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| Research Article

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Improvement of Methods of Calculation and Management of Main Gas Pipelines

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Annotation
The relevance of this study is due to the need to improve the efficiency of main gas pipelines (MGP) operation by improving mathematical models and algorithmic solutions, as well as upgrading the software to optimize their development. Within the framework of this work, a detailed analysis of existing mathematical models was carried out and computational algorithms were developed aimed at improving the control of single-string MGPs with a constant diameter, taking into account all possible boundary conditions and features of the gas flow dynamics in real operating conditions. A generalized methodology for the operational regulation of single-string MGP operating modes has been developed, taking into account concentrated gas extraction and injection, as well as with a variable diameter, which allows adapting the control to dynamic changes in gas consumption under various boundary conditions at the inlet and outlet of compressor stations (CS). A new auxiliary function has been introduced that smooths out gas flow rate discontinuities both within elementary sections and during the transition between different diameters or segments of the gas pipeline, which helps to increase the accuracy of modeling and the stability of control in dynamic operating modes of the gas transportation system.

Keywords: Mathematical model, main gas pipeline, auxiliary function, algorithm, pipeline systems, gas consumption, dynamic mode, gas transport, static mode, gas, numerical method, sweep.

The analytical complexity of processes occurring in technological objects, such as main gas pipelines, is due to many technological limitations and the lack of a universal mathematical description of their operating modes in real time. This circumstance excludes the possibility of a full-fledged analytical study of the functioning of main gas pipelines taking into account dynamically changing factors, which significantly complicates the modeling of their operation, forecasting operating modes and developing effective management methods. At the same time, the gas transportation system is a high-cost infrastructure complex requiring significant capital investments at all stages of the life cycle. Further improvement of algorithms and software requires taking into account many additional factors, including the multi-threaded nature of main gas pipelines, the influence of terrain, temperature gradients, as well as specific operating modes of compressor stations. In this work, the main emphasis is placed on the introduction of an auxiliary function that allows converting the gas consumption calculation into a smooth, continuous dependence (Fig. 1).

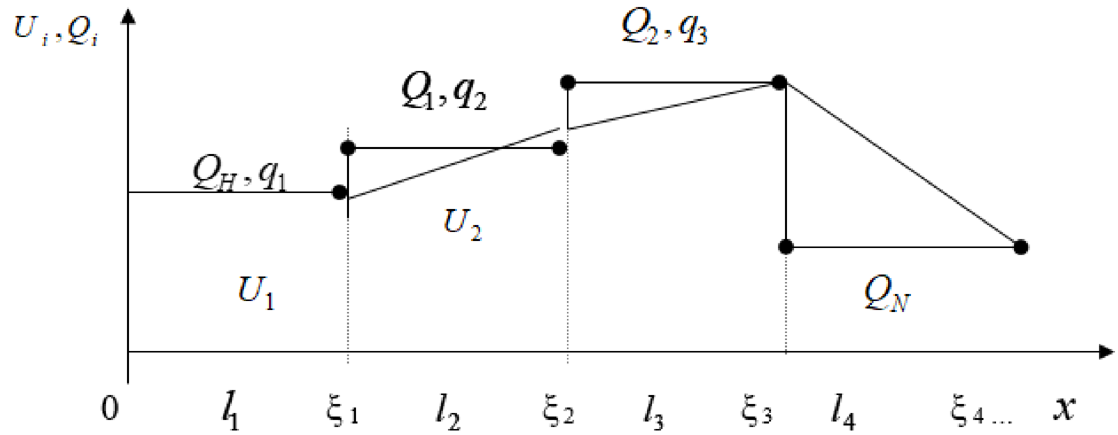

Fig. 1. Change in flow rate (thick line) and auxiliary function (x) along the length of the MG EI.

The gas transportation system is considered as a dynamic environment, the behavior of which is subject to the fundamental laws of conservation of mass, momentum and energy. Based on these laws, the movement of gas in a single-thread main gas pipeline under conditions of changing gas consumption can be described by a system of nonlinear partial differential equations [28, 30–33].

$$\begin{cases} \dfrac{\partial P}{\partial x} + A\dfrac{Q^2}{P} = C\dfrac{\partial Q}{\partial t}; \\ B\dfrac{\partial Q}{\partial x} = -\dfrac{\partial P}{\partial t}, \ 0 < x < L, \ t > 0 \end{cases} \qquad (1)$$

where P and Q are, respectively, the pressure and flow rate of gas at point x at time t;

$$A = \frac{16\lambda\gamma_0^2 ZRT}{\pi^2 D^5}; \qquad B = \frac{4ZRT\gamma_0}{\pi D^2}; \qquad C = \frac{4\gamma_0}{\pi D^2}\delta \qquad (2)$$

