EXAMPLE 2.4 INFLOW PERFORMANCE CALCULATIONS FOR A GAS WELL PRODUCING AT LOW RESERVOIR PRESSURES

A two-rate drawdown/buildup test was run on a new gas discovery well in Kansas, the Medicine Lodge No. 1. For the first buildup following an eight-hour flow period at 6.4 MMscf/D, Horner analysis indicated a permeability-thickness (kh) of 790 md-ft and a skin of +3.62. The second buildup followed a 12-hour flow period at 8.7 MMscf/D, and Horner analysis indicated a kh of 815 md-ft and a skin of +4.63. Other reservoir data included initial reservoir pressure of 1623 psia at a temperature of 128°F. From standard gas property correlations, the initial gas viscosity and Z-factor are 0.0134 cp and 0.879, respectively.

Determine the high-velocity flow term D, used in the radial flow equation (2.44). What is the steady-state skin factor (i.e., when rate equals zero)? Write the IPR equation using the pressure-squared, low-reservoir pressure assumptions. Assume an average kh of 800 md-ft and $\ln(r_e/r_w) - 0.75 = 7$.

EXAMPLE 2.4 continued

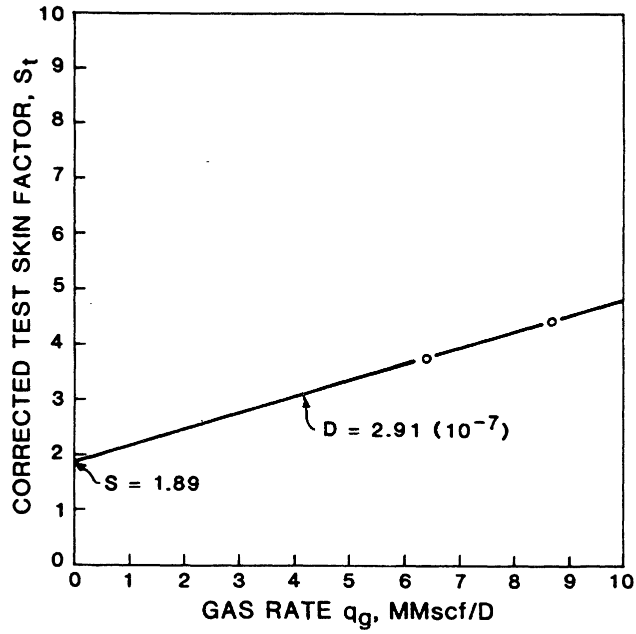

Figure E2.4a Rate-dependent skin factor in the Medicine Lodge No. 1 gas well.

For the second test with rate of 8.7 MMscf/D, corrected skin is

$$\frac{825}{7+4.63}=\frac{800}{7+s_{tc}}$$

or

$$s_{tc}=(800/815)(7+4.63)-7$$

$$=4.42.$$

A plot of corrected test skin versus gas rate is shown in figure E2.4a. The slope of the straight line gives a value of $D = 2.91 \times 10^{-7}$ (scf/D)$^{-1}$. The intercept at zero rate equals the steady-state skin, $s = +1.89$, indicating slight formation damage.

A common error is to plot test skin versus rate without making the kh correction. Had this been done for this example the steady-state skin would be underestimated, rate-dependent skin would be overestimated, and AOF would be underestimated by 1.0 MMscf/D (corresponding to about $700,000 per year for a gas price of $2/Mscf). *It must be emphasized that the skin-versus-rate plot is not valid if kh associated with each skin is different.*

EXAMPLE 2.4 continued

Table E2.4 Calculated Gas IPR for the Medicine Lodge No. 1 Well

p_{wf} (psia)	$p_R^2 - p_{wf}^2$ (psia^2)	q_g (MMscf/D)
0	2.63×10^6	15.8 (AOF)
500	2.38×10^6	14.7
750	2.07×10^6	13.2
1000	1.63×10^6	11.0
1250	1.07×10^6	7.78
1500	3.84×10^5	3.18
1550	2.32×10^5	1.99

The stabilized IPR equation for the Medicine Lodge No. 1 is found by substituting reservoir and test data in equation (2.44).

