



Gas Dehydration (*Dehidrasi Gas*)

Teknologi Pemrosesan Gas (TKK 564)

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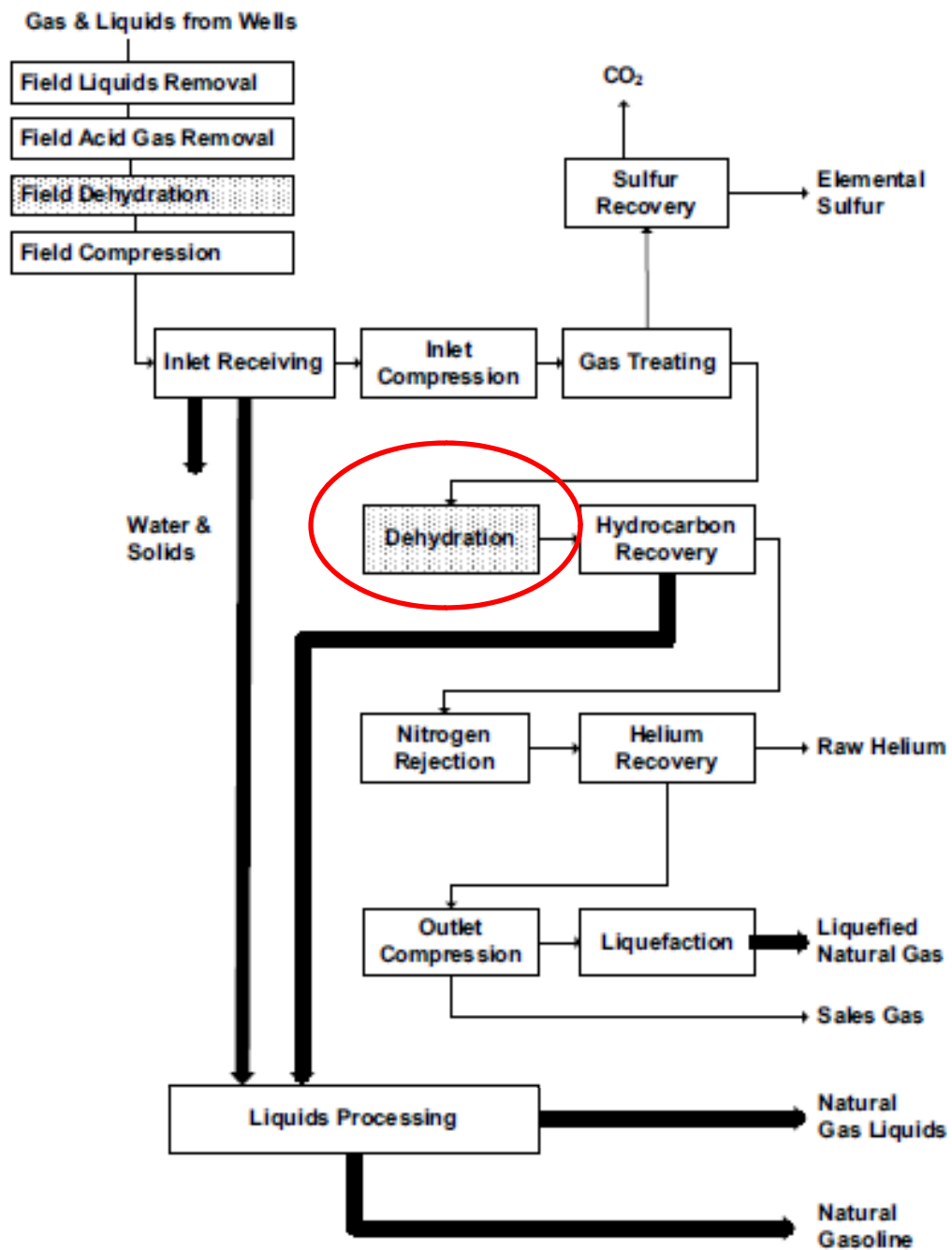
Instructor's Background

- BEng. (1995): Universitas Diponegoro
- Meng. (2000): Institut Teknologi Bandung
- PhD. (2006): Universiti Teknologi Malaysia
- Specialization:
 - Catalyst Design for Energy Conversion
 - Process Design for Energy Conversion
 - Combustion Engineering
 - Computational Fluid Dynamic (CFD)



Course Syllabus: (Part 1)

1. Definitions of Natural Gas, Gas Reservoir, Gas Drilling, and Gas production (*Pengertian gas alam, gas reservoir, gas drilling, dan produksi gas*)
2. Overview of Gas Plant Processing (*Overview Sistem Pemrosesan Gas*)
3. Gas Field Operations and Inlet Receiving (*Operasi Lapangan Gas dan Penerimaan Inlet*)
4. Gas Treating: Chemical Treatment (*Pengolahan Gas: Secara Kimia*)
5. Gas Treating: Physical Treatment (*Pengolahan Gas: Secara Kimia*)
6. **Gas Dehydration (*Dehidrasi Gas*)**
7. Gas Compression System (*Sistem Kompresi Gas*)
8. *Ujian Tengah Semester*



Importance of Dehydration

- **Gas Gathering:**

- to reduce pipeline corrosion
- eliminate line blockage caused by hydrate formation
- water dew point < the lowest pipeline temperature → no water formation

- **Product Dehydration:**

- Sales gas is usually dry if cryogenic hydrocarbon liquid recovery is used
- Liquid and gas streams may be water saturated after amine treatment or coming from underground storage
- Most product specifications, except for propane, require that no free water be present


- **Hydrocarbon Recovery:**

- If acid gases are removed by use of amine processes, → the exit gas leaves water saturated
- To prevent hydrate formation in the cryogenic section of hydrocarbon recovery → water ≤ 0.1 ppmv

