SAPROPEL DRILLING-MUD INFILTRATION INTO A POROUS MEDIUM

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UDC 622.245.14

Sapropel drilling muds show a high rate of decrease in the infiltration, which have been tested to produce controlled blocking in productive strata.

Advances in borehole management are particularly important in relation to surveying and exploiting oil and gas deposits having adverse characteristics.

One promising method is controlled permeable-stratum blocking [1], and here sapropel muds are important, as tests show that they can be used in drilling [2, 3] and in managing productive strata [4].

The present results deal with sapropel systems and the blocking mechanism they produce in porous media.

A UIPK-1M apparatus has been used under laboratory conditions to determine the blocking capacity of a 4% sapropel suspension passing through rock specimens having known permeabilities. All the tests were performed at 8 MPa on the cores, 20°C, and counterpressure 5 MPa. The main difference from existing methods was that the conditions ensured that the infiltration was not accompanied by the formation of a crust [5], because there are substantial differences in the static and dynamic infiltration.

Table 1 gives the core characteristics. The 4% suspension had $\rho = 1.02 \times 10^3$ kg/m^3, T = 40 sec, $\Phi_{30} = 2$ cm^3, $CHC_{1/10} = 9/13$ dPa, pH 9.38, η_f 16 mPa·sec, and τ_0 93.9 dPa.

Table 2 shows that the infiltration rate drops sharply in the first 10 min and then tends to a limit. The instantaneous rate and the blocking were quite low for all the specimens, which is very important for preventing deterioration in the collector behavior caused by the solid in the drilling mud. The infiltration parameters are reduced by the sapropel mud to an extent largely dependent on the initial permeability and to a smaller one on the pressure difference.

The model was for an inhomogeneous system with a porous baffle [6], which is acceptable, since laboratory conditions were involved and the model enables one to use standard laws. There are some substantial differences between infiltration during exploitation and for the drilling muds, so we compared the two only as regards the permeability variation.

There are the following forms of infiltration [6] as the permeability in the barrier falls at constant pressure difference: a) complete pore blocking; b) gradual blocking; c) intermediate; and d) with deposit formation.

Table 3 gives the linear equations for each of these forms.

The sapropel infiltration was evaluated by ES-1022 computer processing, which showed that none of the standard linear equations applies. Figure 1 shows the relation between the sapropel parameters for a specimen having permeability 237 Φ/m^2. For the other specimens whose characteristics are given in Table 1, we obtained analogous results, and further stud-

Gomel Borehole Drilling and Testing Division, Belorussian Geological Surveying Research Institute. Peat Research Institute, Belorussian Academy of Sciences, Minsk. Gomel Division, Ukrainian State Petroleum Industry Research and Development Institute. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 55, No. 4, pp. 594-599, October, 1988. Original article submitted September 4, 1987.

TABLE 1. Core Characteristics

Specimen No.	Initial permeabil. K, Φ/m²	Length ℓ, cm	Infiltration area F, cm²	Porosity m, %	Residual water σ, %	Pore space volume V, %
1	237	4,69	3,30	14	1,0	2,2
2	249	4,86	3,30	13	4,0	2,1
3	377	5,60	3,30	14	4,0	2,6
4	216	5,02	3,36	17	1,0	2,9
5	57	4,92	3,30	18	0,2	2,9
6	138	3,01	3,30	15	0,1	1,5
7	618	4,30	3,35	14	0,1	2,1

ies showed that Q/T = f(1/T) and W = f(1/T) exhibit linearity for the sapropel suspension. Parts e and f of Fig. 1 show that the final parts of the graphs are straight lines that fit the measurements very accurately (correlation coefficients close to one). The linearity means that the relations can be taken as characteristic for the sapropel in a porous medium.

