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REVIEW ARTICLE

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CREATION OF AN INFORMATION BASE FOR THE EFFICIENT MANAGEMENT OF RECONSTRUCTED COMPLEX GAS PIPELINE SYSTEMS

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ABSTRACT

A highly reliable and efficient technological scheme has been proposed for managing emergency processes in gas transportation based on the principles of the reconstruction phase. For complex gas pipeline systems, new approaches have been investigated for the modernization of existing control process monitoring systems. These approaches are based on modern achievements in control theory and information technology, aiming to select emergency and technological modes. One of the pressing issues is to develop a method to minimize the transmission time of measured and controlled data on non-stationary flow parameters of gas networks to dispatcher control centers. Therefore, the reporting schemes obtained for creating a reliable information base for dispatcher centers using modern methods to efficiently manage the gas dynamic processes of non-stationary modes are of particular importance.

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INTRODUCTION

The increasing consumption volumes and resource usage to meet the gas demand in the country can be ensured not only through the design and construction of new networks and structures but also through the reconstruction of gas pipelines and efficient management by utilizing potential reserves. Gas pipeline systems are complex systems characterized by numerous elements, and managing them requires a large amount of information corresponding to the number of possible elements. Managing such complex gas pipelines is impossible without a systematic approach based on the combined consideration of complex concepts of control theory, such as system, information, goal-oriented, and feedback. New approaches to reconstruction methods aimed at ensuring a higher level of quality are required in managing these systems. The theory of selecting justified parameters for the operation and reconstruction of main gas pipelines requires the calculation of non-stationary processes resulting from any emergency [8, 9]. This task should be considered one of the most pressing issues. The operating conditions of a reconstructed gas pipeline must ensure its ability to perform specified functions reliably for a fixed period.The novelty of the work lies in the development of reporting schemes for solving several important new problems related to the management and regulation of technological processes in gas transportation based on optimization methods and mathematical modeling. For this purpose, an algorithm for the operational management of gas transportation systems has been developed. This algorithm is based on the information obtained about the emergency state of pipelines by monitoring changes in the technological parameters of gas flow at the peripheral parts of the pipelines during emergency modes. This significantly enhances the reliability of gas supply management and the efficiency of transportation processes during the reconstruction phase of complex gas pipelines. At the current stage, the issues we face differ fundamentally from those already addressed[3,6,7,10]in that they involve imposing specific requirements and time constraints during the development phase of the reconstruction concept for complex gas pipeline systems. This ensures the acquisition of structural, technical, and technological bases within the framework of future operation of complex gas pipeline systems, the clarification and elimination of technical and technological contradictions in the process of gas transportation system development and reconstruction, and the efficient management of the gas transportation system under modern conditions.

Justification of an effective gas transportation scheme for the reconstruction of the existing parallel gas pipeline: The essence of the studied method is to justify a targeted technological variant for reconstruction by increasing the efficiency of gas transportation under non-stationary conditions. The reconstruction of gas transportation systems is characterized by the reliability of multi-level information bases transmitted to the dispatcher control center for complexes of local management systems of individual technological processes and objects.

The reconstruction phase is based on the following key principles:

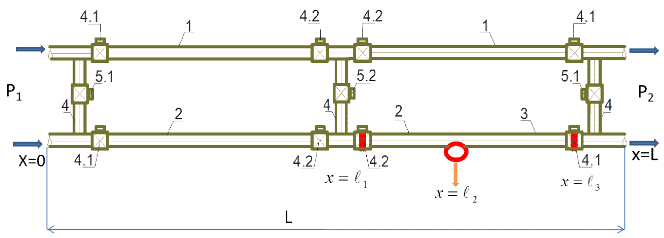
- The advantages of an efficient technological scheme for complex gas pipeline systems;
- The uninterrupted transportation of planned gas flows to consumers;
- The level of reliability indicators for complex gas pipeline systems;
- The safety of the operation and environmental aspects of complex gas pipeline systems;
- Maximum conservation of energy and resources;
- The enhancement of technological and economic efficiency levels of complex gas pipeline systems.