WATER CONTENT OF HYDROCARBONS

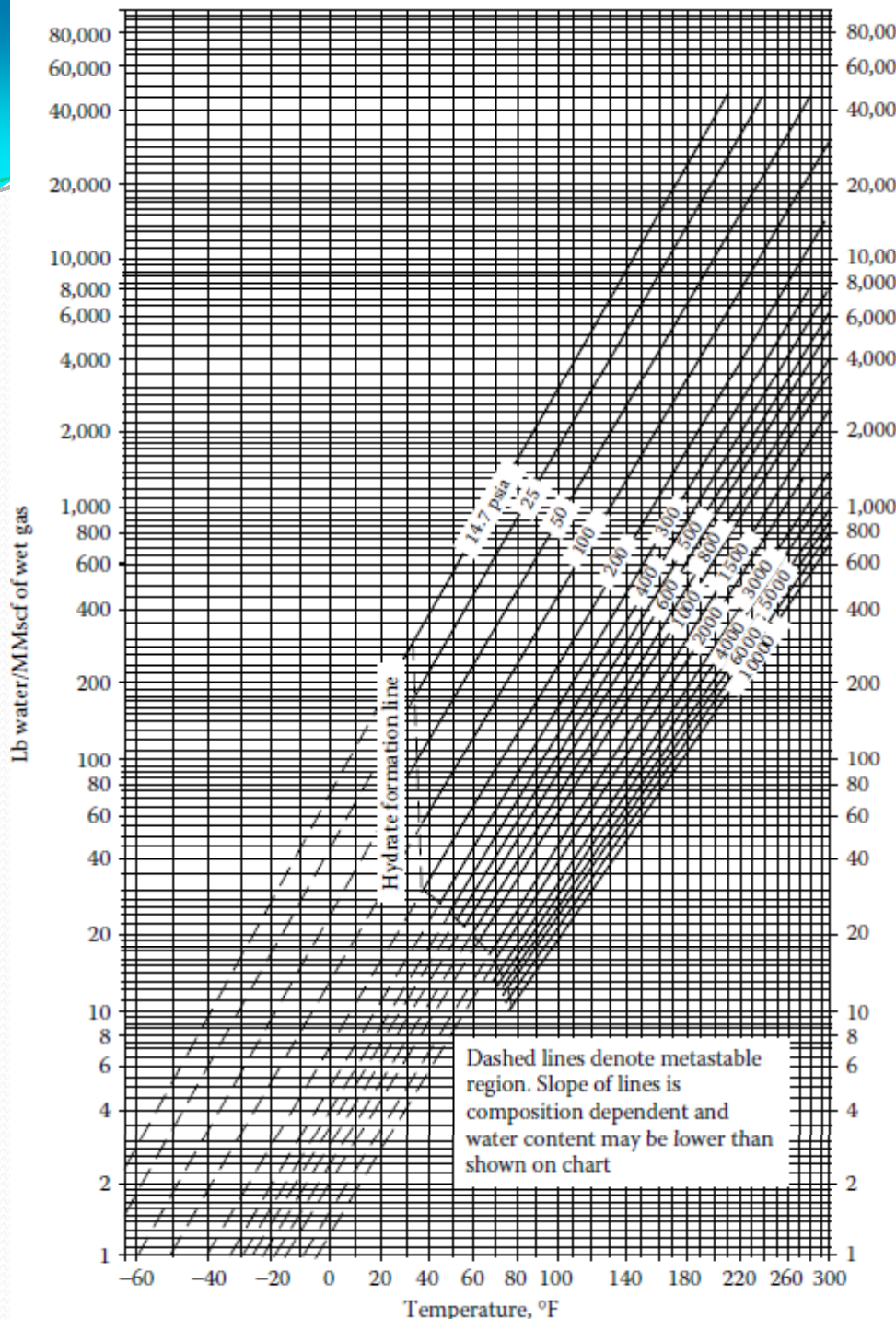
- **Water content is stated** in a number of ways:
 - **Mass of water per volume** of gas, lb/MMscf (mg/Sm³)
 - **Dew point temperature**, °F (°C)
 - **Concentration**, parts per million by volume (ppmv)
 - **Concentration**, parts per million by mass (ppmw)
- First assume: ideal behavior
- In any mixture, where both the gas and liquid phases are in equilibrium → non ideal

$$x_i \gamma_i P_i^{Sat} = y_i \phi_i P$$

- 
- The **vapor pressure** is temperature dependent,
 - the **activity** and **fugacity coefficients** are temperature, pressure, and composition dependent
 - The activity and fugacity coefficients can be calculated by use of **equations of state** and **empirical equations**
 - If we make the good assumption of **negligible hydrocarbon in the liquid water phase**, which, thus makes both x_i and γ_i unity for water and assume the gas phase to be ideal, which makes j_i unity.