γ_0 – specific gravity of gas referred to normal condition;

$$\delta = \begin{cases} 0, \text{ for long gas pipelines,} \\ 1, \text{ for short gas pipelines.} \end{cases}$$

We will select the hydraulic resistance coefficient according to [34]

$$\lambda = 0{,}067\left(\frac{158}{\mathrm{Re}} + 2\frac{K_ш}{D}\right)^{0{,}25},$$

where is the Re -Reynolds number; $K_ш$ - is the pipe roughness coefficient.

To solve the system of equations (1), it is necessary to specify the initial and boundary conditions.

Initial conditions: at *t=0*

$$P(x,0) = f_1(x),\ 0 \le x \le L;$$

$$Q(x,0) = f_2(x),\ 0 \le x \le L;$$

Boundary conditions can be *x=0*

$$P(0,t) = F_1(t),\ t > 0$$

or

$$Q(0,t) = F_2(t),\ t > 0$$

at *x=L:*

$$P(L,t) = \varphi_1(t),\ t > 0$$

or

$$Q(L,t) = \varphi_2(t),\ t > 0;$$

where *L* is the length of the gas pipeline.

To develop a numerical algorithm for solving the problems posed, it is necessary to make the transition to dimensionless variables, which allows us to normalize the equations, simplify their analysis and increase the stability of the calculations. In this case, we will rewrite the system of equations (1) with initial and boundary conditions in the following form:

$$\begin{cases} \dfrac{\partial P^*}{\partial x} + A^* \dfrac{Q^{*2}}{P^*} = -C^* \dfrac{\partial Q^*}{\partial t^*}, 0 < x^* < 1; \\ B^* \dfrac{\partial Q^*}{\partial x} = -\dfrac{\partial P^*}{\partial t^*},\ t^* > 0 \end{cases} \quad (3)$$

$$\begin{cases} P^*(x^*,0) = f_1(x^*), \quad 0 \le x^* \le 1; \\ Q^*(x^*,0) = f_2(x^*), \quad 0 \le x^* \le 1. \end{cases} \quad (4)$$

$$P^*(0,t^*) = F_1(t^*), \quad t^* > 0; \quad (5)$$

$$Q^*(0,t^*) = F_2(t^*), \quad t^* > 0; \quad (6)$$

$$P^*(1,t^*) = \varphi_1(t^*), \quad t^* > 0; \quad (7)$$

$$Q^*(1,t^*) = \varphi_2(t^*), \quad t^* > 0; \quad (8)$$

where $P^* = P/P_x;\ Q^* = Q/Q_x\ \ x^* = x/L;\ t^* = t/\tau$

P_x, Q_x – maximum possible values of pressure and gas flow rate by main gas pipeline; τ – estimated time interval;

$$A^* = A\frac{Q^2 L}{P_x^2},\ B^* = B\frac{Q_x \tau}{P_x L},\ C^* = C\frac{Q_x L}{P_x \tau}. \quad (9)$$

This approach helps to eliminate dimensional effects, improve the convergence of numerical methods and facilitate the interpretation of the results obtained at different calculation scales. In what follows, for simplicity of presentation, we omit the asterisks and linearize the system of equations (3), in contrast to the works [29], as follows

$$\begin{cases} \dfrac{\partial P^2}{\partial x} + \tilde{A}Q = -\tilde{C}\dfrac{\partial Q}{\partial t}, \\ \tilde{B}\dfrac{\partial Q}{\partial x} = -\dfrac{\partial P^2}{\partial t}, \qquad 0 \le x \le 1; \qquad t > 0 \end{cases} \quad (10)$$

with the corresponding initial (4) and boundary conditions (5)-(8), where

$$\tilde{A} = 2A\tilde{Q};\ \tilde{B} = 2B\tilde{P};\ \tilde{C} = 2C\tilde{P};$$

$\tilde{P}$ and $\tilde{Q}$ - average or iterative values of pressure and gas flow at a point *x*.

