Lessons Learned

From Natural Gas STAR Partners

NaturalGas
EPA POLLUTION PREVENTER

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

REPLACING GLYCOL DEHYDRATORS WITH DESICCANT DEHYDRATORS

Executive Summary

There are approximately 30,000 high-pressure, on-shore gas wells producing 4 trillion cubic feet (Tcf) of natural gas annually in the United States. About 700 of these wells have conventional glycol dehydrators, emitting an estimated 1 billion cubic feet (Bcf) of methane per year to the atmosphere. Glycol dehydrators vent methane, volatile organic compounds (VOCs), and hazardous air pollutants (HAPs) to the atmosphere from the glycol regenerator and also bleed natural gas from pneumatic control devices. This process wastes gas, costs money, and contributes to local air quality problems as well as global climate change.

Natural Gas STAR partners have found that replacing glycol dehydrators with desiccant dehydrators reduces methane, VOC, and HAP emissions by 99 percent and also reduces operating and maintenance costs. In a desiccant dehydrator, wet gas passes through a drying bed of desiccant tablets. The tablets pull moisture from the gas and gradually dissolve in the process. Since the unit is fully enclosed, gas emissions occur only when the vessel is opened, such as when new desiccant tablets are added.

Economic analyses demonstrate that replacing a glycol dehydrator processing 1 million cubic feet per day (MMcfd) of gas with a desiccant dehydrator can save up to $4,403 per year in fuel gas, vented gas, and operation and maintenance (O&M) costs and reduce methane emissions by 564 thousand cubic feet (Mcf) per year. This Lessons Learned study describes how partners can identify areas where desiccant dehydrators can be implemented and determine their economic and environmental benefits.

Method for Reducing Gas Loss[1]	Annual Methane Emission Savings (Mcf)[2]	Annual Gas Savings (Mcf)[3]	Value of Gas Saved ($)[4]	Capital and Installation Cost ($)[5]	O&M Cost ($)[6]	Payback (Years)
Replacing a Glycol Dehydrator with a Desiccant Dehydrator	564	1,063	3,189	12,750	(1,214)	2.9

1 Based on a 1 MMcfd dehydrator operating at 450 psig and 47°F.
2 Difference between methane vented from the glycol and desiccant dehydrators.
3 Sum of net gas emissions reduction and fuel gas savings.
4 Based on $3 per Mcf price of gas.
5 Installed cost of desiccant dehydrator minus surplus equipment value for the replaced glycol dehydrator.
6 Difference between glycol and desiccant dehydrators O&M costs.

This is one of a series of Lessons Learned Summaries developed by EPA in cooperation with the natural gas industry on superior applications of Natural Gas STAR Program Best Management Practices (BMPs) and Partner Reported Opportunities (PROs).

Technology Background

Produced natural gas is normally saturated with water. If not removed, the water can condense and/or freeze in gathering, transmission, and distribution piping causing plugging, pressure surges, and corrosion. To avoid these problems, the produced gas is typically sent through a dehydrator where it contacts a dewatering agent such as triethylene glycol (TEG), diethylene glycol (DEG), or propylene carbonate. In the most common process, glycol dehydration, the TEG absorbs water from the gas along with methane, VOCs, and HAPs. The absorbed water and hydrocarbons are then boiled off in a reboiler/regenerator and vented to the atmosphere. (See EPA's *Lessons Learned: Optimize Glycol Circulation and Install Flash Tank Separators in Glycol Dehydrators*.)

Natural Gas STAR partners have reported success using an alternative method for drying gas: desiccant dehydrators. These dehydrators use moisture-absorbing salts to remove water from the gas without emitting large quantities of methane, VOCs, or HAPs.

Desiccants

Deliquescent salts, such as calcium, potassium and lithium chlorides, have been used by the oil and gas industries to dehydrate petroleum products for more than 70 years. These salts naturally attract and absorb moisture (hygroscopic), gradually dissolving to form a brine solution. The amount of moisture that can be removed from hydrocarbon gas depends on the type of desiccant as well as the temperature and pressure of the gas. Calcium chloride, the most common and least expensive desiccant, can achieve pipeline-quality moisture contents at temperatures below 59ºF and pressures above 250 psig. Lithium chloride, which is more expensive, has a wider operating range: up to 70ºF and above 100 psig. Appendix A provides equilibrium moisture contents of natural gas dehydrated by commercially available calcium and lithium chloride salts.

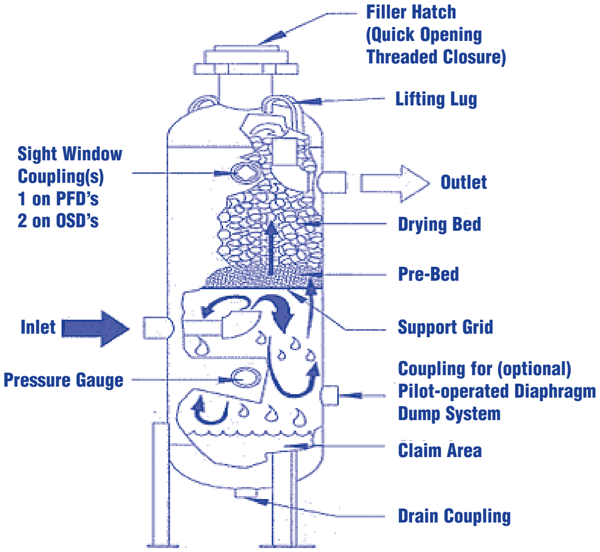
Process Description

A desiccant dehydrator is a very simple device; it has no moving parts and needs no external power supply; therefore, it is ideal for remote sites.