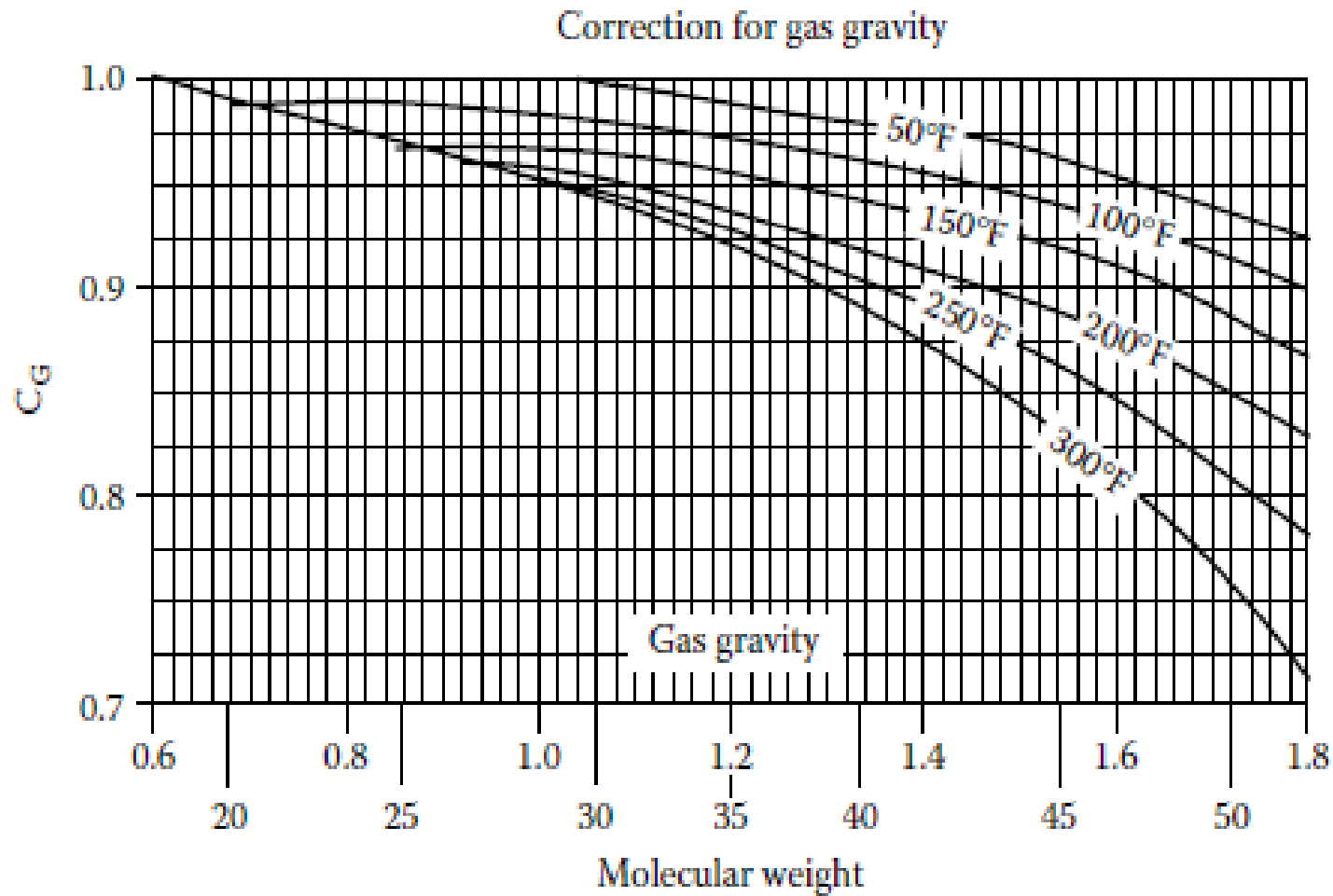
$$y_{H_2O} = \frac{p_{H_2O}^{Sat}}{p}$$

Water content of hydrocarbon gases as a function of temperature and pressure (P<500 psia(34 bar))



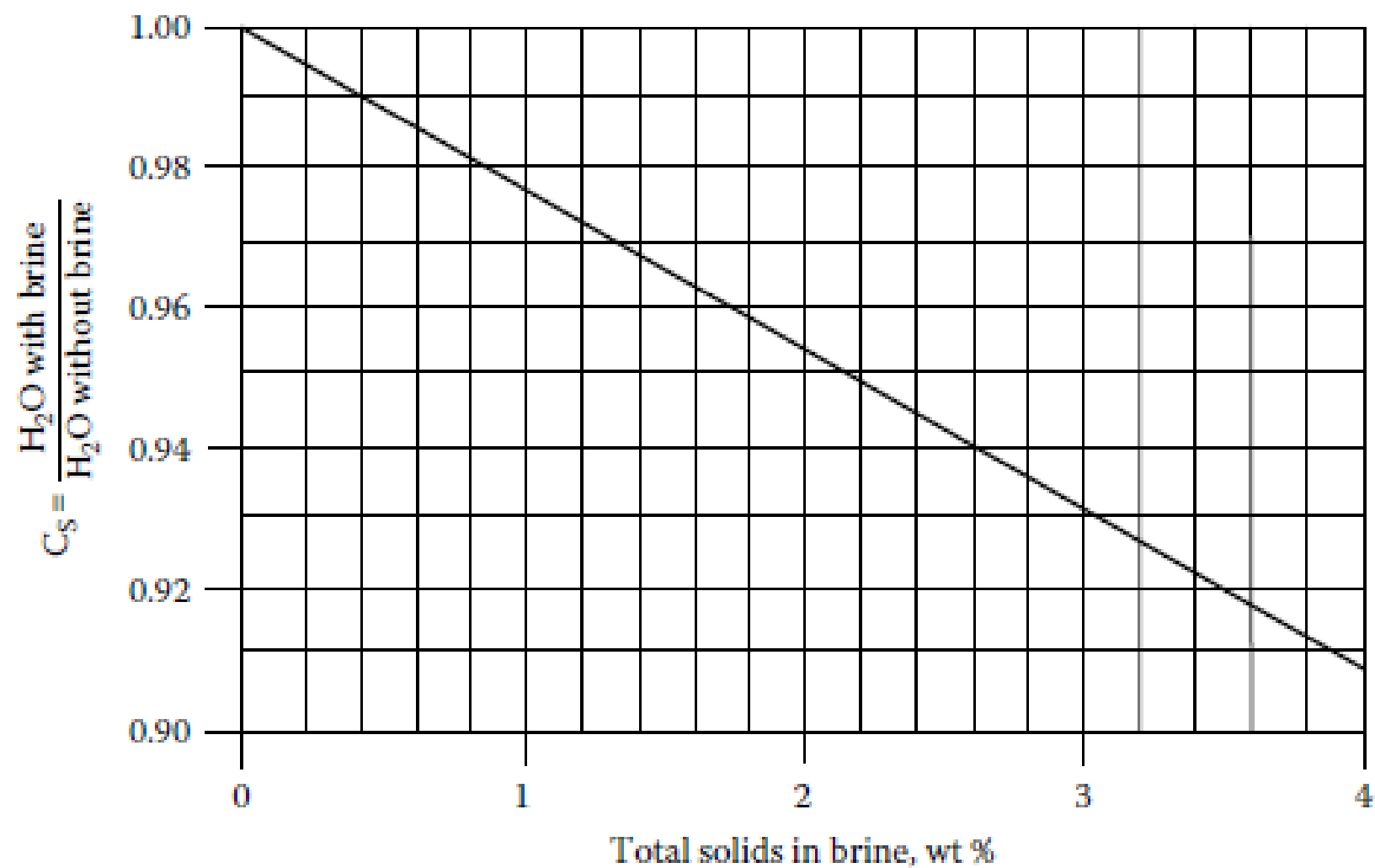
$$y_{H_2O} = \frac{p^{Sat}_{H_2O}}{p}$$

Gas gravity and salinity corrections to water content in hydrocarbon gases





Correction for salinity



Example 6.1

- Problem: Calculate the water content of the sweet natural gas shown in Table 6.1 at 300 psia (20.7 bar) and 80°F (26.7°C) by use of Equation 6.2 and Figure 6.1.