Let us consider the system of equations in dimensionless form

$$\begin{cases} \dfrac{\partial P^2}{\partial x} + \tilde{A}_j Q_j + \tilde{C}_j \dfrac{\partial Q_j}{\partial t} = 0; \\ \dfrac{\partial P^2}{\partial t} + \tilde{B}_j \dfrac{\partial Q_j}{\partial x} = 0. \end{cases} \quad (11)$$

On the plots $(0;\xi_1)$, (ξ_1,ξ_2), (ξ_2,ξ_3),... the consumption is

$Q_H(t)$, $Q_1(t) = Q_H(t) + q_1(t)$, $Q_2(t) = Q_1(t) + q_2(t)$..

i.e. at the nodal points $i = 1,2,3,...k$, gas is extracted (with intensity $q_i < 0$) or pumped (with intensity $q_i > 0$) into the system, the intensity of which depends on time t.

Let's introduce a new auxiliary function $U(x,t)$ for each section. Unlike those used in previous works, it turned out to be more economical when conducting a computational experiment and gives good results compared to other methods for calculating a complex pipeline [3,9,15,24,29]

$$U_1(x,t) = Q_H(x,t), \quad x \in (0,\xi_1];$$

$$U_2(x,t) = Q_1(x,t) + \frac{x-\xi_1}{\xi_2-\xi_1} q_1(t), \quad x \in (\xi_1,\xi_2];$$

$$U_3(x,t) = Q_2(x,t) + \frac{x-\xi_2}{\xi_3-\xi_2} q_2(t), \quad x \in (\xi_2,\xi_3];$$

...

$$U_i(x,t) = Q_{i-1}(x,t) + \frac{x-\xi_{i-1}}{\xi_i-\xi_{i-1}} q_{i-1}(t), \quad x \in (\xi_{i-1},\xi_i].$$

Because $Q_{i-1}(x,t) = Q_i(x,t) - q_{i-1}(t)$,

that $U_i(x,t) = Q_i(x,t) - q_{i-1} + \dfrac{x-\xi_{i-1}}{\xi_i - \xi_{i-1}} q_{i-1}$

or

$$U_i(x,t) = Q_i(x,t) + \frac{x-\xi_i}{l_i} q_{i-1}(t), \qquad (12)$$

where $l_i = \xi_i - \xi_{i-1}$ - length of the i -th section.

This function, as can be seen from Fig. 1, is continuous, like the function used in the works [3,9,21,22,27,28], but in the internal boundaries of the elementary section (ES) (at the points of selection and pumping) it takes on a value equal to the flow rate in the left part of this node.

Thus, the auxiliary function acquires a physical meaning: at the beginning of the i -th section with a l_i length, a selection (pumping) is carried out, the intensity of which is distributed uniformly along the l_i length. The practical benefit from this is that it has become possible to control changes in the auxiliary function: its value at the points of selection (pumping) coincides with the value of the flow rate at a given point on the inlet side.

We will introduce this auxiliary function into the system of dimensionless equations for a long gas pipeline $(\tilde{C}_i = 0)$

Because $Q_i = U(x,t) - \dfrac{x-\xi_j}{L_j} q_{j-1}(t)$, then the system of equations takes the form

$$\begin{cases} \dfrac{\partial P}{\partial x} + \tilde{A}_j \left(\overline{U} - \dfrac{x-\xi_j}{L_j} q_{j-1}(t) \right) = 0 \\ \dfrac{\partial P}{\partial t} + \overline{B}_j \dfrac{\partial U}{\partial x} - \dfrac{\overline{B}_j}{L_j} q_{j-1} = 0. \end{cases} \qquad (13)$$

Next we move on to the discrete analogue of this system.

Let us introduce discrete coordinates: spatial $h_j = L_j / m_j = const$ and temporary $\Delta t = t_k - t_{k-1}$. To make the inner boundaries coincide with the grid point, m_j took on even values, i.e. $\lfloor \xi_j / h_j \rfloor$ rounded to an even number. Thus, the beginning of the count in time was $t_0 = 0$, and in space $x = 0$ $(j = 1)$.

Since different conditions were set at the beginning and end of the linear section under consideration, we will, based on this, compose finite-difference analogues of the system of equations.

Problem 1. The questions are $P_н$ and $Q_{\text{Н}}$.

Discrete derivatives of pressure are represented by odd coordinates, and functions by U - even ones. This step is explained by the necessity of implementing boundary conditions both in this and in subsequent problems.

$$\begin{cases} \dfrac{P_{i+1}-P_{i-1}}{2h_i}+\tilde{A}_j\left(U_i-\left(x-\xi_j\right)\dfrac{q_{j-1}}{l_j}\right)=0 \\ \dfrac{P_{i-1}-\overline{P}_{i-1}}{\Delta t}+B^*_{j-1}\dfrac{U_i-U_{i-2}}{2h_i}-B^*_{j-1}\dfrac{q_{j-1}}{l_j}=0 \end{cases} \qquad (14)$$

Here $\overline{P}_{i-1}$ - is the pressure value in the previous time layer, and the values h_i, $\tilde{A}_j$, B^*_{j-1} are taken for the corresponding elementary j -th section.