As shown in Exhibit 1, wet natural gas enters near the bottom of the dehydrator vessel, below the desiccant support grid. The support grid and ceramic ball pre-bed prevent the desiccant tablets from dropping down into the brine sump (claim area). The wet gas flows upward through the drying bed. When the gas comes into contact with the surface of the tablets, the desiccant salts remove water vapor from the gas (hydrate). As the desiccant continues to remove water vapor from the gas, droplets of brine form and drip down through the drying bed to the brine collection sump (claim area) at the bottom of the vessel. This brine formation process gradually dissolves the desiccant.

Brine collected in the claim area can be periodically drained to either a brine (or produced water) storage tank, or (where permitted) to an evaporation

Exhibit 1: Schematic of Single Vessel Desiccant Dehydrator



Source: Van Air

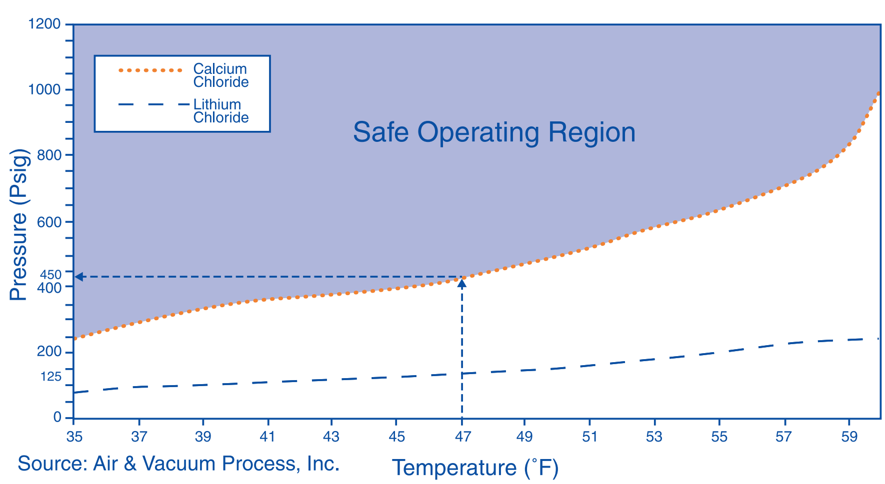
pond. Produced water and brine may be deep-well injected near the site, or periodically picked up for disposal offsite.

With a drying bed of sufficient depth, the gas reaches equilibrium moisture content with the desiccant before it reaches the top of the drying bed. Excess salt, above the minimum depth needed to achieve equilibrium moisture content, is referred to as the "working salt bed." This working inventory is refilled periodically. To avoid halting gas production or bypassing wet gas to a sales line when refilling the desiccant dehydrator, most installations use a minimum of two vessels: one in drying service while the other is being refilled with salt.

Operating Requirements

To protect their pipelines, producers dry gas to a dew point below the minimum temperature expected in the pipeline. If the gas is not dried appropriately, water and other free liquids can precipitate as the gas cools which can lead to pipeline blockage or corrosion. To avoid this, producers normally dehydrate gas to a pipeline moisture specification between 4 and 7 pounds of water per MMcf of gas. Desiccant performance curves show the temperature and pressure combinations that will result in gas meeting pipeline moisture standards. Exhibit 2, derived from the moisture content table in Appendix A, shows the gas temperature and pressure combinations that would result in 7 pounds of water per MMcf of gas for two of the most common desiccants. The shaded region above the saturation line in Exhibit 2 represents a "safe operating region" for calcium chloride dehydrators where the gas will be at or below pipeline moisture specification. Operators use these curves to determine the minimum gas pressure required to ensure a given moisture content. In this example, an inlet gas at 47ºF passing through a calcium chloride desiccant dehydrator must be pressurized to at least 450 psig to meet the 7 pounds of water per MMcf standard. Curves for both calcium and lithium chloride are shown, although lithium chloride is rarely used because of its cost.

Exhibit 2: Desiccant Performance Curves at Maximum Pipeline Moisture Content Requirement (7 lb. of water/MMscf)



Source: Air & Vacuum Process, Inc.

Refilling Desiccants and Draining Brine

As the desiccant tablets absorb moisture from the gas, the depth of the desiccant tablets in the drying bed slowly decreases. Some manufacturers place a “window” (sight-glass) on the vessel (see Exhibit 1) at the minimum desiccant level. When the top of the desiccant reaches the sight-glass, the operator needs to refill the desiccant up to the maximum level. Refilling the working bed is a manual operation that involves switching gas flow to another dehydration vessel, shutting valves to isolate the “empty” vessel, venting gas pressure to the atmosphere, opening the top filler hatch, and pouring desiccant pellets into the vessel. This requires the operator to dump one or more 30 to 50 pound bags of salt into the vessel, depending on dehydrator design. Because this procedure needs to be performed more frequently the higher the gas throughput, desiccant dehydrators are usually used when the volume of gas to be dried is 5 MMcfd or less.

The brine in the claim area is sometimes drained manually (desiccant dehydrators typically accumulate from 10 to 50 gallons of brine a week). Draining to an evaporation pond is best done after the vessel is depressured, while draining to a produced water tank can be done before the vessel is depressured—taking advantage of the gas pressure to push the brine into the tank. On rare occasions brine may be pumped into a tank truck using a pneumatic “duplex-type” pump.

Economic and Environmental Benefits

Using desiccant dehydrators as alternatives to glycol dehydrators can yield significant economic and environmental benefits, including:

- ★ **Reduced capital cost—**The capital costs of desiccant dehydrators are low compared to the capital costs of glycol dehydrators. A desiccant dehydrator does not use a circulation pump, pneumatic controls, a gas heater, or a fired reboiler/regenerator.
- ★ **Reduced operation and maintenance cost—**Glycol dehydrators burn a significant amount of produced gas for fuel in a gas heater and glycol regenerator. If the brine drain valve is automatic, the only O&M cost for a desiccant dehydrator is for refilling the desiccant bed.
- ★ **Minimal methane, VOC, and HAP emissions—**Glycol dehydrators continuously vent gas to the atmosphere from pneumatic devices and the TEG regenerator vent. The only gas emissions from desiccant dehydrators occur during desiccant vessel depressuring for salt refilling, typically one vessel-volume per week. Brine is produced in small quantities and absorbs little hydrocarbon.