TABLE 6.1
Gas Composition Data for Example 6.1

Component	Mole Fraction	Molar Mass	Mol Fraction \times Molar Mass
CH ₄	0.90	16.043	14.44
C ₂ H ₆	0.04	30.070	1.20
C ₃ H ₈	0.03	44.097	1.32
n-C ₄ H ₁₀	0.02	58.123	1.16
N ₂	0.01	28.013	0.28
Totals	1.00		18.41

- Equation 6.2 using vapor-pressure data from Appendix B gives:

$$y_{H_2O} = \frac{P_{H_2O}^{Sat}}{P} = \frac{0.507 \text{ psia}}{300 \text{ psia}} = 0.0017 \text{ mol fraction}$$

- convert to lb Water/MMscf:

$$W = \left(0.0017 \frac{\text{mol H}_2\text{O}}{\text{mol gas}} \right) \left(18 \frac{\text{lb H}_2\text{O}}{\text{lb-mol}} \right) \left(\frac{1 \text{ lb-mol}}{379.5 \text{ scf}} \right) (10)^6 = 81 \frac{\text{lb H}_2\text{O}}{\text{MMscf}}$$

$$= \left(1,300 \frac{\text{mg}}{\text{m}^3} \right)$$

- From Table 6.1, the MW of the gas mixture is 18.41 and the specific gravity is:

$$\text{SpGr} = \rho_{\text{gas}} / \rho_{\text{air}} = 18.41 / 28.96 = 0.636$$



- From Figure 6.1(a). $W^{\text{sat}} = 85 \text{ lb/MMscf}$ ($1,400 \text{ mg/Sm}^3$).
- Correct for specific gravity: by obtaining C_g from Figure 6.19b) ($C_g = 0.99$), and multiplication gives:

$$W^{\text{Sat}} = (0.99)(85) = 84 \text{ lb/MMscf } (1,400 \text{ mg/Sm}^3)$$

Main Process of Gas Dehydration

- Gas Absorption → Solvent
- Gas Adsorption → Adsorbent
- Dessicant → dessicant
- Membran Separation → membran material

1. ABSORPTION PROCESSES

- Water levels in natural gas can be **reduced to the 10 pmmv range** in a physical absorption process
- **Solvent Properties** used:
 - A *high affinity for water* and a *low affinity for hydrocarbons*
 - A *low volatility* at the absorption temperature to reduce vaporization losses
 - A *low viscosity* for ease of pumping and good contact between the gas and liquid phases
 - A *good thermal stability* to prevent decomposition during regeneration
 - A *low potential for corrosion*

Absorbents Commonly Used:

- The glycols:
 - ethylene glycol (EG),
 - diethylene glycol (DEG),
 - Triethylene glycol (TEG),
 - tetraethylene glycol (TREG)
 - and propylene glycol (PG)

Glycols Used in Dehydration

TABLE 6.2
Glycols Used in Dehydration

Name	Formula		Maximum Recommended Regeneration Temperature, °F (°C) ^a
Ethylene glycol (EG)	HO—(CH ₂) ₂ —OH	C ₂ H ₆ O ₂	
Diethylene glycol (DEG)	HO—((CH ₂) ₂ —O)—(CH ₂) ₂ —OH	C ₄ H ₁₀ O ₃	325 (160)
Triethylene glycol (TEG)	HO—((CH ₂) ₂ —O) ₂ —(CH ₂) ₂ —OH	C ₆ H ₁₄ O ₄	360 (180)
Tetraethylene glycol (TREG)	HO—((CH ₂) ₂ —O) ₃ —(CH ₂) ₂ —OH	C ₈ H ₁₈ O ₅	400 (200)
Propylene glycol	HO—(CH ₂) ₃ —OH	C ₃ H ₈ O ₂	

^a Source: Kohl and Nielsen (1997).