The "Main Pipeline Design" standards state that parallel gas pipelines are complex systems consisting of two or more pipeline lines. These lines have the same pressure at the beginning and end sections and are equipped with at least two connectors and connecting fittings to ensure the transfer of gas flow between the pipelines during technical operations and emergencies. These systems, having the same initial and final pressure and operating in a unified hydraulic regime, create challenges for the application of modern control systems in dispatcher centers during emergency regimes. In other words, the information obtained from changes in gas flow parameters at the end sections of the system due to the failure of one of the pipeline lines in parallel gas pipelines is not reliable. According to the research conducted in reference [2], it was confirmed that depending on the operating conditions of gas pipelines, the pressure values at the beginning and end sections of damaged (ruptured) and undamaged pipeline lines were equal. Moreover, it was even observed that, at any given time during operation, the change in pressure at the beginning and end of the gas pipeline was greater for the undamaged pipeline line than for the damaged one. In such conditions, identifying the damaged section in the dispatcher center becomes impossible. Indeed, the information obtained from the non-stationary nature of gas dynamic processes makes it unreliable for the effective management of gas pipeline systems. Therefore, the development of effective gas transportation schemes for the reconstruction of existing parallel gas pipelines has become a pressing issue. This is crucial for ensuring the long-term utilization and environmental safety of complex gas pipeline transportation, as well as for achieving reliable and trouble-free operation and efficient management of emergency situations.

To prepare the technological-based reporting scheme for this purpose, the following issues need to be addressed:

1) Optimization of the operating regime of complex gas pipeline systems;
2) Implementation of effective strategies for managing parallel laid distributor pipeline systems during normal technological operating regimes and in case of emergencies;
3) Utilization of new methods with high quality for analyzing and optimizing the management of emergency and technological conditions and the selection of rational operating regimes;
4) Prevention and minimization of the consequences of emergency situations;
5) Ensuring the accuracy of damage location determination, automatic detection in real-time mode, and minimizing the impact of interventions in detection modes.

As mentioned above, accidents occurring in parallel gas pipelines operating in a unified hydraulic regime cause a decrease in pressure throughout all sections of both pipeline networks over time. The decrease in pressure at the end section of the pipeline deteriorates the process of gas supply to consumers. If we assume that the pressure difference is fully utilized by all consumers, then as the consumption of the initial gas mass in the network increases, the pressure at its end point will decrease again, leading to various devices and appliances experiencing different levels of disruption. Devices and appliances operating at maximum pressure will immediately sense the drop in gas pressure, reducing their numbers in operation simultaneously. In such a regime, only devices and appliances close to the nominal pressure will be able to operate. Therefore, these issues should be addressed in the reconstruction of existing gas pipelines. Based on the principles of the reconstruction phase, selecting an efficient technological scheme that perfectly manages the technological and emergency processes of gas transportation is essential. As we know, the reliability indicator of main gas pipelines directly depends on providing consumers with the required uninterrupted gas supply [5]. Among the complex gas pipeline systems that excel at fulfilling this function is the parallel gas pipeline system. As a result of accidents, we adopt the following technological scheme for the efficient management of gas pipelines, the detection of leakage points, and the provision of uninterrupted gas supply to consumers in complex gas pipeline systems [2].



Scheme 1. Principle diagram of a complex gas pipeline during the reconstruction phase

1 - Undamaged pipeline ($0 \le x \le L$);
2 - Section from the starting point to the leakage point of the damaged pipeline ($0 \le x \le \ell_2$),
3 - Section from the leakage point to the end point of the damaged pipeline ($\ell_2 \le x \le L$);
4- Connectors;
4.1 and 4.2 - Automatic valves on the pipeline;
5.1 and 5.2 - Automatic valves on the connectors;
P_1 - Pressure at the starting section of the gas pipeline, Pa;
P_2 - Pressure at the end section of the gas pipeline, Pa;
L - Length of the gas pipeline, m.
ℓ_1, ℓ_3 – Distance from the starting point of the damaged pipeline to the nearest shut-off fittings to the left and right of the leakage point, respectively.

