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IKKI QATLAMLI O‘ZARO DINAMIK BOG‘LANGAN GAZ KONLARI FILTRATSIYA JARAYONINI MATEMATIK MODELLASHTIRISH

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Annotatsiya. Ushbu maqolada g‘ovak muhitlarda ikki qatlamli gaz nostatsionar filtratsiya jarayonining matematik modeli va hisoblash algoritmi keltirilgan. Modellashtirish jarayonida qatlam bosimi hamda o‘tkazuvchanlik koeffitsientlarining fazoviy va vaqtga bog‘liq o‘zgaruvchanligi inobatga olingan. Chegaraviy masalani sonli modellashtirishda chekli-ayirmalar usuli, kvazichiziqli usul va Gauss usullaridan foydalanilgan. Shuningdek, samarali sonli usullar va algoritmlar asosida dasturiy ta’minot ishlab chiqilgan. Shu bilan birga kompyuterda hisoblash tajribalarini o‘tkazish va olingan sonli natijalarni vizuallashtirish jarayonlari keltirilgan.

Kalit so‘zlar: Matematik model, algoritm, dastur, sonli usullar, ko‘p qatlamli, dinamik aloqa, sust o‘tkazuvchan qatlam, chekli ayirmalar usuli, Gauss usuli.

Abstract. This article presents a mathematical model and a computational algorithm describing the unsteady gas filtration process in a two-layer porous medium. In the modeling process, variations of the formation pressure and permeability coefficients with respect to both space and time are taken into account. To solve the boundary value problem numerically, the finite difference method, the quasi-linear approach, and the Gauss method are applied. In addition, software has been developed based on efficient numerical methods and algorithms, allowing for computer simulations and visualization of the obtained numerical results.

The outcomes of this research can be effectively used for the analysis and optimization of gas field development processes.

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Keywords: Mathematical model, algorithm, software, numerical methods, multilayer filtration, dynamic interaction, low-permeability layer, finite difference method, Gauss method.

Аннотация. В данной статье представлена математическая модель и вычислительный алгоритм, описывающие нестационарный процесс фильтрации газа в двухслойной пористой среде. При моделировании учитываются изменения пластового давления и коэффициентов проницаемости в пространстве и во времени. Для численного решения краевой задачи использованы методы конечных разностей, квазилинейный подход и метод Гаусса. Кроме того, на основе эффективных численных методов и алгоритмов разработано программное обеспечение, позволяющее проводить компьютерные эксперименты и визуализировать полученные численные результаты. Результаты исследования могут быть эффективно применены для анализа и оптимизации процессов разработки газовых месторождений.

Ключевые слова: математическая модель, алгоритм, программное обеспечение, численные методы, многослойная фильтрация, динамическая связь, слабопроницаемый слой, метод конечных разностей, метод Гаусса.

1. Kirish

Hozirgi kunda ko‘p qatlamli o‘zaro dinamik bog‘langan gaz konlari filtratsiya jarayonlarini matematik modellashtirish va gaz sanoatiga tatbiq etish dolzarb masalalardan hisoblanadi. Gaz sanoati xalq xo‘jaligining muhim tarmoqlaridan biri bo‘lib, tabiiy yonuvchi gazlar sanoat va kundalik hayotda keng qo‘llaniladi. Mamlakatning yoqilg‘i balansida tabiiy gazning ulushi tobora ortib bormoqda. Gazdan foydalanish texnologik jarayonlarning samaradorligini oshirish, mehnat unumdorligini yuksaltirish va moddiy ishlab chiqarish sohasida resurslardan samarali foydalanishni ta’minlashda muhim omil hisoblanadi. Gaz konlarini o‘zlashtirish va ulardan oqilona foydalanish murakkab filtratsion jarayon bo‘lib, uni real vaqtda tadqiq qilish juda katta mablag‘ va vaqt talab qiladi. Shu sababdan ushbu jarayonni matematik va sonli modellar asosida tadqiq qilish, kompyuterli modellashtirish va dasturiy mahsulotlar ishlab chiqib ilmiy tadqiq qilish dolzarb masalalardan biri hisoblanadi.

G‘ovak muhitda gazning filtratsiya jarayoni, gaz parametrlarining turli qiymatlari hamda filtratsiya maydonining turli konfiguratsiyalari uchun kompyuterda bir qator hisoblash tajribalari olib borilmoqda "Ikkita o‘zaro dinamik bog‘langan gaz va neft konlaridagi qatlam tizimi uchun matematik model hamda uni echish usullari adabiyotlarda batafsil yoritilgan bo‘lib, ushbu maqolada keng foydalanilgan. Maqolada oddiy differensial tenglamalar tizimlari uchun Koshi masalalarini echishning chegaraviy masalalari, shuningdek, elliptik tipdagi

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tenglamalar sistemalari, parabolik va giperbolik tipdagi tenglamalar uchun boshlang‘ich va chegara shartlari bilan masalalarni echish, hamda elliptik tipdagi operatorlar uchun o‘zaro qiymat masalalari ko‘rib chiqilgan [1].

