**Tishk International University**
**Engineering Faculty**
**Petroleum and Mining Department**

# Petroleum Production Engineering II

## Lecture 5: Dehydration System

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# 5.1 Dehydration System

- **All-natural gas** downstream from the separators still contain **water vapor** to some degree.
- Water vapor is probably the most common **undesirable impurity** found in the untreated natural gas.
- The **main reason** for removing water vapor from natural gas is that water vapor becomes liquid water under low-temperature and/or high-pressure conditions.

# 5.1 Dehydration System

Water content can affect long-distance transmission of natural gas due to the following facts:

(a) Liquid water and natural gas can form **hydrates** that may plug the pipeline and other equipment.

(b) Natural gas containing **CO2 and/or H2S** is corrosive when liquid water is present.

(c) Liquid water in a natural gas pipeline potentially causes **slugging flow** conditions resulting in lower flow efficiency of the pipeline.

(d) Water content decreases the **heating value** of natural gas being transported.

**Dehydration systems are designed** for further separating water vapor from natural gas before the gas is transported by pipeline.

# 5.1.1 Water Content of Natural Gas Streams

Solubility of water in natural gas increases with temperature and decreases with pressure. The **presence of salt** in the liquid water reduces the water content of the gas.

Water content of untreated natural gases is normally in the magnitude of a **few hundred pounds** of water per million standard cubic foot of gas (lbm/MMscf); while gas pipelines normally require water content to be in the range of **6-8** lbm/MMscf and even lower for offshore pipelines.

The **water content of natural gas** is indirectly indicated by the ‘‘**dew point**,’’ defined as the temperature at which the natural gas is saturated with water vapor at a given pressure. At the dew point, natural gas is in equilibrium with liquid water; **any decrease in temperature or increase in pressure will cause the water vapor to begin condensing**.

The difference between the dew point temperature of a water-saturated gas stream and the same stream after it has been dehydrated is called ‘‘dew-point depression.’’

# Example Problem 5-1:

Estimate water content of a natural gas at a pressure of 3,000 psia and temperature of 150 $^{o}$F.

*Solution:*

The chart in Figure 5-1 gives water contents of:

*Cw 140 F* = 84 lbm/MMcf

*Cw 160 F* = 130 lbm/MMcf

Linear interpolation yields:

*Cw 150 F* = 107 lbm/MMcf

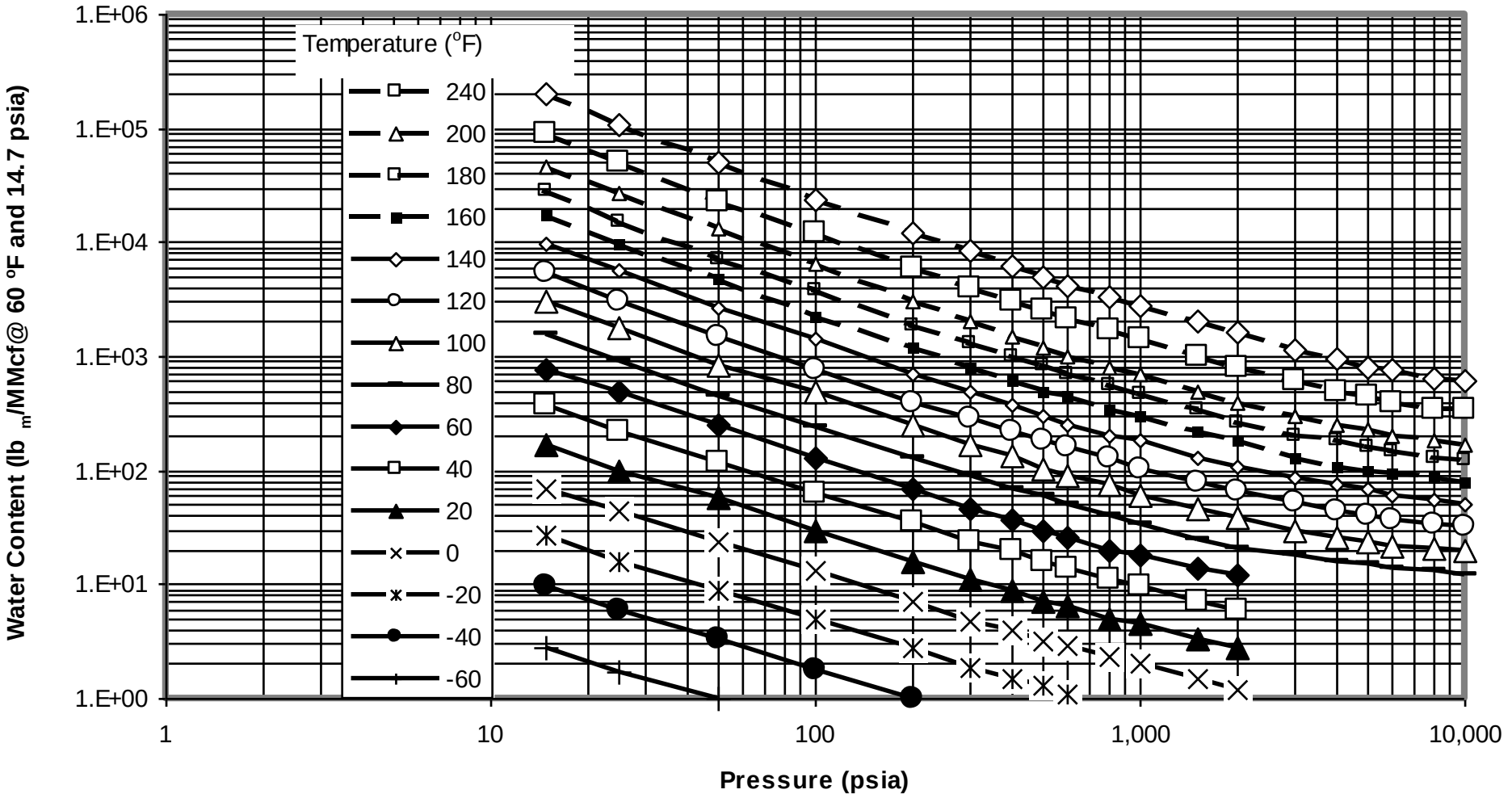


*Figure 5-1: Water content of natural gases*

# 5.2 Methods for Dehydration

Dehydration techniques used in the petroleum industry fall into four categories in principle:

1. Direct cooling
2. Compression followed by cooling,
3. Absorption
4. Adsorption

Dehydration in the **first two methods does not result in sufficiently low water contents to permit injection into a pipeline**. Further dehydration by absorption or adsorption is often required.

