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ВЕСТНИК

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NAS RK is pleased to announce that Bulletin of NAS RK scientific journal has been accepted for indexing in the Emerging Sources Citation Index, a new edition of Web of Science. Content in this index is under consideration by Clarivate Analytics to be accepted in the Science Citation Index Expanded, the Social Sciences Citation Index, and the Arts & Humanities Citation Index. The quality and depth of content Web of Science offers to researchers, authors, publishers, and institutions sets it apart from other research databases. The inclusion of Bulletin of NAS RK in the Emerging Sources Citation Index demonstrates our dedication to providing the most relevant and influential multidiscipline content to our community.

Қазақстан Республикасы Ұлттық ғылым академиясы "ҚР ҰҒА Хабаршысы" ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Web of Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабаршысының Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді мультидисциплинарлы контентке адалдығымызды білдіреді.

НАН РК сообщает, что научный журнал «Вестник НАН РК» был принят для индексирования в Emerging Sources Citation Index, обновленной версии Web of Science. Содержание в этом индексировании находится в стадии рассмотрения компанией Clarivate Analytics для дальнейшего принятия журнала в the Science Citation Index Expanded, the Social Sciences Citation Index и the Arts & Humanities Citation Index. Web of Science предлагает качество и глубину контента для исследователей, авторов, издателей и учреждений. Включение Вестника НАН РК в Emerging Sources Citation Index демонстрирует нашу приверженность к наиболее актуальному и влиятельному мультидисциплинарному контенту для нашего сообщества.

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FLUID FILTRATION TO MULTI-BORE HORIZONTAL WELLS IN A DEFORMABLE POROUS MEDIUM

Abstract. The scientific work considers finite element modeling of fluid filtration in a deformable porous medium. A transversely isotropic medium has been taken as a deformable medium. Fluid filtration process to a horizontal well in the transversely isotropic medium has been analyzed. Numerical solution of the problem is carried out by high-performance finite element modeling.

Key words: fluid, filtration, horizontal well, deformation, transversely isotropic medium, finite element modeling.

Introduction. Nowadays refining computer technologies are giving a lot of opportunities to solve difficult problems on personal computers. Currently, numerical computer simulation of filtration process is much more important as other types of simulations. Therefore, using numerical methods in order to solve filtration problem going through a deformable porous medium we must carry out computer modeling in association with it.

In the work there is designed computer modeling of fluid filtration process which goes to the multi-bore well in the transversely isotropic medium. Numerical solution of the problem has been done by the finite element method and a software package has been created. In the software package the program automatically divides the computational area into finite elementsaccording to its given parameters, in addition, the parameters of the well trunks and layers have been taken into account. Additionally, in the software package the element properties will be added to the computational scheme extracted from finite element in [1]. Algebraic equation system will be done and the algorithm of the problem depends on thenodenumbers of the computational areas. Whilethe node points of the computational area are increased or decreased respectively the area division is increased or decreased automatically. Therefore, nowadays designing computer modeling of fluid filtration to multi-bore horizontal wells in a deformable porous mediumby the gained results is an actual problem.

Problem statement. There two wells locatedin elastically deformable transversely isotropic porous media in the depth of H from the ground level.

General type of drift and crosscut type multi-bore horizontal wells is considered and we can call it diagonal type. Diagonal well – its longitudinal axis makes a corner with any directions of the drift type direction. Flat pleats in the elastic horizontal pleat porous medium are inclined to horizontal plane with φ corner. *O* pointis taken as the coordinate origin, *Oz* is directed vertically upward. *Ox* and *Oy* are horizontal with each other, and the well makes ψ corner withhorizontal *Ox* axis laid along this pleat (figure 1).

As tackling such kind of problem statement the influence of porous media on stress-strain state around the well can be estimated.

