Evaluation of the state of pipeline system using the exergy analysis

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Abstract. Using the foreign and Russian experience of the exergy analysis of energy systems, a method is proposed for assessing the efficiency of gas main pipelines with the help of exergy characteristics. Since the exergy characteristic of the installation uniquely determines the measure of the process reversibility, this method of energy expenditure distribution can be considered objectively justified and sufficiently reflecting the energy efficiency of each unit. The exergy expenditure by the unit or exergy characteristic can be calculated by the proposed dependencies.

1. Introduction
The gas transportation system of Russia has a number of features which determine the increased risk of its operation. Multiline main gas pipelines, assembled in technological corridors, create a high concentration of power-generating pipeline capacities. Gas pipelines and corridors have intersections with each other and oil pipelines. The reliability and safety of such units are subject to special requirements. Concentration of energy objects creates a natural zone of increased risk. The increased risk of pipeline operation is objectively related to their age, as the aging of pipelines causes a reduction in the protective properties of insulating coatings, the accumulation and development of defects in pipes and welded joints as well as aging of pipe metal [1].

2. Methodology
During the operation of pipelines under the influence of workloads, temperature, atmospheric precipitation and corrosive substances, the state of the pipes and the reliability of their operation change.

Design errors and defects made during the manufacture of construction, installation and repair work manifested in the operation process in the form of failures that reduce the efficiency of the functioning of pipeline systems. When considering the causes leading to pipeline failures, it is important that a significant part of pipe failures is of a random nature and not directly related to pipe properties. They are usually caused by the presence of hidden defects, which, under the influence of internal and external factors, lead to failures.

During operation of main gas pipelines, the regularity of the change in the mechanical properties of the base metal and welded joints over time was established. During the first 5-10 years of operation of the gas pipeline, the pipes properties remain practically unchanged. The decrease in the plastic and viscosity properties of the base metal and welded joints occurs in the second time dependence interval exceeding 10-15 years [4].

Statistics on the destruction of pipelines and special studies of pipe steels and welded joints have shown the effect of loading time and operating conditions on the change in the metal properties. The research results led to the formulation of a comprehensive task of assessing the pipeline condition, taking into account the time and technological parameters of operation, as well as the initial properties of pipe steels. The diameter and working pressure of the pipelines determine their through-put capacity, which is practically proportional to the maximum operating pressure. Although some disturbance is observed due to the influence of the compressibility coefficient, this effect is insignificant at positive gas transport temperatures and pressures of 7.5 ... 12 MPa. The thickness of the gas pipe wall, as well as the diameter, determines the metal costs. Since long-term operation results in local thinning of the pipe walls caused by the action of the environment (corrosion, erosion or mechanical damage), the optimality criterion must be supplemented by another indicator. In the opinion of many experts such an indicator may be a minimum of metal specific costs, defined as the ratio of metal to the amount of transported gas [7]. Analysis of the ratio of options for gas pipelines that differ in terms of service life, conditions and parameters of operation and the strength properties of the metal can be made using the expression:

$$\Psi = \frac{g_2}{g_1} = \left(\frac{D_1}{D_2}\right)^{0,5} \frac{\sigma_{вр1}}{\sigma_{вр2}} \frac{(K_1)_2}{(K_1)_1} \frac{(K_н)_2}{(K_н)_1} , \tag{1}$$

where g – unit costs of metal; D – outer diameter of gas pipeline; K_1 – safety factor for material; $K_н$ – reliability index; indices 1 and 2 indicate the option number.

Analysis of the above mentioned expression allows us to conclude that the increasing in the diameter of the gas pipeline leads to a decrease in the specific metal costs. The same trend is observed when the temporary resistance increase in and improvement in the quality of the metal pipes. The working pressure increase is impossible without increasing in the pipe material strength. Therefore, the priority direction of reducing metal costs is the efficiency increase of the pipe steels and preserving it in the exploitation process. The direction was realized on the basis of studies of domestic and foreign authors, which resulted in the belief that the improvement of hydrocarbon transportation technology and maintenance of the unit is the most priority direction of maintaining the pipeline's working capacity and increasing its residual resource.

