Radius of Investigation for Permeability Distributions in Heterogeneous Reservoirs

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1. Introduction

The estimation of permeability in reservoirs with radial discontinuity in permeability has been studied. The pressure in the wellbore continues to decrease as flow rate time increases. Simultaneously, the size of the area from which fluid is drained increases. The slope of the semi-log straight line represents the permeability of the size of area. Thus, we need to use the radius of investigation to obtain the permeability distributions from the pressure derivative.

The radius of investigation is defined as the point in the formation beyond which the pressure drawdown is negligible, and is a measure of how far a transient has moved into a formation following any rate change in a well.(Lee, 1982) Many different definitions have been given for the radius of investigation, but they contain arbitrary numbers and not physical boundaries or location of discontinues. The radius of investigation was fully exploited in the homogeneous reservoir by van Poolen.(1964).

An "area of influence" is used in order to compute permeability distributions from pressure derivative values in multi-well testing, much as a "radius of investigation is used in single well testing. The area of influence is defined as the region of the reservoir that can be affect the pressure drawdown at the observation well. Multi-well testing has been used to estimate formation properties between wells, in which case the area of influence was presumably thought to be small. Oliver(1992) showed that the value of the constant in the area of influence can be chosen to make the definition of the area of influence consistent with definitions proposed for single well testing. This study is to discuss the radius of investigation in the multi well testing and to perform a sensitivity study to determine the effect of the radius of investigation on the calculated permeability distribution in multi-well testing.

2. Discussions

The radius of investigation for the multi-well testing is given by

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$$r_i = C\sqrt{\frac{0.0002637\,\dot{k}t_i}{\phi\mu c_t}} \qquad (1)$$

where t is hours, and k is the instantaneous permeability and its unit is md.

Here, the instantaneous permeability is given by,

$$\dot{k} = \frac{70.6qB\mu}{h\Delta p'}\exp\left(-\frac{r_D^2}{4\dot{t}_D}\right) \qquad (2)$$

and the instantaneous dimensionless time, t_D, as

$$t_D^{\cdot} = \frac{0.0002346\,kt}{\phi \mu c_t r_{wa}^2} \tag{3}$$

The instantaneous permeability at the observation well can be obtained from pressure derivative which is a slope in a plot of p_{wf} vs. ln$t$ at the instantaneous time. We call this pressure derivative the instantaneous pressure derivative, Δp′, which is given by

$$\Delta p' = p_{wDo}' = \frac{\partial p_{wDo}}{\partial \ln t_D} = \frac{1}{2}\exp\left(-\frac{r_D^2}{4t_D}\right) \tag{4}$$

where p_{wDo} is dimensionless pressure at the observation well.

The weighting function, K, is shown in the pressure derivative solutions for multi-well testing in radially heterogeneous reservoirs, and is very important in obtaining permeability distributions in the radially heterogeneous reservoirs, for we calculate permeability distributions from pressure derivatives. The weighting functions for the dimensionless pressure derivative is given by

$$K(r_D, t_D) = \frac{\sqrt{\pi} r_D}{2t_D^2} \exp\left(-r_D^2/2t_D\right) W_{1/2,1/2}\left(-r_D^2/t_D\right) \tag{5}$$

Fig. 1 shows a single curve for the normalized weighting function in terms of the Bolzman variable, $r_D/\sqrt{t_D}$. The normalized weighting function, $K(r_D,t_D)$ is multiplied by $\sqrt{t_D}$. The shape determines the degree of smoothing for the semi-log plot and clarifies the meaning of the radius of investigation in terms of permeability distributions. The permeability determined from the pressure derivative is a weighted average of permeability throughout the reservoir with the weighting function, $K(r_D,t_D)$. Beyond the radius at which the weighting function becomes small, the permeabilities do not contribute to the slope of the semi-log plot. From the shape of the weighting function, K, not only does the radius of investigation increase with time, but also the volume over which averaging occurs increases. The most of the permeability information comes from the region of the reservoir centered at $r_D = 1.92\sqrt{t_D}$.

The integral of the area under the curve is a measure of the cumulative contribution to the permeability estimate, since the weighting function represents the average permeability estimate. The total area of under curve is 0.5. Fig. 2 shows the cumulative contribution profile to the permeability estimate. The numbers on Fig. 1 results from Fig. 2. The annular region between $r_D = 0.12\sqrt{t_D}$ and $r_D = 2.34\sqrt{t_D}$ is 98% of the confidence. The permeability the region of beyond $r_D = 2.34\sqrt{t_D}$ cannot be detected because it is essentially excluded from the averaging.

The cumulative contribution of 82% for describing the permeability estimate with radial distance is obtained from the region beyond $r_D = 1.5\sqrt{t_D}$, and the cumulative contribution of 82% for describing the permeability estimate with radial distance is obtained from the region beyond $r_D = 2.0\sqrt{t_D}$. These numbers are in good agreement with the radius of investigation estimate of other authors.

