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FILTRATION AND INFILTRATION IN A ZONALLY INHOMOGENEOUS POROUS MEDIUM

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Based on experimental investigations carried out under laboratory conditions, the features of filtration and infiltration of a liquid have been studied in a linear model of a bed. The model consisted of two zones of different permeabilities and was manufactured in the form of a cylindrical tube of length 1.1 m and inside diameter 0.032 m. It has been shown that, in filtration of water from a lower permeability to a higher one, the productivity coefficient increases, on the average, by 15% as compared to infiltration. The mechanism of the phenomena observed has been proposed.

As is well known, a bed becomes drowned with advancement of the water-oil contact, and part of the producing well stock is brought to injection. An analysis of geological-field data on drowned wells of the Neftyanye Kamni field that were brought to injection (see Table 1) has shown that the pickup coefficient exceeds the productivity coefficient in all cases.

The regularities of motion of a liquid from a bed to a well and from a well to a bed have been established in [1] on a radial model of the bed; the difference in the filtration and infiltration indices is due to the diffuser and confuser effect.

In this work, we carried out experiments on a laboratory setup (Fig. 1) with the aim of investigating in detail the features of filtration and infiltration of a liquid. To produce the above effect in the linear model of a bed we created two zones with different permeabilities in it. Contraction of the jet was attained in filtration from a higher permeability to a lower one (HL) (corresponding to a producing well), and expansion of the jet was attained in infiltration (corresponding to an injection well).

The setup whose diagram is shown in Fig. 1 incorporated the following elements: a self-recorder (1), a BP-49 power supply (2), standard pressure gauges (3), a linear model of a bed (4), a 22DI Sapfir pressure strain gauge (5), a PVT bomb (6), a tank with a chaser (7), a thermostat (8), a manifold (9), a bender (10), a shutoff valve (11), and an R-333-D resistance box (12).

We carried out the experiments on a linear bed model, which was manufactured in the form of a cylindrical tube with a length of the working section of 1.1 m and an inside diameter of 0.032 m. The model was filled with a porous medium and was saturated with water according to the standard procedure.

In the first set, the experiments were carried out in a homogeneous bed model (permeability k = 228 mD). We took the dynamics of the flow rate of water at pressure differences of 0.01, 0.015, and 0.026 MPa and plotted indicator curves (Fig. 2, curves 1 and 2) based on it. It is clear from an analysis of the results of the first set of experiments that the indicator diagrams are identical in both directions.

In the second set, the experiments were carried out in a zonally inhomogeneous bed model with a permeability of the zones of 200 and 1800 mD respectively. Water was used as the working agent. The results of the experiments are presented in Fig. 2 (curves 3 and 4). It is seen that, in filtration from a lower permeability to a higher one (LH), the productivity coefficient increases, on the average, by 15% as compared to filtration from a higher permeability to a lower one.

In the third set, with the aim of investigating the possibility of controlling the characteristics of the flow, we carried out experiments analogous to those of the second series, with the only difference that a 0.05% aqueous solu-

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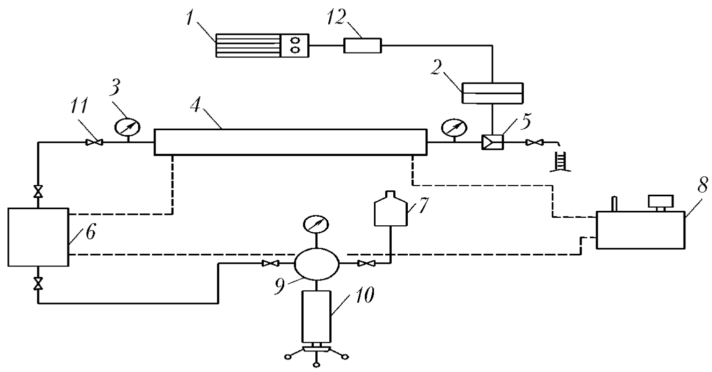
TABLE 1. Data on the Drowned Wells of the Neftyanye Kamni Field That Have Been Brought to Injection