$$q_g = \frac{0.703(800)(1623^2 - p_{wf}^2)}{(128 + 460)(0.0134)(0.879)[7 + 1.89 + 2.91 \times 10^{-7} q_g]}$$

$$= 81.2 \frac{(2.63 \times 10^6 - p_{wf}^2)}{(8.89 + 2.91 \times 10^{-7} q_g)}$$

or

$$\frac{2.63 \times 10^6 - p_{wf}^2}{q_g} = 0.1095 + 3.58 \times 10^{-9} q_g,$$

giving $A = 0.1095$ and $B = 3.58 \times 10^{-9}$. Solving the quadratic equation for rate,

$$Bq_g^2 + Aq_g - \Delta p^2 = 0$$

$$q_g = \frac{[A^2 + 4B\Delta p^2]^{0.5} - A}{2B}$$

$$= \frac{[(0.1095)^2 + 4(3.58 \times 10^{-9})(2.63 \times 10^6 - p_{wf}^2)]^{0.5} - 0.1095}{2(3.58 \times 10^{-9})}$$

$$= \frac{[0.0120 + 1.43 \times 10^{-8}(2.63 \times 10^6 - p_{wf}^2)]^{0.5} - 0.1095}{7.16 \times 10^{-9}}.$$

Table E2.4 gives a few rates and flowing pressures, which are plotted in figure E2.4b on log–log paper. From about 5 MMscf/D to the maximum rate (AOF) of 16 MMscf/D, the IPR curve is a straight line on the log–log plot. The slope is 1.89, corresponding to a backpressure exponent of $n = 0.766$.

EXAMPLE 2.4 continued

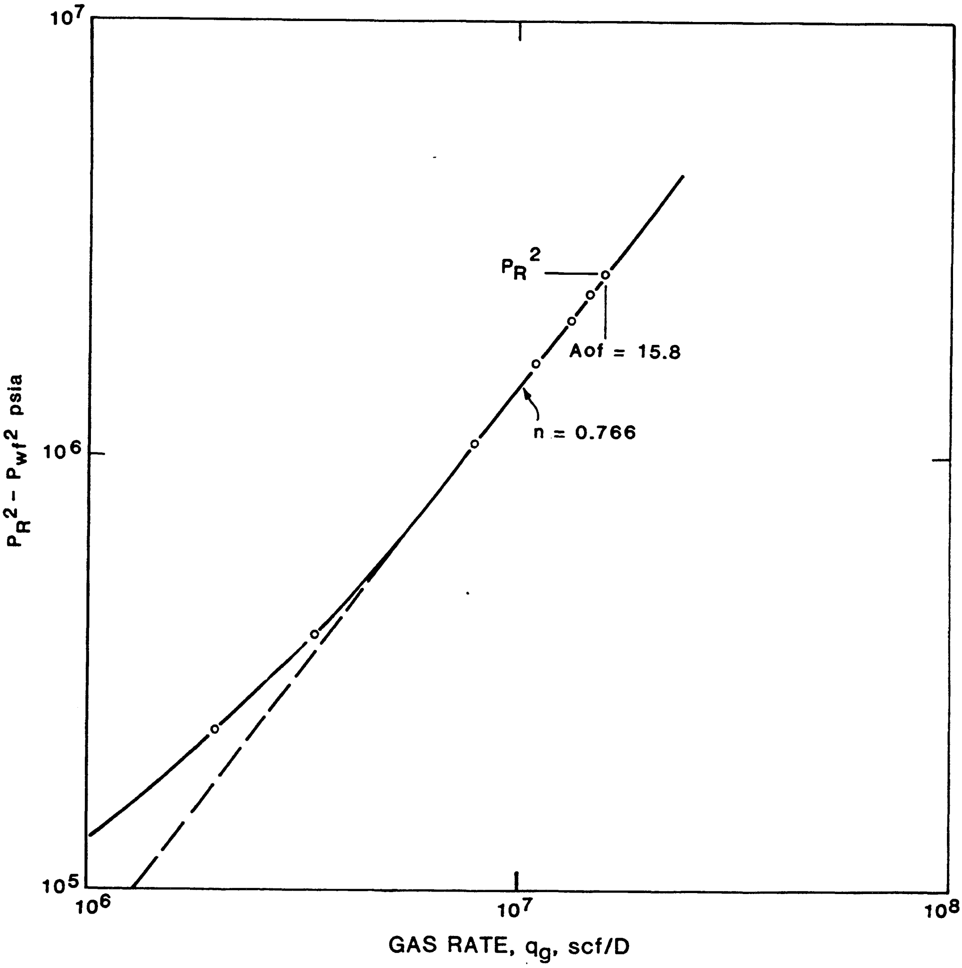

Figure E2.4b Backpressure curve of the Medicine Lodge No. 1 gas well.

At high pressures, usually greater than 3000 to 3500 psia, the pressure function $p/\mu_g Z$ is nearly constant. The pressure integral in equation (2.40) is solved analytically to give

$$2\int_{p_{wf}}^{p_R} \frac{p}{\mu_g Z}dp = 2\frac{p}{\mu_g Z}(p_R - p_{wf}), \tag{2.45}$$