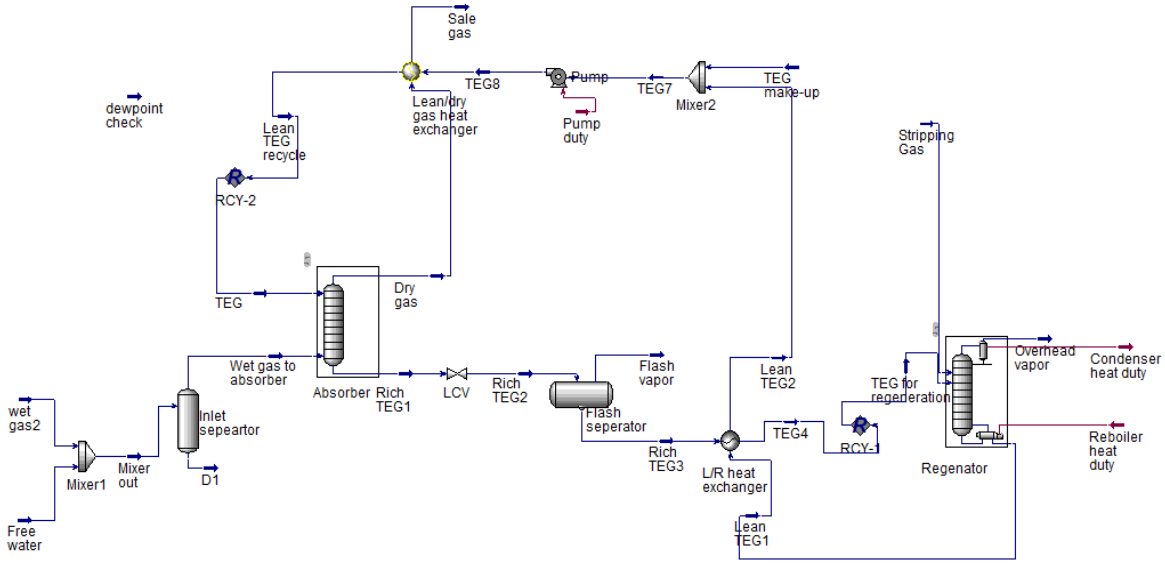

Figure 13: The HYSYS model of TEG dehydration unit.

TEG Pump

Because of the pressure difference between the regenerator and the absorber (Isa, 2009) such as, TEG regenerator operates at low pressure (1.014 bar) and the absorber operates at high pressure (69.57 bar), so to increase the Lean TEG stream pressure it was needed to add a pump before entering to the absorber, where allowing the rich TEG stream to flow. The pump generates the necessary pressure increase and maintains the circulation rate of TEG entering the absorber.

Make up mixer

There are TEG losses that must be accounted for during the gas dehydration and TEG regeneration process. Therefore, a make-up mixer was added to combine the TEG make-up stream with the lean TEG2. The total TEG loss was determined by adding the losses at the dry gas outlet, the flash gas stream exiting the rich TEG flash, and the regenerator exhaust stream (overhead vapor) exiting the TEG regenerator (Vizi et al., 2017).

5.2 Simulation model:

As mentioned earlier, the simulation has been conducted using industrial simulation software, Aspen HYSYS that is widely used software in chemical process industry. The aspen technology has recommended glycol property package, which is used as the thermodynamic fluid package. In particular, it provides better representation of TEG flow rate, dew points, purities of lean TEG, and water content on the gas stream (Twu et al., 2005). The glycol property package can be applicable in a typical water-TEG dehydration system with TEG regeneration within a wide range of pressures, temperatures, and component concentrations. This property package contains the Twu-Sim-Tassone [TST] equation of state, which extended with experimental parameters to determine phase behavior of water-TEG-natural gas systems more precisely and consistently. For the gas dehydration, the glycol package reasonably predicts properties between 1.5℃ and 50℃ and 10 atm to 100 atm, and for glycol regeneration, between 202 and 206℃ and 1.2 atm (Fujishige et al., 1999).

Since the aim of the dehydration process is to eliminate water, the acceptable level of water content in natural gas transmission pipelines is usually 6-7lb/MMSCF (Anyadiegwu et al., 2014). Therefore, the design basis of natural gas dehydration is to reach the required dew point of the dried gas of the inlet gas of the absorber. The TEG circulation rate is usually 2-5gal TEG/lb H2O removed (Dooley et al., 2011). Higher TEG concentrations are needed for higher dew point depressions. At above 99 wt.% TEG, stripping gas is commonly does not reach 204℃ to prevent glycol degradation. Figure 13 represents the simulated diagram of stripping gas process for natural gas dehydration. In this approach a dry gas is injected into the TEG regeneration system. Detail will be discussed in next section.

5.2.1 The TST cubic equation of state:

For hydrocarbons and polar components, the TST CEOS allows for a more accurate calculation of liquid densities. TST CEOS also provides better handling of polar and heavy components and a more reliable estimate of vapor pressure, which is defined by the following equation (Twu et al., 2005).

$$P = \frac{RT}{v-b}\frac{Ra}{(v+3b)(v-0.5b)} \quad \text{Eq1.}$$

Basically, making the first and second derivatives of pressure with respect to volume to zero. T_e and P_e is the critical Temperature and pressure.

$$a_c = 0.470507\,\frac{R^2T_e^2}{P_e} \quad \text{Eq2.}$$

$$a_c = 0.470507\,\frac{RT_e}{P_e} \quad \text{Eq3.}$$

$$a_c = 0.2962 \quad \text{Eq4}$$

The Z_c values from the Soave-Redlich-kwong (Soave, 1972) and peng-Robinson (Peng et al., 2002) models are both larger than 0.3 (0.33333 and 0.307401), respectively), but the Z_c value for TST is slightly below 0.3, a is the temperature, it can be measured using the following formula.

$$a(T) = \propto (T)\, a_c \qquad \text{Eq5}$$

The parameter a is a function of reduced temperature where, $a(T)$ can be used to measure the value of a at any temperature $a(T)$ and the Twu alpha function can be represented as:

$$\propto = T_r^{N(M-1)} e^{L(1-T_r^{NM})} \qquad \text{Eq. 6}$$

Eq. 6 L, M and N parameters can used to determine vapor pressure data of the pure component (Twu et al., 2005).

The TST mixing rules:

The mixing rule used influences the ability of a cubic equation of state to predict phase equilibrium of mixtures. The TST zero-pressure mixing rule can be described as (Twu et al., 2005) for the parameters a and b.

$$a^* = b^*[\frac{a^*_{vdw}}{b^*_{vdw}} + \frac{1}{C_r}(\frac{A^E_0}{RT} - \frac{A^E_{0vdw}}{RT})] \qquad \text{Eq.7}$$

$$b = b_{vdw} \qquad \text{Eq.8}$$

The zero-pressure mixing rule assumes that the reduced liquid volume, as determined from a cubic equation of state using the van der waals mixing rule for its a and b parameter, can be either constant or have no difference.

A^E_0 is the excess Helmholtz energy of van der waals fluid at zero pressure and A^E_{0vdw} indicates that it is calculated using van der waals mixing rules from the cubic equation of state (Twu et al., 2005).

$$C_r = \frac{1}{w-u}\ln(\frac{r+w}{r+u}) \qquad \text{Eq. 9}$$

C_r in eq 9 is a function of parameter r. For the Twu-Sim-Tassone cubic equation of state u=3 and w=0.5, these are equations of state dependent constants shown in eq 9.

