DESIGNING GLYCOL DEHYDRATION UNITS THAT UTILIZE STAHL COLUMNS WITH STRIPPING GAS

Laurance Reid Gas Conditioning Conference
February 24-27, 2020 – Norman, Oklahoma USA

Paul A. Carmody
Director Product Development
OTSO Energy Solutions, LLC
7102 N. Sam Houston Pkwy W., Suite 200
Houston, TX 77064
Phone: (936) 827-0661
pcarmody@otsoenergy.com

ABSTRACT

The "Effect of Stripping Gas on TEG Concentration" chart has been utilized for more than 50 years to design glycol regeneration units that utilize stahl columns to improve lean glycol purity downstream of a reboiler. A revised chart, developed from simulations, reveals that stahl columns can achieve any desired level of lean glycol purity. To achieve high purity lean glycol requires tall stahl columns. The relationship of column equilibrium stages and stripping gas required can be read directly from the revised chart, even to purities of 0.1 ppm water by weight in the lean glycol. The water concentration of the stripping gas can impact the level of drying achieved. This impact is quantified.

Three stahl column performance enhancers are also evaluated in order to develop a supporting cast of technologies that work together to reliably achieve cryogenic spec glycol. These are:

1. Split the stahl column into two stahl columns with a glycol reheater in between them.
2. Introduce gas from the flash gas separator as supplemental stripping gas into the stahl column preferably at the glycol reheater return to the stahl column
3. Install a Lifterator™ which is an apparatus where the glycol exiting the stahl column is further dried and lifted to a higher elevation in order to feed the lean/rich exchanger. Stripping gas that is used to lift the glycol is simultaneously conditioned prior to entering the stahl column. The conditioning includes heating and saturating the stripping gas with glycol and absorbing water from the glycol.

DESIGNING GLYCOL DEHYDRATION UNITS THAT UTILIZE STAHL COLUMNS WITH STRIPPING GAS

Paul A. Carmody, OTSO Energy Solutions, LLC, Houston, TX

Introduction

The two mainstays of gas dehydration utilize either glycol or molecular sieve as desiccants. Glycol dehydration is much more common with an estimate of 20,000+ units having been installed.[1] While glycol dehydration has a commanding presence, mole sieve dehydration has carved out an important niche. Namely, "[i]n processes where cryogenic temperatures will be encountered, molecular sieve desiccant is used exclusively."[2] This niche had been established by the early 1950's.

The first paper presented at the first Gas Conditioning Conference in 1952 made it clear that glycol dehydration can be successful "if the gas is to be dehydrated to meet normal pipeline specifications, which are usually 7 pounds of water/MMSCF."[3] That article also made it clear that dry bed desiccants are used to achieve "bone dry gas."[4] Even though the advance of mole sieve had yet to be commercially available, the dry bed desiccants of that time, such as silica gel, were already preferred for the most stringent dehydration specs. Once mole sieve had been perfected, it became the sole desiccant utilized for cryogenic specs.[5]

Stahl columns utilize stripping gas to improve water removal from glycol

Meanwhile, advances continued to be made in glycol dehydration technology. Of these, the development of the stahl column has been the most successful in improving water removal from glycol. It was developed by 1957 with a patent being issued to Willi Stahl as shown in Figure 1. Glycol exiting the reboiler is contacted in a countercurrent fashion with stripping gas within the stahl column. Stripping gas rises in the stahl column intimately contacting the glycol descending through the column with water being absorbed into the stripping gas. The lean glycol then descends into the surge accumulator.

Normally a column of this type would be referred to as a stripping column. But as Figure 1 shows, that term had already been used for the distillation column, which will be referred to as a still. Consequently, the term stahl column, named after the inventor, has been adopted and will be used in this paper.

---

[1] Curtis O. Rueter, Kevin S. Fisher, Patrick A. Thompson, Duane B. Meyers, "R-BTEX™ Prototype Performance Testing Results, Report No. GRI-94/0430", Gas Research Institute, Austin, August 1994, pg. 8-3
Throughout this paper the word "glycol" refers to triethylene glycol or TEG.

[2] Jensen, Daryl R, et.al., "Designing Molecular Sieve Dehydration Units to Prevent Upsets in Downstream NGL/LPG Recovery Plants", Laurance Reid Gas Conditioning Conference Norman, OK, 2012 pg. 419-420

[3] Campbell, John M., "Design and Choice of Equipment for Gas Dehydration", Gas Conditioning Conference, Norman, OK, 1952, pg. 8, This was for gas of 90°F or lower.

[4] Ibid., pg. 3

[5] For purposes of this paper cryogenic spec is defined as process gas containing 0.1 ppmv or less water. See: Jensen, Daryl R, et.al.

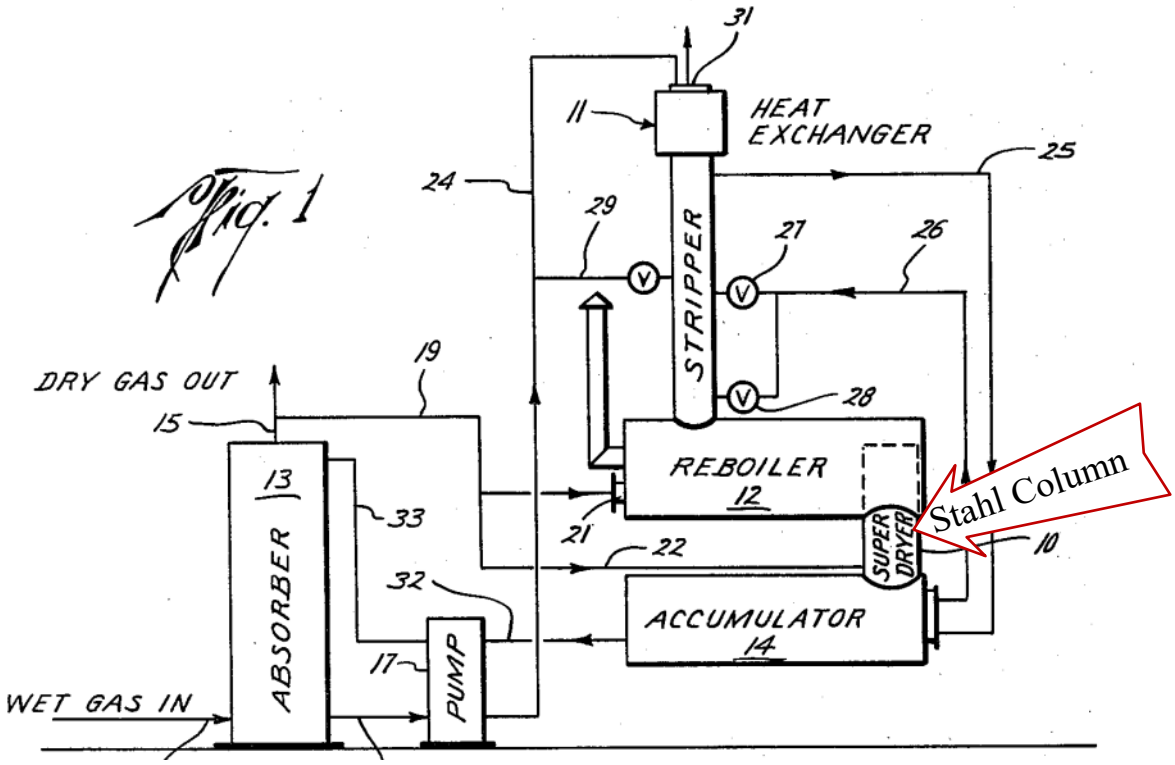

Figure 1 – The stahl column as disclosed in U.S. Patent 3,105,748

The stahl column is relatively easy to install and operate and reliably removes water from glycol. Consequently, the stahl column has become "by far the most commonly used technique for enhancing TEG concentration."[6] Through the early 1960's, while the stahl column was known to be effective, its performance was not quantified.

It was in 1966 that an article was published that quantified just how effective stripping gas would be at removing water from glycol by using a stahl column.[7] The graph from that article is reprinted here as Figure 2 - "Effect of Stripping Gas on TEG Concentration." This graph has been widely utilized in the industry and has been modified many times.[8] It continues to be the industry standard today.

