Suggested solution to the re-sit exam in Welltest Analysis, Feb. 15, 2012

Problem 1

a) We see linear flow early on, radial flow in the middle, and apparently hemi-radial flow at the end with doubling in slope caused by a nearby sealing boundary.

b) Based on Fig. 1 we see that semilog analysis should be based on data in the range 0.3 to 2 hours. The closest points in the table are $p_{ws} = 3869.63$ psia at $\Delta t = 0.2049$ hrs and $p_{ws} = 3894.54$ psia at $\Delta t = 0.8158$ hrs. From these we get the slope

$$m = \frac{3894.54 - 3869.63}{\log\left[0.8158/(12+0.8158)\right] - \log\left[0.2049/(12+0.2049)\right]} = \frac{24.91}{0.5788} = 43.04 \text{ psi/log-cycle.}$$

The pressure p_{1hr} at $\Delta t = 1$ hr can be determined by extrapolation from the pressure $p_{ws} = 3894.54$ psia at $\Delta t = 0.8158$ hrs as follows:

$$p_{1hr} = 3894.54 + m\left\{\left[\log 1/(12+1)\right] - \log\left[0.8158/(12+0.8158)\right]\right\}$$

$$= 3894.54 + 43.04(-1.11394 + 1.19616) = 3894.54 + 3.54 = 3898.08 \text{ psia.}$$

From the slope above we also get

$$kh = \frac{162.6 qB\mu}{m} = \frac{(162.6)(3600)(1.28)(0.95)}{43.04} = 16538 \text{ md}\cdot\text{ft}$$

and

$$k = \frac{kh}{h} = \frac{16538}{56} = 295.3 \text{ md.}$$

The skin value can be determined from the formula

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

$$= 1.151\left[\frac{3898.08 - 3816.89}{43.04} - \log\frac{12}{12+1} - \log\frac{295.3}{(0.11)(0.95)(2.6\times 10^{-5})(0.354)^2} + 3.23\right]$$

$$= 1.151(1.8864 + 0.0348 - 8.9382 + 3.23) = -4.36\,.$$

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

$$\Delta p_S = \frac{m}{1.151} S = \frac{43.04}{1.151}(-4.36) = -163.04 \text{ psi.}$$

From Fig. 1 it can be seen that boundary effects appear after about 3 hours into the buildup. If the radius of investigation at this time is used to estimate the distance to the nearest boundary we get

$$d = r_{inv} = 0.0246\sqrt{\frac{k\Delta t}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(295.3)(3)}{(0.11)(0.95)(2.6\times10^{-5})}} = 444 \text{ ft.}$$

c) We can determine the slope at the end and extrapolate from the last point to infinite shut-in. From the last two points $p_{ws} = 3956.74$ psia at $\Delta t = 139.328$ hrs and $p_{ws} = 3956.84$ psia at $\Delta t = 144$ hrs we get the slope

$$m = \frac{3956.84 - 3956.74}{\log\left[144/(12+144)\right] - \log\left[139.328/(12+139.328)\right]} = \frac{0.1}{0.00112} = 89.29 \text{ psi/log-cycle.}$$

Extrapolation from last point to infinite shut-in we thus get the estimate

$$p^* = 3956.84 + m'\left\{\log 1 - \log\left[144/(12+144)\right]\right\} = 3956.84 + 89.29\left\{0.0476\right\} = 3959.94 \text{ psia}$$

of the reservoir pressure. Extrapolation from a point at 12 hours into the buildup would not work since Fig. 1 shows that the correct slope would not be reached at this point.

d) The radius of investigation at the end of the buildup based on elapsed time is

$$d = r_{inv} = 0.0246\sqrt{\frac{k\Delta t}{\phi\mu c_t}} = 0.0246\sqrt{\frac{(295.3)(144)}{(0.11)(0.95)(2.6\times10^{-5})}} = 3076 \text{ ft.}$$

The minimal drainage area is a circle of radius 3076 ft with a “slice” of width 3076 – 444 = 2632 ft removed. Since 444 is much smaller than 2632, we can use as a rough estimate the area consisting of a half circle and a rectangle of width 444 ft and length 2*3076 = 6152 ft, with total area

A = 0.5*3.14*3076*3076 + 444*6152 = 1.76E7 sqft.