Having designated $S_j=\dfrac{q_{j-1}}{l_j}$ and $S_i=\left(x-\xi_j\right)\dfrac{q_{j-1}}{l_j}$, we give the equations the form

$$\begin{cases} \dfrac{1}{h_j\tilde{A}_j}\left(P_{i+1}-P_{i-1}\right)+U_i-S_i=0, \\ \dfrac{2h_i}{\Delta t B^*_{j-1}}\left(P_{i-1}-\overline{P}_{i-1}\right)+U_i-U_{i-2}-2h_jS_j=0, \end{cases}$$

or

$$\begin{cases} U_i=a_i\left(P_{i-1}-P_{i+1}\right)+S_i, \\ U_i=U_{i-2}-b_{i-1}P_{i-1}+2h_iS_j+b_{i-1}\overline{P}_{i-1}, \end{cases} \qquad (15)$$

where the notations were used

$$a_i=\frac{1}{2h_i\tilde{A}_j}, \quad (16)$$

$$b_{i-1}=\frac{2h_i}{\Delta t B^*_{j-1}}. \qquad (17)$$

We organize the run along U_i even coordinates according to the dependence

$$U_i=a'_{i+2}U_{i+2}+b'_{i+2}.$$

In particular, $U_0=a'_2U_2+b'_2=Q_н$,

where $a'_2=0$, $b'_2=Q_н$.

From the running dependence for the previous value of *i* it follows

$$U_{i-2}=a'_iU_i+b'_i. \quad (18)$$

Let's insert this into the second equation of system (15)

$$U_i=a'_iU_i+b'_i-b_{i-1}P_{i-1}+2h_iS_j+b_{i-1}\overline{P}_{i-1}.$$

Transforming the latter, we obtain

$P_{i-1} + \alpha_i U_i = \beta_i$, (19)

where $\alpha_i = \dfrac{1 - a_i^{'}}{b_{i-1}}$, (20)

$\beta_i = \dfrac{b_i^{'} + 2h_i S_j}{b_{i-1}} + \overline{P}_{i-1}$. (21)

Together with (19) and the first equation of system (15), the system is composed

$$\begin{cases} U_i = \dfrac{\beta_i}{\alpha_i} - \dfrac{P_{i-1}}{\alpha_i}, \\ U_i = a_i(P_{i-1} - P_{i+1}) + S_i, \end{cases}$$

from which follows the running formula for pressure

$P_{i-1} = \alpha_{i+1} P_{i+1} + \beta_{i+1}$, (22)

where $\alpha_{i+1} = \dfrac{\alpha_i a_i}{1 + \alpha_i a_i}$, (23)

$\beta_{i+1} = \dfrac{\beta_i - S_i}{1 + \alpha_i a_i}$. (24)

From the approximation of the 1st and 2nd equations (11), with the involvement of

$P_{i-1} + \alpha_i U_i = \beta_i$, (25)

we find that $U_i = a_{i+2}^{'} U_{i+2} + b_{i+2}^{'}$, (26)

where $a_{i+2}^{'} = \dfrac{a_i}{a_i + b_{i+1}(1 + a_i \alpha_i)}$, (27)

$$b_{i+2}^{'} = \frac{b_{i+1}(a_i \beta_i + S_i) - a_i\left(2h_i S_j^{(i+1)} + b_{i+1}\overline{P}_{i+1}\right)}{a_i + b_{i+1}(1 + a_i \alpha_i)}. \quad (28)$$

Having introduced the appropriate modifications taking into account the values of $a_{i+2}^{'}$ and $b_{i+2}^{'}$, to find the pressure value we have

$P_{i+1} = -\alpha_{i+2} u_{i+2} + \beta_{i+2}$, (29)

where

$$\alpha_{i+2} = \frac{1 - a_i\alpha_i}{a_i + b_{i+1}(1 + a_i\alpha_i)}, \qquad (30)$$

$$\beta_{i+2} = \frac{a_i\beta_i + (1 + a_i\alpha_i)\left(b_{i+1}\overline{P}_{i+1} + 2h_i S_j^{(i+1)}\right) + S_i}{a_i + b_{i+1}(1 + a_i\alpha_i)}. \qquad (31)$$