Moreover, $a^* = \frac{Pa}{R^2T^2}$ Eq. 10

$$b^* = \frac{Pb}{RT} \qquad \text{Eq. 11}$$

The following equations measure the a and b parameters evaluated using van der waals mixing rules, respectively a_{vdw} and b_{vdw}(Twu et al., 2005):

$$a_{vdw} = \sum_i \sum_j x_i x_j \sqrt{a_i} a_j (1 - k_{ij})$$ Eq.12

$$b_{vdw} = \sum_i \sum_j x_i x_j [\frac{1}{2} (b_i + b_j)]$$ Eq. 13

5.3 Sensitivity analysis:

In sensitivity analysis, independent and dependent parameters are investigated during the simulation study (Nemati Rouzbahani et al., 2014) in order to distinguish the effect of such input parameters on the output variables. The independent parameters are such as, TEG flow rate, reboiler temperature, and stripping gas flow rate, while the dependent parameters include operational parameters such as water content of dry gas, reboiler duty, condenser duty, TEG loss, and TEG purity at the regenerator column. To find the most suitable values, independent parameters are optimized by adjusting and analyzing their effects on dependent parameters. Table 6 shows three input processing parameters (chosen to be varied) at 3 different levels for the optimization purpose while other remaining parameters were kept constant.

Table 6: Input operating parameters for optimization

Parameters	Value	Units
TEG flow rate	3250, 3750, 4250	Kg/h
Reboiler Temperature	180, 190, 204	℃
Stripping gas flow rate	1000, 1900, 3000	Kg/h

From some references it was found that temperature varied between 180 to 204℃, which is often used in the reboiler and these three stripping gas flow rate also found from some references. SO basically 27 new simulations have been performed for different stripping gas flow rate, TEG flow rate and reboiler temperature to see the performance.

Sensitivity analysis is a powerful tool for validating engineering models, simulations and understanding their primary systems. By this technique, to check the performance of the process, one may use this technique to observe the effect on the dependent parameters by changing the independent parameters. The results of the sensitivity analysis will aid in identifying the most sensitive parameters that influence the performance of the process (Salman et al., 2020). A summary of input and output variables, which used in the current sensitivity analysis is available in Table 7.

Table 7. Input and output variables of the dehydration system.

Independent variable	**Dependent variable**
TEG rate	Water content of dry gas
Stripping gas rate	Water dew point of dry gas
Reboiler temperature	Reboiler heat duty
	Condenser heat duty
	TEG loss
	TEG purity
	Pump duty

Chapter 6

6. Result and discussion:

6.1 Analyses:

A high purity recycled solvent is needed for deep dehydration of natural gas. The pressure and temperature and reflux ratio in the regenerator can be handled to increase TEG purity. To avoid the contamination with air that could facilitate the unwanted oxidation of the glycol, the pressure in the regenerator was set at atmospheric pressure 1.014 bar.

To build a suitable dehydration process for natural gas using TEG as the liquid desiccant, at first the operating parameters of the system are investigated for the optimization of the process. The initial operating parameters for feed are shown in Table 4. The number of trays for regenerator and absorber is 3 and 4 trays respectively. However, for the analyses of the dehydration process the reboiler temperature was varied between 175 to 204℃ to see the result. The process flow diagram has been represented in Figure 13.

6.1.1 Effect of TEG flow rate:

TEG feed rate is the most important parameters determining the performance of the process. The TEG feed rate must be increased to reduce the water content of the outlet-dried gas. However, increasing the TEG feed rate increases the operational costs and material losses (Campbell, 1976); hence the minimum feasible rate for TEG flow is a critical factor in absorption column optimization [68], but the reason for higher TEG loss is entrainment caused by the wet gas. In this case study, different TEG flow rate is used to see how they affect the water of dry gas, reboiler duty, water dew point and TEG loss.

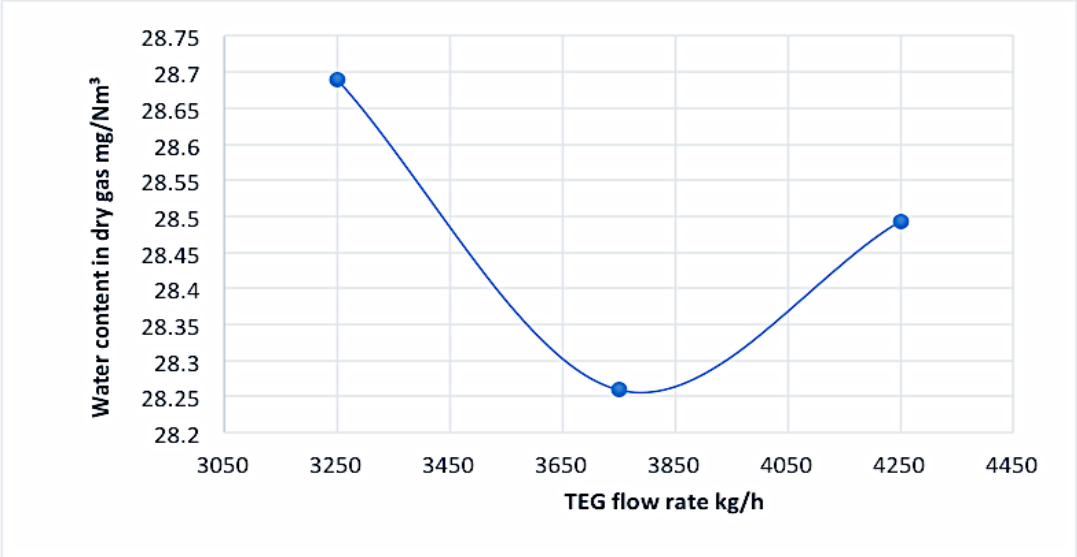

Figure 14: TEG flow rate vs. water content of dry gas.

In Figure 14, 15, and 16 we depicted these results, respectively. The result is obvious; raising the TEG flow rate lowers the water content because it has a greater ability to absorb water. However, since more solvent means more heat duty in the reboiler, this increase would also increase the heat duty

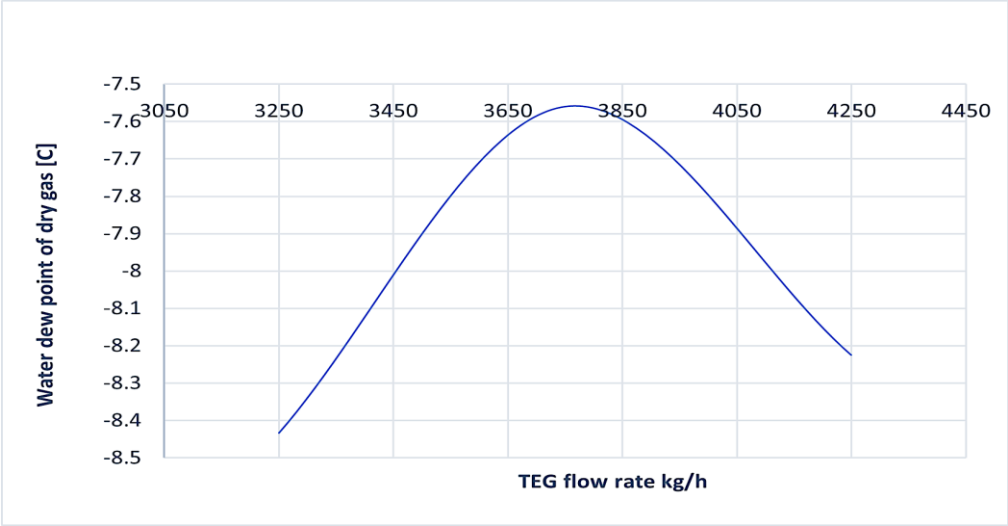

Figure 15: TEG flow rate vs. water dew point [C].

