Characterization of the impact of Process Variables on Glycol losses in TEG Dehydration of Natural Gas

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Abstract
Triethylene Glycol (TEG) dehydrators are by far the most commonly used process for the absorption of water vapour in natural gas, whether sweet or sour. This study investigates and characterizes the impacts of the following key process performance indicators on glycol losses: the temperature difference between the outlet gas and the inlet glycol, glycol concentration, gas flow rate and glycol circulation rate. Following a process simulation with Hysys package for dehydration and a proper and close proxy fitting with Microsoft Excel, the following results giving the coefficient of determination, R^2 were obtained: the temperature difference between the outlet gas and the inlet glycol, $R^2 = 0.998$; glycol concentration, $R^2 = 0.995$; gas flow rate, $R^2 = 0.961$; glycol circulation rate, $R^2 = 0.994$. The temperature difference between the outlet gas and the inlet glycol is exponentially directly proportional to glycol losses. Glycol concentration, gas flow rate, and glycol circulation rate are inversely proportional to glycol losses. The simulation of the process and characterization of the variables provide some insight into the nature of the effect of these independent variables for an improved management of glycol losses.
Keywords: TEG, Dehydration, Simulation, proxy equation, coefficient of determination.

I. INTRODUCTION

Today, natural gas is the primary source of energy for domestic use and feedstock in the petrochemical industry. Hence natural gas studies are being intensified for more efficient exploration, production and exploitation of this fastest growing fossil energy source. Raw natural gas must first of all undergo a compulsory conditioning process in order to meet the quality standards specified by the major pipeline transmission, storage and distribution companies. Although most free water is removed after the gas-liquid separation at or near the wellhead, there is still a significant amount of water vapor associated with the main natural gas stream that requires further treatment by dehydration to remove. This key stage in gas conditioning is the dehydration, which is the process of removing water vapour from a gas stream in order to lower the water dew point.

The most widely used method for natural gas dehydration is the TEG absorption process but glycol losses through replacement and replenishment constitute a major challenge of the process [1] This study investigates the character of key independent process variables with respect to glycol losses. These variables include: the temperature difference between the outlet gas and inlet glycol, gas temperature, glycol temperature, glycol concentration, gas flow rate, and glycol circulation rate. Simulation of the process and characterization of the variables give insight into nature of the effect of these independent variables for an enhanced control of glycol losses.

I.I   Glycol Circuit
The Triethylene Glycol circulation system is composed of
- Glycol regenerator
- Cartridge filters,
- Glycol pumps,
- Glycol coolers,
- Heat exchangers,
- Dry glycol pumps and
- Dry glycol tank.
- Glycol vapour coolers and condensers,
- Glycol degassing tanks (for drains),
- Glycol drain pumps,

- Waste glycol tank,
- Glycol recovery pump [6]

1.2   TEG Dehydration Process

The TEG dehydration process could be divided into two main parts, gas dehydration and solvent regeneration. In the dehydration stage, water is removed from the gas; while in the regeneration stage, water is removed from the solvent. After this process, the fresh glycol solution is ready again to be used in the contactor tower. Fig.1 is a schematic diagram of the typical process flow and equipment for glycol dehydration. While the overall process equipment is similar for all glycol dehydration units, there can be considerable variations among installations.
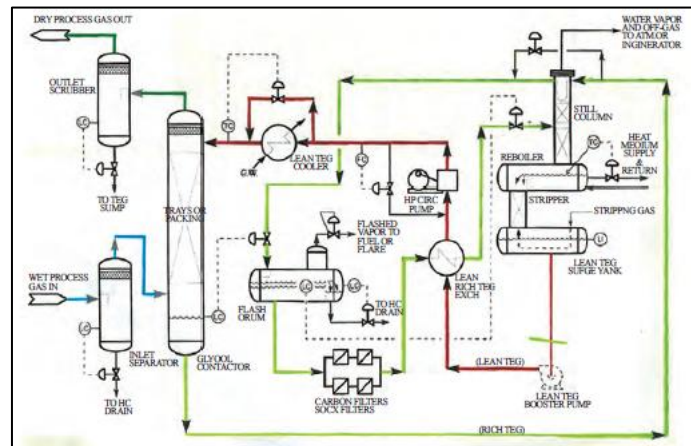

