

Energy and material saving technologies for construction of main pipelines for oil and gas transportation

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Abstract. Based on the study and analysis of technologies and technical means for transporting oil and gas through main pipelines, energy and material-saving methods of their construction are scientifically substantiated. A method for designing trunk oil and gas pipelines with variable wall thickness is proposed, which is possible under the conditions of the current interstate standard GOST 31447-2012. The technique is based on the use of methods of mathematical and statistical modeling and construction of a multifactor experiment and processing of experimental data. Based on the results of the construction of the model, the optimal parameters for the construction of pipelines were found, new technical solutions were proposed that would significantly reduce the energy and material consumption of laying pipes during one run, i.e. between transfer pumping stations.

1 Introduction

As it is known, the share of pipeline transport, especially for the main transportation of hydrocarbons, is about 56% for the delivery of natural gas, 41% for the movement of oil and 4% for the transportation of refined petroleum products [1]. Considering that hydrocarbons are one of the strategically important carriers of energy in the fuel and energy complex (FEC), the role of trunk transport in ensuring the performance of various sectors of the economy becomes obvious.

For the successful competition of the main transport of hydrocarbons with other kinds of transport, the main factor should be a reduction in the cost of pumping. At the same time, one of its essential components may be a reduction in the cost of energy and material resources. Analysis of modern literature shows that by now there are many developments, ways, as well as methods, and all of them are mainly aimed at reducing energy costs and less often devoted to saving material resources. According to the researchers, the reduction in energy consumption can be achieved by saving (reducing) electricity to drive mainline pumps, namely [2]:

- reduction of the hydraulic resistance of the pipeline by means of periodic cleaning or the implementation of anti-turbulent additives;
- optimization of pumping modes using modern methods of regulating pump performance;
- reduction of electricity losses in distribution networks and operating equipment;
- transfer of energy supply to modern energy-saving technologies.

Meanwhile, there are also ways to reduce electricity losses in pipeline transportation of gas and oil by [1]:

- optimization of production modes for pumping oil or gas, which is achieved through high-quality selection and replacement of pumps, maintenance, as well as the introduction of a variable frequency drive;
- increasing the efficiency of cleaning the internal cavity of oil and gas pipelines, which is carried out by pumping hot liquid or steam. Heating in this case is carried out using a unit for dewaxing wells and pipes;
- timely cleaning of dirt traps;
- modernization of the pumping fleet of pipelines, the use of digital excitation regulators of synchronous electric motors to increase the power factor of oil and gas pumping stations;
- implementation of automatic control systems in the transportation process.

From the above examples, it can be noticed that, despite the many and diverse interpretations and opinions regarding the concept of reducing the energy consumption of pipeline transportation of hydrocarbons, all of them are mainly aimed at improving the operation of pumps, modernization and efficiency of their electric drives, as well as increasing the rheological properties of the transported fluid. At the same time, there is a lack of information about resource-saving, namely, material-saving technologies, ways and methods of reducing the cost of transportation in modern literature. Exception for that are the results of private developments, highlighted in the materials of the conferences held earlier and collections of works. So, in the studies of the authors cited in [3, p.: 73], the directions of optimization and criteria for the efficiency of hydrocarbon transport are well shown. The presented results can be taken as a basic model (algorithm) for the further development of methods for assessing the efficiency of enterprises for the transport of oil and gas. According to the authors, the

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optimization of enterprises should be focused on increasing the income and reducing the expenditure side.

The income can be increased by raising transfer and transshipment tariffs, an increase in supply volumes, an increase in the distance of transportation and a change in the direction of cargo flows.