The fall in the infiltration rate in this sapropel system is approximated by

$$W = A + \frac{B}{T}. \tag{1}$$

Differentiating the characteristic linear equations readily gives analogous ones for the major forms of infiltration (Table 4). Here the asymptotes coincide with the horizontal axis W = 0, in contrast to (1), which has the nonzero horizontal asymptote W = A. Nevertheless, a relation can be derived between (1) and the equations in Table 4, namely by parallel transfer of the coordinates axes in accordance with W_1 = W–A and T_1 = T. Then (1) gives $W_1 = B/T_1$, so the rate of fall in the infiltration rate is such that the sapropel is intermediate between the intermediate type and the deposit formation one. The process combines characteristic features of the two (Table 3), so the basic equation can be put as

$$\frac{dR}{dQ} = kR^{0,5}.$$

An inverse coordinate transformation gives the variation in the infiltration rate as a law with a nonzero horizontal asymptote, which means that the sapropel infiltration rate rapidly becomes constant, so the infiltration does not cease, which is possible only if there is dynamic equilibrium between the crusting and the disruption. This is confirmed by Fig. 2, which shows the tendency to straight lines for Q = f(T) for sapropel entering various cores.

A stationary crust is formed by growth and simultaneous erosion, which is characteristic of all drilling muds under dynamic conditions [7]. Sapropel muds favor stationary crusts also in static conditions. Figure 3 shows the infiltration rates for 4% sapropel and 3% Sarigyukh bentonite as functions of time under static conditions for permeability 237 Φ/m^2. The clay suspension shows a slower fall in the rate and the absence of a stationary crust. The infiltration rates for clay muds are [7] described by

$$W = \frac{c}{2\sqrt{T}},$$

in which c is a constant.

The permeability fall with a clay mud is thus similar to infiltration with deposit formation, whereas a sapropel mud shows a sharp fall in the rate and the formation of a stationary crust in 10-12 min, so one suggests that the sapropel deposit has a low shear stress.

The qualitative features can be processed [8, 9] and used with the permeability reduction mechanism related to clays [10] to describe the sapropel blocking.

The particles in the sapropel mud penetrate a little way and produce partial pore blocking; the sapropel material has a high blocking capacity and forms a largely impermeable film at the boundary with the porous medium, which consists of organomineralic particles and contains very thin capillaries, which pass only water, and this is the basis for the in-

TABLE 2. Infiltration of 4% Sapropel into Cores with Various Permeabilities

Specimen No.	Initial resis. $R_i \cdot 10^{-12}$, m^{-1}	Initial infil. rate $W \cdot 10^6$, m/sec	Starting resis. $R_s \cdot 10^{-14}$, m^{-1}	Final infil. rate $W \cdot 10^6$, m/sec	Final resis. $R_f \cdot 10^{-17}$, m^{-1}	Instantaneous infil. $\Phi \cdot 10^3$, m	Blocking factor	
							$k_1 \cdot 10^{-5}$	$k_2 \cdot 10^{-3}$
1	0,194	27,1	1,800	0,259	0,188	0,97	0,970	0,100
2	0,191	116,1	0,422	0,175	0,279	2,33	1,400	0,660
3	0,145	220,7	0,222	0,143	0,342	3,82	2,300	1,500
4	0,228	53,0	0,925	0,407	0,120	1,30	0,527	0,130
5	0,852	69,5	0,705	0,339	0,144	2,15	0,169	0,200
6	0,214	31,4	1,156	0,214	0,229	0,93	1,070	0,147
7	0,068	659,5	0,071	0,079	0,599	5,42	8,780	8,400

Note. $k_1 = \frac{R_f}{R_i}$; $k_2 = \frac{R_f}{R_s}$.