The calculation of the running coefficients for pressure is carried out at internal points along the entire length of the calculated linear section and begins with the calculation

$$\alpha_2 = \frac{1}{B_1^*},\ \beta_2 = \frac{Q_н}{B_1^*} + \overline{P}_1.$$

The backscattering starts with calculating the value

$$P_{N-1} = \beta_N - \alpha_N U_N, \qquad (32)$$

with the help of which the meaning is determined P_N. Approximating the equations $\frac{\partial P}{\partial x} + \tilde{A}Q = 0$ for $N - 1/2$- fictitious point

$\frac{P_N - P_{N-1}}{h_{N-1}} = \tilde{A}_N Q_N$, we will receive

$$P_N = P_{N-1} - h\tilde{A}_N Q_N, \qquad (33)$$

where Q_N - the flow rate at the outlet of the calculated section, depending on time. After performing the reverse run, we obtain the values U_i in even numbers, and P_i - at odd points. To fill the array U at odd points we use the approximation of the second equation

$$\frac{P_{i+1} - \overline{P}_{i+1}}{\Delta t} + B_j^*\frac{U_{i+2} - U_{i+1}}{h_i} - B_j^* S_j = 0,$$

and to obtain values P at even points - by approximating the first equationa для получения значений в четных точках

$$\frac{P_{i+1} - P_i}{h_i} + \tilde{A}_j Q_{i+1} = 0.$$

In the final stage of the running process, the following are calculated:

$U_1 = Q_1 = Q_н - \frac{\mathrm{h}}{\mathrm{B}_1^*\Delta\mathrm{t}}\left(P_1 - \overline{P}_1\right)$ and

$$P_н = P_2 + 2\tilde{A}_1 h_1 Q_1. \qquad (34)$$

Thus, for a fixed time layer, the following approximations of the values P_i and Q_i for Problem 1 are obtained. For task 1, the graphical result of the calculation is (Fig. 2, 3).

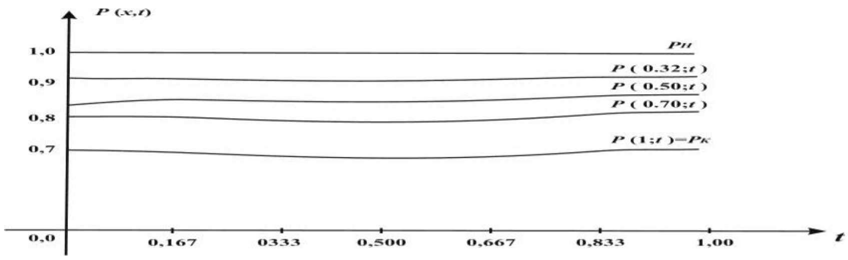

Fig. 2. Change in pressure during one day at different points along the length of the main gas pipeline for Problem 1

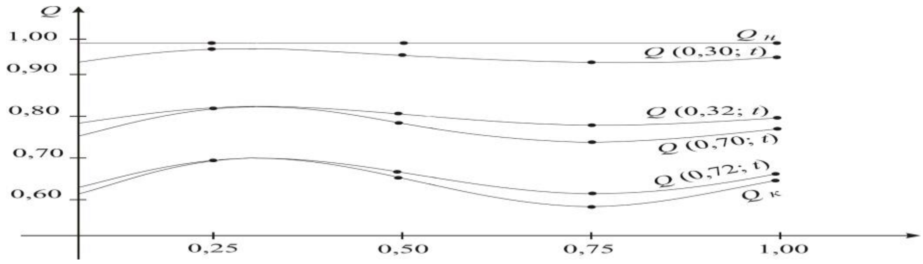

Fig. 3. Change in gas Q_i consumption per day for Task 1

Problem 2. Given $P_н$ and $P_к$.

Since the pressure values are known at the extreme (odd) points, the approximation of the equations and the running process are constructed for the pressure at odd points, and for the function U - at even points. In this regard, the discrete analogue of the system being solved has the form

$$\begin{cases} \dfrac{P_i - P_{i-2}}{2h_{i-1}} + \tilde{A}_j\left(U_{i-1} - S_{i-1}\right) = 0, \\ \dfrac{P_i - \overline{P}_i}{\Delta t} + B_j^* \dfrac{U_{i+1} - U_{i-1}}{2h_i} + B_i^* S_j^{(i)} = 0, \end{cases} \qquad (35)$$

where $S_{i-1} = \left(x_{i-1} - \xi_j\right)\dfrac{q_{j-1}}{l_j}$, (36)

$$S_j^{(i)} = \frac{q_{j-1}}{l_j}. \qquad (37)$$

After modifications, we get

$$\begin{cases} U_{i-1} = a_{i-1}\left(P_{i-2} - P_i\right) + S_{i-1}, \\ U_{i+1} = U_{i-1} - b_i P_i + 2h_i S_j^{(i)} + b_i \overline{P}_i, \end{cases} \qquad (38)$$

where $a_{i-1} = \dfrac{1}{2h_{i-1}\tilde{A}_{j-1}}$, $b_i = \dfrac{2h_i}{\Delta t B_j^*}$.