# 5.2.1 Dehydration by Cooling

- The ability of natural gas to contain **water vapor decreases as the temperature is lowered** at constant pressure. During the cooling process, the excess **water in the vapor state becomes liquid** and is **removed** from the system.

- Natural gas containing less water vapor at low temperature is output from the cooling unit.

- The gas dehydrated by cooling is still at its water dew point unless the temperature is raised again or the pressure is decreased.

- Cooling for the purpose of gas dehydration is sometimes economical if the gas temperature is unusually high. It is often a good practice that cooling is used in conjunction with other dehydration processes.

# 5.2.1 Dehydration by Cooling

- **Gas compressors** can be used partially as dehydrators. Because the saturation **water content** of gases decreases at higher pressure, some water is condensed and removed from gas at compressor stations by the compressor discharge coolers.

- Modern lean oil absorption gas plants use mechanical refrigeration to chill the inlet gas stream.

- Ethylene glycol is usually injected into the gas chilling section of the plant, which simultaneously dehydrates the gas and recovers liquid hydrocarbons, in a manner like the low-temperature separators.

# 5.2.2 Dehydration by Adsorption

- "Adsorption" is defined as the ability of a substance to hold gases or liquids on its surface.
- In adsorption dehydration, the water vapor from the gas is concentrated and held at the surface of the solid desiccant by forces caused by residual valiancy.
- Solid desiccants have very large surface areas per unit weight to take advantage of these surface forces.
- The most common solid adsorbents used today are **silica, alumina, and certain silicates known as molecular sieves**.
- Dehydration plants can remove practically all water from natural gas using solid desiccants. Because of their great drying ability, solid desiccants are employed where higher efficiencies are required.

# 5.2.2 Dehydration by Adsorption

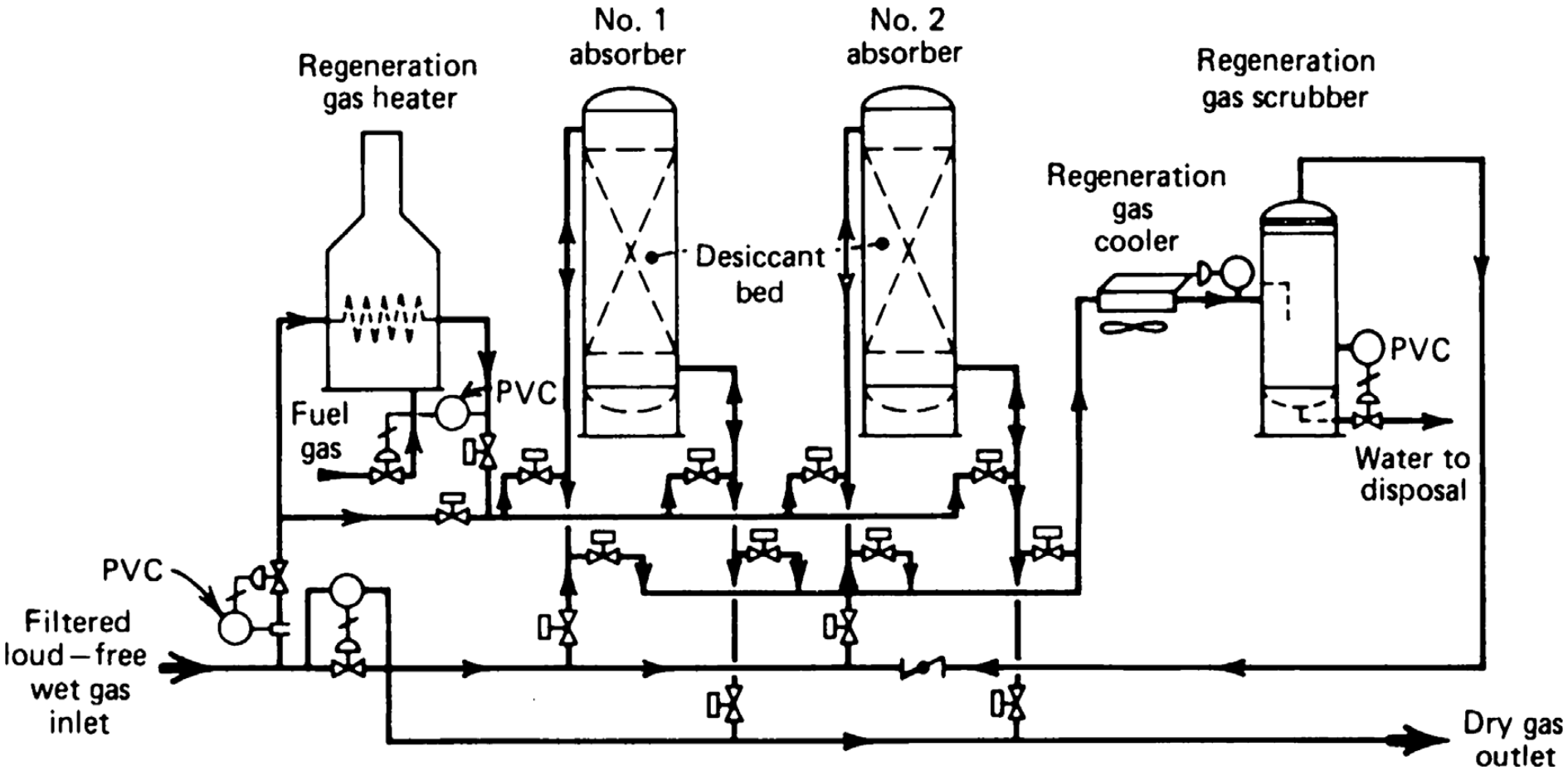


*Figure 5-2: Flow diagram of a typical solid desiccant dehydration plant*

# 5.2.2 Dehydration by Adsorption

Shown in Fig. 5-2 is a typical solid desiccant dehydration plant.

- The incoming wet gas should be cleaned preferably by a filter separator to remove solid and liquid contaminants in the gas.
- The filtered gas flows downward during dehydration through one adsorber containing a desiccant bed.
- The down-flow arrangement reduces disturbance of the bed caused by the high gas velocity during the adsorption.
- While one adsorber is dehydrating, the other adsorber is being regenerated by a hot stream of inlet gas from the regeneration gas heater.
- A direct-fired heater, hot oil, steam, or an indirect heater can supply the necessary regeneration heat.

# 5.2.2 Dehydration by Adsorption

- The regeneration gas usually flows upward through the bed to ensure thorough regeneration of the bottom of the bed, which is the last area contacted by the gas being dehydrated.
- The hot regenerated bed is cooled by shutting off or bypassing the heater.
- The cooling gas then flows downward through the bed so that any water adsorbed from the cooling gas will be at the top of the bed and will not be desorbed into the gas during the dehydration step.
- The still-hot regeneration gas and the cooling gas flow through the regeneration gas cooler to condense the desorbed water.
- Power-operated valves activated by a timing device switch the adsorbers between the dehydration, regeneration, and cooling steps.

