Suggested solution to the re-sit exam in Welltest Analysis, Feb. 11, 2011

Problem 1

a) Early data (from the buildup) are dominated by (formation) linear flow to the fracture, and late data (from the drawdown) are approaching radial flow.

b) The end of the data is best suited for semilog analysis. We can therefore, for instance, use the point $p_{wf} = 1238.61$ psia at $t = 114.128$ hrs and $p_{wf} = 1185.25$ psia at $t = 120$ hrs to determine the semilog slope

$$m = \left| \frac{1185.25 - 1238.61}{\log(120) - \log(114.128)} \right| = 2448.94 \text{ psi/log-cycle,}$$

and next the flow capacity

$$kh = \frac{162.6 qB\mu}{m} = \frac{(162.6)(5200)(1.14)(3.8)}{2448.94} = 1495.67 \text{ md·m}$$

and the permeability

$$k = \frac{kh}{h} = \frac{1495.67}{62} = 24.124 \text{ md.}$$

The pressure p_{1hr} at $t = 1$ hr can be determined by extrapolation from the pressure $p_{wf} = 1238.61$ psia at $t = 114.128$ hrs as follows:

$$p_{1hr} = 1238.61 - m(\log 1 - \log 114.128) = 1238.61 - m(-\log 114.128)$$

$$= 1238.61 - 2448.94(-2.05739) = 1238.61 + 5038.43 = 6277.04 \text{ psia.}$$

From the initial pressure $p_i = 5000$ psia we then get the skin value

$$S = 1.151\left(\frac{p_i - p_{1hr}}{m} - \log \frac{k}{\phi\mu c_t r_w^2} + 3.2275 \right)$$

$$= 1.151\left[\frac{5000 - 6277.04}{2448.94} - \log \frac{24.124}{(0.23)(3.8)(2.8\times10^{-5})(0.354)^2} + 3.2275 \right]$$

$$= 1.151(-0.5215 - 6.8958 + 3.2275) = 1.151(-4.1898) = -4.82\,.$$

The added pressure drop at the wellbore can next be computed as

$$\Delta p_S = \frac{m}{1.151} S = \frac{2448.94}{1.151}(-4.82) = -10264 \text{ psi.}$$

c) With linear flow from the start of the buildup we can for instance pick the first two points from Table 3 to determine the slope

$$m' = \left| \frac{1219.2 - 1207.49}{\sqrt{0.005} - \sqrt{0.0022}} \right| = 491.882 \text{ psi}/\sqrt{\text{hr}}\,.$$

From this slope we get the fracture half-length

$$x_f = \frac{4.064 qB}{hm'} \sqrt{\frac{\mu}{k\phi c_t}} = \frac{(4.064)(5200)(1.14)}{(62)(491.882)} \sqrt{\frac{3.8}{(24.124)(0.23)(2.8 \times 10^{-5})}} = 123.55 \text{ ft.}$$

Since the theoretical skin value for a fracture with uniform flux will be

$$S = \ln \frac{er_w}{x_f} = \ln \frac{(2.718)(0.354)}{123.55} = -4.855\,,$$

and the corresponding skin value for a fracture with infinite conductivity will be

$$S = \ln \frac{2r_w}{x_f} = \ln \frac{(2)(0.354)}{123.55} = -5.162\,,$$

it follows that a uniform-flux fracture is most likely.

d) Since the actual drawdown after 120 hrs was

$$p_i - p_{wf}(120) = 5000 - 1185.25 = 3814.75 \text{ psi}$$

with skin value -4.82, and would have been

$$\Delta p_{S=0} = 3814.75 - \Delta p_S = 3814.75 - (-10264) = 14078.75 \text{ psi}$$

with 0 skin, we would get

$$\Delta p_{S=0,q=2600} = \Delta p_{S=0} / 2 = 14078.75 / 2 = 7039.375 \text{ psi}$$

with rate 2600 STB/D. Using a theoretical skin value with double fracture length, we get

$$S = \ln \frac{er_w}{x_f} = \ln \frac{(2.718)(0.354)}{247.1} = -5.55\,.$$

With rate reduced by one half the semilog slope will also be reduced by one half, and hence yield the “skin effect”

$$\Delta p_S = \frac{m}{1.151} S = \frac{2448.94/2}{1.151}(-5.55) = -5904.265 \text{ psi.}$$

