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INTERPRETATION OF THE TRACER INVESTIGATION RESULTS CONSIDERING CONVECTIVE MASS TRANSFER

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The paper discusses the results of interpreting well tracer studies. It is shown that from the law of mass conservation it follows that when filtering a volume of an indicator, part of the injected tracer flows into the matrix. With the flow of fluid containing the indicator from the low-filtration resistance channel (LFR) into the surrounding matrix, the linear dimensions of the flow area depend on the permeability and porosity properties of the high-permeability channel and the matrix. While another part of the tracer moves toward the production well, its mass is lost due to diffusion processes. From the solution of the diffusion equation, it follows that the initial concentration of the tracer decreases in the course of filtration along the LFR channel. To interpret the results of the tracer studies, different cases of the LFR channels' location in the volume of the productive formation are considered. The varied parameter ω allows characterizing the presence of several peaks in the concentration of the indicator and calculation the filtration parameters of the LFR channels. Depending on the known technological indices, several methods for determining pore volumes in the LFR channels have been proposed. To reduce the water cut in producing wells and to apply the technology of changing or aligning the injectivity profiles, calculations of the pore channels' radii in the mass of highly permeable seams are presented. It is shown that the volume of the chemical reagent pumped into the injection well to isolate the LFR channel is affected by the linear dimensions of the drainage area for the aqueous solution of indicator. Examples of the calculation for the permeability and porosity parameters of the LFR, the volume of pore channels necessary to isolate water inflow, and the radii of pore filtration channels, which influence the selection of the size of chemical reagent molecules, are given.

***Key words**: tracers; low-filtration resistance channels; pore channels volume*

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Introduction. Hydrocarbon deposits are local fluid dynamic systems, which can be subjected to precise measurements, systematic observations and control of individual processes. As it is known, they are dominated by convective mass transfer, which contributes to the formation of specific anomalies. Work [15] studies localized convective flows by indicating the reservoirs of the Yu_{10-11} reservoir of the Tallinnskoe field. It is established that the marked fluid, moving from the injection to the production well, moves at a speed of 5840 m/day.

Numerous studies [4, 7-10, 13, 15] showed that a number of fields in Western Siberia have fractured zones and high conducting spots. For example in [15], the interpretation of the indicators' injection results at Trehozernoe field indicates the presence of a zone height of fluid-conducting cracks in the production object. Well injection capacity reaches 1980 m^3/day. This is a confirmation of the R.I.Medvedskii hypothesis about the formation of a «streamlet» filtration in the course of long-term operation carried out through low filtration resistance channels [9]. Considerable reservoir heterogeneity causes selective advancement of injected water. Already at the stage of prospecting and exploration in the Jurassic reservoir of the Yuzhnoe field (Nizhnevartovsk dome), it was revealed that the cracks connect the oil-saturated areas into a single hydrodynamic system and, with a slight depression, the drainage of the reservoir occurs mainly laterally.

Statement of the problem. The formation of low filtration resistance channels as a result of the long-term development of the field object can be determined by analyzing the initial and current period of wells operation. The significant difference between the design calculated values of flow rates and costs from the actual technological indicators after the commissioning of the RPM system indicates a poor exploration state of the reservoir. Consequently, LFR channels of tectonic origin existed before the start of development, and artificial channels with high hydro- and piezoconductivity formed in the process of filtration flows transformation.

Methodology. As a result of the tracer and hydrodynamic studies of S.I.Grachev and A.S.Trofimov [4, 7, 13] at many fields of Western Siberia filtration channels with high hydro- and piezoconductivity in the zones between the injection (IW) and production wells (PW) were discovered. During this period, the well-known technique of SevKavNIPIneft did not allow to identify the

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nature of the hydrodynamic relationship between IW and PW on the basis of indicator studies, the actual dynamics of injectivity, flow rates and wellhead pressures. In work [3], devoted to the adaptation of hydrodynamic models to the conditions of an artificial elastic water-drive mode, special attention was paid to the conditions and mechanism of the LFR channels formation. A mathematical model, which takes into account the factors of dynamic development of cracks is proposed. Assumptions have been made that, depending on the current pressure values, vertical cracks from the center of the cell perpendicular to its side may form on the sides of the cell. However, it is necessary to further improve the quality of reflecting the actual conditions of the development and operation of oil fields in numerical hydrodynamic models. In addition to artificial, cracks of tectonic origin are involved in the formation of the secondary permeability and porosity system. The effect of stress-strain state on permeability and porosity properties of the reservoir is considered in [6, 14].