Decision Process

Partners can evaluate potential locations and economics for replacing existing glycol dehydrators with desiccant dehydrators using the following five steps.

Five Steps for Evaluating A Desiccant Dehydrator:

1. Identify appropriate locations
2. Determine dehydrator capacity
3. Estimate the capital and operating costs
4. Estimate savings
5. Conduct economic analysis

Step 1: Identify appropriate locations. Desiccant dehydrators are an economic choice under certain operating conditions. Their applicability is determined primarily by gas throughput and produced gas temperature and pressure. Desiccant dehydrators work best when the volume to be dried is 5 MMcfd or less, and absorb moisture down to pipeline specifications when the wellhead gas temperature is low and the pressure is high. If the inlet temperature of the gas is too high, desiccants can form hydrates that precipitate from the solution and cause caking and brine drainage problems. While it is possible to cool or compress the produced gas in order to use desiccant dehydrators, these measures increase system complexity and typically are cost prohibitive.

In contrast, glycol dehydrators are a better choice for higher producing well sites and work best for higher temperature gas at any pressure. If the produced gas temperature is too low for the TEG process, however, operators will need to heat the gas prior to entering the dehydrator. Since heating the gas requires more product to be burned as fuel, these situations are likely to be good candidates for desiccant dehydrators. Exhibit 3 shows which gas drying systems work best under various operating conditions.

Exhibit 3: Optimum Operating Conditions for Dehydration Technologies		
	Low Pressure (<100 psig)	**High Pressure** (>100 psig)
Low Temperature (<70°F)	Desiccant/Glycol[1]	Desiccant
High Temperature (>70°F)	Glycol	Glycol/Desiccant[2]

[1] The gas may need to be heated to use a glycol dehydrator, or the gas may need to be compressed to use a desiccant dehydrator.
[2] The gas may need to be cooled to use a desiccant dehydrator.

Step 2: Determine dehydrator capacity. The first step in estimating the size of a desiccant dehydrator is to determine the inlet and outlet moisture content of the gas. This is required to calculate the quantity of desiccant needed, and from that the size of the vessel. Operators use a natural gas water vapor content graph (example shown in Appendix B), a moisture content table, or a sizing program such as the Hanover Company's Quick Size program, found at <www.hanover-co.com/home/products/index.html>, to estimate the water content in the gas stream. For this analysis, we will assume the dehydrator is being designed to handle a 1 MMscf/day gas stream at 47ºF and 450 psig. For this scenario, using any of these methods yields the same results—the natural gas stream contains 21 pounds of water per MMcf.

Vendor's Rule-of-Thumb
One pound of desiccant removes three pounds of moisture from the gas.

In order to meet a pipeline moisture specification of 7 pounds per MMcf, calcium chloride desiccant must remove 14 pounds of water per MMcf of gas. For a 1 MMcfd dehydrator, and using a vendor's rule-of-thumb that 1 pound of desiccant removes 3 pounds of water, 4.7 pounds of calcium chloride will be dissolved per day. Exhibit 4 summarizes this calculation.

The next step is to size the vessel. Vendors supply desiccant dehydrator vessels in standard sizes, usually specified by outside diameter and maximum gas throughput at various operating pressures, as shown in Exhibit 6. The bed dimensions are fixed to achieve equilibrium gas moisture content. This includes a standard size working bed depth: 5 inches for this vendor.

Partners can select the desiccant vessel size from the vendor's table or calculate the size using the equations in Exhibit 5. For the 1 MMcfd dehydrator example above, using Exhibit 5 gives a vessel with a 16.2 inch inside diameter (about 17 inch outside diameter with a 3/8 inch wall thickness). To use Exhibit 6, follow the 450-psig column down to the throughput capacity equal to or greater than what is needed; in this example, 1,344 Mcfd (1.344 MMcfd). Following this row to the left yields an outside diameter of 20 inches.

Exhibit 4: Determine the Daily Consumption of Desiccant

Where:

D	= Daily consumption of desiccant (lb/day)
F	= Gas flow rate (MMcf/day)
I	= Inlet water content (lb/MMcf)
O	= Outlet water content (lb/MMcf)
B	= Desiccant-to-water ratio (lb desiccant/lb water)

Given:

F	= 1 MMcf/day of production gas at 47°F and 450 psig
I	= 21 lb/MMcf
O	= 7 lb/MMcf (pipeline moisture requirement)
B	= 1 lb desiccant/3 lb water (vendor rule-of-thumb)

Calculate:

D = F * (I-O) * B
= 1 * (21-7) * 1/3
= 4.7 lb desiccant/day

Exhibit 5: Determine the Size of the Desiccant Dehydrator

Where:

ID	= Inside diameter of the desiccant vessel (in)
D	= Daily desiccant consumption (lb/day)
H	= Working salt bed height (in)
T	= Time between refilling (days)
B	= Bulk density (lb/ft^3)

Given:

D	= 4.7 lb/day (Exhibit 4)
H	= 5 in (vendor rule-of-thumb)
T	= 7 days (operator's choice)
B	= 55 (lb/ft^3) (vendor's data)

Calculate:

$$ID = 12 * \sqrt{\frac{4 * D * T * 12}{H * \Pi * B}}$$

$$= 12 * \sqrt{\frac{4 * 4.7 * 7 * 12}{5 * \Pi * 55}}$$

= 16.2 in

Select standard vessel size from Exhibit 6:

- Select next larger size than ID = 20 in

Exhibit 6: Cost and Maximum Throughput Capacity (Mcfd) of Desiccant Dehydrators								
Outside Diameter (Inches)	Cost[1,2] ($)	100 Psig	200 Psig	300 Psig	350 Psig	400 Psig	450 Psig	500 Psig
10	2,850	95	177	260	301	342	383	424
12	3,775	132	247	362	419	476	533	590
16	5,865	214	400	587	680	773	866	959
20	6,500	311	620	909	1,054	1,199	1,344	1,489
24	8,895	481	900	1,319	1,528	1,738	1,948	2,158
30	12,850	760	1,422	2,085	2,416	2,747	3,078	3,409
36	17,034	1,196	2,230	3,270	3,789	4,308	4,827	5,346

[1] The capital cost is for pressure ratings up to 500 psig, including one vessel with vessel supports, valves, piping, all appurtenances and the initial fill of calcium chloride desiccant tablets.