TABLE 3. Basic Equations and Characteristics for Various Forms of Infiltration [6]

Infiltration type	Basic equation	Characteristic linear relation
With complete blocking	$\frac{dR}{dQ} = k_1 R^2$	$W = A_1 + B_1 Q$
With gradual blocking	$\frac{dR}{dQ} = k_2 R^{3/2}$	$\frac{T}{Q} = A_2 + B_2 T$
Intermediate	$\frac{dR}{dQ} = k_3 R$	$\frac{1}{W} = A_3 + B_3 T$
With deposit formation	$\frac{dR}{dQ} = k_4$	$\frac{T}{Q} = A_4 + B_4 Q$

Note: R resistance in infiltration in m^{-1}; Q filtered liquid volume from unit area in m; W infiltration rate in m/sec; T blocking time in min; and k_i, A_i, B_i $(i = 1, \ldots, 4)$ empirical coefficients.

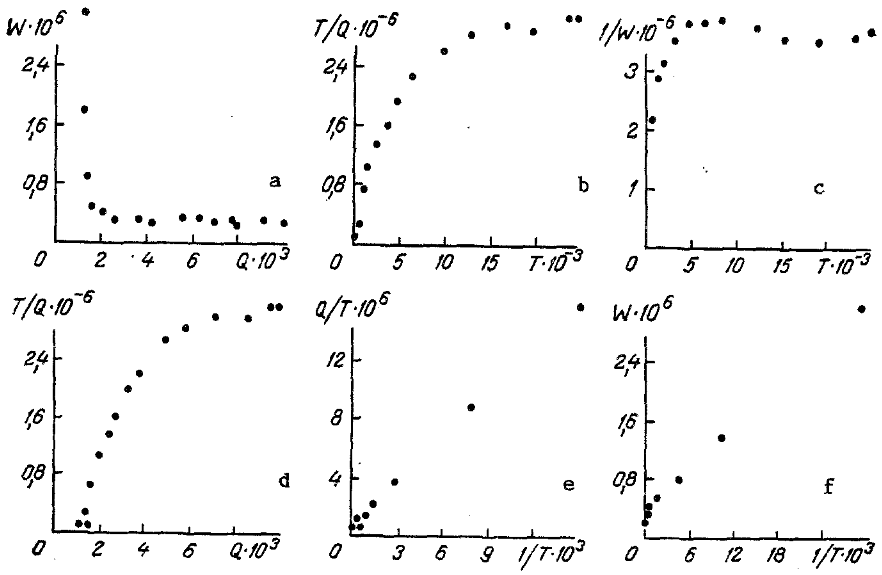

Fig. 1. Relationships between parameters for sapropel infiltrating through a porous specimen having initial permeability k = 237 Φ/m^2: a) W = f(Q); b) T/Q = f(T); c) 1/W = f(T); d)T/Q = f(Q); e) Q/T = f(1/T); f) W = f(1/T). Q/T, W, $m \cdot sec^{-1}$; 1/W, T/Q, $sec \cdot m^{-1}$; Q, m; T, sec; 1/T, sec^{-1}.

TABLE 4. W - f(T) for Various Forms of Infiltration

Infiltration type	Dependence $W = f(T)$
With complete blocking	$W = A_1 \cdot e^{-B_1 T}$
With gradual blocking	$W = \frac{A_2}{(A_2 + B_2 T)^2}$
Intermediate	$W = \frac{1}{A_3 + B_3 T}$
With deposit formation	$W = \frac{B_4}{\sqrt{A_4^2 + 4B_4 T}}$

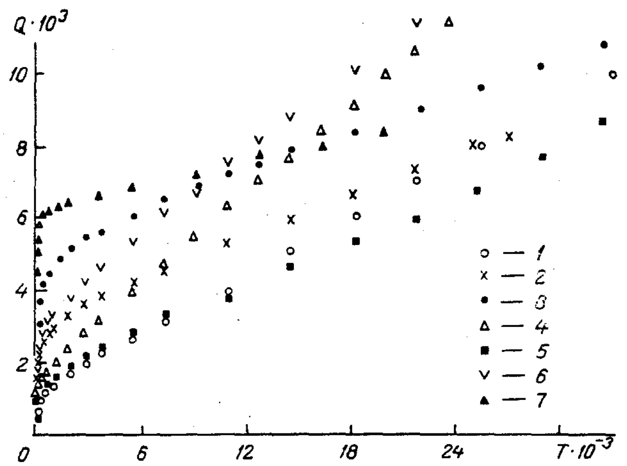

Fig. 2. Dependence of filtrate volume from unit area on time for sapropel passing through porous specimens with various initial permeabilities: 1) 237 Φ/m^2; 2) 249; 3) 377; 4) 216; 5) 57; 6) 138; 7) 618. Q, m.