As it is known, the purpose of tracer studies is to determine the existence of hydrodynamic connections between injection and production wells. Depending on the characteristics of the geological structure of the reservoir in the formation, the LFR channels exist a priori or are formed during exploitation. The presence of the LFR channels indicates a reservoir with a complex, uneven permeability. Moreover, there may be both zonal heterogeneity and the presence of different permeability seams in the formation. In this case, the LFR channels are highly permeable seams (HS). The permeability of the HS or LFR channels is much greater than the permeability of low-permeable seams (LS) or the matrix, which constitutes a large part of the productive reservoir. The volume of the capacitive space, the radii of the pore channels, the permeability of the HS or the LFR channel are determined by the results of the indicator studies interpretation. The concentration values of the tracer, the mass of the indicator in the samples of the selected fluid marks only the existence of a seam with high permeability, indicates the features of the geological structure of the reservoir, but does not affect the permeability and porosity properties (PPP) of the HS. The ratios of concentration peak values, tracer mass show the different values for the parameters of the LFR PPP channels and allows making an assumption about the geometrical location in the studied section of the reservoir, as well as for some data to calculate the length and volume of HS.

Discussion and research results. From the law of mass conservation at a constant water density for stationary filtration

$$M_0 = M + M_{\mathrm{los}}, \tag{1}$$

where M_0 – mass of injected tracer; M –mass of the indicator recorded on the production wells during the research; M_{los} – mass of lost tracer.

The mass of the injected indicator at the initial time is determined by the following formula:

$$M_0 = V_0 c_0 = Q_0 t_0 c_0, \tag{2}$$

where V_0 – the volume of water containing the tracer of initial concentration c_0, injected at time t_0; Q_0 – flow rate (injectivity) of the marked water volume at the injection well.

Upon contact of the injected volume of water, marked with an indicator and pumped by clean water, molecular and convective diffusion occurs, as the flow of marked water from the HS into the surrounding area of the formation with lower permeability. Therefore, by the lost mass M_{los} the sum is meant

$$M_{\mathrm{los}} = M_D + M_A, \tag{3}$$

where M_D – mass losses due to diffusion during filtration by LFR channels; M_A – mass of the indicator, flowing into the area A with low filtration parameters (matrix), surrounding channel. The mass M_D is determined from the mass transfer equation obtained from the diffusion equation of the indicator in a porous medium and Fick's law [5]:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial c}{\partial x}\right) - v\frac{\partial c}{\partial x}, \tag{4}$$

where D – diffusion coefficient; v – filtration speed; c – current concentration.

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For the marginal conditions specified for the injection and production wells, the concentration distribution in the LFR channel is

$$c(t,\xi)=c_0-1{,}5(c_0-c_1)\frac{\xi}{\lambda(t)}+0{,}5(c_0-c_1)\frac{\xi^3}{\lambda^3(t)};\ \lambda(t)=2\sqrt{2Dt},\ M_D=m_0\sum_{i=1}^{n}S_i\int_0^{L_i}c(x)dx, \quad (5)$$

where c_0 – initial concentration at the injection well; c_1 – concentration at the peak of the production well; $2\lambda(t)$ – the size of the mixing zone (diffusion) at indicator movement; ξ – moving mixing coordinate, $\xi = x - vt$; S_i – filtration area of HS; L_i – distance between the i production and injection wells; m_0 – open porosity coefficient; n – number of production wells. With a known distance between the wells $x = L_i$, time $t = t_L$ and filtration speed v concentration distribution in the channel LFR can be determined.

