

On Determining Flow Rate and Hydraulic Loss Indicators in The Process of Oil Transportation Through Pipelines

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Abstract— Transportation of oil and oil products through pipelines is an important technological process, and its proper implementation requires the implementation of appropriate justified control and management measures. For this purpose, there is an urgent need to fully take into account the characteristics of the flow processes occurring within the pipelines when making the necessary decisions. Among these characteristics, the need to take into account the characteristics of pressure and flow rate changes, in addition to the possibility of various physical phenomena occurring along the pipeline trajectory - the formation of a shock wave, leakage, changes in flow regimes, the emergence of various thermodynamic effects, etc., is of particular importance. In connection with the above, the work considered a mathematical problem for determining the characteristics of flow rate changes in the process of oil transportation through pipelines. Determining the characteristics of flow rate changes in the process of oil transportation through pipelines also made it possible to estimate hydraulic pressure losses.

Keywords— pipeline, flow rate, hydraulic loss, pressure, boundary value problem, finite differences

I. INTRODUCTION

One of the priorities of the state policy of the countries of the world is ensuring their national security. The most important component of national security is energy security, since the reliable operation of the energy sector is a necessary condition for ensuring the economic development and economic security of the country. The basis of the country's energy sector is the fuel and energy complex, which ensures the operation of all sectors of the national economy and makes a significant contribution to the formation of the country's financial and economic indicators. The most important element of the fuel and energy complex are energy communication systems, in particular, systems designed for the transportation of hydrocarbon energy carriers in liquid and gaseous form through main pipelines. The transit function of main pipelines is of no small importance for the country's economy, which brings significant foreign exchange income to the state and strengthens its financial security.

The main pipeline is a production and technological complex consisting of underground, underwater, above-ground pipelines and other facilities that ensure the safe transportation of products.

To fulfill its functions and successfully solve the problems facing main pipeline transport, many new approaches are needed. These approaches involve solving a wide range of problems, starting from the application of information systems and developing new management decisions using various theoretical methods.

The operation of main oil pipelines can lead to serious problems in the economic, social and environmental spheres due to the occurrence of serious accidents during their operation. These can be solved mainly in the areas of increasing the reliability of main pipeline vehicles and creating effective systems for protecting natural environment objects in the event of accidents [1].

Many research works have been systematically carried out to study various issues encountered in the process of oil and gas transportation through pipelines. The results of these studies allow for a reliable justification of the control and management measures established for the purposeful implementation of the process of transportation of hydrocarbon products through pipelines [1] – [6]. However, in this direction, there is still a need to obtain solutions that allow making the necessary decisions within the framework of fully taking into account the characteristics of the flow processes occurring inside the pipelines. In connection with the above, a mathematically formulated problem is considered in the work to determine the characteristics of the flow rate change in the process of oil transportation through pipelines.

II. STATEMENT OF THE PROBLEM AND ITS SOLUTION

It is known that the movement of oil moving through a pipeline of fixed radius D and length L , taking into account the effect of intermediate pumping units, is expressed by the following system of linearized differential equations [7]:

$$\frac{\partial P(x, t)}{\partial x} = -\rho \frac{\partial V(x, t)}{\partial t} - 2\rho \bar{V}V(x, t) - \rho \bar{V}_0 - \rho g \sin \alpha(x) + u(x, t) \quad (1)$$

$$\frac{\partial P(x, t)}{\partial t} = -c^2 \rho \frac{\partial V(x, t)}{\partial x} \quad (2)$$

Where P and V are the pressure and flow velocity changes along the cross-section and length of the pipe during the flow of oil through the pipeline, respectively ($t \geq 0, x \in [0, L]$); \bar{V} and \bar{V}_0 are the linearization coefficients [7]–[9]:

$$\frac{\lambda(V)V^2}{2D} = 2\bar{V}V + \bar{V}_0; \quad (3)$$

u - function that takes into account the influence of pressure sources; α - angle of inclination of the pipeline axis relative to the horizontal plane; c - wave speed of the transported liquid (oil) in the pipeline; g - free fall acceleration; D - diameter of the pipeline.