In the proposed gas transportation scheme, at the fixed moment $t=t_1$, technological measures are implemented to isolate the damaged section from the main part of the pipeline. Specifically, the location of the damaged section is detected in the shortest possible time (ℓ_2), and the positions of the valves installed to the right (ℓ_1)and left (ℓ_3) of the leakage point are identified and closed by the dispatcher center at that moment. Based on the principle of managing technological measures, it is recommended to install automatic valves at the starting section of the pipeline network to the right of the first connector (4.1) and to the left of the last connector (4.2). In the normal (stationary) operating regime of gas pipelines, the valves on the connectors are closed, while the valves on the pipelines are open. In emergency situations (when the pipeline's integrity is compromised), the valves to the right and left of the leakage point on the pipeline are closed (ℓ_1, ℓ_3), isolating the damaged section from the main part of the gas pipeline. To ensure an adequate gas supply to consumers, the valves (5.1 and 5.2) located to the right and left of the leakage point on the connecting pipeline are opened under the control of dispatcher center management panels. The main distinguishing feature of the proposed gas pipeline compared to the existing one is its operation in an independent hydraulic regime. Another key difference of the reconstructed gas pipeline is the independence of the pipeline dynamics from each other during emergencies and technological regimes. The proposed parallel gas pipeline is a complex system characterized by a compressor station serving each pipeline at the starting section and numerous elements such as connectors and valves.

Establishing an information database for the efficient management of the reconstructed gas pipeline system: To establish an information database for the efficient management of the reconstructed gas pipeline system, the reporting scheme was implemented in the following sequence. First, let's assume that the integrity of the second pipeline in the parallel gas pipeline has been compromised, resulting in a large amount of gas leaking from the damaged section ($x = \ell_2$) into the environment (Scheme 1). At this time, the undamaged pipeline continues to operate in its previous stationary regime. In other words, the non-stationary regime that arises in the damaged pipeline does not affect the undamaged pipeline. The non-stationary regime of gas flow in the damaged gas pipeline due to the accident is divided into three different technological sections:

- The section from the starting point of the pipeline to the shut-off valve to the left of the leakage point ($0 \le x \le \ell_1$),
- The damaged section of the pipeline, between the shut-off valves to the left and right of the leakage point ($\ell_1 \le x \le \ell_3$),
- The section from the shut-off valve to the right of the leakage point to the end point of the pipeline ($\ell_3 \le x \le L$).

The hydraulic models of all three sections are different. The hydraulic model of the pipeline system is constructed from the models of its components: multi-line pipelines with loops and connectors, shut-off valves, compressor stations, etc. The models of these components, in turn, consist of the computational expressions for the elements.The solution to this problem necessitates considering the entire system as a whole rather than just a separate section of the pipeline. Initially, there is a significant need for analytical expressions to solve the equations describing non-stationary events in parallel gas pipelines and for mathematical expressions to solve these equations that reflect real events in the pipeline. The non-stationary operating conditions of pipelines lead to significant pressure changes and disruptions in the normal operation of gas delivery to consumers. Studying these processes to efficiently manage the pipelines and considering the results of the obtained analytical solution methods at dispatcher control points will significantly enhance the reliability of gas supply and the efficiency of transportation processes.

For this purpose, it is essential to obtain the analytic expressions reflecting the non-stationary events in the two-line parallel gas pipelines and ensure the management of physical processes through the solution of these equations. The mentioned analytic expressions have been determined based on the resolution of the problem addressed in our published work [2], which specifically deals with the non-stationary flow of gas in each of the three sections. These expressions are as follows:

$$P_1(x,t)=P_1-2aG_0x+\frac{8aLG_0}{\pi^2}\sum_{n=1}^{\infty}Cos\frac{\pi nx}{L}\frac{e^{-(2n-1)^2\alpha_3 t}}{(2n-1)^2}-\frac{4aL}{\pi^2}G_0\sum_{n=1}^{\infty}((1-(-1)^n)Cos\frac{\pi nx}{L}*$$
$$*\frac{e^{-n^2\alpha_3 t}}{n^2}-2aG_{ut}\left(\frac{x^2}{2L}+\frac{\ell_2^2}{2L}+\frac{L}{3}-\ell_2\right)+\frac{4aL}{\pi^2}G_{ut}\sum_{n=1}^{\infty}Cos\frac{\pi nx}{L}Cos\frac{\pi n\ell_2}{L}\frac{e^{-n^2\alpha_3 t}}{n^2} \quad (1)$$

$$P_{2,3}(x,t)=P_1(x,t)-2aG_{ut}(x-\ell_2) \quad (2)$$

Here, $\alpha_3=\frac{\pi^2c^2}{2aL^2}$

By considering x=0 in equation (1) and x=L in equation (2), we establish the conformity of the pressure distribution at the beginning and end points of the gas pipeline over time.