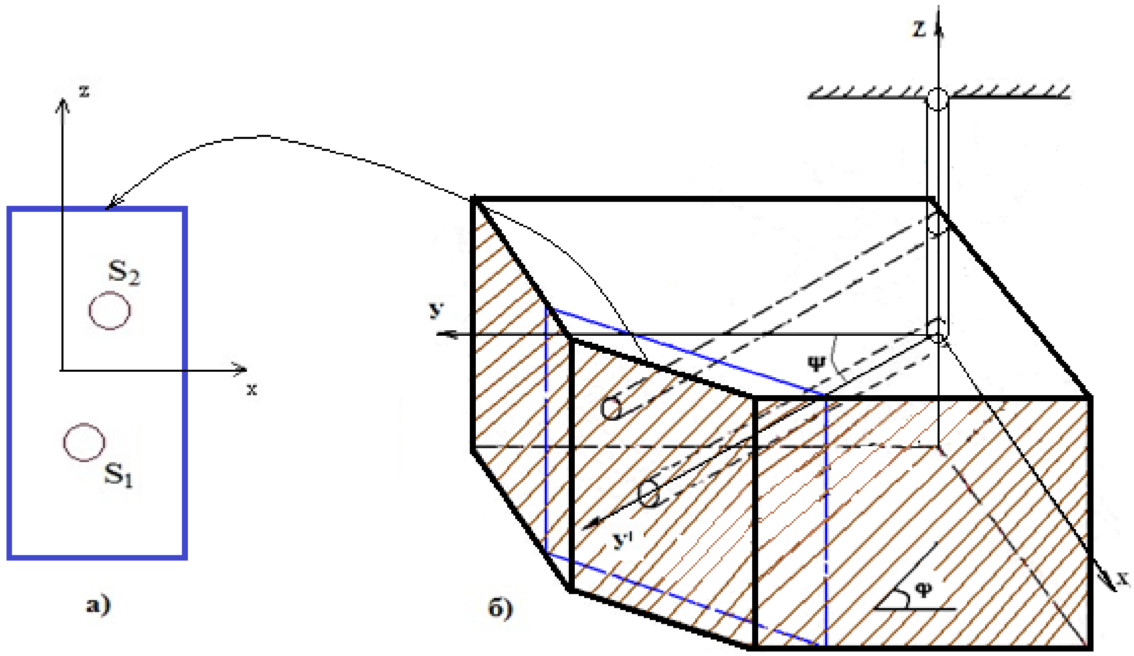


Figure 1 – Horizontal wells with differently directed multi-bores

It is a drift type horizontal well when $\psi = 0$. When general rotation angle of the horizontal well near its truck is $0 \le \psi \le 90°$, it will be given by Hooke's Law [2-4]:

$$\sigma_{ij} = d_{iklj}\varepsilon_{ij} + \delta_{ij} p \tag{1}$$

thereare σ_{ij} and ε_{ij} – components of stress and strain, δ_{ij} – Kronecker symbols, p – fluid pressure. Deformation coefficients of differently directed horizontal wells are shown in works [5, 6].

Filtration coefficients according to the change of angle ψ in the transversely isotropic medium [7].

$$\begin{aligned} k_x &= \left(k_{x'}\cos^2\psi + k_{y'}\sin^2\psi\right)\cos^2\varphi + k_{z'}\sin^2\varphi, \\ k_{xz} &= k_{x'}\cos^2\psi + k_{y'}\sin^2\psi, \\ k_z &= \left(k_{z'}\cos^2\psi + k_{y'}\sin^2\psi\right)\cos^2\varphi + k_{x'}\sin^2\varphi. \end{aligned} \tag{2}$$

We consider initial and boundary conditions as below:

$$p(x, y, z, 0) = p_0 \tag{3}$$

$$p\big|_{AB} = p_1,\ p\big|_{DC} = p_2. \quad p\big|_{S_1,S_2} = p^*. \tag{4}$$

$$\left.\frac{\partial p}{\partial n}\right|_{AD,BC} = 0. \tag{5}$$

$$u_x\big|_{AD,BC} = 0,\ u_z\big|_{DC} = 0. \tag{6}$$

The solutions of problems of stresses and displacements around crosscut and drift wells in the case of homogeneous porous media are presented in [8-11] but porous media in all the works are considered as isotropic media.

The use of the finite element modeling. Numerical simulation, additionally, the method of division into triangles for modeling of fluid filtration in inhomogeneous porous media are shown in the work of B. Amaziane, M.E. Ossmani, Ch. Serres [12] and so on. Finite element requiresa general flat deformation calculated algorithm withfour-point rectangular isoperimetric element in order to gain the numerical solution of the problem. $x_i, z_i, (i = 1,2,3,4)$ coordinates of any "*e*" element points and components u_i, w_i, v_i of displacements have been characterized through function h_i.