# 5.2.2 Dehydration by Adsorption

- Under normal operating conditions, the usable life of a desiccant ranges from **1 to 4 years**.
- Solid desiccants become less effective in normal use because of loss of effective surface area as they age.
- Abnormally fast degradation occurs through blockage of the small pores and capillary openings lubricating oils, amines, glycols, corrosion inhibitors, and other contaminants, which cannot be removed during the regeneration cycle.
- Hydrogen sulfide can also damage the desiccant and reduce its capacity.

# 5.2.2 Dehydration by Adsorption

The advantages of solid-desiccant dehydration include:

1. Lower dew point, essentially dry gas (water content less than 1.0 lb/MMcf) can be produced
2. Higher contact temperatures can be tolerated with some adsorbents.
3. Higher tolerance to sudden load changes, especially on startup.
4. Quick start up after a shutdown.
5. High adaptability for recovery of certain liquid hydrocarbons in addition to dehydration functions.

Operating problems with the solid-desiccant dehydration include: Space adsorbents degenerate with use and require replacement.

# 5.2.2 Dehydration by Adsorption

- Operating problems with the solid-desiccant dehydration include:
- Space adsorbents degenerate with use and require replacement.

- Dehydrating tower must be regenerated and cooled for operation before another tower approaches exhaustion. The maximum allowable time on dehydration gradually shortens because desiccant loses capacity with use.

- Although this type of dehydrator has high adaptability to sudden load changes, sudden pressure surges should be avoided because they may upset the desiccant bed and channel the gas stream resulting in poor dehydration. If a plant is operated above its rated capacity, high-pressure loss may introduce some attrition to occur. Attrition causes fines, which may in turn cause excessive pressure loss and result in loss of capacity.

# 5.2.3 Dehydration by Absorption

- Water vapor is removed from the gas by intimate contact with a hygroscopic liquid desiccant in absorption dehydration.
- The contacting is usually achieved in packed or trayed towers. Glycols have been widely used as effective liquid desiccants.
- Dehydration by absorption with glycol is usually economically more attractive than dehydration by solid desiccant when both processes are capable of meeting the required dew point.
- Glycols used for dehydrating natural gas are ethylene glycol (EG), diethylene glycol (DEG), triethylene glycol (TEG), and tetraethylene glycol (T4EG). Normally a single type of pure glycol is used in a dehydrator, but sometimes a glycol blend is economically attractive.

# 5.2.3 Dehydration by Absorption

- Triethylene Glycol **(TEG) has gained nearly universal acceptance** as the most cost effective of the glycols because of its superior dew-point depression, operating cost, and operation reliability. TEG has been successfully used to dehydrate sweet and sour natural gases over wide ranges of operating conditions.

- Dew-point depression of 40–140 F can be achieved at a gas pressure ranging from 25 to 2,500 psig and gas temperature between 40 and 160 F.

- The dew-point depression obtained depends on the equilibrium dew-point temperature for a given TEG concentration and contact temperature.

- Increased glycol viscosity may cause problems at lower contact temperature. Thus, heating of the natural gas may be desirable. Very hot gas streams are often cooled before dehydration to prevent vaporization of TEG.

# 5.2.3 Dehydration by Absorption

- The **feeding-in gas must be cleaned to** remove all liquid water and hydrocarbons, wax, sand, drilling muds, and other impurities.

- **These substances can cause severe** foaming, flooding, higher glycol losses, poor efficiency, and increased maintenance in the dehydration tower or absorber. These impurities can be removed using an efficient **scrubber, separator, or even a filter separator** for very contaminated gases.

- Methanol, injected at the wellhead as hydrate inhibitor, can cause several problems for glycol dehydration plants.

- It increases the heat requirements of the glycol regeneration system. Slugs of liquid methanol can cause flooding in the absorber.

- Methanol vapor vented to the atmosphere with the water vapor from the regeneration system is hazardous and should be recovered or vented at nonhazardous concentrations.