Figure 1: Typical PFD for TEG Dehydration [3]

The gas flows through a separator to remove condensed liquids or any solids that might be in the gas [2] Some absorbers incorporate the separator in a bottom section of the vessel, in which case the gas then flows upward through a chimney tray into the glycol absorber portion of the vessel. The glycol contactor or absorber can contain trays, random packing, or structured packing. If it is a trayed vessel, it will be fitted with several bubble-cap trays. Lean glycol is pumped into the upper portion of the contactor, above the top tray but below the mist eliminator. The trays are flooded with glycol that flows down from tray to tray in downcomer sections. The gas rises in counter-current flow through the bubble caps and is dispersed as bubbles through the glycol on the trays. This provides the intimate contact between the gas and the glycol. The glycol is highly hygroscopic, and most of the water vapor in the gas is absorbed by the glycol. The rich glycol, containing the absorbed water, is withdrawn from the contactor near the bottom of the vessel above the chimney tray through a liquid level control valve and passes to the regeneration section. The treated gas leaves the contactor at the top through a mist eliminator and usually meets the specified water content.

The rich glycol is routed through a heat exchange coil in the top of the reboiler column called the still. The heat exchange generates some reflux for the separation of the water from the glycol in the top of the still and also heats the rich glycol. The rich solution passes to a flash tank operating at about 15 to 50 psig, which allows absorbed hydrocarbon gas to separate from the glycol. The glycol then flows into the still through a filter and a heat exchanger, exchanging heat with the regenerated glycol. It gravitates through a packed section in the still into the glycol reboiler vessel, where it is heated to the regeneration temperature at near atmospheric pressure. At this high temperature, the water is evaporated and exits through the top of the still. The regenerated glycol flows to the surge tank, from which it is routed through the lean/rich heat exchanger to the glycol pump. The pump boosts the pressure of the lean glycol to the contactor pressure. Prior to entering the contactor, it exchanges heat with the dry gas leaving the contactor or some other heat exchange medium.

1.3   Glycol Loss

The physical loss of glycol is probably the most important operating problem in the dehydration system. The glycol contactor (absorber) and glycol regenerator are the most significant locations where most of glycol loss occurs. High gas velocity through the glycol contactor brings about carryover of glycol into the exit gas pipeline, and a poor mist extractor in the top section of the glycol contactor will pass some glycol even at normal gas velocity. High glycol temperatures will result in high water content in the overhead gas. However, this temperature is normally no cooler than 10^OF above the inlet gas to prevent hydrocarbons in the feed gas from condensing in the solution [6]. This limit is normally maintained by a gas/glycol exchanger that cools the lean glycol to approximately a 10^OF approach using the dry gas.

The glycol losses occurring in the glycol regenerator are usually caused by excessive reboiler temperature which promotes either vaporization or thermal decomposition of the glycol. Again, excessive top temperature in the still column allows vaporized glycol to escape from the still column to atmosphere with the water vapour. Table 1 shows the major categories of glycol losses.

Table 1. Glycol Loss Categories

Vaporization	Carryover	Mechanical
Lean glycol to absorber is too hot	Foaming and high gas velocity in absorber	Loss of glycol from pinholes in a gas – glycol heat exchanger at the absorber top
Inadequate reflux. (Temperature too high at still column OHD)	Inadequate mist extractor at gas outlet	Spillage of glycol or pump leakage

II. DATA ACQUISITION

The gas composition is as in X-Gas plant located in Nigeria's Nigel Delta (Table 2). The process data that were investigated were as reported in the Daily Report for Gas Dehydration of the same X-Gas Plant. These include: the difference between the outlet gas and inlet glycol temperatures, glycol concentration, gas flow rate and glycol circulation rate.