3. Results

In this section, we observe the effects of radius of investigation in obtaining the permeability distributions in radially heterogeneous reservoirs. Among the studies of the estimation of permeability in reservoirs with radial discontinuity in permeability, We consider two methods which are an inverse solution algorithm (ISA). The ISA is a recursive method for multi-well testing, considering the inter-well region to describe the permeability distribution profile from pressure responses at an observation well.

Fig. 3 shows a comparison of the permeability distribution profiles using the ISA method. We consider r_D = 10. The triangles are the permeability distributions using the constant of 2.0 in the radius of investigation, which Feitosa *et al.*(1994) used. The circles are ones using the constant of 1.5 in the radius of investigation. The crosses are ones using the constant of 1.784 in the radius of investigation, as suggested by Raghavan.(1993) When the constants of 1.784 and 2.0 are used, then there is some oscillation in permeability distribution, However, there is no oscillation for the constant of 1.5, and we maintain better stability in permeability distribution when the constant of 1.5 is used.

4. Conclusions

We should choose the constant of radius of investigation to maintain better stability of the inverse methods and keep the accuracy of the methods.

We can use the constant of 1.5 in the radius of investigation with the cumulative contribution of 82% for radial of investigation in the permeability distribution.

5. References

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Key words: radius of investigation, multi-well testing, heterogeneous reservoirs, permeability distribution

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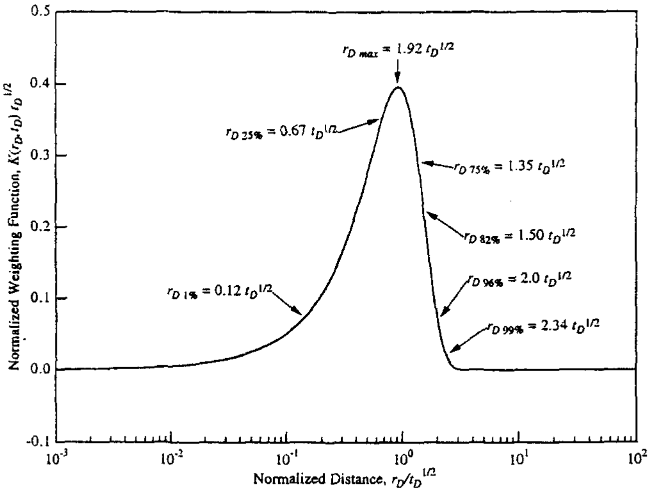

Fig. 1: Inner and Outer Radii of Investigation from the Weighting Function, K

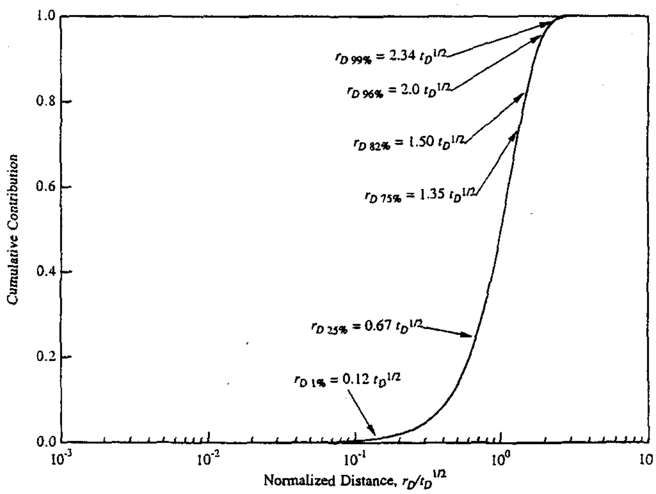

Fig. 2: Profile of Cumulative Contribution to Permeability

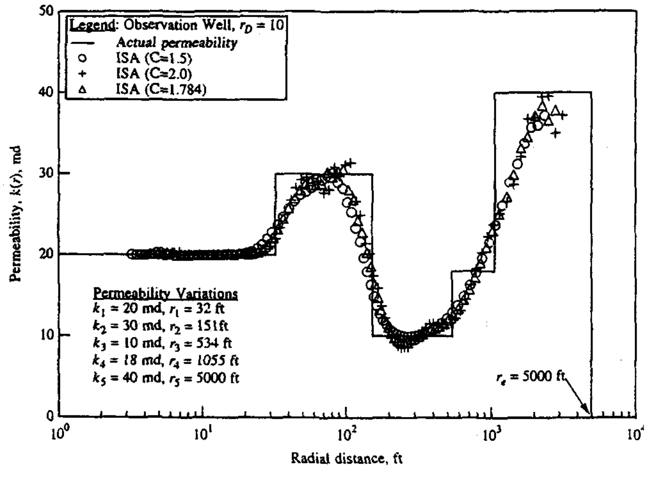

Fig. 3: Effect of Radius of Investigation on Permeability Distribution