Maqolada ko‘rib chiqilayotgan har bir masalada yuzaga keladigan klassik tenglamalarni echishning raqamli usullarini qurishni ko‘rsatish, asosiy g‘oyalar va tushunchalarni berish, shuningdek, amaliyotda yuzaga keladigan muammolarni hal qilish uchun zarur bo‘lgan ba’zi tadqiqot ko‘nikmalarini berishdir. Monografiyada algoritmlarning konstruksiyalari va ayrim tadqiqotlari bayon etilgan, sonli usullarni qo‘llash shartlari shakllantirilgan va ularga qisqacha tavsif berilgan. Ammo matematik modelni qurish shartlarini (dastlabki ma’lumotlarni spetsifikatsiya xatosi, muammo echimlarining mavjudligi va o‘ziga xosligi va boshqalar) hisobga olmasdan hal qilish usullari haqida gapirish mumkin emas. Shu bilan birga, masalaning har bir mashina echimi matematik yoki fizik model tenglamalarining echimi emas, shuning uchun kitobda mashinalarda olingan hisoblash natijalarini tahlil qilishning ba’zi masalalari ko‘rib chiqilgan va echimning to‘g‘riligini tekshirish bo‘yicha ba’zi tavsiyalar berilgan.[2]

Maqolada mahsuldor qatlamlardan gaz qazib olishni ko‘paytirish va tadqiqot obyektining asosiy ko‘rsatkichlarini aniqlash maqsadida gaz konlarini o‘zlashtirishning dolzarb muammosi ko‘rib chiqilgan. Sust o‘tkazuvchan qatlamlarga ega bo‘lgan bir jinsli bo‘lmagan uch qatlamli g‘ovak muhitda gaz filtratsiyasi jarayonining matematik modeli va ularning dinamik aloqasi ko‘rib o‘tilgan. Ushbu murakkab jarayonni sonli modellashtirishda chekli ayirmalar usuli, kvazichiziqli usul va iteratsion usullardan foydalanilgan[4].

Maqolada neft -gaz tizimida ikki fazali filtratsiya jarayonini sonli modellashtirish masalalari ko‘rib chiqilgan, hamda masalani echishning sonli algoritmi va neft va gaz konlarini o‘zlashtirishning asosiy ko‘rsatkichlari bo‘yicha hisoblash tajribalari keltirilgan. Maqolda keltrilgan sonli algoritm turli chegara va boshlang‘ich shartlarga ega bo‘lgan bosim hamda to‘yinganlik sohalarini hisoblash uchun mos keladi. Shuningdek, ishlab chiqilgan matematik model ko‘rib chiqilayotgan jarayonlarni etarli darajada aniqlik bilan tavsiflaydi, bu esa neft va gaz konlarini o‘zlashtirishni tahlil qilishda va ko‘rsatkichlarni hisoblash uchun ishlatilishi mumkin[5-6]

Maqolada bir jinsli bo‘lmagan g‘ovak muhitda turli xil qatlam o‘tkazuvchanlikka ega bo‘lgan neft filtratsiya jarayonining matematik modellashtirish masalasi ko‘rib o‘tilgan. Qo’yilgan masalani echish uchun chekli-ayirmalar usulidan foydalanilgan. Maqolada taklif etilgan dasturiy vosita neft konlarini o‘zlashtirish bo‘yicha asosiy ko‘rsatkichlarni hisoblash, shuningdek hisoblash tajribalari natijalarini grafik ko‘rinishda vizual tarzda aks ettirish va neft konlarini prognozlashda qo‘llanilishi mumkin[8-9].

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2. Matematik model

Ko‘p qatlamli gaz konlarini o‘zlashtirishda qatlamlar o‘rtasidagi dinamik o‘zaro ta’sirlarni hisobga olgan holda, oraliq qatlamlar sust o‘tkazuvchanlikka ega bo‘lgan bir jinsli bo‘lmagan uch qatlamli g‘ovak muhitda gazning filtratsiya jarayoni va qatlamlar o‘rtasidagi dinamik bog‘liqlik ko‘rib chiqiladi.

Oraliq qatlamlarning o‘tkazuvchanligi sust bo‘lgani sababli, bu qatlamlarda suyuqlik harakati faqat vertikal yo‘nalishda sodir bo‘ladi. Shu tufayli bunday jarayonning matematik modeli ikkita bir o‘lchamli parabolik tipdagi o‘zaro bog‘langan differensial tenglamalardan iborat quyidagi tenglamalar tizimidan tashkil topadi.

$$\begin{cases} \dfrac{\partial}{\partial x}\left[K_1(x)h_1(x)\dfrac{\partial P_1^2}{\partial x}\right] = 2a\mu m h_1(x)\dfrac{\partial P_1}{\partial t} - \dfrac{K_{\Pi 1}(x)}{h_{\Pi 1}(x)}(P_2^2 - P_1^2); \\ \dfrac{\partial}{\partial x}\left[K_2(x)h_2(x)\dfrac{\partial P_2^2}{\partial x}\right] = 2a\mu m h_2(x)\dfrac{\partial P_2}{\partial t} - \dfrac{K_{\Pi 1}(x)}{h_{\Pi 1}(x)}(P_2^2 - P_1^2) - Q; \\ K = K_0\left[1 - a_k\left(P_0 - P\right)\right]. \qquad 0 < x < L,\ t>0. \end{cases} \quad (1)$$

Masalaning boshlang‘ich va chegaraviy shartlari quydagicha:

$$P_1(x,t_0) = P_{1H}(x),\ P_2(x,t_0) = P_{2H}(x); \quad (2)$$

$$-K_1 h_1 \left.\frac{\partial P_1}{\partial x}\right|_{x=0} = \alpha\lambda(P_A - P_1);\ K_1 h_1 \left.\frac{\partial P_1}{\partial x}\right|_{x=L} = \alpha\lambda(P_B - P_1); \quad (3)$$

$$-K_2 h_2 \left.\frac{\partial P_2}{\partial x}\right|_{x=0} = \alpha\lambda(P_A - P_2);\ K_2 h_2 \left.\frac{\partial P_2}{\partial x}\right|_{x=L} = \alpha\lambda(P_B - P_2); \quad (4)$$

$$Q = \sum_{i_q}^{N_q} q_{i_q}\delta(x - x_{i_q});\ \ i_q = 1,...N_q; \quad (5)$$

Bu yerda:

δ – Dirak delta funksiyasi; n – chegara sohadagi normal; μ – gaz qovushqoqligi; P_A – chegaradagi bosim; P_1, P_2 – mos ravishda qatlamlardagi bosimlar; P_{1H}, P_{2H} – qatlamlar boshlang‘ich bosimi; K_1, K_2 – qatlamlar o‘tkazuvchanlik koeffitlar ; $K_{\Pi 1}, K_{\Pi 2}$ – sust o‘tkazuvchanlik qatlam koeffitsentlari; h_1, h_2 – qatlamlar quvvati; m – qatlamlar g‘ovaklik koeffitsenti; q_{i_q} – i_q chi debiti; a – gaz to‘yinganligi; L – qatlam uzunligi; N_q – quduqlar soni; λ – o‘lchamga keltiruvchi parametr.

$$\alpha = \begin{cases} 0, - \text{ chegara mahkamlangan;} \\ 1, - \text{ chegara mahkamlanmagan.} \end{cases}$$

Qo‘yilgan chegaraviy masalani sonli usulda echish uchun uni o‘lchamsiz holatga keltiramiz. Buning uchun (2.1) tenglamalar tizimida quyidagi belgilashlarni kiritamiz:

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$$x^* = \frac{x}{L};\ \tau = \frac{K_x t P_x}{2am\mu L^2};\ K_1^* = \frac{K_1}{K_x};\ K_2^* = \frac{K_2}{K_x};\ K_{П1}^* = \frac{K_{П1}}{K_x};\ h_1^* = \frac{h_1}{h_x};$$
$$h_2^* = \frac{h_2}{h_x};\ h_{П1}^* = \frac{h_{П1}}{h_x};\ P_1^* = \frac{P_1}{P_x};\ P_1^* = \frac{P_1}{P_x};\ q^* = \frac{\mu L^2}{K_x h_x P_x} Q;\ \lambda^* = \frac{L}{K_x h_x} \lambda. \quad (6)$$

Bunda K_x, h_x, P_x mos ravishda qatlam o‘tkazuvchanligi, quvvati va bosimning ma’lum kattalikdagi qiymatlari:

$$K_x = \max(K_1,\ K_2,\ K_{П1});\ h_x = \max(h_1,\ h_2,\ h_{П1});\ P = \max(P_1,\ P_2). \quad (7)$$

Tenglamalar tizimida bu almashtirishlarni bajarib quyidagi o‘lchamsiz tenglamalar tizimiga kelamiz:

$$\begin{cases} \dfrac{\partial}{\partial x}\left[K_1(x) h_1(x) \dfrac{\partial P_1^2}{\partial x} \right] = \dfrac{h_1 \partial P_1}{\partial \tau} - \dfrac{K_{П1} L^2}{h_{П1} h_x^2} (P_2^2 - P_1^2); \\ \dfrac{\partial}{\partial x}\left[K_2(x) h_2(x) \dfrac{\partial P_2^2}{\partial x} \right] = \dfrac{h_2 \partial P_2}{\partial \tau} - \dfrac{K_{П1} L^2}{h_{П1} h_x^2} (P_2^2 - P_1^2) - \delta q; \\ K = K_0 \left[1 - a_k \left(P_0 - P \right) \right]. \qquad 0 < x < L,\ t>0. \end{cases} \quad (8)$$

Tenglamalar tizimida qulaylik uchun $T_1 = K_1 h_1$, $T_2 = K_2 h_2$, $\mathrm{R}_1 = \dfrac{K_{П1} L^2}{h_{П1} h_x^2}$ belgilashlarni kiritamiz.

O‘lchamsiz chegaraviy masalani chekli ayirmali usulini qo‘llab echamiz.

3. Sonli modellashtirish

Qo‘yilgan (8) o‘lchamsiz chegaraviy masalani echish uchun uning sonli modellashtiramiz, bunda chekli ayirmalar usulini qo‘llaymiz. Buning uchun x o‘qida G soha uchun $0 < t < T_0$ vaqt oraliqlarida quyidagi to‘rni quramiz:

$$\omega_{x,\tau} = \left\{ x_i = i\Delta x;\ \tau_l = l\Delta\tau;\ l=0,1,2,...,\mathrm{N}_\tau;\ \Delta\tau = \frac{T}{N_\tau} \right\}.$$

Bu erda $\Delta x -$ x o‘qi bo‘yicha qadam; $\omega_{x,\tau} -$ to‘r soha.

Ma’lumki parabolik tipdagi tenglamalar tizimini diskretlash usullaridan biri chekli ayirmali usuldir. Bu usulni chegaraviy masalaga qo‘llab (8) differensial tenglamalar tizimini quyidagi chekli ayirmali tenglamalar tizimiga keltiramiz:

$$\frac{T_{1i-0,5} P_{1i-1}^{2(l)} - (T_{1i-0,5} + T_{1i+0,5}) P_{1i}^{2(l)} + T_{1i+0,5} P_{1i+1}^{2(l)}}{\Delta x^2} = h_{1i} \frac{P_{1i}^{l+1} - P_{1i}^{l+1}}{\Delta\tau} - R_1 P_{2i}^{2(l+1)} + R_1 P_{1i}^{2(l+1)};$$
$$\frac{T_{2i-0,5} P_{2i-1}^{2(l)} - (T_{2i-0,5} + T_{2i+0,5}) P_{2i}^{2(l)} + T_{2i+0,5} P_{2i+1}^{2(l)}}{\Delta x^2} = h_{2i} \frac{P_{2i}^{l+1} - P_{2i}^{l+1}}{\Delta\tau} + R_1 P_{2i}^{2(l+1)} - R_1 P_{1i}^{2(l+1)} - \delta_i q_i.$$
$$K_i = K_0 \left[1 - a_k \left(P_0 - P_i \right) \right].$$

Olingan chekli ayirmali tenglamalar tizimi bosim funksiyasiga nisbatan chiziqsiz bo‘lgani uchun uni to‘g‘ridan-to‘g‘ri yechish ancha murakkab, shu sabab tenglamalarga kvazichiziqli usulni qo‘llaymiz [5]. Kvazichiziqli usulga ko‘ra tenglamani nochiziq qismlarini quyidagicha yozish mumkin:

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$$\varphi(P) \cong \varphi(\tilde{P}) + (P - \tilde{P})\frac{\partial \varphi(\tilde{P})}{\partial P}. \qquad (9)$$

Bunda $\tilde{P}-$ funksiyasi P ning taqribiy qiymati bo‘lib, u iteratsion jarayonda aniqlanadi. Agar (9) formulani bosim funksiyasiga nisbatan yozadigan bo‘lsak, u holda quyidagi formulalarga ega bo‘lamiz:

$$P_{1i}^{2(l+1)} = 2\tilde{P}_{1i}^{(l+1)}P_{1i}^{(l+1)} - \tilde{P}_{1i}^{2(l+1)}; \qquad P_{2i}^{2(l+1)} = 2\tilde{P}_{2i}^{(l+1)}P_{2i}^{(l+1)} - \tilde{P}_{2i}^{2(l+1)}.$$

$$\frac{T_{1i-0,5}(2\tilde{P}_{1i-1}^{(l)}P_{1i-1}^{(l)} - \tilde{P}_{1i-1}^{2(l)}) - (T_{1i-0,5} + T_{1i+0,5})(2\tilde{P}_{1i}^{(l)}P_{1i}^{(l)} - \tilde{P}_{1i}^{2(l)}) + T_{1i+0,5}(2\tilde{P}_{1i+1}^{(l)}P_{1i+1}^{(l)} - \tilde{P}_{1i+1}^{2(l)})}{\Delta x^2} =$$

$$= h_{1i}\frac{P_{1i}^{l+1} - P_{1i}^{l+1}}{\Delta\tau} - R_1(2\tilde{P}_{2i}^{(l+1)}P_{2i}^{(l+1)} - \tilde{P}_{2i}^{2(l+1)}) + R_1(2\tilde{P}_{1i}^{(l+1)}P_{1i}^{(l+1)} - \tilde{P}_{1i}^{2(l+1)});$$

$$\frac{T_{2i-0,5}(2\tilde{P}_{2i-1}^{(l)}P_{2i-1}^{(l)} - \tilde{P}_{1i-1}^{2(l)}) - (T_{2i-0,5} + T_{2i+0,5})(2\tilde{P}_{2i}^{(l)}P_{2i}^{(l)} - \tilde{P}_{2i}^{2(l)}) + T_{2i+0,5}(2\tilde{P}_{2i+1}^{(l)}P_{2i+1}^{(l)} - \tilde{P}_{2i+1}^{2(l)})}{\Delta x^2} =$$

$$= h_{2i}\frac{P_{2i}^{l+1} - P_{2i}^{l+1}}{\Delta\tau} + R_1(2\tilde{P}_{2i}^{(l+1)}P_{2i}^{(l+1)} - \tilde{P}_{2i}^{2(l+1)}) - R_1(2\tilde{P}_{1i}^{(l+1)}P_{1i}^{(l+1)} - \tilde{P}_{1i}^{2(l+1)}) - \delta_i q_i.$$

$$K_i = K_0\left[1 - a_k\left(P_0 - P_i\right)\right].$$

bu yerda $\mathrm{R}_1 = \dfrac{K_{\Pi 1}L^2}{h_{\Pi 1}h_x^2}$.

Ushbu tenglamalar tizimida $P_{1i,j}^{(s)} = \tilde{P}_{1i,j}^{(l+1)}$, $P_{2i,j}^{(s)} = \tilde{P}_{2i,j}^{(l+1)}$ belgilashlarni kiritamiz va iteratsiya jarayonini quyidagi shartga qadar davom ettiramiz:

$$\left|P_{1i,j}^{(s)} - P_{1i,j}^{(s-1)}\right| < \varepsilon, \ \left|P_{2i,j}^{(s)} - P_{2i,j}^{(s-1)}\right| < \varepsilon.$$

Bu tenglamalar tizimida belgilashlarni kiritib, uni P_{1i}^{l+1}, P_{2i}^{l+1} noma’lumlarga nisbatan quyidagicha yozish mumkin (qulaylik uchun $(l+1)$ yuqori indeksni tushirib qoldiramiz, ya’ni P_{1i}^{l+1}, P_{2i}^{l+1} larni P_{1i}, P_{2i} ko‘rinishida yozamiz):

$$\begin{cases} \alpha_{1i}^{'}P_{1i} + \alpha_{2i}^{'}P_{2i} = \beta_{1i}^{'} \\ \alpha_{1i}^{''}P_{1i} + \alpha_{2i}^{''}P_{2i} = \beta_{1i}^{''} \end{cases}$$

Bu yerda :

$$\alpha_{1i}^{'} = h_{1i} + R_1\Delta\tau 2\tilde{P}_{1i}^{(l+1)}, a_{2i}^{'} = -R_1\Delta\tau 2\tilde{P}_{2i}^{(l+1)}$$

$$\beta_{1i}^{'} = h_{1i}P_{1i}^{l} - \Delta\tau R_1\tilde{P}_{2i}^{(l+1)} + \Delta\tau R_1\tilde{P}_{1i}^{(l+1)} + (\Delta\tau/\Delta x^2)*$$

$$*\left(\left[T_{1i-0,5}(2\tilde{P}_{1i-1}^{(l)}P_{1i-1}^{(l)} - \tilde{P}_{1i-1}^{2(l)}) - (T_{1i-0,5} + T_{1i+0,5})(2\tilde{P}_{1i}^{(l)}P_{1i}^{(l)} - \tilde{P}_{1i}^{2(l)}) + T_{1i+0,5}(2\tilde{P}_{1i+1}^{(l)}P_{1i+1}^{(l)} - \tilde{P}_{1i+1}^{2(l)})\right]\right);$$