Table 2: Process Gas Composition of X-Gas Plant

	Inlet Gas, %Mol	Outlet Gas, %Mol
Methane C_1	81.46	81.46
Ethane C_2	8.85	8.86
Propane C_3	4.52	4.53
Iso-Butane iC_4	0.85	0.85
Butane C_4	0.94	0.94
Pentane C_5+	0.88	0.88
CO_2	2.21	
N_2	0.12	
Water H_2O	Saturated 96.14 lbs/MMSCF	≤ 4.7 lbs/MMSCF

III. PROCESS SIMULATION
3.1   TEG Process Modeling and Impact Characterization

Process simulations using HYSYS to evaluate the impact of the selected parameters on glycol losses were carried out, and Microsoft Excel was deployed for the proxy equations and characterization.
1. The difference between the outlet gas and inlet glycol temperatures.
2. Glycol Concentration
3. Gas Flow rate
4. Glycol Circulation Rate

This process is the "traditional" Triethylene Glycol (TEG) based dehydration process and represents a unit with gas absorption and extraction solvent regeneration (figure 2).
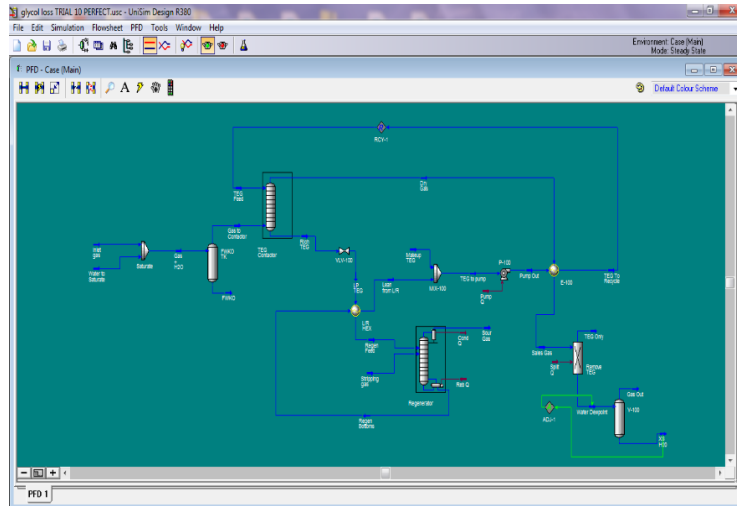
Figure 2. HYSYS Simulation PFD

The following assumptions were made:
- Water dew point is set at -10^0C (14^0F) and a pressure of 80 bars for the dry gas.
- Low reflux ratio is used
- The TEG regenerator consists of a condenser, a reboiler and one ideal stage.

The water saturated gas passes through free water knockout tank before entering the contactor at 80 bars gauge. This column absorbs a part of the water in the gas in the Triethylene Glycol (TEG) mixture. At the end of the regeneration loop, the lean TEG feeds the top part of the contactor and absorbs water.

Rich TEG leaves the bottom by level control and is depressurized to 5 bars. The rich stream flows through a cartridge filter to remove solid particles coming from corrosion or TEG degradation. The wet TEG then enters a flash tank in which gaseous hydrocarbons that were absorbed along with the water in the contactor are vaporized. These hydrocarbons are heated in heat exchanger and used as stripping fluid in the stripper. The liquid phase heated in the heat exchanger then feeds the regenerator overhead. This column is used to strip water from the TEG and operates at atmospheric pressure. Waste gases consisting of water vapour and the hydrocarbons dissolved in the TEG leave the regenerator at the top. The liquid bottom stream feeds the stripping column. This column reduces the TEG water concentration by stripping using hydrocarbon vapours from the flash tank. Lean TEG is then sent from the bottom of the column to a storage tank. This storage tank has no meaning in terms of steady state simulation but allows the regulation of the TEG flow. Consequently, it is represented by a mixer module [5]. The TEG make-up is required to compensate the losses due to gas entrainment, degradation and vaporization. Lean TEG is then pumped in and feed the contactor head