[2] Dehydrator cost includes all appurtenances: vessel, support structure, valves, and piping.

Source: Van Air

Step 3: Estimate the capital and operating costs. Capital costs for single vessel desiccant dehydrators suitable for gas production rates from 0.1 to 5 MMcf per day (including the initial fill of desiccant) range between $3,000 and $17,000. After determining the necessary vessel size (Step 2), partners can use Exhibit 6 to determine the capital costs of a desiccant dehydrator. For the example given in Step 2, the capital cost of a 20-inch, single vessel desiccant dehydrator is $6,500. For a two-vessel dehydrator, the cost would be $13,000.

Installation costs typically range from 50 to 75 percent of the equipment cost. Using an installation factor of 75 percent of the equipment cost, the single vessel desiccant dehydrator described above would cost $4,875 to install. The two-vessel dehydrator would cost $9,750 to install.

The operating cost of using a desiccant dehydrator includes the costs of desiccant replacement and brine disposal. Because the desiccant tablets dissolve as they remove moisture from the gas, the working salt bed will need to be replenished periodically. The resulting brine also requires removal and treatment or disposal.

Exhibit 7 shows the operating cost calculations for the 1 MMcfd dehydrator example. Depending on the vendor, the cost of calcium chloride can range from \$0.65 to \$1.20 per pound. Using \$1.20 per pound for the cost of calcium chloride, the total cost for refilling 4.7 pounds per day (from Exhibit 4) is \$2,059 per year. In the example given in Exhibit 4, very little brine is produced removing moisture from gas to achieve the desired pipeline moisture specification (i.e., 7 pounds per MMcf): 4.7 pounds per day of salt plus the 14 pounds of water per day removed from the gas, or 18.7 pounds of brine per day—a little over 2 gallons per day.

Exhibit 7: Determine the Operating Cost of a Desiccant Dehydrator

Where:

TO	= Total operating cost (\$/year)
CD	= Cost of desiccant (\$/year)
CB	= Cost of brine disposal (\$/year)
I	= Inlet water content (lb/MMcf)
O	= Outlet water content (lb/MMcf)
F	= Gas flow rate (MMcf/day)
P	= Price of the desiccant (\$/lb)
D	= Daily desiccant consumption (lb/day)
S	= Density of $CaCl_2$ brine (lb/bbl)
BD	= Cost of brine disposal (\$/bbl)
LC	= Labor cost (\$)
LT	= Labor time for operator to refill with desiccant (hr)
LR	= Labor rate for operator (\$/hr)

Given:

F	= 1 MMcf/day of production gas at 47ºF and 450 psig
P	= \$1.20/lb of calcium chloride (vendor data)
D	= 4.7 lb desiccant/day (Exhibit 4)
S	= 490 lb/bbl
BD	= \$1.00/bbl[1]
LT	= 1 hr/week
LR	= \$30/hr

Calculate:

CD = D*P*365 days/yr
= 4.7*1.2*365
= \$2,059/yr

$$CB = \frac{[((I-O)*F)+D]*BD*365\ \text{days/yr}}{S}$$

$$= \frac{[((21-7)*1)+4.7]*1.0*365}{490}$$

= \$14/yr

LC = LT*LR*52 weeks/yr
= 1*30*52
= \$1,560/yr

TO = CD+CB+LC
= \$2,059+\$14+\$1,560
= \$3,633/yr

[1] GRI *Atlas of Gas-Related Produced Water for 1990*, May 1995.

Step 4: Estimate savings. Replacing a glycol dehydrator with a desiccant dehydrator significantly saves gas and reduces operation and maintenance costs.

Determining Net Gas Savings

The amount of gas saved can be determined by comparing the gas emissions and usage for the existing glycol dehydrator to the gas vented from a desiccant dehydrator. Partners can determine the gas savings by determining the following five factors.

Determine the Net Gas Savings:

Add Savings from eliminating:

- Gas vented from glycol dehydrator.
- Gas vented from pneumatic controllers.
- Gas burned as fuel in glycol reboiler.
- Gas burned as fuel in a gas heater.

Subtract:

- Gas vented from desiccant dehydrator.

★ **Estimate the gas vented from glycol dehydrator—**The amount of gas vented from the glycol regenerator/reboiler is equal to the gas entrained in the TEG. To determine this, partners will need to know the gas flow rate, the inlet and outlet water content, the glycol-to-water ratio, the percent over-circulation, and the methane entrainment rate.