The efficiency of gas pipelines is a metal property to withstand avalanche brittle and extended viscous fractures. As a normative characteristic of the mentioned feature, the work of development of destruction a_p is assumed. This value characterizes the pipe material resistance to the crack development and can be determined from expression

$$a_p = \frac{\pi(1-\mu^2)}{8E} \frac{P^2 D^3 n^2}{\delta^2} \left[1 - \left(1 - e^{-3c}\right)^2\right], \tag{2}$$

where μ – Poisson's ratio, $\mu = 0,25...0,33$; P – operating pressure; D – diameter of the pipeline; n – overload factor; c – sound velocity; $\pi/(8E) = 0,0017$; E – standard modulus of steel elasticity; δ – pipe wall thickness.

The fracture development is a characteristic which reflects the state of the material in the unit, but does not take into account the system of performance indicators, in particular, the loading and technical condition of the pipeline, which depend on the productivity of the gas pipeline, determined by seasonal unevenness of gas consumption, the state of the environment and the consistency of the system: field – pre-operation unit – main pipeline – gas supply system. During the pipeline operation, various types of energy are transformed. The amount of elastic energy in the metal changes and the electrical or mechanical energy is converted into the gas flow or thermal energy. Thus, the load factors, the technical condition of the pipeline and the destruction development to a certain extent are indicators of the energy perfection of the gas pipeline. For the analysis of the pipeline condition, it is possible to propose a general thermodynamic method which makes it possible to evaluate the efficiency of technical processes in a convenient and visual way. The implementation of the method is carried out by compiling the exergy system balance, since the exergy assessment takes into account

the interaction of the system in question with the environment [5, 8 and 9]. The technical value of energy depends not only on its own parameters, the form and state of the object which it possesses, but also on the parameters of the environment.

Energy research methods were proposed by Griffiths for spontaneous destruction of the pipeline. They were further refined and developed by many researchers. Since the basis of the energy research methods is the first law of thermodynamics, then considering the pipeline as an isolated system, it can be assumed that the energy of an isolated system remains constant for all changes occurring in this system. At present, there is no acceptable theory of the energy evaluation of pipeline systems which adequately describes the various states. The need for such a theory is confirmed by studies of the scale effects of the energy nature which take place on pipelines of considerable length and high throughput.

Exergy as a general indicator which determines the maximum ability to perform work allows evaluation of the energy quality (its practical availability). To establish the zero level of the mentioned indicator, it is necessary to take into account the influence of the environment on the flow of all processes during the transportation of hydrocarbon raw materials. The zero level of the overall quality index is determined by the conditions of thermodynamic equilibrium with the universal components of the environment. The system's exergy is the maximum ability of this system to perform work in such a process, which final state is determined by the condition of thermodynamic equilibrium with the environment [2, 3].

For an adapted assessment of the pipeline quality (its practical availability), it is proposed to introduce a general indicator which determines the maximum ability to perform work. To establish the zero level of the mentioned indicator, it is necessary to take into account the influence of the environment on the flow of all processes during the transport of hydrocarbon raw materials. The zero level of the overall quality index is determined by the conditions of thermodynamic equilibrium with the universal components of the environment. The system's exergy is the maximum ability of this system to perform work in such a process, which final state is determined by the condition of thermodynamic equilibrium with the environment.

Using the foreign and Russian experience of the exergy analysis of energy systems, a method is proposed for assessing the efficiency of a pipeline using exergy characteristics [10].

Loss can be produced according to their exergy characteristics. Since the exergy characteristic of the installation uniquely determines the degree of reversibility of the process, this method of energy expenditure distribution can be considered objectively justified and sufficiently reflecting the energy efficiency of each unit. The exergy expenditure by the unit or the exergy characteristic can be calculated by the formula:

$$E_X = E_i' - E_i'' + E_q' - E_q'' - W' - W'',$$

$$(3)$$

where E_i', E_i'' - the amount of exergy introduced into the unit and carried out from it by flows of various materials,

E_q', E_q'' - the amount of exergy of the heat flow introduced into the installation and taken out from it

W', W'' - the amount of electrical or mechanical energy is equal to the exergy, respectively consumed and produced by the unit.

The energy costs for the process implementation can be calculated by the average cost of exergy consumed by the pipeline system:

$$Ц_X = \frac{Ц_j(E_i' - E'') + Ц_q(E_q' - E_q'') + Ц_W(W' - W'')}{E_X},$$

$$(4)$$

where $Ц_j Ц_j Ц_j$ - costs of the unit of exergy, those of the transported product, heat flow and electricity respectively.

3. Conclusion
Thus, the use of the exergy analysis method for pipeline systems can be considered objectively justified and making it possible to determine and evaluate the system efficiency in order to predict the residual resource.

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