# SHAPE OF PRESSURE RECOVERY CURVES IN INJECTION WELLS OF A FISSURE COLLECTOR

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A substantial proportion of oil and gas deposits in the USSR is associated with fissure collectors. However, hydrodynamic methods of studying such collectors have not been developed to the same extent as in the case of porous collectors, so that the information about the bed that can be deduced from the pressure recovery curves often leads to incorrect interpretation. An example of this kind is discussed in the present note.

It was suggested in [1] that a fissured bed could be regarded as an infinite set of fine, low-permeability blocks, divided by a system of random cracks. On this basis the authors of [1] proposed to describe nonstationary filtration of a homogeneous fluid in a fissure collector by the equation

$$\frac{\partial p}{\partial t} - \eta \frac{\partial \Delta p}{\partial t} = \varkappa \Delta p \qquad \left(\eta = \frac{k}{\alpha}\right), \tag{1}$$

where p is the pressure in the cracks, $\Delta p$ is the Laplacian operator applied to the pressure, t is time, $\varkappa$ is the piezoconductivity, $\eta$ is a coefficient characteristic of the fissured medium, k is the permeability of the cracks, and $\alpha$ is the mass transfer coefficient between the cracks and blocks.

It was shown in [1] that the rate of filtration was given by

$$u = -\frac{k}{\mu}\left[\operatorname{grad} p - \tau \frac{\partial}{\partial t} \operatorname{grad} p\right] \qquad \left(\tau = \frac{\eta}{\varkappa}\right), \tag{2}$$

where $\tau$ is a parameter having the dimensions of time. It was called the "delay time" in [2].

As shown in [1], the difference between the fissured medium and the porous medium increases with increasing delay time.

Equation (1) was generalized in [3] to the case of pressure-dependent bed parameters.

It is clear that Eq. (1) differs substantially from the piezoconduction equation [4], suggesting that nonstationary filtration in a fissured medium occurs in a different way from that in the porous medium. In the present note we shall use Eqs. (1) and (2) to investigate the effect of the fissured structure of the bed on the shape of the pressure recovery curves.

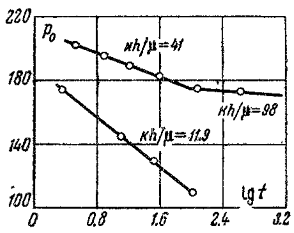


Fig. 1

Data on injection wells feeding fissured Devonian sandstone in the Romashkinskii deposit show [5] that the pressure recovery curves, plotted as ln t against $\Delta p$, consist of two straight sections joined by a short smooth junction. The slope of the first of these is much greater than the slope of the second. It is known (see, for example, [5]) that a pressure recovery curve of this form is characteristic for cracks whose conductance ($kh/\mu$) in the face zone is lower than in the remaining part of the bed. Assuming that the knee of the pressure recovery curve is exclusively due to the difference in conductance, the authors of [5] determine the size of the zone of reduced permeability for the Romashkinskii region, and find it to be between 10 and 140 m. Since the size of the reduced-conductance region increases with increasing injection pressure and volume of injected water, the authors of [5] conclude that the change in the permeability is due to the contamination of the bed by suspended particles (in the injected water), which can propagate through the bed along the cracks to considerable distances.

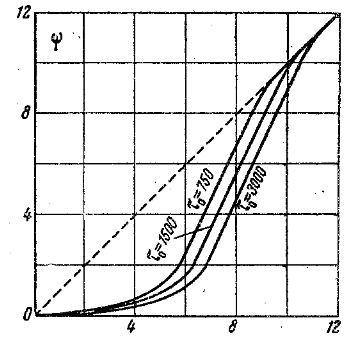


Fig. 2

The problem is whether the fissured structure is in itself sufficient to account for the knee in the pressure recovery curve plotted on the semilogarithmic scale. The analysis given below involves the solution of Eq. (1) and experimental data on well No. 651, and has given a definite answer to this problem