$$\alpha_{1i}^{''} = -R_1\Delta\tau 2\tilde{P}_{1i}^{(l+1)}; \ a_{2i}^{''} = h_{1i} + R_1\Delta\tau 2\tilde{P}_{2i}^{(l+1)};$$

$$\beta_{2i}^{''} = h_{2i}P_{2i}^{l} - \Delta\tau R_1(\tilde{P}_{1i}^{2(l+1)} - \tilde{P}_{2i}^{2(l+1)}) + (\Delta\tau/\Delta x^2)*$$

$$*\left(\left[T_{1i-0,5}(2\tilde{P}_{1i-1}^{(l)}P_{1i-1}^{(l)} - \tilde{P}_{1i-1}^{2(l)}) - (T_{1i-0,5} + T_{1i+0,5})(2\tilde{P}_{1i}^{(l)}P_{1i}^{(l)} - \tilde{P}_{1i}^{2(l)}) + T_{1i+0,5}(2\tilde{P}_{1i+1}^{(l)}P_{1i+1}^{(l)} - \tilde{P}_{1i+1}^{2(l)})\right]\right) - \delta_i q_i.$$

Bu tenglamalar tizimini P_{1i}, P_{2i} ga nisbatan Gauss usulida echib, ichki nuqtalarda bosim funksiyasi quydagicha aniqlanadi:

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$$\begin{cases}\alpha_{1i}^{'}P_{1i}+\alpha_{2i}^{'}P_{2i}=\beta_{1i}^{'}\\ \alpha_{1i}^{''}P_{1i}+\alpha_{2i}^{''}P_{2i}=\beta_{2i}^{''}\end{cases}$$

$$P_{1i}=\frac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\frac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}P_{2i};$$

$$\alpha_{1i}^{''}\left(\frac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\frac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}P_{2i}\right)+\alpha_{2i}^{''}P_{2i}=\beta_{2i}^{''};\quad \alpha_{1i}^{''}\frac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\alpha_{1i}^{''}\frac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}P_{2i}+\alpha_{2i}^{''}P_{2i}=\beta_{2i}^{''};$$

$$\alpha_{1i}^{''}\frac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\beta_{2i}^{''}=\left(\alpha_{1i}^{''}\frac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}-\alpha_{2i}^{''}\right)P_{2i};$$

$$P_{2i}=\frac{\alpha_{1i}^{''}\dfrac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\beta_{2i}^{''}}{\alpha_{1i}^{''}\dfrac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}-\alpha_{2i}^{''}};\quad P_{1i}=\frac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\alpha_{2i}^{'}\left(\frac{\alpha_{1i}^{''}\dfrac{\beta_{1i}^{'}}{\alpha_{1i}^{'}}-\beta_{2i}^{''}}{\alpha_{1i}^{''}\dfrac{\alpha_{2i}^{'}}{\alpha_{1i}^{'}}-\alpha_{2i}^{''}}\right).$$

Bosim funksiyalarining chegaraviy nuqtadagi qiymatlarini topish uchun chegaraviy shartlarni chekli ayirmali tenglamalar ko‘rinishida yozamiz:

$$\begin{cases}(3k_{10}h_{10}-2\Delta x\alpha\lambda)P_{10}-4k_{11}h_{11}P_{11}+k_{12}h_{12}P_{12}=2\Delta x\alpha\lambda P_A;\\ (3h_{1n}k_{1n}-2\Delta x\alpha\lambda)P_{1n}-4k_{1n-1}h_{1n-1}P_{1n-1}+k_{1n-2}h_{1n-2}P_{1n-2}=-2\Delta x\alpha\lambda P_A;\end{cases}$$

$$\begin{cases}(3k_{20}h_{20}-2\Delta x\alpha\lambda)P_{20}-4k_{21}h_{21}P_{21}+k_{22}h_{22}P_{22}=2\Delta x\alpha\lambda P_A;\\ (3k_{2n}h_{2n}-2\Delta x\alpha\lambda)P_{2n}-4k_{2n-1}h_{2n-1}P_{2n-1}+k_{2n-2}h_{2n-2}P_{2n-2}=-2\Delta x\alpha\lambda P_A;\end{cases}$$