During the operation of wells in a complex-built reservoir, flows arise between the interlayers (seams) [12], the pattern of fluid movement in the areas of production wells [1] changes, and the filtration flows are transformed [16]. Part of the fluid injected into the LFR channel when water moves from the injection to the production wells flows into area A. In the case of several highly permeable channels, a certain amount of tracer from each channel will flow into area A_i. The total mass of the indicator M_A is determined by the formula

$$M_A=m_0\sum_{i=1}^{n}S_i^*\int_0^{L_i^*}c_i(x)dx, \quad (6)$$

where S_i^* – filtration area of the tracer flow from the HS into the matrix area A_i; $c_i(x)$ – indicator concentration in A_i; L^*_i – distance from injection well in direction of i production well, $L^*_i < L_i$, is determined by the formulas given in [16]. Considering that only water moves in the LFR channel $L_i^*=0{,}5L_i$.

The concentration of the indicator flowing from the HS in equation (6) for each region A_i will be different, therefore instead of equation (4) a system of equations is obtained:

$$\frac{\partial c_i}{\partial t}=\frac{\partial}{\partial y_i}\left(D\frac{\partial c_i}{\partial y_i}\right)-v_i\frac{\partial c_i}{\partial y_i}, \quad (7)$$

where y_i – coordinate in area A_i, perpendicular to the coordinate x_i; v_i – filtration speed; c_i – current concentration in area A_i. To solve equations (7), as well as to solve equation (4), it is necessary to set boundary conditions, and the conditions will be different.

Thus, the total mass of the lost tracer (3) will be equal to the sum of the masses of the expressions (5) and (6).

Mass of tracer M according to (1)

$$M=\sum_{i=1}^{n}M_i, \quad (8)$$

where M_i – total mass of the indicator, determined on the i production well; n – the number of production reacting wells.

If at the i production well the presence (arrival) of the tracer is fixed k times, then the expression (8) takes the form

$$M=\sum_{i=1}^{n}\sum_{j=1}^{k}M_{ij}. \quad (9)$$

Rock volume of the HS channel V_i and the capacitive space V_{ipor} between the injection and production well are determined from the ratios

$$V_{ij\mathrm{por}}=V_i s m_0=s m_0 S_i L_i=\frac{\beta Q_{bi}t_{ij}}{k};\quad V_i=\frac{V_{i\mathrm{por}}}{s m_0}, \quad (10)$$

where $V_{ij\mathrm{por}}$ – the volume of the HS pore space of LFR channel, saturated with water, between the injection and production well; m_0 – HS open porosity coefficient; s – water saturation coefficient; S_i – filtration area; Q_{bi} – production water flow rate through HS; t_{ij} – fixation time of local j tracer

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extremum at the i production well; L_i – distance between the i production and injection wells; β – correction coefficient, $0 < \beta \le 1$, characterizing the proportion of water flowing through LFR channels; k – the number of LFR channels on the i production well.

If the water flow rate at the production well is not known, and the water flow rate of the injection well is determined, then instead of relations (10)

$$V_{i\text{por}} = \alpha \frac{Q_0}{n} t_i, \quad v_i = \frac{Q_0}{nS_i}\alpha; \; sm_0 S_i = \alpha\frac{Q_0 t_i}{nL_i} = \alpha\frac{Q_0}{nv_i^*}, V_i = S_i L_i, \tag{11}$$

where t_i – the time it takes for the tracer to reach the bottom of the production well; α – correction coefficient, $0 < \alpha \le 1$, characterizing the proportion of water in the LFR channels.

For stationary filtration, if Darcy law is observed, the true speed of the injected water v_i^* and filtration speed v_i are determined from the following relationships:

$$v_i^* = \frac{L_i}{t_i}; \quad v_i = \frac{k_{bi}}{\mu_b}\frac{\Delta p_i}{L_i}, v_i = v_i^* m_0, \tag{12}$$

where Δp_i – repression, bottomhole pressure difference between injection and production wells; μ_b – dynamic viscosity of water; k_{bi} – HS phase permeability to water,

$$k_{bi} = \frac{m_0 v_i^* \mu_b L_i}{\Delta p_i}. \tag{13}$$

Thus, to determine the volume and permeability of the LFR channel, it is necessary to know the open porosity coefficient m_0, which is not equal to the open porosity coefficient of the matrix.

