ENP100 - Prosess og produksjon

Øving 7 - Løsningsforslag

Oppgave 1

a) Number of moles in 1 cubic feet of gas @ std. conditions:

mol = g mole (defined by metric units); p_std = 14.7 psi = 101325 Pa (rounded off), 60 °F = 288.71 K.

$$1\,ft^3 = (0.3048\,m)^3 = 0.0283\,m^3$$

$$N = \frac{101325\,N/m^2 \cdot 0.0283\,m^3}{8.3144\,Nm/molK \cdot 288.71\,K} \approx \underline{\underline{1.195\,mol}} \qquad \text{QED}$$

Water molecules are considered a part of the "dry" gas (i.e. small amount, but not zero)
Mw for water is 18.02 g/mol; 5 lbm = 5 * 0.4536 kg/lbm = 2.268 kg = 2268 g

$$N_w = \frac{2268\,g}{18{,}02\,g/mol} = 125.86 \text{ moles (of water in 5 lbm)}$$

$$X = \frac{N_w}{N_{tot}} = \frac{125.86}{1.195 \cdot 10^6} = 1{,}05 \cdot 10^{-4} \times 10^6 = \underline{\underline{105\,ppm}}$$

b) Water content of incoming "wet" gas:

p = 50 bar = <u>725 psi.</u>
T = 34 °C = <u>93.2 °F</u>

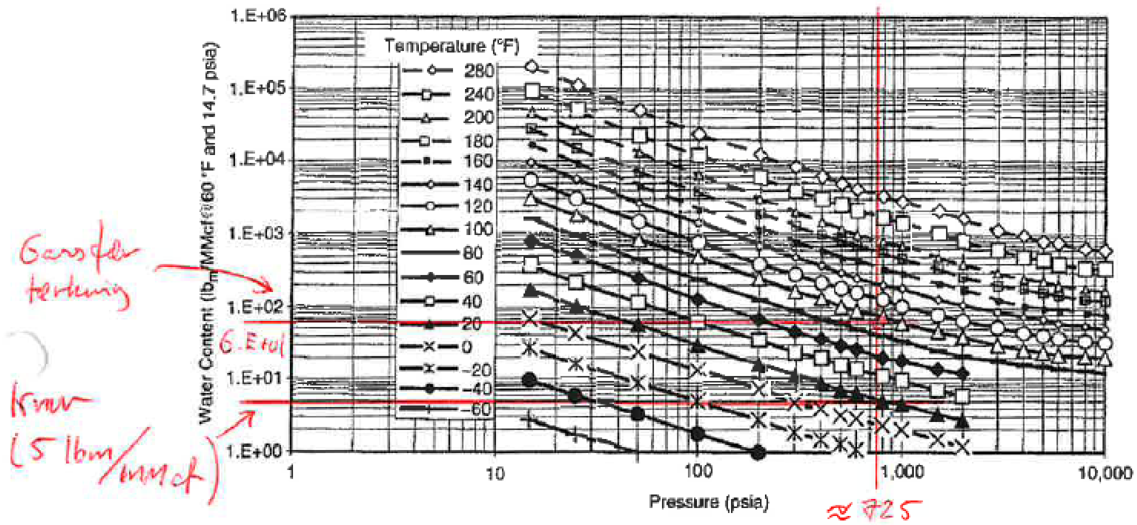


Figure 10.6 Water content of natural gases (Guo and Ghalambor, 2005).

Water content ≈ <u>60 lbm/MMScf</u>

Similar to a): 60 lbm = 60 * 0.4536 kg/lbm = 27.216 kg = 27216 g

$$X = \frac{27216\ g}{18.02\ g/mol} \cdot \frac{1}{1.195 \cdot 10^6\ mol} = \underline{\underline{1264\ ppm}}$$

c) Tables 10.9 and 10.10 give correction factors according to a reference gas with γ = 0.7 and T = 100 °F, which is very close to the gas in question. Both factors are therefore practically unity. Anyway; the following should demonstrate their use:

Table 10.9 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

Source: Used, with permission, from Sivalls, 1977.

Table 10.10 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

Source: Used, with permission, from Sivalls, 1977.

