

DESIGN TIPS FOR DEHYDRATING CO₂ WITH GLYCOL (Revised)

*Laurance Reid Gas Conditioning Conference
February, 2022 – Norman, Oklahoma USA*

Paul A. Carmody
Director Product Development
OTSO Energy Solutions, LLC
7102 N. Sam Houston Pkwy W., Suite 100
Houston, TX 77064
Phone: (936) 827-0661
pcarmody@otsoenergy.com

ABSTRACT

Triethylene glycol (TEG) is used to dehydrate carbon dioxide gas. There are considerable differences between dehydrating carbon dioxide with TEG as compared to the much more common dehydration of natural gas with TEG. TEG is limited to dehydrating vapor phase carbon dioxide; it is unsuitable for dehydrating liquid phase or in the dense phase carbon dioxide. TEG can dehydrate carbon dioxide to meet stringent dehydration specifications; it is able to reliably achieve a -40° F (-40° C) dew point at about 600 psia (4140 kPaa).

The saturated water content of carbon dioxide in the vapor phase somewhat higher than methane but similar in that as pressure increases the saturated water decreases for a given temperature. But the liquid phase and dense phase saturated water content of carbon dioxide reverses as compared to natural gas. Once carbon dioxide condenses into a liquid phase it holds dramatically more water than it could in the vapor phase before it saturates with water. This the opposite of natural gas, which continues to contain less water as its pressure increases. Carbon dioxide's saturated water content behavior may result in the adoption of substantially less demanding dehydration specifications as compared to natural gas, at least for pipeline applications.

In order to mitigate corrosion, TEG dehydration equipment carbon dioxide will have more stainless steel requirements than needed for natural gas dehydration, although much of the equipment can be made of carbon steel.

Carbon Dioxide Water Content and Applicability of TEG Dehydration

The water absorption system's design intent is to remove enough water from the wet process gas to meet the downstream water specification. This spec is often stipulated in contracts, but it should

be set regardless in order to avoid hydrate formation and corrosion. Both methane and carbon dioxide can form hydrates. In the presence of liquid water, corrosion associated with carbon dioxide is much more aggressive than corrosion associated with methane. That is because, in the presence of liquid water, carbon dioxide forms carbonic acid which attacks carbon steel. Water in the vapor phase is completely noncorrosive so dehydration is an important tool available for carbon dioxide handling.

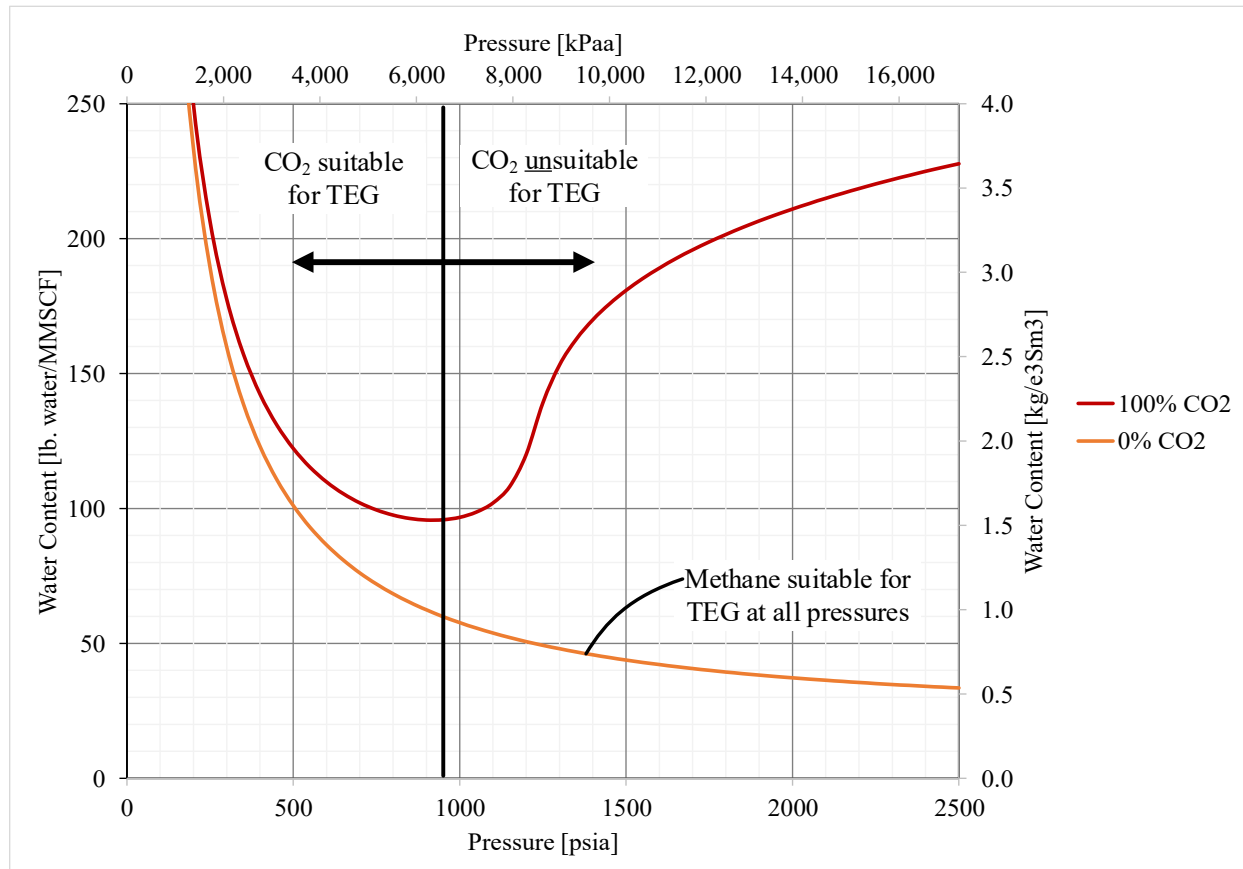


Figure 1 – Comparison of saturated water content of carbon dioxide and methane vs. pressure¹

Figure 1 shows a comparison of carbon dioxide and methane water content where each gas is at 100°F/37.8°C. Consider first the water content of methane. The water content reduces as the pressure rises. It is customary to dehydrate at the maximum system pressure. Most of the water will have been removed through separation prior to glycol dehydration, thereby reducing the water to be removed from the process gas with glycol. Also, higher pressure dehydration reduces the diameter of the contactor which often reduces costs.

¹ Process Program “Symmetry v2020.4 (Build 52)” with “APR for Natural Gas 2” thermo was utilized to derive the graph data

The water content for carbon dioxide is similar to that of methane at lower pressures but then diverges even to the point where large increases in water content can be contained without creating a liquid phase after the pressure reaches a certain level. For a 100°F (37.8°C) temperature, the water content decreases until it reaches about 950 psia (6550 kPaa) and then starts to increase dramatically.

At pressures below about 950 psia (6550 kPaa), the glycol is in the vapor phase; it will act as a gas. The water content at saturation will always be somewhat higher than for methane at the same temperature and pressure but it can be dehydrated with TEG in much the same fashion as methane.

At pressures above about 950 psia (6550 kPaa) TEG is not suitable for use as a desiccant. At higher pressures, the carbon dioxide density increases dramatically, reaching liquid specific gravity of 0.83 at a temperature of 100°F (37.8°C) and 2500 psia (17,200 kPaa). This density increase is associated with a massive increase in solubility of TEG into the carbon dioxide. TEG losses become excessive.