$$P_1(0,t)=P_1-\frac{c^2t}{L}G_{ut}+\frac{8aLG_0}{\pi^2}\sum_{n=1}^{\infty}\frac{e^{-(2n-1)^2\alpha_3 t}}{(2n-1)^2}-2aG_{ut}\left(\frac{\ell_2^2}{2L}+\frac{L}{3}-\ell_2\right)+$$
$$+\frac{4aL}{\pi^2}G_{ut}\sum_{n=1}^{\infty}Cos\frac{\pi n\ell_2}{L}\frac{e^{-\alpha_2 t}}{n^2} \quad (3)$$

$$P_3(L,t)=P_2-\frac{c^2t}{L}G_{ut}+\frac{8aLG_0}{\pi^2}\sum_{n=1}^{\infty}(-1)^n\frac{e^{-(2n-1)^2\alpha_3 t}}{(2n-1)^2}-2aG_{ut}\left(\frac{L}{2}+\frac{\ell_2^2}{2L}+\frac{L}{3}-\ell_2\right)+ \quad (4)$$
$$+\frac{4aL}{\pi^2}G_{ut}\sum_{n=1}^{\infty}(-1)^nCos\frac{\pi n\ell_2}{L}\frac{e^{-\alpha_2 t}}{n^2}-2aG_{ut}(\ell_2-L)$$

Based on equations (3) and (4) and the results of the analysis conducted in [1], we obtain the following expression:

$$\theta=\frac{1}{2}+\left[\frac{1-p(t)}{1+p(t)}\right]\cdot\left[\frac{2}{3}+\frac{e^{-2\alpha_2 t}-4e^{-\alpha_2 t}}{\pi^2}\right] \quad (5)$$

Here, $\alpha_2=\frac{\pi^2c^2}{2aL^2}$; p(t)= $\frac{P_1-P_1(0,t)}{P_2-P_2(L,t)}$; $\theta=\frac{\ell_2}{L}$

G_{ut}- Mass flow rate at the leakage point for the gas pipeline accident regime, Pa·sec/m

G_0- Mass flow rate at the beginning of the gas pipeline in the stationary regime, Pa·sec/m

c - Speed of sound propagation for gas in an isothermal process, m/s

P - Pressure at the ends of the gas pipeline, Pa

x - Coordinate along the length of the gas pipeline, m

t - Time coordinate, sec

2a - Charney linearization, 1/sec

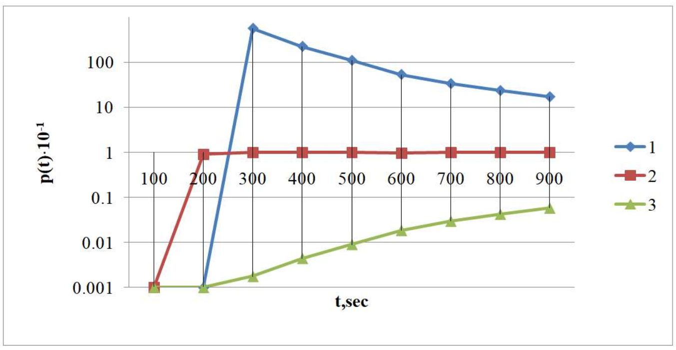
It should be noted that the function p(t) characterizes the ratio of pressure values at the beginning and end points of the gas pipeline. Based on the analysis of the parameters involved in equation (5), it becomes evident that there is a functional dependence between θ and p(t). Based on the conducted research, it was determined that if P(t) = 1, then θ takes a value of 0.5. This indicates that the gas leakage occurs in the exact middle section of the pipeline. When p(t) takes values greater than 1, θ takes values less than 0.5, confirming that the gas leakage occurs between the initial and middle sections of the pipeline. Conversely, when p(t) takes values less than 1, θ takes values greater than 0.5, confirming that the gas leakage is situated between the middle and final sections of the pipeline. To confirm the above ideas, the expressions (3) and (4) were examined, and the following parameters of the gas pipeline were considered to determine the law of pressure change along the gas axis at different characteristic points of gas leakage location (at the beginning, ℓ_2 = 0,5 · 10^4 m ; in the middle, ℓ_2 = 5·10^4 m, and at the end, ℓ_2 = 9,5·10^4 m).

P_1= 55·10^4 Pa: P_2= 25· 10^4 Pa: G_0= 30 Pa ·sec/m ; $c = 383{,}3\frac{m}{sec}$;

L = 10·10^4m:

Currently, the calculation of gas flow regimes is implemented through the use of modern software. Firstly, the pressure values of the gas pipeline at the beginning and end of the pipeline are calculated for each of the three characteristic points of the gas leakage every 100 seconds. The results are recorded in Table 1 below.