Tabell 10.9: $C_1 = 1.00 - \frac{100 - 93.2}{100 - 90} \cdot (1.00 - 1.01) = \underline{1.0068}$

Tabell 10.10: $C_g = 0.97 - \frac{0.75 - 0.71}{0.75 - 0.7} \cdot (0.97 - 1.00) = \underline{0.994}$

$$\Rightarrow q_s = \frac{2.54\ MMSm^3/d}{1.0068 \cdot 0.994} = 2.538 \cdot 35.32\ ft^3/m^3 = \underline{89.6\ MMscfd}$$

$\underline{\underline{OD = 72\ in}}$

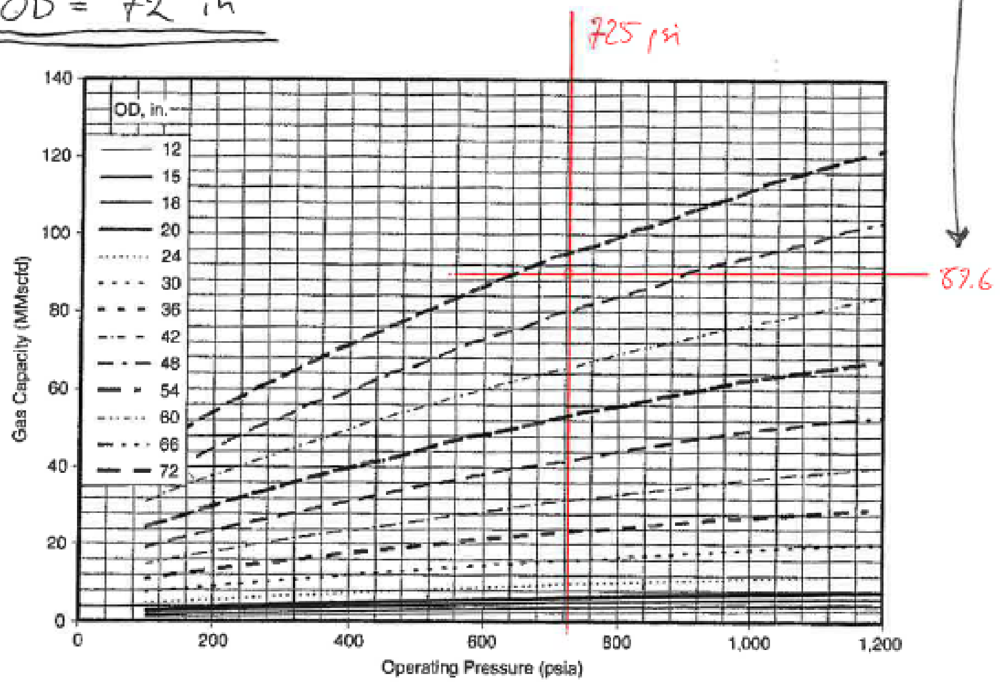


Figure 10.10 Gas capacity for trayed glycol contactors based on 0.7-specific gravity at 100 °F (Sivalls, 1977).

d) Same diagram as in b); Water dew point @ p = 725 psi is given by the iso-line for temperature at intersection between p = 725 and water content = 5 lbm/MMScf (solid triangles):
Td ≈ 18 °F = - 7.78 °C

e) Dew point prior to drying is the gas temperature (by definition, since the wet gas is saturated with water). Dew-point depression in °F is then ΔTd = 93.2 - 18 = 75.2 °F

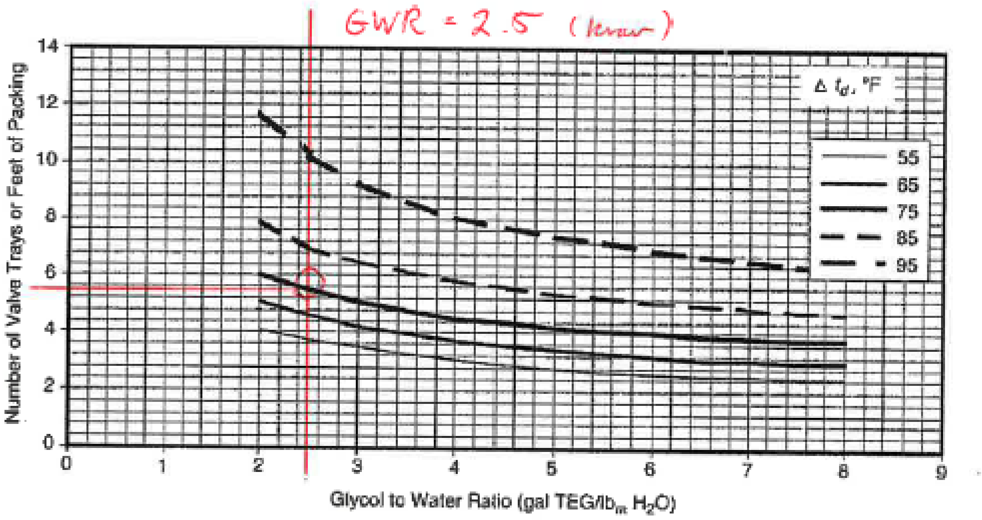


Figure 10.12 The required minimum height of packing of a packed contactor, or the minimum number of trays of a trayed contactor (Sivalls, 1977).