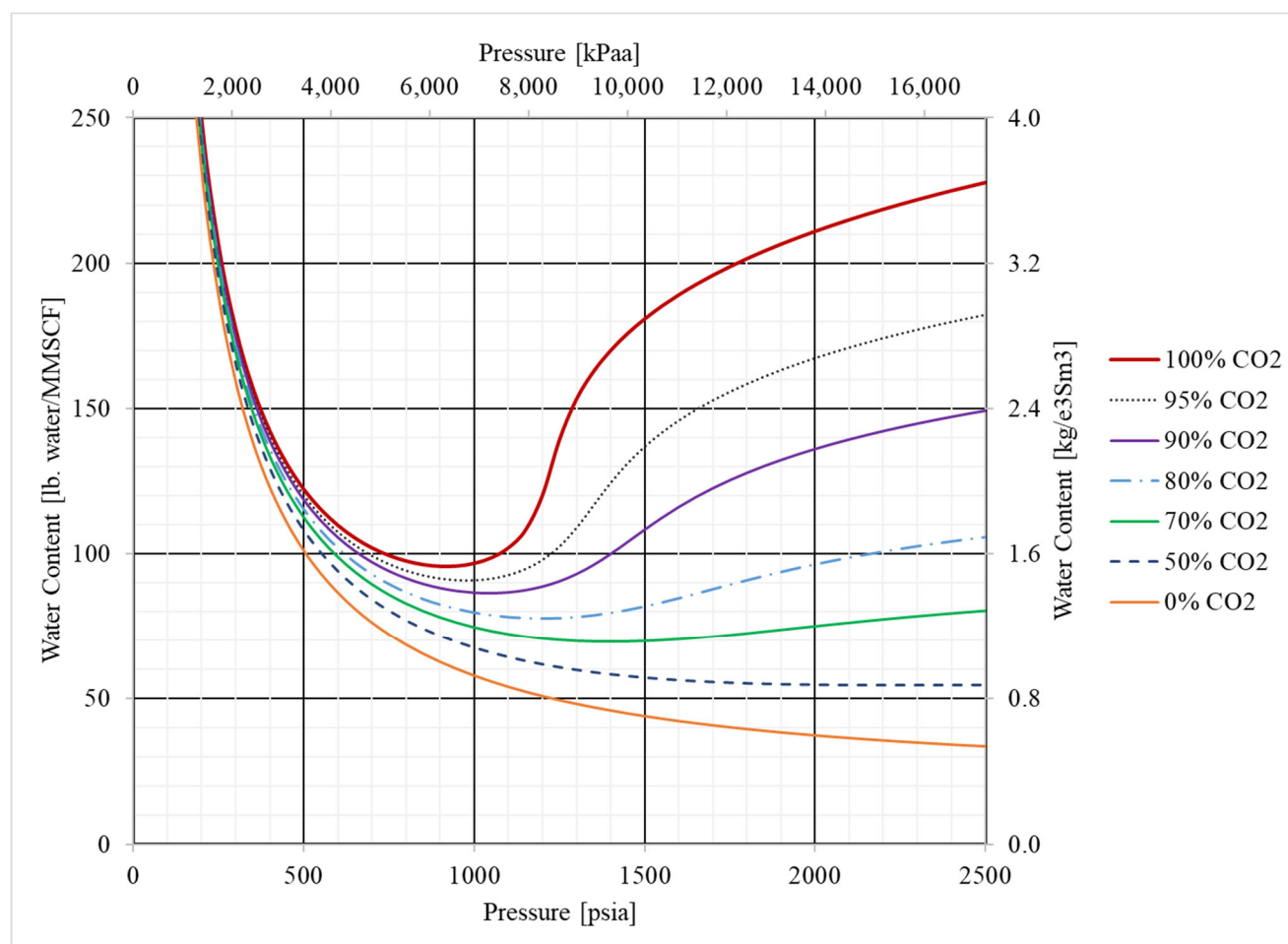


Figure 2 – Comparison of saturated water content of variable carbon dioxide and methane concentration vs. pressure¹

Figure 2 fills in the graph of figure 1 with the varying compositions of carbon dioxide and methane. This becomes evident from this graph, by the time about 30% of the stream is methane, it acts more like a methane stream than a carbon dioxide stream.

For CO₂ EOR (Enhanced Oil Recovery) floods, the carbon dioxide builds with time. It starts oftentimes with almost no carbon dioxide ultimately reaching levels greater than 90% carbon dioxide. TEG dehydration is able to handle the dehydration as the composition changes from almost no carbon dioxide to almost entirely carbon dioxide. The key element is to recognize upon initial design, that the dehydration pressure must be able to dehydrate the maximum carbon dioxide percentage. At low carbon dioxide concentrations, the system will work satisfactorily and will not need to be replaced as the carbon dioxide levels increase.