---

[6] *Engineering Data Book FPS Version*, Tulsa, Gas Processors Suppliers Association, fourteenth edition, Tulsa, 2016, Section 20, pg. 20-43

[7] Worley, Steve, "Twenty Years of Progress with TEG Dehydration", Canadian Natural Gas Processors Association, Calgary, Alberta, Canada, December 3, 1966, pg. 255, This graph and portions of the that article were reprinted and expanded upon in the 1967 Gas Conditioning Conference. See: Worley, Steve, Super-Dehydration with Glycols, Gas Conditioning Conference, Norman, OK 1967, Fig. 7

[8] Examples include: *Engineering Data Book FPS Version*, Tulsa, Gas Processors Suppliers Association, fourteenth edition, 2016, Fig. 20-73 and John Campbell, et. al., (2004), *Gas Conditioning and Processing*, 8th edition Volume 2, John M. Campbell & Company, Norman, OK, Page 361

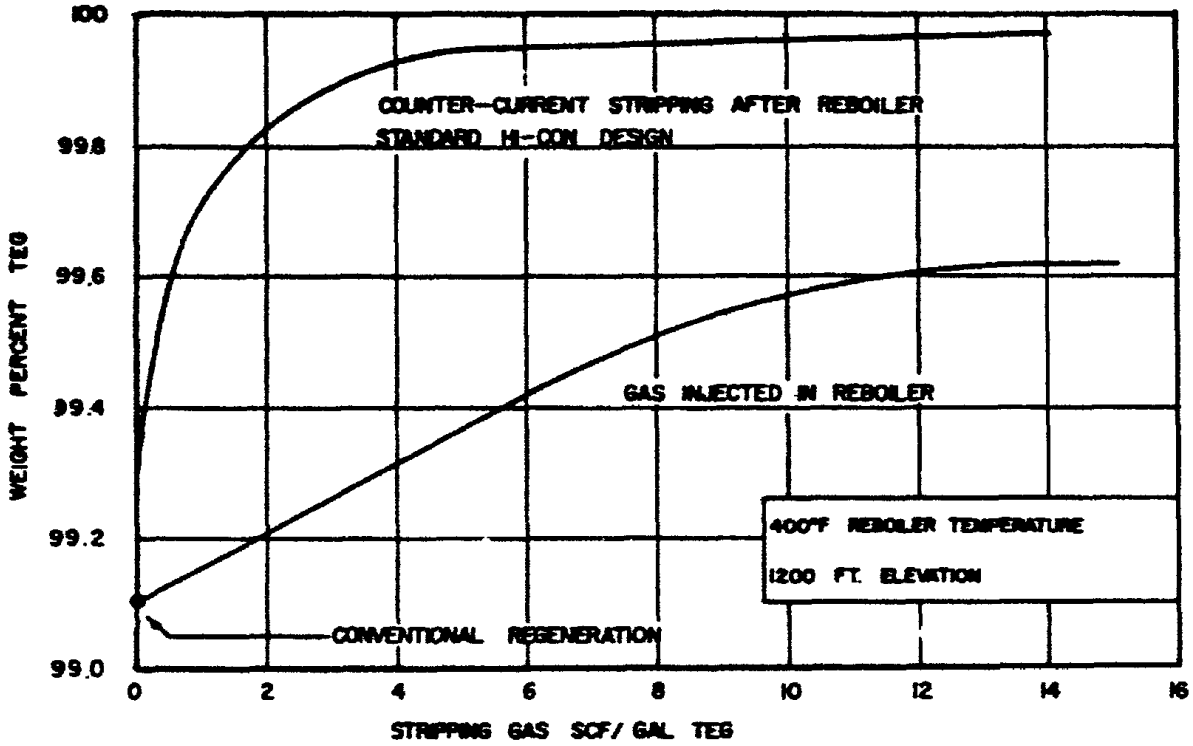

Figure 2 - "Effect of Stripping Gas on TEG Concentration"

This graph is easy to use and leads to suitable estimates of stripping gas requirements. In the days before widespread availability of process simulators, this graph was greatly appreciated. Even today, versions of this graph allow for quick estimates that can then be used as initial estimates in process simulations to enhance design decisions.

In all its forms, however, the graph fails to provide guidance when attempting to design for extremely low water content. The graph of Figure 2 would be hard to read past about 99.97% purity. There is another ambiguity concerning what is meant by purity. Is only water to be considered as the impurity or are other non-glycol contaminants to be considered? The other contaminants within the glycol become important and may be greater than the amount of water when extremely high purity is required. This issue does not appear to have been addressed in prior papers. It will be addressed later in this paper.

Non-condensable stripping gas sources with open and closed loop gas dispositions

The source of stripping gas is typically the dehydrated process gas or dehydrated fuel gas. The sources of stripping gas are mainly methane and are non-condensable. The stripping gas becomes wet with the water removed from glycol, usually just slightly above atmospheric pressure. Its temperature is usually too high to flow directly to a vapor recovery unit.

In many units, especially those that were in service in the 1960's, the gas would be vented after exiting the still. Some glycol dehydration units use the hot wet stripping gas as fuel, typically for the reboiler. An alternative that is utilized in more recent glycol dehydration units is to combust the vapors. For these scenarios the stripping gas is an open loop; it is used once and disposed of.

It is possible to close the stripping gas loop by recompressing the wet, low pressure, hot stripping gas. It would then be introduced upstream of the glycol contactor. It would then be dehydrating the gas in the glycol contactor, and reusing it as stripping gas. The glycol contactor regenerates the stripping gas.

The challenge is to cool the gas, condensing most of the water along with possible hydrocarbons sufficiently for a vapory recovery unit to compress it. This must be done with minimal pressure drop. Quench cooling is a means of conditioning the gas for compression with low pressure drop.

Drizo™ is a closed loop condensable stripping gas system

Drizo™ is a trade name for a method of supplying a condensable stripping gas in a closed loop. This condensable stripping gas is sourced from the heavy components from the process gas that are absorbed by the glycol and then recovered from the vapors exiting the still. Since the stripping gas consists of heavy hydrocarbon constituents absorbed from the process gas, it doesn't run out; instead, excess hydrocarbons are generated.

The vapors from the still are condensed, the water phase is separated, the condensed stripping gas is pumped, flowed through a coalescer, and dried further in a solid bed dryer (note: this dryer is needed for cryogenic spec dehydration). The condensed stripping gas is then vaporized to become the stripping gas to be utilized in the stahl column. It then flows through the still which closes the stripping gas regeneration loop.

Drizo™ has been described as the type of glycol dehydration that achieves lean glycol with the lowest water concentration.[9] Such claims are misleading. So far as the performance of the stahl column is concerned, it doesn't matter how the stripping gas is sourced. What matters are the following:

- water content of the glycol entering the stahl column,
- temperature and pressure of the stahl column,
- the amount of water contamination in the stripping gas,
- the ratio of stripping gas to glycol, and
- the height of the stahl column.

Drizo™ has had some excellent results.[10] Drying that allows for the use of glycol for cryogenic service has been achieved.[11] That is mainly because of high stripping gas rates and very tall stahl columns. As will be described shortly, non-condensable stripping gas can achieve the same excellent drying of glycol.

---

[9] At least two sources claim that Drizo™ achieves the leanest glycol. Smith, Robert S., "Enhancements of Drizo Gas Dehydration," Laurance Reid Gas Conditioning Conference, Norman, OK, 1997, pg. 307, Commercial literature: https://www.axens.net/product/process-licensing/20122/drizo.html

[10] Smith, Robert S. and Humphrey, "High Purity Glycol Design and Operating Parameters," Laurance Reid Gas Conditioning Conference, Norman, OK, 1994, A west Texas plant regularly achieve ~100 ppmw water in lean glycol, now for 30+ years.

[11] Szuts, A., et al, "Drizo Unit competes with Solid Bed Desiccant Dehydration", Laurance Reid Gas Conditioning Conference, Norman, OK, 2002.

Stahl Column Sizing Chart

The "Stahl Column Sizing Chart" shown as Figure 3, is a new look at how to address the sizing and operation of stahl columns with an emphasis on achieving high water removal from glycol. Figure 3 takes the data from "Effect of Stripping Gas on TEG Concentration" of Figure 2, restates and expands it.

