Suggested solution to the re-take exam in Welltest Analysis, Feb. 18, 2010

Problem 1

a) Early data are dominated by wellbore storage, the middle of the data by radial flow, and the end of the data by nearby boundaries with linear flow response, for instance caused by parallel faults. The first (wellbore storage) ends at roughly t = 0.007 hrs in terms of pressure differences, but earlier in terms of derivatives. The radial-flow periods covers te period 0.22 to 4 hrs (roughly), with the last period starting at around 7 hrs and lasting through the rest of the data.

b) If we use the first two points from Table 2 we get the slope

$$m' = \left| \frac{449.7778 - 449.8818}{0.004 - 0.002} \right| = \frac{0.104}{0.002} = 52 \text{ bar/hr}$$

in absolute value. Extrapolation to time 0 therefore yields the initial pressure

$$p_i = 449.8818 + m'(0.002 - 0) = 449.8818 + 52(0.002) = 449.8818 + 0.104 = 449.9858 \text{ bar.}$$

From the linear equation

$$\Delta p = \frac{qB}{24C} t = m't$$

we next get

$$C = \frac{qB}{24m'} = \frac{(900)(1.36)}{(24)(52)} = 0.9808 \text{ Rm}^3\text{/bar.}$$

The corresponding dimensionless wellbore storage then takes the value

$$C_D = \frac{C}{2\pi\phi h c_t r_w^2} = \frac{0.9808}{(6.2832)(0.31)(41)(1.4\times10^{-4})(0.108)^2} = 7521$$

c) Based on Fig. 1 we can pick points near $t = 1$ hr, such as $p_{wf} = 448.7228$ bar at $t = 0.802$ hrs and $p_{wf} = 448.6949$ bar at $t = 1.271$ hrs. We then get the semilog slope (absolute value)

$$m = \left| \frac{448.6949 - 448.7228}{\log 1.271 - \log 0.802} \right| = \frac{0.0279}{0.2} = 0.1395 \text{ bar/log-cycle.}$$

From the slope *m* we get the flow capacity

$$kh = \frac{21.49 qB\mu}{m} = \frac{(21.49)(900)(1.36)(0.48)}{0.1395} = 90508 \text{ md}\cdot\text{m}$$

and the permeability

$$k = \frac{kh}{h} = \frac{90508}{41} = 2208 \text{ md.}$$

The pressure p_{1hr} at $t = 1$ hr can be determined by extrapolation from the pressure $p_{wf} = 448.7228$ bar at $t = 0.802$ hrs as follows:

$$p_{1hr} = 448.7228 - m(\log 1 - \log 0.802) = 448.7228 - m(-\log 0.802)$$

$$= 448.7228 - 0.1395(0.0958) = 448.7228 - 0.0133 = 448.7095 \text{ bar.}$$

By using the initial pressure $p_i = 449.9858$ bar from the point above we can determine the skin value from the formula

$$S = 1.151\left(\frac{p_i - p_{1hr}}{m} - \log\frac{k}{\phi\mu c_t r_w^2} + 3.098\right)$$

$$= 1.151\left[\frac{449.9858 - 448.7095}{0.1395} - \log\frac{2208}{(0.31)(0.48)(1.4\times 10^{-4})(0.108)^2} + 3.098\right]$$

$$= 1.151(9.1491 - 9.9584 + 3.098) = 2.63\,.$$

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

$$\Delta p_S = \frac{m}{1.151}S = \frac{0.1395}{1.151}(2.63) = 0.3188 \text{ bar.}$$

d) If we use the last two data points from Table 2 we get the slope (absolute value)

$$m' = \left|\frac{448.4164 - 448.4504}{\sqrt{36} - \sqrt{28.461}}\right| = \frac{0.034}{0.6651} = 0.0511 \text{ bar}/\sqrt{\text{hr}}\,,$$

and hence the half-width

$$\frac{W}{2} = \frac{0.6236qB}{hm'}\sqrt{\frac{\mu}{k\phi c_t}} = \frac{(0.6236)(900)(1.36)}{(41)(0.0511)}\sqrt{\frac{0.48}{(2208)(0.31)(1.4\times 10^{-4})}}$$

$$= (364.32)(2.2381) = 815.4 \text{ m}$$

with full width, and hence distance between the faults, given by

$W = (2)(815.4) = 1630.8$ m.