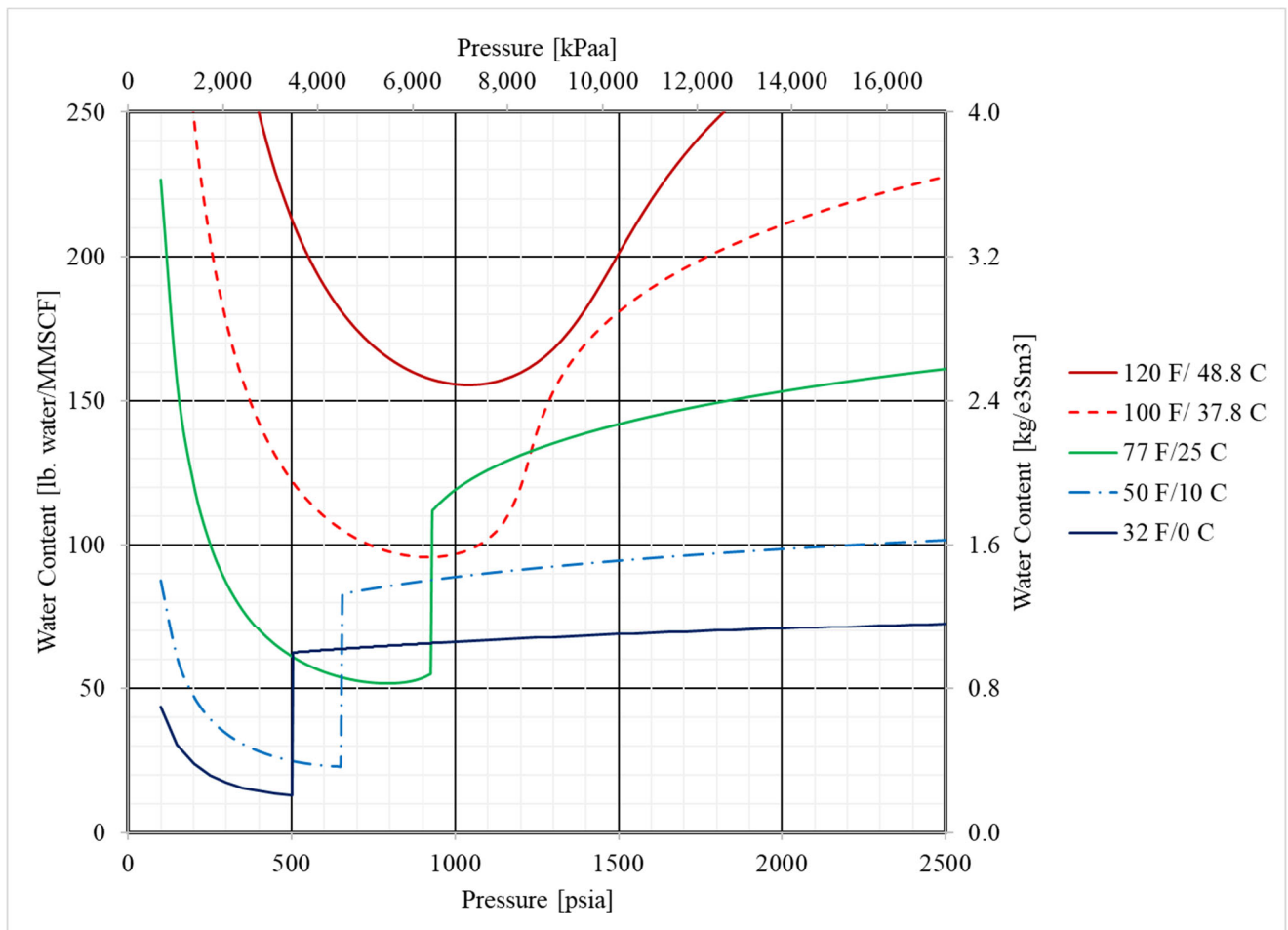


Figure 3 – Comparison of saturated water content carbon dioxide vs. pressure at various temperatures¹

Figure 3 shows a graph of pressure versus water content for multiple temperatures ranging from 32°F (0°C) to 120°F (48.9°C). Each of these curves shows that the water saturation reaches a

minimum and then increases dramatically. At temperatures less than the critical temperature (87.9°F/31.0°C) there is a discontinuity with a sudden jump in the saturated water content. The water saturation discontinuities are associated with carbon dioxide entering the vapor-liquid phase envelope. Thus, at a single pressure pure carbon dioxide can have both a vapor and liquid phase associated with it. The vapor phase has a relatively low saturation water content in and the liquid phase it will have a much higher water saturation content. This makes the graph rather untidy to examine, but it reflects the physical properties of carbon dioxide. Once the carbon dioxide temperature exceeds the critical temperature the curves are no longer discontinuous but smoothly change as pressure changes as there is a single dense phase.

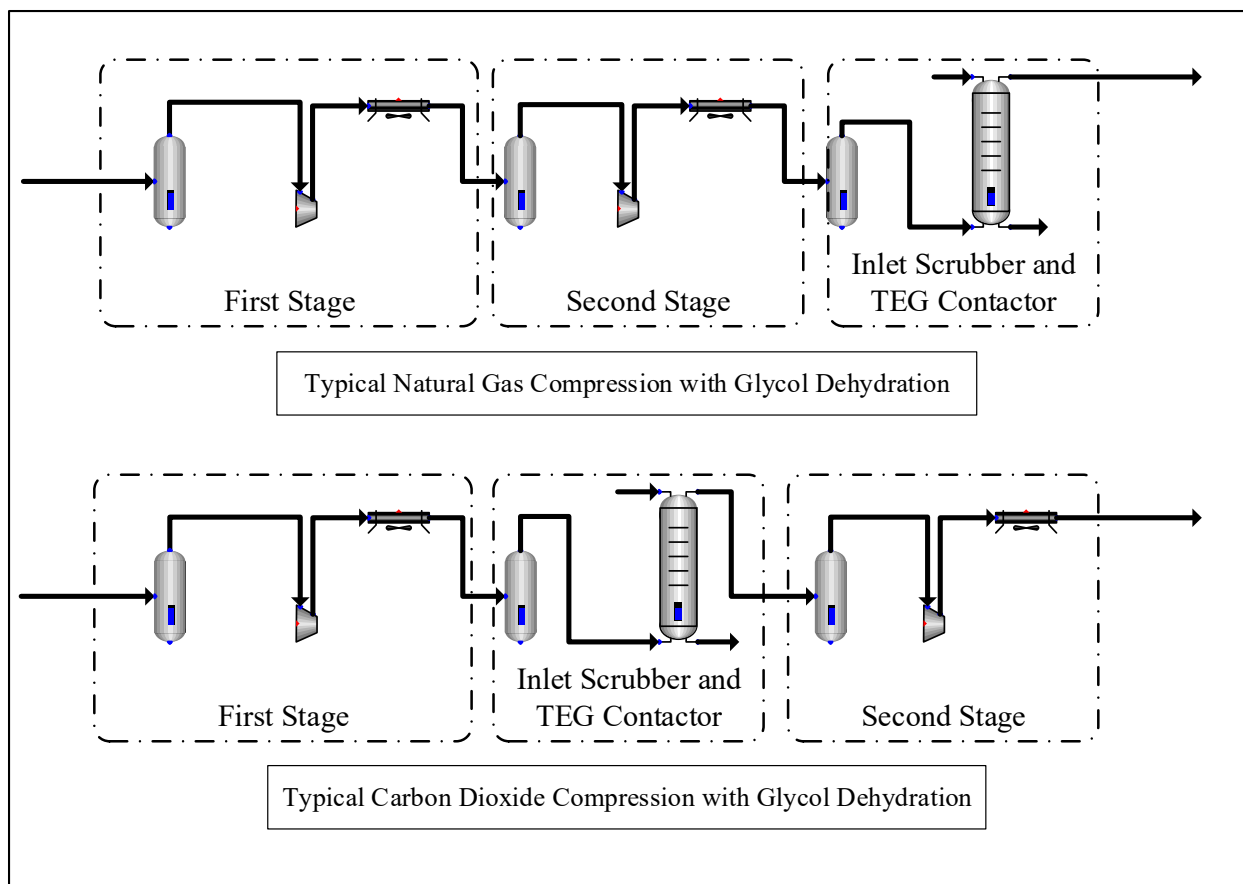


Figure 4 – Typical arrangement of dehydration for natural gas and carbon dioxide compression and dehydration

Figure 4 shows first a comparison of how natural gas and carbon dioxide are dehydrated with TEG. For natural gas, it is a customary to compress the gas followed by dehydration downstream of the last stage of compression. Two stages of compression are shown; however, it is common to have additional stages of compression.

Carbon dioxide compression frequently involves compression (often multiple stages) followed by dehydration followed which is then by a last stage of compression. That last stage of compression takes the carbon dioxide process gas from a vaporous subcritical pressure up to a supercritical

pressure. The hot carbon dioxide is then converted into a dense phase fluid through the use of the aftercooler for the last stage.

Since dense phase dehydration is not feasible with TEG, and it is often desirable to use TEG, installing the dehydration at an interstage of compression becomes the logical choice. From a removal of water standpoint, the best place to perform dehydration is as high as possible but below the pressure at which the carbon dioxide condenses. In practice, the optimal place for dehydration from a pressure standpoint is determined in part by the requirements of compressor design.

Liquid carbon dioxide must not enter either a glycol contactor or a compressor cylinder. Since both compressors and glycol dehydration require gas phase carbon dioxide, the design point for dehydration is often located just upstream of the last stage of compression. It is well understood how to design compression to avoid liquid dropout for carbon dioxide applications. These design techniques also work to assure that a proper application for TEG dehydration will be acceptable.

Of course, sometimes TEG dehydration is not associated with compression. One common example is for the carbon dioxide rich stream from a CO₂ EOR flood. For this application, the gas temperature might be close to the ground temperature. The requirement to separate oil and water from the carbon dioxide rich gas assures that the carbon dioxide will be a vapor state prior to TEG dehydration.

Dehydration Specifications

The amount of water contained within carbon dioxide results in a different set of specifications as compared to natural gas for many applications. Three different types of applications are considered.

