Gas Treating: *Physical Treatments* (*Pengolahan Gas: secara fisika*)

Teknologi Pemrosesan Gas (TKK 564)

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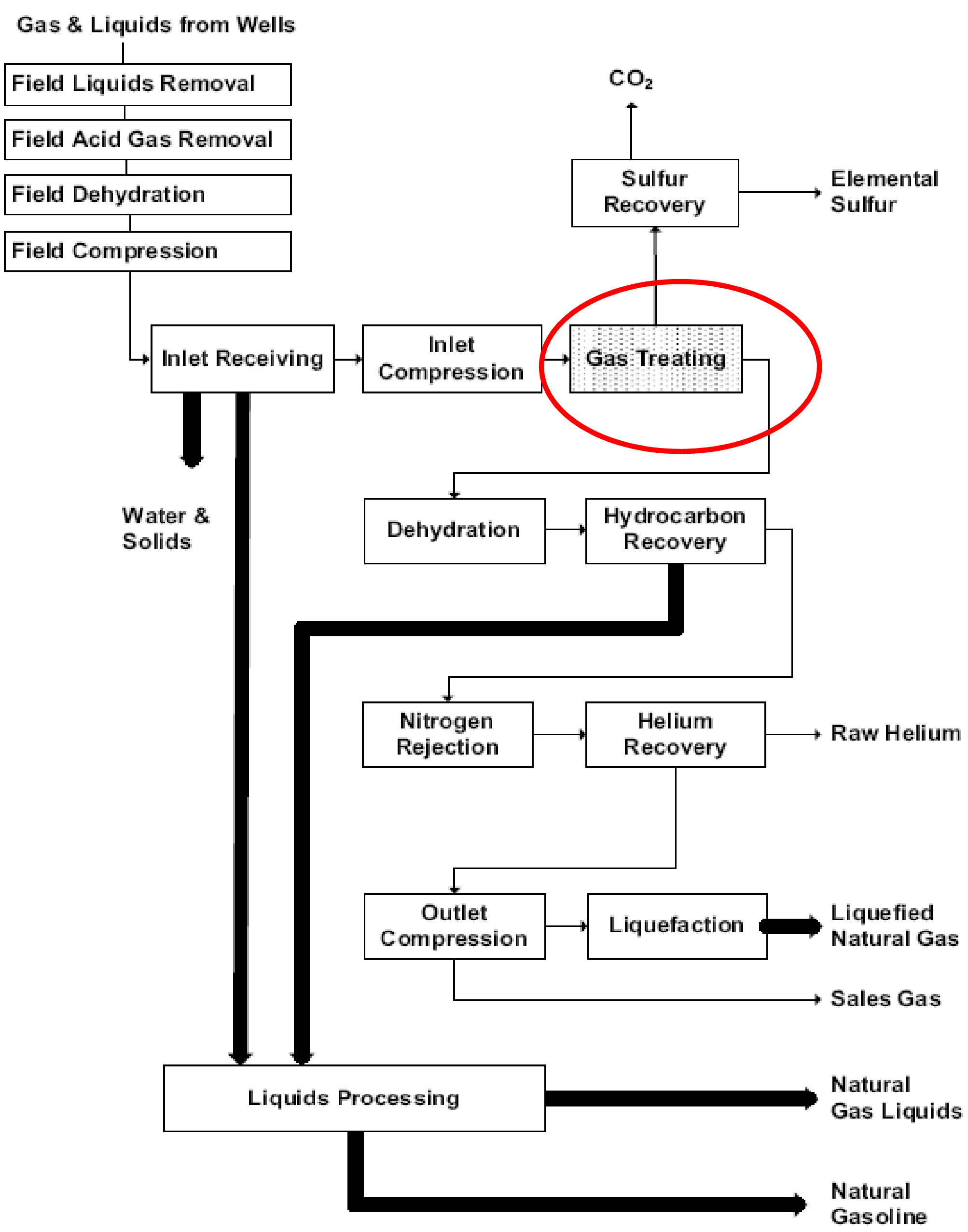
Instructor's Background

- 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 (*Pengolahan Gas*)**
5. Gas Dehydration (*Dehidrasi Gas*)
6. First Assignment
7. Gas Compression System (*Sistem Kompresi Gas*)
8. *Ujian Tengah Semester*



Gas & Liquids from Wells

Field Liquids Removal

Field Acid Gas Removal

Field Dehydration

Field Compression

CO_2

Sulfur Recovery

Elemental Sulfur

Inlet Receiving

Inlet Compression

Gas Treating

Water & Solids

Dehydration

Hydrocarbon Recovery

Nitrogen Rejection

Helium Recovery

Raw Helium

Outlet Compression

Liquefaction

Liquefied Natural Gas

Sales Gas

Liquids Processing

Natural Gas Liquids

Natural Gasoline

PHYSICAL ABSORPTION

- Absorption processes are generally **most efficient when the partial pressures of the acid gases are relatively high**, because partial pressure is the driving force for the absorption.
- Heavy hydrocarbons are strongly absorbed by the solvents used, and consequently **acid gas removal is most efficient in natural gases with low concentrations of heavier hydrocarbons**.
- Solvents can be chosen for **selective removal of sulfur compounds**, which allows CO2 to be slipped into the residue gas stream and reduce separation costs.
- **Energy requirements for regeneration of the solvent are lower** than in systems that involve chemical reactions.
- Separation can be carried out at **near-ambient temperature**.
- Partial processes produce **a water saturated product stream** that must be dried in most applications.

SOLVENT PROPERTIES

- Selexol is a typical application of physical absorption and a number of open literature articles describe the process
- Selexol ➔ polyethylene glycol
- $(CH_3—O—CH_2—(CH_2—O—CH_2)N—CH_2—O—CH_3)$

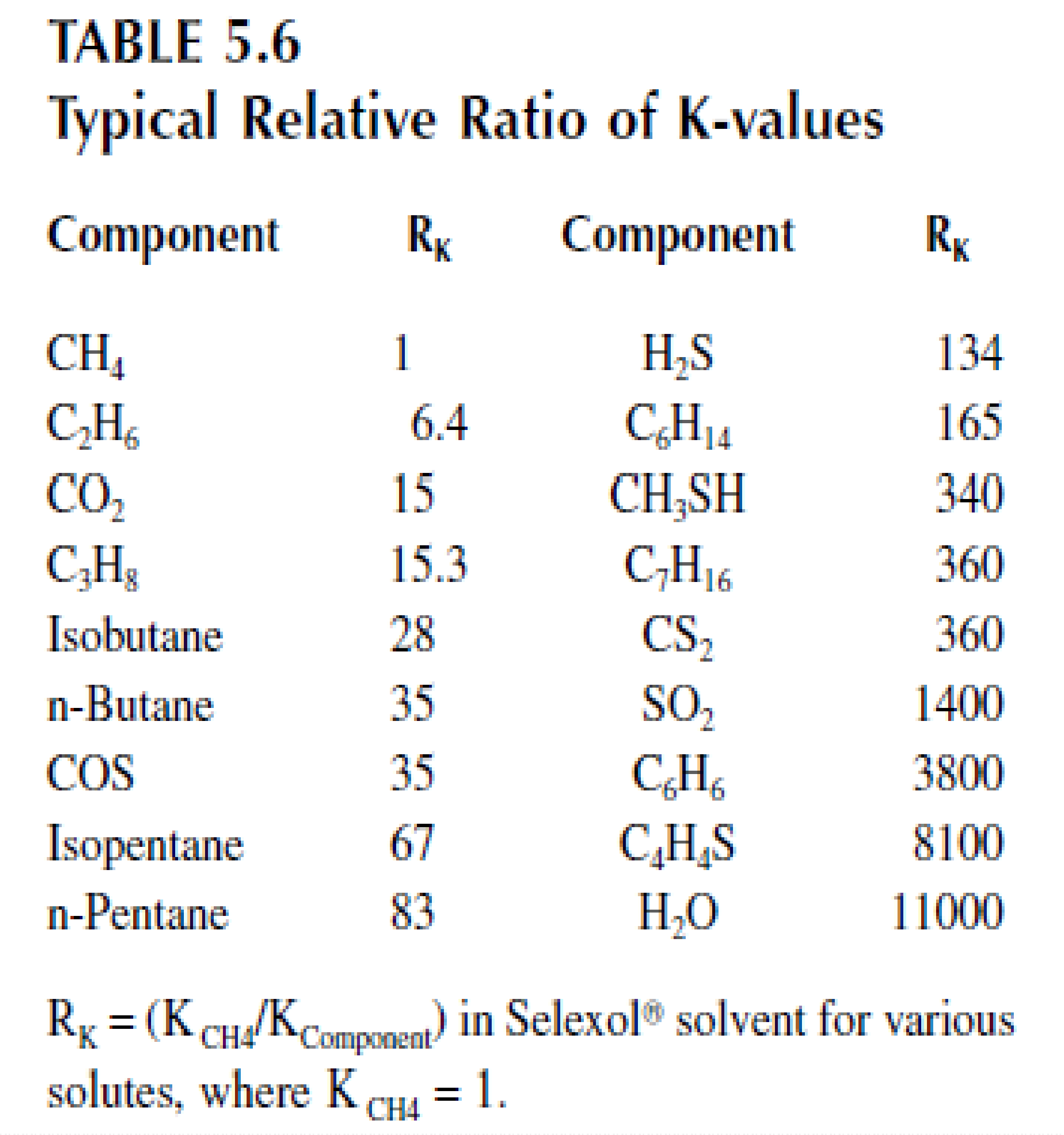


TABLE 5.6

Typical Relative Ratio of K-values

Component	R_K	Component	R_K
CH_4	1	H_2S	134
C_2H_6	6.4	C_6H_{14}	165
CO_2	15	CH_3SH	340
C_3H_8	15.3	C_7H_{16}	360
Isobutane	28	CS_2	360
n-Butane	35	SO_2	1400
COS	35	C_6H_6	3800
Isopentane	67	C_4H_4S	8100
n-Pentane	83	H_2O	11000

$R_K = (K_{CH4}/K_{Component})$ in Selexol® solvent for various solutes, where $K_{CH4} = 1$.