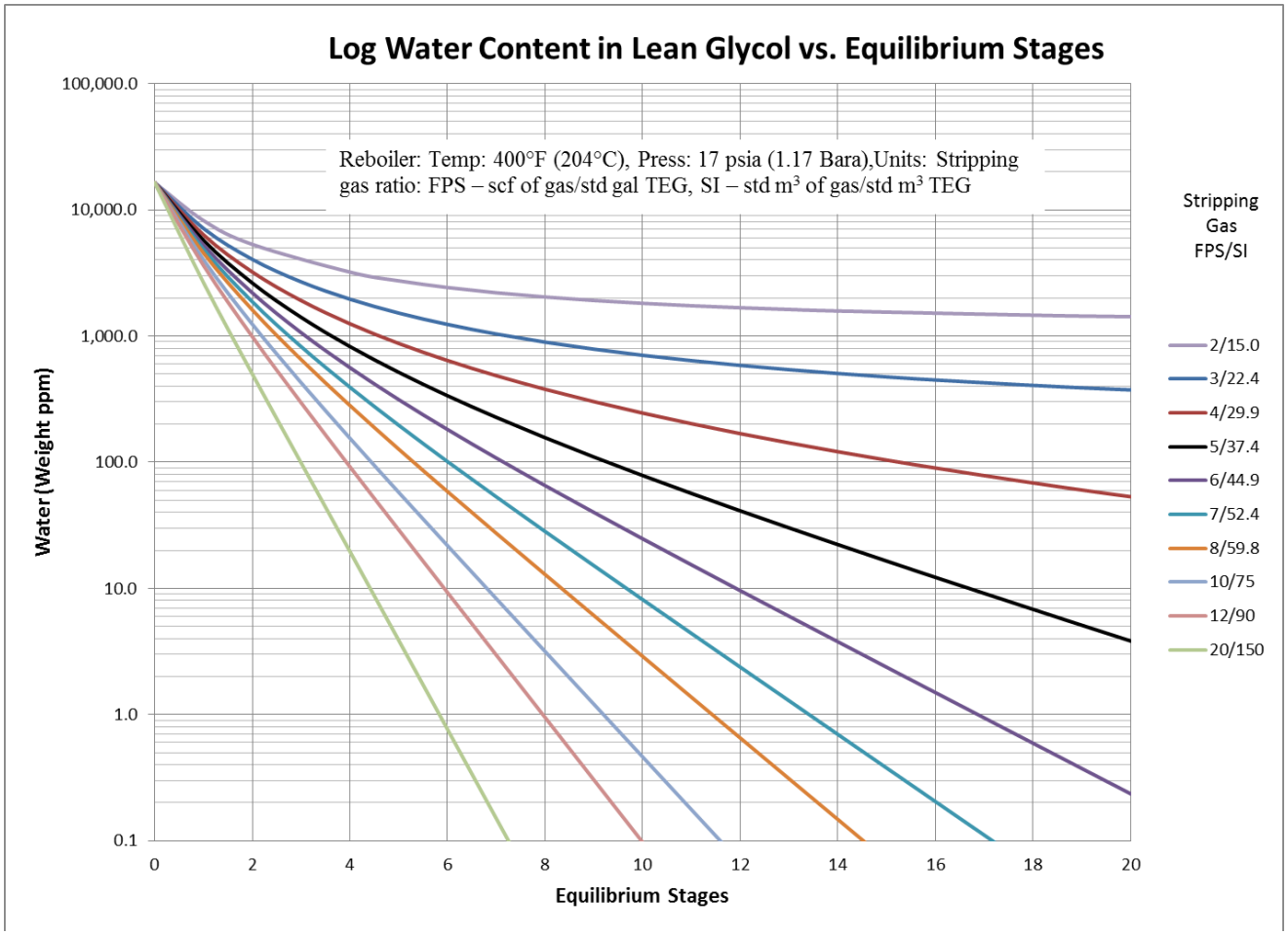

Figure 3 – Stahl Column Sizing Chart

To that end, the first step is to stop examining the purity of the glycol and to plot the amount of water contaminating the glycol instead. After all, it is the water in the glycol that limits how well the lean glycol can strip water from process gas within the glycol contactor. By plotting the semi-log of the water on the y-axis, it becomes easy to determine the impact of stripping gas rates and column equilibrium stages. As lower and lower water concentrations are reached the graph becomes easier rather than more difficult to read, as was the case with the Figure 2 graph.

The second change from the Figure 2 graph is to change the x-axis variable from stripping gas ratio to equilibrium stages of contact. The stripping gas ratio is now shown as individual lines on the graph. It was found that this change created straighter lines on the graph than using stripping gas ratio as the x-axis variable.

All of the curves start from a single point representing zero equilibrium stages.[12] That is the condition as the glycol exits reboiler and enters the stahl column. The y-axis water impurity semi-log scale lower limit is 0.1 ppmw water. This is an arbitrary limit; the scale can be extended as needed. The x-axis showing the equilibrium stages stops at 20 stages. That limit is also arbitrary; it can be extended as needed. It follows that any desired level of water remaining in the lean glycol can be achieved with sufficient stahl column equilibrium stages and stripping gas.

Lean glycol with 10 ppmw water can be utilized dehydrate process gas to meet cryogenic dehydration specs for saturated process gas at 100°F (38°C) and 815 psia (56.2 Bara)

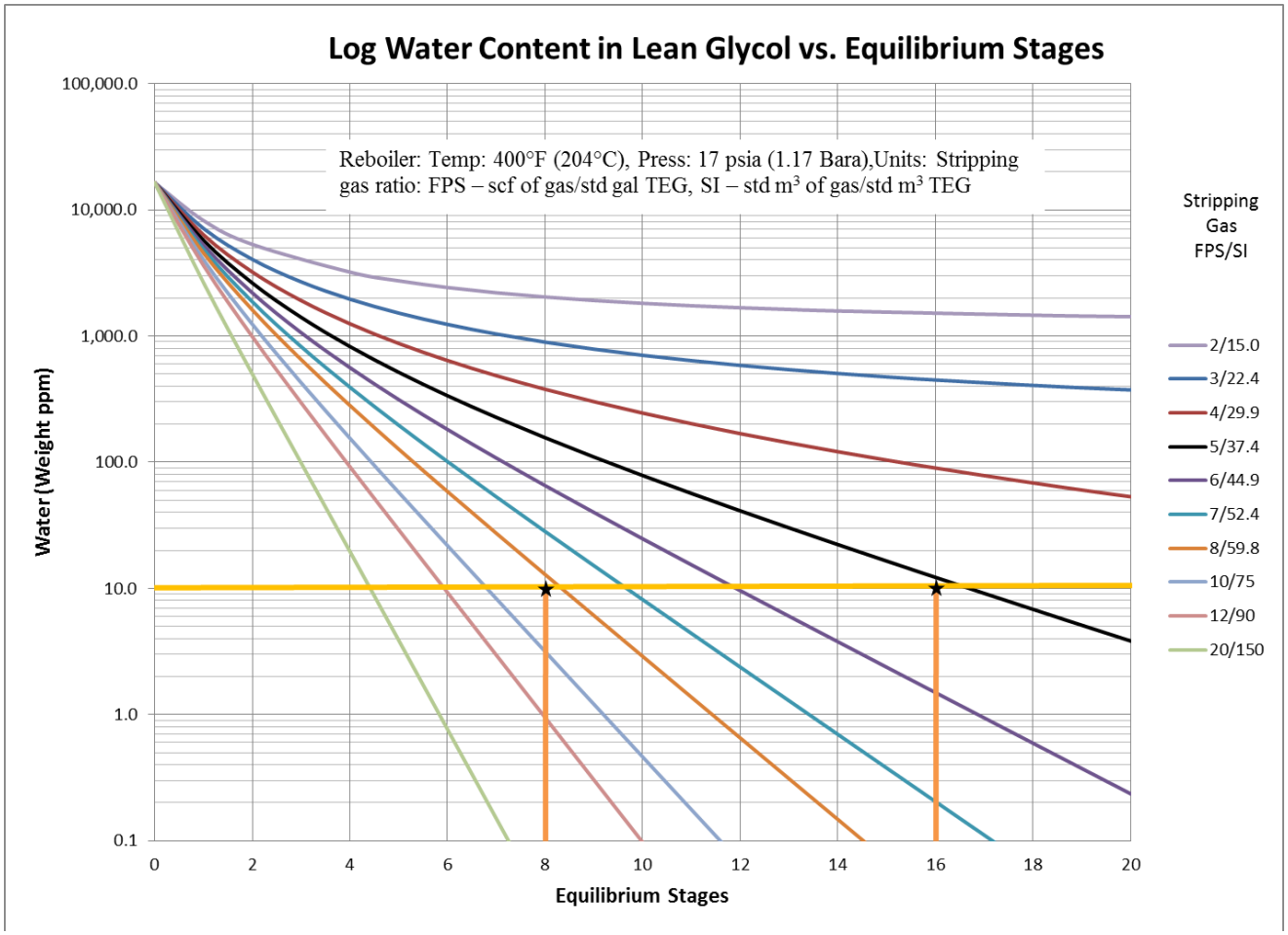

Figure 4 – Stahl Column Sizing Chart with two stahl column configurations to meet a 10 ppmw lean glycol spec

Just as process gas has a cryogenic dehydration spec, it follows that the lean glycol also has a cryogenic dehydration spec. That lean glycol water spec would be determined on a case by case basis. A hypothetical process gas is considered wherein 10 ppmw lean glycol is used to achieve a cryogenic dehydration spec. Only three constituents are considered, methane, TEG, and water.

[12] Figure 2 includes a curve for injecting stripping gas into the reboiler. The Figure 3 graph, in contrast, assumes that stripping gas is injected only at the bottom of the stahl column, thus the water concentration in the glycol exiting the reboiler is constant and independent of stripping gas rate.

The process gas to be dehydrated consists of water saturated methane at 100°F (38°C) and 815 psia (56.2 Bara). It is dehydrated with lean glycol circulating at a ratio of 28 pounds of glycol/pound of water in the process gas. A contactor with 7 equilibrium stages is required[13] to achieve the desired cryogenic dryness spec of 85 ppbv water in dehydrated the process gas.

With the establishment of the 10 ppmw as a glycol cryogenic spec enables the design of a stahl column equilibrium stages and stripping gas requirement. Two design solutions are shown on Figure 4. Figure 4 is identical to Figure 3 except for the addition of these design solutions. The first solution is for a stahl column with eight equilibrium stages. This requires 8.4 scf/gal (63 std m^3 gas/std m^3 TEG) of stripping gas to achieve the desired 10 ppmw spec. The second solution is for 16 equilibrium stages. This requires 5.2 scf/gal (39 std m^3 of gas/std m^3 TEG) of stripping gas. Of course, a whole range of solutions are available.

