A NOTE on the SKIN EFFECT

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Horner$^7$ and van Everdingen$^4$ have shown that the pressure drop within the wellbore, as a result of having produced the well at a constant rate $q$ for time $t$, where $t$ is sufficiently large, is:

$$
\Delta p_s = \frac{q \mu}{4 \pi k_h} \left[ \ln \left( \frac{k_t}{\mu c f_r^2} \right) + .809 \right].
$$

(1)

van Everdingen observed that better agreement between theory and well performance can be obtained if, instead of assuming the permeability is $k_e$ everywhere about the well, it is assumed the permeability near the wellbore is substantially reduced as a result of drilling, completion and/or production practices. In order to account for the additional pressure drop introduced he the dimensionless quantity $S$, the skin effect factor, so that Eq. 1 becomes:

$$
\Delta p_s = \frac{q \mu}{4 \pi k_h} \left[ \ln \left( \frac{k_t}{\mu c f_r^2} \right) + .809 + 2S \right].
$$

(2)

Eq. 2 might have also been obtained as follows. Assume a zone of altered permeability $k_e$ exists about the well out to a radius $r_e$, and beyond that the unaltered, external permeability $k_x$. The additional pressure drop required to overcome this skin of reduced permeability may be calculated with sufficient accuracy using the incompressible flow equation; for Brownscombe and Collins$^5$ have shown almost no difference between compressible and incompressible steady-state flow, in the vicinity of the wellbore, and the small volume of fluid in the vicinity of the wellbore makes unsteady-state mechanics unnecessary. Then,

$$
\Delta p_s = \frac{q \mu \ln (r_e/r_u)}{2 \pi k_h} - \frac{q \mu \ln (r_u/r_x)}{2 \pi k_h}
$$

$$
\Delta p_s = \frac{q \mu}{2 \pi h} \left[ \frac{k_e - k_x}{k_x} \ln \left( \frac{r_e}{r_x} \right) \right].
$$

(3)

The sign of this skin pressure drop will be positive or negative depending upon whether the altered permeability $k_e$ is smaller or larger, respectively, than the external permeability $k_x$. Adding the pressure drop of Eq. 3 to Eq. 1 to find the total pressure drop:

$$
\Delta p_t = \frac{q \mu}{4 \pi k_h} \left[ \ln \left( \frac{k_t}{\mu c f_r^2} \right) + .809 \right]
$$

$$
+ \frac{q \mu}{2 \pi h} \left[ \frac{k_e - k_x}{k_x} \ln \left( \frac{r_e}{r_x} \right) \right]
$$

$$
\Delta p_t = \frac{q \mu}{4 \pi k_h} \left[ \ln \left( \frac{k_t}{\mu c f_r^2} \right) + .809 + 2 \left( \frac{k_e}{k_x} - 1 \right) \ln \left( \frac{r_e}{r_x} \right) \right].
$$

(4)

Comparing Eq. 4 with Eq. 2 it is seen that the skin effect may be defined by:

$$
S = \left( \frac{k_e}{k_x} - 1 \right) \ln \left( \frac{r_e}{r_x} \right).
$$

(5)

The skin effect $S$ and the external permeability $k_x$ can be determined from pressure build-up tests$^{2,6,7,7,8,8,8,9}$. The average permeability $k_{ave}$, including the altered and external permeabilities, can be determined from PI tests, and may be defined approximately on the basis of steady-state flow, as was done by Thomas$^9$ in defining the damage factor, by:

$$
k_{ave} = \frac{k_e k_x}{k_e \ln \left( \frac{r_e}{r_u} \right) + k_x \ln \left( \frac{r_x}{r_u} \right)}.
$$

(6)

The productivity ratio is the ratio of the average to the external permeability, $k_{ave}/k_x$, or

$$
\text{P.R.} = \frac{k_e \ln \left( \frac{r_e}{r_u} \right) + k_x \ln \left( \frac{r_x}{r_u} \right)}{k_x \ln \left( \frac{r_x}{r_u} \right)}.
$$

(7)

Substituting $k_e \ln \left( \frac{r_e}{r_u} \right) = k_x [S + \ln \left( \frac{r_e}{r_u} \right)]$ from Eq. 5 in Eq. 7:

$$
\text{P.R.} = \frac{\ln \left( \frac{r_u}{r_e} \right) + S}{\ln \left( \frac{r_u}{r_x} \right)}.
$$

(8)

This equation shows that the productivity ratio and the skin effect are not uniquely related, because of the uncertainty in the drainage radius, and also, in many instances, the wellbore radius. Fortunately, they enter in the logarithm.

The curves of Fig. 1 are plots of Eq. 8 for $r_u/r_x$ values from 100 to 50,000. The points represent the skin effects and corresponding productivity ratios from a large number of well tests, taken from Fig. 15 of Ref. 5 or Fig. 13 of Ref. 9. While some of the data

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$^7$References given at end of paper.

$^8$Original manuscript received in Petroleum Branch office on May 25, 1956. Revised manuscript received July 22, 1956.
spread is due to inaccuracies in the various data used to compute the skin effect and productivity ratio, the agreement between the theoretical curves, using \( r_s/r_w \) as a parameter, and the observed well data appears to support the definition of the skin effect by Eq. 5, and also the validity of Eq. 8 relating productivity ratio and skin effect, in which the value of \( r_s/r_w \) is important. Only approximate agreement is expected because Eq. 8 applies to steady-state conditions whereas the plotted points of Fig. 1 involve a combination of both steady-state and unsteady-state conditions, for which the \( r_s/r_w \) values assumed are not reported. The fairly large number of points with negative skin effects lying below the curves might be interpreted as the effect of extremely large drainage radii, while those with negative skin effects lying above the curves may be wells with severely restricted drainage radii.

Fig. 2 is a plot of Eq. 5, the skin effect vs the ratio of the altered zone radius to the wellbore radius, \( r_s/r_w \), at several values of the parameter \( k_s/k_r \). The change of the scale for the negative skin effects should be noted. The curves indicate that well improvements denoted by skin effects more negative than \(-6\) are obtainable only by extreme permeability improvement extending out beyond 200 times the wellbore radius. The scarcity of skin effects more negative than \(-6\), as shown in Fig. 1, supports this prediction, and indirectly the definition of the skin effect. All wells with skin effects more negative than \(-6\), reported in Ref. 5, had apparently received about average fracturing or acidizing treatment, the success being due apparently to the fortuitous nature of the permeability about the well; for some wells which received excessive treatment did not respond as well, and two untreated sand wells (M-4 and M-6) had skin effects near \(-5\). An indication of the extent of fracture extension might be inferred from these considerations.

Fig. 3 is a plot of Eq. 7 which is based on the steady-state radial flow equation, using \( r_s = 660 \) ft and \( r_w = 0.35 \) ft. It is included to complete the viewpoint of well stimulation and well damage in terms of the radial extent of the zone of altered permeability, and of the degree of alteration, \( k_s/k_r \).

REFERENCES