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

$$m' = \frac{3825.13 - 3822.10}{\sqrt{0.0036} - \sqrt{0.0014}} = 134.17 \text{ psi}/\sqrt{\text{hr}}\,.$$

From this slope we get the fracture half-length

$$x_f = \frac{4.064qB}{hm'}\sqrt{\frac{\mu}{k\phi c_t}} = \frac{(4.064)(3600)(1.28)}{(56)(134.17)}\sqrt{\frac{0.95}{(295.3)(0.11)(2.6\times10^{-5})}} = 83.6 \text{ ft.}$$

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

$$p_{wf,s} = p_1 - m'\sqrt{0.0014} = 3822.1 - 134.17\sqrt{0.0014} = 3817.08 \text{ psia.}$$

This value is close to the listed value 3816.89 psia from Table 1, but not spot on. The theoretical skin values for a fracture half-length is

$$S = \ln\frac{er_w}{x_f} = \ln\frac{(2.718)(0.354)}{83.6} = -4.46$$

for uniform flux, and

$$S = \ln\frac{2r_w}{x_f} = \ln\frac{(2)(0.354)}{83.6} = -4.77$$

for infinite conductivity. Since skin value -4.36 was determined above, we can assume that the fracture has uniform flux.

<u>Problem 2</u>

a) The diffusivity

$$\eta = \frac{k}{\phi\mu c_t}$$

is the key parameter group for the timing of the pressure response. Permeability has therefore a direct effect on the timing (higher implies faster), while porosity, viscosity and total compressibility have an inverse effect (lower implies faster).

b) The degree of pressure change depends mostly one the quantity

$$\frac{qB\mu}{kh}$$

with change directly proportional with rate, volume factor and viscosity, and inversely proportional with permeability and thickness.

Problem 3

a) Since the pressures are high we should use a direct pressure formulation. Therefore, if we use the first and the last transient points we get

$$\frac{\Delta p}{q} = \frac{352 - 306.2}{256000} = 0.000179\,.$$

and

$$\frac{\Delta p}{q} = \frac{327.3 - 183.3}{539100} = 0.000267$$

From these we get the slope

$$b = \frac{0.000267 - 0.000179}{539100 - 256000} = 3.1084E - 10\,.$$

From the stable flow point

$$\frac{\Delta p}{q} = \frac{352 - 220.5}{463000} = 0.000284$$

we can next determine

$$a = 0.000284 - (3.1084E - 10)(463000) = 0.00014\,.$$

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

$$\bar{p} - p_{wf} = aq + bq^2 = 0.00014q + (3.1084E - 10)q^2\,.$$

We furthermore get the open flow potential

$$\text{AOF} = \frac{1}{(2)(3.1084E - 10)}\left[-0.00014 + \sqrt{0.00014^2 + (4)(3.1084E - 10)(352)}\right] = 862521\ \text{m}^3/\text{d}.$$

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

$$\Delta p_1 = 352 - 306.2 = 45.8$$

and

$$\Delta p_2 = 327.3 - 183.3 = 144$$

to determine the slope

$$\frac{1}{n} = \frac{\log \Delta p_2 - \log \Delta p_1}{\log q_2 - \log q_1} = \frac{\log(144) - \log(45.8)}{\log(539100) - \log(256000)} = 1.5382 \, ,$$

and hence the exponent $n = 0.6501$ for the back-pressure equation $q = C(\bar{p} - p_{wf})^n$. Using the stable point we next get

$463000 = C(352 - 220.5)^{0.6501} = C(23.851)$, and therefore $C = 19412$ with

$AOF = C(\bar{p})^n = (19412)(352)^{0.6501} = 878168$ m^3/d.

Note: Since the last analysis is based on a correlation, we could also use a p^2 formulation for this point.