Forces in each nodal point under the influence of weight are calculated by elements weight concentrated on it. For the problem statementthe basic matrix 3N- order equations system of the finite element modelingis written by the displacement components of N nodal points[13]:

$$\{F\} = [K]\{U\} \tag{7}$$

here $[K] = \sum_{i=1}^{n} [k^e]_i$ – stiffness matrix of the system; $\{U\} = (u_1,...,u_N, w_1,...,w_N, v_1,...,v_N)^T$ – displacement vector; $\{F\} = (F_{x_1},...,F_{x_N}, F_{z_1},...,F_{z_N}, F_{y_1},...,F_{y_N})$– force vector.

Numerical solution of the problem. The influence of the stress-strain state of the transversely isotropic porous medium and filtration coefficients on the flow rate of the horizontal well have been analyzed. Experiments will be developed with the following initial data for the problem (1)-(7) in accordance with the real conditions of conducting the horizontal well:

h_1 = 8m, h_2 = 14m, h = 22m, h_3 = 150m, μ = 2.4 cps, p_0 = 10 atom, $p_1 = p_0 + 1.2$, $p_2 = p_1 + \gamma h$, γ= 0.908 t/m^2.

k = 0.106d, E = 1 t/m^2, ν = 0.25, G_2 = 0.4 t/m^2.

The area having lots of wellbores is divided into 2464 triangle elements and 1362 nodes. Stationary filtration problem is given to solve 1362 and 4046 consistent algebraic equation systems according to the pressure and displacement. It is solved, taking into consideration its boundary conditions, by Zeidel-Gauss iteration method which has a high coefficient of $\beta\,(1 \le \beta \le 2)$ relaxation.

The developed algorithm and software package have been tested in a special task in determining the flow rate of the horizontal well in the isotropic planes. The gained results (table 1) fluctuate just for 1-2% compared to the real solution.We examine anisotropy which depends on the horizontal angle of the presented pleat and deformation impact in the case of $k_z = k_x / 10$, $k_z = 10 k_x$ are shown in tables 2, 3.

The software package divides the area automatically into finite elements with the given results. With the help of it, the computational area is divided into triangle elements in accordance with the wells dimensions.

On the basis of the computational results, when the vertical and horizontal permeability of the anisotropic transversely isotropic deformable and undeformable pleats changes, we can observe that its stress-strain state will significantly influence on the flow rate of the horizontal well, because the flow rate of the horizontal well in 45^{o}inclined angle layer with tiny pleats has the lowest value (figure 2).

Table 1 – (T/day) value of *l* debit of the horizontal well in different length in the isotropic layer

l	Q_{anal}	Q_{nedef}	Q_{def}	$\lvert Q_{anal}-Q_{nedef}\rvert$	$\lvert Q_{anal}-Q_{def}\rvert$	$\lvert Q_{nedef}-Q_{def}\rvert$
1	2.91	2.91	2.25	0	0.66	0.66
2.4	6.98	6.99	5.39	0.01	1.59	1.6
13.7	39.87	39.9	30.76	0.03	9.11	9.14
20	58.2	58.25	44.91	0.05	13.29	13.34
50	145.5	145.62	112.26	0.12	33.24	33.36
100	291	291.25	224.53	0.25	66.47	66.72

Table 2 – Comparative analysis of the horizontal well debit (T/day) in the deformable and undeformable inclined transversely isotropic layers with permeability $\frac{k_z}{k_x} = 0,1$

l		1	2.4	13.7	20	50	100
$\varphi = 0$	Q_{nd}	2.54	6.09	34.76	50.74	126.85	253.70
	Q_d	2.52	6.04	34.46	50.30	125.75	251.50
$\varphi = 30°$	Q_{nd}	1.46	3.50	19.96	29.14	72.85	145.70
	Q_d	1.01	2.41	13.78	20.12	50.30	100.60
$\varphi = 45°$	Q_{nd}	1.60	3.84	21.95	32.04	80.10	160.20
	Q_d	0.85	2.05	11.70	17.08	42.70	85.40
$\varphi = 60°$	Q_{nd}	2.90	6.96	39.70	57.96	144.90	289.80
	Q_d	1.87	4.49	25.63	37.42	93.55	187.10
$\varphi = 90°$	Q_{nd}	6.27	15.05	85.93	125.44	313.60	627.20
	Q_d	5.20	12.47	71.19	103.92	259.80	519.60

Table 3 – Comparative analysis of the horizontal well debit (T/day) in the deformable and undeformable inclined transversely isotropic layers with permeability $\frac{k_z}{k_x} = 10$