As it can be seen from Figure 15, by increasing the TEG flow rate; the water dew point of natural gas can be reduced down to -8.5℃. Since for high solvent purity more water content can be removed. In addition, from figure 2 the most sensitive parameter to the change in the TEG flow rate is the water content of dry gas that causes TEG to absorb more water. Hence it is obvious that more energy is consumed in the regeneration section to separate water from TEG. Moreover, after 3050kg/h the

sensitivity of water content decreases until it becomes constant at 3750kg/h and there is no substantial decrease in water content after this value.

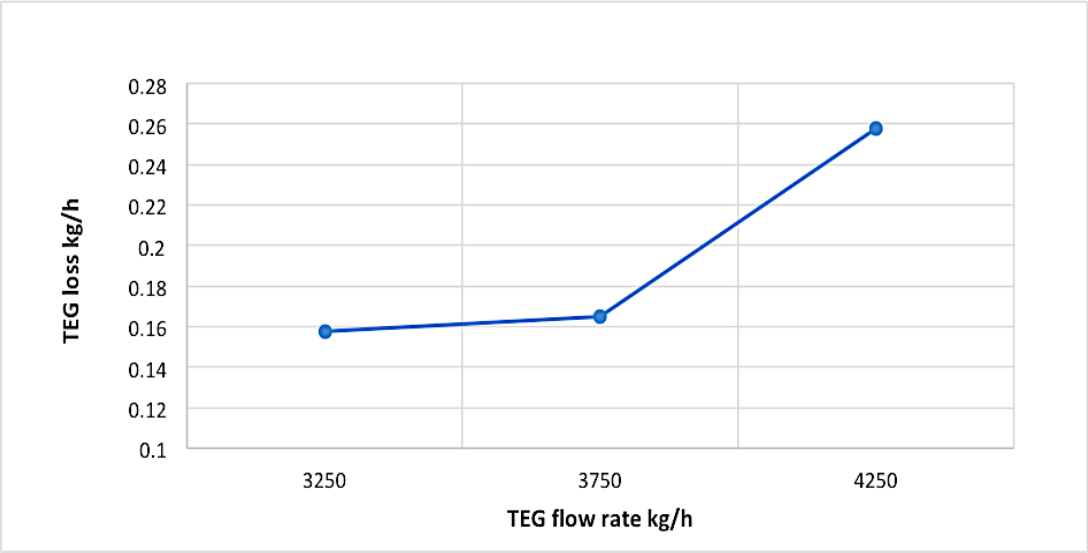

Figure 16. TEG flow rate vs. TEG loss.

However, in the case of TEG losses in figure 16 the sensitivity is initially quite low then gradually starts increasing at around 3750 kg/h of feed rate. It is clear that; higher TEG rate causes more the regeneration process to loss higher amount of TEG. TEG on the top of the regenerator also depends on the stripping gas flow rate, which will be discussed on the process optimization section. To develop the reboiler temperature analysis on TEG purity in the bottom of the regenerator a range of 175℃ to 204℃ was chosen to see the effect on simulation.

6.1.2 Effect Stripping gas flow rate:

Stripping gas flow rate is actually a parameter in the stripping column of TEG regenerator process, which is actually a function with the reboiler duty. In addition, the regeneration columns operational parameters have the greatest influence on the purity of TEG introduced into the dehydration cycle. In this section the effect of stripping gas in the process to be observe its effect on the purity of TEG and to estimate the overall performance for process optimization. In this study, stripping gas feed stream injected into the regenerator. The rate at which TEG is stripped has a significant impact on TEG purity and TEG losses.

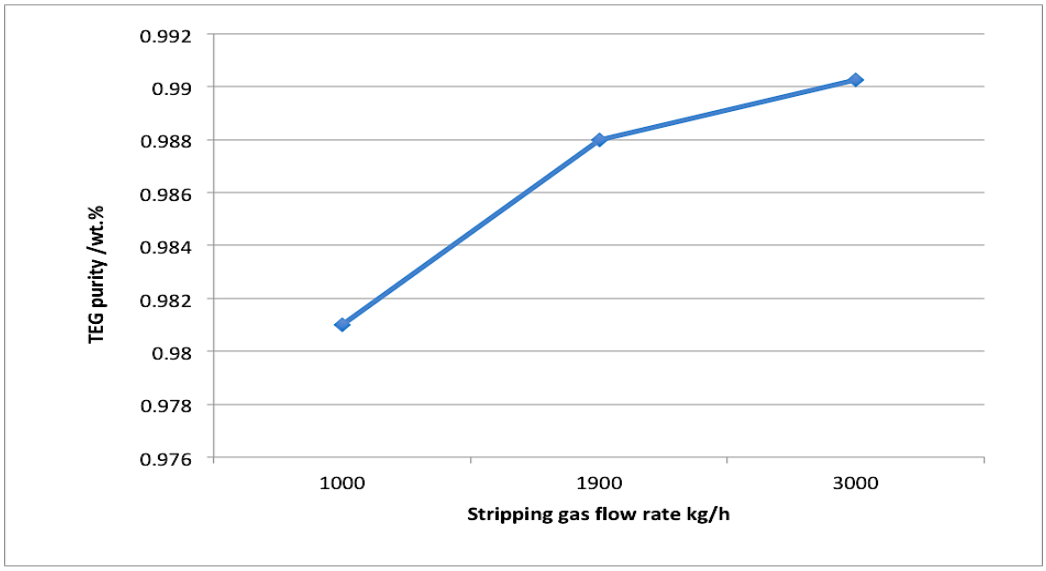

Figure 17. Stripping gas flow rate vs. TEG purity.

Figure 17 shows the relation of stripping gas rate with TEG purity. TEG purity will be improved by increasing the stripping gas rate in this case study. The reason is apparent: more stripping gas lowers the vapor pressure of water vapor, forcing it to move higher up into the condenser. In this figure TEG purity increased with increasing flow rate of stripping gas but then became constant after 3000 kg/h of stripping gas rate. In next section the effect of stripping gas rate on TEG loss with TEG flow rate will be investigated.

6.1.3 Effect of Reboiler temperature:

Higher reboiler temperature will produce a high purity of TEG. However it should not exceed the limit of the thermal decomposition temperature of TEG as mentioned earlier. So this limitation of the reboiler temperature is going to affect on the purity of lean TEG. To analyze the reboiler temperature on TEG purity in the bottom of the regenerator on a range of 170 to 204℃ with a step size of 12℃ was chosen in the case study section.

