University of Stavanger

Faculty of Science and Technology

Dato: August 27^{th}, 2015

Exam in : PET 540, Natural Gas Reservoir and Production Engineering
Duration : 4 hours
Supporting materials : Use of simple calculator is permitted
Content: 4 exercises on 5 pages
Course responsible : Prof. Jann Rune Ursin

Exercise 1

The formation factor for gas is defined,

$$B_g = \frac{V}{V_{sc}},$$

where the subscript sc means "standard conditions".

1. Use the above equation and show how B_g varies a function of pressure. Make a sketch showing $B_g(p)$.
2. Use the definition of the gas flow rate and show that

$$q = B_g(p) \cdot q_{sc},$$

   where q is the gas rate at pressure p.

Darcy law for radial flow in a cylindrical reservoir with a hight h, is written

$$q = A\frac{k}{\mu}\frac{dp}{dr}.$$

3. Show that the solution of the above equation is,

$$q_{sc} = \frac{2\pi hk}{\overline{\mu Z}(T/T_{sc})}\frac{1}{\ln(r_e/r_w)}\frac{p_e^2 - p_w^2}{2p_{sc}},$$

   where q_{sc} is assumed to be constant. Consider μ and Z to be slowly varying functions, being represented by their average values. The pressure at the peripheral of the reservoir is given by $p(r = r_e) = p_e$ and P_w is the well-bore pressure.

4. Show that the above solution also can be written as,

$$\Delta p = \frac{\overline{q\mu}}{2\pi hk}\ln\frac{r_e}{r_w}.$$

   Define the parameters Δp and $\overline{q}$.

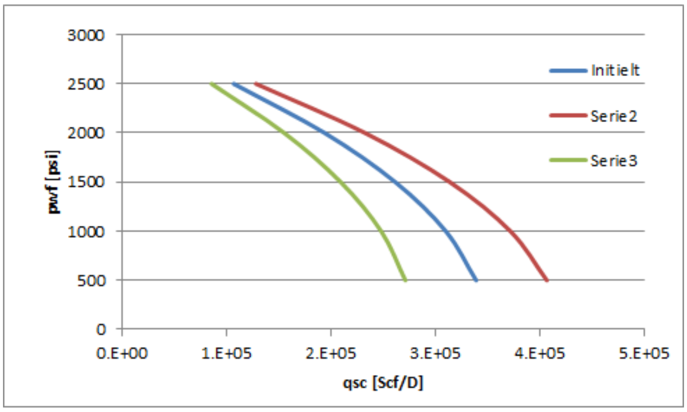

Figure 1

Figure 1 shows the bottom-hole pressure as function of surface flow rate for three choices of reservoir permeability.

5. Use the pressure-rate equation above to identify the two cases where the reservoir permeability are higher or lower than the initial case.

A well is producing $10 \cdot 10^6\ scf/day$. The bottom-hole pressure and temperature are respectiviely $1500\ \ psia$ og $180\,^oF$. The critical pressure and temperature of the gas are respectively given as $670\ \ psia$ og $370\,^oR$, where the definition of Rankine is as follows $^oF + 460 =^o R$.

6. Define the pseudo-reduced pressure and temperature, when the gas pressure and temperature are given above.
7. Use Standing and Katz, Figur 5 (see end of exercise), and define the gas compressibility factor (the Z-factor).
8. Assume the gas volume factor $B_g(p)$ can be expressed as,

$$B_g[res\ ft^3/scf] = 0.0283\frac{ZT}{p},$$

   where the pressure and temperature are measured in respectively psi and ^oR.

   Calculate the bottom-hole flow rate.
9. Verify the numeric value (0.0283) in the equation above.

Exercise 2

The Z-factor may generally be calculated as function of pressure and temperature. Figur 2 shows the gas correction factor (or gas compressibility factor) as function of pressure, p.