A simple process model underpins the Stahl Column Sizing Chart[14]

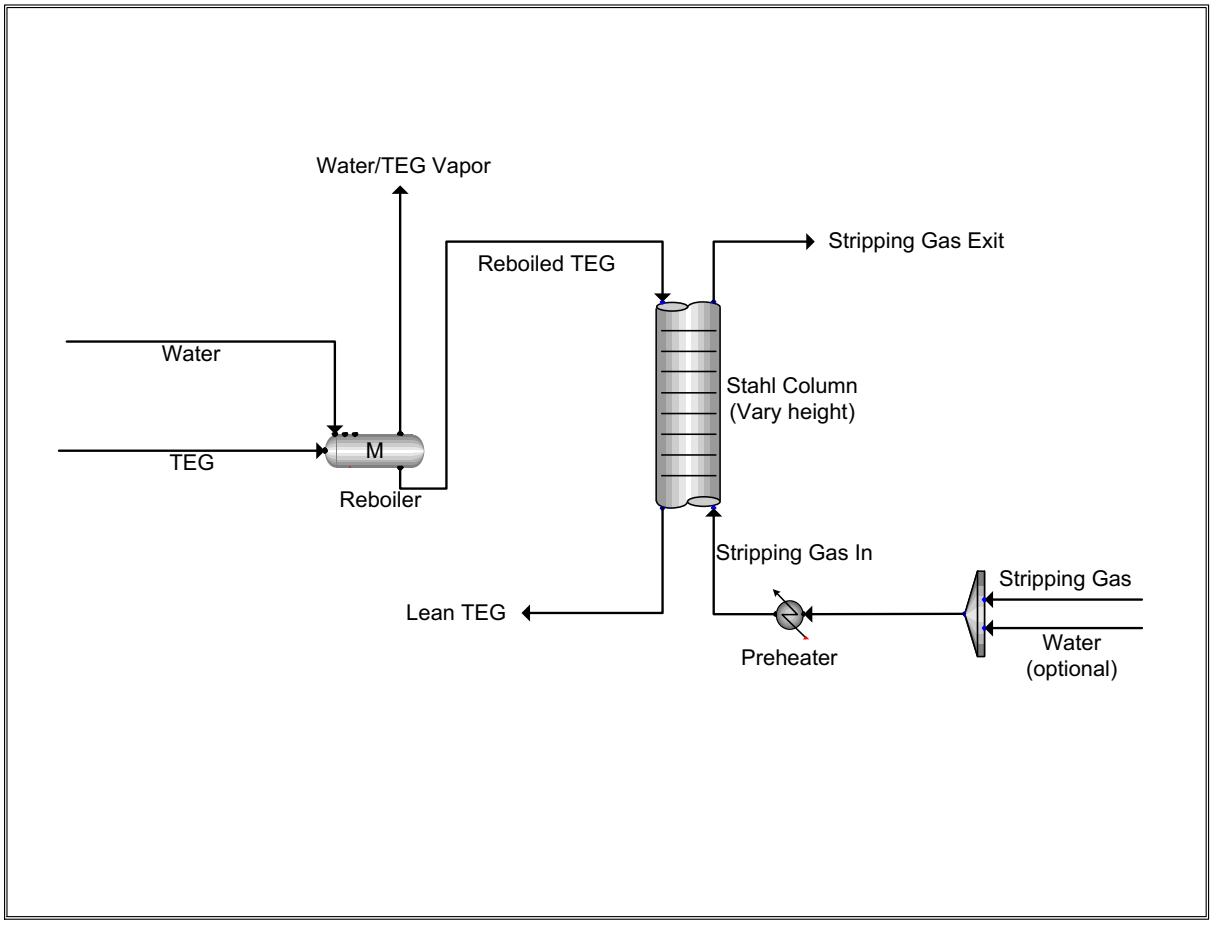

Figure 5 – Basis of the Stahl Column Sizing Chart

Figure 5 shows a representation of the basis of how the Stahl Column Sizing Chart was created. Simplifying assumptions have been made in order to create the chart. This is a very simple model for process simulators. As for the prior example, only three constituents are considered,

[13] This requires two to three times the number of equilibrium stages compared to a typical pipeline dehydration spec
[14] Process Simulator: Symmetry Version 2018 build (377), Thermo: Apr for Natural Gas 2

methane, TEG, and water. Water and glycol are mixed and then heated in the reboiler to 400°F (204°C). A portion of the water and glycol are boiled off. The still is omitted from this design. The reboiled glycol flows into the top of the stahl column. All equilibrium stages of the stahl column are held at a constant pressure which is equal to the reboiler pressure of 17 psia (1.17 Bara). Lean TEG exits the bottom. Stripping gas is preheated to 400°F (204°C) and then enters the stahl column. While both the TEG and stripping enter the column at 400°F (204°C), the column does not have a constant temperature. Water and glycol are vaporized into the stripping gas lowering the temperature within the stahl column. The lean TEG outlet temperature is about 380°F (193°C) for the stripping gas ratio of 5 scf/gal (37 std m^3 of gas/std m^3 TEG).

The stahl column equilibrium stages and the stripping gas rates are varied. A matrix of the many results is created and then curves are plotted. Clearly, models similar to the one described here can be created. Process simulations can be created to create customized Stahl Column Sizing Charts for other temperatures and pressures.

Quantifying the Impact of Water Content in Stripping Gas

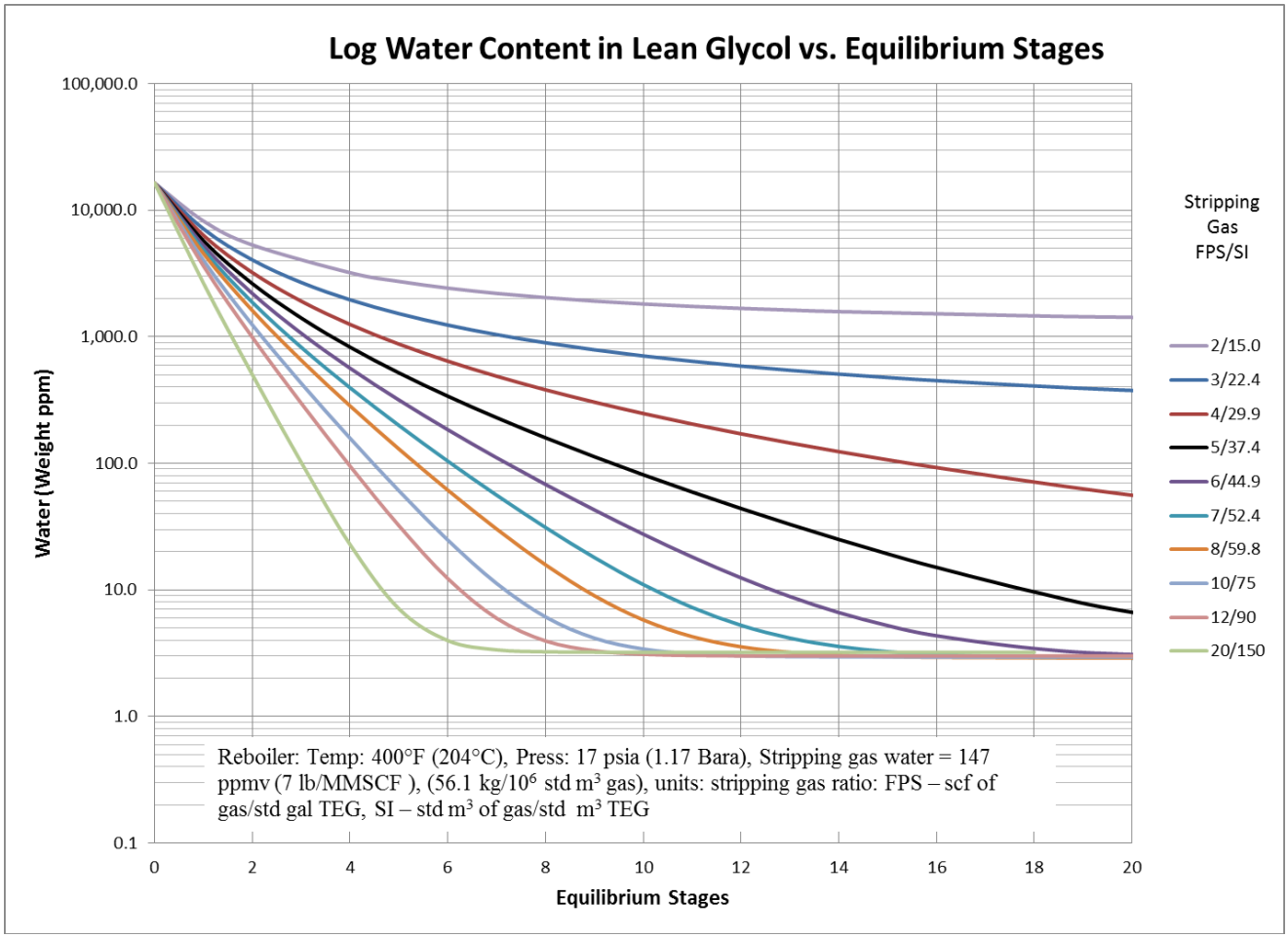

Figure 6 – Impact of stripping gas with water that meets a pipeline spec on the Stahl Column Sizing Chart

It is safe to assume that all stripping gas will be contaminated with water. But the contamination is often insufficient to impair the required drying of glycol within a stahl column. The graph of

Figure 2 is of no benefit in addressing this issue as it assumes dry stripping gas. This demonstrates one of the virtues of utilizing a graph with the semi-log water content as the y-axis. The limit on dehydration is evident once stripping gas containing water is simulated.

The process simulation illustrated in Figure 5 now includes water that has been added to the stripping gas. The percentage of water is kept constant. The impact of the water is obvious.

Figure 6 shows the impact of utilizing stripping gas that meets a pipeline spec of 7 pounds of water/MMSCF of gas. Water contamination in the stripping gas places a distinct limit on the level of drying that can be achieved. Once the stripping gas is saturated, no amount of stripping gas or equilibrium stages of stahl will make a difference.

Further simulation work shows that hydrocarbons do not act as contaminants (note: foaming is beyond the scope of this paper). So long as there are not enough hydrocarbons to dilute the glycol substantially, they won't appreciably impact the drying capacity of the stripping gas.

