Suggested solution to the final exam in Welltest Analysis, Nov. 29, 2010

Problem 1

a) Early data are dominated by (formation) linear flow to the fracture, and late data by hemi-radial flow (radial flow from one side). The first (linear) starts at beginning of the data and ends after 2-3 hrs, while the last starts after roughly 300 hrs and ends at the end of the data.

b) Since the last part of the data must represent hemi-radial flow with slope 2m in a semilog plot, we can use late points such as $p_{wf} = 6039.81$ psia at $t = 616.08$ hrs and $p_{wf} = 6019.17$ psia at $t = 720$ hrs to determine the slope

$$2m = \left| \frac{6019.17 - 6039.81}{\log(720) - \log(616.08)} \right| = 304.9 \text{ psi/log-cycle}$$

in absolute value. From the slope

$$m = \frac{304.9}{2} = 152.45 \text{ psi/log-cycle}$$

we get

$$kh = \frac{162.6 qB\mu}{m} = \frac{(162.6)(300)(1.33)(1.8)}{152.45} = 766.02 \text{ md}\cdot\text{m}$$

and the permeability

$$k = \frac{kh}{h} = \frac{766.02}{103} = 7.44 \text{ md.}$$

c) With linear flow from the start we can pick the first two points from Table 2 to determine the slope

$$m' = \left| \frac{6498.36 - 6499.05}{\sqrt{0.0086} - \sqrt{0.0029}} \right| = 17.745 \text{ psi/}\sqrt{\text{hr}}\,.$$

From this slope we get the fracture half-length

$$x_f = \frac{4.064 qB}{hm'} \sqrt{\frac{\mu}{k\phi c_t}} = \frac{(4.064)(300)(1.33)}{(103)(17.745)} \sqrt{\frac{1.8}{(7.44)(0.09)(1.7\times10^{-5})}} = 352.8 \text{ ft.}$$

The initial pressure can be obtained by extrapolating the square-root-of-time line from the first point to 0 with the result

$$p_i = p_1 + m'\sqrt{t_1} = 6499.05 + 17.745\sqrt{0.0029} = 6500.01 \text{ psia.}$$

d) We can use the radius of investigation at the onset of boundary effects seen in the half-slope line at roughly $t = 2.5$ hrs, with the distance

$$d = r_{inv} = 0.0246\sqrt{\frac{kt}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(7.44)(2.5)}{(0.09)(1.8)(1.7\times10^{-5})}} = 63.9\,\text{ft.}$$

The radius of investigation at the end of the data determines how close a second boundary can be placed without being seen in the data, i.e., at

$$d = r_{inv} = 0.0246\sqrt{\frac{kt}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(7.44)(720)}{(0.09)(1.8)(1.7\times10^{-5})}} = 1085\,\text{ft.}$$

e) If the well had been placed close enough to the boundary it should be possible to observe hemi-linear flow after the initial linear flow period (long transition), and finally hemi-radial flow as before. The hemi-linear flow regime will have lines parallel to the initial linear-flow lines in a loglog plot (both sets consist of half-lope lines).

Problem 2

a) With permeability 105 md based on a thickness of 78 m we get the flow capacity

$$kh = (105)(78) = 8190 \text{ md·m}$$

and hence the new permeability

$$k = \frac{8190}{14} = 585 \text{ md.}$$

We can of course also set

$$k = 105\frac{78}{14} = 585 \text{ md}$$

directly. A change in thickness only affects one term in the equation

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

We can therefore set

$$\frac{S_{new}}{1.151} - \frac{S_{old}}{1.151} = -\log\frac{k_{new}}{\phi\mu c_t r_w^2} + \log\frac{k_{old}}{\phi\mu c_t r_w^2} = \log\frac{k_{old}}{k_{new}},$$

and hence conclude that

$$S_{new} = S_{old} + 1.151\log\frac{k_{old}}{k_{new}} = 5.2 + 1.151\log\frac{105}{585} = 5.2 - 0.86 = 4.34\,.$$

It is also possible to take a more detailed approach based on specific parameters.

b) We just need to use the identity

$$r_{inv,new} = 0.0286\sqrt{\frac{k_{new}t}{\phi\mu c_t}} = 0.0286\sqrt{\frac{k_{old}t}{\phi\mu c_t}}\sqrt{\frac{k_{new}}{k_{old}}} = 720\sqrt{\frac{585}{105}} = 1699.5\ \text{ft.}$$

Problem 3

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

$$\frac{\Delta p^2}{q} = \frac{1881.1^2 - 1797^2}{12501} = \frac{309328.2}{12501} = 24.744$$

and

$$\frac{\Delta p^2}{q} = \frac{1862.3^2 - 1620.1^2}{22707} = \frac{843437.3}{22707} = 37.144\,.$$

From these we get the slope

$$b = \frac{37.144 - 24.744}{22707 - 12501} = 0.001215\,.$$

From the stable flow point

$$\frac{\Delta p^2}{q} = \frac{1881.1^2 - 1611.3^2}{18200} = \frac{942249.5}{18200} = 51.772$$

we can next determine

$$a = 51.772 - (0.001215)(18200) = 29.659\,.$$

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

$$\bar{p}^2 - p_{wf}^2 = aq + bq^2 = 29.659q + 0.001215q^2\,.$$

Furthermore we get

$$\text{AOF} = \frac{1}{(2)(0.001215)}\left[-29.659 + \sqrt{29.659^2 + (4)(0.001215)(1881.1^2)}\right] = 43124.5 \text{ Mscf/d.}$$

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

$$\Delta p_1^2 = 1881.1^2 - 1797^2 = 309328.2$$

and

$$\Delta p_2^2 = 1862.3^2 - 1620.1^2 = 843437.3$$

to determine the slope

$$\frac{1}{n} = \frac{\log \Delta p_2^2 - \log \Delta p_1^2}{\log q_2 - \log q_1} = \frac{\log(843437.3) - \log(309328.2)}{\log(22707) - \log(12501)} = 1.681,$$

and hence the exponent $n = 0.595$ for the back-pressure equation $q = C(\bar{p}^2 - p_{wf}^2)^n$. Using the stable point we next get

$18200 = C(1881.1^2 - 1611.3^2)^{0.595} = C(3580.4)$, and therefore $C = 5.083$ with

$$AOF = C(\bar{p}^2)^n = (5.083)(1881.1^2)^{0.595} = 39986.2 \text{ Mscf/d.}$$