Exhibit 8: Gas Vented from the Glycol Dehydrator

Where:

GV	= Amount of gas vented annually (Mcf/yr)
F	= Gas flow rate (MMcf/day)
W	= Inlet-outlet water content (lb/MMcf)
R	= Glycol-to-water ratio (gal/lb)[1]
OC	= Percent over-circulation
G	= Methane entrainment rate (ft^3/gal)[1]

Given:

F	= 1 MMcfd of gas at 47ºF and 450 psig
W	= 21 - 7 = 14 lb water/MMcf (Exhibit 4)
R	= 3 gal/lb (rule-of-thumb)[1]
G	= 3 ft^3/gal for energy exchange pumps (rule-of-thumb)[1]
OC	= 150%

Calculate:

$$GV = \frac{(F*W*R*OC*G*365days/yr)}{1{,}000cf/Mcf}$$

$$= \frac{(1*14*3*1.5*3*365)}{1{,}000}$$

$$= 69 \text{ Mcf/yr}$$

[1] From EPA's *Lessons Learned: Optimize Glycol Circulation and Install Flash Tank Separators in Glycol Dehydrators*.

Exhibit 8 demonstrates this calculation for the 1 MMcfd dehydrator example. In this example, an energy exchange pump without a flash tank separator is assumed. Using rules-of thumb from EPA's *Lessons Learned: Optimize Glycol Circulation and Install Flash Tank Separators in Glycol Dehydrators*, methane gas emissions of 69 Mcf per year is calculated.

★ **Estimate the gas vented from pneumatic controllers—**Pneumatic controllers are commonly used to monitor and regulate gas and liquid flows, temperature, and pressure in glycol dehydrator units. Specifically, the controllers regulate gas and liquid flows in dehydrators and separators, temperature in dehydrator regenerators, and pressure in flash tanks (when in use). In this example, the glycol dehydrator unit with a gas heater is assumed to have four bleeding pneumatic controllers—level controllers on the contactor and reboiler and temperature controllers on the reboiler and gas heater. It does not have a flash tank separator. It also is assumed that all the pneumatic devices are high bleed devices (i.e., they bleed in excess of 50 Mcf of gas per year during operation). Based on the GRI/EPA study, *Methane Emissions From the Natural Gas Industry, Volume 12–Pnuematic Devices*, the annual emission factor for an average high bleed pneumatic device is estimated to be 126 Mcf per year. Therefore, the four pneumatic devices will contribute 504 Mcf of the methane emissions annually. Exhibit 9 summarizes this example.

Exhibit 9: Gas Vented from Pneumatic Controllers	
Where:	
GB	= Gas bleed (Mcf/yr)
EF	= Emission factor (Mcf natural gas bleed/pneumatic device per year)[1]
PD	= Number of pneumatic devices
Given:	
EF	= 126 Mcf/device/yr
PD	= 4 pneumatic devices/glycol dehydrators
Calculate:	
GB	= EF*PD
	= 126* 4
	= 504 Mcf/yr

[1] GRI/EPA study, *Methane Emissions from the Natural Gas Industry*, Volume 12.

★ **Estimate the gas burned for fuel in glycol reboiler—**The glycol dehydrator uses natural gas in the reboiler/regenerator to boil-off water from the rich glycol. Assuming that the heat duty of the reboiler is 1,124 Btu per gallon of TEG, the gas used by the reboiler is 17 Mcf per year. Exhibit 10 summarizes this calculation.

Exhibit 10: Gas Burned for Fuel in Glycol Reboiler

Where:

FGR	= Fuel gas for reboiler (Mcf/yr)
F	= Gas flow rate (MMcfd)
W	= Inlet-outlet water content (lb/MMcf)
Qr	= Heat duty of reboiler (Btu/gal TEG) [1]
Hv	= Heating value of natural gas (Btu/scf)[2]
R	= Glycol-to-water ratio (gal TEG/lb water) [3]

Given:

F	= 1 MMcfd
W	= 21 - 7 = 14 lb water/MMcf
Qr	= 1,124 Btu/gal TEG
Hv	= 1,027 Btu/scf
R	= 3 gal TEG/lb water removed

Calculate:

$$FGR = \frac{(F*W*Qr*R*365days/yr)}{Hv*1{,}000cf/Mcf}$$

$$= \frac{(1*14*1{,}124*3*365)}{1{,}027*1{,}000}$$

= 17 Mcf/yr

[1] Based on calculation in *Engineering Data Book, Volume II*, 11th edition, Gas Processors Supply Association, 1998, Section 20-Dehydration.
[2]Energy Information Administration (EIA), Monthly Engineering Review, Table A4.
[3]From EPA's *Lessons Learned: Optimize Glycol Circulation and Install Flash Tank Separators in Glycol Dehydrators.*

★ **Estimate the gas burned for fuel in a gas heater—**TEG does not perform well on low temperature gas. As a result, the gas is typically heated prior to entering the dehydrator unit. Natural gas is used to fuel the gas heater. The amount of fuel gas used to heat 1 MMcfd of produced gas from 47ºF to (assumed) 90ºF is 483 Mcf per year. Exhibit 11 shows this calculation.

★ **Estimate the gas loss from desiccant dehydrator—**The gas loss from a desiccant dehydrator is determined by calculating the amount of gas vented from the vessel every time it is depressurized for the refilling process. To determine the volume of gas vented, partners will need to determine the volume of the dehydrator vessel and what percentage of this volume is occupied by gas. The 20-inch OD vessel in Exhibit 6 would have an approximately 19.25-inch ID (assuming a 3/8 inch wall thickness). The vessel has an overall length of 76.75 inches with 45 percent of its volume filled with gas. Using Bolye's Law, the amount of gas vented to the atmosphere during depressurizing of the vessel is 10 Mcf per year. Exhibit 12 summarizes this calculation.