Using the data provided in Table 1, we plot the graph of p(t) as a function of time for each of the three characteristic points (Graph 1).



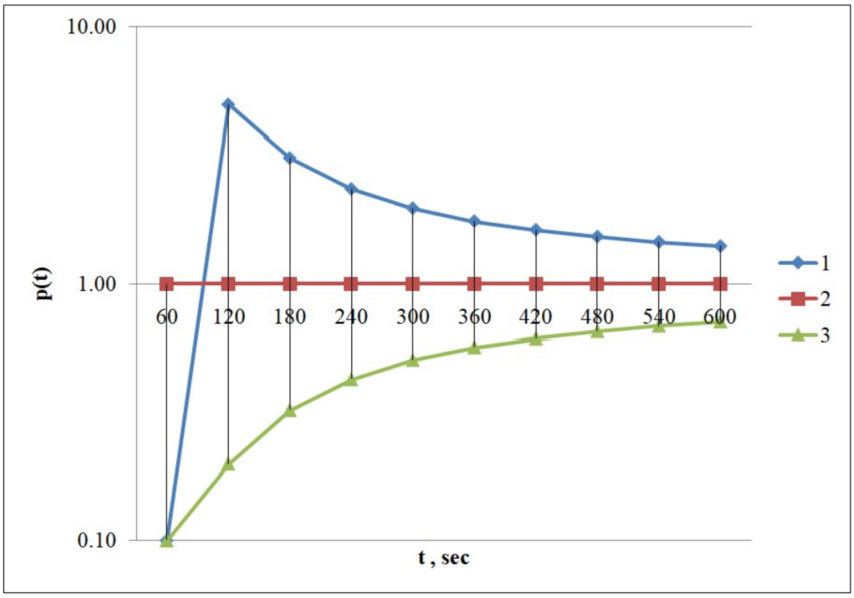
Graph 1. Variation pattern of p(t)p(t)p(t) function over time, dependent on the location of the gas pipeline rupture. (1- ℓ_2 =0,5·10^4 m; 2- ℓ_2 =5·10^4 m; 3- ℓ_2 =9,5·10^4 m)

Table 1. Pressure values at the point of rupture of the gas pipeline depending on time

t, sec	$\ell_2 = 0,5 \cdot 10^4$ m		$\ell_2 = 5 \cdot 10^4$ m		$\ell_2 = 9,5 \cdot 10^4$ m	
	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	Pressure in the last part, $P_3(L,t)$, 10^4 Pa	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	Pressure in the last part, $P_3(L,t)$, 10^4 Pa	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	Pressure in the last part, $P_3(L,t)$, 10^4 Pa
100	52,23	25	55	24,99	55	22,23
200	50,58	25	54,9	24,89	55	20,58
300	49,3	24,99	54,66	24,66	54,99	19,3
400	48,21	24,97	54,34	24,33	54,97	18,21
500	47,25	24,93	53,96	23,96	54,925	17,25
600	46,38	24,84	53,56	23,49	54,84	16,38
700	45,58	24,72	53,14	23,14	54,72	15,58
800	44,83	24,57	52,71	22,71	54,565	14,84
900	44,13	24,37	52,28	22,27	54,37	14,14

Table 2. Pressure values of the gas pipeline depending on the location of the leakage and time

t, sec	The location of the gas pipeline failure.					
	$\ell_2 = 0,5 \cdot 10^4$ m		$\ell_2 = 1,5 \cdot 10^4$ m		$\ell_2 = 2,5 \cdot 10^4$ m	
	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	The pressure in the last part, $P_2(L,t)$, 10^4 Pa	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	The pressure in the last part, $P_2(L,t)$, 10^4 Pa	The pressure in the starting part, $P_1(0,t)$, 10^4 Pa	The pressure in the last part, $P_2(L,t)$, 10^4 Pa
60	13,37	10,97	13,83	10,83	13,97	10,37
120	12,95	10,79	13,54	10,54	13,79	9,95
180	12,61	10,55	13,24	10,24	13,55	9,61
240	12,29	10,27	12,95	9,95	13,27	9,29
300	11,99	9,98	12,66	9,66	12,98	8,99
360	11,70	9,69	12,36	9,36	12,69	8,70
420	11,40	9,40	12,07	9,07	12,40	8,40
480	11,11	9,11	11,77	8,77	12,11	8,11
540	10,81	8,81	11,48	8,48	11,81	7,81
600	10,52	8,52	11,19	8,19	11,52	7,52