Equations (1) and (2) reduce to the following simple form in the case of a horizontal pipeline, where the effect of pressure sources is not taken into account:

$$\frac{\partial P(x,t)}{\partial x} = -\rho \frac{\partial V(x,t)}{\partial t} - 2\rho\bar{V}V(x,t) - \rho\bar{V}_0 \quad (4)$$

$$\frac{\partial P(x,t)}{\partial t} = -c^2\rho \frac{\partial V(x,t)}{\partial x} \quad (5)$$

Note that, within the framework of flow continuity, this system of equations can be reduced to the following equation:

$$\frac{\partial^2 V(x,t)}{\partial t^2} - c^2 \frac{\partial^2 V(x,t)}{\partial x^2} + 2\bar{V} \frac{\partial V(x,t)}{\partial t} = 0. \quad (6)$$

Since the flow conditions in a liquid pipeline are related to the flow regime, the flow velocity directly affects the properties characterizing this regime.

As we know, the flow regime in a liquid pipeline is expressed by the Reynolds number, which is also used to estimate the hydraulic resistance coefficient λ for a specific flow regime [5]. The Reynolds number is determined according to the following formula, depending on the flow velocity of the liquid:

$$Re = \frac{VD}{\nu}, \quad (7)$$

where ν is the kinematic viscosity of the fluid.

The quantity h , which allows estimating hydraulic pressure losses depending on the value of the hydraulic resistance coefficient λ , is calculated as follows:

$$h = \lambda \frac{L V^2}{D 2g}. \quad (8)$$

Using relations (3) and (8), we obtain the following approximate relation, which allows us to estimate the hydraulic pressure losses:

$$h = \frac{2L\bar{V}}{g} V + \frac{L\bar{V}_0}{g}. \quad (9)$$

As can be seen, the evaluation of hydraulic pressure losses based on formula (9) directly excludes the determination of the hydraulic resistance coefficient λ by preliminary calculation, and in this regard, its determination is carried out in a convenient manner. The quantity V , which expresses the flow rate of the liquid in the pipeline, is determined based on the solution of equation (6) given above within the framework of certain initial and boundary conditions.

Let us note that on the basis of the results of the approximate evaluation of hydraulic pressure losses carried out in this way, an actual evaluation of the Reynolds number and the hydraulic resistance coefficient (Re and λ) can be carried out.

In accordance with the case where the pipeline is put into operation with a certain initial flow rate of the liquid under a certain initial pressure and its end part is connected to a reservoir with a large volume, the following initial and boundary conditions can be set for equation (6):

$$V(x, 0) = V_0, \quad \left. \frac{\partial V}{\partial t} \right|_{t=0} = 0, \quad \left. \frac{\partial V}{\partial x} \right|_{x=0} = 0, \quad \left. \frac{\partial V}{\partial x} \right|_{x=L} = 0. \quad (10)$$

Thus, we will seek a solution to equation (6) within the initial and boundary conditions (10) [10]. To solve the problem using the finite difference method, let us define the following network area in terms of space and time variables:

$$\omega = \{(x_i, t_j): x_i = i\Delta x, t_j = j\Delta t, \Delta x = \frac{L}{N}, \Delta t = \frac{T}{M}, \\ i = \overline{0, N}, j = \overline{0, M}\}.$$

Here Δx and Δt are the network steps for the variables x and t , respectively; T is the selected maximum value of time; N and M are the numbers of divisions of the network area for the variables x and t , respectively.