Exhibit 11: Amount of Fuel Gas Used to Heat the Gas

Where:

FGH	= Fuel gas used in heater (Mcf/yr)
Hv	= Heating value of natural gas (Btu/cf)
Cv	= Specific heat of natural gas (Btu/lb°F)
D	= Density of natural gas (lb/cf)
ΔT	= $(T_2 - T_1)$ change in temperature (F°)
F	= Flow rate (MMcf/d)
E	= Efficiency

Given:

Hv	= 1,027 Btu/cf
Cv	= 0.441 Btu/lb°F
D	= 0.0502 lb/cf
ΔT	= 43 F° (90 - 47) F°
F	= 1 MMcf/d
E	= 70%

Calculate:

$$FGH = \frac{(F * D * Cv * \Delta T * 365\text{days/yr} * 1{,}000\text{Mcf/MMcf})}{(Hv * E)}$$

$$= \frac{(1 * 0.0502 * 0.441 * 43 * 365 * 1{,}000)}{(1{,}027 * 0.7)}$$

= 483 Mcf/yr

★ **Estimate the total gas savings—**The total gas savings is the total avoided emissions and gas use of the glycol dehydrator minus the gas lost from venting of the desiccant dehydrator when replacing the desiccant. In this example, total gas savings are 1,063 Mcf per year. Using a gas price of $3.00 per Mcf, the gas value saved is $3,189 per year. Natural gas contains 90 percent methane. Therefore, the total methane emission savings is 90 percent of the difference between the gas emitted by the glycol dehydrator and its pneumatic controllers (Exhibits 8 and 9 respectively), and the desiccant dehydrator (Exhibit 12); in this case, 507 Mcf per year. Exhibit 13 summarizes this example.

Exhibit 12: Gas Lost from the Desiccant Dehydrator

Where:

GLD	= Gas loss from desiccant dehydrator (scf/yr)
H	= Height of the dehydrator vessel (ft)
D	= Inside diameter of the vessel (ft)
P_1	= Atmospheric pressure (psia)
P_2	= Pressure of the gas (psig)
Π	= pi
%G	= Percent of packed vessel volume that is gas
T	= Time between refilling (days)

Given:

H	= 76.75 in (6.40 ft)[1]
D	= 19.25 in (1.6 ft)
P_1	= 14.7 psia
P_2	= 450 psig + 14.7 (464.7 psig)
Π	= 3.14
%G	= 45% (vendor's rule-of-thumb)[1]
T	= 7 days

Calculate:

$$GLD = \frac{(H * D^2 * \Pi * P_2 * \%G * 365 days/yr)}{(4 * P_1 * T * 1{,}000 cf/Mcf)}$$

$$= \frac{(6.4 * 1.6^2 * 3.14 * 464.7 * 0.45 * 365)}{(4 * 14.7 * 7 * 1{,}000)}$$

= 10 Mcf/yr

[1] Based on product data provided by Van Air.

Exhibit 13: Total Gas Savings

Calculate:

TGS = Total Gas Savings (Mcf/yr)
= Exhibit 8 + Exhibit 9 + Exhibit 10 + Exhibit 11 - Exhibit 12
= 69 + 504 + 17 + 483 - 10
= 1,063 Mcf/yr

Savings = 1,063 Mcf/yr * $3/Mcf
= $3,189/yr

Methane Emissions Reduction

TMER = Total methane emissions reduction
TMER = 90% * (Exhibit 8+ Exhibit 9 - Exhibit 12)
= 0.9 * (69 + 504 - 10)
= 507 Mcf/yr

Determining Operations and Maintenance Savings

Other savings include the difference between the operating and maintenance cost (labor cost) of a desiccant dehydrator and a glycol dehydrator.

The operation cost of a desiccant dehydrator includes the refill cost of the desiccant, disposal of the brine, and labor costs. Since a desiccant dehydrator has no moving parts and does not require power to operate, maintenance costs are negligible. The refill and brine disposal costs previously calculated in Exhibit 7 are $2,059 and $14 per year, respectively. Labor costs assume one hour per week for the operator to refill the desiccant dehydrator. At $30 per hour, this would cost about $1,560 per year.

Operating cost for a glycol dehydrator includes topping-up the glycol sump to maintain glycol levels. Maintenance and labor include inspecting and cleaning the mechanical systems, periodically repairing the circulation pump and pneumatic controls, and annually cleaning the fire-tubes of the reboiler and gas heater. Glycol costs $4.50 per gallon, and a typical make-up rate is 0.1 gallons per MMcf of gas processed. For this example, this works out to about 37 gallons of glycol per year, or $167 per year. Labor costs assume operators spend an average of two hours per week maintaining and repairing the unit. At $30 per hour this amounts to about $3,120 per year. Spare parts are estimated at half the labor cost, or $1,560 per year. Based on this, total operation, maintenance, and labor costs for our example glycol dehydrator system is $4,847 per year.

Step 5: Conduct economic analysis. The final step is to compare the implementation and annual operating and maintenance costs of each option and the value of gas saved or used/lost by each unit. Exhibit 14 provides a comparison of the implementation and operating and maintenance costs of a desiccant dehydrator and a glycol dehydrator (dehydrating 1 MMcfd natural gas at 450 psig pressure and 47ºF temperature). Exhibit 15 compares the amount and the value of gas used and lost by each system.

Exhibit 16 shows the savings a Natural Gas STAR partner could expect over a 5-year period by replacing an existing glycol dehydrator of 1 MMcfd at 450 psig and 47ºF gas with a desiccant dehydrator.

Exhibit 14: Cost Comparison of Desiccant Dehydrator and Glycol Dehydrator		
1 MMcfd natural gas at operating 450 psig and 47ºF		
Type of Costs and Savings	**Desiccant ($/yr)**	**Glycol ($/yr)**
Implementation Costs		
Capital Costs		
Desiccant[1] (includes the initial fill)	13,000	
Glycol		20,000
Other costs (installation and engineering)[2]	9,750	15,000
Total Implementation Costs:	22,750	35,000
Annual Operating and Maintenance Costs		
Dessicant		
Cost of desiccant refill[3] ($1.20/lb)	2,059	
Cost of brine disposal[3]	14	
Labor cost[4]	1,560	
Glycol		
Cost of glycol refill[4] ($4.50/gal)		167
Material and labor cost[4]		4,680
Total Annual Operation and Maintenance Costs:	3,633	4,847

[1] Based on two desiccant vessels used alternatively. See Exhibit 5.
[2] Installation costs assumed at 75% of the equipment cost.
[3] Values are from Exhibit 7.
[4] See Step 4, Estimate Savings.