The fissured structure of the zone of immediate influence of well No. 651 ($PK_2$ level) can be established by the method described in [6]. The well has been receiving seawater over a period of more than 5 years with a mean discharge rate q = 300 $m^3$/day. The concentration of suspended particles (largely rust) is 5–7 g/$m^3$. Drainage is carried out very rarely, at intervals of 1.5 to 2 years, so that in one year alone the face of the well receives an amount of material equivalent to a thickness of 55 m, assuming a sample diameter of 152 mm and a specific weight of the suspension equal to 2 g/$m^3$. Since a plug is not formed the suspended material spreads over the bed. The pore size in the $PK_2$ level, according to our measurements, does not exceed 10 $\mu$, while the rust particles, according to [7], have linear dimensions of 30–40 $\mu$, so that the suspended material propagates through the bed only along the cracks.

To obtain the pressure recovery curves, well No. 651 was shut off at $p°$ = 210 atm and q = 330 $m^3$/day. The experimental curve is shown in semilogarithmic scale in Fig. 1. There is a clear knee on the curve corresponding to a face pressure of $p°$ = 181 atm. The permeability calculated from the slope of the first and second straight lines was found to be 41 and 98 darcy cm/centipoise.

The conditions were then changed to $p°$ = 180 atm and q = 206 $m^3$/day and it was found that the pressure recovery curve obtained after the second stoppage did not show the knee and consisted of a single straight line. The permeability deduced from the slope of this latter curve is 11.9 darcy cm/centipoise.

Hence it is clear that the knee of the pressure recovery curve is associated with the injection pressure and cannot be due to the contamination of the face.

To resolve this problem let us return to Eq. (1). We shall suppose that the injection well operates at a constant discharge rate $q_0$ up to the shut-off time t = 0. After closure, i.e., for t > 0, the pressure p(r, t) in the cracks satisfies Eq. (1), where r is the distance from the face of the well. The time-dependent discharge rate q(t) is then given by a modified form of Eq. (2)

$$q(t) = \frac{2\pi kh}{\mu}\left[\left(r\frac{\partial p}{\partial r}\right) + \tau \frac{\partial}{\partial t}\left(r \frac{\partial p}{\partial r}\right)\right]_{r=r°}, \tag{3}$$

where r° is the radius of the well. Assuming that

$$p(r, t) = p_0(r) - \frac{\mu}{2\pi kh} U(r, t), \tag{4}$$

where $p_0(r)$ is the initial distribution of pressure in the bed, we have

$$\frac{2\pi kh}{\mu}\left(r\frac{\partial p_0}{\partial r}\right)_{r=r^\circ}=-q\ .$$

To determine the function U(r, t) we must solve the following boundary-value problem:

$$\frac{\partial U}{\partial t}-\eta\frac{\partial}{\partial t}\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right)=\varkappa\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right),$$

$$U(r,0)=0 \quad \text{for} \quad t=0,$$

$$q_0-q(t)=\left[\left(r\frac{\partial U}{\partial r}\right)+\tau\frac{\partial}{\partial t}\left(r\frac{\partial U}{\partial r}\right)\right] \quad \text{for} \quad r=r_\circ\ . \qquad (5)$$

Since we are interested in the first phase of the filtration process, we can regard the bed as an infinite medium and take the second boundary condition in the form $U(\infty, t) = 0$. To solve the boundary-value problem defined by Eq. (5), consider the Laplace transforms

$$U(r,s)=\int_0^\infty e^{-st}U(r,t)\,dt,$$

$$Q_0-Q(s)=\int_0^\infty e^{-st}\left[q_0-q(t)\right]dt, \qquad Q=\frac{q}{s}\ .$$

The relations given by Eq. (5) then take the form

$$\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial U}{\partial r}\right)-\frac{s}{\varkappa(1+\tau s)}U=0\ ,$$

$$\left(r\frac{\partial U}{\partial r}\right)_{r=r_0}=\frac{Q_0-Q(s)}{1+\tau s}\ .$$

Since $U(\infty, s) = 0$ we have

$$\frac{U(r_0,s)}{Q_0-Q(s)}=\frac{1}{1+\tau s}\frac{K_0(\zeta)}{\zeta K_1(\zeta)}\ ,$$

$$\zeta=\left(\frac{1}{m}\frac{s}{1+\tau s}\right)^{1/2}, \qquad m=\frac{\varkappa}{r^{\circ 2}} \qquad (6)$$

where $K_0$ and $K_1$ are the Macdonald functions of order zero and one.