The following difference relation was obtained, which allows the iterative determination of the flow velocity for each new node point in time for the given network region of problem (6), (10):

$$V_i^{j+1} = AV_i^j + BV_i^{j-1} + C(V_{i+1}^j + V_{i-1}^j),$$

$$i = \overline{1, N-1}, j = \overline{1, M-1}$$

$$V_i^0 = V_0, \quad V_i^1 = V_i^0, \quad V_0^j = V_1^j, \quad V_N^j = V_{N-1}^j,$$

$$i = \overline{0, N}, \quad j = \overline{0, M},$$

where

$$A = \frac{2\bar{V}\Delta t(\Delta x)^2 + 2(\Delta x)^2 - 2c^2(\Delta t)^2}{(\Delta x)^2(1+2\Delta t\bar{V})}, \quad B = -\frac{1}{1+2\Delta t\bar{V}},$$

$$C = \frac{c^2(\Delta t)^2}{(\Delta x)^2(1+2\Delta t\bar{V})}.$$

To determine the flow velocity in the pipeline, corresponding numerical calculations were performed to solve the boundary value problem (6), (10) using the obtained finite difference relation. The following initial data were adopted in the calculations:

$$V_0 = 1,1574 \frac{m}{sec}, \quad \bar{V} = 0,016 \frac{1}{sec},$$

$$\bar{V}_0 = -0,007 \frac{m}{sec^2}, \quad c = 315 \frac{m}{sec},$$

$$L = 1000 \text{ m}, T = 100 \text{ day}, N = 1000, M = 100.$$

The corresponding graphical dependencies obtained as a result of calculations for the change in the fluid flow rate in the pipeline and, accordingly, the pressure losses due to hydraulic friction in the pipeline over time are presented in Fig. 1 and 2.

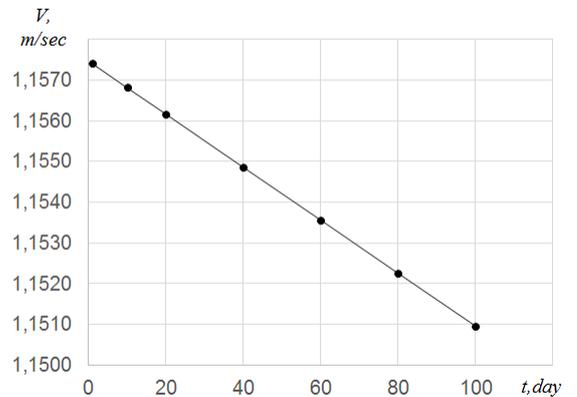


Fig. 1. Variation of fluid flow rate in a pipeline with time

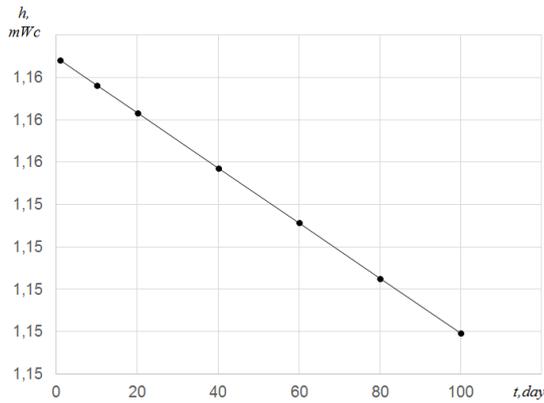


Fig. 2. Time variation of pressure losses due to hydraulic friction during fluid flow in a pipeline

The graphical dependencies depicted in the figures show that over time, the fluid flow rate in the pipeline and the pressure losses due to hydraulic friction decrease. This may be due to a decrease in the total inertia of the operation of the pipeline system within the accepted conditions. At the same time, it is clear from Fig. 1 that the maximum and minimum values of the fluid flow rate do not exceed the accepted interval (0.8; 1.22) of the linearization condition (3).

II. CONCLUSION

A mathematical problem was considered to determine the characteristics of the flow rate change in the process of oil transportation through a pipeline. The determination of the characteristics of the flow rate change in the process of oil transportation through a pipeline also allowed to estimate the hydraulic pressure losses. The described solution scheme can be used for the study of other correspondingly set tasks representing the process of oil transportation by pipeline.

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