- The K-value is the ratio of the mole fraction of the component in the vapor phase (y) to its mole fraction in the liquid phase (x), K = y/x.
- High K-values indicate the material is predominately in the vapor phase, whereas low K-values indicate a higher concentration in the liquid phase (x).

R_k Value

- An **R_k value greater than unity indicates the solubility of the component in Selexol is greater than that of methane**, whereas a value less than unity indicates the opposite
- Because R_K for CO_2 and H_2S are 15 and 134, respectively, these gases are preferentially absorbed (relative to CH_4), and, consequently, physical absorption is an effective technique for acid gas removal.
- The process can reduce H_2S to 4 ppmv, reduce CO_2 to levels below 50 ppmv, and essentially remove all mercaptans, CS_2, and COS.
- **R_K values for hydrocarbons heavier than CH_4 are fairly high** (6.4 for C_2H_6, 15.3 for C_3H_8, and 35 for n-C_4H_{10}), Selexol will remove substantial quantities of these hydrocarbons, a feature that can be either positive or negative, depending on the composition of the gas being processed and the desired products.
- Finally, the **R_K value of H_2O is extremely high** and consequently, Selexol provides some dehydration

- Need gas solubility data in the form of absorption coefficients (volume of gas absorbed per volume of liquid).

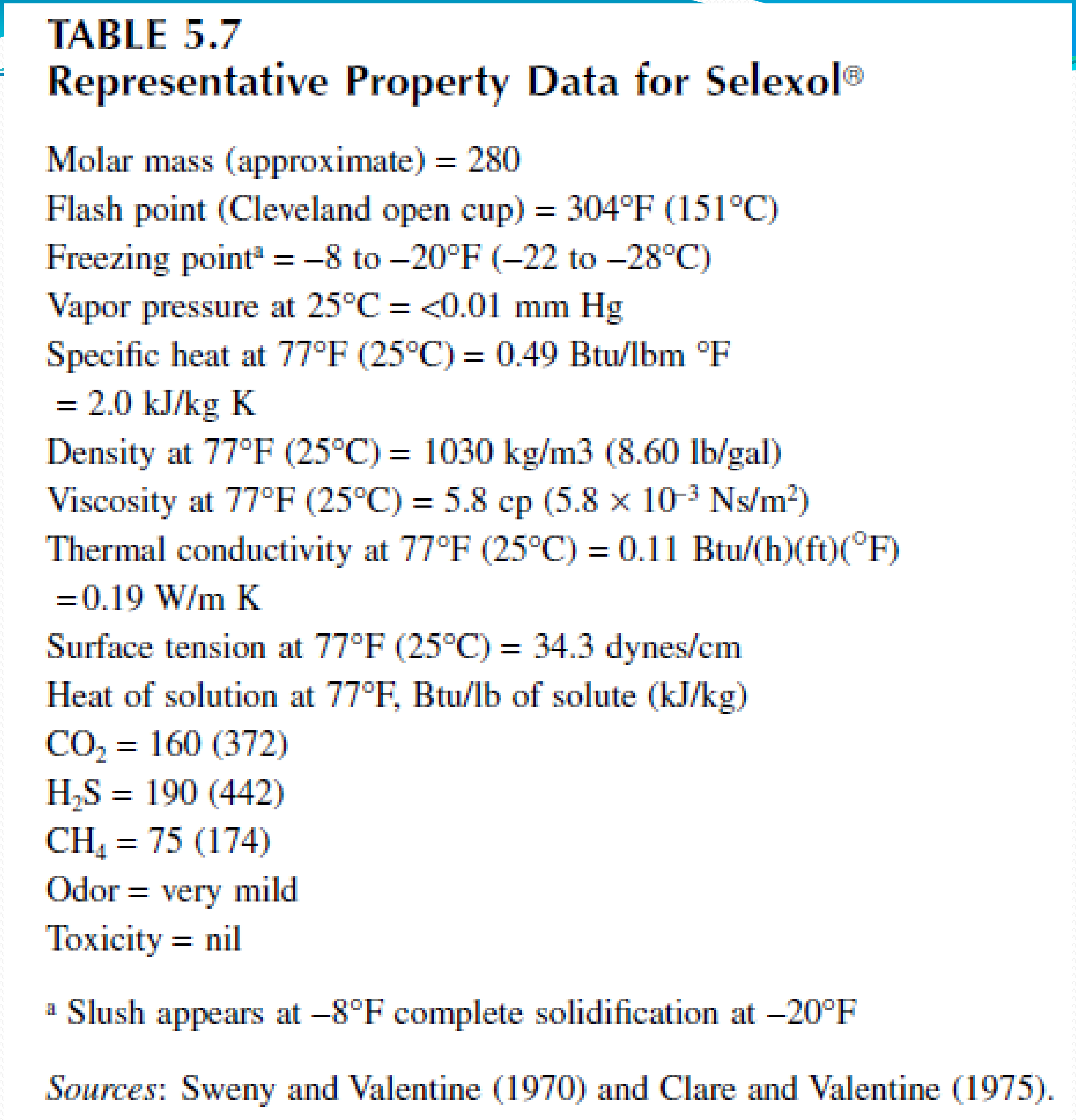


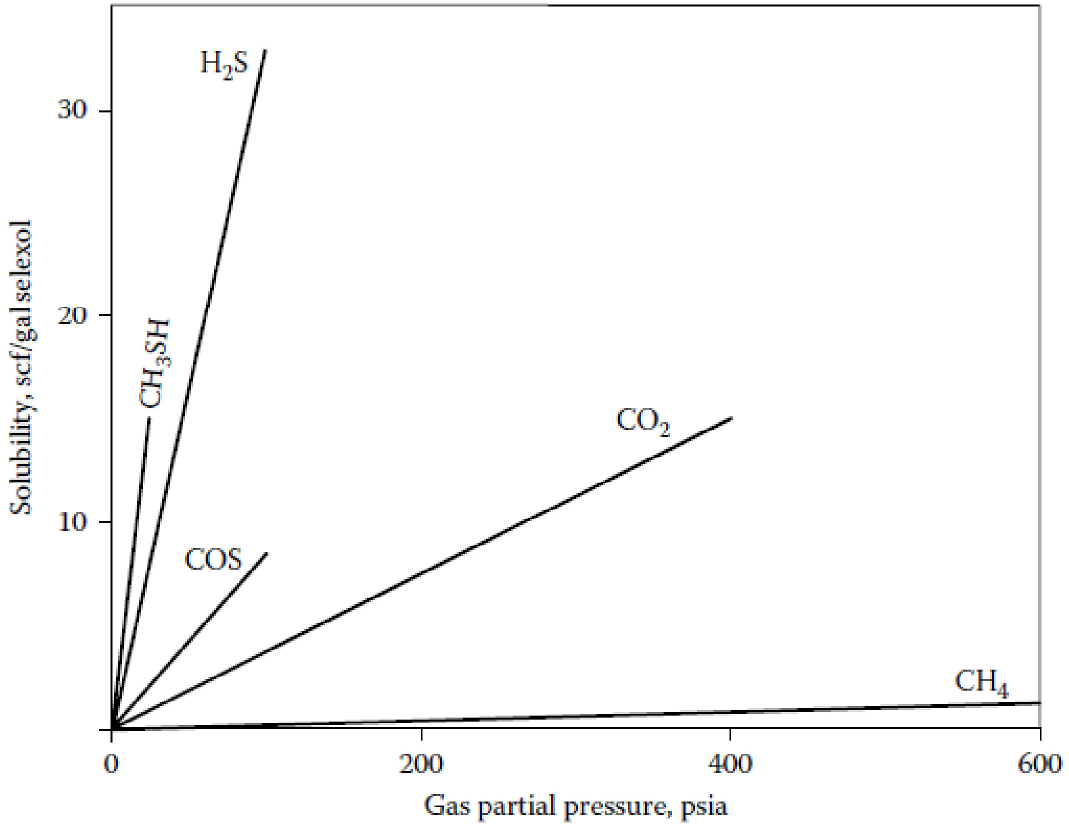
TABLE 5.7
Representative Property Data for Selexol®