Reducing the expenditure part is facilitated by:

- reduction in the cost of the facility (reduction in the cost of construction, manufacturing, delivery, disposal of pipelines, stations and their equipment);
- increasing the resource and reliability of pipelines and equipment (increasing the life span, reducing the cost of repairing and backing up pipelines and equipment);
- improving the characteristics and increasing the efficiency of the equipment (reducing energy costs);
- optimization of transportation modes (reducing energy costs, increasing environmental and industrial safety of operation);
- optimization of delivery times, considering climatic and weather conditions (reducing energy costs, cost of work);
- reduction of the purchase cost of energy carriers (reduction of costs for electricity, fuel, heat);
- the use of alternative energy sources, solar, wind, hydraulic, geothermal (reducing energy costs);
- reducing the hydraulic resistance of pipelines by heating the transported liquid, using additives, special pipe coatings, changing the roughness, using ultrasound, reducing the coefficients of local resistances, profiling channels, etc. (reducing energy costs);
- reduction of operating costs (reduction of costs for repairs, diagnostics, maintenance, security);
- improving safety, reducing environmental risks (reducing insurance payments, reducing the cost of maintaining environmental and fire safety);
- automation of control and management processes (improvement of industrial and environmental safety, performance indicators of pipelines);
- increase in labor productivity, decrease in labor intensity, decrease in the number of employees and decrease in the salaries of service personnel (decrease in the wage fund);
- reduction of taxes (minimization of tax deductions) and other expenses of the enterprise (minimization of expenses).

As a result of the study, according to the researchers, to assess the feasibility of performing certain measures in the plans and programs of the enterprise, it is necessary to select the appropriate optimization criteria. These aspects depend on the goals and objectives set, can be conditionally divided into energy, economic, safety, reliability, social, environmental, etc. They can be specific, referred to a unit of production, productivity, power, expenditures, time, distance, weight, cost, etc.; absolute or complex, consisting of several criteria, etc.

The paper [4] analyzes the methods used for laying the oil pipeline in the conditions of the northern regions of Russia. The author considered the area of the pipeline construction, its climatic and geological conditions. Possible unaccounted indicators for calculating the stress-strain state of the pipeline are analyzed. In

particular, the temperature difference during the construction of the oil pipeline was considered, as well as the fact that the air temperature changes both during the month and during the day. As a result, it was concluded that due to the uniqueness of the climatic and geological conditions of the construction area, subsidence and floating of the laid oil pipeline may occur. To prevent such situations, the author proposed to carry out calculations and forecasts for the stress-strain state of the oil pipeline, which, considering all factors, significantly increases the reliability of operation of the entire main oil pipeline.

In the work of the authors [5], based on the research carried out, it was concluded that in the development of pipeline transport facilities, one of the main criteria is operational reliability. The latter, according to the authors, is becoming an increasingly responsible and important task in modern industry. Operational reliability contributes to the introduction of innovations in the oil and gas production system, and to improvement of the reliability parameters of technological systems.

The analysis of works in foreign peer-reviewed scientific journals has shown that many studies are aimed at preventing and minimizing corrosion in steel pipelines and tanks. Thus, in [6], the application of the time-of-flight diffraction (TOFD) is proposed for the study of welded joints with uneven wall thickness of vertical steel tanks. In this paper, one of the metrological methods for improving the reliability of pipelines and reservoirs for oil transportation and storage is scientifically justified. The authors of next work [7] carried out a full analysis of the possibility of using superhydrophobic coatings to protect steel pipelines in the oil and gas industry. Based on the analysis of the literature data of all available methods, it was suggested to apply the spray method to create superhydrophobic coatings for steel pipelines. This method is the most versatile and provides a simple and cost-effective mass production of coatings on various steel substrates with a given microstructure.

Analyzing the current state of research aimed at reducing the cost of transporting hydrocarbons and gas, it was concluded that at present, more attention should be paid to the introduction of such technologies and technical means. This refers to the development of ways and methods for reducing material consumption in the construction of trunk pipelines and transportation of oil and gas through them, which, ultimately, should also contribute to a decrease in energy consumption. Thus, in contrast to direct ways and methods, in this case, indirect ways of reducing energy intensity is the new approach we propose.

2 Materials and methods

When calculating the main oil pipelines, the thickness of the pipeline wall is calculated using the well-known formula [8, 9]:

$$\delta_1 = \frac{np_1 D_{out}}{2(np_1 + R_1)}$$

and take the same along the entire length of the main oil pipeline. It follows from the formula that the pressure in the pipeline determines the thickness of the pipeline wall (Fig. 1).