Schematic of typical glycol dehydration unit -- Absorption

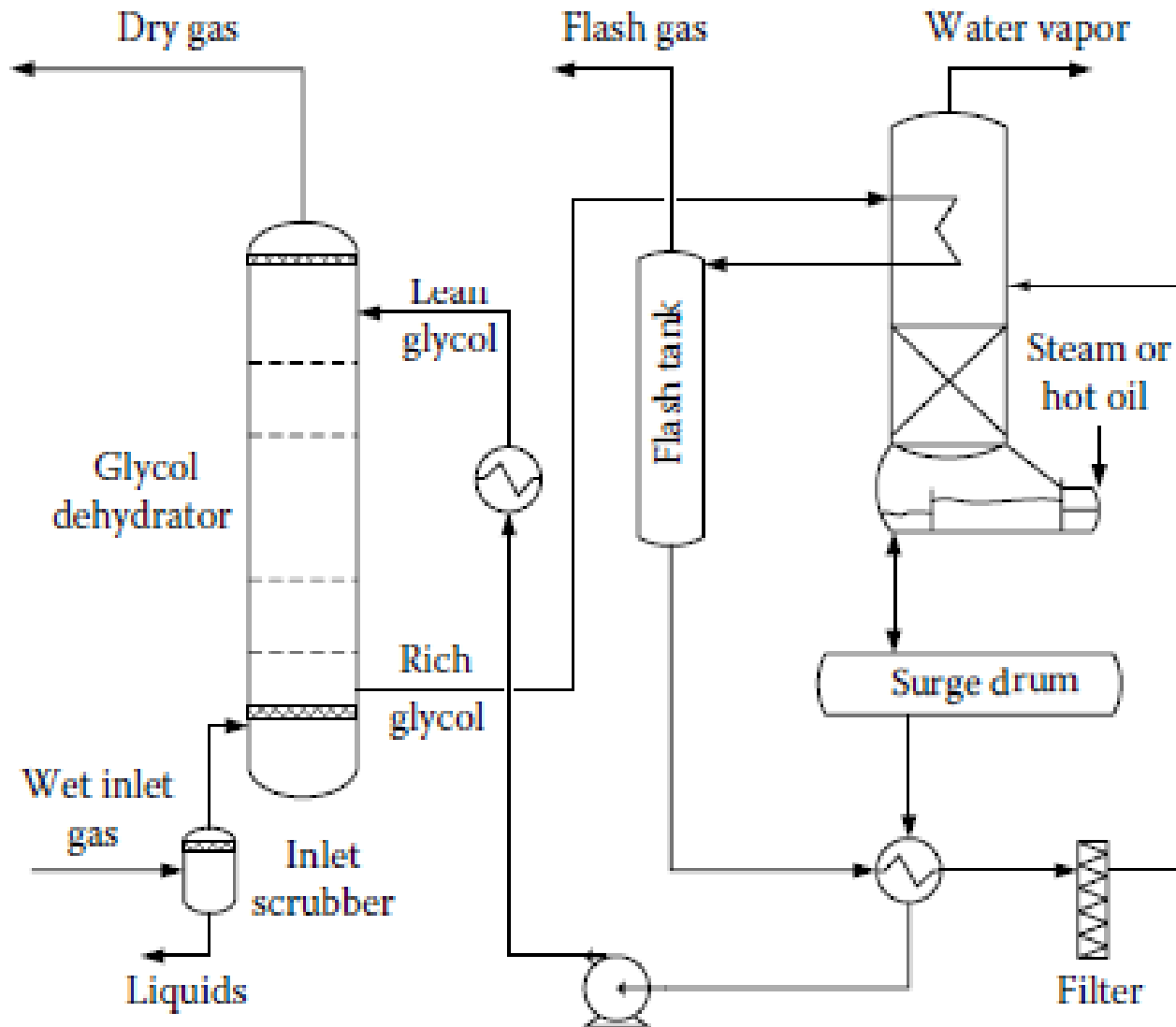


TABLE 6.3
Typical Operating Conditions of TEG Dehydrators

Contactor	
Inlet pressures	<2000 psig (139 bar)
Inlet temperatures	60°F to 100°F (16°C to 38°C) (Lower temperatures enhance absorption capacity but can lead to hydrate formation at high pressure.)
Pressure drop	5 to 10 psi (34 to 69 kPa)
Glycol circulation rate	2 to 5 gal/lb H ₂ O removed, with 3 common. (17 to 42 L/kg)
Tray efficiencies	25 to 30%.
Dew points	> -25°F (-32°C) (Enhanced regeneration required for lower dew point temperatures.)
Glycol losses	
Vaporization	~ 0.012 gal/MMscf (1.6 L/MM Sm ³)
Total	0.025 gal/MMscf (3.3 L/MM Sm ³)
Regenerator (reboiler and still)	
Column internals	Packed equivalent to 3 or 4 trays
Reboiler temperatures	375°F to 400°F (191°C to 204°C)
Flash tank	
Pressure	50 to 75 psig (446 to 618 kPa)
Temperature	150°F (66°C)
Retention times ^a	
C4+ Lean Gas	~10 minutes.
C4+ Rich Gas ^a	~20 minutes (Use three-phase separator.) TEG absorbs about 1 scf gas/gal TEG at 1,000 psig and 100°F (0.0076 Sm ³ /L at 70 barg and 38°C)

^a For treatment of gas streams that contain high concentrations of C4+, adequate time needs to be allowed for removal of the less-volatile components from the glycol to minimize hydrocarbon losses in the still overhead.

Typical Operating Conditions of TEG Dehydrators

Operating Conditions


- **Operating conditions** for glycol units are governed principally by:
 - the *degree of dehydration* required,
 - the *physical properties of the glycol* solutions,
 - and the *inlet pressure of the gas* to the processing unit.

Other Factors That Affect Glycol Dehydrator Performance

- Oxygen reacts with the glycols to form *corrosive acidic* compounds.
- The products also *increase the potential for foaming* and glycol carryover
- A dry natural gas blanket is often put over the storage and surge tanks → to *minimize air intrusion*.
- low pH accelerates *glycol decomposition*
→ suggestion: addition of trace amounts of basic hydrocarbons


2. ADSORPTION PROCESSES


- **The two types of adsorption** are:
 - physical adsorption
 - Chemisorption
- **Physical adsorption**: the bonding between the adsorbed species and the solid phase is called van der Waals forces, the attractive and repulsive forces that hold liquids and solids together and give them their structure.
- **Chemisorption**: a much stronger chemical bonding occurs between the surface and the adsorbed molecules.

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- Physical adsorption is an equilibrium process like *vapor–liquid equilibria* and
 - equations analogous to *Equation 6.1* apply.
 - Thus, for a given vapor-phase concentration (partial pressure) and temperature, *an equilibrium concentration exists* on the adsorbent surface
 - that is the *maximum concentration of the condensed component* (adsorbate) on the surface