Molar mass (approximate) = 280
Flash point (Cleveland open cup) = 304°F (151°C)
Freezing point[a] = –8 to –20°F (–22 to –28°C)
Vapor pressure at 25°C = <0.01 mm Hg
Specific heat at 77°F (25°C) = 0.49 Btu/lbm °F
= 2.0 kJ/kg K
Density at 77°F (25°C) = 1030 kg/m3 (8.60 lb/gal)
Viscosity at 77°F (25°C) = 5.8 cp (5.8×10^{-3} Ns/m^2)
Thermal conductivity at 77°F (25°C) = 0.11 Btu/(h)(ft)(°F)
=0.19 W/m K
Surface tension at 77°F (25°C) = 34.3 dynes/cm
Heat of solution at 77°F, Btu/lb of solute (kJ/kg)
CO_2 = 160 (372)
H_2S = 190 (442)
CH_4 = 75 (174)
Odor = very mild
Toxicity = nil

[a] Slush appears at –8°F complete solidification at –20°F

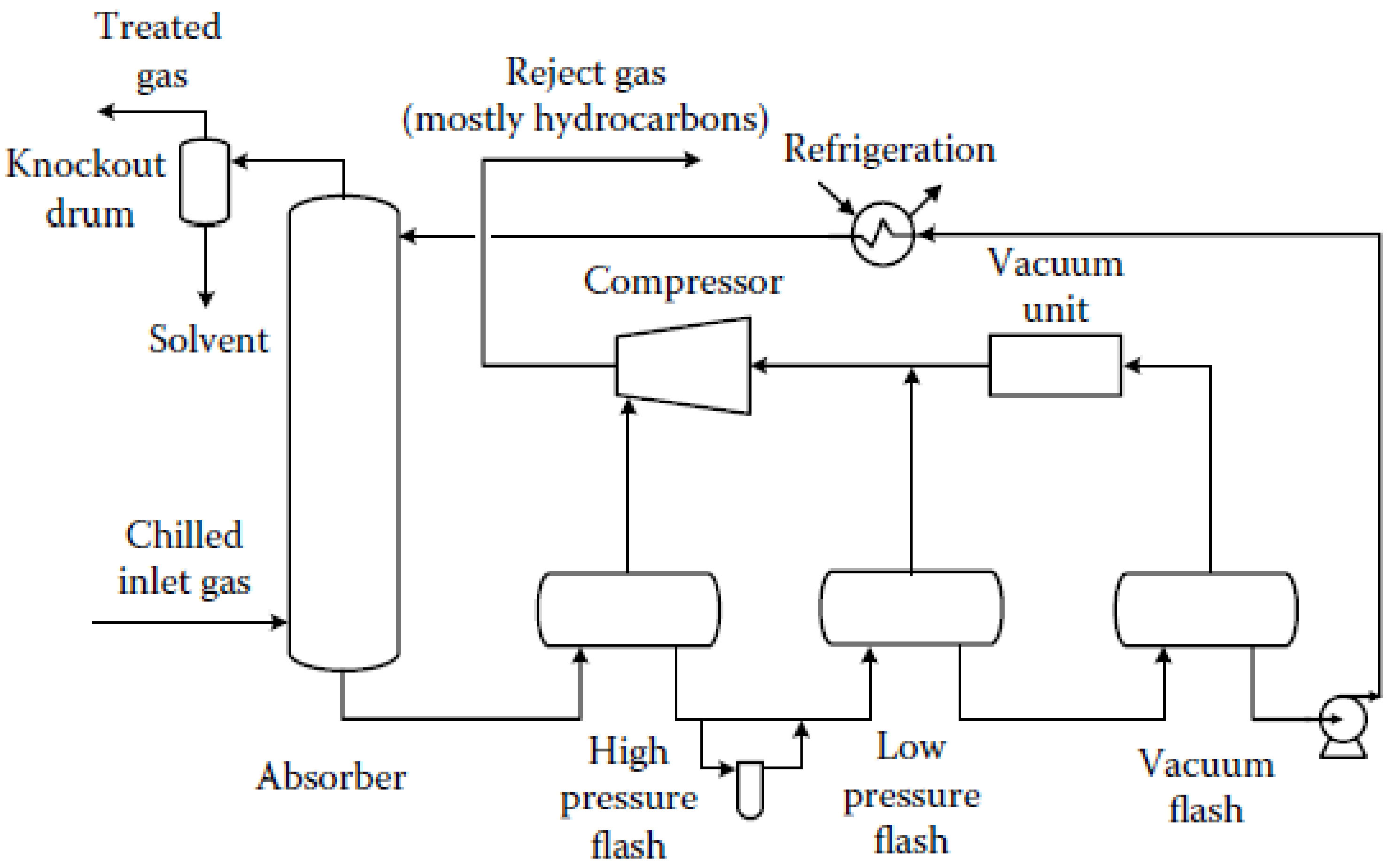
Sources: Sweny and Valentine (1970) and Clare and Valentine (1975).

Solubility of various gases in Selexol® solvent at 70°F (21°C) as a function of partial pressure.

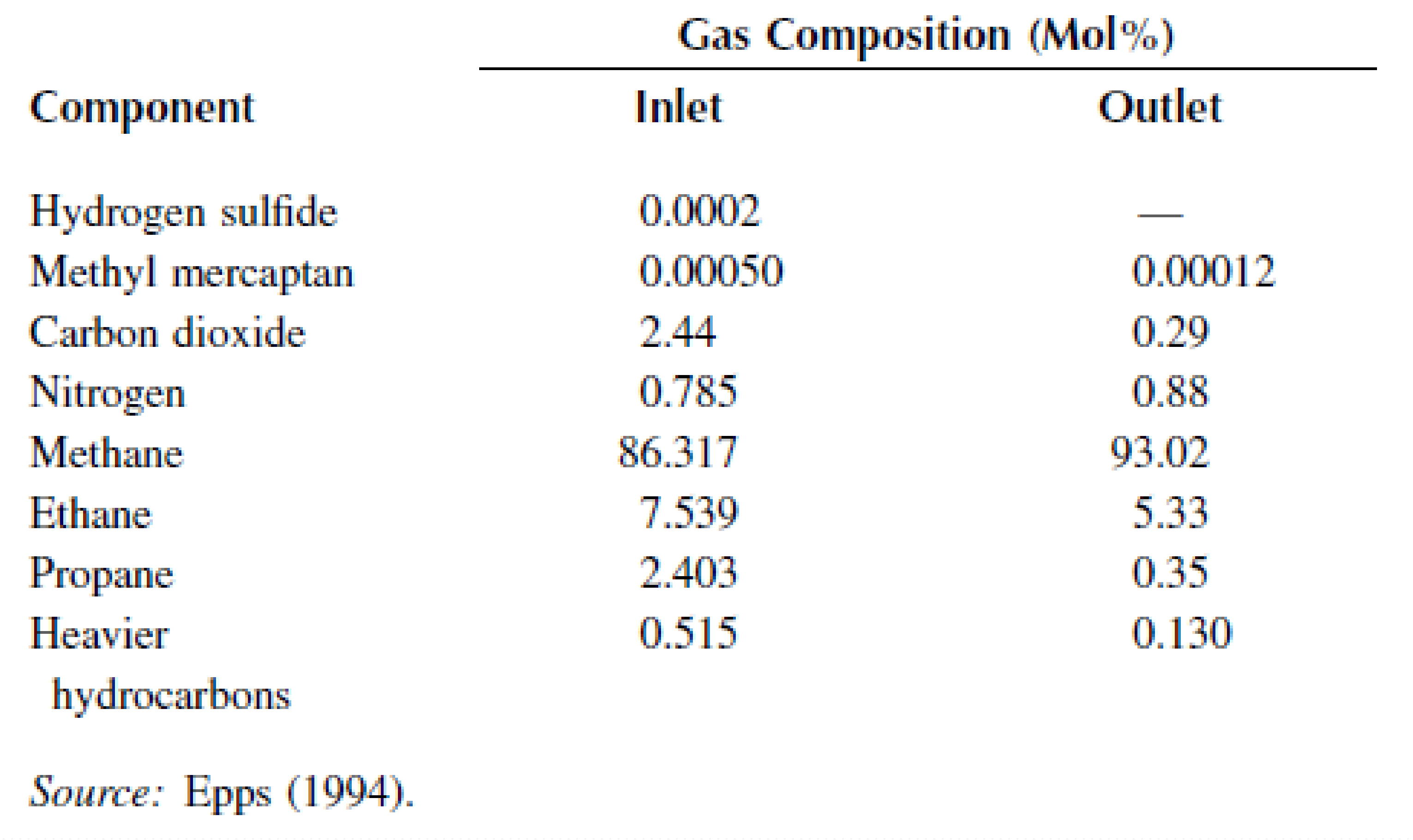


- For an ideal system, Henry's law assumes a linear relation between the solubility of gas component i and its partial pressure, $y_iP = k_ix_i$ where k_i is the Henry's constant.