If the HS is simulated by a fictitious formation consisting of equal diameter spheres, then the open porosity coefficient of the LFR channels can be determined by the Slichter formula [11]:

$$m_0 = 1 - \frac{\pi}{6(1-\cos\theta)\sqrt{1+2\cos\theta}},$$

where θ – package angle, $60° \le \theta \le 90°$.

Porosity varies in range of $0{,}26 \le m_0 \le 0{,}48$.

The relationship between porosity, permeability and the radius of the pore channels r in loosely coupled soils according to the formula of Kotyakhov

$$r = \sqrt{\frac{8k\varphi}{m_0}}, \quad \varphi = \frac{0{,}5035}{m_0^{1,1}}. \tag{14}$$

In this case, additional laboratory rock samples tests are needed to clarify the value of the parameter φ.

For non-stationary filtration, a formula is known, which relates the distances between the wells and the permeability and porosity parameters,

$$L_i = \sqrt{C\chi_i t_i} = \sqrt{C\frac{k_i}{\mu_b \beta_i^*}} = \sqrt{C\frac{k_i}{\mu_b(m_0\beta_b + \beta_c)}} = \sqrt{C\frac{k_i}{\mu_b m_0(\beta_b + \beta_{\text{por}})}}, \chi_i = \frac{L_i^2}{Ct_i}, \tag{15}$$

where χ – piezoconductivity coefficient; β_i^* – reservoir elasticity coefficient; β_b, β_c, β_{por} – compressibility coefficients of water, bulk formation elasticity and pore space; C – numerical coefficient, $C = \pi$, 4, 6, 12, the value of which depends on the method used to derive the Chekalyuk formula (15), the successive change of stationary states, Pirverdyan, Barenblat, respectively. Knowing L_i and t_i, the coefficient of piezoconductivity of the LFR can be determined.

From formulas (13)-(15), the dependence between the filtration parameter k_i, the capacitance parameter m_0 and the filtration area, which has a significant effect on the interpretation of the indicator studies results, is obvious. If m_0 is known, then (11) determines the filtration area S_i.

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Let us consider a few examples.

Example 1. According to the data given in [4], in the operational area of the West Asomkinskoye field (formation JS_1) in well 147 indicator by volume $V_0 = 20$ m^3 has been injected with initial concentration $c_0 = 10$ mg/l$=10\cdot10^{-3}$ kg/m^3. Injectivity $Q_0 = 720$ m^3/day, number of response wells $n = 7$. Distance between injection and production wells L_i is known, pressure drop between wells Δp_i and tracer passing time t_i. Water saturation and porosity coefficients $s = 0.8$, $m_0 = 0.4$, parameter $\alpha = 0.8$, $\mu = 0.44$ mPa·s, $C = 4$. The data and the results of the calculations are shown in Table 1.

Table 1

Research data and calculation results of tracer filtration from injection well 147

Well	L_i, m	t_i, h	Δp_i, MPa	v_i^*, m/s (12)	V_{ipor}, m^3 (11)	V_i, m^3 (11)	S_i, m^2 (11)	v_i, m/s (12)	k_{ib}, D (13)	χ_i, m^2/s (15)
185	2000	48	22.2	0.012	131.7	411.4	0.92	0.005	184	5.79
176	2300	48.1	22.7	0.013	164.9	412.3	0.802	0.005	237	7.64
158	425	26.1	20.5	0.005	89.5	223.7	2.354	0.002	17	0.48
157	575	3.2	14.4	0.05	11.0	27.4	0.213	0.02	351	7.18
800	300	3.4	14.4	0.025	11.7	29.1	0.434	0.01	90	1.84
172	975	15.2	19.5	0.018	52.1	130.3	0.598	0.007	157	4.34
174	1725	15.4	19.5	0.031	52.8	132.0	0.342	0.012	484	13.42

The total volume of the LFR pore channels is 514 m^3. Phase permeability of HS to water is given in Darcy. If the coefficient of porosity is taken less ($m_0 = 0.3$), then the filtration area increases, and filtration rates and permeability decrease. If the HS is taken as a tube with radius R_i, then, using the data of the 9th column, the radii of the HS tubes vary within $0.12 \text{ m} \le R_i \le 0{,}41$ m. Calculated by the Kotyakhov formula (14) radii of the pore channels $r_i = 0.021\text{-}0.116$ mm. Consequently, they are capillary channels with high filtration capacity [11].