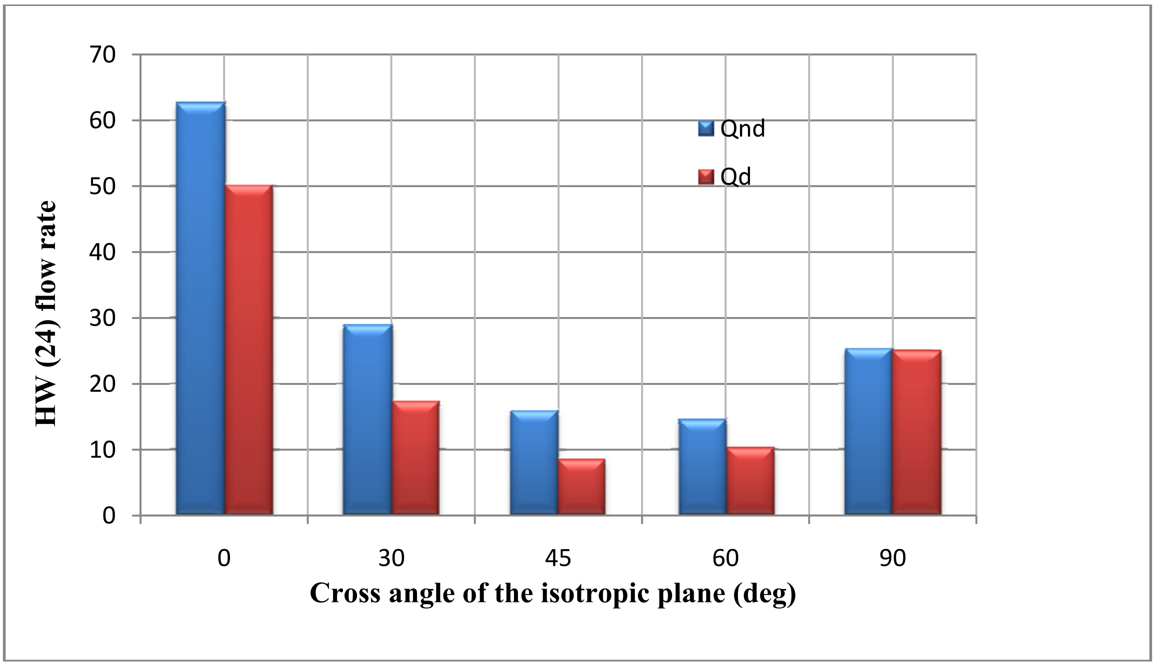
l		1	2.4	13.7	20	50	100
$\varphi = 0$	Q_{nd}	62.72	150.54	859.31	1254.46	3136.15	6272.30
	Q_d	50.26	120.63	688.60	1005.26	2513.15	5026.30
$\varphi = 30°$	Q_{nd}	28.99	69.56	397.09	579.70	1449.25	2898.50
	Q_d	17.35	41.64	237.70	347.00	867.50	1735.00
$\varphi = 45°$	Q_{nd}	16.02	38.45	219.46	320.38	800.95	1601.90
	Q_d	8.54	20.49	116.94	170.72	426.80	853.60
$\varphi = 60°$	Q_{nd}	14.57	34.97	199.62	291.42	728.55	1457.10
	Q_d	10.25	24.60	140.41	204.98	512.45	1024.90
$\varphi = 90°$	Q_{nd}	25.37	60.89	347.56	507.38	1268.45	2536.90
	Q_d	25.04	60.10	343.08	500.84	1252.10	2504.20

Wells debit in the highest vertical permeability on average goes up for 20.2(T/day). The elastic deformation in $k_z = k_x / 10$ makes horizontal well debit reduce on average to 0.665 (T/day) and in $k_z = 10k_x$ on average to 7.045 (T/day).