Process schematic for a Selexol gas treating facility



Example: Composition of Inlet and Outlet Gas in a Selexol Unit



	Gas Composition (Mol%)	
Component	Inlet	Outlet
Hydrogen sulfide	0.0002	—
Methyl mercaptan	0.00050	0.00012
Carbon dioxide	2.44	0.29
Nitrogen	0.785	0.88
Methane	86.317	93.02
Ethane	7.539	5.33
Propane	2.403	0.35
Heavier hydrocarbons	0.515	0.130

Source: Epps (1994).

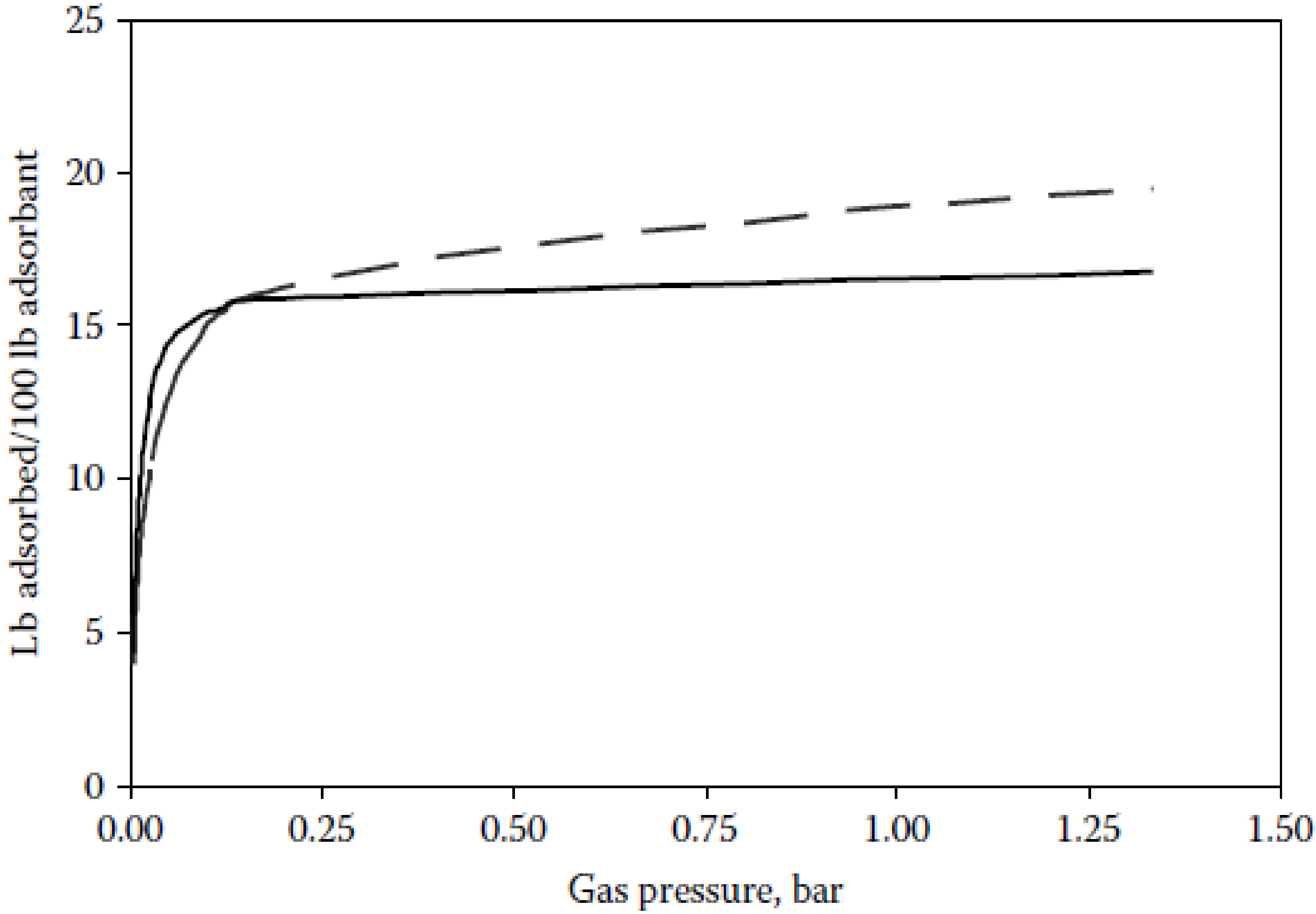
HYBRID PROCESSES

- the strengths and weaknesses of amine and physical solvent system
- To take advantage of the strengths of each type, a number of hybrid processes commercially used, and under development, combine physical solvents with amines
- Depending upon the solvent–amine combination, nearly complete removal of H_2S, CO_2, and COS is possible
- Sulfinol®: The process uses a combination of a physical solvent (sulfolane) with DIPA or MDEA.
- Like the physical solvent processes, the hybrid systems may absorb more hydrocarbons, including BTEX, but that property can be adjusted by varying water content.

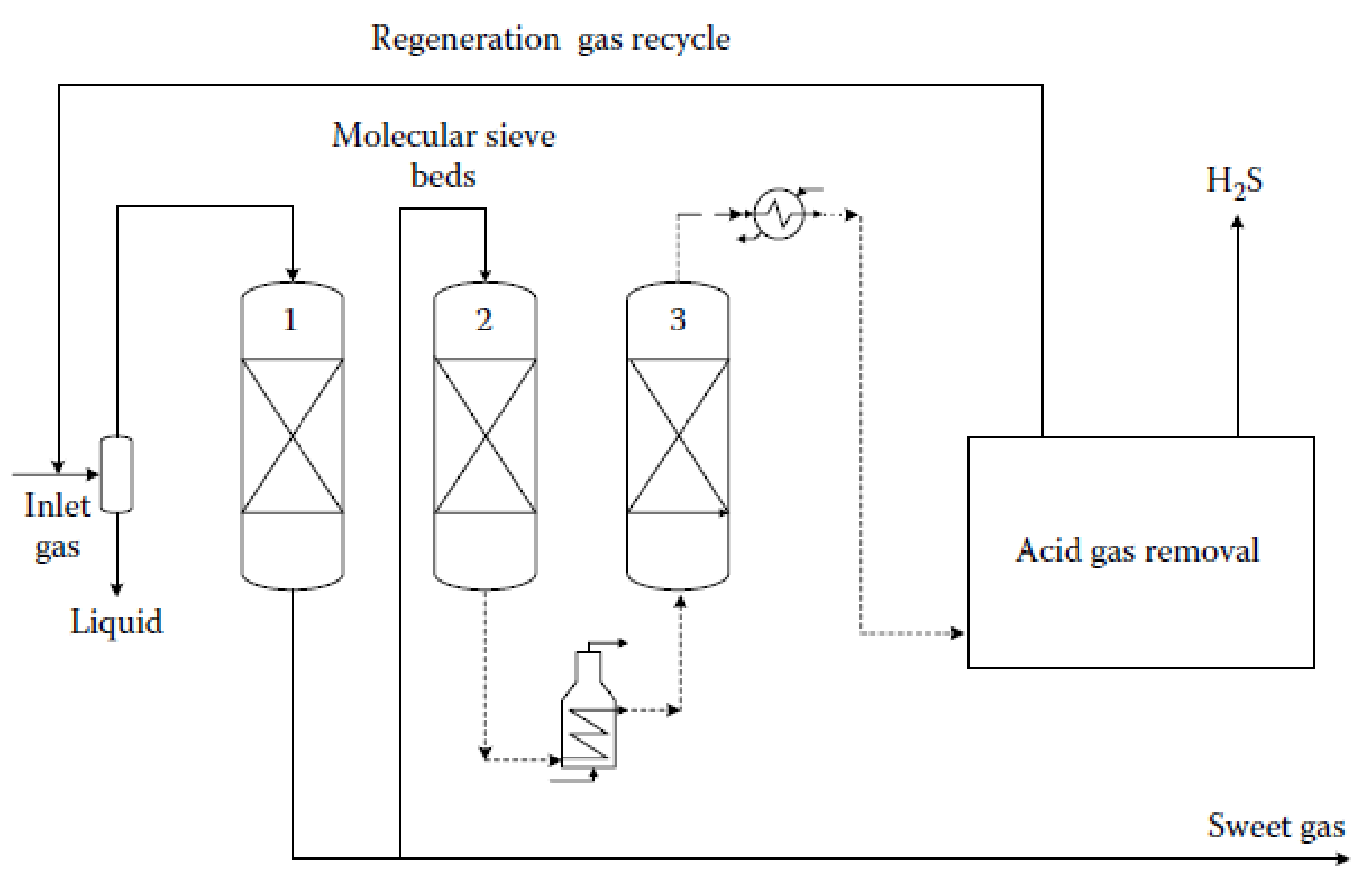
ADSORPTION

- Acid gases, as well as water, can be effectively removed by physical adsorption on synthetic zeolites
- Applications are limited because water displaces acid gases on the adsorbent bed
- From typical isotherms for CO_2 and H_2S on molecular sieve, indicates that at ambient temperatures substantial quantities of both gases are adsorbed even at low partial pressures
- Molecular sieve can reduce H_2S levels to the 0.25 gr/100 scf (6 mg/m3) specification.
- However, this reduction requires regeneration of the bed at 600°F (315°C) for extended time