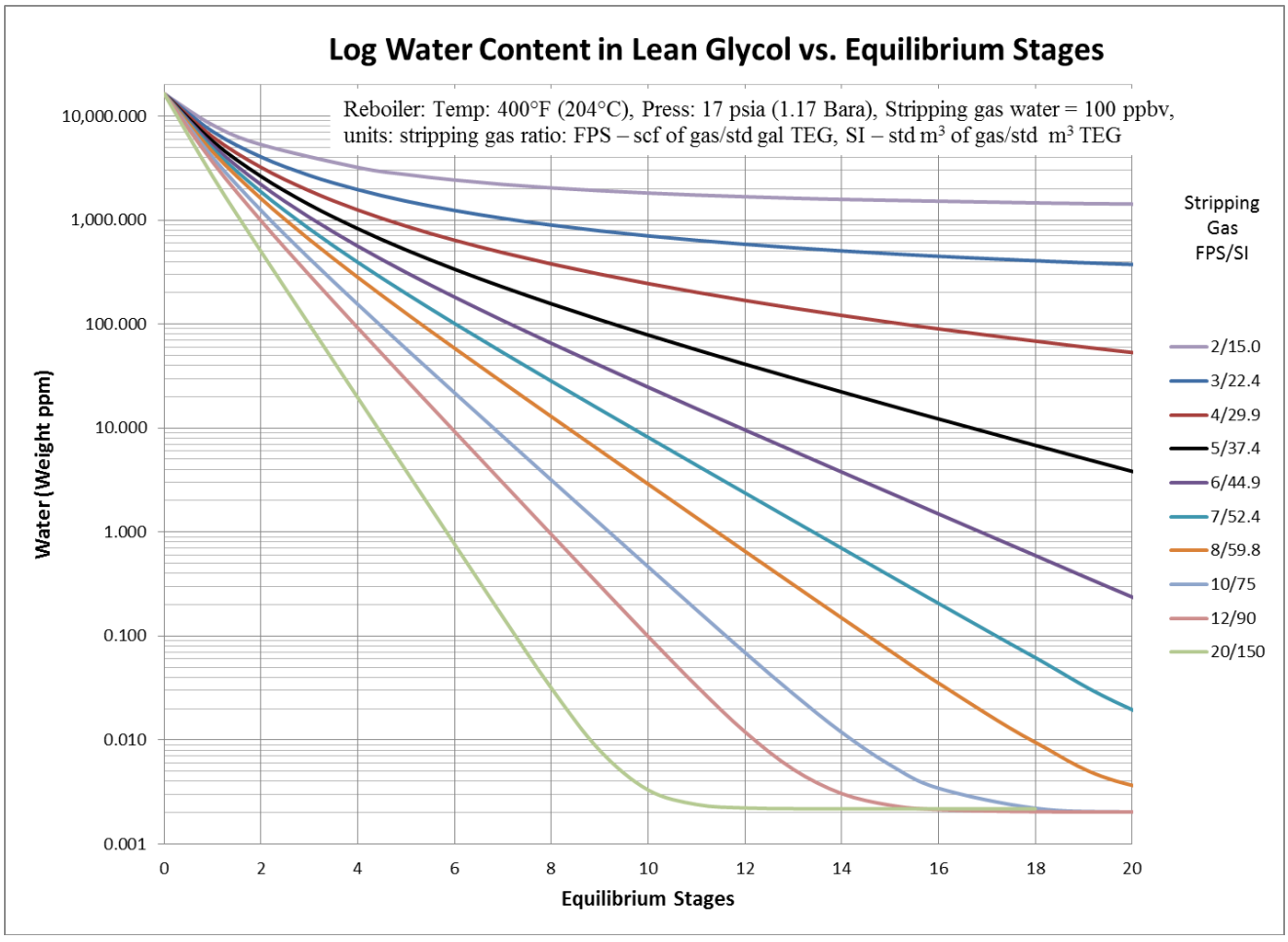

Figure 7 – Impact of stripping gas with water that meets a pipeline spec on the Stahl Column Sizing Char

The example of Figure 6 uses ordinary pipeline gas, which is not nearly dry enough for cryogenic processes. Yet, it could potentially be used to make lean glycol suitable for

dehydrating process gas for cryogenic dehydration specs. As can be observed in Figure 6, the 10 ppmw lean glycol spec could be reached.

Figure 7 is considers sourcing stripping gas from process gas that has 0.1 ppmv of water (i.e. it meets the cryogenic dehydration spec). If that gas is used as stripping gas, the limits on lean glycol concentration are in the parts per billion range. The y-axis was extended by two orders of magnitude to show where the dryness asymptote is reached.

The conclusion is clear; on-spec process gas is always dry enough to be used as stripping gas. In fact, there is a process margin of about three orders of magnitude when using on spec gas. This is in contrast to Drizo™ which requires further drying of the stripping gas before it can be used to generate lean glycol for cryogenic dehydration specs.

A series of simulations show that the dryness limit asymptote is proportional to the water concentration in the stripping gas. That limit is quantified as shown in Equation 1 below:

$$\boldsymbol{Dryness\ Limit = Constant\ x\ Water\ Content = Z\ PPM} \qquad \text{(Equation 1)}$$

Where

- Dryness Limit" is the lowest water content achievable in lean glycol given a stripping gas containing water
- Constant is: FPS: .408, SI: .0509, Dimensionless: 0.01937
- "Y" is the amount of water in the stripping gas in pounds of water/MMSCF of gas
- "Z" is the lowest amount of water possible in the lean glycol for the stripping gas utilized

Constant	x Stripping Gas Water Concentration	= Water Limit in Glycol
0.408	7 lb water/MMSCF gas	= 2.9 ppmw
0.05094	56 kg water/$10^6 Sm^3$ of gas	= 2.9 ppmw
0.01937	147 ppmv Water	= 2.9 ppmw

Figure 8 – Example of Dryness Limit for Pipeline spec Gas

This equation is applicable only for the case of 400°F (204°C) and 17 psia. A different constant is needed whenever temperature or pressure is changed. If a different the stahl column pressure or temperature is selected, a new constant would be required.

How equilibrium stages relate to height and achieving stahl column performance

Equilibrium stages must be converted to actual height of packing. A rate based simulator was utilized to make this determination and it would take about 2 feet (0.61 m) of random packing to equal one equilibrium stage. Different types of packing or using trays would generate somewhat different results. It is recommended that simulator based determinations of height be prepared to support actual installations.

Stahl columns can underperform dehydration expectations.[15] In order to achieve expected performance it is important to design the stahl column as any other process column would be designed. Proper distribution of glycol is important as is the packing selection. Frequently, stahl column design is minimal, often without a distributor and with the height being determined based on how far the reboiler is above the surge tank rather than process considerations. In many applications this approach is acceptable; it is not acceptable when attempting to reach extremely low concentrations of water in lean glycol.

Column performance is also strongly affected by ratio of stripping gas to glycol flow. Steps should be taken to keep that ratio constant. Stripping gas flow is normally easy to keep constant. Even small variations in glycol flow will impact performance. Glycol flow rates can be variable due to variations in control valve performance. Dampen the dumping of level control valves from the absorber and flash gas separator to minimize glycol flow variation. Allow sufficient surge volume within the absorber and flash gas separator to accommodate any surging of glycol flow.

Keep reboiler duty from rapid changes. On-off control of a reboiler can be expected to upset the operation of the condenser continuously.[16] This upset condition impacts glycol purity since large quantities of water descending through the still can suddenly increase the water content of the rich glycol.

Install high quality condensing equipment. Often the condenser is not of high quality. In some instances, fins are used to exchange heat with the air. These are, of course, highly dependent on the weather, time of day, as well as seasons. Frequently, rich glycol is used, often without any controls. Such systems are inexpensive but do not provide precise control. High quality condensing, that has proper controls, will avoid problems associated with over refluxing.

Stahl Column Performance Enhancer Technologies

The discussion thus far has explored the nature of stahl column performance with emphasis on achieving extremely low water content in the lean glycol. A glycol dehydration unit could potentially be designed to achieve any desired level of lean glycol by making a tall enough stahl column and utilizing enough stripping gas to make the needed dryness spec. And yet much is demanded of this column.

Three stahl column performance enhancers are next evaluated in order to develop a supporting cast of technologies that work together to reliably achieve cryogenic spec glycol. These are:

1. Split the stahl column into two stahl columns with a heater in between them. The glycol from the reboiler enters a first stahl column which will be called the primary stahl column. The glycol will then be heated in the glycol reheater, and the final stahl column will be called the polishing stahl column.

[15] Hoogwater, Sjoerd ,"TEG Dehydration Systems for Very Low Dew Points", Laurance Reid Gas Conditioning Conference, Norman, OK ,2017

[16] Rueter, Curtis and Beitler, Carrie, Design and Operation of Glycol Dehydrators and Condensers, Laurance Reid Gas Conditioning Conference, Norman, OK 1997, pg. 139

2. Introduce gas from the flash gas separator preferably in between the primary and polishing stahl column where the glycol from the reheater enters the column. This increases the amount of gas available to strip water from glycol.
3. Install a Lifterator™ which is an apparatus where the glycol exiting the polishing stahl column is further dried and lifted to a higher elevation in order to feed the lean/rich exchanger. Stripping gas that is used to lift the glycol is simultaneously conditioned prior to entering the polishing stahl column. The conditioning includes heating and saturating the stripping gas with glycol and absorbing water from the glycol.