=> For discrete trays; 6 stages.

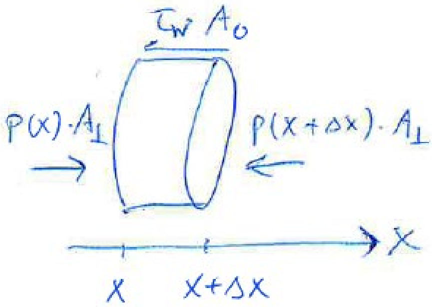
f) Glycol circulation rate by eq. (10.31); Take gas flow rate in MMscfd from c)

$$q_G = \frac{GWR \cdot C_{wi} \cdot q}{24} = \frac{2.5 \, \frac{gal\,(TEG)}{lbm\,(H_2O)} \cdot 60 \, \frac{lbm\,(H_2O)}{MMscf} \cdot 89.6 \, \frac{MMscf}{d}}{24 \, hr/d}$$

$$= 560 \, gal\,(TEG)/hr$$

Oppgave 2

a) No accelleration (constant density and area) => Zero sum of forces on liquid element:



$$\sum F_x = 0:$$

$$\underbrace{P(x)\cdot\frac{\pi}{4}D^2}_{A_\perp} - P(x+\Delta x)\cdot\underbrace{\frac{\pi}{4}D^2}_{A_\perp} - \tau\cdot\underbrace{\pi D \Delta x}_{A_0} = 0$$

Cancel factors: $\frac{D}{4}\left(P(x) - P(x+\Delta x)\right) - \tau \Delta x = 0$

$$\rightarrow \frac{P(x+\Delta x) - P(x)}{\Delta x} = -\frac{4}{D}\tau_w$$

$$\lim_{\Delta x \to 0} \frac{P(x+\Delta x) - P(x)}{\Delta x} = \boxed{\frac{dP}{dx} = -\frac{4}{D}\tau_w}$$

b) All methods require the Reynold's number (Re) and relative roughness (eD) to be calculated. Using the SI system, the viscosity must be converted to Pa s (1 cP = 10^{-3} Pa s) and the diameter to m:

$$Re = \frac{883\ \mathrm{kg/m^3} \cdot 5\ \mathrm{m/s} \cdot 0.075\ \mathrm{m}}{1.69\cdot 10^{-3}\ \mathrm{Pa\cdot s}} = \underline{195932}$$

$$\left[\frac{\mathrm{kg}}{\mathrm{m^3}}\cdot\frac{\mathrm{m}}{\mathrm{s}}\cdot\mathrm{m}\cdot\frac{\mathrm{m^2}}{\mathrm{N}\ \mathrm{s}} = \frac{\mathrm{kg}\cdot\mathrm{m}}{\mathrm{s^2}}\cdot\frac{1}{\mathrm{N}} = 1\right]$$