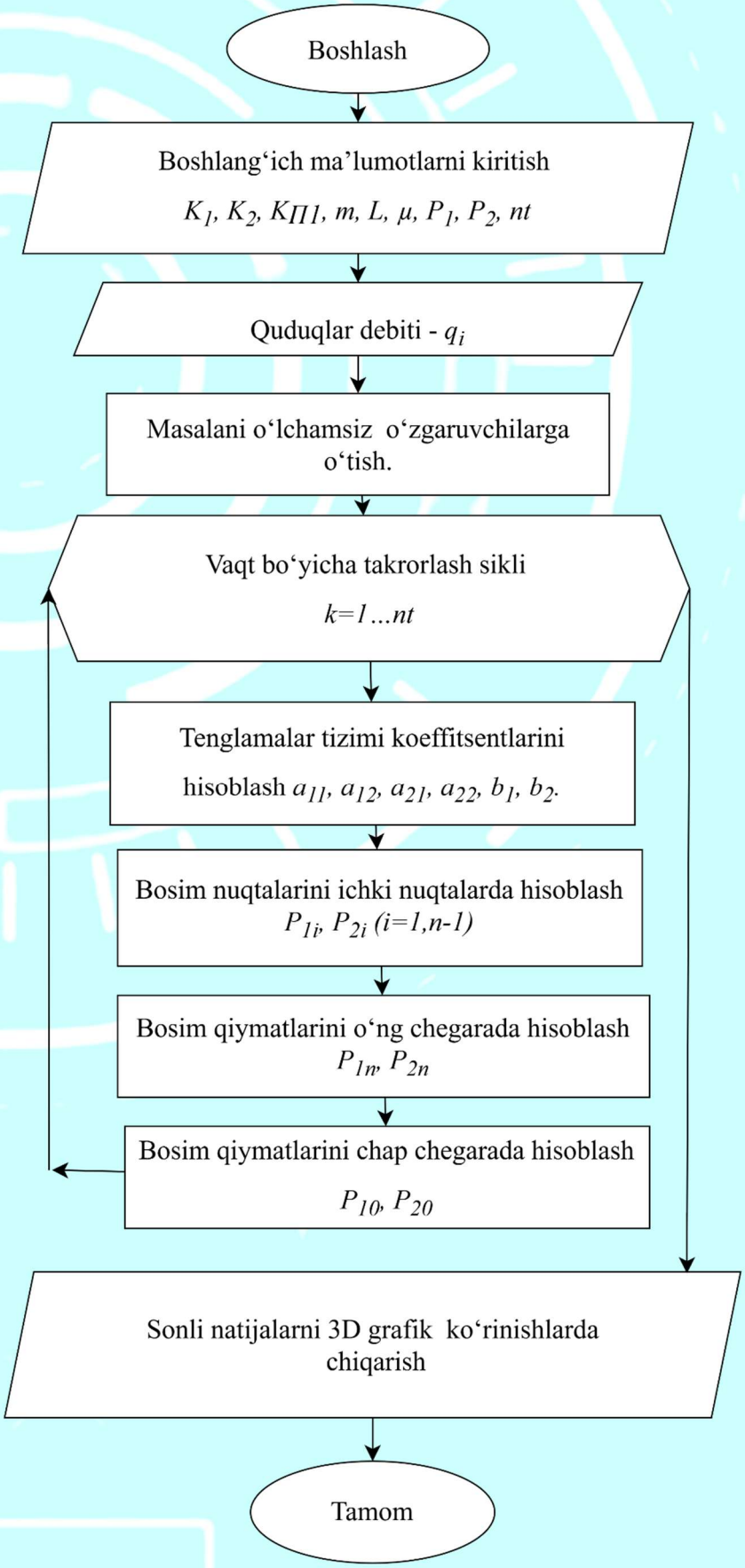
Bu yerdan

$$P_{10}=\frac{4k_{11}h_{11}P_{11}-k_{12}h_{12}P_{12}+2\Delta x\alpha\lambda P_A}{3k_{10}h_{10}-2\Delta x\alpha\lambda};\qquad P_{1n}=\frac{4k_{1n-1}h_{1n-1}P_{1n-1}-k_{1n-2}h_{1n-2}P_{1n-2}+2\Delta x\alpha\lambda P_A}{3k_{1n}h_{1n}-2\Delta x\alpha\lambda};$$

$$P_{20}=\frac{4k_{21}h_{21}P_{21}-k_{22}h_{22}P_{22}+2\Delta x\alpha\lambda P_A}{3k_{20}h_{20}-2\Delta x\alpha\lambda};\qquad P_{2n}=\frac{4k_{2n-1}h_{2n-1}P_{2n-1}-k_{2n-2}h_{2n-2}P_{2n-2}+2\Delta x\alpha\lambda P_A}{3k_{2n}h_{2n}-2\Delta x\alpha\lambda}.$$

Bosim funksiyalarining chegaraviy nuqtadagi qiymatlari har bir vaqt oralig‘ida aniqlab boriladi.

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1-rasm. O‘zaro dinamik bog‘langan g‘ovak muhitlarda gaz filtratsiya chegaraviy masalasini echish algoritmi blok-sxema chizmasi.

4. Hisoblash algoritmi quyidagicha amalga oshiriladi:

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1. Boshlang‘ich ma’lumotlar qiymatlarini berish:

– vaqt bo‘yicha takrorlanishlar soni - nt

– o‘tkazuvchanlik koeffitsentlari qiymati – $K_1,\ K_2, K_{\Pi 1}$.

– g‘ovaklik koeffitsienti qiymati - m;

– qatlam uzunligi - L;

– neft qovushqoqlik koeffitsienti qiymati - μ;

– quduqlar debiti - q;

– neftning qatlamlardagi boshlang‘ich bosimi – $P_1,\ P_2$.

O‘zgaruvchilarni o‘lchamsiz qiymatlarga o‘tkazish;

3. Vaqt bo‘yicha takrorlash sikli $l = 1...nt$;

4. Tenglamalar tizimi koeffitsientlarini hisoblash $a_1^{'},\ a_1^{''},\ a_2^{'},\ a_2^{''},\ b_1^{'},\ b_2^{''}$

5. $P_{1i},\ P_{2i},\ (i = 1, n-1)$ qatlam bosim qiymatlarini $l+1$ - vaqt oralig‘i uchun hisoblash.

6. $P_{10},\ P_{20},\ P_{1n},\ P_{2n}$ bosim qiymatlarini o‘ng va chap chegaralarda hisoblash.

Topilgan $l+1$ vaqt oralig‘idagi echimlar keyingi $l+2$ qadam uchun boshlang‘ich bo‘ladi.