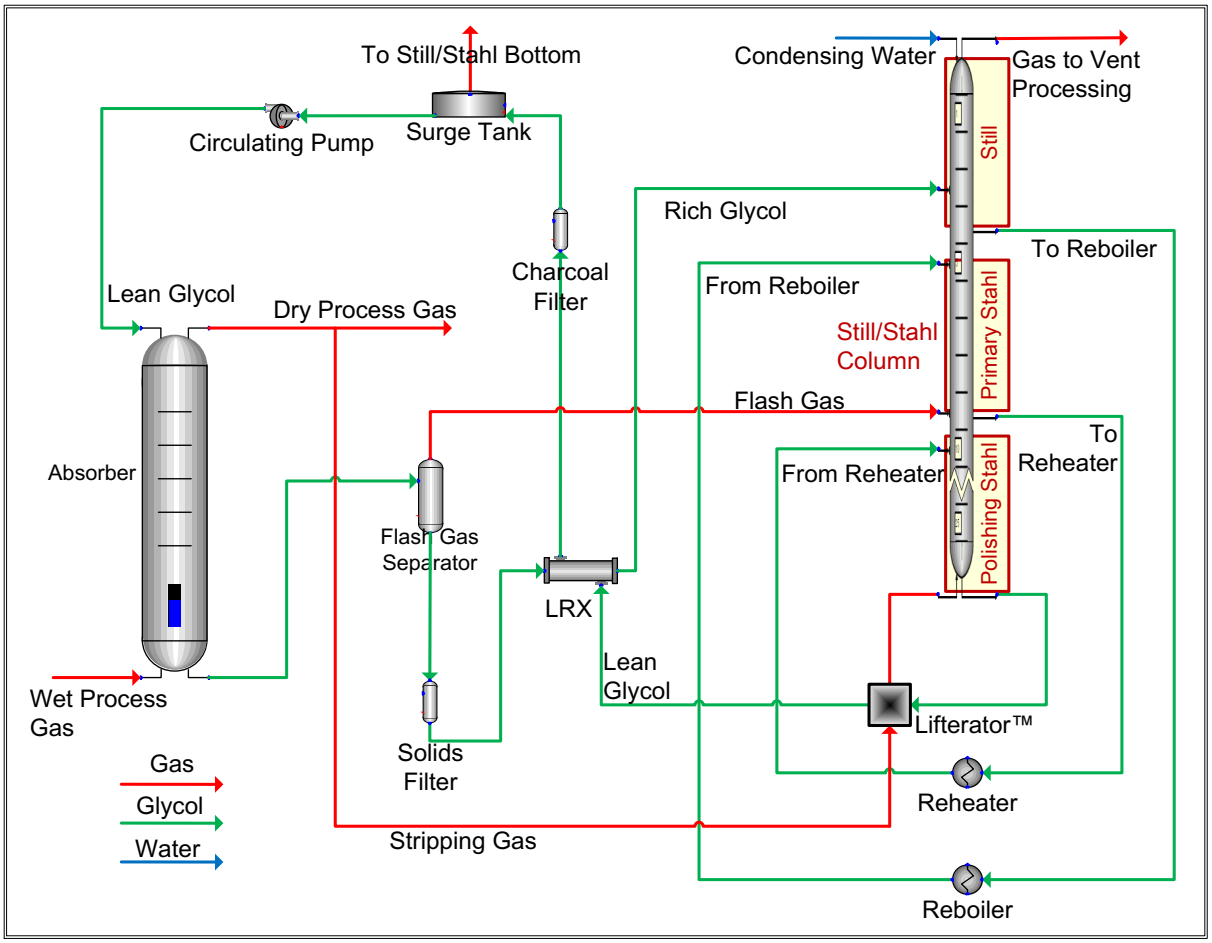

Figure 9 – Glycol dehydration unit to meet a cryogenic spec

Figure 9 discloses a full glycol dehydration unit including the three performance enhancers. Glycol circulation rates would be similar to current glycol units. Although the absorber is much taller than typical absorbers, its function would be similar to current absorbers. The flash gas separator and solids filter would be of similar design to current dehydration units. The lean/rich exchanger heats the glycol prior to entering the still of the glycol unit.

The glycol enters a still that sits atop the stahl column. This combined column is called the still/stahl column. The stahl column is subdivided in to two portions, the primary stahl column and the polishing stahl column. The glycol reboiler adds heat between the still and primary stahl

column. The glycol reheater adds heat between the primary and polishing stahl columns. Flash gas is introduced between the primary and polishing stahl columns.

The glycol exiting the polishing stahl column enters the Lifterator™ as it flows to the hot side of the lean/rich separator. The stripping gas also enters the Lifterator™ as it flows to vapor inlet of the polishing stahl column. The lean glycol feeds into a close approach, high heat recovery lean/rich exchanger with a downstream charcoal filter, uninsulated surge tank, and circulating pump. There is no requirement for lean glycol cooling.

Performance enhancer #1: Two stahl columns with a glycol reheater

If one stahl column is good, can two stahl columns be better? The answer is "yes" provided heat is added between the columns. Reboiler and stahl column temperature is known to have a pronounced impact on glycol purity; hence glycol units are operated at the highest temperatures feasible. As Figure 10 shows, the temperature within the stahl column is not constant. Rather, it reduces the temperature as the water is stripped from the glycol that is descending through the column. This is true regardless of whether or not a glycol reheater is added to the system.

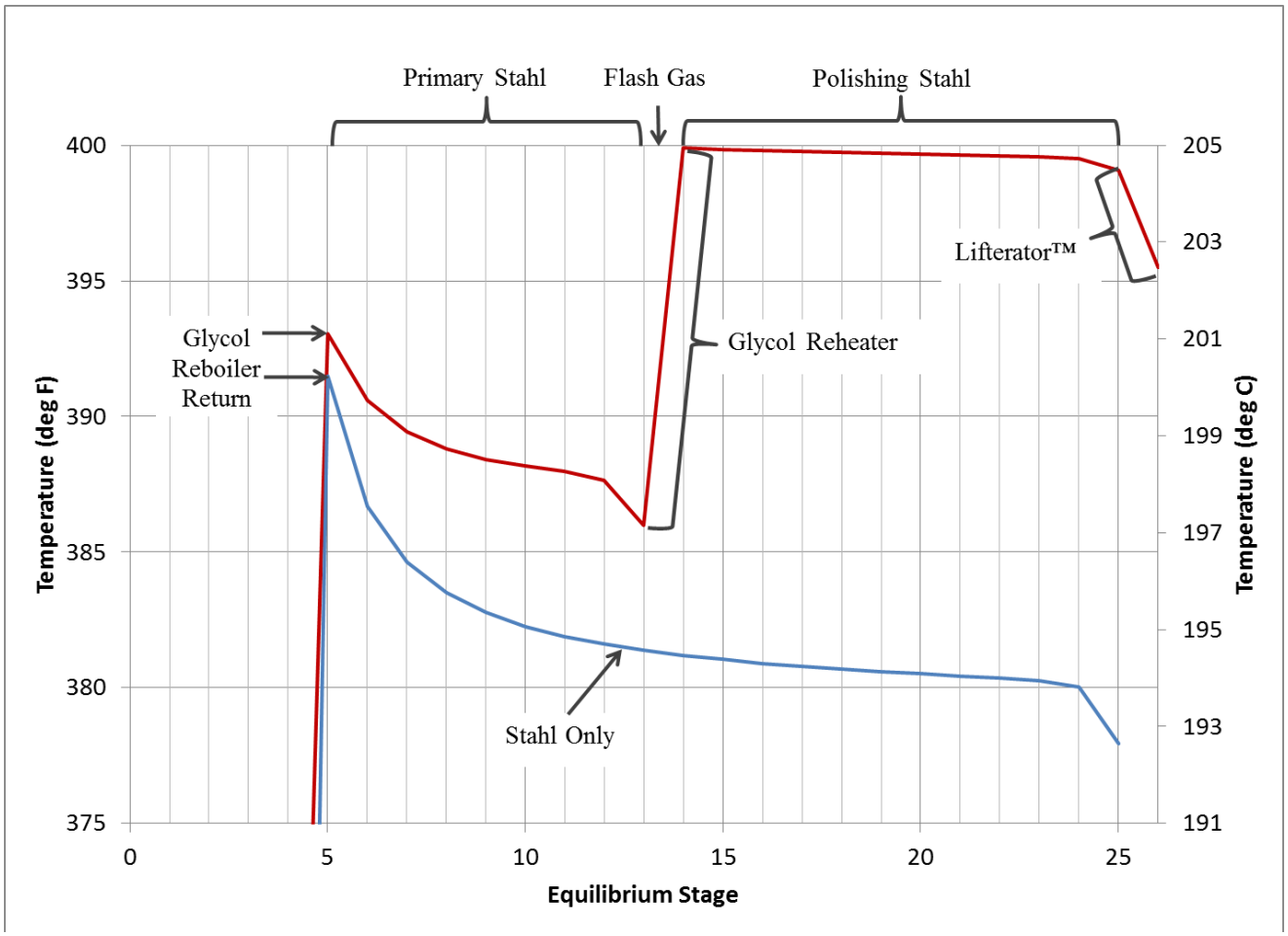

Figure 10 – Temperature profile of stahl column with and without performance enhancers

This temperature reduction is principally a result of the latent heat of vaporization of water into the stripping gas. Reheating the glycol at a suitable place within the column will mitigate the temperature reduction.

Figure 10 shows two temperature profiles of a stahl column, one that has a stahl column with no other performance enhancers and the other that includes all three performance enhancers.[17]

The "stahl only" case shows a regular decline in temperature as the glycol descends through the column. At the last stage, the temperature decline is larger. This is due to the stripping gas saturating with glycol as it enters the stahl column. Even though the stripping gas been preheated to 400°F (204°C) saturating it with glycol causes this larger temperature decline. Most of the stahl column is minimally affected by this saturation stage. In shorter stahl columns, this effect is more important since there is less column length.

