Suggested solution to the re-sit exam in Well-Test Analysis, Dec. 7, 2012

Problem 1

a) Three flow regimes are evident in the data: 1) Wellbore storage dominated early data, from the beginning to about 8E-4 hrs, (2) radial-flow data in the middle, from about 0.06-0.5 hrs, and (3) hemi-radial data caused by a single no-flow boundary at the end, from about 6 hrs. Data from the first can be used to determine the wellbore storage constant (C). Data from the second can be used to determine the flow capacity (kh) and hence the permeability (k). Data from the last, or the onset of deviation from the second, can for instance be used to estimate the distance (d) to the boundary based on the radius of investigation.

The storage constant can be determined through the steps

$$C = \frac{qB}{24}\frac{\Delta t}{\Delta p} = \frac{(3300)(1.4)}{24}\frac{0.0001}{7262.45 - 7260.87} = \frac{(3300)(1.4)(0.0001)}{(24)(1.58)} = 0.012184 \text{ RB/psi}$$

by using the first entry in Table 2 and the pressure at shut-in.

Since we have radial-flow buildup data between 0.06 and 0.5 hrs, we can use the data points $p_{ws} = 7354.46$ psia at $\Delta t = 0.0802$ hrs and $p_{ws} = 7363.30$ psia at $\Delta t = 0.3193$ hrs to determine the semi-log slope

$$m = \frac{7363.30 - 7354.46}{\log\left[0.3193/(16+0.3193)\right] - \log\left[0.0802/(16+0.0802)\right]} = \frac{8.84}{0.5936} = 14.89 \text{ psi/log-cycle.}$$

From the slope we get

$$kh = \frac{162.6 qB\mu}{m} = \frac{(162.6)(3300)(1.4)(0.35)}{14.89} = 17657.8 \text{ md}\cdot\text{m}$$

and

$$k = \frac{kh}{h} = \frac{17657.8}{106} = 166.6 \text{ md.}$$

If we use the radius of investigation at the time 0.6 hrs we can set

$$d = r_{inv} = 0.0246\sqrt{\frac{k\Delta t}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(166.6)(0.6)}{(0.16)(0.35)(3.3\times 10^{-5})}} = 178.4 \text{ ft.}$$

b) We can use the points and steps above to determine m, kh and k. Moreover, with the point $p_{ws} = 7354.46$ psia at $\Delta t = 0.0802$ hrs on the semi-log straight line by construction, we can extrapolate to p_{1hr} at $\Delta t = 1$ hr as follows:

$$p_{1hr} = 7354.46 + m\left\{\left[\log 1/(16+1)\right] - \log\left[0.0802/(16+0.0802)\right]\right\}$$

$$= 7354.46 + 14.89(-1.23045 + 2.30212) = 7354.46 + 15.96 = 7370.42 \text{ psi.}$$

The skin value can next be determined from the formula

$$S = 1.151\left(\frac{p_{1hr} - p_{wf,s}}{m} - \log\frac{t}{t+1} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.23\right)$$

$$= 1.151\left[\frac{7370.42 - 7260.87}{14.89} - \log\frac{16}{16+1} - \log\frac{166.6}{(0.16)(0.35)(3.3\times10^{-5})(0.25)^2} + 3.23\right]$$

$$= 1.151(7.3573 + 0.0263 - 9.1591 + 3.23) = 1.67\,.$$

The added pressure drop at the wellbore can now also be computed as

$$\Delta p_S = \frac{m}{1.151}S = \frac{14.89}{1.151}(1.67) = 21.60 \text{ psi.}$$

The pressure at shut-in would have been

$$p_{wf,s} = 7260.87 + 21.6 = 7282.47 \text{ psia}$$

without damage (no skin).

c) The radius of investigation was used above to estimate the distance $d = 178.4$ ft to a nearby fault. An alternative approach can be to use the point of intersection of the two straight lines with slopes *m* and 2*m*. This happens at the value -1 on the Horner plot, corresponding to

$$\log\frac{\Delta t}{t+\Delta t} = -1,$$

$$\frac{\Delta t}{t+\Delta t} = \frac{1}{10},$$

and hence to the equivalent time

$$\Delta t_e = \frac{t\Delta t}{t+\Delta t} = \frac{16}{10} = 1.6 \text{ hrs.}$$

From this value we can estimate the distance from the identity

$$d = 0.01217\sqrt{\frac{kt}{\phi\mu c_t}} = 0.01217\sqrt{\frac{(166.6)(1.6)}{(0.16)(0.35)(3.3\times10^{-5})}} = 146.1 \text{ ft.}$$

With only one boundary indicated, the radius os investigation at the end of the buildup (48 hrs) can be used to estimate the minimal distance to a possible next boundary, with the distance

$$d = r_{inv} = 0.0246\sqrt{\frac{k\Delta t}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(166.6)(48)}{(0.16)(0.35)(3.3\times 10^{-5})}} = 1618 \text{ ft.}$$