Typical isotherms for CO2 and H2S on molecular sieve



Schematic of integrated natural gas desulfurization plant

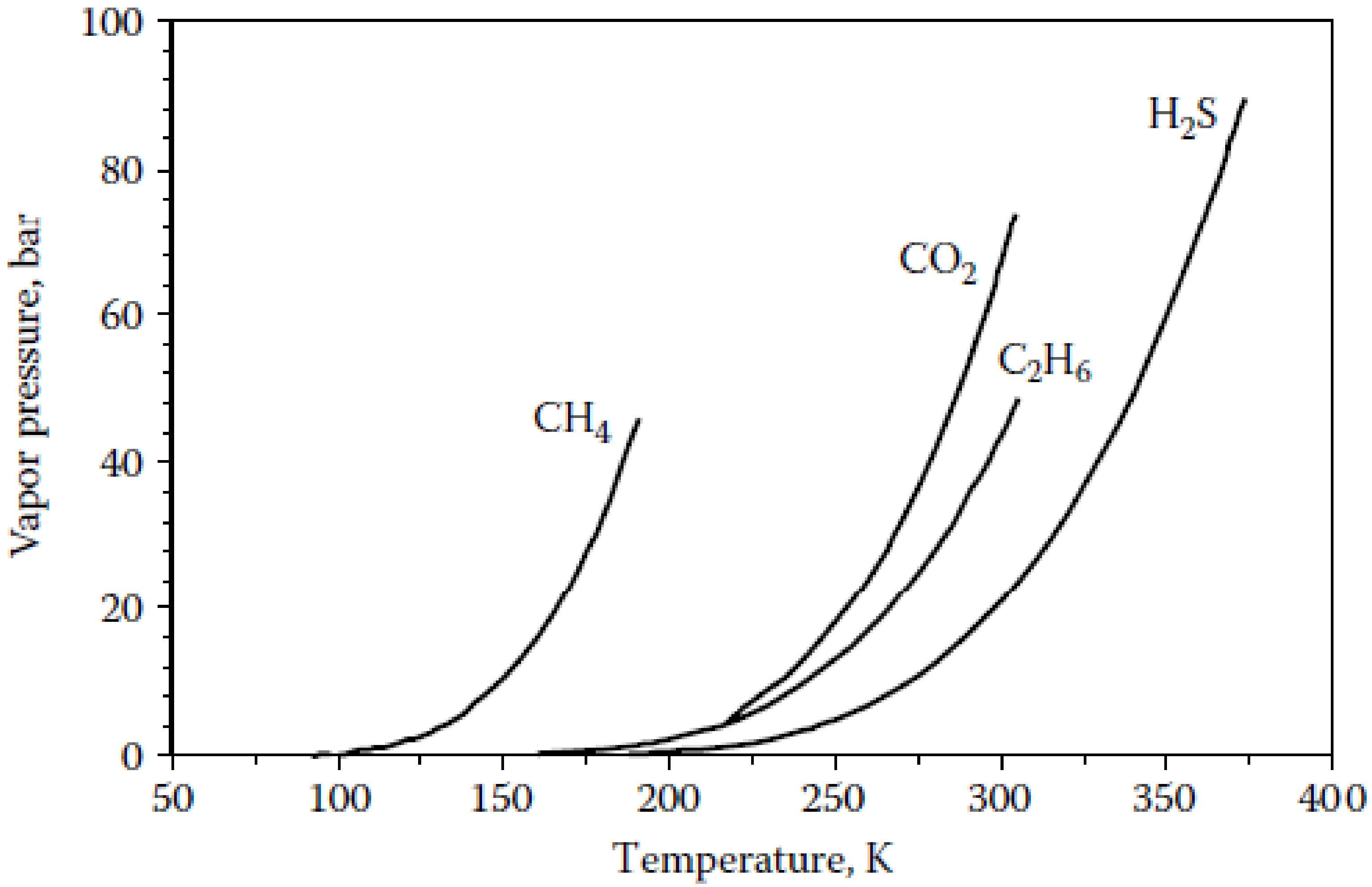


- Dashed line denotes regeneration gas stream.

CRYOGENIC FRACTIONATION

- Distillation ➔ the most widely used process to separate liquid mixtures
- It seems a good prospect for removing CO_2 and H_2S from natural gas, because the vapor pressures of the principal components are differents
- However, problems are associated with the separation of CO_2 from methane, CO_2 from ethane, and CO_2 from H_2S

Difference of Vapor Pressures

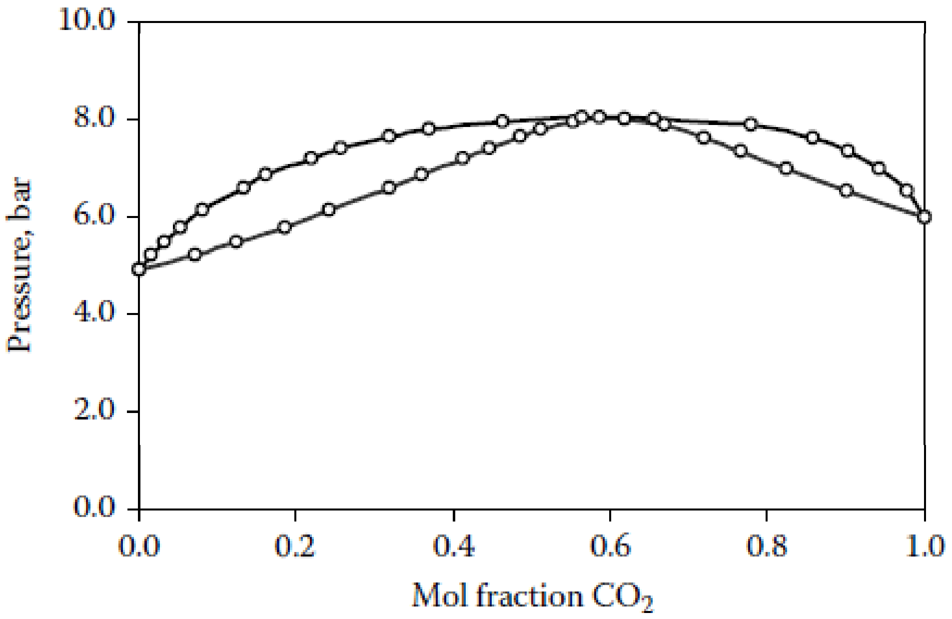


Distillation: CO2 from methane

- Relative volatilities (K_{C_1}/K_{CO_2}) at typical distillation conditions are about 5 to 1. Therefore one would expect simple fractionation to work.
- However, because the liquid CO2 phase freezes when it becomes concentrated, the practical maximum-vapor concentration of methane is only 85 to 90 mol%.

Distillation: CO2 from ethane

- In addition to solidification problems, CO2 and ethane form an azeotrope (liquid and vapor compositions are equal) and
- consequently, complete separation of these two by simple distillation is impossible