The solution is sought in the form $P_i = \alpha_{i+2} P_{i+2} + \beta_{i+2}$, which is the same

$P_{i-2} = \alpha_i P_i + \beta_i$.

Since from the first equation (38) it follows

$U_{i-1} = a_{i-1}(\alpha_i P_i + \beta_i - P_i) + S_{i-1}$, that

$$U_{i-1} + \alpha_{i-1} P_i = \beta_{i-1}, \qquad (39)$$

where

$$\alpha_{i-1} = a_{i-1}(1 - \alpha_i), \qquad (40)$$

$$\beta_{i-1} = a_{i-1}\beta_i + S_{i-1}. \qquad (41)$$

Combining the second equation (38) with (39), taking into account $P_i = -\frac{U_{i-1}}{\alpha_{i-1}} + \frac{\beta_{i-1}}{\alpha_{i-1}}$,

we will receive

$$U_{i-1} = a'_{i+1} U_{i+1} + b'_{i+1}, \qquad (42)$$

where

$$a'_{i+1} = \frac{\alpha_{i-1}}{b_i + \alpha_{i-1}} \qquad (43)$$

$$b'_{i+1} = \frac{b_i(\beta_{i-1} - \alpha_{i-1})\overline{P}_i - 2h_i \alpha_{i-1} S_j^{(i)}}{b_i + \alpha_{i-1}}. \qquad (44)$$

Solving (38) and (39) together, we obtain

$$P_i = \alpha_{i+2} P_{i+2} + \beta_{i+2}, \qquad (45)$$

where

$$\alpha_{i+2} = \frac{a_{i+1}}{b_i + a_{i+1} + \alpha_{i-1}}, \qquad (46)$$

$$\beta_{i+2} = \frac{\beta_{i-1} + b_i \overline{P}_i + 2h_i S_j^{(i)} - S_{i+1}}{b_i + a_{i+1} + \alpha_{i-1}}. \qquad (47)$$

Given α_{i+2} and β_{i+2}, we can calculate the coefficients for

$$U_{i+1} = \beta_{i+1} - \alpha_{i+1} P_{i+2} : \qquad (48)$$

$$\alpha_{i+1} = \frac{a_{i+1}(b_i + \alpha_{i-1})}{b_i + a_{i+1} + \alpha_{i-1}}, \qquad (49)$$

$$\beta_{i+1} = \frac{a_{i+1}\left(\beta_{i-1} + b_i \overline{P}_i + 2h_i S_j^{(i)}\right) + (b_i + \alpha_{i-1}) S_{i+1}}{b_i + a_{i+1} + \alpha_{i-1}} \qquad (50)$$

Backtracking starts with calculations

$$U_{N-1} = \beta_{N-1} - \alpha_{N-1} P_N \ , \ Q_{N-1} = U_{N-1} - S_{N-1}. \quad (51)$$

After the reverse run has been carried out, similarly to the solution of Problem 1, the intermediate values P and U are filled in.

In particular, the dependency is used

$$U_N = U_{N-1} + \frac{B_N^*}{2}\left(P_{N-1} - \overline{P}_{N-1}\right) + h_{N-1} S_j^{(N-1)}, \qquad (52)$$

$$Q_N = U_N - S_i. \quad (53)$$

For problem 2, the graphical result of the calculation is (Fig. 4, 5).

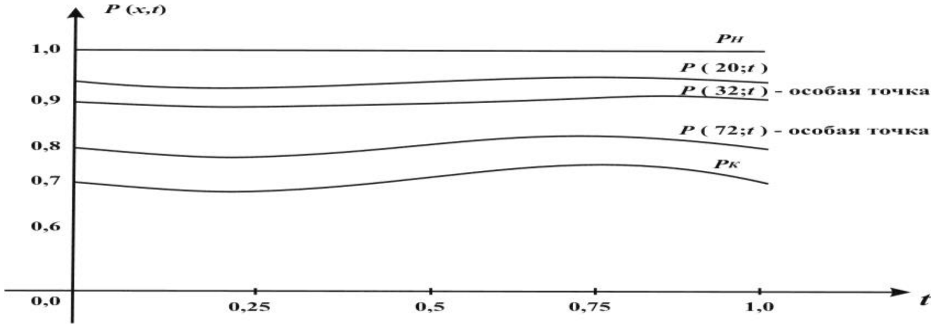

Fig. 4. Pressure change during the day at the beginning, in the section x =20 km, at special points and at the end of the GP for Problem 2