# 5.3 Glycol Dehydration Process

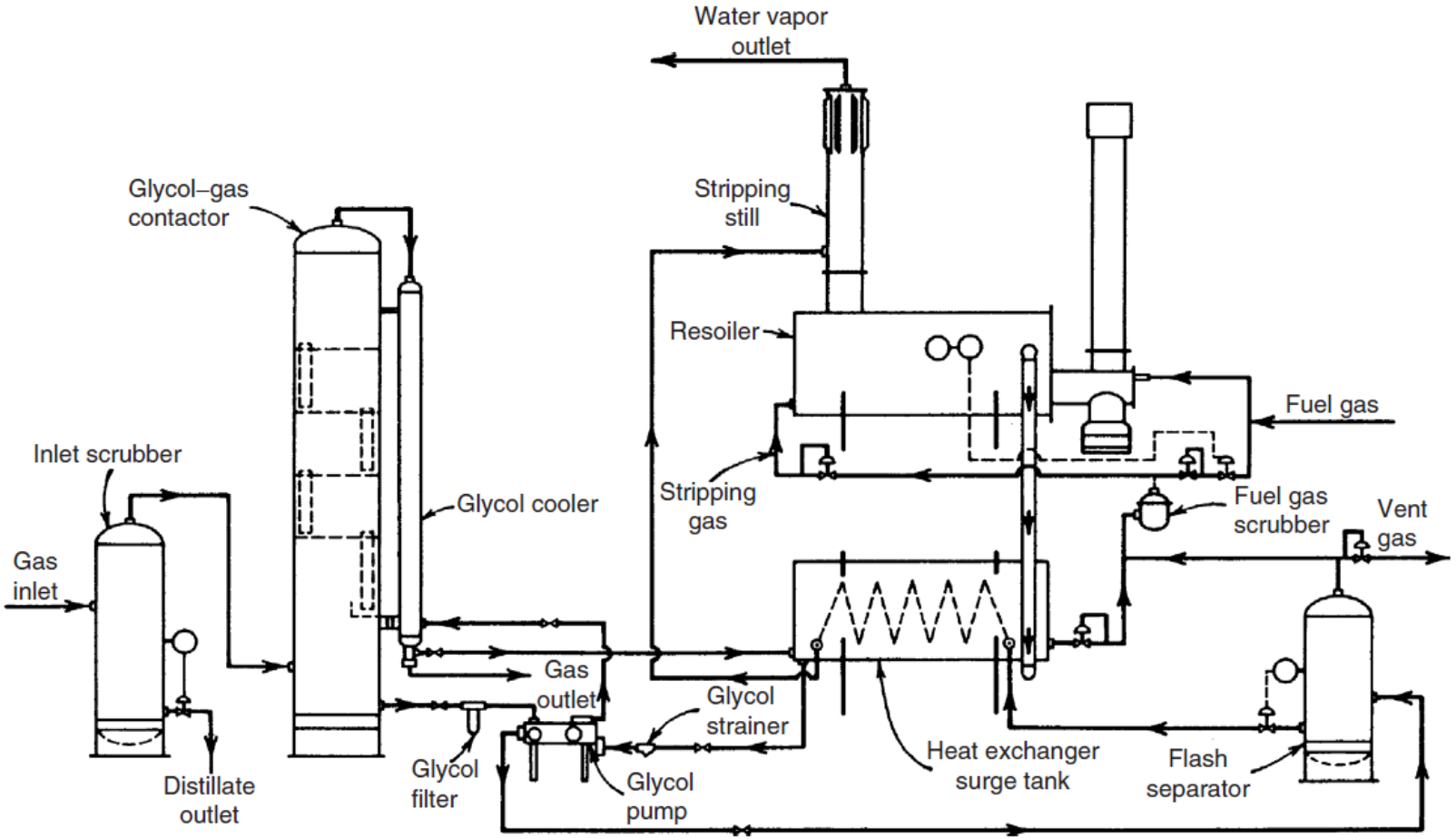


*Figure 5-3: Flow diagram of a typical glycol dehydrator*

# 5.3 Glycol Dehydration Process

The dehydration process can be described as follows:

1) The feeding-in gas stream first enters the unit through an inlet gas scrubber to remove liquid accumulations. A two-phase inlet scrubber is normally required.

2) The wet gas is then introduced to the bottom of the glycol-gas contactor and allowed to flow upward through the trays, while glycol flows downward through the column. The gas contacts the glycol on each tray and the glycol absorbs the water vapor from the gas steam.

3) The gas then flows down through a vertical glycol cooler, usually fabricated in the form of a concentric pipe heat exchanger, where the outlet dry gas aids in cooling the hot regenerated glycol before it enters the contactor. The dry gas then leaves the unit from the bottom of the glycol cooler.

# 5.3 Glycol Dehydration Process

4) The dry glycol enters the top of the glycol-gas contactor from the glycol cooler and is injected onto the top tray. The glycol flows across each tray and down through a downcomer pipe onto the next tray. The bottom tray downcomer is fitted with a seal pot to hold a liquid seal on the trays.

5) The wet glycol, which has now absorbed the water vapor from the gas stream, leaves the bottom of the glycol-gas contactor column, passes through a high-pressure glycol filter, which removes any foreign solid particles that may have been picked up from the gas stream, and enters the power side of the glycol pump.

6) In the glycol pump the wet high-pressure glycol from the contactor column pumps the dry regenerated glycol into the column. The wet glycol stream flows from the glycol pump to the flash separator which allows for the release of the entrained solution gas.

# 5.3 Glycol Dehydration Process

7) The gas separated in the flash separator leaves the top of the flash separator vessel and can be used to supplement the fuel gas required for the reboiler. Any excess vent gas is discharged through a backpressure valve. The flash separator is equipped with a liquid level control and diaphragm motor valve that discharges the wet glycol stream through a heat exchange coil in the surge tank to preheat the wet glycol stream.

8) The wet glycol stream leaves the heat exchange coil in the surge tank and enters the stripping still mounted on top of the reboiler at the feed point in the still. The stripping still is packed with a ceramic intalox saddle- type packing, and the glycol flows downward through the column and enters the reboiler. The wet glycol passing downward through the still is contacted by hot rising glycol and water vapors passing upward through the column. The water vapors released in the reboiler and stripped from the glycol in the stripping still pass upward through the still column through an atmospheric reflux condenser that provides a partial reflux for the column. The water vapor then leaves the top of the stripping still column and is released to the atmosphere.

# 5.3 Glycol Dehydration Process

**9**) The glycol flows through the reboiler in essentially a horizontal path from the stripping still column to the opposite end. In the reboiler, the glycol is heated to approximately 350 ºF to 400 ºF to remove enough water vapor to re-concentrate it to 99.5% or higher. In field dehydration units, the reboiler is generally equipped with a direct-fired firebox, using a portion of the natural gas stream for fuel.

10) The re-concentrated glycol leaves the reboiler through an overflow pipe and passes into the shell side of the heat exchanger/surge tank. In the surge tank the hot re-concentrated glycol is cooled by exchanging heat with the wet glycol stream passing through the coil. The surge tank also acts as a liquid accumulator for feed for the glycol pump. The re-concentrated glycol flows from the surge tank through a strainer and into the glycol pump. From the pump it passes into the shell side of the glycol cooler mounted on the glycol gas contactor. It then flows upward through the glycol cooler where it is further cooled and enters the column on the top tray.

# 5.3.1 Advantages and Limitations

Glycol dehydrators have several advantages including:

1. Low initial-equipment cost
2. Low-pressure drop across absorption towers
3. Continuous operation
4. Makeup requirements may be added readily
5. Recharging of towers presents no problems
6. The plant may be used satisfactorily in the presence of materials that would cause fouling of some solid adsorbents

Glycol dehydrators also present several operating problems including:

1. Suspended matter, such as dirt, scale, and iron oxide, may contaminate glycol solutions.
2. Overheating of solution may produce both low and high boiling decomposition products.
3. The resultant sludge may collect on heating surfaces, causing some loss in efficiency, or, in severe cases, complete flow stoppage.
4. When both oxygen and hydrogen sulfide are present, corrosion may become a problem because of the formation of acid material in glycol solution.
5. Liquids (e.g., water, light hydrocarbons, or lubrication oils) in inlet gas may require installation of an efficient separator ahead of the absorber. Highly mineralized water entering the system with inlet gas may, over long periods, crystallize and fill the reboiler with solid salts.
6. Foaming of solution may occur with a resultant carry over of liquid. The addition of a small quantity of antifoam compound usually remedies this problem.

Glycol dehydrators also present several operating problems including:

7. Some leakage around the packing glands of pumps may be permitted because excessive tightening of packing may result in the scouring of rods. This leakage is collected and periodically returned to the system.

8. Highly concentrated glycol solutions tend to become viscous at low temperatures and, therefore, are hard to pump. Glycol lines may solidify completely at low temperatures when the plant is not operating. In cold weather, continuous circulation of part of the solution through the heater may be advisable. This practice can also prevent freezing in water coolers.

9. To start a plant, all absorber trays must be filled with glycol before good contact of gas and liquid can be expected. This may also become a problem at low-circulation rates because weep holes on trays may drain solution as rapidly as it is introduced.

