University of Stavanger

Faculty of Science and Technology

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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
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Exercise 1

We often use somewhat simplified models in characterizing production from natural gas reservoirs.

1. How would you characterize volumetric pressure depletion?
2. List 3 possible reasons for no-volumetric depletion.

Assume an aquifer water rate, q_w connecting an aquifer water volume V_w with a natural gas reservoir at pressure p. The aquifer compressibility is c_w.

3. Write up the definition of isotherm compressibility and show that the water rate q_w can be written,

$$q_w = c_w V_w \frac{\Delta p}{t},$$

where t is the time and where the pressure drop Δp is small.

4. Find an expression for cumulative aquifer influx in to the gas reservoir at constant pressure drop Δp.
5. If the aquifer influx is as described above, - how would you characterize the water zone compared to the reservoir (strong or weak)? Support your answer with an argument!

Aquifer influx are modeled by solutions of the a modified diffusivity equation for cylindrical and some non-cylindrical aquifer zones, where the following dimensionless parameters are used (the parameters are assumed known);

$$r_D = \frac{r}{r_b}, \qquad t_D = \frac{kt}{\phi \mu c r_b^2}, \qquad \text{og} \qquad q_D = \frac{q\mu}{2\pi h k \Delta p}.$$

6. Explain very briefly why it is appropriate to use the diffusivity equation in solving the aquifer influx problem.

7. Use the definition for cumulative aquifer influx

$$We = \int_0^t q dt,$$

and show thet the influx is written

$$We = U \Delta p We_D(t_D).$$

8. Write up the expressions U and $We_D(t_D)$.

9. When calculating the dimensionless aquifer influx $We_D(t_D)$, which parameters are naturally part of such an expression?

In connection to production from a gas reservoir, the following pressure and production data are given in the table below. As part of a general analysis of the reservoir, there has been included a possible model for cumulative aquifer influx, as seen in the table.

Table 1: The table shows reduced pressure and production data for gas 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

The following equation describeds dry - and wet gas production,

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

.

Assume the available space (volume) for the gas in the reservoir, V_{HC} is to a high degree only dependent on the aquifer influx We.

10. Show that the equation describing the dry - and wet gas production can be written as,

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

.

11. Plott the data in the table above and find GIIP. (The hydrocarbon volume, $V_{HC} \sim 3.2 \cdot 10^6$ Rm^3 is known, based on geological data.)

12. If we would have assumed no aquifer influx, i.e. $We = 0$, what would then be the estimated GIIP and what would be the error in this estimate?

Exercise 2

In natural gas production it is the pressure difference between reservoir and surface that causes the gas to flow; first through the reservoir rock towards the well and later through the well-bore and tubing, up to the surface. The surface production rate is therefore determined by the pressure drop in reservoir and tubing.

1. Write up the pressure equation that demonstrates this relationship, where the following pressures are considered known: $\Delta p_{reservoir}$, Δp_{tubing}, $\overline{p}$, p_{bh} and p_{wh}.

2. Define the pressure differences above: $\Delta p_{reservoir}$ and Δp_{tubing}.

3. The surface rate q_{sc} is during normal gas production limited by essentially three effects. Name these and explain how?

Well-inflow performance refers to the production well rate as function of the pressure draw-down between the reservoir and the producing well. For a given reservoir pressure, the well can produce the reservoir gas at a certain flow rate, maintaining a particular bottom-hole pressure $p_{bh} = p_{bh}(q_{sc})$.

Expressed in pseudo-pressures, the steady state inflow equation is written

$$\overline{m} - m_{bh} = a q_{sc} + b q_{sc}^2,$$

where $\overline{m}$ and m_{bh} are the mean - and bottom-hole pseudo-pressure. q_{sc} is the flow rate at standard conditions and a and b are constants defined as

$$\begin{aligned} a &= \frac{(\mu B)_r [\ln(r_e/r_w) - 0.75 + S]}{2\pi k h}, \\ b &= \frac{(\mu B)_r}{2\pi k h} D, \text{ where } D = \frac{k}{\phi \mu c}. \end{aligned}$$

(Note: That the reservoir under consideration is cylindrical with the well at the center.)

4. Identify and characterize the above parameters: $\ln(r_e/r_w)$, -0.75 , S and D.

5. Some of the above parameters are obviously constants, but not all. Identify those parameters which would be pressure dependent and draw this pressure dependence in a plot.

6. How should these parameters be updated in a simulation situation?

The conversion between pseudo pressure, m and pressure, p is given by the Kirchhoff's transformation

$$\frac{dp_{bh}}{dq_{sc}} = \frac{\mu B}{(\mu B)_r} \frac{dm_{bh}}{dq_{sc}}.$$

The mean pseudo pressure $\overline{m}$, is considered to be constant under derivation with respect to the gas rate q_{sc}, since the mean pressure in the reservoir is not directly affected by the change in flow rate.

7. Show that the steady state inflow equation, above, can be written as follows using Kirchhoff's transformation,

$$\frac{dp_{bh}}{dq_{sc}} = -\frac{\mu B}{2\pi k h}(\ln(r_e/r_w) - 0.75 + S + 2Dq_{sc}).$$

8. Based on the equation above, draw the well-inflow performance curve in a $p(q_{sc})$-plot.

9. In the plot, - mark the crossing point on the pressure axis for $q_{sc} = 0$ and the two limiting flow rates q_{min} and q_{max}.

10. Explain the existence of the above limiting rates.

11. Draw the well-inflow performance curve for a reservoir where the productivity kh, is lower than anticipated. NB: Use the same plot as above.

In much the same way as for the well-inflow performance, the well tubing performance can be described by an equation $p_{bh} = p_{bh}(q_{sc})$. An approximated equation has been derived,

$$p_{bh} \sim p_{wh}\sqrt{e^{2N_{gp}} + \frac{\overline{f} q_{sc}^2}{A^2 d_h} \cdot \text{constant}},$$

where the "constant" in the equation above does not depend on the flow rate and is as such not of interest when considering the bottom-hole pressure as function of gas flow rate.

11. Identify and briefly explain the significance of the parameters; $\overline{f}$, A and d_h.

12. Make a plot showing the tubing flow performance $p(q_{sc})$.

13. Use the same plot and draw the curve a slightly increasing tube diameter.

14. Show that the above approximate pressure solution is identical to the barometric hight formula.

Best of luck!
JRU