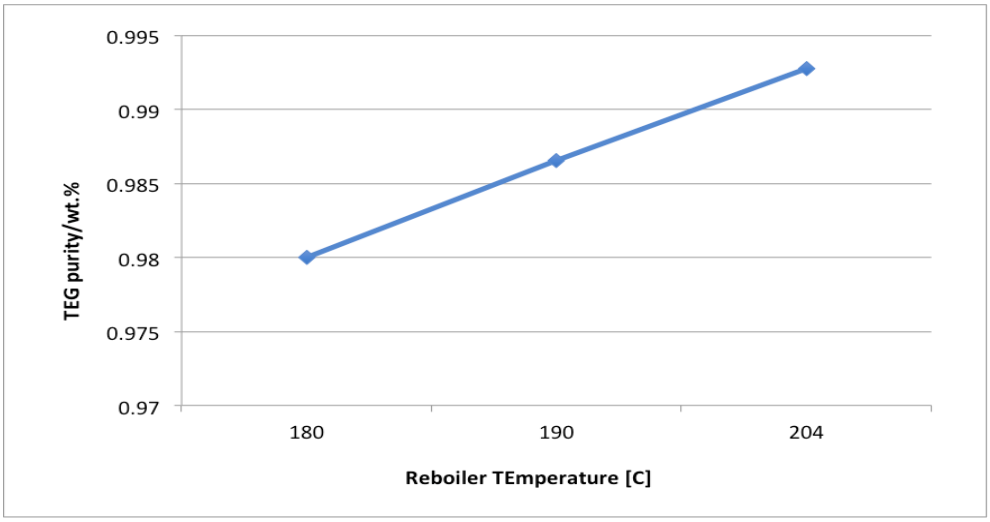

Figure 18. Reboiler temperature [C] vs. TEG purity/wt.%

Figure 18 shows that TEG purity increases with regeneration temperature. The TEG loss at the top of the regenerator and reboiler heat duty are both depends on the reboiler temperature and been studied in the optimization section. However, the high TEG purity of TEG will have higher absorption capacity and results in the lower water content of the dry natural gas.

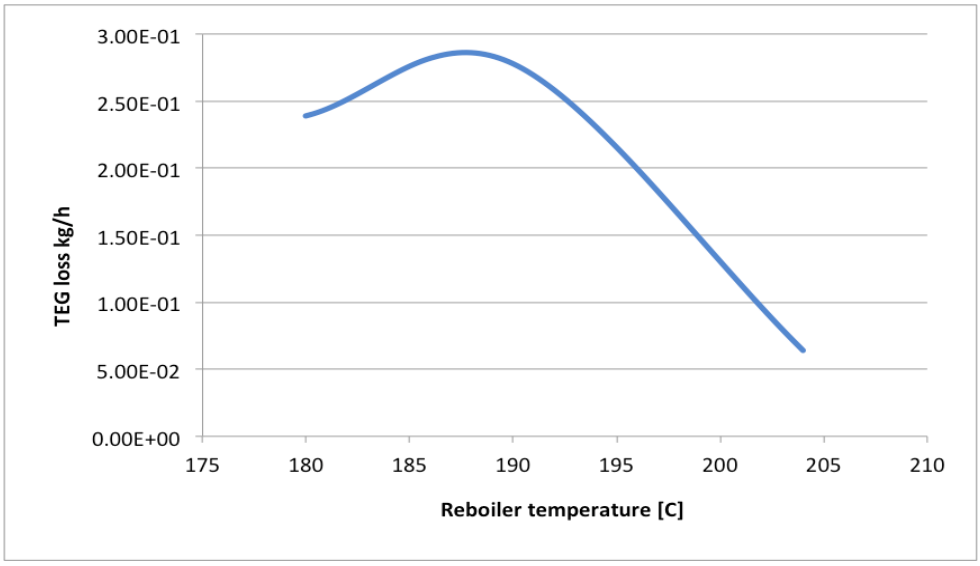

Figure 19. Reboiler temperature vs. TEG loss kg/h

Figure 19 illustrates the variation of TEG loss with regenerator temperature. The TEG loss and the few hydrocarbon vapors stripped form rich TEG. TEG loss increases exponentially with the regenerator temperature but after 180℃ it slightly increased and then started to decrease after 190℃. Because the mass flow rate of stripping vapor produced by reboiler increases as the regeneration temperature rises.

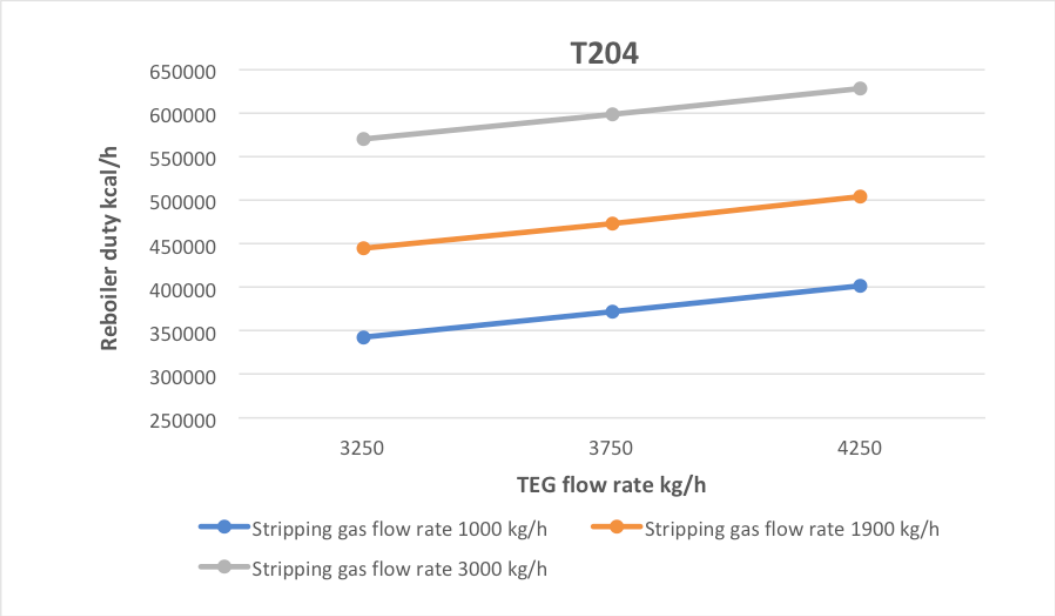

Figure 15. TEG flow rate vs. reboiler heat duty kcal/h and stripping gas flow rate kg/h at 204℃.

6.2 Process optimization:

The dehydration process was optimized to have an acceptable concentration of water in the dry gas and a weight percent of regenerated TEG and above the minimum loss of TEG, minimum reboiler duty and minimum temperature for hydrate formation. Therefore summarizing all the results that have been analyzed at previous section can be carried out in this section to find the optimum result. For this purpose,

Figure 8 to 15 and so on is plotted based on the effect of TEG flow rate, stripping gas flow rate at different reboiler temperature.

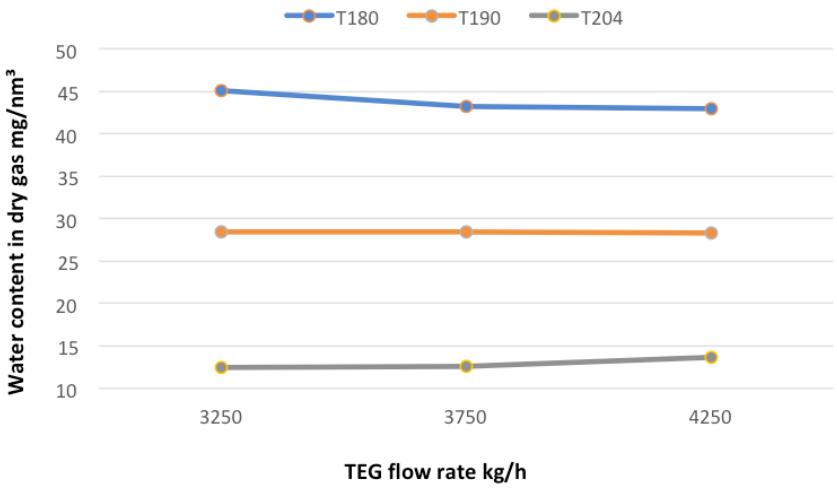

Figure 16. Water content vs. TEG flow rate and reboiler temperature [℃].