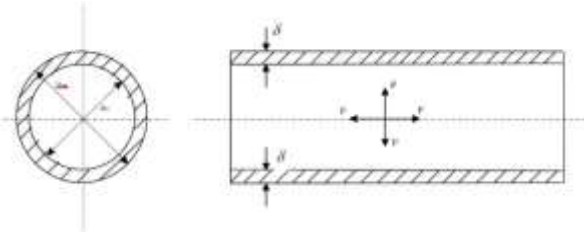


Fig. 1. Pipeline cross section.

However, the pressure in the pipeline decreases along the stretch from the maximum value at the outlet of the pumping station to the minimum value at the end of the stretch. Thus, with a constant pipe wall thickness along the length of the stretch, at the exit from the pumping station, the pipeline material operates with a stress close to the maximum permissible. It means that the bearing capacity of the pipe is used almost completely, and at some distance from the pumping station the pipe metal is already underloaded. Therefore, as the pressure decreases, the thickness of the pipeline wall can also be reduced, i.e. construct a pipeline with variable wall thickness along the length.

Since the pipes are produced according to some standards, it is possible to reduce the thickness of the pipeline wall only stepwise [10] - [11].

Because a huge amount of metal is consumed in the construction of oil trunk pipelines, the task of saving metal by using a variable thickness of the pipeline wall is relevant.

The validity of the above reasoning can be demonstrated with a specific example. The scheme of the main oil pipeline is considered below, more precisely, one line of the oil pipeline from the main pumping station to the next intermediate station (Fig. 2). As it is known, the distance between the pumping stations of the pipeline is determined by hydraulic calculations and is approximately $70 \div 120$ km, depending on the terrain. In this certain case, we take an arbitrary distance of 120 km and divide it into three equal intervals of 40 km each and determine the required pipeline wall thickness for each interval. The problem is to determine the pressure in the pipeline at the beginning of each gap. After that, we determine the thickness of the pipeline walls $\delta_1, \delta_2, \delta_3$ for each P_1, P_2, P_3 .

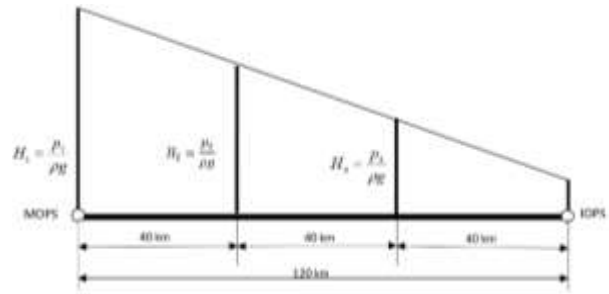


Fig. 2. Hydraulic diagram of one-line haul oil pipeline (inclined line - pressure drop along the length of oil pipeline, main oil pumping station (MOPS), intermediate oil pumping station (IOPS)).

It can be assumed that the main pumping station has three main-line pumps of the HM 2500–230 brand, connected in series. Then the pressure head of the station is:

$$H_1 = (230 \times 3) = 690 \text{ m}$$

Calculating the oil pressure at the outlet of the pumping station:

$$P_1 = \rho g H_1 = 5.7 \text{ MPa}$$

where ρ – the density of the transported liquid, kg/m^3 .

Now it is necessary to find the drop in pressure for each kilometer:

For the first 40 km at

$$5.75 \times 40 \text{ km} = 230 \text{ m}$$

i.e., pressure head drops to

$$H_2 = 690 - 230 = 460 \text{ m}$$

Then

$$P_2 = \rho g H_2 = 3.8 \text{ MPa}$$

Further, after another 40 km, i.e., on 80 km at

$$5.75 \times 80 \text{ km} = 460 \text{ m}$$

pressure head of the station and oil pressure will be

$$H_3 = 230 \text{ and } P_3 = \rho g H_2 = 1.9 \text{ MPa}$$

The results of the calculation of the pipeline's wall thickness for the three selected sections are shown in Table 1.

