University of Stavanger

Faculty of Science and Technology

Dato: 1. of June 2015

Exam in : PET 540, Natural Gas Reservoir and Production Engineering
Duration : 4 hours
Supporting materials : Use of simple calculator is permitted
Content: 3 exercises on 4 pages
Course responsible : Prof. Jann Rune Ursin

Exercise 1

Consider single-phase gas flow in a simple strait conduct section of constant cross-section, A and at a deviation angle α. The flow direction is upward with a flow velocity u. The well distance co-ordinate system, denoted by y, is parallel to the well conduit direction, where the flow of gas is modeled by looking at a slab of gas moving upwards.

1. Define the forces acting on the slab by drawing a figure and identify the forces and their action points.
2. In addition to these forces, the modeling of tubular gas flow is done by using three laws of nature. Name these three laws and write down the formulas and explain parameters not accounted for.

The basic equation for flow of real gases in strait flow conducts is written:

$$\frac{w^2}{A^2}\frac{RT}{M_g}d\left(\frac{Z}{p}\right) + dp + \frac{M_g}{RT}g\cos(\alpha)\frac{p}{Z}dy + \frac{2f}{d_h}\frac{w^2}{A^2}\frac{RT}{M_g}\frac{Z}{p}dy = 0.$$

3. Identify the different groups of parameters, by referring to the above forces.
4. Show that the pressure distribution in a shut-in well is written,

$$p = p_{bh}e^{-N_{gp}y/L}$$

   and define the constant N_{gp}.

5. Write down the barometric hight formula and explain how this formula can explain the atmospheric pressure at the surface of the earth.

In the equation above, the dimensionless number N_{gp} is dependent on the gas characteristics defined by $\overline{Z}$, where one might write,

$$p = ae^{b/\overline{Z}}.$$

Recognizing that $\overline{Z}$ is an average value, we may introduce an uncertainty ΔZ which reflects the error done by substituting an average z-factor when integrating along the well.

6. Define the relative uncertainty in the pressure $\Delta p/p$, when the relative uncertainty in Z is 3$\%$. Assume $N_{gp} = 0.25$

Since the dimensionless number N_{gp} is also dependent on the temperature T, in the well. The above equation can be written,

$$p = ae^{b'/(\overline{ZT})},$$

where $b' \neq b$.

The temperature in the well will normally vary somewhat, such that $T_{bh} > T_{wh}$. Using the bottom-hole temperature as a reference when calculating the well head pressure p_{wh}, we may expect an uncertainty in this pressure related to the uncertainty in the well-bore temperature.

7. If the bottom-hole temperature is $390K$ and the well-head temperature is only $350K$, what is the relative uncertainty in the well-head pressure due to this temperature decline?
8. What is the dominating uncertainty, comparing Z and T ?
9. Given an uncertainty in both Z and T, as described above, what is the combined uncertainty of both uncertainties in the well head pressure?

Exercise 2

1. It is quite common to subdivide gas reservoirs into three different subcategories. Name these and explain their principle differences.
2. Make a figure as depicted in Figure 1, where point A is defining the reservoir initial condition and point B the first separator stage.

   Draw the two-phase envelopes for the three gas reservoirs mentioned above.
3. Draw Figure 1 again for a general gas condensate reservoir where the gas is initially in one phase.

   Define the critical point and label the dew-point curve. Draw also the iso-line for maximum reservoir liquid dropout.

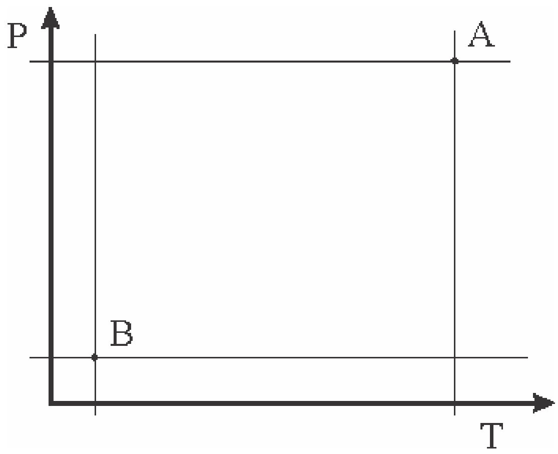

Figure 1: PT-diagram.

4. Explain the problems related to gas condensate reservoir production when the reservoir temperature is close to the critical fluid temperature.

Phase equilibrium has been defined by the following equation,

$$G(V) = \sum_{i=1}^{N} \frac{z_i(K_i - 1)}{1 + (K_i - 1)V} = 0,$$

where N is the number of compounds in the fluid and V is the gas fraction or the gas split fraction ($V + L = 1$).

5. Define the parameter K_i.

6. Calculate the derivative $G'(V) = dG(V)/dV$ and classify the function (say something about how it behaves).

The function $G(V)$ above, is normally solved by Newton-Raphson's iteration method based on an approximate Taylor expansion

$$G(V) \approx G(V^0) + G'(V^0)(V - V^0),$$

where V is an expansion close to the "true" solution V^0 and where $G(V^0) = 0$

7. Show that the iteration formula based on the Taylor expansion can be written

$$\frac{G(V^k)}{V^{k+1} - V^k} = G'(V^k).$$

   Define the parameter k in the above equation.

8. Draw the function $G(V)$ (in a GV- plot) and show how the iteration process can be represented in the plot.

Exercise 3

The equation below is describing dry and wet gas production,

$$\frac{p}{Z} = \frac{p_i}{Z_i}\frac{V_{HCi}}{V_{HC}}\left(1 - \frac{G_p}{G_i}\right).$$

1. Define volumetric dry gas production, based on the equation above.
2. Make a plot showing reduced pressure as function of cumulative gas produced.

   Mark the abandonment pressure (reduced pressure) on the plot, where $(p/Z)_a$ is 10% of the initial pressure.
3. Define the estimated recovery for such a dry gas reservoir.
4. Draw the alternative production profile, $p/Z(G_p)$ for the case of moderate aquifer influx and for the case of very strong aquifer influx.
5. How would the recovery vary between the three cases above and why?

In connection to production from a gas condensate reservoir, both reduced pressure and production volumes are measured (see Table 1). In addition, the strength of an aquifer has been evaluated and an approximate model is established.

Table 1: The table shows reduced pressure, cumulative production volume and estimated cumulative aquifer influx.

reduced pressure [bar]	cumulative production [$10^6 Sm^3$]	cumulative aquifer influx [Rm^3]
394.54	2.5	0
378.42	52.5	47021
365.92	102	132000
352.88	177	299000

6. Assume the reservoir hydrocarbon volume V_{HC}, is mainly influenced by the aquifer influx W_e and show that the equation describing dry and wet gas production can be written as,

$$\frac{p}{Z}\left(1 - \frac{W_e}{V_{HCi}}\right) = \frac{p_i}{Z_i}\left(1 - \frac{G_p}{G_i}\right)$$

.

7. Make a plot based on the data in Table 1 and determine GIIP. (Based on geological data, the initial hydrocarbon volume is approximately $3.2 \cdot 10^6\ Rm^3$.)
8. If we would have assumed the aquifer influx to be negligible, i.e $W_e = 0$, what would then the percentage error in our estimate of GIIP be?