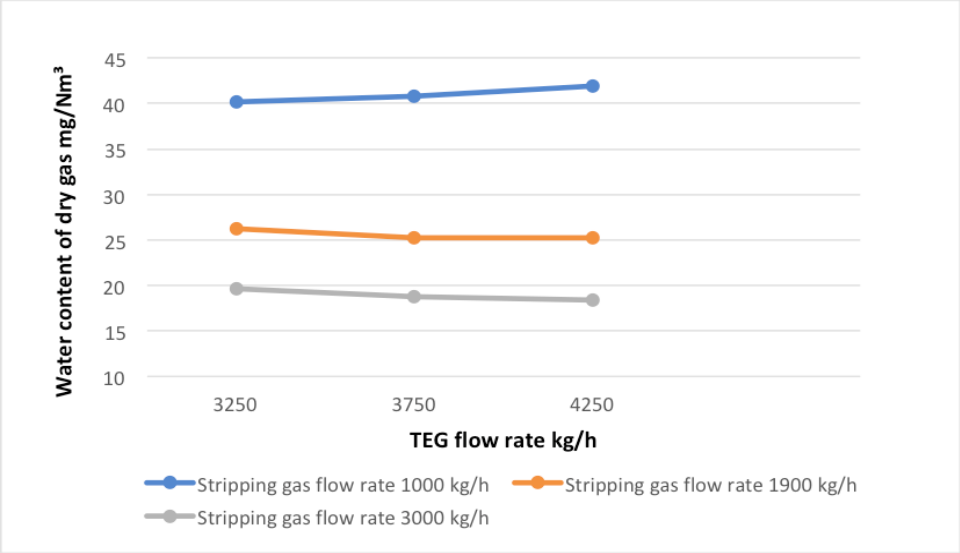

Figure 17. Water content vs. TEG flow rate and stripping gas flow rate kg/h.

To be mentioned that the main purpose of the optimization is to minimize dependent variables (including TEG losses, reboiler duty) as low as possible while the dry gas production rate doesn't change preferably and even became greater if it is possible. As depicted in the figure 8 the result does not shows any remarkable change on the operating point of TEG reboiler units. Although, the optimum TEG flow rate is considered to be 45 mg/Nm^3water content value at reboiler temperature 180℃.

To get the standard water content value, one of the independent parameter stripping gas flow rate used also in figure 17. Since it is a very sensitive value we can achieve the targeted value of water content of dry gas by adjusting the TEG flow rate by decreasing from 4250 to 3750 kg/h at 204℃ reboiler temperature we can achieve lowest water content, which is 13 mg/Nm^3. From the figure it can be seen that, at higher stripping gas flow rate 3000 kg/h and 3750 kg/h of TEG flow rate will result in much lower water content of the dry natural gas 17 mg/Nm^3 we can achieve, which is good.

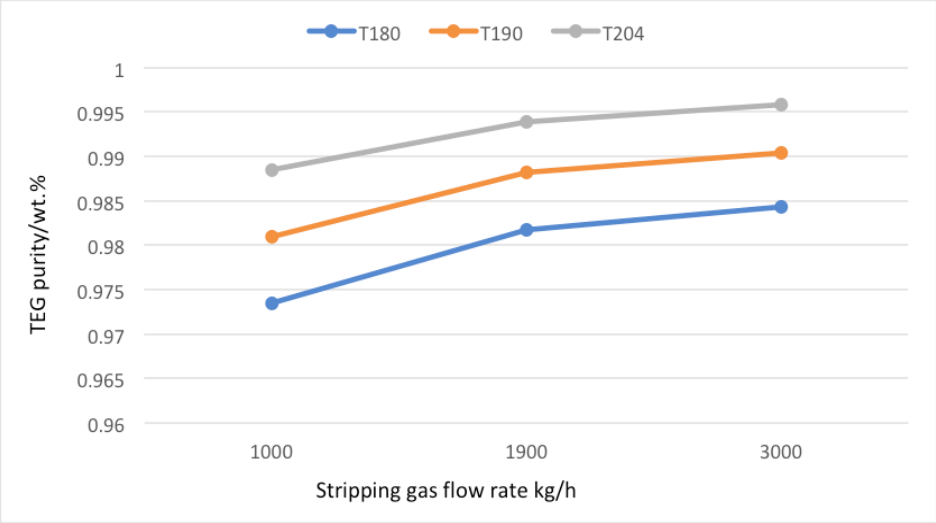

Figure 18. TEG purity vs. stripping gas flow rate kg/h and reboiler temperature.

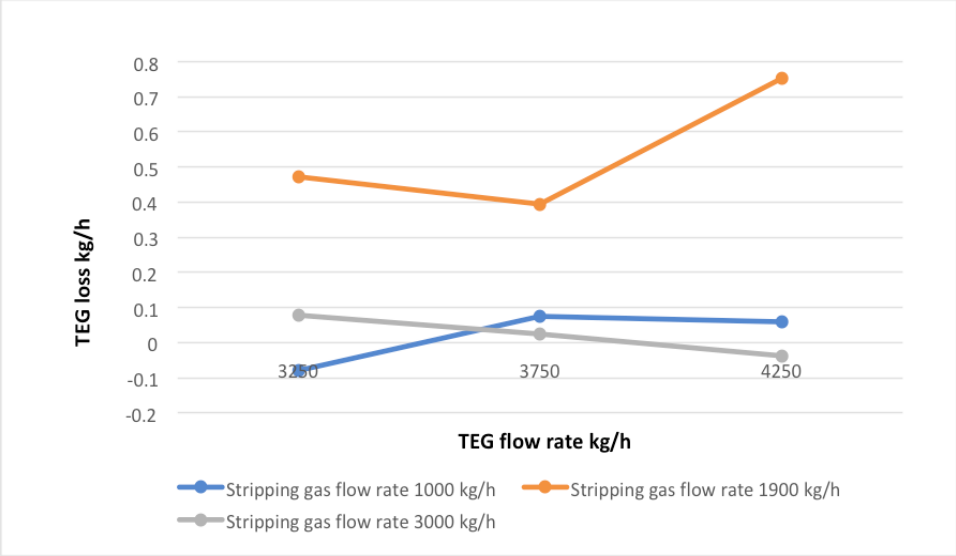

Figure 19. TEG loss vs. TEG flow rate and stripping gas flow rate kg/h.

In figure 18 and 19 shows the relation stripping gas rate with TEG purity and TEG losses where we can see that the increase in stripping gas rate will increase the TEG purity at reboiler temperature 204℃. TEG purity increases at the start with the increase in reboiler temperature, and the stripping gas flow rate and then almost becoming constant after 3000kg/h of stripping gas rate. Next the effect of stripping gas rate on TEG loss is investigated. In figure 19 for different TEG flow rate with the increase in stripping gas rate the increase in TEG losses has shown. Higher the stripping gas rate higher will be the TEG losses. However in this figure we can see negative loss means quite excessive glycol losses at 1000 and 3000 kg/h due to the lower reboiler temperature, which blows the liquid out of the top of the column that is not good oviously. At 1900 kg/h of stripping gas flow rate and TEG flow rate of 4250 kg/h the TEG loss was higher.

From figure 18 and 19, to find the optimum stripping gas rate, the sensitivities of TEG purity and TEG losses against the stripping gas rate have been observed with 3250, 3750 and 4250 kg/h of TEG flow rate and 180, 190 and 204℃ of reboiler temperature. According to these figure, TEG purity is the most sensitive parameter showing a peak at 3000kg/h with 204℃ besides we achieved higher TEG loss at 1900 kg/h is found as the optimum stripping flow rate. Furthermore, we will discuss more regarding to this chosen value as optimum.