10. Sudden surges should be avoided in starting and shutting down a plant. Otherwise, large carry-over losses of solution may occur.

# 5.4 Sizing Glycol Dehydrator Unit

Dehydrators with Triethylene Glycol (TEG) in trays or packed-column contactors can be sized from standard models by using the following information:

1. Gas flow rate
2. Specific gravity of gas
3. Operating pressure
4. Maximum working pressure of contact
5. Gas inlet temperature
6. Outlet gas water content required

# 5.4 Sizing Glycol Dehydrator Unit

One of the following two design criteria can be employed:

- Glycol to water ratio (GWR). A value of 2-to-6-gal TEG/lbm H2O removed is adequate for most glycol dehydration requirements. Very often 2.5-to-4-gal TEG/lbm H2O is used for field dehydrators.

- Lean TEG concentration from re-concentrator. Most glycol re-concentrators can output 99.0 to 99.9% lean TEG. A value of 99.5% lean TEG is utilized in most designs.

# 5.4 Sizing Glycol Dehydrator Unit

- Inlet Scrubber. It is essential to have a good inlet scrubber for efficient operation of a glycol dehydrator unit. Two-phase inlet scrubbers are generally constructed with $7^{1/2}$ -ft shell heights. The required minimum diameter of a vertical inlet scrubber can be determined based on the operating pressure and required gas capacity using Fig. 5.4

- Glycol-Gas Contactor. Glycol contactors are generally constructed with a standard height of $7^{1/2}$ ft. The minimum required diameter of the contactor can be determined based on the gas capacity of the contactor for standard gas of 0.7 specific gravity at standard temperature 100 F.

# 5.4 Sizing Glycol Dehydrator Unit

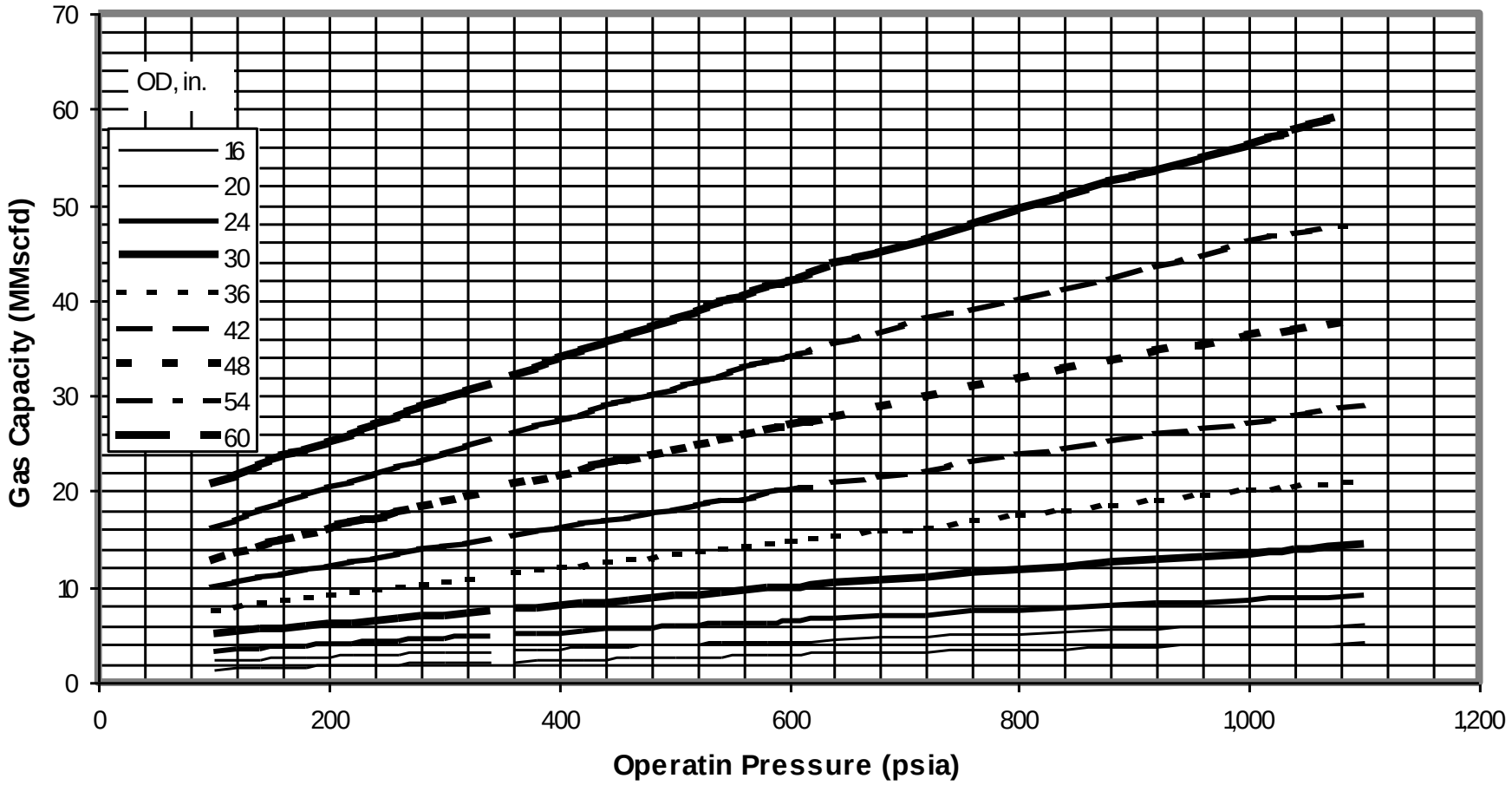


*Figure 5-4: Gas capacity of vertical inlet scrubbers based on 0.7 specific gravity at 100 $^{o}$F*

# 5.4 Sizing Glycol Dehydrator Unit

If the gas is not the standard gas and/or the operating temperature is different from the standard temperature , a correction should be first made using the following relation:

$$q_s = \frac{q}{C_t C_g} \qquad (5.7)$$

$q$= gas capacity of contactor at operating conditions, MMscfd
$q_s$= gas capacity of contactor for standard gas (0.7 specific gravity) at standard temperature (100 ºF), MMscfd
$C_t$= correction factor for operating temperature
$C_g$= correction factor for gas-specific gravity

# 5.4 Sizing Glycol Dehydrator Unit

The temperature and gas-specific gravity correction factors for trayed glycol contactors are given in Tables 5.1 and 5.2, respectively.

The temperature and specific gravity factors for packed glycol contactors are contained in Tables 5.3 and 5.4, respectively.

Once the gas capacity of the contactor for standard gas at standard temperature is calculated, the required minimum diameter of a trayed glycol contactor can be calculated using Fig. 5.5.