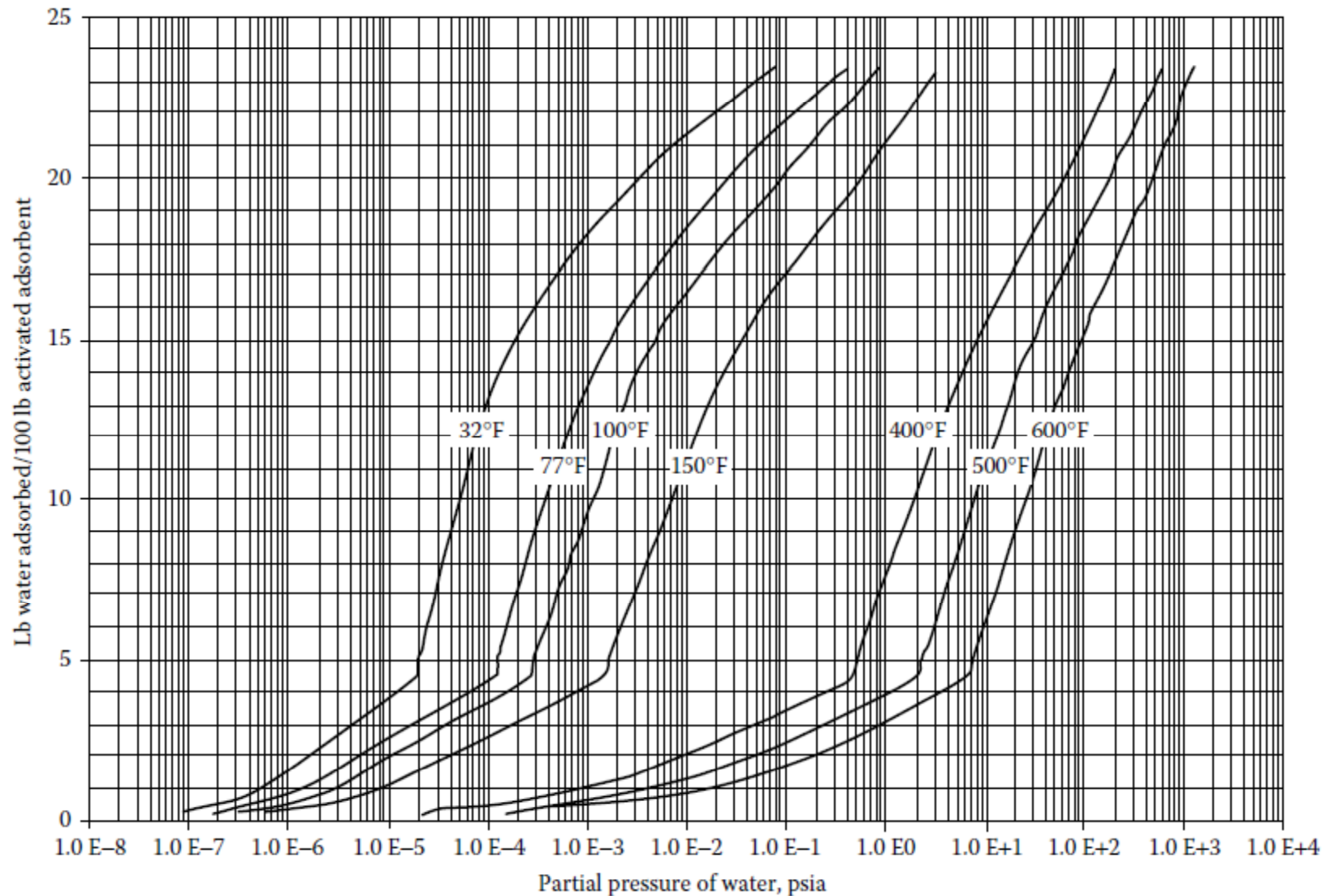
Physical Adsorption

- **Adsorbate concentrations** are usually low → only a few layers of molecules will build up on the surface.
- Thus, adsorption processes use **solids with extremely high surface-to-volume ratios**. (synthetic zeolites (i.e, molecular sieves) have surface-to-volume ratios: $750 \text{ cm}^2/\text{cm}^3$).
- **Molecular sieves** → the adsorbent consists of extremely fine zeolite particles held together by a binder.
- Therefore, adsorbing species travel through the macropores of the binder into the micropores of the zeolite.
- Adsorbents such as **silica gel and alumina** are formed in larger particles and require no binder.
- **Pore openings** that lead to the inside of commercial adsorbents are of molecular size (4 \AA ($1 \text{ \AA} = 10^{-8} \text{ cm}$) to 100 \AA).

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- **Molecular sieves** have an extremely narrow pore distribution, whereas silica gel and alumina have wide distributions.
 - However, a molecular sieve binder (about 20% of the total adsorbent) has large pores capable of adsorbing heavier components.
 - Two steps are involved in adsorbing a trace gas component:
 - The first step is to have the component contact the surface and
 - the second step is to have it travel through the pathways inside the adsorbent.
 - Because this process is a two-step process and the second step is relatively slow, solid adsorbents take longer to come to equilibrium with the gas phase than in absorption processes.

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- In addition to concentration (i.e., partial pressure for gases), two properties of the adsorbate dictate its concentration on the adsorbent surface: **polarity** and **size**.
 - Unless the **adsorbent is nonpolar**, which is not the case for those used in gas plants, polar molecules, like water, will be more strongly adsorbed than weakly polar or nonpolar compounds.
 - Thus, **methane is displaced** by the weakly polar acid gases that are displaced by the strongly polar water