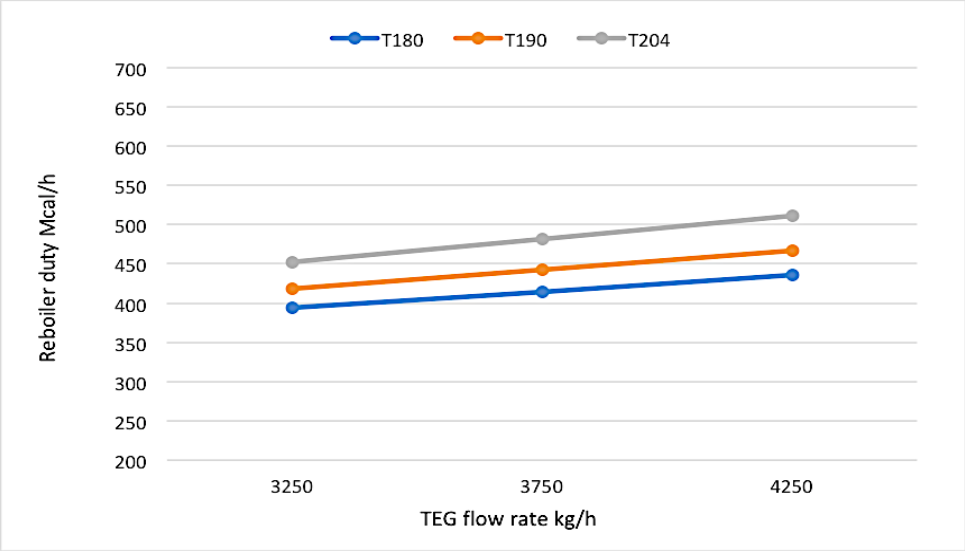

Figure 20. TEG flow rate vs. reboiler heat duty Mcal/h and reboiler temperature [C].

By looking closer into the figure 20, higher reboiler duty is achieved by increasing the reboiler temperature and the TEG flow rate. The total reboiler heat duty provides sensible heat for heating rich TEG from a fixed fed temperature to reboiler temperature, and it provides latent heat for vaporizing water. Therefore, the latent heat of water vaporization is primarily responsible for the difference in regenerator heat duty. The figure shows higher reboiler heat duty achieved by increasing the TEG flow rate in according to the increasing reboiler temperature. However, at 3750 kg/h of TEG flow rate we can get the lowest water content but will result more duties, operating cost and TEG losses. Besides at 3750 kg/h water content of dry gas is 13 mg/Nm^3, which is well below the limit. Therefore, 3750 kg/h is the optimum flow rate for the dehydration process.

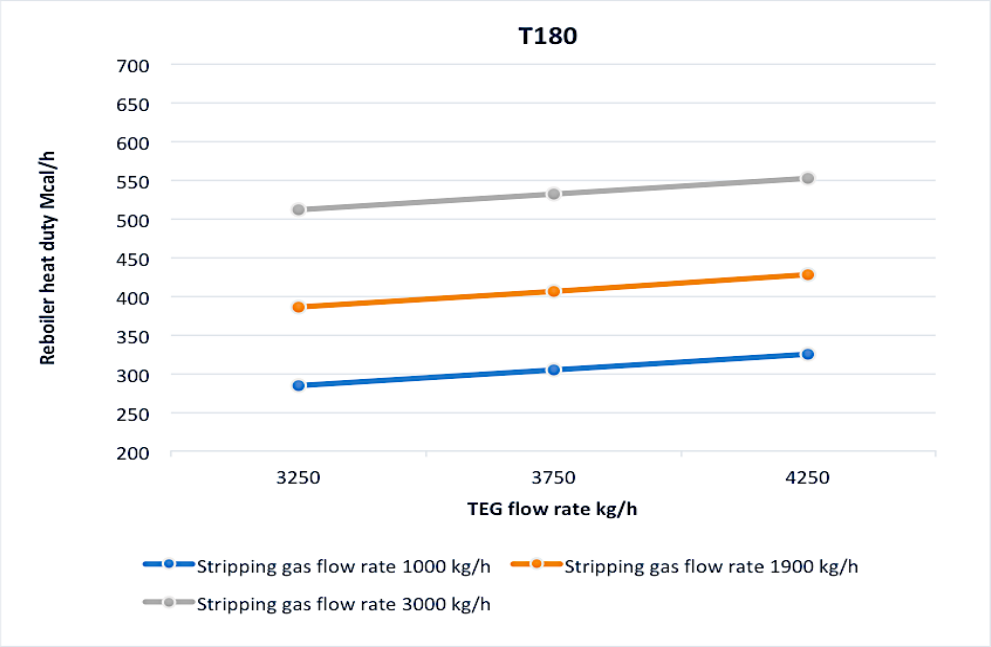

Figure 21. TEG flow rate vs. reboiler heat duty Mcal/h and stripping gas flow rate kg/h at 180℃.

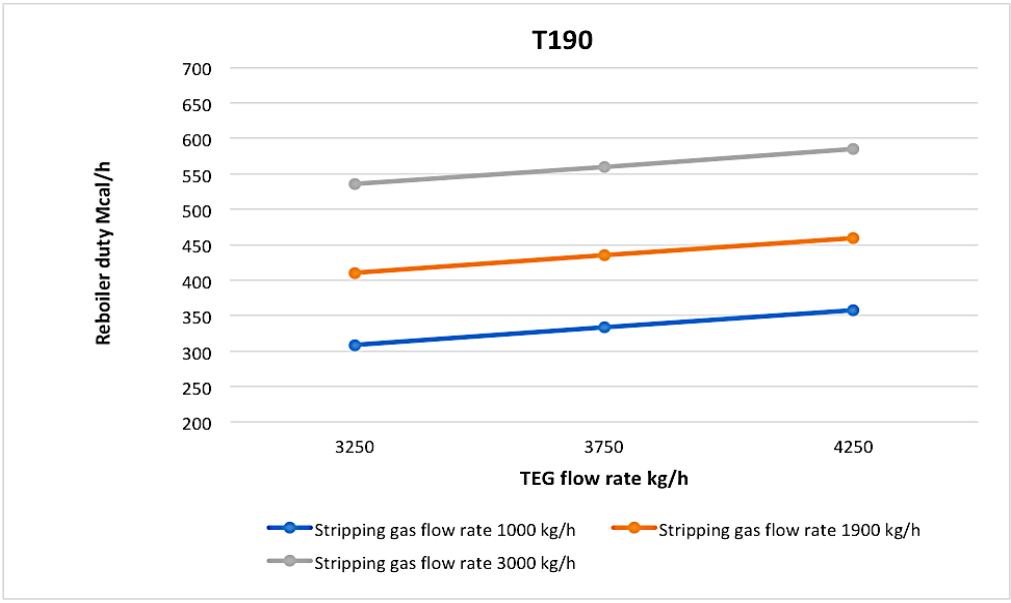

Figure 22. TEG flow rate vs. reboiler heat duty Mcal/h and stripping gas flow rate kg/h at 190℃.