The required minimum diameter of a packed glycol contactor can be determined based on Fig. 5.6.

# 5.4 Sizing Glycol Dehydrator Unit

Table 5-1: Temperature Correction Factors for Trayed Glycol Contactors

| *Operating temperature* (°F) | *Correction factor* ($C_t$) |
|---|---|
| 40 | 1.07 |
| 50 | 1.06 |
| 60 | 1.05 |
| 70 | 1.04 |
| 80 | 1.02 |
| 90 | 1.01 |
| 100 | 1.00 |
| 110 | 0.99 |
| 120 | 0.98 |

# 5.4 Sizing Glycol Dehydrator Unit

*Table 5-2: Specific Gravity Correction Factors for Trayed Glycol Contactors*

| *Gas-specific gravity* (air = 1) | *Correction factor* ($C_g$) |
|---|---|
| 0.55 | 1.14 |
| 0.60 | 1.08 |
| 0.65 | 1.04 |
| 0.70 | 1.00 |
| 0.75 | 0.97 |
| 0.80 | 0.93 |
| 0.85 | 0.90 |
| 0.90 | 0.88 |

# 4.4 Sizing Glycol Dehydrator Unit

*Table 5-3: Temperature Correction Factors for Packed Glycol Contactors*

| *Operating temperature* (°F) | *Correction factor* ($C_t$) |
|---|---|
| 50 | 0.93 |
| 60 | 0.94 |
| 70 | 0.96 |
| 80 | 0.97 |
| 90 | 0.99 |
| 100 | 1.00 |
| 110 | 1.01 |
| 120 | 1.02 |

# 4.4 Sizing Glycol Dehydrator Unit

*Table 5-4: Specific Gravity Correction Factors for Packed Glycol Contactors*

| *Gas-specific gravity* (air = 1) | *Correction Factor* ($C_g$) |
|---|---|
| 0.55 | 1.13 |
| 0.60 | 1.08 |
| 0.65 | 1.04 |
| 0.70 | 1.00 |
| 0.75 | 0.97 |
| 0.80 | 0.94 |
| 0.85 | 0.91 |
| 0.90 | 0.88 |

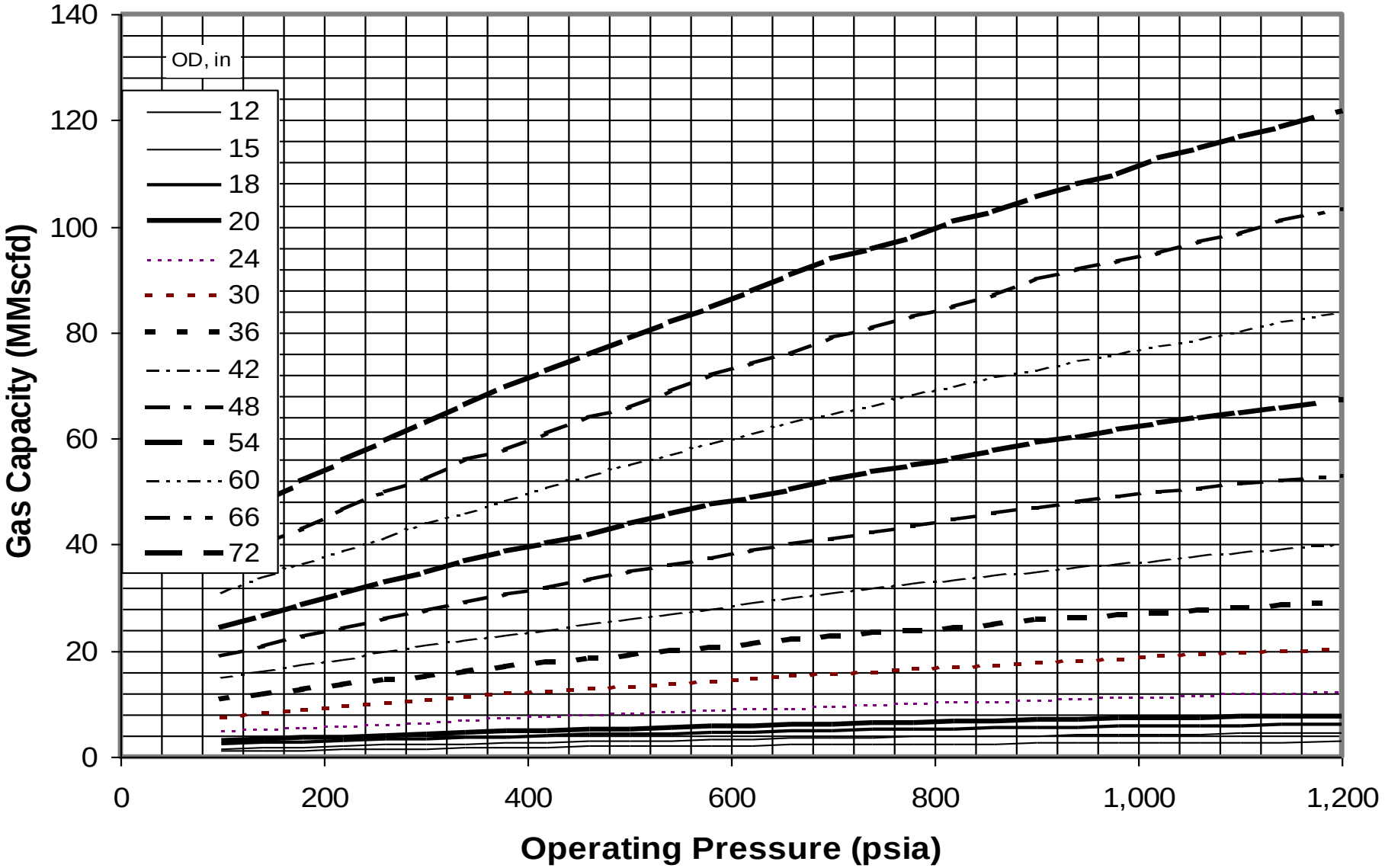


*Figure 5-5: Gas capacity for trayed glycol contactors based on 0.7 specific gravity at 100 F*