The "performance enhancers" case includes all three performance enhancers. The glycol reheater has the most pronounced impact on the column temperature profile. As is evident, the glycol in the polishing stahl column below the glycol reheater operates very close to the reheater temperature of 400°F (204°C). Note that the reheater and reboiler are designed to operate at the same temperature. The Lifterator™ is external to the column but acts much as an extra stage from a temperature standpoint. That is why it is shown as an extra stage to the column, a stage which absent from the stahl column only case. The flash gas causes a small reduction of the temperature at stage 14 where it is injected. This flash gas is unheated, so there is both a need to increase the sensible temperature as well as saturate the stripping gas with glycol.

The temperature of the glycol entering the column at stage 5 is higher for the "performance enhancers" case than the "stahl only" case. This is mainly due to having less water to reboil for the "performance enhancers" case. It loses less temperature as it flows to the column. A reason for the lower water content is that a higher heat recovery lean/rich exchanger is utilized for the "performance enhancers' case. The glycol temperature exiting the lean/rich exchanger increases from 305°F (152°C) for the "stahl only" case to 356°F (180°C) for the "performance enhancers" case.

Description of operation of the still/stahl column

Returning to Figure 9, the first thing to observe about the still/stahl column is that it would be quite tall and thin. For the simulations shown in the Appendix, this would be about an 18" OD X 60' (457 mm X 18.3 m) tall column. Nonetheless, much of it would function much as current still, reboiler, and stahl columns.

The glycol would feed into the still. The vapors would ascend to the top of the still where the glycol is condensed but vaporous water, stripping gas, and some other hydrocarbons would exit for vent gas processing. Although there are various methods of condensing the glycol, introducing small water stream into the top of the column is shown. The vapors from the top of the still are flow off system for handling.

[17] The Appendix summarizes these two different tall stahl cases. These cases are compared side-by-side. This Appendix is the basis for temperatures, pressures, duties, equipment sizing, etc., discussed in this paper.

Since it is so tall, the glycol would be removed from the bottom of the still via a liquid draw rather than flowing directly into a reboiler. The glycol reboiler could be considered a side reboiler and the feed and return lines a pumparound. The reboiler would be located at a convenient elevation in order to optimize cost and accessibility.

The return from the reboiler takes the glycol to the top of the primary stahl column. It then descends though the primary stahl column with water being stripped into the rising stripping gas. The temperature of the glycol reduces due to the removal of the water from the liquid glycol into the vaporous stripping gas.

A liquid draw removes glycol from the bottom of the primary stahl column. It descends to the reheater where the temperature is heated preferably to the same temperature as the reboiler and returned to the still/stahl column at the top of the polishing stahl column. This also constitutes a pumparound with a side reheater.

There is very little water left in the glycol as it enters the top of the polishing stahl column so there is little temperature drop within it. It intimately contacts stripping gas that has entered the bottom of the polishing stahl column. While the amount of water removed from the glycol is small as the glycol descends, this portion of the still/stahl column is where the water content is finally reduced to the concentration where the glycol can be used for cryogenic dehydration applications.

Performance enhancer #2: Utilizing flash gas as supplemental stripping gas

An unheated flash gas separator would have flash gas that is too wet for injection into the bottom of the polishing stahl column. But even at an approximate water content of 160 lb/MMSCF (1281kg water/$10^6 Sm^3$), the gas is dry enough to be injected at a point within the still/stahl column where the stripping vapor in the column is wetter than the flash gas stream. The glycol return from the reheater is such a point with the added benefit that it a place designed for fluid entry into the column. As shown in the Appendix, the amount of flash gas is significant at about 23% of the total stripping gas to the column.

It is desirable to introduce flash gas at the same stage in the column as the glycol return from the glycol reheater. This space in the column would include a chimney tray and be located between the bottom of the primary stahl column and the top of the polishing stahl column. It would ideally have a separate feed point above the return point of the glycol returning from the reheater. This flash gas stream does not need to be preheated (i.e. preheating offers very little process improvement) as the glycol reheater adds heat to the liquid entering just below this point within this stage. The flash gas mixes with the stripping gas that has exited from the top of the polishing stahl column and the larger flow of gas ascends through the primary stahl column and still removing water as the stream rises.

Performance enhancer #3: Installing a Lifterator™ apparatus

Figure 11 shows the Lifterator™ works by mixing stripping gas and glycol that has exited the bottom portion of polishing stahl column. The mixed liquid and gas is lifted at a sufficient velocity to minimize breakout of vapor from liquid. At a higher elevation the mixed fluid enters

a separator in which the vapor and liquid substantially separate. About one equilibrium stage of contact is anticipated to occur.

The mixing heats the stripping gas to about 395.5°F (201.9°C) which is only slightly less than the reboiler/reheater temperature. The mixing is anticipated to remove more than half of the water from the glycol into the stripping gas. It also saturates the stripping gas with glycol. The saturated stripping gas would be about 6.6 mole percent glycol which 34.5% by weight glycol.

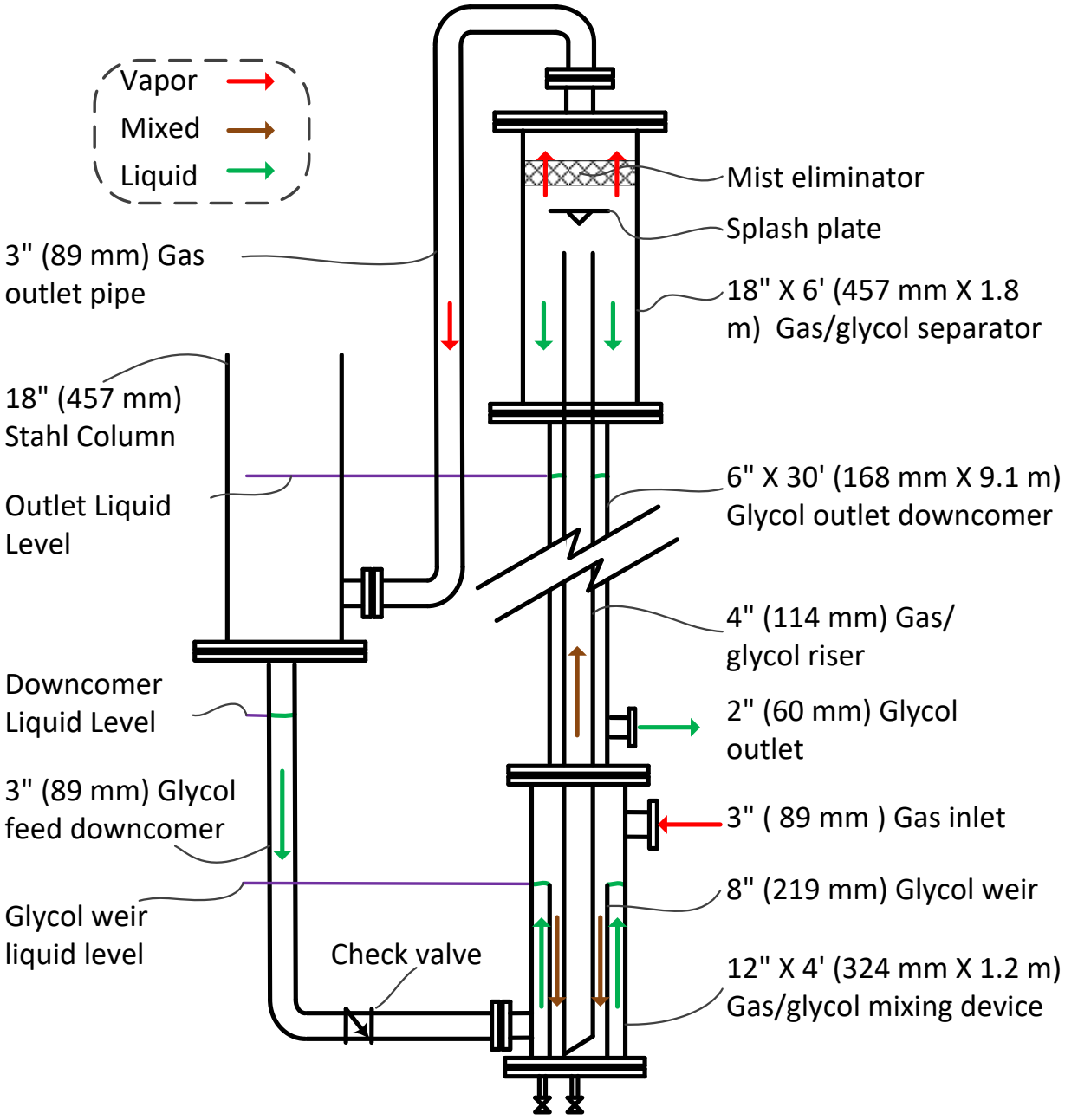

Figure 11 – Schematic of a Lifterator™ apparatus dimensioned based on Appendix simulation flows

This higher elevation results in higher pressure at the lean/rich exchanger since the lean lean/rich exchanger is at a lower elevation. A close approach, high heat transfer lean/rich exchanger can be installed, which would reduce the heat duty of the glycol dehydration unit by more than one third. The higher heat transfer creates hotter rich glycol as it enters the still/stahl column. This hotter rich glycol boils off more water than would occur with ordinary lean/rich exchangers which further improves water removal from the still/stahl column. Thus, the Lifterator™ improves lean glycol dryness both directly and indirectly.

The lean/rich heat exchanger will pinch on the cold side and with close approach heat exchange the glycol will exit at just a few degrees hotter than the process gas. The surge tank need not be insulated and there is no need for a lean glycol cool or gas/glycol exchanger. The lean/rich exchanger has already accomplished that objective.