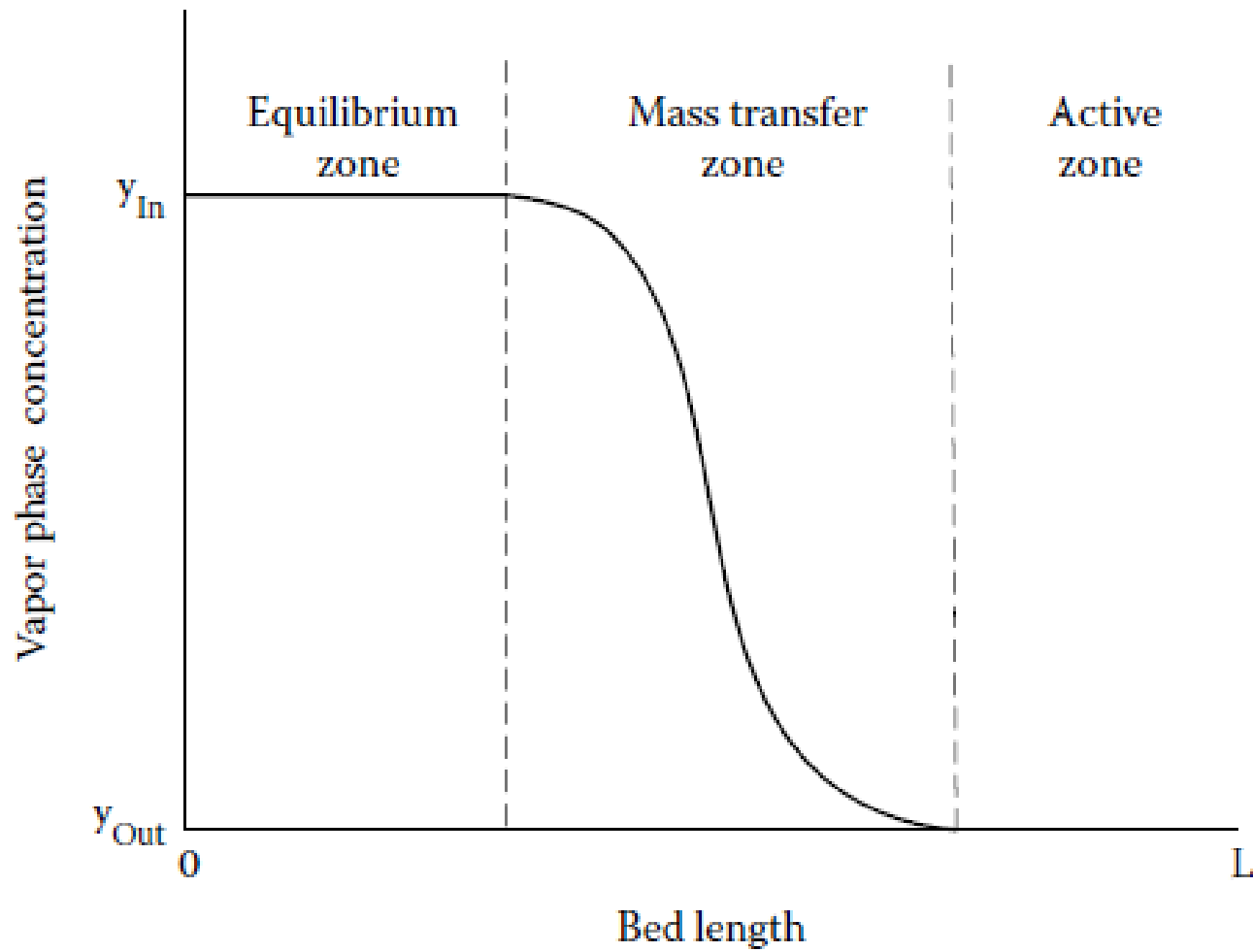
Equilibrium Conditions for water on a commercial molecular sieve





Commercial Adsorption

- **Commercial practice** → adsorption is carried out in a vertical, fixed bed of adsorbent, with the feed gas flowing down through the bed.
- → the formation of a *mass transfer zone (MTZ)* in the bed.
- Figure 6.7 shows **the three zones in an adsorbent bed**:
 - The **equilibrium zone**, where the adsorbate on the adsorbent is in equilibrium with the adsorbate in the inlet gas phase and no additional adsorption occurs
 - The **mass transfer zone (MTZ)**, the volume where mass transfer and adsorption take place
 - The **active zone**, where no adsorption has yet taken place

Vapor-phase concentration profile of an adsorbate in the three zones of an adsorption bed.



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- In the **mass transfer zone (MTZ)**, the concentration drops from the **inlet value**, y_{in} , to the **outlet value**, y_{out} , in a smooth S-shaped curve.
 - If the mass transfer rate were infinite, the MTZ would have zero thickness.
 - The MTZ is usually assumed to form quickly in the adsorption bed and to have a constant length as it moves through the bed, unless particle size or shape is changed.
 - The value of y_{in} is dictated by upstream processes; the y_{out} value is determined by the regeneration gas adsorbate content.

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- When used as a purification process, **adsorption has two major disadvantages:**
 - It is a fixed-bed process that *requires two or more adsorption beds* for continuous operation.
 - It has *limited capacity* and is usually *impractical* for removing large amounts of impurity.
 - However, **adsorption is very effective in the dehydration of natural gas**, because water is much more strongly adsorbed than any of the alkanes, carbon dioxide, or hydrogen sulfide.
 - Generally, a higher degree of dehydration can be achieved with adsorbents than with absorption processes.


Industrial Adsorbents for Dehydration

- Three types of **commercial adsorbents** are in common use in gas processing plants:
 - **Silica gel**, which is made of pure SiO_2
 - **Activated alumina**, which is made of Al_2O_3
 - **Molecular sieves**, which are made of alkali aluminosilicates and can be altered to affect adsorption characteristics