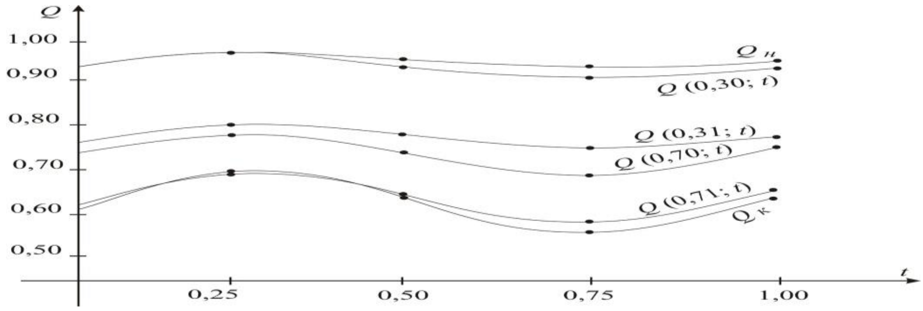

Fig. 5. Change in gas consumption Q_i by MG per day for Task 2

Problem 3. Given $Q_н$ and $P_к$. The sweep process is organized with the coefficients that are given in part of Problem 1, but the beginning of the reverse sweep is somewhat different.

In the first equation

$$\frac{P_N - P_{N-1}}{h_{N-1}} = -\tilde{A}_N U_N - \tilde{A}_N S_N \quad (54)$$

insert value

$$P_{N-1} = \beta_N - \alpha_N U_N \qquad (55)$$

and we get

$$P_N - \beta_N + \alpha_N U_N = -h_{N-1} \tilde{A}_N U_N - h_{N-1} \tilde{A}_N S_N. \quad (56)$$

From here

$$U_N = \frac{\beta_N - P_N - h_{N-1}\widetilde{A}_N S_N}{\alpha_N + h_{N-1}\widetilde{A}_N}, \qquad (57)$$

by means of which it is determined

$$Q_k = Q_N = U_N - \alpha_N U_N. \qquad (58)$$

The gaps in the arrays P and U are filled in using the formulas given in part of Task 1. For Task 3, the graphical result of the calculation is (Fig. 6, 7).

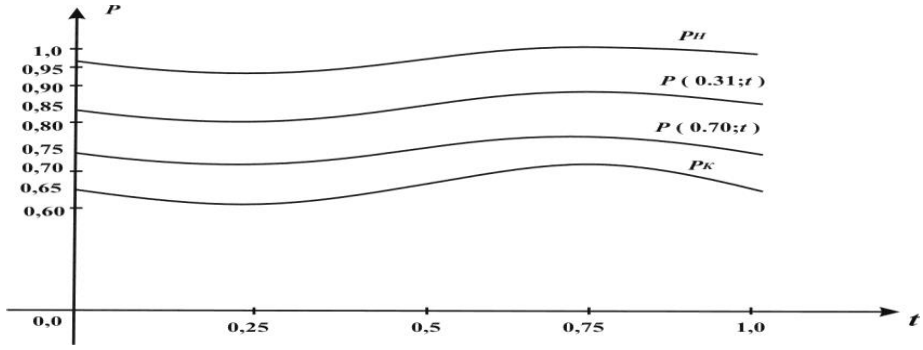

Fig. 6. Change in pressure during the day at points

$\bar{x}$=0; 0,31; 0,70 and 1 MG for Task 3

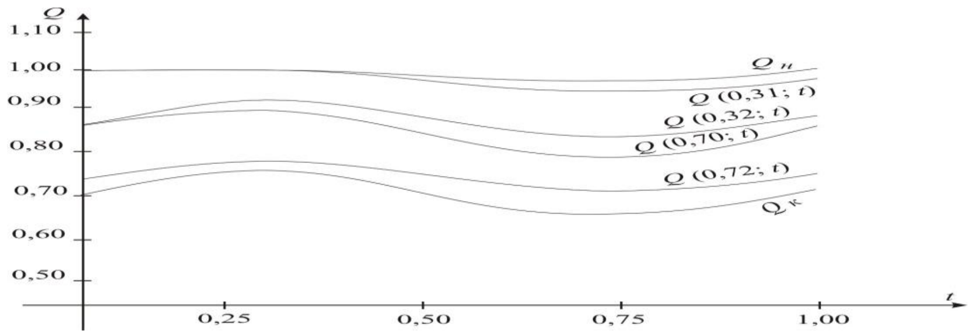

Fig. 7. Change in gas consumption Q_i by MG per day for Task 3

Problem 4. Given $P_н$ and Q_k.

