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A POSSIBLE EXPLANATION FOR VARIABLE SKIN

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In well testing it has long been recognized that some wells, especially high rate producers, seem to exhibit a variable skin factor. This has often been attributed to non-Darcy flow or even to turbulence in the region where fluids enter the wellbore. It is interesting to note, however, that there may be another explanation for the variable skin efect, due not to a failure of Dary's Law, but to a failure of the fundamental “skin” equation. In this note it will be shown that the normal skin equation used in ressure transient analysis does not conserve mas and that the error in the mass balance is dependent on pressure. Since higher flow rates also mean more pressure drop, in many cases this might be a more reasonable explanation for the variable skin effect.

To the best of my knowledge, this evaluation has not been published in the literature, but the conclusions were arrived at through discussiions with P. S. Fair. If someone knows of a published literature reference, please contact wfair@comportco.com.

Mathematical Background

The analysis of pressure transient well tests is normally governed by the radial flow form of the single phase diffusivity equation shown in Equation 1.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(\frac{k\rho}{\mu}r\frac{\partial p}{\partial r}\right)=\phi\mu c_t\frac{\partial p}{\partial t} \qquad \text{where} \quad c_t=\frac{d(\phi\rho)}{dt} \qquad \text{.......... (1)}$$

In the case where all reservoir and fluid properties, k,ρ,μ,ϕ , depend only on pressure, a “pseudo-pressure, m, can be defined as shown in Equation 2.

Reference 4 also shows that the short time pressure solution, when wellbore effects dominate, is equal to Equation 2. This implies that the slope of a pressure vs. time plot will be as indicated in Equation 3.

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial m}{\partial r}\right)=\frac{\phi\mu c_t}{k}\frac{\partial m}{\partial t} \qquad \text{where} \quad m=\int_{p_0}^{p}\frac{k\rho}{\mu}dp \qquad \text{.......... (2)}$$

For well test analysis, this equation is solved with appropriate boundary and initial conditions. Similar equations are derivable for flow geometries other than radial, but will not be presented here.

The boundary condition for constant mas flow rate is shown in Equation 3.

$$\left(r\frac{\partial m}{\partial r}\right)_{r_w}=\left(\frac{\rho q_w}{2\pi h}\right) \quad (3)$$

It has long been recognized that the pressure solution obtained for the slightly compressible fluid case (when $m=\left(\frac{k}{B}\mu\right)\Delta p$ and B is the formation volume factor) does not represent pressures measured in wells. For that reason, a “skin” factor[1] was defined to explain the difference as due to a damage near the wellbore. The skin equation is generally written as Equation 4.

$$m_w=m_{(r=r_w)}+2\pi hS\left(r\frac{\partial m}{\partial r}\right)_{r_w} \quad (4)$$

Solutions to the diffusivity equation, however, are not usually expressed in terms of pseudo-pressure, but are expressed in terms of actual or dimensionless pressure. The standard form of the skin equation is shown in Equation 5, in terms of pressure.

$$p_w=p_{(r=r_w)}+2\pi hS\left(r\frac{dp}{dr}\right)_{r_w} \quad (5)$$

Comparing Equations and 5 seems to indicate a complete symmetry, however, there is a subtle difference. Expanding Equation 4 results in Equation 6, where we've assumed that both permeability and viscosity are constant. Note that the conclusions hold for the general case with pressure dependent permeability and viscosity, too.

$$\int_{p_{r_w}}^{p_w}\rho\,dp=\frac{2\pi kh}{\mu}S\left(\rho r\frac{\partial p}{\partial r}\right)_{r_w} \quad (6)$$

This can also be solved for the skin factor, S, as shown in Equation 7. In the case of constant rate, note that all of the terms are constant, except those involving density, so the skin is proportional to the density terms as shown in Equation 8. In this form, it is apparent that the skin must be a function of pressure and will change as the pressure changes if the fluid is compressible.

$$S=\{\left(\frac{\mu}{2\phi kh}\right)/\left(\rho r\frac{\partial p}{\partial r}\right)_{r_w}\}\int_{p_{r_w}}^{p_w}\rho\,dp \quad (7)$$

$$S\propto\frac{1}{\rho_{r_w}}\int_{p_{r_w}}^{p_w}\rho\,dp \quad (8)$$

The reason for the apparent problem is that the skin equation is defined for steady state flow in an infinitesimally small region around the wellbore. Obviously if there is a pressure drop across the skin region, the fluid density must change between the reservoir and the wellbore. However, the skin equation evaluates the fluid density outside the wellbore and assumes that it is constant. Therefore, the standard skin equation will not conserve mass and as a result, it must change with pressure and fluid density, which invalidates the solution.

Conclusions

In conclusion, it appears that for compressible fluids, the skin factor normally deteremined in pressure transient analysis must depend upon the pressure and will be a variable. Rather than the skin changing with flow rate due to non-Darcy flow, however, it seems apparent that it should change as a function of pressure.

Nomenclature

m pseudo-ressure

p pressure

p_w wellbore pressure

q volumetric flow rate

t time

r radius

ρ density

References

1. Van Everdingen, A. F., “The Skin Effect and Its Influence on the Productive Capacity of a Well,” Trans., AIME (1953) **198**, 171-176.