Conventional No. of the well	$Q_{pp}\cdot10^5$, m^3/sec	$Q_{pr}\cdot10^5$, m^3/sec	$K_{pck} = (Q_{pp}/\Delta P)\cdot10^4$, m^3/(sec·MPa)	$K_{pd} = (Q_{pr}/\Delta P)\cdot10^4$, m^3/(sec·MPa)	K_{pck}/K_{pd}
1	72.45	2.98	1.64	1.49	1.10
2	98.95	1.11	2.41	0.55	4.38
3	110.18	2.68	2.68	1.34	2.00
4	264.81	10.99	6.45	5.49	1.17
5	64.23	2.19	1.56	1.09	1.43
6	141.43	3.15	3.36	1.57	2.14
7	127.66	1.95	3.04	2.12	1.43
8	161.92	0.47	3.68	0.24	15.33
9	155.67	1.75	3.54	0.87	4.06



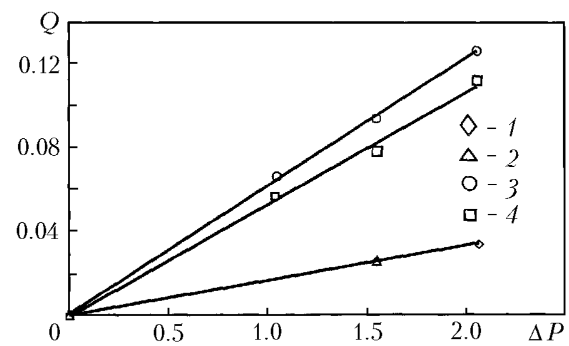


Fig. 1. Diagram of the experimental setup.

Fig. 2. Indicator diagram ($Q = 10^{-6}$ m^3/sec and $\Delta P = 10^{-2}$ MPa): 1 and 2) filtration and infiltration of water in a homogeneous porous medium; 3 and 4) filtration of water from a lower permeability to a higher one and from a higher permeability to a lower one in an inhomogeneous porous medium.

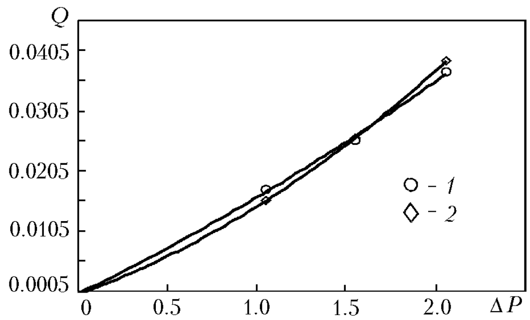
tion of polyacrylamide (PAA) was used in them as the working agent. The results of measurements are presented in Fig. 3, in which it is seen that the indicator curves are identical, in practice.

An analysis of the indicator diagrams allows the assumption that the zonal inhomogeneity and rheological properties of the working agent exert a substantial influence on the process of filtration and infiltration.

Then we carried out experiments on determination of the time variation of the flow rate of the liquid at a constant pressure difference of 0.015 MPa. The result of one experiment is presented in Fig. 4. For each time series, we determined the Hurst index [2–5].

The Hurst indices H are the same, in practice, for the first and third sets of experiments in both directions (in filtration from a lower permeability to a higher one, we have $H = 0.89$ for the first set and $H = 0.69$ for the third set; in filtration from a higher filtration to a lower one, the Hurst index has not changed for the first set and we have $H = 0.72$ for the third set). An analysis of the results of the second set of experiments has shown that there is a certain disagreement in the Hurst indices (LH, $H = 0.7$; HL, $H = 0.50$). It is well known [2] that a change in the Hurst index in the interval $0.5 \le H < 1$ is inherent in persistent systems. Persistence (subsequent values of the time series depend on the previous ones) is characteristic of systems with a "memory," i.e., the influence of the prehistory of motion has an effect on filtration indices.