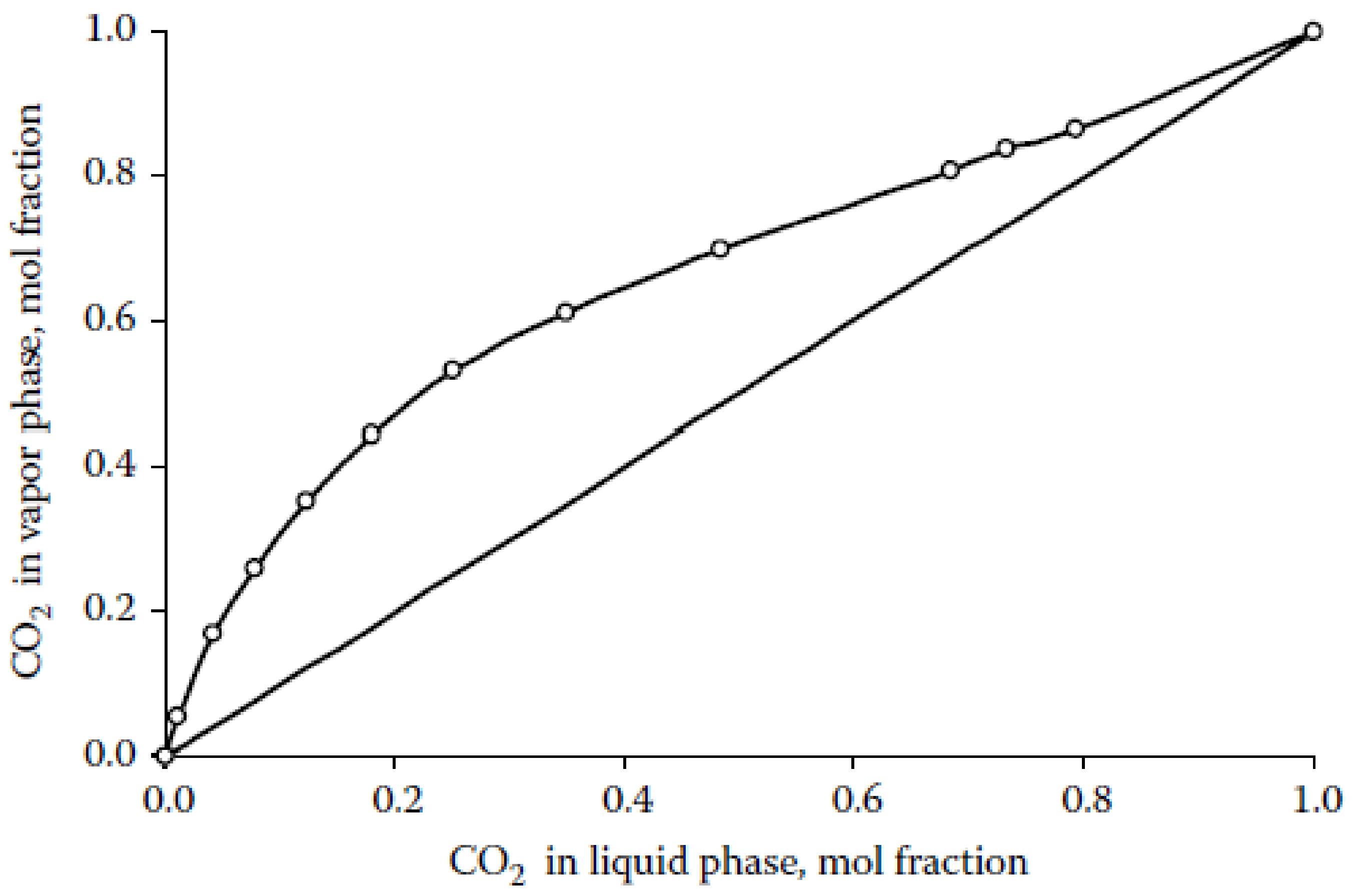
Distillation: CO_2 from H_2S

- The distillation is difficult
- The mixture forms a pinch at high CO_2 concentrations.
- This separation by conventional distillation is complicated by the need to have an overhead product that has roughly 100 ppmv H_2S if the stream is vented.
- The bottoms product should contain less than two-thirds CO_2, assuming the stream is feed to a Claus unit.

Extractive Distillation

- This process is an extractive distillation process* that uses hydrocarbons to significantly alter the behavior of the system and thus, effectively eliminate the distillation problems.
- The hydrocarbons are normally mixtures of propane and heavier hydrocarbons obtained from the feed mixture.
- As a result, no additional separations are required.
- Extractive distillation makes distillation of close boiling components possible by addition of a solvent to the mixture to alter the relative volatility of the two key components.
- The products from the distillation include one of the keys at high purity and a mix of the other key plus the solvent.
- This mixture is fractionated in another column for recovery of the solvent and production of the pure second key.

Vapor–liquid equilibrium curve for CO2 and H2S at 20 atm



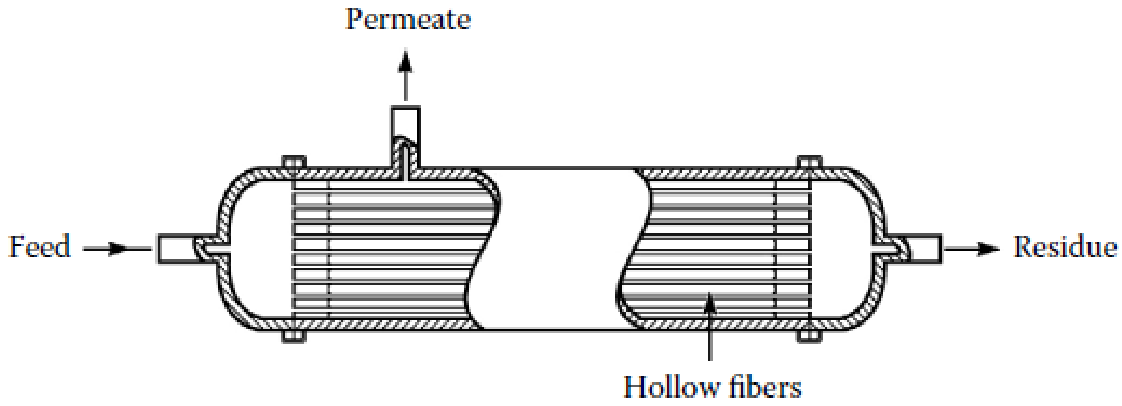
Membrane Separation

- Membranes are used in natural gas processing for dehydration, fuel-gas conditioning, and bulk CO_2 removal, but presently CO_2 removal is by far the most important application
- PLEASE READ THE MEMBRANE FUNDAMENTAL AT PAGE 119-121

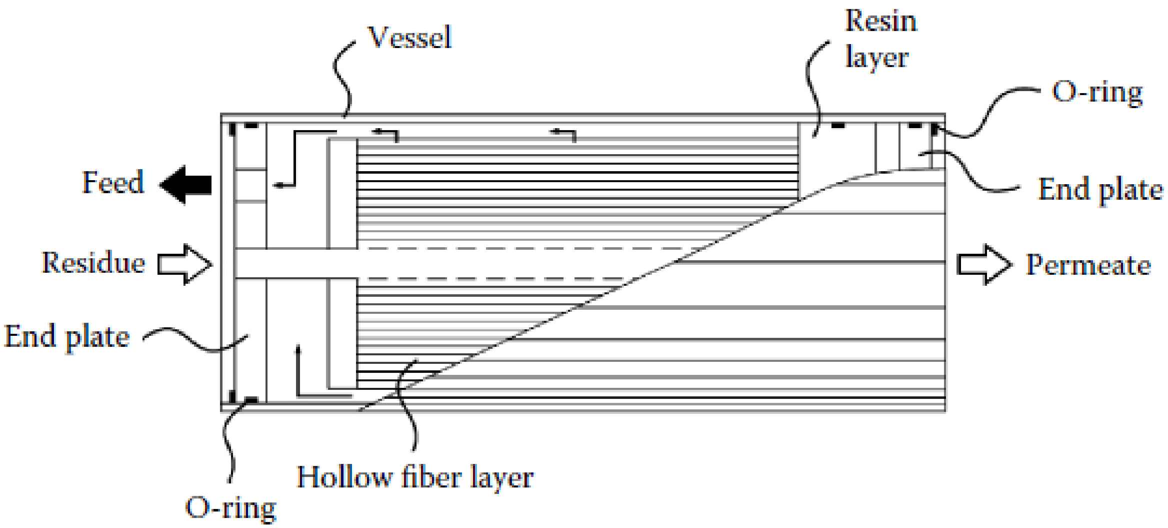
CARBON DIOXIDE REMOVAL FROM NATURAL GAS

- For CO2 removal, the industry standard is presently cellulose acetate.
- These membranes are of the solution-diffusion type, in which a thin layer (0.1 to 0.5 μm) of cellulose acetate is on top of a thicker layer of a porous support material.
- Permeable compounds dissolve into the membrane, diffuse across it, and then travel through the inactive support material.
- The membranes are thin to maximize mass transfer and, thus, minimize surface area and cost, so the support layer is necessary to provide the needed mechanical strength.