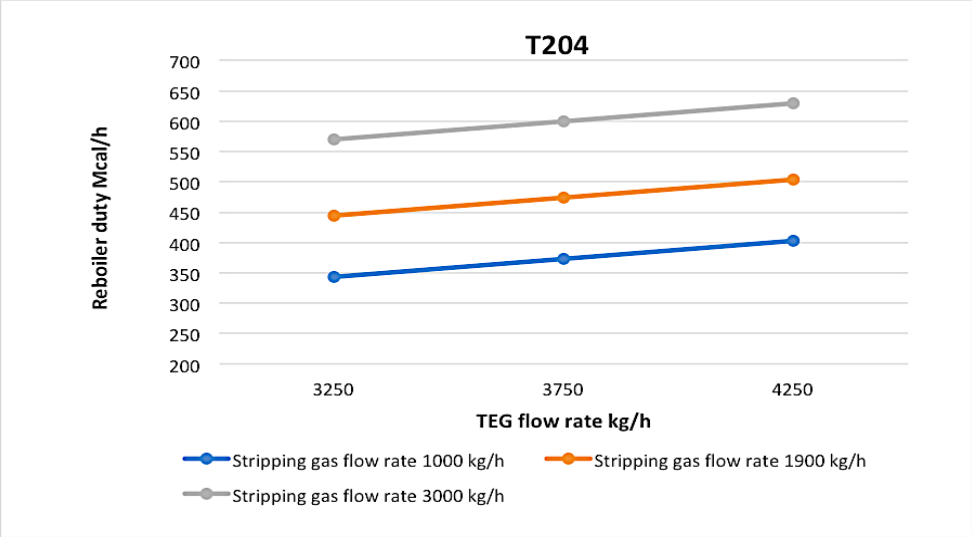

Figure 23. TEG flow rate vs. reboiler heat duty Mcal/h and stripping gas flow rate kg/h at 204℃.

Now, if we look at the figure 21, 22 and 23 respectively the reboiler duty values increase with increasing the stripping gas flow rate with increasing reboiler temperature. Here we can see at stripping gas flow rate 1900 kg/h at reboiler termperature 204℃ with TEG flow rate 3750 at almost reached 452 Mcal/h reboiler duty. But for every case at 4250kg/h TEG flow rate the performance was high. However, regarding optimization and lower energy consumption it is important to take into account more favorable optimum parameter at lower TEG flow rate and stripping gas flow rate with better performance. In addition, stripping gas flow rates, some column parameters such as reboiler duty, condenture temperature, reflux rate and column pressure exhibit easier variability and can be utilized to investigate the sensitivity of the glycol purity to changes in any of those parameters. So, taking into account the TEG purity it turns out that it is enough 1900 kg/h of stripping gas flow rate to increase the TEG purity from 97.2 % to 99.2%.

According to all previous comments regarding process optimization, the optimal operating condition for natural gas dehydration process cannot be chosen very easily. Although, taking into account all the comments it turns out that is more favorable to operate the regenerator at higher temperature. From the discussion it is adequate to use a temperature of 204℃ in the reboiler of the regenerator.

As it can be mentioned that, before making any adjustments, the operational parameters for the dehydration unit, such as the minimum and maximum required natural gas and solvent flow must be met in order to avoid any undesirable complications throughout the process (Nemati Rouzbahani et al., 2014).

6. 3 Energy consumption:

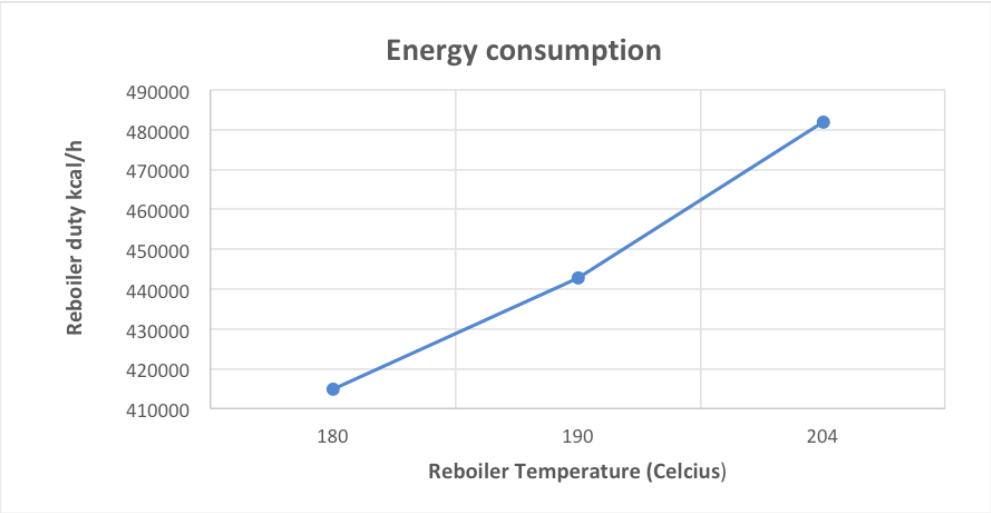

Figure 24. Reboiler temperature [℃] vs. reboiler duty kcal/h.

Figure 24, shows the sensitivity of reboiler heat duty is increasing with increasing reboiler temperature, which implies that increasing reboiler temperature will increase the reboiler heat duty or energy consumption in dehydration and regeneration increases linearly. The main reason is that more energy is required for gas cooling and water removal from the natural gas that also increases the TEG flow rate.

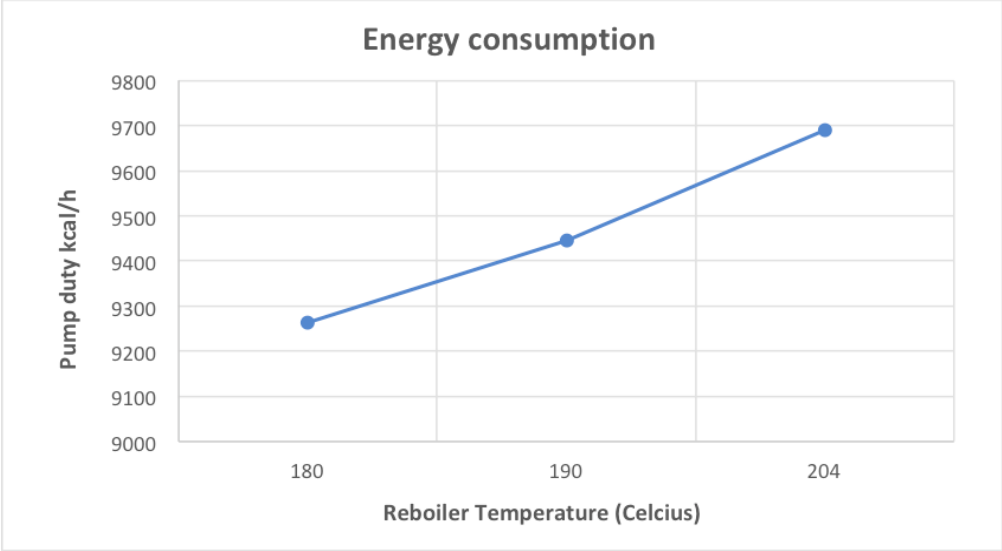

Figure 25. Reboiler temperature [℃] vs. pump duty kcal/h.