IV. RESULTS AND DISCUSSION
4.1 The Temperature Difference between the Outlet Gas and the Inlet Glycol
In principle, most designs call for a lean glycol temperature that is $10°F$ (5.6^OC) hotter than the gas, and the inlet temperature of TEG is generally kept between 25^oC to 40^oC as a higher temperature considerably lowers both the viscosity and the absorption capacity of the TEG. High glycol vaporization losses to the gas exiting the contactor occur when the lean glycol temperature gets too hot.
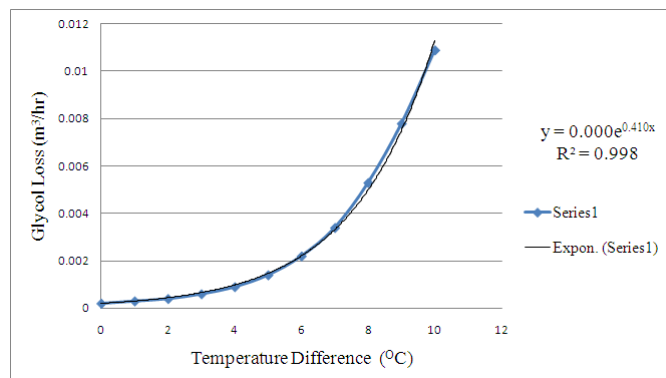

Figure 3. Glycol Losses as a function of the temperature difference between the outlet gas and the inlet glycol

y $\quad$ = $0.000e^{0.410x}$
R^2 $\quad$ = 0.998

Where $\quad$ y = Glycol loss (m^3/hr)
$\qquad$ x = Temperature difference between the outlet gas and the inlet glycol (^{O}C)
R^2 is the coefficient of determination, and its value provides an indication of how good the fit is. R^2 = 1 indicates perfect fit, and R^2 values that are near zero indicate extremely poor fits.

This result shows that as the temperature difference between the inlet lean glycol and the outlet dry gas increases, the glycol loss increases exponentially (Figure 3). This is mainly as a result of the higher concentration of TEG vapours in the dried gas stream.

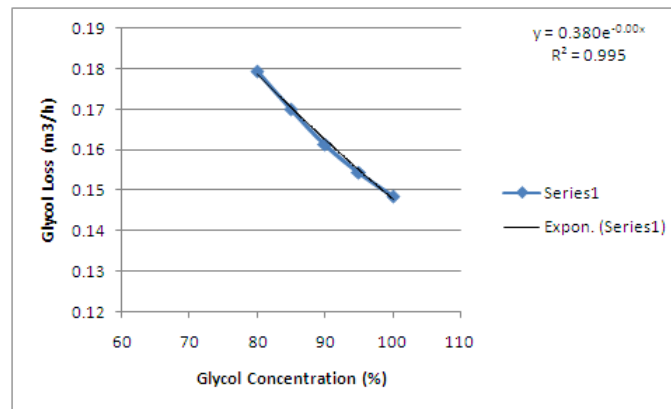## 4.2 Glycol Concentration and Glycol Loss