Injection into wells

This is a special case where carbon dioxide oftentimes mixed with hydrogen sulfide is injected in a nearby well. This case is applicable for gas plants that have amine units. Re-injecting the acid gas from the amine vent allows for the elimination of a sulfur recovery unit at plants with hydrogen sulfide. Requirements to sequester carbon dioxide may lead to new injection requirements for plants that have amine units that remove only carbon dioxide. Currently, there appear to be no regulations requiring such reinjection in the United States although there is a carbon dioxide injection program for the Sleipner field,² offshore Norway. Hydrogen sulfide has a similar curve shape as carbon dioxide with the lowest water saturation occurring just before the hydrogen sulfide condenses.

If an injection well is available nearby, the injected acid gas is sometimes not dehydrated beyond what is accomplished with separators. Separation of water at the last stage of suction for the

² Many sources of data are available: search Google using term "Sleipner CO₂ Storage Project." Example: <https://www.equinor.com/en/news/2019-06-12-sleipner-co2-storage-data.html>

compression has proven sufficient at removing water. The gas is not cooled very much (or at all) after the last stage of compression and the hot gas is moved down the wellbore and into a formation with no further dehydration required. The special circumstance relies on being able to control the temperature of the gas. This is a niche application.

Pipelines

Pipeline dehydration is the level dehydration needed to distribute carbon dioxide through pipelines that are long enough that the carbon dioxide temperature within the pipe approaches the temperature of the ground. For such applications, enough water needs to be removed to assure that no liquid water or hydrates form in the pipeline.

Common pipeline specifications for natural gas for this application are often 7 lbm water/MMSCF ($117 \text{ kg}/10^6 \text{ stdm}^3$) or sometimes 4 lbm water/MMSCF ($66.9 \text{ kg}/10^6 \text{ stdm}^3$) for pipeline situated in colder climates. For carbon dioxide, much more water can be allowed to remain in the gas. Specifications of 25 to 30 lbm water/MMSCF of CO_2 (418 to $501 \text{ kg}/10^6 \text{ stdm}^3$) have been included in commercial carbon dioxide pipeline contracts. Many of the original contracts were executed in the 1970s and 1980s. Our understanding of water content in carbon dioxide has advanced since that time and even higher water content may be permissible, perhaps as high as 40 lbm water/MMSCF ($669 \text{ kg}/10^6 \text{ stdm}^3$).

These water content specifications are readily achievable with TEG units that are similar in design to ordinary TEG units in natural gas service. Some TEG units originally built to meet natural gas dehydration requirements have been modified and placed into carbon dioxide dehydration service.

Process

Process dehydration requires dehydrating carbon dioxide to meet lower dew points associated with plant processes. While there are a number of different applications for processing carbon dioxide rich gas, the Ryan-Holmes process is the most demanding process currently in commercial operation.

The Ryan-Holmes process is a process utilized to recover hydrocarbons from CO_2 EOR floods. While not reaching truly cryogenic temperatures, this process does require reaching a -40° F (-40° C) process temperature at about 600 psi (4140 kPaa). A Permian Basin processing plant has utilized glycol dehydration in this application since 1984. This is an exceptionally low dewpoint to achieve with glycol dehydration. This shows unequivocally that TEG dehydration of carbon dioxide can reach the very driest of conditions currently achieved utilizing TEG. To achieve this level of dehydration the lean glycol is regenerated to approximately 100 ppmw of water and the carbon dioxide rich gas is dehydrated to approximately 10 ppmv. The DRIZO® process is used to generate the stripping gas for this application.

Circulation Rates: in order to achieve dehydration, the glycol circulation rate is calculated in just the same manner as for natural gas. Determine the amount of water to be removed and then use a suitable multiplier to achieve the desired circulation rate. For pipeline specifications a circulation

ratio of about 20 mass of glycol/mass of water removed is often appropriate (2.1 lbm TEG/lbm water; 17.8 L TEG/kg water). For process specifications a circulation ratio of about 28 mass of glycol/mass of water removed is often appropriate (3.0 lbm TEG/lbm water; 25.0 L TEG/kg water).

Carbon Dioxide Absorption into TEG

Viscosity

The interaction between natural gas and TEG is limited for most constituents (BTEX is an exception). Interaction between carbon dioxide and glycol is substantial. As noted above, dense phase and liquid carbon dioxide is unsuitable for dehydration with glycol because of solubility problems. Carbon dioxide in the vapor phase is suitable but an understanding of the interactions with TEG is important. The TEG will absorb a substantial portion of carbon dioxide. The carbon dioxide causes a substantial reduction in the viscosity of the TEG.

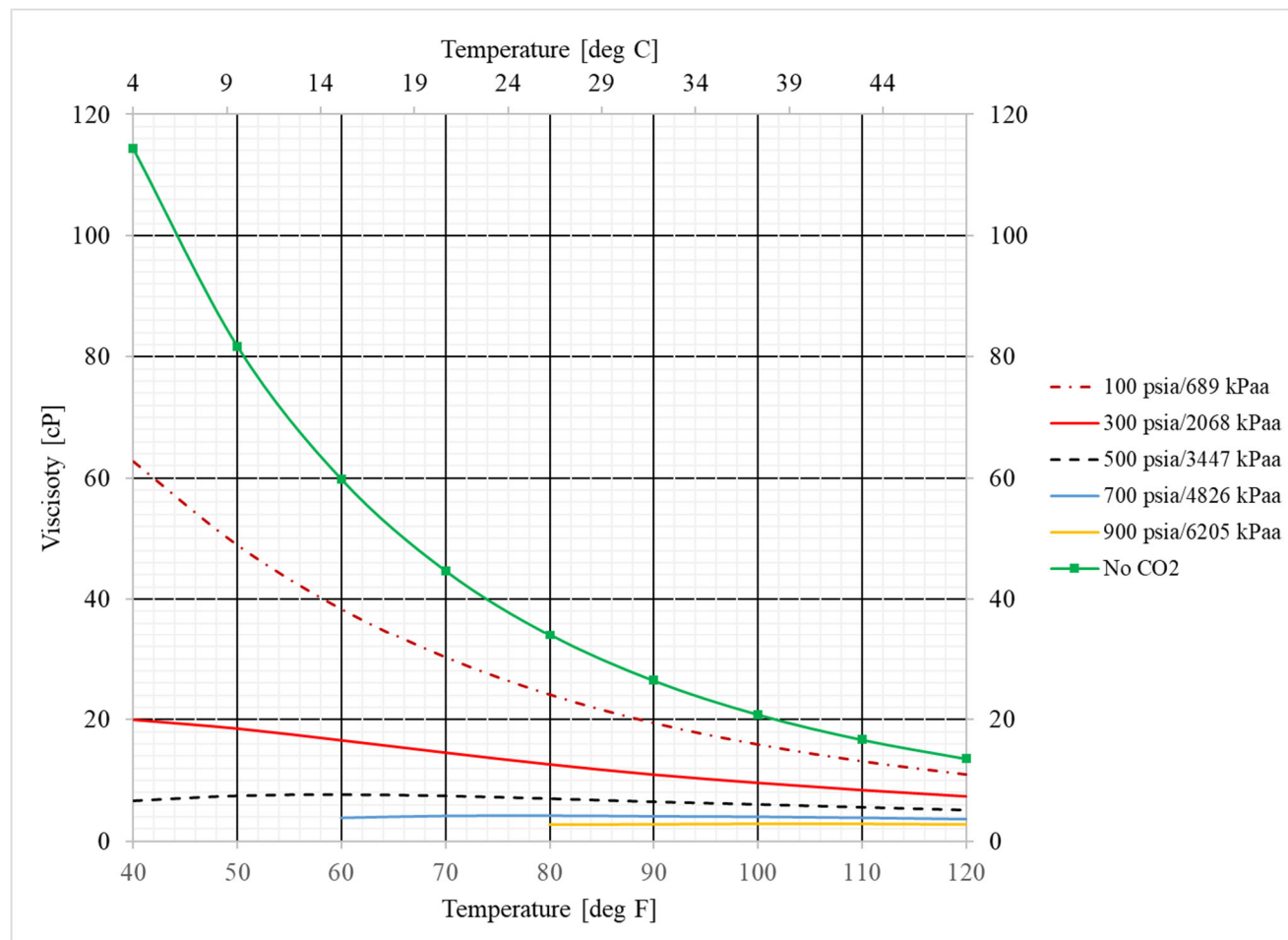


Figure 5 – Viscosity of TEG vs. Temperature for pure TEG and for TEG in CO₂ service¹