Hollow Fiber Membrane

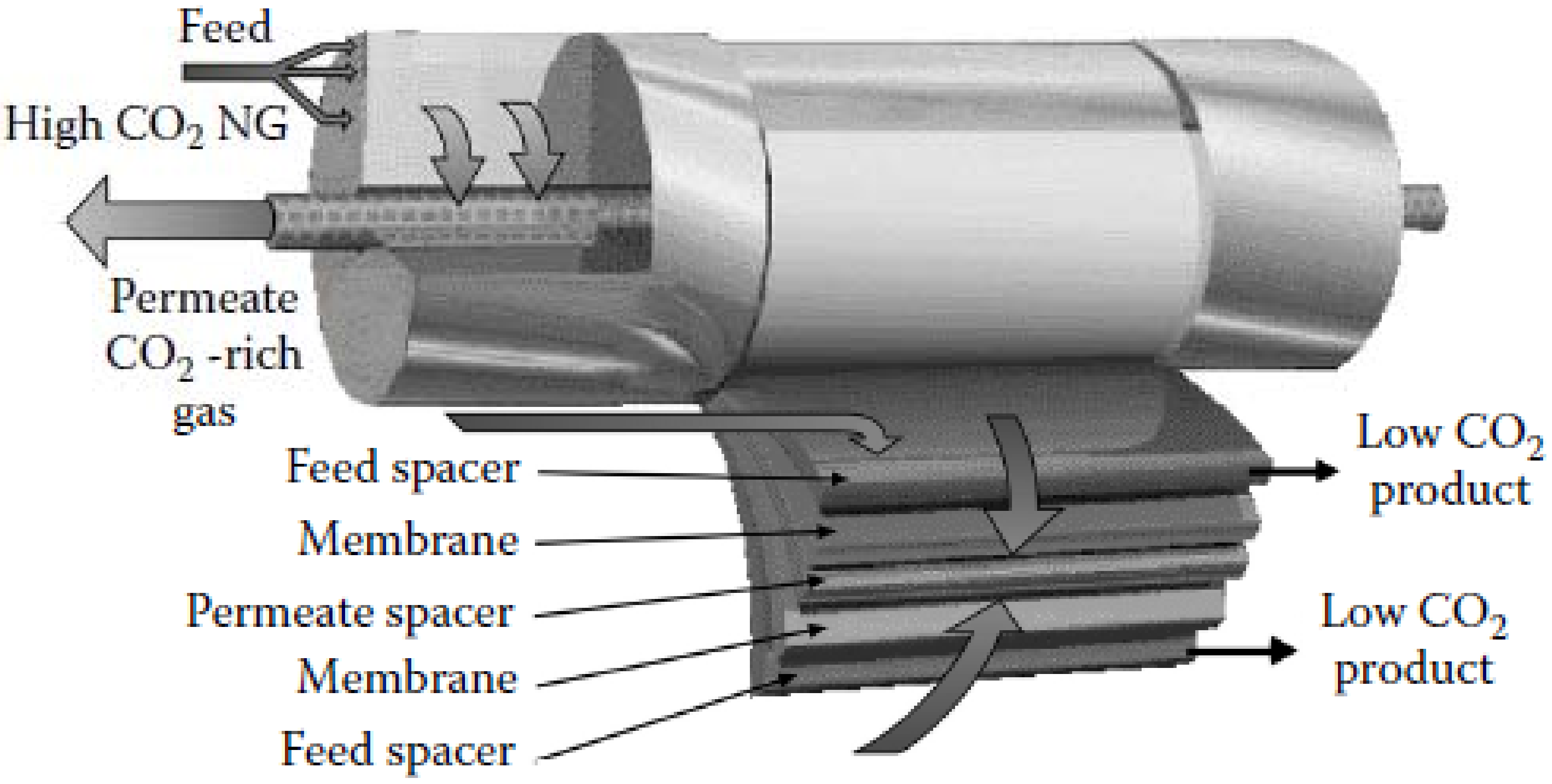


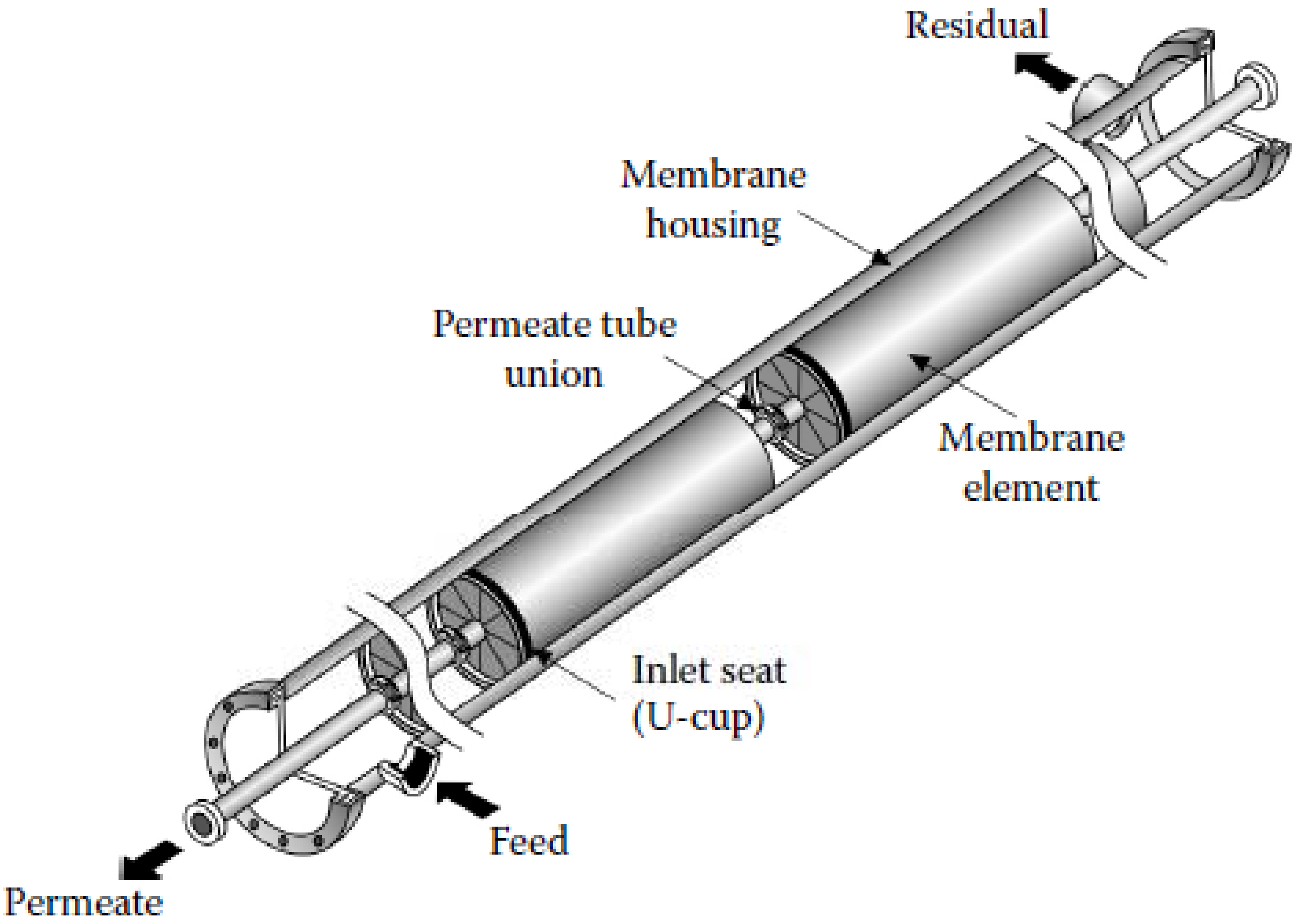
Low pressure, bore-side gas feed module



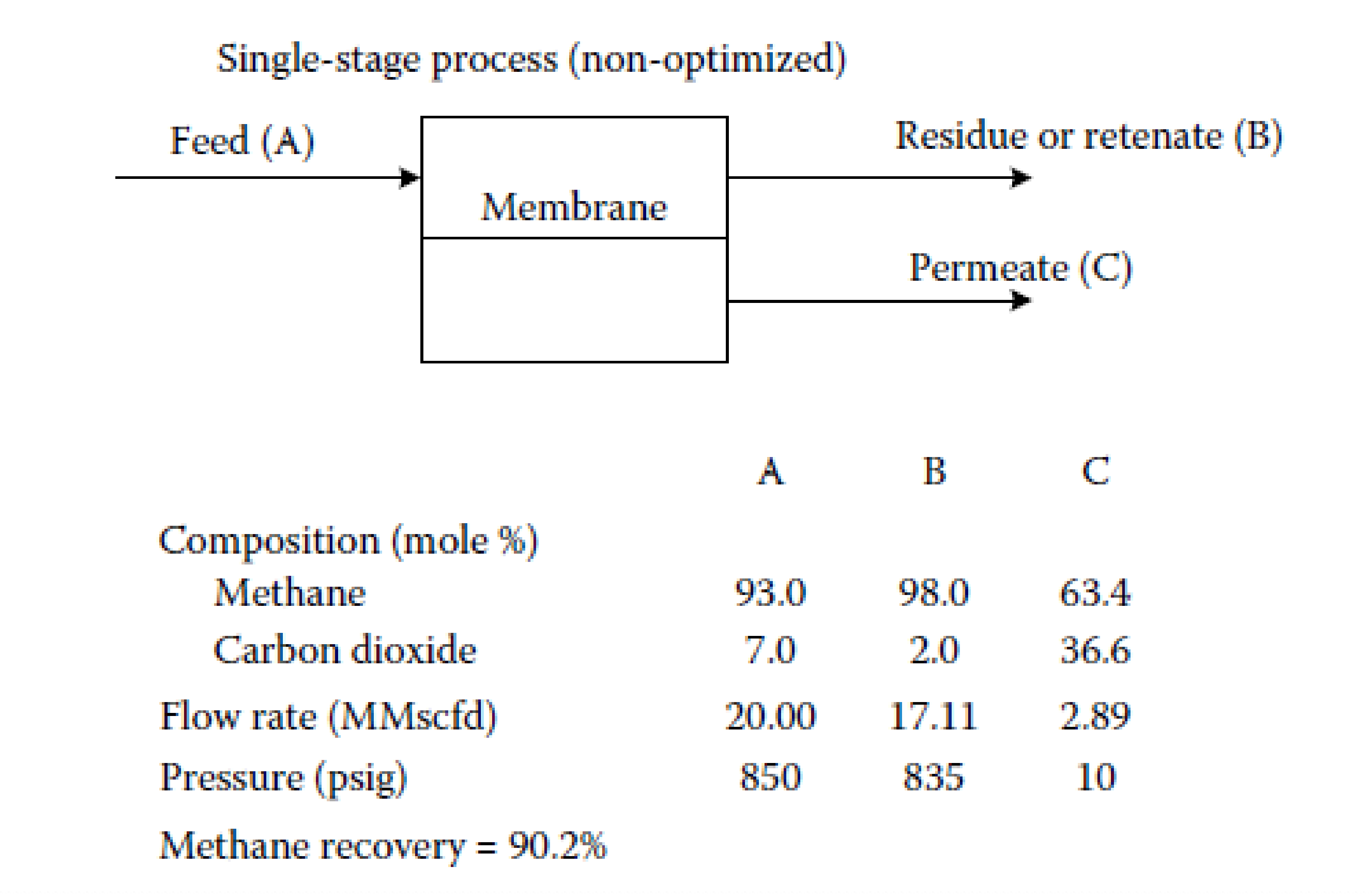
High pressure, shell-side gas feed module