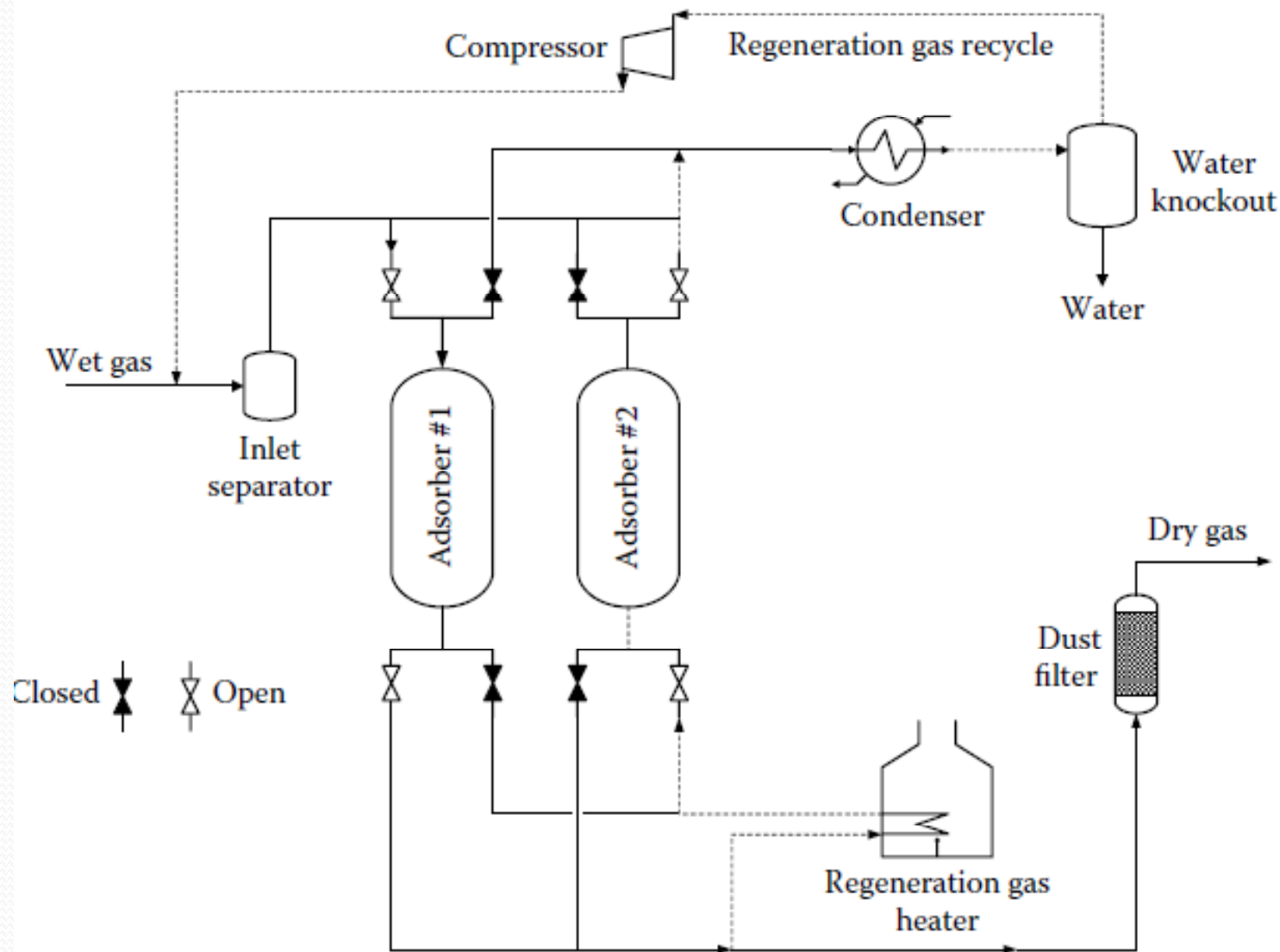
Properties of Commercial Silica Gels, Activated Alumina, and Molecular Sieve 4A

TABLE 6.4
Representative Properties of Commercial Silica Gels, Activated Alumina,
and Molecular Sieve 4A

	Silica Gel	Activated Alumina	Molecular Sieve 4A
Shape	Spherical	Spherical	Pellets (extruded cylinders) and beads
Bulk density lb/ft ³ (kg/m ³)	49 (785)	48 (769)	40 –45 (640 – 720)
Particle size	4 – 8 mesh 5 –2 mm	7–14 mesh, 1/8-inch, 3/16-inch, 1/4-inch diameter (3-mm, 5-mm, 6-mm)	1/16-inch,1/8-inch,1/4-inch diameter cylinders (1.6-mm, 3.2-mm, 6-mm)
Packed bed % voids	35	35	35
Specific heat Btu/lb-°F (kJ/kg-K)	0.25 (1.05)	0.24 (1.00)	0.24 (1.00)
Surface area m ² /g	650 – 750	325 – 360	600 – 800
Pore volume cm ³ /g	0.36	0.5	0.28
Regeneration temperature, °F (°C)	375 (190)	320 to 430 (160 to 220)	400 to 600 (200 to 315)
Average pore diameter (Å)	22	NA	3,4,5,10
Minimum dew point temperature of effluent, °F (°C) ^a	–80 (–60)	–100 (–75)	–150 (–100)
Average minimum moisture content of effluent gas, ppmv	5 –10	10 – 20	0.1

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- **Silica gels** are used:
 - where a high concentration of water (>1 mol%) vapor is present in the feed,
 - and low levels of water in the dehydrated gas are not needed.
 - noncatalytic compounds.
 - **Aluminas** are very polar and strongly attract water and acid gases.
 - They are used for moderate levels of water in the feed when low levels of water in the product are not required.
 - They have the highest mechanical strength of the adsorbents considered here.
 - **molecular sieve:** for gas going into cryogenic processing
 - Of these, 4A is the most common, but the smaller pore 3A is sometimes used

Adsorption Process: Molecular Sieve



Typical Operating Conditions for Molecular Sieve Dehydration Units

TABLE 6.5

Typical Operating Conditions for Molecular Sieve Dehydration Units

Feed rate	10 to 1500 MMscfd (0.3 to 42 MMSm ³ /d)
Superficial velocity	Approximately 30 to 35 ft/min (9 to 11 m/min)
Pressure drop	Approximately 5 psi (35 kPa), not to exceed 10 psi (69 kPa)
Cycle time	Four to 24 hours; 8 or a multiple thereof is common
Temperatures and pressures	
Adsorption	Temperatures: 50 to 115°F (10 to 45°C) Pressures: to 1500 psig (100 barg),
Regeneration	Temperatures: 400 to 600°F (200 to 315°C) Pressures: Adsorption pressure or lower.

3. DESICCANT PROCESSES

- In some situations, such as remote gas wells, use of a consumable salt desiccant, such as CaCl_2 , may be economically feasible.
- The system can reduce the water content down to 20 ppmv.
- Typical salt capacities are 0.3 lb CaCl_2 per lb H_2O .

4. MEMBRANE PROCESSES

- **Membranes offer an attractive option** for cases in which drying is required to meet pipeline specifications.
- Their modular nature, light weight, large turndown ratio, and low maintenance make them **competitive with glycol units** in some situations
- **The inlet gas must be free of solids** and droplets larger than 3 microns
- **Inlet gas temperature** should be at least 20°F (10°C) above the dew point of water to avoid condensation in the membrane.
- membranes used for natural gas dehydration are **economically viable** only when dehydration is combined with acid-gas removal

Membrane Operation

- Units operate at pressures up to **700 to 1,000 psig (50 – 70 barg)** with **feed gases containing 500 to 2,000 ppmv of water**.
- They produce a **product gas stream of 20 to 100 ppmv** and 700 to 990 psig (48 to 68 barg).
- The **low-pressure** (7 to 60 psig [0.5 to 4 barg]) **permeate gas volume is about 3 to 5%** of the feed gas volume

THANK YOU