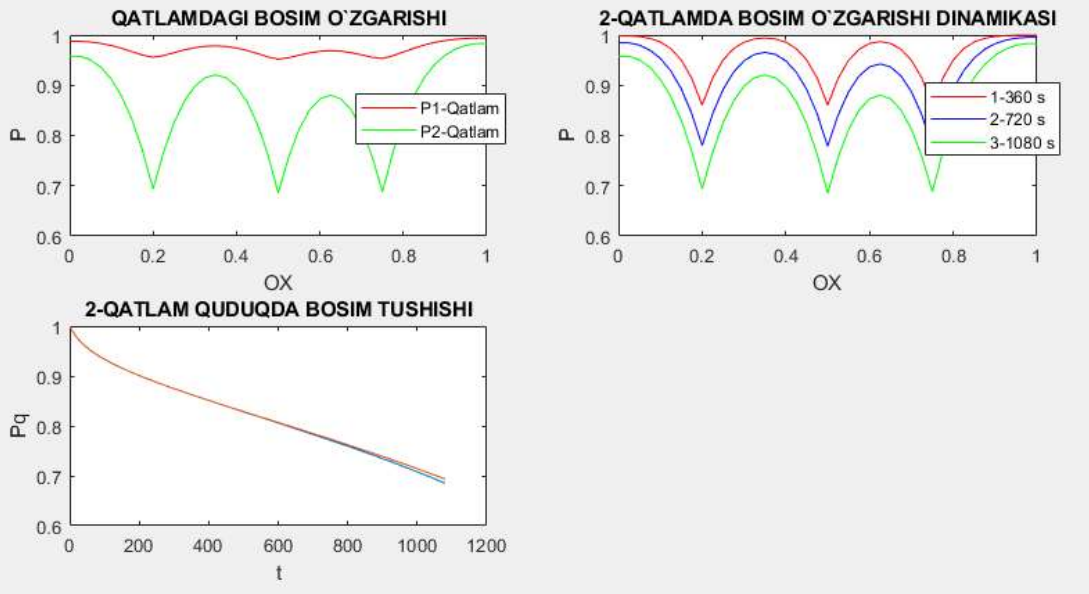
7. Sonli natijalarni jadval va grafik ko‘rinishlarida ekranga chiqarish.

8. Vaqt bo‘yicha takrorlanish sikli oxiri.

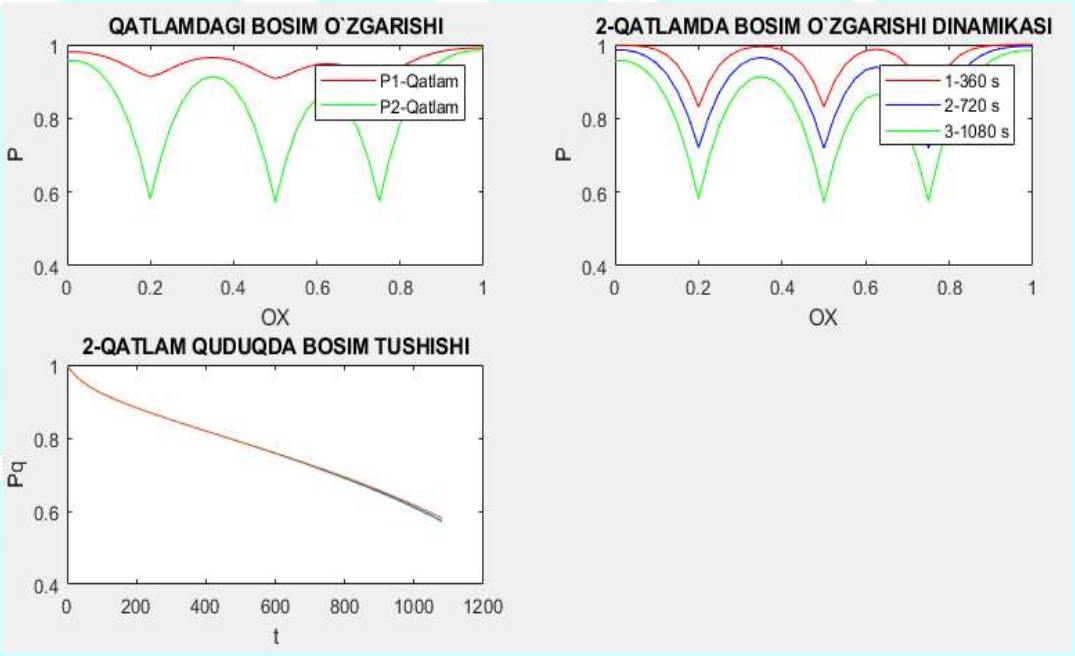
5. Hisoblash tajribalari

Sust o‘tkazuvchan qatlam bilan o‘zaro bog‘langan ikki qatlamli gaz filtratsiya tizimida g‘ovak muhitning ikkinchi qatlamidan gaz qazib olish jarayonida yuqori va pastki qatlamlarda bosim o‘zgarishiga bo‘lgan ta’sirni o‘rganish maqsadida kompyuterda hisoblash tajribalari o‘tkazilib, tahlil qilingan. Hisoblash tajribalari aniq dastlabki kiritiladigan parametrlar bilan amalga oshirilgan: har ikkala qatlamning uzunligi $L_x = 10000\ m;$ gaz qatlamlarining boshlang‘ich bosimi $P_1=300\ kg/sm^2,\ P_2=300\ kg/sm^2;$ gazning qovushqoqlik koeffitsienti $\mu=0.001$; g‘ovaklik koeffitsienti m=0.1; ikkinchi gaz qatlamida quduqlar bir xil debitga teng, ya’ni $Q=500000m^3/sut$. Gaz qatlamlarida bosimning tarqalishi bo‘yicha hisoblash tajribalari 360, 720 va 1080 kun davomida o‘tkazilgan. Hisoblash tajribalari natijalari asosan qatlamlar o‘tkazuvchanlik koeffitsientlarining turli qiymatlarida hamda quduqlar debiti bo‘yicha olingan bo‘lib ular asosida tahlillar qilingan.