Consider the dimensionless parameters $m/s = t_0$, $m\tau = \tau_0$, for which $\zeta = \zeta_0$.

In practice, m is frequently not less than 50 $sec^{-1}$, so that the right side of Eq. (6) can be represented by

$$\frac{t_0}{t_0+\tau_0}\frac{K_0(\zeta_0)}{\zeta_0K_1(\zeta_0)}=\frac{1}{2}\frac{t_0}{t_0+\tau_0}\ln(t_0+\tau_0)\ ,$$

with considerable accuracy even for $\tau > 2$ sec.

Bearing in mind Eq. (4), let us substitute

$$\frac{1}{2}\psi(t_0)=\frac{U(r_0,s)}{Q_0-Q(s)}=\frac{2\pi kh}{\mu}\frac{\Delta p}{Q_0-Q(s)}\ ,$$

$$\Delta p=p^\circ-p(r^\circ,t)\ ,$$

where $\Delta p$ is the drop in the face pressure in the well on stoppage.

Equation (6) can then be rewritten in the form

$$\psi(t_0)=\frac{t_0}{t_0+\tau_0}\ln(t_0+\tau_0)\ . \qquad (7)$$

The function $\psi(t_0)$ is plotted against $\ln t_0$ in Fig. 2. It is clear that each curve bends over and the position at which this occurs moves to the right as the dimensionless delay time $t_0$ increases. All the curves tend to a common asymptote $\psi(t_0) = \ln t_0$.

An exact solution of the pressure recovery problem was given in [8] in terms of the Laplace transforms for a well containing an annular zone around which the conductance is lower than in the remainder of the bed. It is clear from Fig. 2 of [8] that the pressure recovery curve for this well, plotted in the form $\psi(t_0)$, $\ln t_0$, also has a knee completely analogous to that shown in Fig. 2 of the present paper.

It is obvious that the pressure recovery curves for a bed with a contaminated face and for a fissured bed are similar when they are plotted in the form $\Delta p$, $\ln t_0$.

Therefore, the problem formulated at the beginning of this note has the following solution: the fissured structure of the bed is a sufficient reason for the appearance of the knee on the pressure recovery curve plotted on a semilogarithmic scale, and this occurs in the same direction as in the case of a contaminated face zone. Hence it follows that the first sections of the pressure recovery curve for wells in a fissure collector cannot be used to deduce information about the state of the face zone of the bed, although this is often done in practice (see, for example, [5]).

REFERENCE

1. G. I. Barenblatt, Yu. P. Zheltov, and I. N. Kochina, "Fundamentals of the theory of filtration of homogeneous liquids in fissured rocks," PMM, vol. 24, no. 5, 1960.

2. A. Ban, "Determination of the delay time in pressure recovery in fissured rock," Izv. AN SSSR, Mekhanika i mashinostroenie, no. 4, 1961.

3. A. Ban, K. S. Basniev, and V. N. Nikolaevskii, "Basic equations for liquid and gas filtration in deformed porous media," PMTF, no. 3, 1961.

4. V. N. Shchelkachev, Working of Oil-Bearing Beds Under Elastic Conditions [in Russian], Gostoptekhizdat, 1959.

5. A. A. Litvinov and A. F. Blinov, Industrial Investigation of Wells [in Russian], Izd. Nedra, 1964.

6. I. E. Apel'tsin, "Effect of fissured face structure in injection wells on the injection of water into the bed," Neft. khoz-vo, no. 2, 3, 1964.

7. G. F. Trebin, Filtration of Liquids and Gases in Porous Media [in Russian], Gostoptekhizdat, 1959.

8. G. I. Barenblatt and V. A. Maksimov, "Effect of inhomogeneities on the parameters of an oil-bearing bed deduced from nonstationary influx of liquid into wells," Izv. AN SSSR, OTN, no. 7, 1958.

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