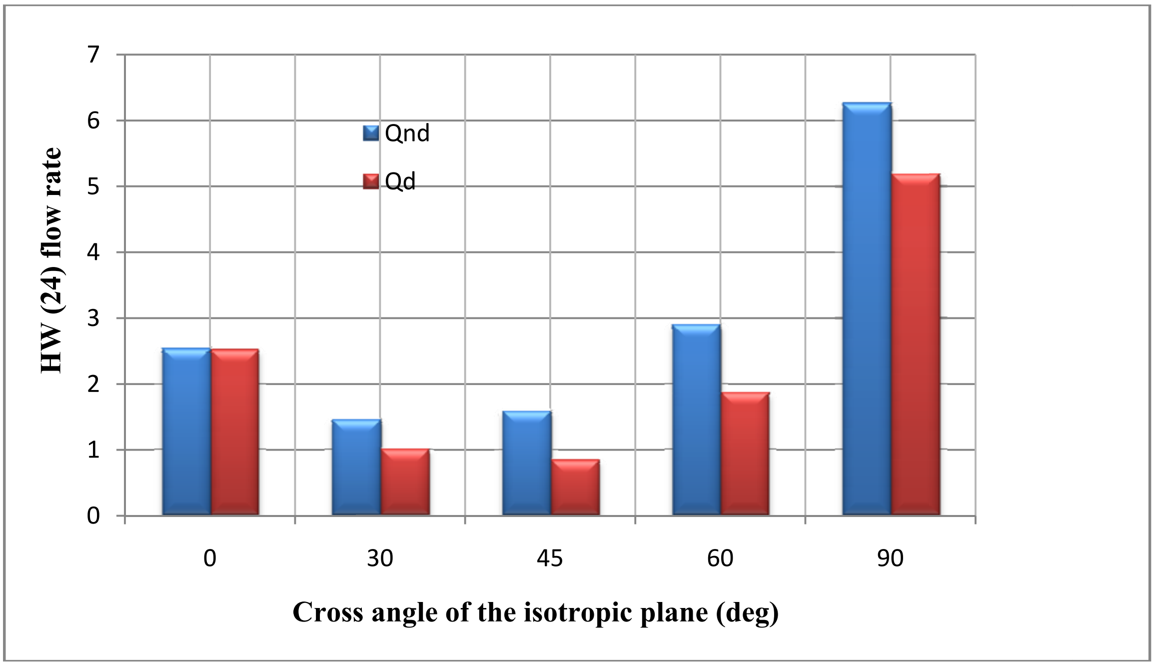
Different versions of computational experiments have been carried out by verifying with the help of the software package. The results demonstrated below will be revealed according to the shown parameters

$$k_x = 0.106\text{д}, \quad k_z = 2k_x,$$
$$E_1 = 1.074\text{т/м}^2, \quad E_2 = 0.523\text{т/м}^2,$$
$$\nu_1 = 0.413, \quad \nu_2 = 0.198, \quad G_2 = 0.12\text{т/м}^2.$$

In figure 3 the impact of stress-strain state on the field of pleats pressure is demonstrated. In the feature the dashed lines*φ=0*show the value of isolation, and the solid lines infer to the other values of the isotropic plane inclined angle.



a



b

Figure 2 – Charts of the horizontal well debits with unit length in the deformable and undeformable anisotropic media: a – $\frac{k_z}{k_x} = 0.1$ and b – $\frac{k_z}{k_x} = 10$