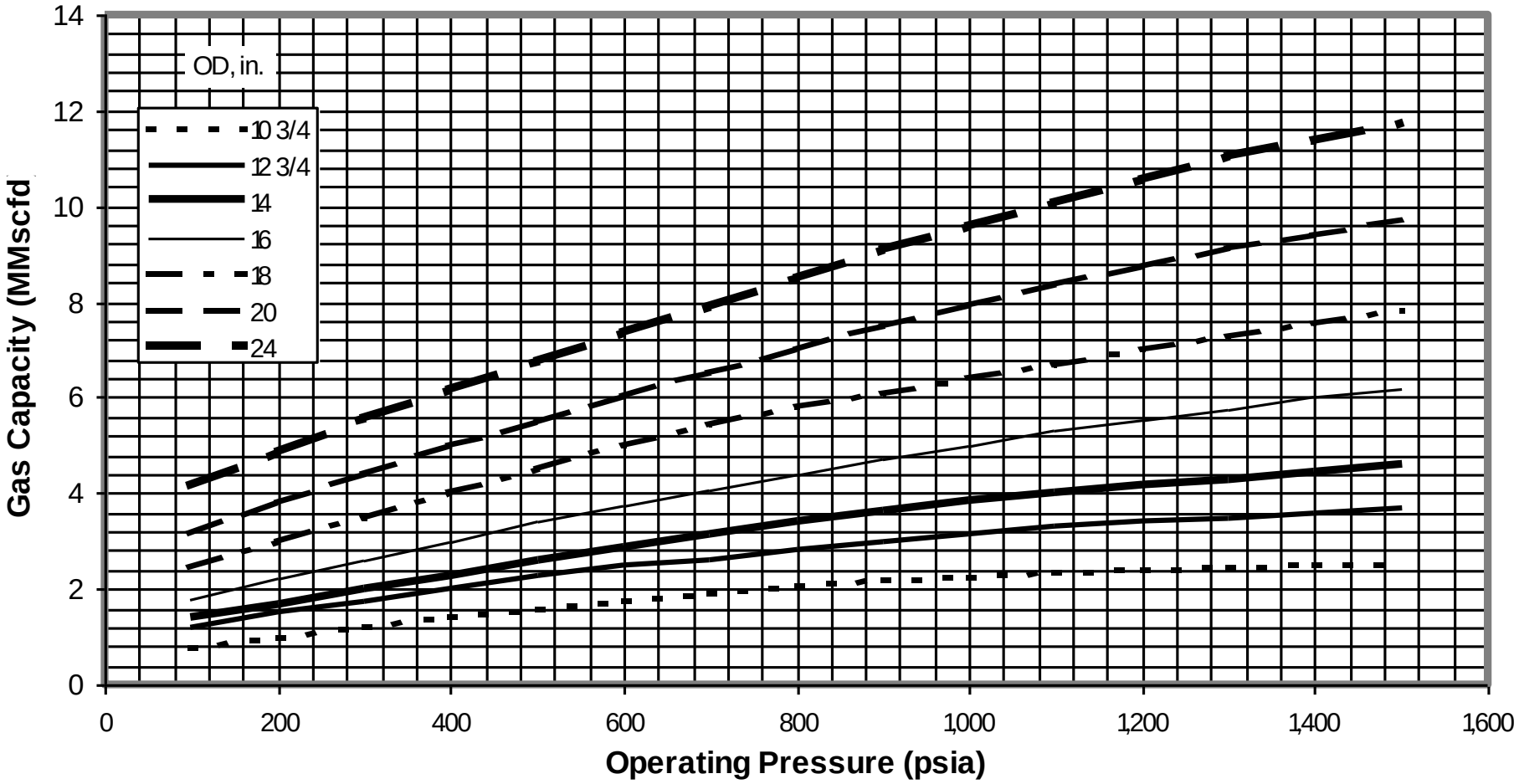


*Figure 5-6: Gas capacity for packed glycol contactors based on 0.7 specific gravity at 100 F*

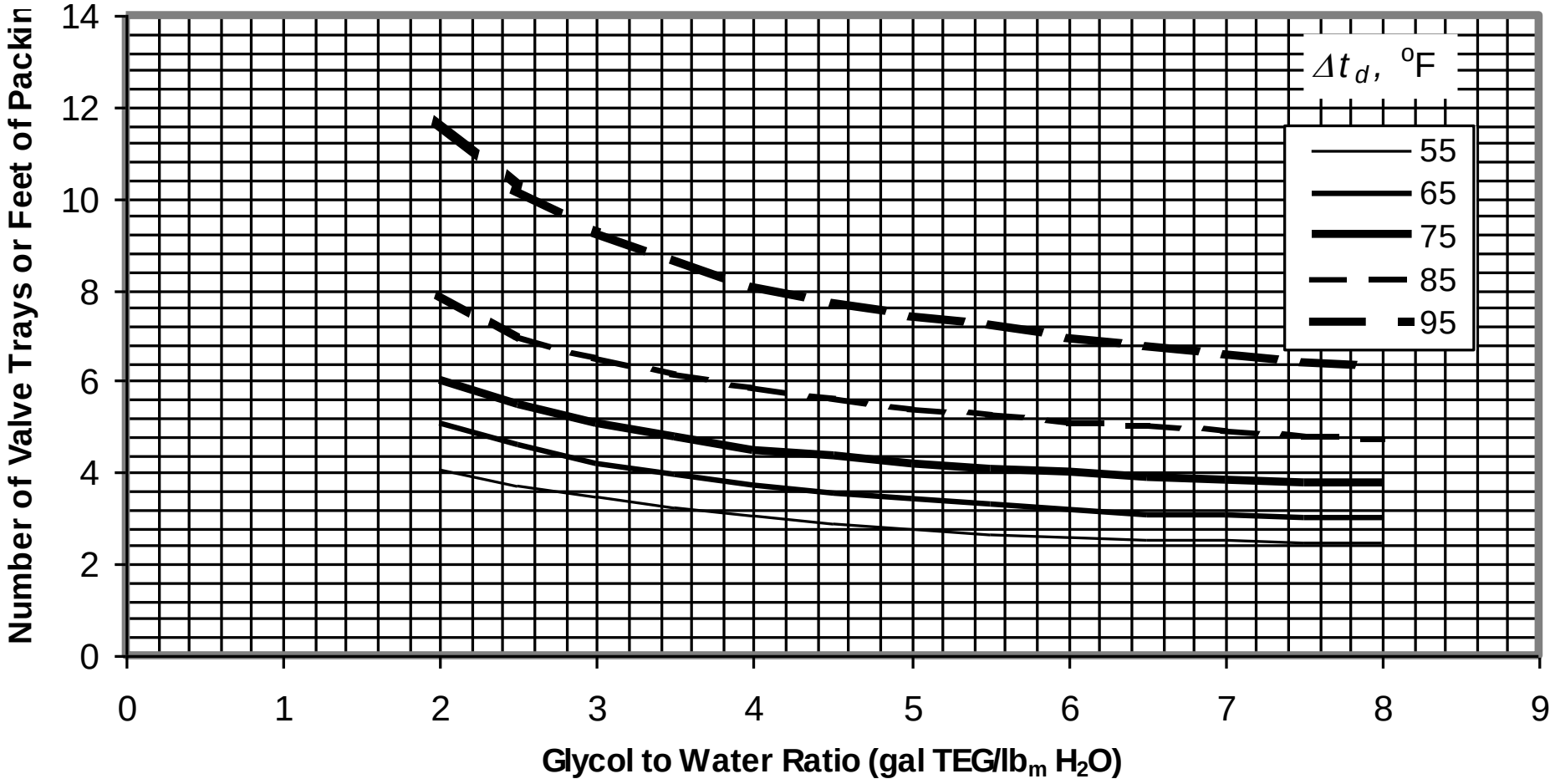


*Figure 5-7: The required minimum height of packing of a packed contactor, or the minimum number of trays of a trayed contactor*