$$e_D = \frac{0.05\ \mathrm{mm}}{75\ \mathrm{mm}} = 0.00067$$

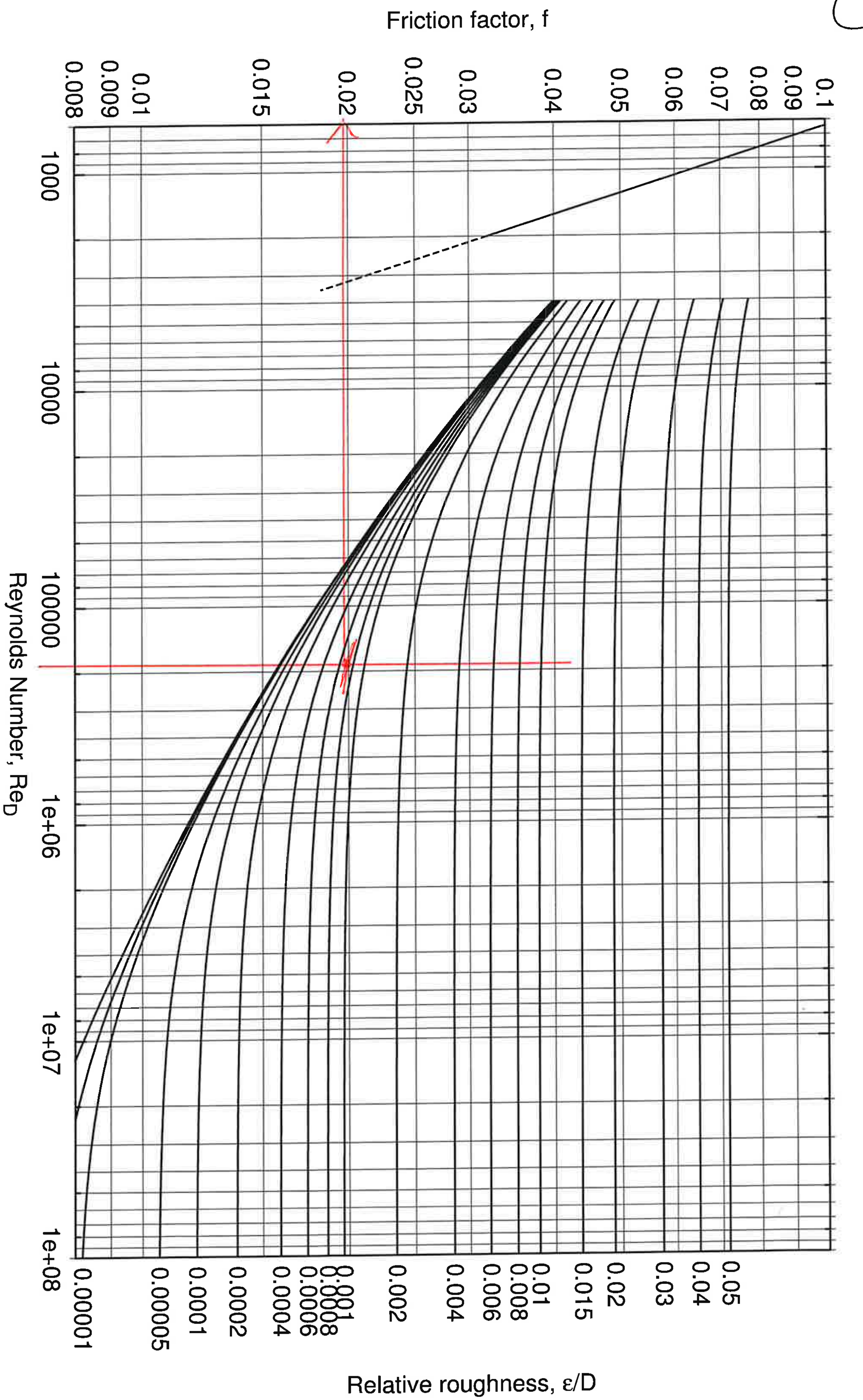
Jain's formula (H.89):

$$\frac{1}{\sqrt{f_D}} = 1.14 - 2\cdot\log\left(0.00067 + \frac{21.25}{195932^{0.9}}\right) = \underline{7.109}$$

$$\rightarrow f_D = \frac{1}{7.109^2} = \underline{\underline{0.0198}}$$

The moody diagram (see next page) matches this value.

7a


Friction factor, f
0.008
0.009
0.01
0.015
0.02
0.025
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Reynolds Number, Re_D
1000
10000
100000
1e+06
1e+07
1e+08
0.00001
0.00005
0.0001
0.0002
0.0004
0.0006
0.0008
0.001
0.002
0.004
0.006
0.008
0.01
0.015
0.02
0.03
0.04
0.05
Relative roughness, ε/D

c) Use the definition of the Darcy friction factor to find the wall shear tension tw. Then integrate the expression from a):

$$\tau_w = \frac{1}{8} f_D \rho u^2 = \frac{1}{8} \cdot 0.0198 \cdot 883 \cdot 5^2 = \underline{54.6 \ \frac{N}{m^2}}$$

$$dp = -\frac{4}{D} \tau_w \cdot dx \rightarrow \int_{P_1}^{P_2} dp = -\frac{4}{D} \cdot \tau_w \cdot \int_0^L dx$$

$$\Rightarrow P_2 - P_1 = -\frac{4 \tau_w \cdot (L-0)}{D} \Rightarrow P_1 - P_2 = \frac{4 \cdot 54.6 \cdot 100}{0.075}$$

(Sign changes)

$$= 291200 \ \underbrace{N/m^2}_{Pa} = \underline{\underline{2.91 \text{ bar}}}$$