Figure 4. Glycol Concentration vs Glycol Loss

y $\quad$ = -0.001x + 0.301
R^2 $\quad$ = 0.990

Glycol-water mixtures generally have physical properties between those of water and anhydrous glycols [7]. Consequently, the addition of water to a glycol result in a mixture having a boiling point lower than that of the anhydrous glycol. The smaller the concentration of glycol, the lower the boiling point will be. It follows that any glycol loss that is attributable to glycol concentration should be as a result boiling off from the glycol regenerator. This is corroborated by the inverse proportionality captured by the simulation result as shown in the figure. R^2 is 0.995 (Figure 4).
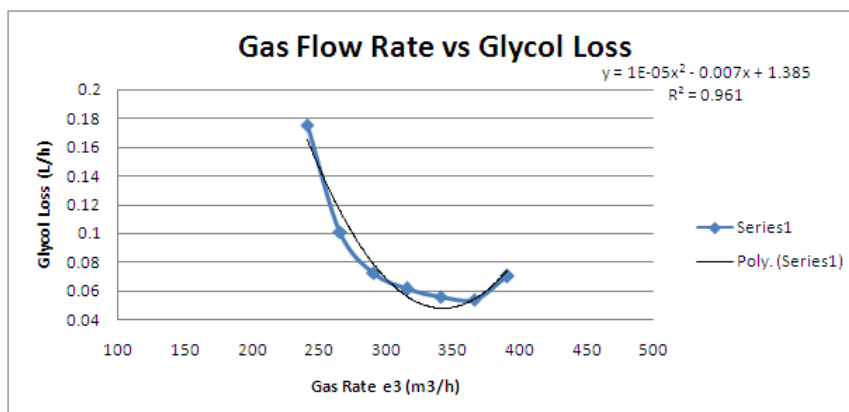
4.3 Gas Flow Rate and Glycol loss

Figure 5. Glycol loss as a function of Gas Flow Rate

y $\quad$ = $1E-05x^2$ - 0.007x + 1.385
R^2 $\quad$ = 0.961

The gas flow rate is directly proportional to the amount of water removed from the gas. This in turn affects both the regenerator heat duty and the lean glycol concentration. And as previously noted, the lower the glycol concentration, the lower the boiling point of the glycol [7]. Higher glycol losses at lower gas flow rates could be attributed to partial flooding, especially if the glycol is not effectively distributed through the structured package as a result of blocked holes in the distributor tray. Higher glycol losses at higher gas flow rates should be as a result of carry–over of glycol downstream of the absorber (Figure 5).

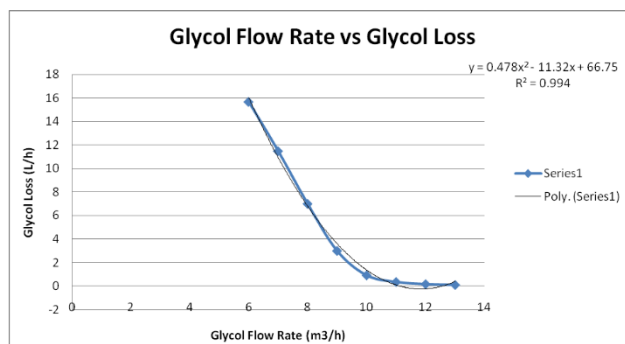**4.4 Glycol Circulation Rate and Glycol Loss**

Figure 6. Glycol Circulation Rate vs Glycol Loss

y $= 0.478x^2 - 11.32x + 66.75$
R² $= 0.994$

From the result obtained ($R^2 = 0.994$), it could be adduced that the higher glycol losses at lower circulation rates are largely as a result of carry over downstream of the absorber. At higher glycol flow rates, the inlet gas velocity is fairly counterbalanced (Figure 6).

V. CONCLUSION

Typical problems in process design or plant operation have various possible solutions. Optimization is concerned with selecting the best among the entire set by efficient quantitative methods such as is in this case, the application of the Hysys Glycol Package for Natural Gas Dehydration with TEG. By emphasizing the characteristic pattern of the impact of the process variables, a more informed decision will make for a better management of glycol losses in particular. The temperature difference between wet gas and lean glycol in the contactors is most probably the worst cause of hydrocarbons condensation. This problem is worsened by high pressure (with the attendant retrograde condensation), and therefore demands a more stringent control of the temperature differences between the glycol and the gas in the absorber for improving operational efficiencies of natural gas processing plants.

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