For a hemi-radial model we need to extrapolate late data with slope 2*m* to infinite shut-in. To be on the safe side, we should determine the actual slope of late data and extrapolate based on the new slope. By this approach we can use the last two points from Table 2 to determine the late-time semi-log slope

$$m' = \frac{7396.59 - 7396.42}{\log\left[48/(16+48)\right] - \log\left[45.346/(16+45.346)\right]} = \frac{0.17}{0.006306} = 26.95 \text{ psi/log-cycle.}$$

Extrapolating from the last point to infinite shut-in time we then get

$$p_i = 7396.59 + m\left\{\log 1 - \log\left[48/(16+48)\right]\right\} = 7396.59 + 26.95(0 + 0.125) = 7399.96 \text{ psia.}$$

d) We clearly have storage dominated data in the beginning of the buildup, and hence can use the first two points from Table 2 to determine the slope

$$m' = \frac{7263.98 - 7262.45}{0.0002 - 0.0001} = \frac{1.53}{0.0001} = 15300 \text{ psi/hr,}$$

which in turn yields the storage constant

$$C = \frac{qB}{24m'} = \frac{(3300)(1.4)}{(24)(15300)} = 0.01258 \text{ RB/psi,}$$

corresponding to the dimensionless value

$$C_D = \frac{5.615C}{2\pi\varphi h c_t r_w^2} = \frac{(5.615)(0.01258)}{(2\pi)(0.16)(106)(3.3\text{E-5})(0.25)^2} = 321.4$$

The wellbore volume can be estimated from the identity

$$V_{wb} = \frac{C}{c_{wb}} = \frac{0.01258}{4.2\text{E-5}} = 299.5 \text{ RB.}$$

Problem 2

a) Three weeks correspond to 504 hours, and hence a linear slope of

$$m' = \frac{371.6 - 370.4}{504} = 0.002381 \text{ bar/hr.}$$

From this slope and the parameters above we get

$$A = \frac{0.04167qB}{\varphi c_t hm'} = \frac{(0.04167)(800)(1.27)}{(0.21)(1.74\text{E-}4)(36)(0.002381)} = 13517201 = 1.352\text{E}7 \text{ m}^2.$$

b) The assumption is that pseudosteady state was reached at the start of the 3-week test sequence. For a circular drainage area the requirement is

$$t_{DA} = \frac{1}{10} = \frac{0.000355kt}{\phi\mu c_t A} = \frac{(0.000355)(9.5)t}{(0.21)(0.74)(1.74\text{E-}4)(1.352\text{E}7)} = (9.225\text{E-}6)t \text{ ft}$$

The time at the start of the 3-week test must therefore have been

$$t = \frac{1}{(10)(9.225\text{E-}6)} = 10840 \text{ hrs,}$$

or 452 days.

Problem 3

a) Since the pressures are low we need to use a pressures-squared formulation. Therefore, if we use the first and the last points we get

$$\frac{\Delta p^2}{q} = \frac{2103.1^2 - 2018.9^2}{5250} = \frac{347072.4}{5250} = 66.11.$$

and

$$\frac{\Delta p^2}{q} = \frac{2103.1^2 - 1860.8^2}{9540} = \frac{960453}{9540} = 100.68$$

From these we get the slope

$$b = \frac{100.68 - 66.11}{9540 - 5250} = 0.00806.$$

From the first point we can next determine

$a = 66.11 - (0.00806)(5250) = 23.8$.

The deliverability of the well will therefore be given by the identity

$\overline{p}^2 - p_{wf}^2 = aq + bq^2 = 23.8q + 0.00806q^2$.

We furthermore get the open flow potential

$$\text{AOF} = \frac{1}{(2)(0.00806)}\left[-23.8 + \sqrt{23.8^2 + (4)(0.00806)(2103.1^2)}\right] = 21996 \text{ Mscf/d.}$$

b) The points above can be re-used here, i.e., we can use the transient values

$\Delta p_1^2 = 2103.1^2 - 2018.9^2 = 347072.4$

and

$\Delta p_2^2 = 2103.1^2 - 1860.8^2 = 960453$

to determine the slope

$$\frac{1}{n} = \frac{\log \Delta p_2^2 - \log \Delta p_1^2}{\log q_2 - \log q_1} = \frac{\log(960453) - \log(347072.4)}{\log(9540) - \log(5250)} = 1.70422,$$

and hence the exponent $n = 0.5868$ for the back-pressure equation $q = C(\overline{p}^2 - p_{wf}^2)^n$. Using the first point we next get

$5250 = C(2103.1^2 - 2018.9^2)^{0.5868} = C(1782.87)$, and therefore $C = 2.9447$ with

$AOF = C(\overline{p}^2)^n = (2.9447)(2103.1^2)^{0.5868} = 23375$ Mscf/d.