Spiral Wound Membrane




Residual
Membrane housing
Permeate tube union
Membrane element
Inlet seat (U-cup)
Feed
Permeate

Single Stage CO2/CH4 Membrane Separation



Single-stage process (non-optimized)

Feed (A)

Membrane

Residue or retenate (B)

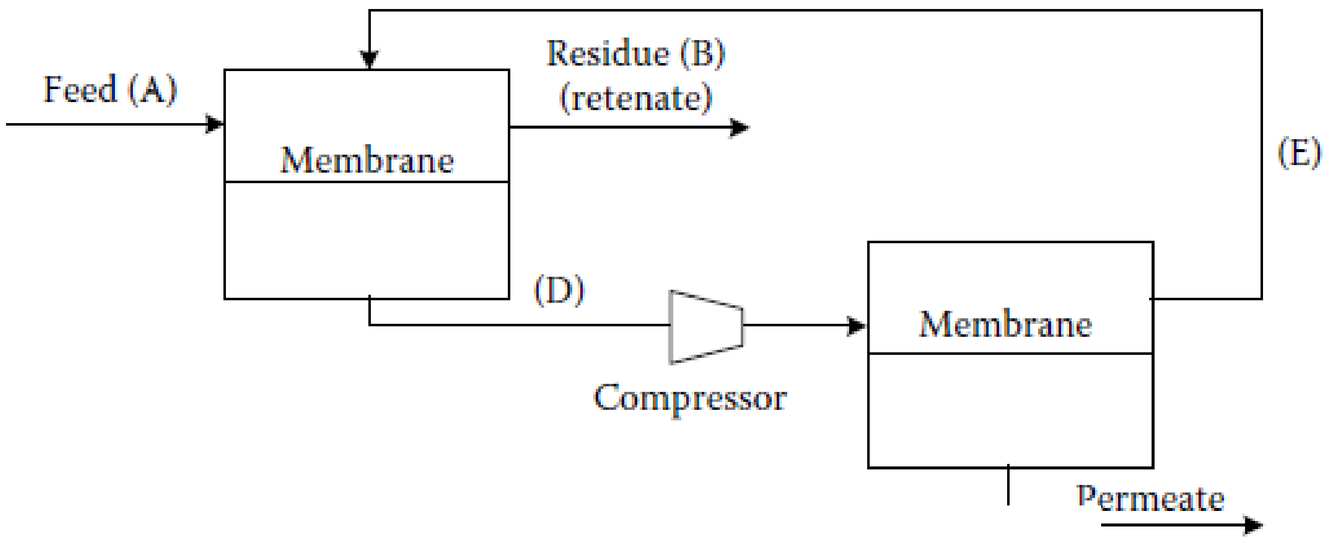
Permeate (C)

	A	B	C
Composition (mole %)			
Methane	93.0	98.0	63.4
Carbon dioxide	7.0	2.0	36.6
Flow rate (MMscfd)	20.00	17.11	2.89
Pressure (psig)	850	835	10

Methane recovery = 90.2%

Two-stage Membrane process

Two-stage process (non-optimized)

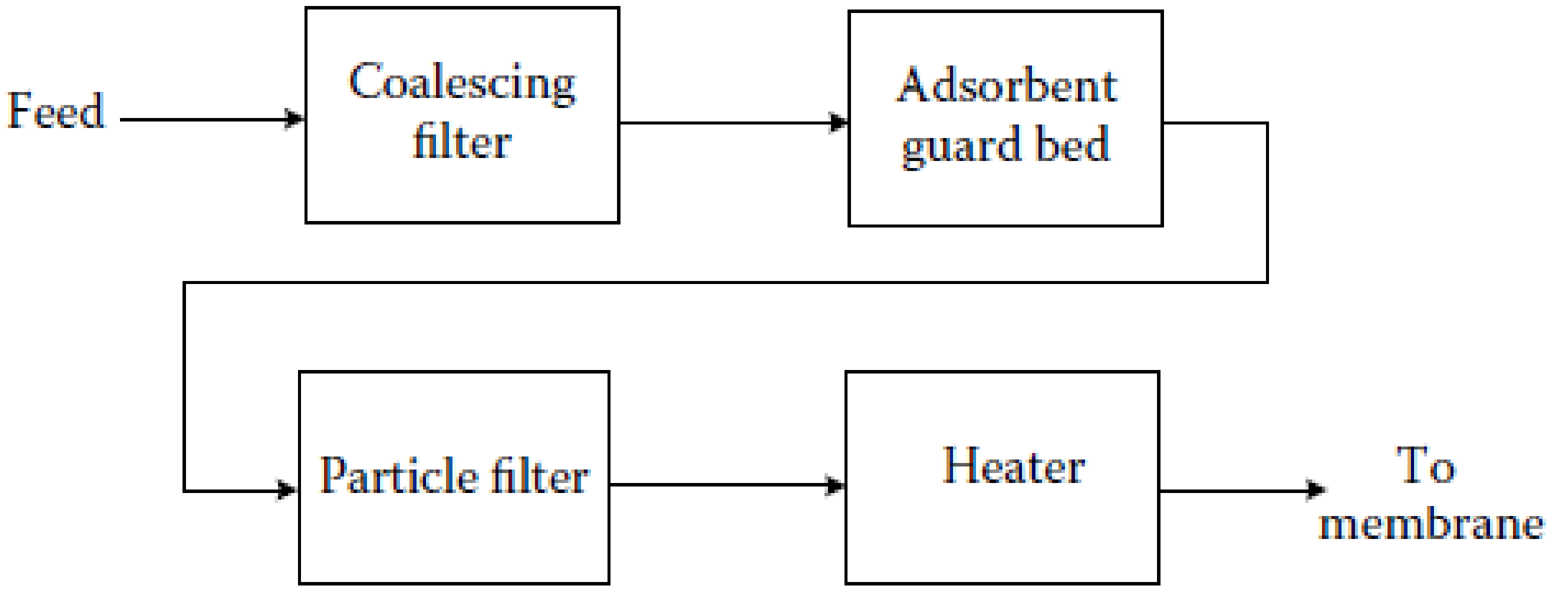


	A	B	C	D	E
Composition (mole %)					
Methane	93.0	98.0	18.9	63.4	93.0
Carbon dioxide	7.0	2.0	81.1	36.6	7.0
Flow rate (MMscfd)	20.00	18.74	1.26	3.16	1.90
Pressure (psig)	850	835	10	10	850

Methane recovery = 98.7%

Feed Gas Pretreatment

- Because membranes are susceptible to degradation from impurities, pretreatment is usually required.
- The impurities possibly present in natural gas that may cause damage to the membrane



Feed

Coalescing filter

Adsorbent guard bed

Particle filter

Heater

To membrane

ADVANTAGES OF MEMBRANE SYSTEMS

- Low capital investment when compared with solvent systems
- Ease of installation: Units are normally skid mounted
- Simplicity: No moving parts for single-stage units
- High turndown: The modular nature of the system means very high turndown ratios can be achieved
- High reliability and on-stream time
- No chemicals needed
- Good weight and space efficiency
- Ease of operation: process can run unattended

DISADVANTAGES OF MEMBRANE SYSTEMS

- Economy of scale: Because of their modular nature, they offer little economy of scale
- Clean feed: Pretreatment of the feed to the membrane to remove particulates and liquids is generally required
- Gas compression: Because pressure difference is the driving force for membrane separation, considerable recompression may be required for either or both the residue and permeate streams
- For natural gas:
  - Generally higher hydrocarbon losses than solvent systems
  - H_2S removal: H_2S and CO_2 permeation rates are roughly the same, so H_2S specifications may be difficult to meet
  - Bulk removal: Best for bulk removal of acid gases; membranes alone cannot be used to meet ppmv specifications

THANK YOU