The running coefficients are calculated according to the sequence described in Part 2 of Problem. The difference is in the calculation of the value P_N. It is determined from the system

$$\begin{cases} \dfrac{P_N - \overline{P}_N}{\Delta t} + B_N^* \dfrac{U_N - U_{N-1}}{h_N} + B_N^* S_j^{(N)} \\ U_{N-1} = \beta_{N-1} - \alpha_{N-1} P_N \end{cases} \qquad (59)$$

and makes up

$$P_N = \frac{h_N \overline{P}_N - B_N^* \Delta t \left(U_{N-1} - h_N S_j^{(N)}\right)}{h + B_N^* \Delta t \alpha_{N-1}}. \qquad (60)$$

Then a reverse run is carried out, as in part of Problem 2, and the gaps in the arrays are filled in P and U using the newly calculated values of the desired ones.

For Problem 4, the graphical result of the calculation is (Fig. 8, 9).

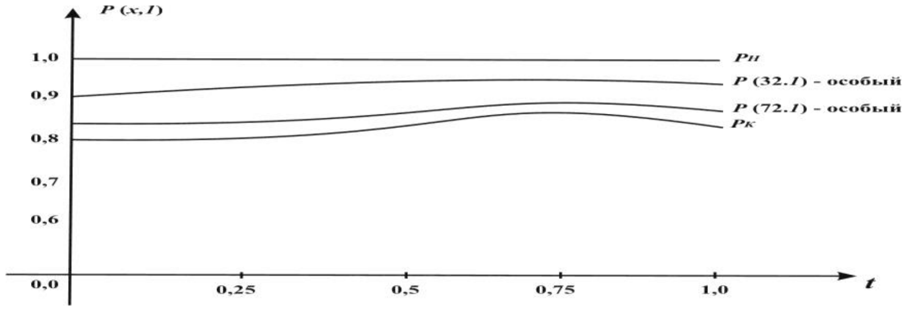

Fig. 8. Pressure change during the day at points

x =0; 32; 72 and 100 km MG for Problem 4

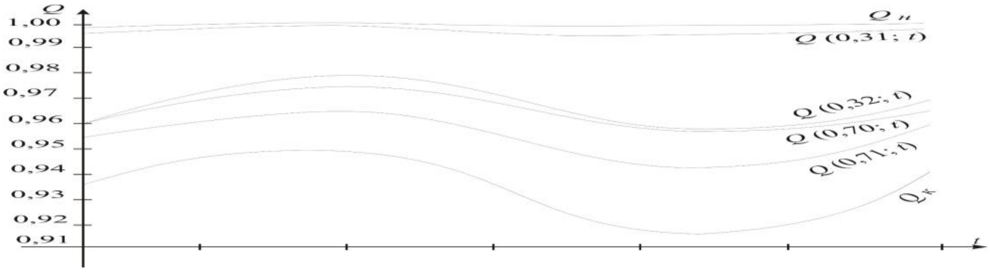

Fig. 9. Change in gas consumption Q_i by MG per day for Task 4

As a result of the conducted research, a universal computational algorithm has been developed, which allows calculating both static and dynamic modes of gas-dynamic parameters of a single-string main gas pipeline (MGP) with a constant diameter. The algorithm takes into account the full range of possible boundary conditions and the dynamics of gas movement in real operating conditions of main gas pipelines. Analysis of the results of computational experiments shows that the time dynamics of changes in pressure, gas flow rate and values of the introduced auxiliary function are largely determined by the choice of boundary conditions at the inlet and outlet of the gas pipeline.

The introduction of an auxiliary function with an extended number of singular points has proven its effectiveness: not only does it not worsen the accuracy of calculations, but also significantly simplifies the construction of a single computational algorithm and its subsequent implementation on personal computing systems.

Thus, the computational experiments conducted and the analysis of their results allow us to conclude that it is advisable to develop a unified methodology for calculating gas-dynamic parameters and operational control of linear sections of the main gas pipeline, taking into account point extractions and gas injections under conditions of dynamic gas consumption.

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