Exhibit 15: Gas Use/Loss and Value Comparison				
1 MMcfd natural gas at operating 450 psig and 47ºF				
Type of Loss/Use	**Desiccant**		**Glycol**	
	Mcf/yr	**$/yr[1]**	**Mcf/yr**	**$/yr[1]**
Gas Use				
Fuel (Exhibits 10 and 11)	—	—	500	1,500
Gas Loss				
Pneumatic devices (Exhibit 9)	—	—	504	1,512
Vents (Exhibits 8 and 12)	10	30	69	207
Total:	10	30	1,073	3,219
Methane Emissions[2]:	10	—	507	—

[1] Gas price based on $3/Mcf.
[2] Values are from Exhibit 12 and Exhibit 13.

Exhibit 16: Economics of Replacing a Glycol Dehydration System with a Two-Vessel Desiccant Dehydrator System						
Types of Costs and Savings[1]	**Year 0 ($/yr)**	**Year 1 ($/yr)**	**Year 2 ($/yr)**	**Year 3 ($/yr)**	**Year 4 ($/yr)**	**Year 5 ($/yr)**
Capital costs	(22,750)					
Avoided O&M costs		4,847	4,847	4,847	4,847	4,847
O&M costs - Desiccant ($/yr)		(3,633)	(3,633)	(3,633)	(3,633)	(3,633)
Value of gas saved		3,219	3,219	3,219	3,219	3,219
Surplus equipment value	10,000[2]					
Total ($)	(12,750)	4,433	4,433	4,433	4,433	4,433

NPV (Net Present Value)[3] = $3,137
IRR (Internal Rate of Return)[4] = 21%
Payback Period (yr) = 2.9

[1] All cost values are obtained from Exhibits 14 and 15. The gas price is assumed to be $3/Mcf.
[2] Based on 50% of the capital cost of glycol dehydrator.
[3] The NPV is calculated based on 10% discount over 5 years.
[4] The IRR is calculated based on 5 years.

Lessons Learned

Desiccant dehydrators can cost-effectively reduce methane emissions for gas dehydration. Partner experience offers the following lessons learned:

★ Desiccant dehydrators can provide significant economic benefits, such as increased operating efficiency and decreased capital and maintenance costs for low flow rate gas at higher pressures and lower temperature conditions.

★ Make-up (replacement) cost of the desiccant is slightly higher than the glycol because the desiccants dissolve in water and must be replaced regularly, while the glycol is recirculated.

★ Desiccant dehydrators are an effective method for eliminating methane, VOC, and HAP emissions, resulting in both economic and environmental benefits.

★ Include methane emissions reduction attributable to replacing glycol dehydrators with desiccant dehydrators in Natural Gas STAR Program annual reports.

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Appendix A

Moisture Content of Natural Gas in Equilibrium with Desiccants (lb water/MMcf of natural gas)