If the filtration area is taken in the form of a rectangular section $S_i = a_i h_i$, (h_i – thickness (height) of the LFR seam, a_i – width of the seam), then with one known parameter, for example, by HWI, one can determine second parameter. Let $h_i = a_i$, $h_i = \sqrt{S_i}$, then $h_i = 0{,}46\text{-}0{,}73$ m.

According to the results of the conducted tracer studies, the indicator has repeatedly appeared on the same production well. The dependence of concentration on time has several local extremes. The fixation of several concentration maxima at a single production well may depend on the geological structure of the reservoir and the location of the LFR channels. Let us consider some cases of channel position.

First case. Suppose that there is only one LFR channel between the production and injection wells. Equation (4) of the tracer mass transfer describes a change in the concentration of a parabolic type, whose solution for a linear flow is expressed in terms of the error integral or power series, which have no local extremes. Consequently, when an indicator is being pumped in a volume with subsequent pushing with water in the same LFR channel, the presence of several concentration peaks is impossible. There should be several channels, the number of extreme concentration values is equal to their number. PPP of each channel are different.

It should be noted that if during pumping the injectivity of the tracer (flow rate) Q_0 varies according to the harmonic law or is described by another non-monotonic function, then in this case there may be local concentration extremes in the same HS channel. In the works of S.N.Buzinov, I.D.Umrikhin [2] it was established that a periodic change in Q_0 entails a change in Δp according to the law of sine or cosine at the production well. This indicates the presence of several concentration peaks in one LFR channel.

Second case. Suppose that several LFR channels between the injection and production wells are located in one plane (see Figure, *a*; $i = 1$).

Denote the smallest distance (the length of the LFR channel) between the wells through L_{11}. Let the following conditions be satisfied:

$$L_{11} < L_{12} < L_{13} < L_{14} < L_{15},\ t_{11} < t_{12} < t_{13} < t_{14} < t_{15}. \tag{16}$$

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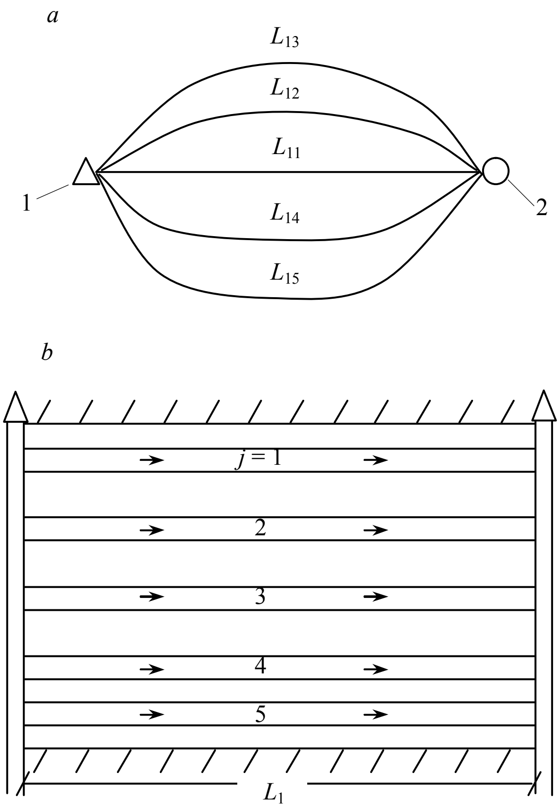

LFR channels located in one horizontal plane (*a*), and highly permeable seams located in one vertical plane (*b*)
1 – injection well; 2 – production well

Value L_{11} is known, other curvilinear L_{1j} – unknown. Times t_{11}, t_{12},t_{13}, t_{14}, t_{15} are determined by the results of the experiment. Tracer concentrations are known c_{1j}, corresponding to times t_{1j}. Introduce a parameter $\omega_j > 1$, characterizing the increase in the tracer path length.