Graph 2. The variation pattern of p(t)p(t)p(t) function depending on the time and the location of the gas pipeline's leakage. (1- ℓ_2 =0,5·10^4 m; 2- ℓ_2 =1,5·10^4 m; 3- ℓ_2 = 2,5·10^4 m)

The analysis of Graph 1 reveals that, regardless of the location of the gas pipeline rupture based on the parameters mentioned above, the p(t) function attains maximum or minimum values within a duration of t=300 seconds. Therefore, the fixed time observed at dispatcher stations for the examined gas pipeline is t_1= 300 seconds. Minimizing the transmission time of information to dispatcher control centers is crucial. Therefore, the adopted value of t_1= 300 seconds ensures the safe operation of gas pipelines. On the other hand, the p(t) function takes different values depending on the dependence on θ, which determines the location of the leakage.

Specifically, when θ > 0.5, the p(t) function takes its minimum value (3rd line in Graph 1), while for θ < 0.5, the p(t) function takes its maximum value (1st line in Graph 1). However, when θ is approximately equal to 0.5, p(t) approaches 1, indicating a scenario where the leakage point is in the middle section of the pipeline (ℓ_2 =5·10^4 m). The analysis of the graph leads to the following conclusion: when p(t) belongs to the interval]0;1[, it characterizes the location of gas pipeline rupture occurrence between $0 < \ell_2 < \frac{L}{2}$. When p(t) is greater than 1, it confirms the occurrence of gas pipeline rupture between $\frac{L}{2} < \ell_2 < L$. When p(t) = 1, it confirms that the location of gas pipeline rupture is at the exact midpoint ($\ell_2 = \frac{L}{2}$). Clearly, these simple and understandable pieces of information are very important for the gas emergency control center. Based on the analysis conducted, it was determined that the fixation period $t=t_1$ remains constant regardless of the location of accidents on the pipeline. To determine whether this time remains constant or varies depending on the parameters of the pipeline, we consider different parallel gas pipelines with the following parameters particular importance.

$P_1 = 14 \cdot 10^4$ Pa: $P_2 = 11 \cdot 10^4$ Pa: $G_0 = 10$ Pa ·sec/m ; $c = 383{,}3 \frac{m}{\sec}$; $L = 3 \cdot 10^4$m:

It is evident from the given information that the length of the newly adopted parallel gas pipeline is at least 3 times shorter than the length of the previously analyzed gas pipeline, and also that the values of other parameters (pressure and consumption) are different. We consider the length of the examined complex parallel pipeline at three characteristic points where the gas leakage occurs, similar to the previous pipeline: near the beginning of the pipeline $\ell_2 = 0{,}5 \cdot 10^4$ m, at the middle $\ell_2 = 1{,}5 \cdot 10^4$ m, and near the end $\ell_2 = 2{,}5 \cdot 10^4$ m. We use equations (3) and (4) to calculate the pressure values of the gas pipeline's beginning and end sections every 60 seconds for each of the three characteristic points where the gas leakage occurs. The results are recorded in the following table (Table 2). Using the data from Table 2, we plot the graph of p(t) as a function of time for each of the three characteristic points (Graph 2). From the analysis of Graph 2, it can be noted that the variation of pressure over time in the outer sections depending on the location of the gas pipeline's leakage is similar to that observed in Graph 1. Specifically, when θ>0.5, the p(t) function takes its minimum value (indicated by the 3rd line in Graph 2), while for θ<0.5, the p(t) function takes its maximum value (indicated by the 1st line in Graph 2). However, regardless of the location of the gas pipeline's leakage, the p(t) function takes its maximum or minimum value over a duration of t=120 seconds.