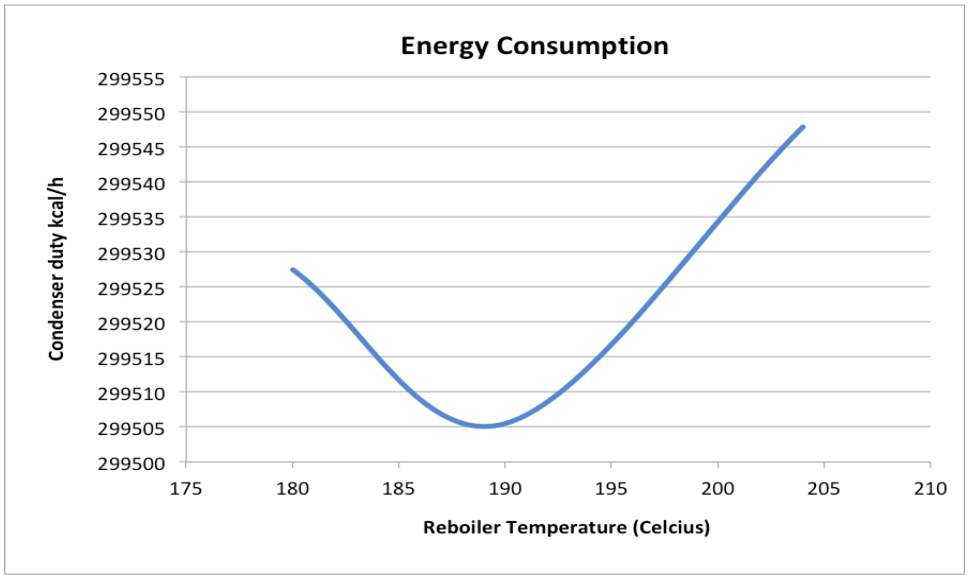

Figure 26. Reboiler temperature [℃] vs. condenser duty kcal/h.

As shown in figure 25 can be seen with increasing reboiler temperature increase pump duty to pump the heat load and in figure 26 with increasing the reboiler temperature the flow rate in vapor phase decreased till 190℃ and after that increased the condenser to condense the heat load will also increase Therefore making the process more expensive to operate which increases the energy consumption cost. Perhaps, both the circulation rate of the TEG and the reboiler temperature must be reduced to reduce reboiler duty. However, lowering the reboiler temperature will lower the reboiler duty, while lowering the TEG flow rate will increase the water content of the dry gas. Thus, the optimal rate of TEG flow rate is considered 3750 kg/h. with the reboiler temperature of 204℃ since the TEG purity wt.% was within the acceptable range i.e., above 99.0 wt.%.

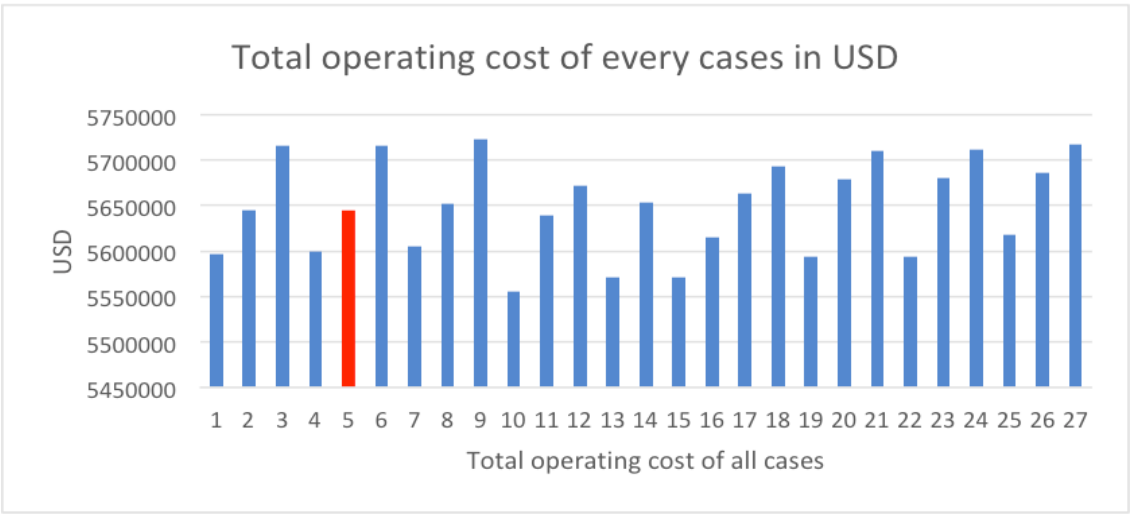

Figure 27: Total operating cost of all randomized cases vs. USD

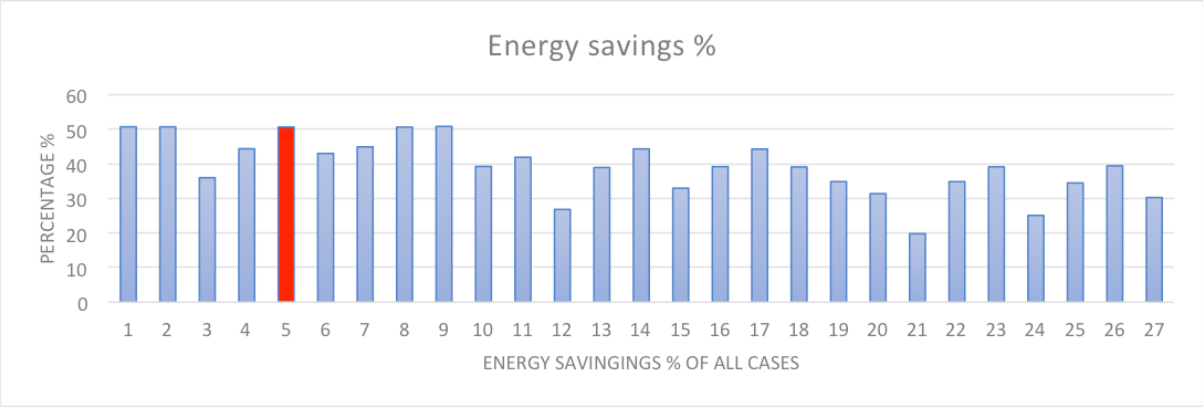

Figure 28: Energy savings % of all randomized cases

In figure 27 and 28 shown all the randomized cases performed in simulation o select optimum data according to the operating cot and percentage of energy savings, where I we found that for (colored in red) 3750 kg/h TEG flow rate with 1900 stripping gas rate and 204℃ of reboiler temperature the process can be optimized where the we can get 50.63 % of energy savings which is lower than other cases and so energy consumption rate will be decreased. In addition to operating cost will be reduced also.

Conclusion

Natural gas is usually accompanied by large amount of water vapor from the reservoir, removing this water is a major task fro the process engineers. Therefore, natural gas plants are designed different offshore and onshore processes to handle water removal from the gas stream is handled to meet pipeline specifications of water content in the processed gas stream. The modeling of the natural gas dehydration and TEG regeneration was successfully completed by HYSYS. The simulation of the TEG regeneration process needs additional attention when fixing the operating conditions, since the column might present convergence problems. Therefore, it was essential throughout to experiment with different parameters throughout the simulation in HYSYS before attaining a consistent convergence of the columns. Moreover, natural gas dehydration unit was chosen as a case study in this study to determine its major effective factors and their effects on the dehydration process efficiency. The key parameters to influence the TEG dehydration process were TEG flow rate, the temperature of the reboiler, reflux ratio, column pressure and the stripping gas flow rate. To obtain the desired level of the parameters under investigations a series of plots were displayed. Those plots were presented are based on the intensive calculations carried out from the case study section in HYSYS. To study the possibility of optimizing the entire process with those optimized parameters were then implemented in a simulation model and found out minimum TEG flow rate and stripping gas flow rate are the key parameter for optimization to get better performance. In addition, result shows that, a minimum TEG flow rate of 3750 kg/h of TEG flow rate can reduce the water content of a gas stream 0.623lb/MMSCF from an initial value of 13.80lb/MMSCF and achieved 99.2 wt. % of TEG purity without a significant rise in the energy consumption.

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