Let

$$L_{1j} = \omega_j L_{11}. \qquad (17)$$

The volume of the *j* pore channel is equal to the volume of pores filled with water during the passage of the tracer to the production well.

From formulas (10), assuming $I = 1$, expressions for determining the filtration and pore volumes of the LFR channels are obtained:

$$V_{1j} = sm_0 V_{i1jpor}; \quad V_{ij\text{por}} = sm_0 S_{1j} L_{1j} = Q_{1j} t_{1j} = \frac{\beta Q_{b1} t_{1j}}{k}, \qquad (18)$$

where Q_{b1} – flow rate of water at the production well; β – water flow rate from the *j* channel. From (17) and (18) the filtration areas of the LFR channels are expressed through the filtration area of the smallest channel:

$$S_{1j} = \frac{\beta Q_{b1} t_{1j}}{ksm_0 L_{1j}} = \frac{\beta Q_{b1} t_{1j}}{ksm_0 L_{11}\omega_j} = S_{11}\frac{t_{1j}}{t_{11}\omega_j},\ S_{11} = \frac{\beta Q_{b1} t_{11}}{ksm_0 L_{11}}. \qquad (19)$$

Phase permeability of the pore channel *j*, determined from (13), after transformations

$$k_{1j} = \frac{v_{1j}\mu L_{1j}}{\Delta p} = \frac{Q_{1j}\mu L_{1j}}{S_{1j}\Delta p} = \frac{Q_{b1}\beta\mu L_{1j}}{kS_{1j}\Delta p} = A_1\frac{\omega_j^2}{t_{1j}}, \quad A_1 = \frac{Q_{b1}\beta\mu t_{11} L_{11}}{k\Delta p S_{11}}. \qquad (20)$$

Parameter A_1 – is constant value and depends only on the parameters of the 1st linear LFR channel.

According to the measured concentrations of the indicator and the time t_{1j}, the mass of the tracer, fixed for the *i* well,

$$M_i = \sum_{j=1}^{k} M_{ij};\ M_{ij} = \frac{Q_{bi}\beta}{k}\int_0^{\Delta t_j} c_{ij}\,d\tau = \frac{Q_{bi}\beta}{k} S_{cij};\ S_{cij} = \int_0^{\Delta t_j} c_{ij}\,d\tau, \qquad (21)$$

where S_{cij} – area, defined according to diagram c_{ij}-t_{ij}, built on the results of tracer measurements on the *i* well; Δt_j – time interval fixing the *j* arrival of the indicator.

Example 2. Initial data: $\Delta p = 11$ MPa; $m_0 = 0.4$; $\beta = 0.8$; $s = 0.8$; $k = 5$; $Q_{b1} = 64.8$ m^3/day; $L_{11} = 505$ m; $C = 4$.

From (20) $A_1 = 3.26\cdot10^{-6}$ m/s. The results of the calculations are given in Table 2.

Table 2

Research results and calculated parameters of a straight channel, L_{11} = 505 m

Peaks *j*	*c*, g/l	t_{1j}, h	Δt_j, h	$V_{1j\text{por}}$, m^3 (18)	S_{11}, m^2 (18)	V_{1j}, m^3 (18)	v^*_{11} m/h	R_{11}, m
1	3	120	72	51.2	0.32	161.9	4.21	0.30
2	10	168	48	72.5		226.7		
3	6	312	72	134.7		421.0		
4	8	456	48	196.9		615.3		
5	4.5	672	72	290.1		906.8		

Note. R_{11} – radius of the straight LFR channel tube with length of 505 m, the total volume of the pore channels $V_{1j\text{por}}$ = 746 m^3.