This means that the fixed duration t_1=120 seconds is applicable for this gas pipeline. It can be concluded that the fixed duration varies depending on the length of the gas pipeline and the parameters of the gas flow. Thus, as the length of the pipeline segment decreases, this duration decreases accordingly. This is because the time required for the parameters of the non-stationary gas flow during the accident to reach the starting point of the gas pipeline is related to the change in the parameters. Considering the short length of the analyzed gas pipeline segment and the reliability of the information transmitted to the dispatcher station, it is necessary to accept a minimum duration of fixation that is sufficient to record the change in pressure of the non-stationary gas flow at the dispatcher station. In other words, even if the speed of the non-stationary gas flow in the pipeline matches its sound propagation speed, the delivery time of information from the last three points of a 100,000-meter pipeline segment to the starting point cannot be faster than 261 seconds. It should be noted that considering this indicator during the reconstruction stage of gas pipelines for efficient management allows for the optimization of the issue of minimizing the transfer time of information and control system data to dispatcher control centers. We conduct theoretical research to examine the consistency of the method for determining the fixing time t=t1, which is one of the measures taken to reduce the workload of the dispatcher station. For this purpose, we perform engineering calculations based on theoretical research. Using equation (5), we determine the location of the pipeline's instability point at each of the three characteristic points, depending on time. First, we calculate based on the data of the gas pipelines under consideration, with a length of L=100,000 m, and record the calculation results in the following table (Table 3). Sequentially, based on the given data for the next gas pipeline with a length of L = 30,000 m, we calculate the locations of instability points at each of the three characteristic points using equation (5) and record the results in the following table (Table 4). Based on the analysis of Tables 3 and 4, it can be noted that the prescribed equation (5) is useful for engineering calculations. The results of both analyzed gas pipelines' calculations showed that only at the fixed time $t=t_1$ is the location of instability accurately determined, with its relative error value not exceeding 0.04, or in other words, less than 4%.

Table 3. Relative Error of the Actual and Calculated Values of the Gas Instability Point Location Depending on Time for a Pipeline with a Length of 100,000 meter

t, sec	Actual values of failure of the pipeline with a length of 100000 m.					
	$\ell_2 = 0{,}5 \cdot 10^4$ m		$\ell_2 = 5 \cdot 10^4$ m		$\ell_2 = 9{,}5 \cdot 10^4$ m	
	Calculated by formula (5) price,	Relative error of actual and calculated prices	Calculated by formula (5) price,	Relative error of actual and calculated prices	Calculated by formula (5) price,	Relative error of actual and calculated prices
100	-	-	5,00	0,00	5,00	0,47
200	-	-	5,20	0,02	9,20	0,03
300	0,55	0,04	5,00	0,00	9,45	0,01
400	0,33	3,44	5,04	0,00	9,67	0,02
500	0,15	1,61	5,00	0,00	9,84	0,04
600	0,04	1,38	5,12	0,01	9,96	0,05

Table 4. The values of the relative error of the actual and calculated positions of instability of the gas pipeline with a length of 30,000 m, depending on time

t, sec	Actual values of failure of the pipeline with a length of 30000 m.					
	Actual values of pipeline failure.					
	$\ell_2 = 0{,}5 \cdot 10^4$ m,		$\ell_2 = 1{,}5 \cdot 10^4$ m		$\ell_2 = 2{,}5 \cdot 10^4$ m	
	Calculated by 5) price,	Relative error of calculated prices	Calculated by 5) price,	Relative error of calculated prices	Calculated by 5) price,	Relative error of calculated prices
60	0,06	0,87	1,50	0,0	2,94	0,175
120	0,28	0,44	1,50	0,0	2,72	0,088
180	0,51	0,02	1,50	0,0	2,49	0,005
240	0,71	0,41	1,50	0,0	2,29	0,083
300	0,85	0,70	1,50	0,0	2,15	0,140
360	0,95	0,91	1,50	0,0	2,05	0,181

Therefore, the prescribed calculation scheme is a suitable method for verifying the compliance of gas pipelines with the requirements for safe and efficient utilization, determining the parameters of gas flow in non-stationary regimes, as well as selecting appropriate parameters for the reconstruction of gas pipelines.

The determination of the analytical expression based on which accidents and technological regimes are selected for dispatcher stations.