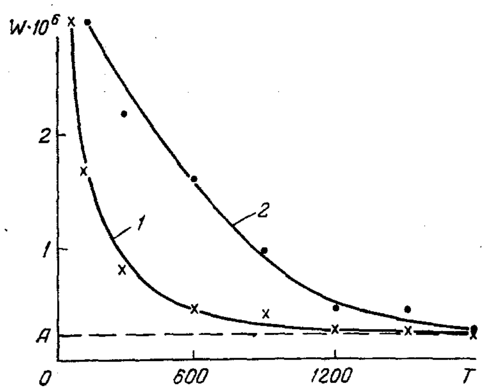

Fig. 3. Infiltration rates for 4% sapropel (curve 1) and 3% Sarigyukh bentonite (curve 2) as functions of time under static conditions for a specimen having initial permeability 237 Φ/m^2.

filtration crust. The crusting is dependent on the infiltration rate, and there is always a tendency for fresh crust to form, while part is removed by the moving liquid. Equilibrium sets in when the formation and destruction rates are equal, after which the crust porosity and permeability remain constant. The shear stress in the crust is quite small. Also, the solid components in a sapropel mud decompose on acid treatment [4], so the sapropel crust can readily be removed by ordinary methods for restoring stratal permeability.

These muds differ from clay ones as regards permeability reduction, as they show a high rate of reduction in infiltration and form thin largely impermeable stationary crusts, so they can be used effectively for controlled blocking.

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WALL GAS-DYNAMIC INHOMOGENEITY IN A FIXED GRANULAR BED

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UDC 532.546

The porosity variation in a granular bed near a wall has been used to calculate the gas profile there for spherical and other surface shapes. Sectioning in a fixed bed affects the uniformity in the gas distribution.

When a granular material contacts a rigid wall bounding it or immersed in it, the random structure becomes ordered to a depth of 3-5 times the particle diameter [1], which increases the hydraulic radius r_h, i.e., increases the gas transmission cross section. For a spherical-particle bed, for which $r_h = \varepsilon d/6(1-\varepsilon)$, our data [1] on the local velocity distribution near a wall give the mean value $\bar{r}_h$ at 0.5d from the wall (Table 1) as 1.5 times that at the core.

The wall effect (increased speed) is related to $\epsilon = f(x/d)$, as has been confirmed by many measurements such as [2-4]. There are several ways of determining $w = f(\epsilon, r)$, analytically, as this is described by the differential equation

$$\frac{dP}{dz} = \mu_a \left(\frac{d^2w}{dr^2} + \frac{1}{r} \frac{dw}{dr} \right) - F(\varepsilon, w). \tag{1}$$

The [5] model gives the bed structure, in which the apparent viscosity μ_a for the infiltrating gas is considered as the same everywhere, apart from a thin layer near the wall (thickness ~0.35d), where $\epsilon = 1$. It has been supposed [6, 7] that the porosity near the wall varies exponentially:

$$\varepsilon = \varepsilon_0 [1 + C \exp(1 - 2x/d)], \tag{2}$$

where C in (2) was [6] fitted to suit ϵ_0, while in [7], C = f(d). In [8], $\epsilon = f(x/d)$ was approximated as a stepped function.

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Kirov Ural Polytechnical Institute, Sverdlovsk. Translated from Inzhenerno-Fizicheskii Zhurnal, Vol. 55, No. 4, pp. 599-605, October, 1988. Original article submitted May 21, 1987.

0022-0841/88/5504-1127$12.50