Figure 5 shows a graph of viscosity versus temperature at various pressures. The highest viscosity is a reference viscosity for pure glycol with no carbon dioxide in it. The remaining data series

show the viscosity of the glycol versus temperature at various operating pressures. Before discussing these characteristics, note that this graph uses temperature rather than pressure on the X-axis. This change of axis was done in order to emphasize how the glycol performs at various pressures of operation.

For the pure TEG reference viscosity at a temperature of 100°F (37.8°C) (a common temperature), the lean glycol has a viscosity of about 20 centipoise. This climbs rapidly to around 118 centipoise at 40°F (4.4°C). This contrasts with glycol in carbon dioxide dehydration service. At 100 psia (689 kPaa), the TEG viscosity drops to about 62 centipoise at 40° F (4.4°C) which reduces as the temperature increases. Once psia (2070 kPaa) operating pressure is utilized, the viscosity at 40° F (4.4°C) is 20 centipoise, the same as glycol for typical natural gas dehydration applications.

At still higher pressures, the viscosity drops to an even lower and for a given pressure is nearly constant over a temperature range from 40°F (4.4°C) to 120°F (48.9°C). Even better, at pressures of 500 psia (3450 kPaa) or greater, the viscosity is always less than 10 centipoise. Please note that the 700 psia (4830 kPaa) and 900 psia (6210 kPaa) lines do not extend over the full range. The carbon dioxide condensation temperatures are reached over a portion of the temperature range.

The benefits of lower temperature dehydration with low viscosity TEG are substantial. First of all, the amount of water contained within the wet gas is much less due to the lower temperature with resultant reduction in circulation rate and duty of the TEG unit. The amount of glycol remaining in the vapor phase of the dehydrated carbon dioxide would be much reduced. This would reduce losses of glycol which in turn reduces the amount of glycol that would make its way into downstream equipment.

Suppose a CO₂ EOR flood operates at 300 psia (2070 kPaa) and for this particular flood the entire stream of gas is compressed dehydrated and reinjected to maintain the flood. It might prove preferable to dehydrate this stream prior to the first stage of compression. The amount of water in the gas may not be much different than it would be at an interstage where the temperatures are higher. Moreover, dehydrating at the inlet to a facility renders all of that facility's equipment noncorrosive. Sizable cost savings that be possible through greater use of carbon steel rather than stainless steel.

Carbon dioxide absorption into TEG/Flash gas desorbing from TEG

The carbon dioxide that has been absorbed into TEG can be shown in terms of flash gas. This is the information presented on Figure 6. Essentially all of the carbon dioxide absorbed into the TEG will flash off during regeneration. The majority occurs due to the de-pressuring of the TEG. Heat added for regeneration flashes the rest of the carbon dioxide from the TEG.

The large absorption of carbon dioxide is in stark contrast to the very limited absorption of methane into TEG. For pure methane, the amount of methane absorption would be only 3% to 9% of the amount of carbon dioxide absorption at the same temperature and pressure.

Temperatures of flashed rich glycol will drop due to the substantial amount of carbon dioxide flashing. This contrasts with methane dehydration, where temperatures may actually increase as glycol drops in pressure.

For a mixture of carbon dioxide and methane, the amount of carbon dioxide absorption is approximately in proportion to the percentage of carbon dioxide in the total vapor stream.

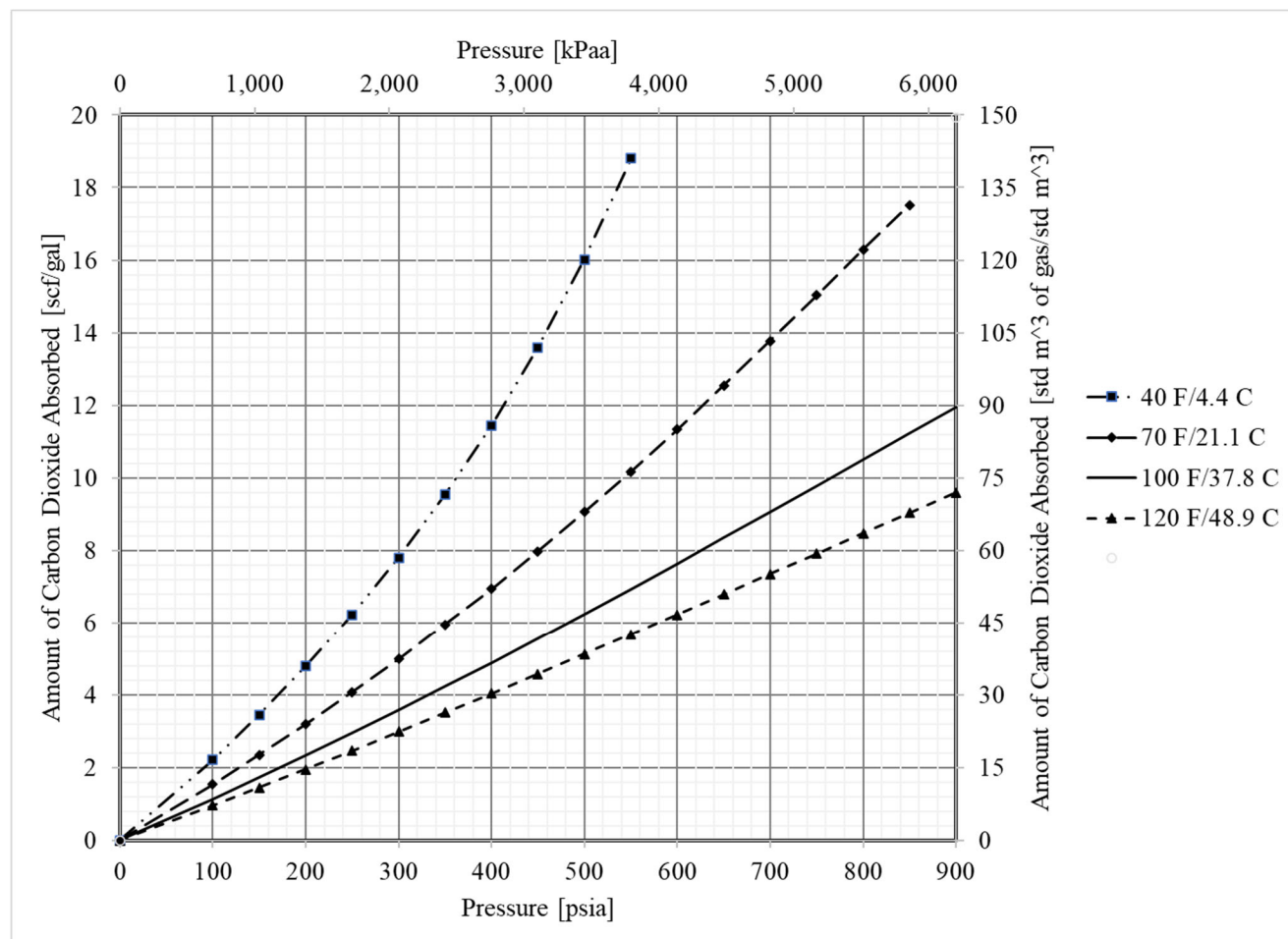


Figure 6 – CO₂ absorbed into TEG vs. Pressure at varying temperatures¹

Material Selection

Materials selection comes down to a choice generally between utilizing carbon steel or stainless steel for the various pieces of equipment utilized for glycol dehydration. Chemicals are not suitable for corrosion control due to the likelihood of the chemicals contaminating the glycol. Internal coatings generally have a short life at the pressures encountered within the inlet scrubber or contactor and thus are discouraged.