The variation in pressure in a gas pipeline can result from both changes in the amount of gas supplied to consumers, the opening and closing of valves in the pipeline, and the operation of various elements within the pipeline. As a result, technological processes cause changes in pressure at the beginning and end sections of the gas pipeline. One of the most important tasks of operational control in gas pipeline technological regimes is to identify critical conditions in gas supply systems at dispatcher stations. For instance, pressure variations at the end sections of the pipeline can occur as a result of changes in technological regimes. Therefore, it is essential to prioritize understanding the pressure changes resulting from technological processes in the event of accidents. The initial model of events and processes occurring in gas transmission systems is not always accurately represented with high precision. Therefore, to solve the problems of operational management of gas transmission systems, it is necessary to use analytical expressions to assess the real situation of gas transmission systems. Having a mathematical expression allows for selecting the parameters and control structures of the pipeline, determining optimality criteria and constraints, assessing accuracy, selecting appropriate technical control devices, and so on.
To solve the problems of managing trunk gas pipelines, it is necessary to understand the non-stationary dynamic characteristics of these systems. It is appropriate to utilize the formalization of technological and accident processes for the transportation of gas in pipeline systems. By employing the method of describing accident processes, it is possible to obtain unit characteristics. Based on theoretical research, the following inequality has been determined:

$$\frac{\varphi-0,5}{\varphi+0,5} < p(t) < \frac{\varphi+0,5}{\varphi-0,5} \qquad (6)$$

Here, $\varphi = \frac{2}{3} + \frac{e^{-2\alpha_2 t} - 4e^{-2\alpha_2 t}}{\pi^2}$

It has been determined that if the function p(t) satisfies the conditions of the inequality mentioned above, the variation of pressure over time corresponds to the lawfulness characterizing accidents in the gas pipeline, otherwise, it is the result of technological processes. Therefore, the function p(t) is a reliable parameter that enables dispatchers to make timely decisions for the efficient management of the gas pipeline. At the point where time $t=t_1$is fixed, the value of θ\thetaθ and the obtained values of the function p(t) are reliable information for the dispatcher station. This is because the accuracy of determining the leakage location is characterized by the moment $t=t_1$. On the other hand, for the reliability and effectiveness of automatic detection of the accident location in online mode, these parameters are useful. For instance, if pressure changes are observed in the initial and final sections of the gas pipeline, the dispatcher station first determines whether this change occurred as a result of the accident based on the conditions of inequality (6). Sequentially, the values of the function p(t) are automatically calculated, and its maximum or minimum value is determined. The obtained values are assumed to be equal to $t=t_1$. Based on the value of p(t) at $t=t_1$ calculated according to the inequality (5), the value of θ is determined. If this value is less than 0.5 and p(t)>1, it is determined that the location of the accident is between the starting and middle sections of the gas pipeline, and based on the value of θ, the location of the gas leak ($\theta = \frac{\ell_2}{L}$) is automatically identified. Also, the valves (ℓ_1, ℓ_3), whose locations are already known, are activated to isolate the damaged section of the pipeline from the main section of the gas pipeline. Based on the results of the research, it can be stated that using expressions (5) and (6), it is possible to distinguish between accidental and technological regimes. On the other hand, from the moment the occurrence of an accident is confirmed, it is possible to determine the location of gas leaks and the sequence of valve activations. Thus, it can be concluded that the values obtained at the fixed time $t=t_1$ and from these expressions provide a reliable information base for monitoring and efficiently managing the technological regimes of gas distribution pipelines under extreme conditions.

CONCLUSION

A highly efficient technological scheme with a high reliability indicator has been proposed, based on the principles of the reconstruction phase, for the management of technological processes in gas transportation. The application of modern technologies and equipment to the proposed gas transportation scheme is of particular importance for optimizing the gasification capabilities of consumers.
Several mathematical models have been developed and an effective computational scheme has been devised to address a number of important new problems related to the management and regulation of technological processes in gas transportation. This will significantly enhance the reliability and efficiency of gas supply management during the reconstruction phase of complex gas pipelines. The calculation results showed that the error in comparing the obtained algorithm values does not exceed 4%. The developed computational scheme can be used to create an information database for the efficient management of gas transportation systems. To ensure the unconditional resolution of efficient management issues, a function characterized by the ratio of pressure drops has been defined and tested. The analysis of the p(t) function and parameters, which can perform multiple operations at the fixed time $t=t_1$, demonstrated that considering this indicator during the reconstruction phase can optimize the minimization of the data transmission time from information and control systems to dispatcher control points. The established relationship enables the differentiation of technological (stationary) and non-stationary operating modes of gas pipelines based on the indicators of changes in the parameters of the gas flow's final sections. Based on the results of the analyses, individual problems related to the reconstruction of parallel main gas pipelines have been solved using the developed algorithms and methods, taking into account the non-stationary regime. Consequently, targeted methods for the reconstruction processes of an efficiently managed gas transport system have been identified as the subject of the research.

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