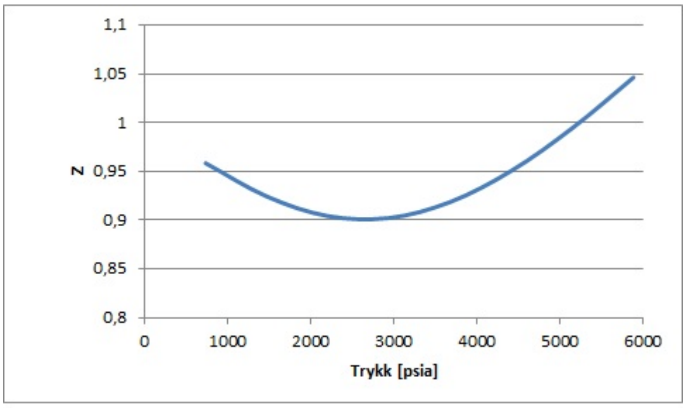

Figure 2

1. If the temperature of the gas is increased somewhat with respect to the gas shown in Figure 2, how would then the curve $Z(p)$, in the figure above be drawn?
2. What is the asymptotic Z value for real gases?

Isothermal compressibility for real gases is defined as,

$$c_g = -\frac{1}{V}\left(\frac{dV}{dp}\right)_T,$$

where V, p and T are respectively; volume, pressure and temperature.

3. Show that the compressibility for real gases can be written,

$$c_g = \frac{1}{p} - \frac{1}{Z}\frac{dZ}{dp}.$$

4. Based on the function $Z(p)$ in Figure 2, explain and describe using the figure, how the correction term in the equation above can be calculated.
5. Figure 3 shows the compressibility factors for a real gas and an ideal gas. Identify (and explain) which gas is real and which is ideal.

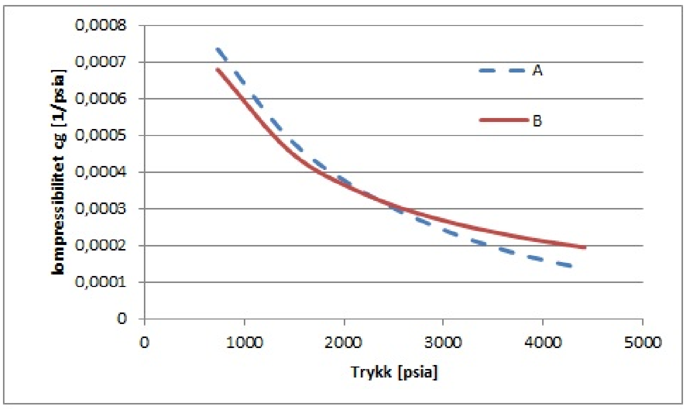

Figure 3

Exercise 3

In offshore natural gas reservoir production, a certain volume of water is always produced alongside with the gas. The amount of water in equilibrium with the gas is given by Dalton's law,

$$y_w = \frac{p_w(\text{water vapor})}{p(\text{reservoir})},$$

where y_w is the water composition in the reservoir fluid, p_w is the vapor pressure (partial pressure) in the reservoir.

Starting with Dalton's law, it is possible to estimate the associate water rate at natural conditions; 15^oC (288^oK) and 1 atm (1.01325 bar), when the gas flow rate is 7 MSm^3/day. Assume the reservoir temperature to be 100^oC and the reservoir pressure, 400 bar.

1. Show that the molar fraction of water vapor in the reservoir is estimated to be 0.25% .

Gas at normal conditions is assumed to have near ideal characteristics, i.e. the molar volume is constant and $V_m = 23.664\, m^3/kmol$.

2. Calculate the molar gas rate, $q_{m,g}$.

The molar water rate $q_{m,w}$ is given by the formula,

$$q_{m,w} = \frac{y_w}{1 - y_w} q_{m,g}.$$

3. Derive the above equation and calculate the molar water rate.
4. When the molar mass of water is 18.015 $kg/k\,mol$ and the density of water is 1000 kg/m^3, - calculate the water rate at natural conditions, measured in m^3/day.
5. Does natural water production, as described above, require spacial water handling facilities in relation to natural gas production?

Exercise 4

Figure 4 shows the reservoir pressure as function of total depth for four different gas reservoirs, where two reservoirs are in hydrostatic equilibrium.