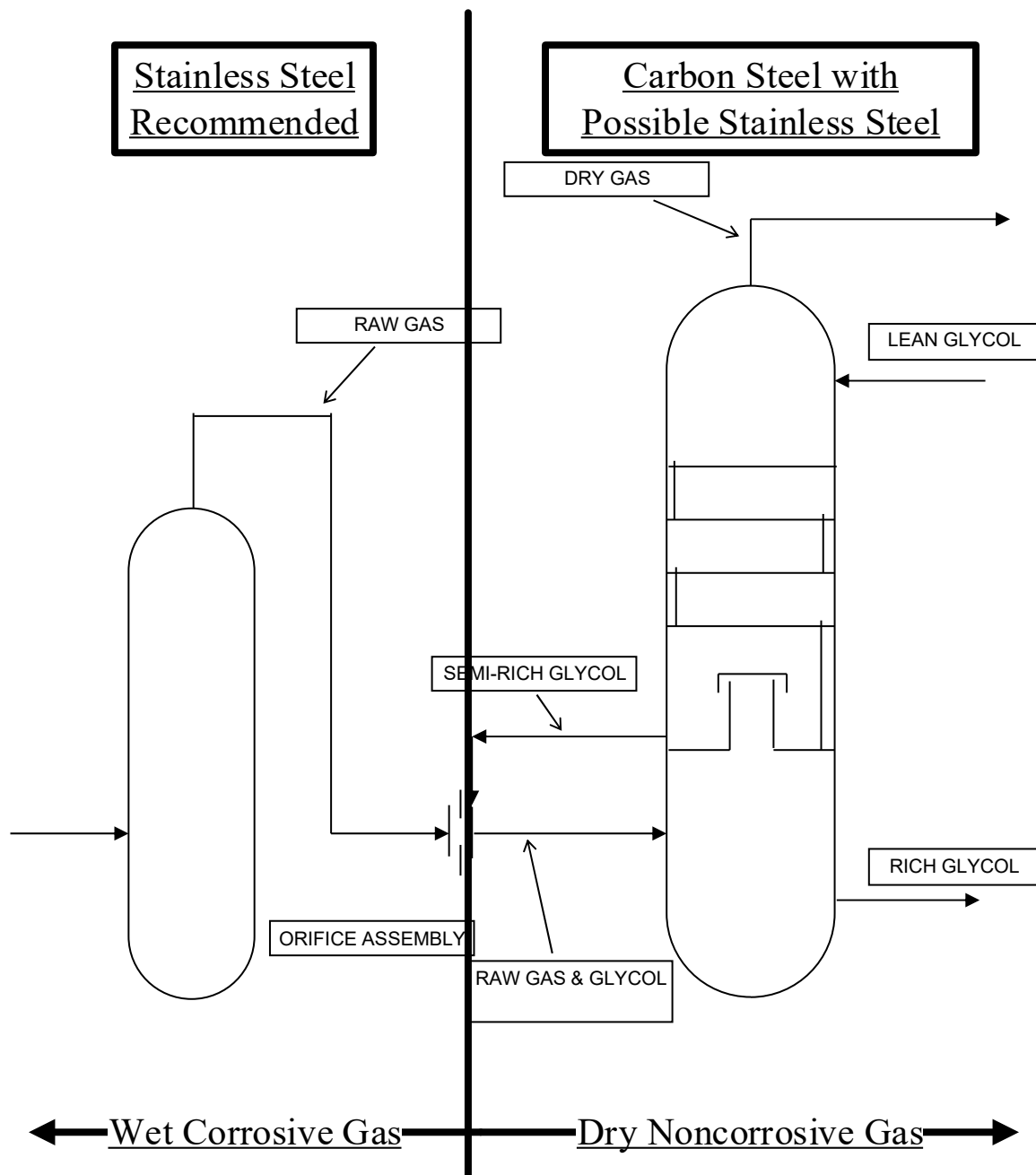


Figure 7 – Inlet scrubber, pre-contactor to dehydrate gas which then feeds into to the glycol contactor

When glycol dehydration technology was pioneered in the 1980s for carbon dioxide service, the tendency was to utilize stainless steel almost everywhere in the system. For instance, entire contactors and even discharge scrubbers would be constructed of stainless steel. For the glycol regeneration system, some of the excessive use of stainless steel involved utilizing stainless steel for all of the lean glycol equipment such as the surge vessel and lean glycol cooler.

Since that time, more carbon steel has been utilized for dehydration. It is possible to take advantage of two facts:

- Carbon dioxide that is undersaturated with water is noncorrosive
- Glycol inhibits corrosion of water and carbon dioxide up to about 10% water by weight

The carbon dioxide on the left side of Figure 7 is saturated with water, in fact some liquid water would often be present. This is a corrosive service so the inlet scrubber along with associated piping and valves should be constructed of stainless steel. For ordinary contactors, the vapor entering the contactor would be saturated with water and thus some portion of the contactor might be subject to corrosion from the vapor.

The right side of Figure 7 shows a pre-contact section upstream of the contactor. Semi-rich glycol is withdrawn from the contactor and mixes with the carbon dioxide vapor. This dehydrates the gas prior to it entering the contactor.³ From that point on, the process gas is no longer corrosive. This configuration is also helpful in that a nearly full equilibrium stage of contact may be achieved thereby allowing for a shorter contact section within the contactor itself for a given level of dehydration.

But the water that was in the vapor phase has now entered the glycol. Does the glycol become corrosive? Some research indicates that such glycol is noncorrosive at water concentrations encountered in glycol dehydration systems.⁴ This author has been involved with the installation of three contactors constructed entirely of carbon steel in carbon dioxide service (>85% CO₂) which have not experienced significant corrosion. Overall, industry experience is limited and literature on this subject is sparse. Since about 80% of the water is captured into the glycol at that first external contact, even a conservative approach would not demand that the packed or trayed section of the contactor be constructed of stainless steel. Instead, at most, the bottom portion of the contactor would need to be protected.

Dehydrated process gas is no longer corrosive. Consequently, all equipment downstream of the contactor may be constructed of carbon steel. In particular, a discharge scrubber may be constructed of carbon steel.

³ Paul A. Carmody, Glycol Pre-dehydration of Gas Before a Contactor, Laurance Reid Gas Conditioning Conference, 2000. This paper provides a more complete assessment of drying gas upstream of a contactor. This was for a high carbon dioxide gas that included hydrogen sulfide.