Table 1. Calculation results of pipe walls in each section.

Oil pipeline section l , km	Maximum pressure in the oil pipeline p , MPa	Calculated wall thickness of the oil pipeline δ , mm
0 – 40	5.7	10.0
40 – 80	3.8	6.5
80 – 120	1.9	3.3

Figure 3 shows the diagram of the change in the wall thickness of the oil pipeline during one stretch of 120 km.

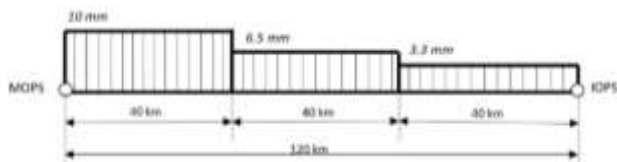


Fig. 3. Diagram of changes in pipe wall thickness along the length of one stretch.

Now it is possible to find the expected metal savings by comparing the calculation results of the two options for:

- 1) a pipeline with constant wall thickness $\delta = 10$ mm
- 2) a pipeline with variable wall thickness in one run $\delta_1, \delta_2, \delta_3$

Metal consumption at a constant thickness of the oil pipeline and a total length of 120 km:

$$V = \frac{\pi(D^2 - d^2)}{4} \times l = 1912 \text{ m}^3$$

$$m = \rho V = 15 \times 10^6 \text{ kg}$$

Metal consumption by sections with variable wall thickness of the oil pipeline:

- section 0 - 40 km

$$V_1 = 637 \text{ m}^3 \text{ and } m = 5000450 \text{ kg}$$

- section 40 - 80 km

$$V_2 = 421 \text{ m}^3 \text{ and } m = 3304850 \text{ kg}$$

- section 80 - 120 km

$$V_3 = 232 \text{ m}^3 \text{ and } m = 1821200 \text{ kg}$$

The total mass of pipes of all three sections:

$$m_1 + m_2 + m_3 = 10.126 \times 10^6 \text{ kg}$$

Then, the difference in metal consumption

$$m - (m_1 + m_2 + m_3) = 4.8735 \times 10^6 \text{ kg}$$

i.e. metal savings will amount to about 5 thousand tons. Moreover, this is only in one section of the pipeline, from one station to another. And on the main oil pipeline there may be several such sections. For example, there are oil pipelines with a length of 1500 km, which have about 10 -12 such sections.

From the above example, it is obvious that when using variable thickness on trunk oil pipelines, the savings in metal are significant.

The task in our case was that it was necessary to determine the optimal number of sections during one stretch, i.e. between transfer pumping stations in the case of oil, or compressor stations in the case of gas transportation.

This is because there are different opinions and proposals regarding the number of sites, which are based on engineering intuition and guesswork. So, according to the authors of [8], the number of steps, i.e. the number of pipe sections with different thicknesses for each stretch should be no more than three, and in this regard, it is recommended to take it equal to three. In our opinion,

the number of sites should be within certain limits and fluctuate depending on natural and climatic conditions and terrain and be taken in each specific case as an integer from this range.

For this purpose, based on the well-known technique [12] - [16], a multifactorial experiment is set up by the method of central compositional planning. In this method the optimization criterion was the number of sections N on one stretch of length L_{str} of the main pipeline. The planning matrix, as well as the results of processing the constructed mathematical and statistical model, are not presented due to the limited volume of the article.

3 Results and discussions

Based on studies of the extrema of the constructed model, the optimal values of the number N were found, which are $N = (2 \div 4)$. In other words, the number of sections along the length of one stretch L_{str} can be taken to be 2, 3 or 4, inclusive. These numbers depend on the peculiarities of the natural and climatic conditions of the main pipeline operation, as well as the technical conditions for transporting liquid (hydrocarbons, water) and gas and the terrain. But it cannot be taken equal to 1, since in this case, the meaning of the variability of the thickness of the pipelines on one stretch becomes meaningless.