Type Calcium Chloride Deliquescent Desiccant Tablets

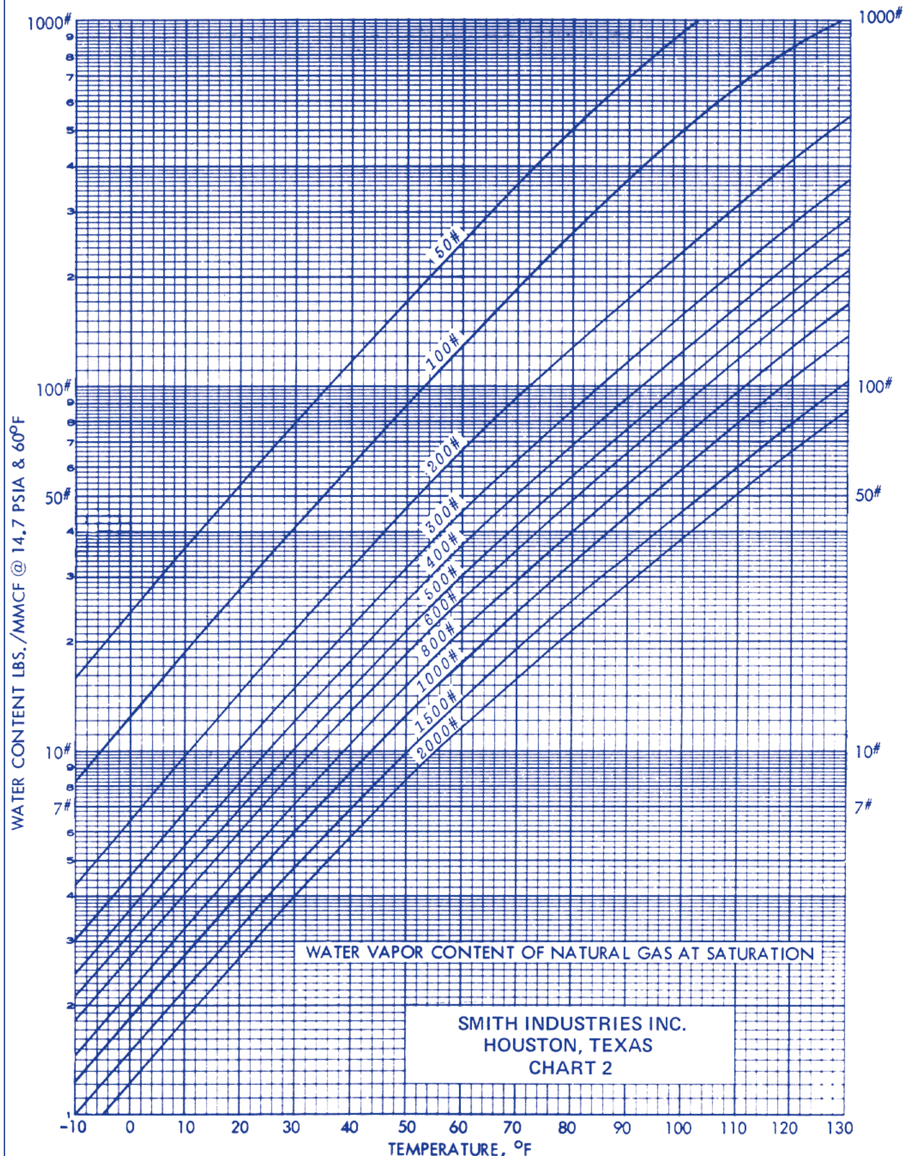
	10 PSIG	25 PSIG	50 PSIG	75 PSIG	100 PSIG	125 PSIG	150 PSIG	175 PSIG	200 PSIG	225 PSIG	250 PSIG	275 PSIG	300 PSIG	350 PSIG	400 PSIG	500 PSIG	750 PSIG	1000 PSIG
80°F	344	219	134	98	77	64	55	48	43	39	35	33	30	27	23.6	19.7	14.3	11.6
75°F	292	186	113	83	65	54	46	41	36	33	30	28	26	22.5	20.1	16.8	12.2	9.9
70°F	246	157	96	70	55	46	39	43	31	27	25	23.4	21.7	19.1	17.1	14.3	10.4	8.5
65°F	207	132	81	59	47	39	33	29	26	23.5	21.4	19.8	18.4	16.2	14.5	12.1	8.9	7.3
60°F	174	111	68	50	39	33	29	24.5	21.9	19.8	18.1	16.8	15.5	13.7	12.3	10.3	7.6	6.2
58°F	162	103	63	46	36	31	26	22.8	20.3	18.4	16.8	15.6	14.4	12.9	11.4	9.6	7	5.8
56°F	150	96	59	43	34	29	24.1	21.2	18.9	17.1	15.7	14.5	13.4	11.8	10.6	8.9	6.6	5.4
54°F	140	89	55	40	32	26	22.5	19.8	17.6	16	14.6	13.5	12.6	11.1	9.9	8.3	6.2	5.1
52°F	130	83	51	37	29	24.5	21	18.4	16.4	14.9	14.4	12.6	11.7	10.3	9.3	7.8	5.8	4.7
50°F	121	77	47	35	27	22.8	19.5	17.1	15.3	13.9	12.7	11.7	10.9	9.6	8.6	7.2	5.4	4.4
45°F	100	64	39	29	22.7	18.9	16.2	14.3	12.7	11.5	10.6	9.8	9.1	8	7.2	6.1	4.5	3.7
40°F	83	53	32	24	18.8	15.6	13.4	11.8	10.5	9.6	8.8	8.1	7.5	6.7	6	5	3.8	3.1
35°F	68	44	27	19.6	15.5	13	11.1	9.8	8.7	7.9	7.2	6.7	6.2	5.5	5	4.2	3.1	2.6

Type Lithium Chloride Deliquescent Desiccant Tablets

	10 PSIG	25 PSIG	50 PSIG	75 PSIG	100 PSIG	125 PSIG	150 PSIG	175 PSIG	200 PSIG	225 PSIG	250 PSIG	275 PSIG	300 PSIG	350 PSIG	400 PSIG	500 PSIG	750 PSIG	1000 PSIG
80°F	128	81	50	36	29	23.7	20.2	17.8	15.8	14.3	13	12	11.1	9.8	8.7	7.3	5.3	4.3
75°F	108	69	42	31	24.2	20	17.2	15.1	13.4	12.1	11.1	10.2	9.5	8.3	7.4	6.2	4.5	3.7
70°F	91	59	36	26	20.4	17	14.5	12.7	11.3	10.3	9.4	8.7	8	7.1	6.3	5.3	3.8	3.1
65°F	77	49	30	21.9	17.2	14.3	12.2	10.8	9.6	8.7	7.9	7.3	6.8	6	5.4	4.5	3.3	2.7
60°F	65	41	25	18.4	14.5	12.1	10.3	9.1	8.1	7.4	6.7	6.2	5.7	5	4.5	3.8	2.8	2.3
58°F	60	38	23.4	17.1	13.5	11.2	9.6	8.4	7.5	6.8	6.2	5.7	5.3	4.7	4.2	3.5	2.6	2.1
56°F	56	37	21.7	15.9	12.5	10.5	8.9	7.8	7	6.3	5.8	5.4	5	4.4	3.9	3.3	2.4	2
54°F	52	33	20.3	14.8	11.7	9.7	8.3	7.3	6.5	5.9	5.4	5	4.6	4.1	3.7	3.1	2.3	1.8
52°F	48	31	18.9	13.8	10.9	9	7.7	6.8	6.1	5.5	5	4.7	4.3	3.8	3.4	2.9	2.1	1.7
50°F	45	29	17.5	12.8	10.1	8.4	7.2	6.4	5.6	5.1	4.7	4.4	4	3.5	3.2	2.7	2	1.6
45°F	37	23.8	14.5	10.7	8.4	7	6	5.3	4.7	4.3	3.9	3.6	3.3	2.9	2.6	2.2	1.6	1.3
40°F	30	19.6	12	8.7	6.9	5.8	4.9	4.4	3.9	3.6	3.2	3	2.8	2.4	2.2	1.8	1.4	1.1
35°F	25	16.1	9.9	7.2	5.7	4.8	4.1	3.6	3.2	2.9	2.7	2.5	2.3	2	1.8	1.5	1.1	0.9

Source: Van Air

Appendix B



Source: Smith Industries, Inc., Houston, Texas

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EPA430-B-03-016
November 2003