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As can be seen from formulas (19), (20), to determine the parameters of curvilinear channels, one should set the dimensionless parameter ω_j, the choice of which is quite arbitrary and depends on the research data. Consider several possible ways to set a parameter ω_j:

1. Let $\omega_j = t_{1j} / t_{11}$. With this setting of the parameter ω, the true velocities in the rectilinear and curvilinear channels, and the filtration areas of the channels are equal. It is true that,

Table 3

Calculation results for $\omega_j = t_{1j} / t_{11}$

ω_j	L_{1j} (17), m	k_{1j}, D	r_{1j}, mm	M_{1j}, g	χ_i, m²/s
1	505	37.78	0.032	46.6	0.15
1.44	707	52.89	0.038	103.6	0.21
2.6	1313	98.03	0.052	93.3	0.38
3.8	1919	143.57	0.063	82.9	0.56
5.4	2828	211.50	0.076	70.0	0.83

Note. r_{1j} – radii of the LFR pore channels, calculated by the formula (14). In this case, the filtration areas are equal, therefore the thickness of the seams $h_{1j} = \sqrt{S_{11}} = 0{,}57$ m .

$$v_j^* = \frac{L_{1j}}{t_{1j}} = \frac{L_{11}\omega_j}{t_{1j}} = \frac{L_{11}t_{1j}}{t_{1j}t_{11}} = v_1^* = 4{,}21 \text{ m/h},\ S_{1j} = S_{11} = 0{,}32 \text{ m}^2 .$$

The results of the calculations are given in Table 3.

2. Let $\omega_j = c_{1j} / c_{11}$. Such choice of the parameter ω_j is possible if $c_{1j} > c_{11}$.

3. Let $\omega_j = c_{1\Delta j}t_{1j}/c_{11\Delta}t_{11}$. Such choice of the parameter ω_j is possible if $\omega_j > 1$.

The results of the calculations are given in Table 4.

Table 4

Calculation results for $\omega_j = c_{1j} / c_{11}$ and $\omega_j = c_{1j}t_{1j} / c_{11}t_{11}$

ω_j	L_{1j}, m (17)	k_{1j}, D	S_{1j} (19), m²	v_{1j}^*, m/h	r_{1j}, mm	R_{1j}, m	h_{1j}, m	χ_i, m²/s
				$\omega_j = c_{1j} / c_{11}$ *				
1	505	37.78	0.32	4.21	0.032	0.30	0.57	0.15
3.33	1683	299.8	0.12	10.02	0.091	0.20	0.37	1.17
2	1010	58.1	0.43	3.24	0.040	0.37	0.64	0.23
2.67	1346	70.7	0.46	2.95	0.044	0.38	0.68	0.28
1.5	758	15.2	1.19	1.13	0.020	0.61	1.09	0.06
				$\omega_j = c_{1j}t_{1j} / c_{11}t_{11}$ **				
1.00	505	37.78	0.32	4.21	0.032	0.30	0.57	0.15
2.22	1122	133.27	0.20	6.68	0.061	0.25	0.45	0.52
2.00	1010	58.13	0.42	3.24	0.040	0.36	0.65	0.23
1.78	898	31.42	0.69	1.97	0.029	0.47	0.83	0.12
1.50	758	15.18	1.20	1.13	0.020	0.62	1.09	0.06

* Sum of the LFR channels thickness 3,35 m. ** Sum of the LFR channels thickness 3,58 m.

Third case. LFR channels or HS are located in one vertical plane (see Fig., *b*; *I* = 1). Length of all LFR channels L_{11} = 505 m, parameter ω_j = 1 (Table 5).

Table 5

Calculation results for LFR channels or HS, located in one vertical plane

Peaks *j*	*c*, mg/l	t_{1j}, h	k_{1j}, D	S_{1j} (19), m²	v_{1j}*, m/h	r_{1j}, mm	R_{1j}, m	h_{1j}, m	χ_i, m²/s
1	3	120	37.78	0.32	4.21	0.037	0.30	0.61	0.148
2	10	168	26.98	0.51	3.01	0.031	0.40	0.72	0.105
3	6	312	14.53	0.95	1.62	0.023	0.55	0.98	0.057
4	8	456	9.94	1.39	1.11	0.019	0.67	1.18	0.039
5	4.5	672	6.75	2.05	0.75	0.016	0.81	1.43	0.026