The obtained optimal range $N = (2 - 4)$ was patented, i.e. to prove the novelty of the obtained theoretical result, an application for a utility model was filed and a corresponding patent was obtained [17].

Figures 4 and 5 show the layout of pipes on the stretch between stations, as well as a method of connecting pipes with different wall thicknesses with the same nominal (outer) diameters.

The proposed method (see Fig. 4) for the transportation of liquid and gas is carried out by means of the main pipeline 1, which consists of transfer pumping stations (in the case of liquid transportation) or compressor stations 2 (CS) (in the case of gas) located between the passes. Standard steel pipes 3 with different wall thicknesses along the length of one span are connected to each other using a welded joint 4 (see Fig. 5) and arranged into sections, the number of which is chosen in the range $(2 \div 4)$ depending on the relief of the route of their layout, as well as on peculiarities of climatic and technical conditions of operation of the main pipeline 1.

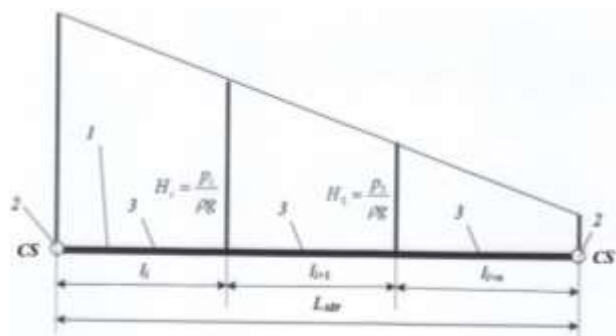


Fig. 4. Layout of pipes with different wall thicknesses at the same outer (nominal) diameter on the stretch between stations.

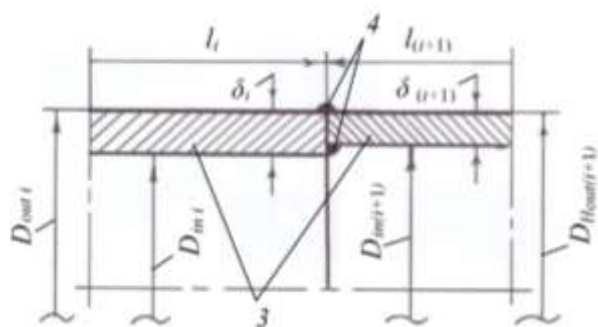


Fig. 5. Scheme of connecting pipes with different wall thicknesses with the same outer (nominal) diameter.

4 Conclusion

In the proposed method for transporting liquid and gas through the main pipeline, the transported liquid or gaseous substance (mainly oil, oil products, water or gas) is supplied under the maximum allowable pressure. It is performed through the main pipeline with the same nominal (outer) diameter D_{out} . At the same time, at the exit from the first pumping or compressor (in the case of gas) station, the pipeline material of the first section 11 (l_i, l_{i+1}, \dots, l_n , where $i = 1, 2, \dots, n$) is the ordinal number of the pipeline section when laying pipes with different wall thicknesses δ_i ($\delta_i, \delta_{i+1}, \dots, \delta_n$, where $i = 1, 2, \dots, n$) along the length of one span L_{str} works with a pressure close to the maximum permissible. This contributes to the fact that the carrier capacity of pipes of this section is used almost completely. In the usual case, when, starting from a certain distance from the CS, as the pressure decreases in the case of laying pipes with the same wall thicknesses, the pipe metal would be underloaded. However, due to the placement of pipes along the length of one stretch L_{str} different internal diameters D_{in} with their identical nominal diameter D_{out} in the required and sufficient quantity, the number of which is selected within (2 - 4), the pipe metal along the length of the run will not experience underload. And also, accordingly, its carrying capacity value will be fully utilized. This, in turn, will also affect the improvement of the rheological properties of the transported substance and reduce the energy intensity of the process. The main thing is that the metal consumption is significantly reduced, which, ultimately, allows saving a substantial amount of metal.

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