e) We can use the radius of investigation to determine if the first boundary effect shows up early than and hence is closer than the half-width. From Fig. 1 it appears that boundary effects are seen after 4 hrs, and possibly earlier. Since the radius of investigation at 4 hrs is given by

$$r_{inv} = 0.0286\sqrt{\frac{kt}{\phi\mu c_t}} = 0.0286\sqrt{\frac{(2208)(4)}{(0.31)(0.48)(1.4\times10^{-4})}} = 589 \text{ m},$$

it is realistic to assume that the distance to the nearest side is around 600 m, and the distance to next side around 1030 m. The length "seen" during the test in one direction will correspond to the radius of investigation at 36 hrs, and hence will be

$$L/2 = 3\cdot 589 = 1767 \text{ m}$$

since 36 = 4·9. The area "seen" during the test will therefore be given by

$$A = WL = (2\cdot 815)(2\cdot 1767) = 5760420 = 5.76\times10^{6} \text{ m}^2.$$

Problem 2

a) The PSS depletion slope will be given by

$$m' = \frac{4.38}{250} = 0.01752 \text{ psi/hr},$$

with the drainage area therefore given by

$$A = \frac{0.2339qB}{\phi c_t hm'} = \frac{(0.2339)(1650)(1.53)}{(0.17)(2.7\times10^{-5})(82)(0.01752)} = 8.95\times10^{7} \text{ ft}^2 = 2056 \text{ acres}.$$

b) We need to use the identity

$$p_0 = p_i - \frac{141.2qB\mu}{kh}\left(\frac{1}{2}\ln\frac{4A}{e^{\gamma}C_A r_w^2} + S\right)$$

with p_0 found by extrapolation in the form

$$p_0 = 6994.49 + m'6001 = 6994.49 + (0.01752)(6001) = 7099.63 \text{ psi}.$$

We therefore get

$$p_i = p_0 + \frac{141.2qB\mu}{kh}\left(\frac{1}{2}\ln\frac{4A}{e^{\gamma}C_A r_w^2} + S\right)$$

$$= 7099.63 + \frac{(141.2)(1650)(1.53)(1.12)}{(105)(82)}\left[\frac{1}{2}\ln\frac{4(8.95\times10^7)}{(1.781)(4.7)(0.354)^2} + 7.8\right]$$

$$= 7099.63 + 46.369(9.824 + 7.8) = 7916.84 \text{ psi.}$$

Problem 3

a) Since the pressures are low we need to use a pressures-squared formulation. Therefore, if we use the endpoints we

$$\frac{\Delta p^2}{q} = \frac{129.7^2 - 123.9^2}{354000} = 0.004155 \quad \text{and} \quad \frac{\Delta p^2}{q} = \frac{129.7^2 - 113^2}{643000} = 0.006303.$$

From these we get the slope

$$b = \frac{0.006303 - 0.004155}{643000 - 354000} = 7.433\text{E-9}.$$

From the first we can also determine the value

$$a = 0.004155 - (7.433\text{E-9})(354000) = 0.001524$$

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

$$\bar{p}^2 - p_{wf}^2 = aq + bq^2 = 0.001524q + (7.433\text{E-9})q^2.$$

Furthermore we get

$$\text{AOF} = \frac{1}{(2)(7.433\text{E-9})}\left[-0.001524 + \sqrt{0.001524^2 + (4)(7.433\text{E-9})(129.7^2)}\right] = 1405354 \text{ Sm}^3\text{/d}$$

b) The same points give us

$$\Delta p_1^2 = 129.7^2 - 123.9^2 = 1470.88 \text{ bar at } q_1 = 354000 \text{ Sm}^3\text{/d}$$

and

$$\Delta p_2^2 = 129.7^2 - 113^2 = 4053.09 \text{ bar at } q_2 = 643000 \text{ Sm}^3\text{/d.}$$

From these points we get the slope

$$\frac{1}{n} = \frac{\log \Delta p_2^2 - \log \Delta p_1^2}{\log q_2 - \log q_1} = \frac{\log(4053.09) - \log(1470.88)}{\log(64300) - \log(354000)} = 1.698,$$

and hence the exponent $n = 0.589$ for the back-pressure equation $q = C(\overline{p}^2 - p_{wf}^2)^n$. Using the first point we next get

$354000 = C(129.7^2 - 123.9^2)^{0.589} = C(73.4012)$, and therefore $C = 4822.8$ with

$AOF = C(\overline{p}^2)^n = (4822.8)(129.7^2)^{0.589} = 1487108$ Sm^3/d.