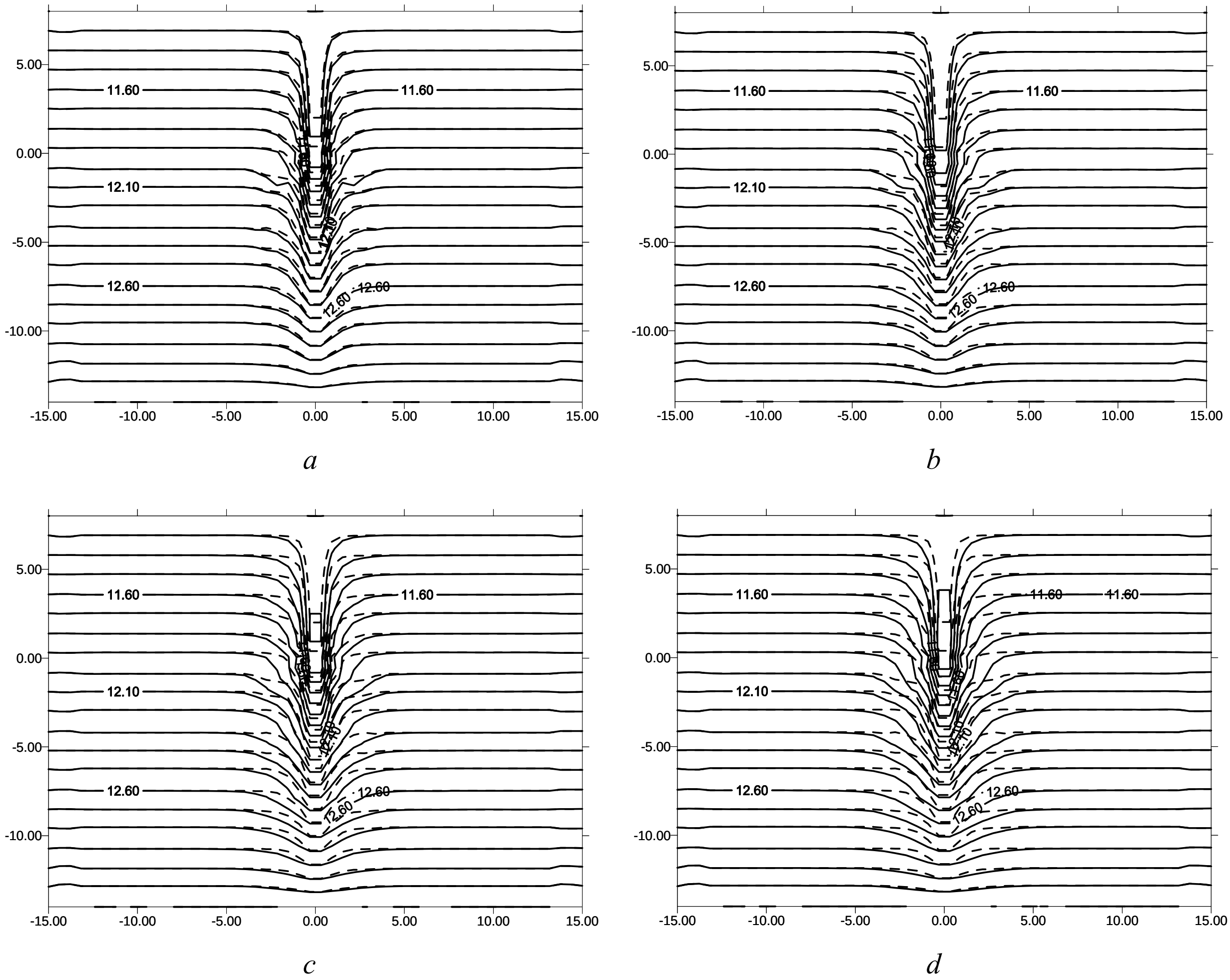


Figure 3 – Changes of the pressure field of the isotropic plane inclined angle: a) φ = 30°; b) φ = 45°; c) φ = 60°; d) 90°

In conclusion, by the gained results the production of fluid is calculated that flows in the horizontal multilayer medium to the drift type multi-bore horizontal well. The stress-strain state of the anisotropic medium and the effect of filtration coefficient on the flow rate of the horizontal well have been considered. The production of the well in the horizontal layer is researched.

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ДЕФОРМАЦИЯЛАНАТЫН КЕУЕК ОРТАДА СҰЙЫҚТЫҚТЫҢ КӨПДІҢДІ ГОРИЗОНТАЛЬ ҰҢҒЫМАҒА ФИЛЬТРАЦИЯЛАНУЫ

Аннотация. Жұмыста деформацияланатын кеуек ортада сұйықтықтың фильтрациялануын шекті элементті модельдеу қарастырылды. Деформацияға ұшырайтын орта ретінде трансверсальды-изотропты орта алынды. Трансверсальды-изотропты ортада горизонталь ұңғы (ГҰ) арқылы сұйықтықтың фильтрациялану процестері қарастырылды. Есептің сандық шешімі жоғары ретті шекті элементті қолдануымен жүзеге асады.

Түйін сөздер: сұйықтық, фильтрация, горизонталь ұңғы, деформация, трансверсальды-изотропты ортада, шекті элементтер әдісі.

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ФИЛЬТРАЦИИ ЖИДКОСТИ К МНОГОСТВОЛЬНЫМ ГОРИЗОНТАЛЬНЫМ СКВАЖИНАМ В ДЕФОРМИРУЕМОЙ ПОРИСТОЙ СРЕДЕ

Аннотация. В работе рассматривается конечное элементное моделирование фильтрации жидкости в деформируемой пористой среде. В качестве деформируемой среды была взята транверсально-изотропно деформируемая среда. Проанализирован процесс фильтрации жидкости к горизонтальной скважине в транверсально-изотропной деформируемой среде. Численное решение задачиосуществлено с помощью высокопроизводительного моделирования конечных элементов.

Ключевые слова: жидкость, фильтрация, горизонтальная скважина, деформация, транверсально-изотропная среда, метод конечных элементов.

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