Operation of the Lifterator™

Figure 10 shows the Lifterator™ and identifies various elements to assist in understanding its operation. The stripping gas provides the pneumatic energy needed to power this apparatus. The stripping gas is preferably preheated and enters into the top portion of the gas/glycol mixing device.

Glycol exits from the bottom portion of the polishing stahl column flows through the glycol feed downcomer into the bottom section of the gas/glycol mixing device. Within the glycol mixing device, the glycol falls over a weir towards the bottom of the gas/glycol mixing device.

The two fluids mix near the bottom of the gas/glycol mixing device. The mixed vapor/liquid density is less than the liquid glycol density and the mixed fluid is gas lifted through the gas/glycol riser into the gas/glycol separator which acts as a diffuser. The velocity in the gas/glycol riser should often be greater than about 15 fps (4.6 m/s) but be less than flows that would create high friction pressure drop. Simulations should be utilized to assure that the gas/glycol riser is properly sized.

For this embodiment, this riser is a vertical pipe routed inside the glycol outlet downcomer. The vapor and liquid exit the top of the gas/glycol riser and separate within the separator with the vapor flowing through a mist eliminator exiting through the top of the gas/glycol separator. The stripping gas then flows through a pipe and into the bottom portion of the polishing stahl column. It then ascends the still/stahl column dehydrating the glycol.

The liquid glycol flows out through the bottom of the gas/glycol separator and then through the glycol outlet downcomer. The glycol then reaches the outlet liquid level. The space above the liquid level is vapor with liquid descending through it. The space below the outlet liquid level is liquid. It builds pressure as it descends and exits the Lifterator™. The glycol then flows to the lean/rich exchanger and other downstream equipment the needed pressure.

The outlet liquid level within this apparatus will self-adjust as needed to supply the pressure to downstream equipment. Two other levels are of interest. The glycol liquid level creates a seal to stop stripping gas from back flowing up the glycol feed downcomer. The last level is the downcomer liquid level which self-adjusts to supply the pressure energy to flow the glycol over

the weir with the Lifterator™. No instrumentation or controls are needed for operation of this apparatus; it self-adjusts as needed.

A check valve is included to assist in starting this apparatus. Drain valves also afford operators a means of draining this apparatus to aid in startup as well as maintenance.

The Lifterator™ would also be a candidate for using in any glycol dehydration unit that utilizes stripping gas, including pipeline dehydration applications.

Indirect heating is strongly preferred to direct fired heating

Low water concentration in the feed to the reboiler makes using a direct fired a problematic choice for reboiling glycol. The glycol feeding the reboiler has an estimated water content of only about 1.2% by weight. Simulations indicate that a side reboiler configuration will result in no boiling at all within the reboiler. The water content of the glycol feeding the glycol reheater is estimated to be only about 0.015% by weight; it will not boil.

Clearly, with limited or no boiling, the fire tubes of direct fired heaters could reach excessive skin temperatures which could rapidly decompose glycol.

Conclusions

1. Glycol can be regenerated sufficiently to dehydrate process gas such that it meets cryogenic dehydration specs
2. The Stahl Column Sizing Chart can be used to assist in selecting the design of stahl column height and stripping gas rates especially for cryogenic dehydration applications
3. Customized Stahl Column Sizing Charts can be readily built using commercially available process simulators
4. Lean glycol with 10 ppmw is considered to be cryogenic spec glycol. That much water can be tolerated and would allow for the glycol to dehydrate process gas to meet cryogenic dehydration specs for common process gas temperatures and pressures.
5. Water contamination of stripping gas can imposes a limit on how much drying can be achieved with stripping gas
6. On-spec process gas is always dry enough to be used as stripping gas
7. Installing two stahl columns in series with a glycol reheater between them can enhance the stripping of water from glycol
8. Flash gas introduced between the stahl columns improves performance because it acts as a supplemental stripping gas
9. Installing a Lifterator™ on the glycol stream downstream of the stahl column improves performance of the system

References

1. Curtis O. Rueter, Kevin S. Fisher, Patrick A. Thompson, Duane B. Meyers, "R-BTEX™ Prototype Performance Testing Results," Report No. GRI-94/0430, Gas Research Institute, Austin, August 1994
2. Jensen, Daryl R, et.al., "Designing Molecular Sieve Dehydration Units to Prevent Upsets in Downstream NGL/LPG Recovery Plants", Laurance Reid Gas Conditioning Conference Norman, OK, 2012
3. Campbell, John M., "Design and Choice of Equipment for Gas Dehydration", Gas Conditioning Conference, Norman, OK, 1952
4. *Engineering Data Book FPS Version*, Tulsa, Gas Processors Suppliers Association, fourteenth edition, Tulsa, 2016
5. Worley, Steve, "Twenty Years of Progress with TEG Dehydration", Canadian Natural Gas Processors Association, Calgary, Alberta, Canada, December 3, 1966
6. Worley, Steve, Super-Dehydration with Glycols, Gas Conditioning Conference, Norman, OK, 1967
7. John Campbell, et. al., *Gas Conditioning and Processing*, 8th edition Volume 2, John M. Campbell & Company, Norman, OK ,2004
8. Smith, Robert S., "Enhancements of Drizo Gas Dehydration," Laurance Reid Gas Conditioning Conference, Norman, OK, 1997
9. https://www.axens.net/product/process-licensing/20122/drizo.html
10. Smith, Robert S. and Humphrey, "High Purity Glycol Design and Operating Parameters," Laurance Reid Gas Conditioning Conference, Norman, OK, 1994
11. Szuts, A., et al, "Drizo Unit competes with Solid Bed Desiccant Dehydration", Laurance Reid Gas Conditioning Conference, Norman, OK, 2002
12. Hoogwater, Sjoerd, "TEG Dehydration Systems for Very Low Dew Points", Laurance Reid Gas Conditioning Conference, Norman, OK ,2017
13. Rueter, Curtis and Beitler, Carrie, Design and Operation of Glycol Dehydrators and Condensers, Laurance Reid Gas Conditioning Conference, Norman, OK 1997

Appendix
Simulations for Two Designs
"All Performance Enhancements" Compared to "Stahl Column Only"

Line	Case	FPS			SI		
		Units	All Enhancements	Stahl Only	Units	All Enhancements	Stahl Only
1	Stahl Column Equilibrium Stages		21	21		21	21
2	Wet Process Gas						
3	Flow	MMSCFD	200	200	$Sm^3 \times 10^3$	5,671	5,671
4	Temperature	deg F	100	100	deg C	38	38
5	Pressure	psia	815	815	Bara	56.2	56.2
6	Water Content	pct vol	0.14	0.14	pct vol	0.14	0.14
7	Water Content	ppmv	1,402	1,402	ppmv	1,402	1,402
8	Water Content	lb/MMSCF	66.5	66.5	$kg/Sm^3 x10^6$	533	533
9	**Dry Gas Water Content**	**ppbv**	**13**	**386**	**ppbv**	**13**	**386**
10	Lean TEG						
11	Circulation Rate	gpm	27.5	27.5	Sm^3/d	150.1	150.1
12	Circulation Ratio	lb/lb	28.0	28.0	kg/kg	28.0	28.0
13	Circulation Ratio	gal/lb	3.0	3.0	l/kg	24.8	24.8
14	**Water Content**	**ppmw**	**1.0**	**53**	**ppmw**	**1.0**	**53**
15	Still/Stahl Column						
16	Overhead Pressure	psia	17	17	Bara	1.17	1.17
17	Bottoms Pressure	psia	19	19	Bara	1.31	1.31
18	Reboiler Temperature	deg F	400	400	deg C	204	204
19	Stripping Gas						
20	Process Gas Flow	MCFD	177	177	$Sm^3 \times 10^3$	5.05	5.05
21	Process Gas Ratio	SCF/gal	4.5	4.5	sm^3/sm^3	33.4	33.4
22	Flash Gas Rate	MCFD	53	---	$Sm^3 \times 10^3$	1.49	---
23	Flash Gas Ratio	SCF/gal	1.3	---	sm^3/sm^3	9.9	---
24	Overall Ratio	SCF/gal	5.8	4.5	sm^3/sm^3	43.3	33.4
25	Duty						
26	Lean/Rich Exchanger	MBTU/hr	2,698	2,072	kW	791	607
27	Reboiler Exchanger	MBTU/hr	613	1,199	kW	180	351
28	Reheater Exchanger	MBTU/hr	152	NA	kW	45	---
29	Stripping Gas Exchanger	MBTU/hr	77	77	kW	22	22
30	Total Duty	MBTU/hr	3,539	3,348	kW	1,037	981
31	Heating Required	MBTU/hr	841	1,276	kW	247	374
32	Heat Recovered	PCT	76%	62%		76%	62%
33	Lean Glycol Cooling	MBTU/hr	---	440	kW	---	129

Two scenarios have been simulated with summary data included here. The first scenario includes all three performance enhancer technologies and the second scenario is the "stahl only" case. It includes the primary stahl column but omits the glycol reheater, omits the polishing stahl column, omits flash gas as stripping gas, and omits the Lifterator™.

The scenario with the enhancements was solved to meet a 1 ppmv spec for the lean glycol (a 10:1 process margin). The process gas reaches a dryness of 12 ppbv as compared to a 100 ppb spec. This required 177 MSCFD of stripping gas. For the same stripping gas "stahl only" option reaches a glycol water content of 54 ppmw water and the process gas reaches a dryness of only 386 ppbv. It takes 239 MSCFD of stripping gas to achieve that level of dryness, an increase of 35%.

Without the Lifterator™ the heat duty increases by 51% from 841 MBTU/hr (247 kW) to 1276 MBTU/hr (374 kW).