We can now estimate the new drawdown after 120 hrs to be

$$p_i - p_{wf,new}(120) = 7039.375 - 5904.265 = 1135.11 \text{ psi,}$$

and hence the pressure after 120 hrs to be 3864.89 psia.

e) The outer radius r_e of a 120 acres circular drainage area will be given by

$$r_e = \sqrt{\frac{(120)(43560)}{\pi}} = 1290 \text{ ft.}$$

If we set the outer radius equal to the radius of investigation we get

$$r_{inv} = 0.0246\sqrt{\frac{kt}{\phi\mu c_t}} = 0.0246\sqrt{\frac{24.124t}{(0.23)(3.8)(2.8\times10^{-5})}} = r_e = 1290 \text{ ft.}$$

we get

$$t = \left(\frac{1290}{0.0246}\right)^2 \frac{(0.23)(3.8)(2.8\times10^{-5})}{24.124} = 2789.5 \text{ hrs.}$$

The drawdown at the current rate would be

$$p_i - p_{wf}(2789.5) = 3814.75 + m\log\frac{2789.5}{120} = 3814.75 + (2448.94)(1.36635) = 7160.86 \text{ psi}$$

after 2789.5 hrs. The new rate should therefore be

$$q_{new} = \frac{2000}{7160.86} 5200 = 1452 \text{ STB/D.}$$

Problem 2

a) Higher mobility of water implies that water (the injected phase) will move easier towards the midpoint, and hence cause the pressure to increase at the midpoint.

b) Higher compressibility to oil implies that more oil can be withdrawn locally from the producer than water injected locally at the injector. The water must therefore move faster towards the midpoint, and hence cause the pressure to rise.

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 transient points we get

$$\frac{\Delta p^2}{q} = \frac{1903^2 - 1818.9^2}{15000} = \frac{313011.8}{15000} = 20.867\,.$$

and

$$\frac{\Delta p^2}{q} = \frac{1903^2 - 1660.8^2}{27250} = \frac{863152.4}{27250} = 31.675$$

From these we get the slope

$$b = \frac{31.675 - 20.867}{27250 - 15000} = 0.000882\,.$$

From the stable flow point

$$\frac{\Delta p^2}{q} = \frac{1903^2 - 1633.2^2}{23040} = \frac{954066.8}{23040} = 41.409$$

we can next determine

$$a = 41.409 - (0.000882)(23040) = 21.088\,.$$

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

$$\bar{p}^2 - p_{wf}^2 = aq + bq^2 = 21.088q + 0.000882q^2\,.$$

We furthermore get flow potential

$$\text{AOF} = \frac{1}{(2)(0.000882)}\left[-21.088 + \sqrt{21.088^2 + (4)(0.000882)(1903^2)}\right] = 53228 \text{ Mscf/d.}$$

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

$$\Delta p_1^2 = 1903^2 - 1818.9^2 = 313011.8$$

and

$$\Delta p_2^2 = 1903^2 - 1660.8^2 = 863152.4$$

to determine the slope

$$\frac{1}{n} = \frac{\log \Delta p_2^2 - \log \Delta p_1^2}{\log q_2 - \log q_1} = \frac{\log(863152.4) - \log(313011.8)}{\log(27250) - \log(15000)} = 1.699\,,$$

and hence the exponent $n = 0.5886$ for the back-pressure equation $q = C(\overline{p}^2 - p_{wf}^2)^n$. Using the stable point we next get

$$23040 = C(1903^2 - 1633.2^2)^{0.5886} = C(3308.1)$$, and therefore $C = 6.965$ with

$$AOF = C(\overline{p}^2)^n = (6.965)(1903^2)^{0.5886} = 50522 \text{ Mscf/d.}$$