⁴ A.M. Sherk, A.L. Lewis, A.H. Rasheed, and A.A. Jabran, Effect of Triethylene Glycol on Corrosion of Carbon Steel in H₂S, CO₂, and O₂ Environments, NACE International Corrosion 2010 Conference and Expo, San Antonio, 2010, Paper 10188

Figure 8 shows an embodiment of a glycol regeneration system. An examination of this figure will show that most of the equipment may be constructed of carbon steel. The only stainless steel vessels are the still and the portions of the lean/rich exchanger in contact with rich glycol. All pipe to and from the still should be stainless steel. This includes the pipe to and from the condenser, the pipe from the lean/rich exchanger, and the pipe taking the overhead vapors to downstream equipment.

The diagram illustrates a TEG dehydration system. The process begins with 'From Contactor' entering a 'Flash Gas Separator'. The 'Rich TEG' (CS) flows from the separator through a pump (SP2) and a valve (TA016) into a 'Lean/Rich Exchanger' (Stainless Steel, Rich Side). The 'Lean TEG' (CS) then flows through a 'Surge Vessel' (CS) and a pump (CS) to a 'Lean Glycol Cooler' (CS), which then leads 'To Contactor'. The 'Rich TEG' (CS) also flows through a valve (TV, CS) into a 'Still' (Stainless Steel). The 'Still' has a 'Vent Gas' (Stainless Steel) outlet leading to a 'Vent Outlet'. The 'Rich TEG' (CS) flows from the 'Still' through a 'Reboiler' (CS) and a 'Stripping Gas' (CS) column. The 'Lean TEG' (CS) flows from the 'Reboiler' through a 'Stahl Column' (CS) and a 'Stripping Gas' (CS) column. The 'Stripping Gas' (CS) then flows through a 'PV' (CS) valve back to the 'Flash Gas Separator'.

The design choice of installing a flash separator upstream of the lean rich exchanger is highly favorable for carbon dioxide dehydration. That is because the vapors from a cool flash separator

can be utilized as stripping gas. This stream is ample for stripping for most carbon dioxide dehydration applications. Since such separators frequently operate at relatively low pressures, there is a good chance that around 90% of the carbon dioxide has flashed into the vapor phase. It is reasonable then to utilize carbon steel for a flash separator. The fact that the rich glycol has dropped in temperature also serves to reduce any potential corrosion. Since the flash gas separator may be constructed of carbon steel, the flash gas separator may also be constructed of carbon steel.

If the flash separator is located downstream of the lean rich exchanger, its operating temperature would be much hotter but this would serve to remove a about two thirds of the remaining carbon dioxide. At this elevated temperature, carbon dioxide corrosion may be particularly aggressive which would suggest utilization of stainless steel instead.

The piping downstream of the lean rich exchanger that feeds into the still should be made of stainless steel as should the still itself. The overhead of the still typically runs around 200°F (93.3°C) which is a highly corrosive temperature for carbon dioxide. Unlike other portions of the system, the top of the still has almost no glycol but it does have liquid water present. Stills tend to be relatively inexpensive since stills operate at near-atmospheric pressure and have a smaller diameter than the contactor. Thus, the cost of the still is not a large portion of the glycol regeneration unit. It cannot reasonably be argued that one should use carbon steel.

Carbon Steel Reboiler

The main reason the reboiler may utilize carbon steel is that there is virtually no carbon dioxide remaining in the liquid glycol that enters the reboiler. The low pressure of the still and reboiler and high temperature of glycol exiting the lean rich exchanger (typically 250°F/121°C) or higher) drive the carbon dioxide out of the liquid phase before it ever reaches the reboiler. Simulation results indicate that 99.6%+ of the carbon dioxide has flashed from the glycol before it reaches the reboiler.

There is also a metallurgical reason that the reboiler can be constructed with carbon steel. The reboiler runs it a temperature of around 400° F. Research has shown that at that temperature carbon steel forms a protective scale that will resist corrosion from carbon dioxide and water.⁵This is nonintuitive, but nonetheless carbon steel is a suitable choice for the reboiler as well as for the fire tube or other heat exchange equipment.

⁵ Jeffrey C. Arnoldi, et. al. Selection of Materials for Sour Gas Processing, Gas Conditioning Conference, Norman, OK. 1987, pg. A2-A17, Figure 1 shows a graph with corrosion v. temperature. Corrosion reaches a maximum at about 200°F and declines rapidly.

T Tanupabrunsun, et. al., Effect of pH on CO₂ Corrosion of Mild Steel at Elevated Temperatures, NACE International Corrosion 2013 Conference and Expo, Orlando, FL, 2013, Paper 2348. This paper shows the reason that corrosion rates decline at higher temperatures. A protective scale forms.

The vapor space in the reboiler is filled principally with water vapor but the high temperature assures that no water can condense. In fact, the vapor phase would typically be around 150°F (65.6°C) above the dew point for water.

Even if a stahl column is installed and the stripping gas from that stahl column is flowed through the reboiler, there is no feasible scenario for liquid water to condense from that vapor stream, provided that the reboiler is insulated. As for the stahl column itself, no corrosion should occur. There is very little water remaining in the lean glycol. If stripping gas consists of carbon dioxide, it will modestly increase the amount of carbon dioxide in the lean glycol but this is at a very low concentration and is not prone to cause corrosion. In addition, the stahl column will operate at a temperature very close to the noncorrosive reboiler temperature. Thus, even if liquid water were present, no corrosion would be anticipated due to their passivation associated with this high temperature stripping.

All equipment downstream of the reboiler may be constructed with carbon steel. Obviously, the lean/rich exchanger is a special case wherein all parts wetted with rich glycol should be constructed with stainless steel.

The surge vessel whether upstream or downstream of the lean/rich exchanger are in a noncorrosive service. The same is true for the circulating pump and the lean glycol cooler. If, instead of the lean glycol cooler a gas/glycol cooler is installed, that too is a noncorrosive service on both the gas and glycol sides of the exchanger.

Converting Natural Gas TEG Units to Carbon Dioxide Dehydration

Can existing glycol dehydration units be converted to carbon dioxide dehydration? The answer is yes. In addition to reviewing and changing some materials, it is usually necessary to derate the equipment (including derating separators, control valves, and relief valves) of a glycol unit that is to be converted to carbon dioxide dehydration from natural gas dehydration. While dehydration is possible in the vapor phase, carbon dioxide is much denser than methane. Typically, the density will be about three times that of methane at the same temperature and pressure. While that density difference may be smaller for rich hydrocarbon streams, carbon dioxide is almost certainly denser than any hydrocarbon stream that an existing unit has been designed for.

This density and high mole weight will result in derating separators, piping, and pressure safety valves. The fact that the initial water content may be higher than natural gas may also result in requiring higher circulation rates.

The current simulation models for design should account for these issues. However, using rules of thumb will likely fail to achieve properly sized equipment.

Some Other Configurations for TEG Dehydration of Carbon Dioxide

Add a second flash separator

The amount of carbon dioxide absorbed into the glycol can be very substantial. As the rich TEG de-pressures, it may prove worthwhile to install a second flash separator to capture a portion of the flash gas without attempting to recover it from the lowest pressure. Of course, this option is only feasible where a lower pressure “home” for the gas can be found. Examples include and interstage scrubber for a compressor or the inlet gas to a plant.

Install a two pressure contactor arrangement

This is actual configuration has been installed and is operating at a Permian Basin CO₂ EOR flood processing plant. Two dehydration specifications are utilized. At the inlet of the facility a contactor is installed the runs at the field gathering pressure. This low pressure contactor meets a pipeline spec. The remainder of the equipment and the plant does not require the use of stainless steel due to this initial dehydration.