A spectral analysis of the time series of the second set of experiments (Fig. 5a) for LH and HL has shown that in both cases the spectral density has two fundamental peaks: one at a low frequency and the other at a higher frequency. For the first and second sets of experiments, the spectral density intensely decreases with increase in the



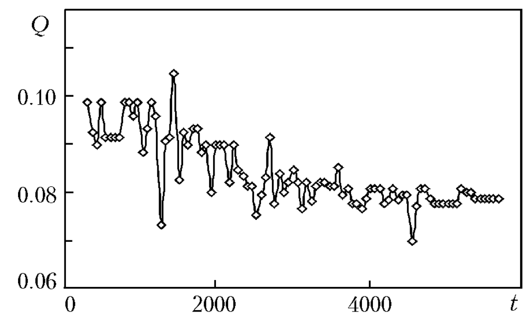


Fig. 3. Indicator diagram ($Q = 10^{-6}$ m^3/sec and $\Delta P = 10^{-2}$ MPa) for an inhomogeneous porous medium (water + 0.05% PAA): 1 and 2) filtration from a lower permeability to a higher one and from a higher permeability to a lower one respectively.

Fig. 4. Dynamics of flow rate ($Q = 10^{-6}$ m^3/sec; t, sec); inhomogeneous porous medium, HL model (water); H = 0.50.

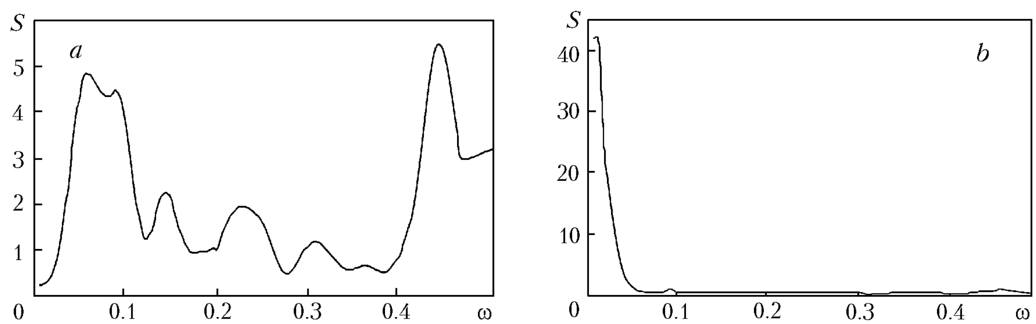


Fig. 5. Spectra of the series of the water flow rate in inhomogeneous [a) filtration from a lower permeability to a higher one and from a higher permeability to a lower one] and homogeneous (b) porous media.

oscillation frequency (Fig. 5b). Such a form of the dependence is characteristic of a correlative sequence of comparatively "smooth" initial data.

A possible mechanism of the phenomena observed is, apparently, as follows [6]. In a zonally inhomogeneous porous medium, the pressure gradient is lower than that in a low-permeability medium by virtue of the constancy of the filtration rate in a high-permeability zone; therefore, the resistance of the system in LH filtration turns out to be lower than that in HL filtration. On this basis, the results of the spectral analysis can be interpreted in the following manner. It is well known that low-frequency oscillations propagate to a larger depth than high-frequency oscillations. It would appear natural that the low-frequency spectral component reflects filtration in the zone that is at the largest distance from the column outlet, whereas the high-frequency component reflects filtration in the zone immediately adjacent to it. In the case of HL filtration, the zone that is at the largest distance from the column outlet is a high-permeability zone, whereas the adjacent zone is a low-permeability zone, but in the case of LH filtration, conversely. Addition of PAA to water imparts elastic properties to the liquid, which contributes to a decrease in the difference in filtration indices [7, 8] in HL and LH motions.

The results of determination of the Hurst index for the time series of the flow rate of the liquid enable us to infer that the influence of the prehistory of motion on filtration indices is also appreciable in the case of linear filtration of water. Indeed, in HL filtration, the pressure gradient increases, whereas in LH motion it decreases. Therefore, as a certain point of the element of the porous medium is approached, its prehistory will be different depending on the direction in which the liquid moves.

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NOTATION

H, Hurst index; K_{pd}, productivity coefficient, $m^3/(sec \cdot MPa)$; K_{pck}, pickup coefficient, $m^3/(sec \cdot MPa)$; k, permeability, mD; ΔP, pressure difference, MPa; Q, flow rate of the liquid, m^3/sec; Q_{pr}, flow rate of the liquid produced, m^3/sec; Q_i, flow rate of the pumped-in liquid, m^3/sec; S, spectral density; t, time, sec; ω, oscillation frequency, Hz. Subscripts: pr, produced; pp, pumped-in; dp, productivity; pck, pickup.

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