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The total LFR channels thickness is 4.91 m. If the oil saturated thickness is 10-20 m, then the LFR channels account for 25-50 % of the effective thickness. Therefore, only vertical or horizontal (lateral) placement of the LFR channels is doubtful. A combined placement of channels is possible, in which several LFR channels are located in the horizontal plane, while others are in the vertical one. The forecast of their position in space depends on the imagination of the interpreter. From Tabl. 2-5, it can be seen that the phase permeability value is more or less accurately determined for the first seam (j = 1) – 37.78 mD. For the remaining channels, the LFR depends on the fixation time of the tracer. In all the considered cases, regardless of the choice of the parameter ω and the location of the LFR channels in space, the volumes of the pore channels remain constant (the 5th column of Table 2). From formula (18) it follows that the volume of the pore channel in j seam depends on the share of water flow rate in the reference production well and does not depend on the concentration.

When choosing a chemical reagent for carrying out the technology of injectivity profile alignment (IPA), the values of permeability and porosity coefficients are needed only to determine the radius of pore channels in HS, which determine the size of molecules of the injected chemical reagent. The total pore volume of the LFR, equal to 746 m^3, is necessary to determine the minimum volume of the injected insulating chemical V_{ijx}. It was established [3] that with simultaneous operation of the production and injection wells, there is a boundary between the drainage areas, at which the current pressure in the HS is equal to the initial reservoir pressure. Moreover, the position of the boundary depends on the coefficients of fluid piezoconductivity. In this case, the flow of water moves along the LFR channel, therefore, in 3-10 hours the linear dimensions of the drainage zones will be equal to half the lengths of the LFR channels. In the drainage area of the injection well, a part of the injected fluid flows into the matrix. In the drainage area of the production well, on the contrary, there is a flow of fluid from the matrix. Thus, the volume of the required insulating chemical reagent is equal to half the volume of the LFR channels' pore space – 373 m^3.

On the graphs of water flow or water content there should be a sharp increase in the corresponding technological indicators, the time of which corresponds to the beginning of the production well watering through the LFR channels. The proportion of water β from the j channel can be determined by the formula

$$\beta = \frac{Q_{bi} - Q_{bi0}}{Q_{bi}}, \tag{21}$$

where Q_{bi0} – water flow rate before the flow of water through LFR. In example 2, the flow rate of water Q_{bi} = 64.8 m^3/day, β = 0.8, water flow rate before the flow of water through LFR channels Q_{bi0} = 13 m^3/day.

If the flow rates of water are unknown, but the injection capacity of the injection well is known Q_0, then

$$\alpha = \frac{Q_0 - Q_{00}}{Q_0}, \tag{22}$$

where Q_{00} – flow rate (injectivity) of the injection well before formation of the LFR channel; Q_0 – flow rate (injectivity) of the injection well after formation of the LFR channel.

In the classical monograph by S.N Buzinov and I.D.Umrikhin [2] the method of determining the parameters of the reservoir based on the interpretation of hydraulic interception in working wells is considered. A graphical method for determining reservoir parameters is proposed, which can be used to determine the PPP of LFR. The solution of the problem, taking into account the interference of wells, is given in images by Laplace. For tracer studies, an injection well is disturbing, and reacting ones are production wells.

If the tensile strength is greater than the stresses arising during operation, then LFR channels existed a priori and were not distinguished by field geophysical or hydrodynamic studies, therefore, determination of the parameters α, β and Q_{00}, Q_0 should be based on the calculated values of the PPP adopted for the matrix.

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Conclusion

1. For the first time, a theoretical premise was proposed that during filtration, a loss of tracer mass occurs due to diffusion and fluid flow into the matrix. Formulas are obtained, allowing determination of the lost indicator mass.

2. The formulas for calculating PPP of the LFR channels with known water flow rates at production wells and water flow rate at the injection well are given.

3. For a reacting well, in which several outputs of the indicator are fixed, different cases of the geometrical position of the LFR channels in space are considered. Examples of calculations are given, in which it has been found that the phase permeability and piezoconductivity coefficients change depending on given parameter ω_j, but the total volume of the pore space of the LFR channels is constant. The choice of the parameter ω_j is influenced by the indicator passage time, the intervals of fixation (registration) times of the tracer on the reacting well, the mass of the measured indicator.

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