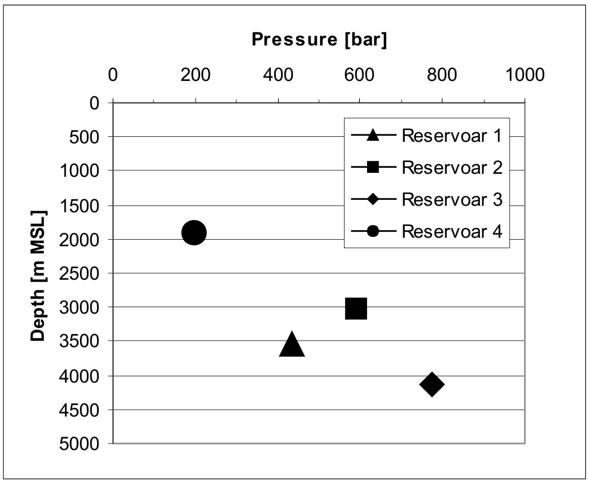

Figure 4: Reservoir pressure as function of total depth.

1. Identify the two reservoirs which are in hydrostatic equilibrium, by calculations. Use the numeric values presented in the figure. (Assume average water density of 1100 kg/m^3 and gravity 9.8 m/s^2.)
2. For the two reservoirs in Figure 4, which seems not to be in hydrostatic equilibrium, - what can generally be said about the size and existence of an associated aquifer?
3. Which factors favours a strong aquifer influx. Mention three different factors related to the aquifer.
4. Is the gas production rate of any importance in relation to pressure support from aquifers (short explanation)?
5. Make an account of advantages and disadvantages related to aquifer influx.

Best of luck!

JRU

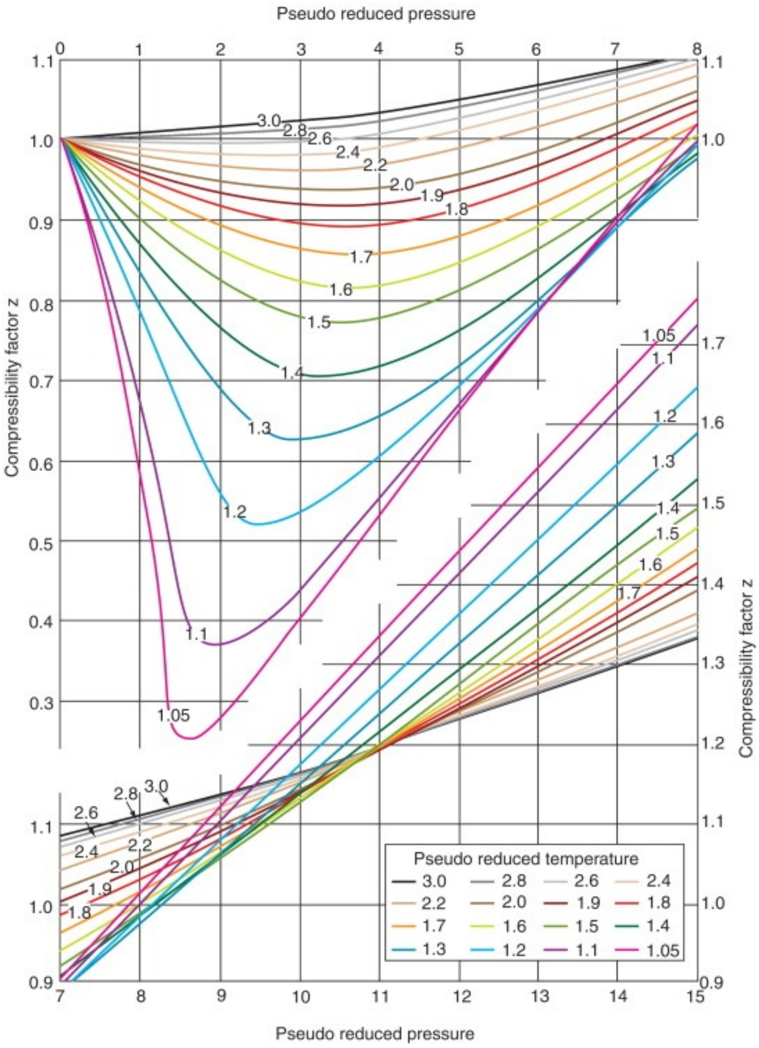

Figure 5: Correction factor for natural gases (Standing and Katz)