A second high pressure contactor is installed for the carbon dioxide downstream of compression. It dehydrates the gas to a meet a stringent process spec. Where the low pressure contactor could not reasonably meet such a spec, the high pressure contactor is suitable. The semi-rich glycol, exiting the bottom of the high pressure contactor, is flowed directly to the low pressure contactor without being regenerated. Since the glycol will flash carbon dioxide as it de-pressures, a chimney tray should be installed in the top portion of the lower pressure contactor to allow for the flash gas to enter the lower pressure process gas stream.

A single glycol regeneration system then dries the glycol and returns it to the high pressure contactor.

Install a two temperature contactor arrangement

This is a potential system similar to the two pressure contactor arrangement. In this one, the initial contactor would meet a pipeline spec, the gas would be chilled to just above the condensation temperature. A second contactor would then be utilized to achieve the stringent plant dehydration spec for downstream equipment. This has the added benefit of having almost no glycol in the carbon dioxide process gas stream exiting this contactor.

Note that for the low temperature application, it may be necessary to install equipment to pre-saturate the lean glycol with carbon dioxide.

Non-TEG Dehydration of Carbon Dioxide

This paper has examined how to utilize TEG for dehydrating carbon dioxide. Other techniques exist for dehydrating carbon dioxide. Two special cases are identified below that are rarely encountered for dehydration.

Using glycerol for dehydration of carbon dioxide

For applications where the pressure is too high to use TEG, another liquid desiccant is available for dehydration. Glycerol as a sufficiently low vapor pressure that in the supercritical range of carbon dioxide it can operate successfully. A commercial installation has been installed that has successfully dehydrated carbon dioxide with glycerol.⁶

Using Separation for Dehydration of carbon dioxide

For applications requiring pipeline dehydration specifications, it may be possible to achieve sufficient dehydration without using glycol dehydration. With chilling a separator may accomplish dehydration. This takes advantage of the minimum water content that is achieved prior to carbon dioxide condensing or entering the dense phase as shown on Figure 3.

“The DEXPro™ process takes advantage of the relatively high Joule-Thomson coefficient characteristic of acid gas and utilizes precision control of pressure and temperature to achieve gas dehydration.”⁷ This patented process requires no moving parts and utilizes no glycol or other desiccant. He relies strictly on separation at the proper temperature and pressure.

Design Tips

Below, are some design tips describing some similarities and differences of carbon dioxide glycol dehydration as compared to natural gas glycol dehydration.

- 1) Dense phase and liquid phase carbon dioxide can hold much more water than natural gas at similar temperatures and pressures. For pipeline applications, the water content specification can be several times the amount of permissible for natural gas at similar temperatures and pressures.
- 2) TEG can reach as stringent a dehydration specification with carbon dioxide as it can with natural gas.
- 3) TEG cannot be used to dehydrate liquid or dense phase carbon dioxide.
- 4) For TEG applications involving compression, the contactor is often installed upstream of the last stage of compression.

⁶ Kevin S. Fisher, et.al, “Use of Glycerol (Glycerin) to Dehydrate CO₂ Above the Critical Pressure at Denbury’s Mississippi Facilities”, Paper Presented at the 10th Annual CO₂ Flooding Conference, Midland, TX, Dec. 2004

Charles A. Wallace, Dehydration of Supercritical CO₂, Gas Conditioning Conference, Norman, OK. 1985

⁷ <https://dexprodehy.com/dexpro-advantage/>

- 5) TEG circulation rates are determined based on the amount of water to be removed, which is the same method as for natural gas dehydration. For a like amount of water to be removed from process gas, the same circulation rate would be required for both a carbon dioxide and natural gas dehydration application.
- 6) Reboiler and lean/rich exchanger duties are similar to natural gas dehydration for the same amount of water removal.
- 7) Condenser duty is similar to natural gas dehydration for applications requiring the same amount of water removal.
- 8) TEG absorbs 10 times to 30 times more carbon dioxide from a pure carbon dioxide stream as compared to methane from natural gas stream at like operating conditions. For carbon dioxide rich streams:
 - a) Carbon dioxide dissolved in TEG reduces the viscosity of TEG. This may prove useful for dehydrating low temperature carbon dioxide that is still in the vapor phase.
 - b) Sufficient carbon dioxide flashes from TEG that the gas from a flash gas separator may be utilized as stripping gas. Flash gas separators that are downstream of a lean/rich exchanger will have too much water to be utilized as stripping gas.
 - c) Carbon dioxide flashing from glycol, as it drops in pressure, substantially reduces the temperature of the glycol. This is in contrast with natural gas systems where pressure drops can modestly increase the temperature of the glycol.
- 9) Materials of construction:
 - a) Contactors are frequently constructed partially or completely with stainless steel although there are successful installations of carbon steel contactors.
 - b) Introducing a glycol stream upstream of a contactor allows for the carbon dioxide to be dehydrated upstream of contactor, thereby mitigating corrosion.
 - c) The flash gas separator may be constructed of carbon steel provided the separator is upstream of the lean/rich exchanger.
 - d) Liquid glycol reaching the reboiler has no appreciable amount of carbon dioxide; it has flashed from the liquid TEG. Consequently, the reboiler can be constructed by using carbon steel.
 - e) Carbon dioxide may be used as stripping gas and it will not introduce any corrosion potential in the stahl column. Therefore, stahl columns may be constructed of carbon steel even if carbon dioxide is utilized as stripping gas.
- 10) Carbon dioxide has a much higher molecular weight than natural gas. In the vapor phase, carbon dioxide density is frequently about three times the density of natural gas. This has a pronounced impact on the sizing of equipment. Equipment capacities are reduced due to carbon dioxide, rather than natural gas, flowing through the equipment. Some equipment that will be derated include:
 - a) Separators
 - b) Control valves
 - c) Relief valves

References

1. Process Program “Symmetry v2020.4 (Build 52)” with “APR for Natural Gas 2” thermo was utilized to derive graph data
2. <https://www.equinor.com/en/news/2019-06-12-sleipner-co2-storage-data.html>
3. Paul A. Carmody, Glycol Pre-dehydration of Gas Before a Contactor, Laurance Reid Gas Conditioning Conference, 2000.
4. A.M. Sherik, A.L. Lewis, A.H. Rasheed, and A.A. Jabran, Effect of Triethylene Glycol on Corrosion of Carbon Steel in H₂S, CO₂, and O₂ Environments, NACE International Corrosion 2010 Conference and Expo, San Antonio, 2010, Paper 10188
5. Jeffrey C. Arnoldi, et. al. Selection of Materials for Sour Gas Processing, Gas Conditioning Conference, Norman, OK. 1987, pg. A2-A17, Figure 1 shows a graph with corrosion v. temperature. Corrosion reaches a maximum at about 200°F and declines rapidly.
6. T Tanupabrungsun, et. al., Effect of pH on CO₂ Corrosion of Mild Steel at Elevated Temperatures, NACE International Corrosion 2013 Conference and Expo, Orlando, FL, 2013, Paper 2348
7. <https://dexprodehy.com/dexpro-advantage/>
8. Kevin S. Fisher, et.al, “Use of Glycerol (Glycerin) to Dehydrate CO₂ Above the Critical Pressure at Denbury’s Mississippi Facilities”, Paper Presented at the 10th Annual CO₂ Flooding Conference, Midland, TX, Dec. 2004
9. Charles A. Wallace, Dehydration of Supercritical CO₂, Gas Conditioning Conference, Norman, OK. 1985