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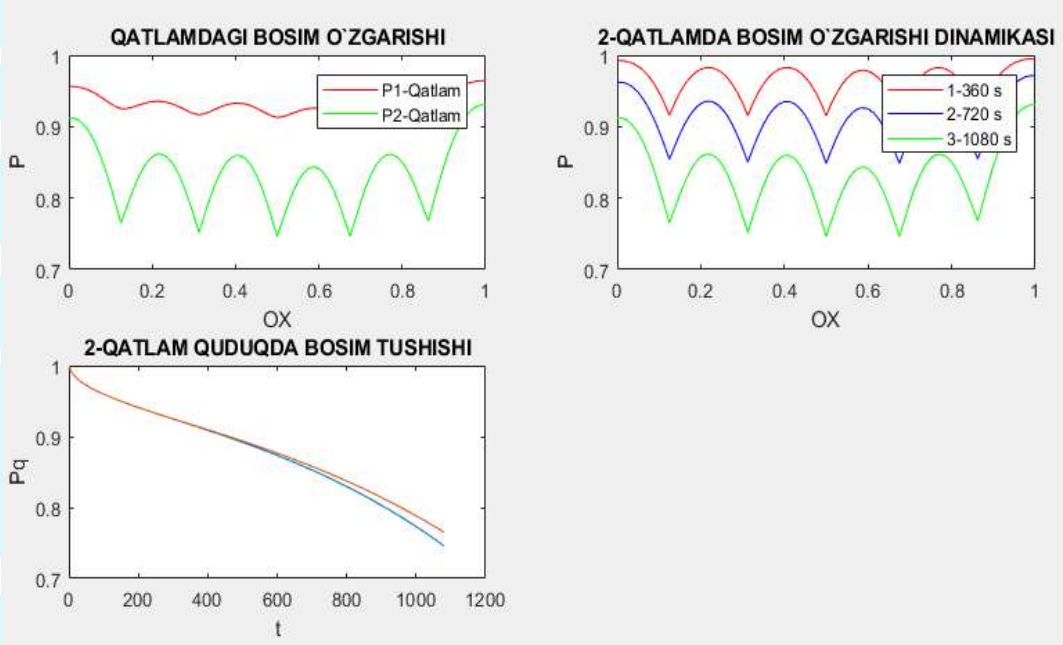


2-rasm. Qatlamlarda bosim tarqalish dinamikasi va tushishi. *n=41, t=1080 sutka* (*K_{10}=0.2; K_{20}=0.1; $K_{П1}$=0.0002; μ=0.0009, $Q_{1,2,3}$=500000m^3/sut*)

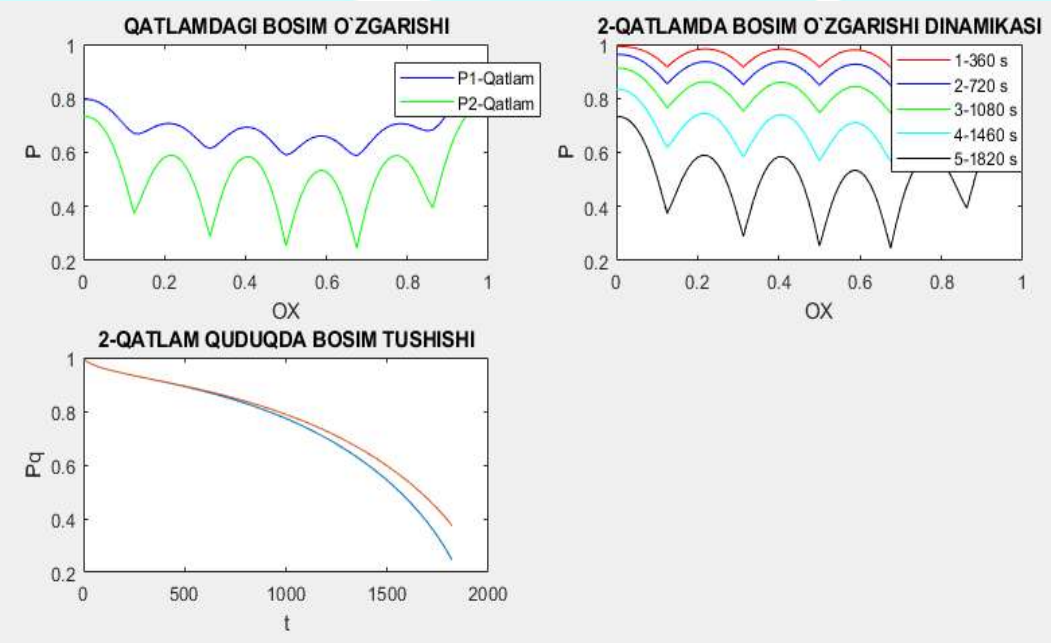


3-rasm. Qatlamlarda bosim tarqalish dinamikasi va tushishi. *n=41, t=1080 sutka* (*K_{10}=0.2; K_{20}=0.1; $K_{П1}$=0.0003; μ=0.001, $Q_{1,2,3}$=500000m^3/sut*)

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4-rasm. Qatlamlarda bosim tarqalish dinamikasi va tushishi. *n=81, t=1080 sutka* (*K_{10}=0.2; K_{20}=0.1; $K_{П1}$=0.00009; μ=0.001, $Q_{1,2,3,4,5}$=300000m^3/sut*)



4-rasm. Qatlamlarda bosim tarqalish dinamikasi va tushishi. *n=81, t=1820 sutka* (*K_{10}=0.2; K_{20}=0.1; $K_{П1}$=0.00009; μ=0.001, $Q_{1,2,3,4,5}$=300000m^3/sut*)

6. Xulosa

Ikki qatlamli o‘zaro dinamik aloqadagi g‘ovak muhitlarda gaz filtratsiya chegaraviy masalasi echishda hisoblash tajribalari shuni ko‘rsatdiki, sust o‘tkazuvchan qatlam o‘tkazuvchanlik parametrining qiymati qancha kichik bo‘lsa, yuqori qatlamda bosim tushishi juda kam bo‘ladi va bu tushish faqat ikkinchi qatlamdagi quduq joylashgan joylarga ta’siri bo‘ladi. Kompyuter modellashtirish va hisoblash tajribalarining o‘tkazilishi qatlam parametrlarining har xil parametrlarida ko‘p qatlamli gaz konlarini o‘zlashtirishda uning asosiy ko‘rsatkichlarini aniqlashga imkon beradi. Olingan sonli natijalar esa dinamik

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aloqaga ega bo‘lgan ko‘p qatlamli neft-gaz konlarining rivojlanishini tahlil qilish uchun foydalidir.

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