# Example Problem 5-2:

Size a trayed-type glycol contactor for a field installation to meet the following requirements:

| | |
|---|---|
| Gas flow rate: | 12 MMscfd |
| Gas specific gravity: | 0.75 |
| Operating line pressure: | 900 psig |
| Maximum working pressure of contactor: | 1,440 psig |
| Gas inlet temperature: | 90 °F |
| Outlet gas water content: | 6 lb $H_2O$/MMscf |
| Design criteria: | GWR = 3 gal TEG/$lb_m$ $H_2O$ with 99.5% TEG |

# Solution:

Because the given gas is not a standard gas and the inlet temperature is not the standard temperature, corrections need to be made. Tables 5.1 and 5.2 give $C_t$ = 1.01 and $C_g$ = 0.97.

The gas capacity of contactor is calculated with Eq (5.7):

$$q_s = \frac{12}{(1.01)(0.97)}$$

= 12.25 MMscfd.

# Solution:

Figure 5-5 gives contactor diameter *DC* = 30 in.

Figure 5-1 gives water content of inlet gas: *Cwi* = 50 lbm/MMscf

The required water content of outlet gas determines the dew point temperature of the outlet gas through Figure 5-1: *tdo* = 28 oF

Therefore, the dew point depression is $\Delta td = 90 - 28 = 62$ oF.

Based on GWR = 3 gal TEG/lbm H2O and $\Delta td = 62$ ºF,

Figure 5-7 gives the number of trays rounded off to be four.

# Glycol Re-concentrator.

Sizing the various components of a glycol re-concentrator starts from calculating the required glycol circulation rate:

$$q_G = \frac{(GWR)C_{wi}q}{24} \qquad \textbf{(5.8)}$$

Where,

$q_G$ = glycol circulation rate, gal/hr
$GWR$ = glycol to water ratio, gal TEG/$lb_m$ $H_2O$
$C_{wi}$ = water content of inlet gas, $lb_m$ $H_2O$/MMscf
$q$ = gas flow rate, MMscfd

# Reboiler.

The required heat load for the reboiler can be approximately estimated from the following equation:

$$H_t = 2{,}000 q_G \qquad \textbf{(5.9)}$$

Ht = total heat load on reboiler, Btu/hr

The general overall size of the reboiler can be determined as follows:

$$A_{fb} = \frac{H_t}{7{,}000} \qquad \textbf{(5-10)}$$

$A_{fb}$ is the total firebox surface area in squared feet.

# Glycol Circulating Pump.

The glycol circulating pump can be sized using the **glycol circulation rate** and the **maximum operating pressure** of the contactor. Commonly used glycol powered pumps use the rich glycol from the bottom of the contactor to power the pump and pump the lean glycol to the top of the contactor. The manufacturers of these pumps should be consulted to meet the specific needs of the glycol dehydrator.

# Glycol Flash Separator.

A glycol flash separator is usually installed downstream from the glycol pump to remove any entrained hydrocarbons from the rich glycol. A small 125-psi vertical two-phase separator is usually adequate for this purpose. The separator should be sized based on a liquid retention time in the vessel of at least 5 minutes.

$$V_s = \frac{q_G t_r}{60} \qquad \textbf{(5-11)}$$

$V_s$ = required settling volume in separator, gal
$q_G$ = glycol circulation rate, gph
$t_r$ = retention time approximately 5 minute

# Glycol Flash Separator

- **Liquid hydrocarbon is not allowed** to enter the glycol-gas contactor. If this is a problem, a three-phase glycol flash separator should be used to keep these liquid hydrocarbons out of the reboiler and stripping still.
- Three-phase flash separators should be **sized** with a **liquid retention time** of 20– 30 minutes. The hydrocarbon gas released from the flash separator can be piped to the reboiler to use as fuel gas and stripping gas. Based on the glycol circulation rate and the operating pressure of the contactor, the amount of gas available from the glycol pump can be determined.

# Stripping Still

- The size of the packed stripping still for the glycol re-concentrator can be determined based on the glycol-to-water circulation rate (gas TEG/lbm H2O) and the glycol circulation rate (gph).

- The required diameter for the stripping still is normally based on the required diameter at the base of the still using the vapor and liquid loading conditions at the base point. The vapor load consists of the water vapor and stripping gas flowing up through the still.

- The liquid load consists of the rich glycol stream and reflux flowing downward through the still column. One tray is normally sufficient for most stripping still requirements for TEG dehydration units. The amount of stripping gas required to re-concentrate the glycol is approximately 2-10 ft3 per gal of glycol circulated.

# Tutorials

**5.1**

Calculate the minimum required size of a standard oil/gas separator for the following conditions (consider vertical, horizontal, and spherical separators):

| | |
|---|---|
| Gas flow rate: | 4.0 MMscfd |
| Gas-specific gravity: | 0.7 |
| Condensate-gas ratio (CGR): | 15 bbl/MMscf |
| Condensate gravity: | 65 °API |
| Operating pressure: | 600 psig |
| Operating temperature: | 70 °F |

**5.2**

A three-stage separation is proposed to treat a well stream at a flowline pressure of 1,000 psia. Calculate pressures at each stage of separation.

**5.3**

Estimate water contents of a natural gas at a pressure of 2,000 psia and temperatures of 40, 80, 120, 160, 200, and 240 F.

# Tutorials

**5.4**

Design a glycol contactor for a field dehydration installation to meet the following requirements. Consider both trayed-type and packed-type contactors.

| | |
|---|---|
| Gas flow rate: | 10 MMscfd |
| Gas-specific gravity: | 0.65 |
| Operating line pressure: | 1,000 psig |
| Maximum working pressure of contactor: | 1,440 psig |
| Gas inlet temperature: | 90 °F |
| Outlet gas water content: | 7 lb $H_2O$/MMscf |
| Design criteria with 99.5% TEG: | GWR = 3 gal TEG/$lb_m$ $H_2O$ |