Determination of the coefficient of hydraulic friction and factors reducing the value of hydraulic resistance along the length

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Abstract. The article discusses issues related to the determination of hydraulic resistances and the coefficient of hydraulic friction based on scientific research conducted relatively recently. Formulas for determining the coefficient of hydraulic friction by various authors and studies on determining the value of hydraulic resistances are presented, which propose a non-traditional method for determining the average speed along the pipeline section. The works studying the influence of liquid temperature and the introduction of polymer additives on the amount of hydraulic losses are analyzed.

1 Introduction

Pipelines are an important part of many hydraulic structures. Therefore, special requirements are imposed on the reliability of pipeline systems at all stages from design to operation, since the safety of hydraulic structures largely depends on how reliably the pipeline systems function. The design of all pipeline systems is based on hydraulic calculation, which is subject to strict requirements. One of the most important energy characteristics of a moving fluid flow is hydraulic pressure loss. Competent design at the preliminary stage of any hydraulic system is impossible without the use of computational methods and the determination of hydraulic resistances and losses, errors in the determination of which may contribute to the wrong choice of pumping equipment [1].

Currently, the Darcy-Weisbach formula is used to determine hydraulic pressure losses in pipes and channels [2]. The main role in the calculation of hydraulic losses is played by the determination of the coefficient of hydraulic friction. There are recommendations for its definition, in round pipes the coefficient depends on the Reynolds number Re and the relative roughness Δ/r. One of the most well-known formulas is the Blasius formula, derived in 1908 and designed to determine the coefficients of hydraulic friction for hydraulically smooth surfaces [4]. The formulas of Nikuradze [5] and Colebrooke [6] are also widely known.

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And although the final version of the formula was written by Julius Weisbach, the method of calculating linear and local hydraulic losses in pipes has a long history. The first empirical dependence for determining pressure losses during the flow of liquid through pipes was obtained in the early nineteenth century by the French mathematician and engineer Gaspard de Prony based on a small number of experiments and mainly with pipes up to 50 mm in diameter. The calculation was further developed and improved in the works of Henri Darcy, who conducted a fundamental hydraulic study using pipes made of different materials and having different roughness values. And it was only in 1847 that Weisbach, conducting hydraulic research and considering together the pipeline with the reservoir, derived a formula close to its modern form [3], which is the basis for the currently used methods of hydraulic flow calculations in circular pressure pipelines and non-pressure channels.

2 Methods and materials

The issue related to determining the value of the coefficient of hydraulic friction has been of interest to researchers for quite a long time, but despite the fact that the basic formulas and patterns have been derived for a long time, research is being conducted and new work is emerging, since conditions arise in the practice of constructing hydraulic structures and pipeline systems that were not previously taken into account, begin to be applied new building materials, which makes adjustments to the previously obtained methods of hydraulic calculations. Additional research in this area allows us to obtain formulas that are used in a wider range. The emergence of new measurement methods and the use of modern effective methods of processing experimentally obtained data using computer technology allow for further development of hydraulic methods for calculating pipeline systems.

The purpose of this study is to identify new methods and conditions for determining the coefficient of hydraulic friction and hydraulic losses along the length. The objectives of the study include a review of scientific papers written relatively recently and related to the calculation of linear hydraulic resistances. In the course of the work, theoretical research methods were used, such as the study of scientific sources and analysis.

3 Results and Discussion

In Oregon and Princeton, unique experiments were conducted to determine the coefficients of hydraulic friction and their dependence on the Reynolds number, as a result of which the formula was obtained [7]:

$$\lambda = \left[0.839 \cdot ln\left(Re\sqrt{\lambda}\right) - 0/537\right]^{-2}. \qquad (1)$$

A refined formula used for large Reynolds numbers may be of interest [8]:

$$\lambda = \left[0.813 lg\left(Re\sqrt{\lambda}\right) - 0.241 - 233/\left(Re\sqrt{\lambda}\right)^{0.9}\right]^{-2}. \qquad (2)$$

In the work of A.P. Lepikhin [9], a formula is presented for determining the value of the coefficient of hydraulic friction for turbulent flows near hydraulically smooth surfaces, obtained based on the analysis of experiments in Oregon and Princeton, which ensures agreement between calculated and experimental values.

$$ƛ = \frac{2e}{\left(ln(Re)\right)^{\sqrt{2e}}} \quad (3)$$

L.V. Vysotsky conducted a comparative analysis of the results of calculations of hydraulic friction coefficients obtained using various formulas [10], which showed that the formulas obtained as a result of experiments conducted in Oregon and Princeton have very high accuracy, and with sufficiently large Reynolds numbers, the second formula is more preferable.

In V.N. Baykov's research, a broad analysis of the patterns of hydraulic resistances and velocity distribution in pipes and wide channels was carried out, which allows avoiding errors when using formulas obtained for hydraulic calculations of pipelines when calculating the movement of liquids in channels [11].

Researchers V.N. Baykov, D.V. Pisarev and D.A. Volynov conducted a comparative analysis of the calculation of hydraulic resistances during laminar fluid flow in round pipes and wide channels [12]. Hydraulic losses were found taking into account the average velocity, which in the case of fluid flow in a round pipe was determined by integrating over the cross-sectional area of the pipe, due to the spatial nature of the velocity distribution in the pipe. The average flow velocity in a wide channel was determined by integrating the depth of the open channel. With the same Reynolds numbers, the coefficients of hydraulic friction calculated for a round pipe and a wide channel differed by 1.5 times. The result obtained by the researchers does not agree with generally accepted conclusions. Due to the lack of additional recommendations and arguments on the choice of the average speed, the researchers propose to use the average speed obtained by averaging the velocity diagram along the radius of the pipe, which ensures equality of the coefficients of hydraulic friction in the laminar regime of fluid flow in round pipes and wide channels with the same Reynolds numbers [12].

In calculations of hydraulic resistances performed according to the Darcy-Weisbach formula, it is recommended to calculate the average flow rate by flow rate, dividing the flow rate by the cross-sectional area of the flow. But in the works of some researchers [13], the results of research are presented and it is concluded that during the turbulent movement of a liquid in a round pipe and a wide channel, there are differences in the obtained values of the coefficients of hydraulic friction, which is associated with the method of determining the average flow velocity. In the case when the average velocity of the liquid in a round pipe is determined taking into account the velocity distribution over the flow section, the coefficients of hydraulic friction are obtained by 10-25% less than the coefficients, the calculation of which uses the average velocity obtained from the flow rate. Thus, when conducting studies related to the determination and comparison of hydraulic pressure losses in streams with different cross-sectional shapes, the method of determining the average velocity is of great importance.

Most modern scientific research in the field of pipeline hydraulics is aimed at finding active methods and tools that increase the energy efficiency of pipeline systems, which is associated with hydraulic losses. The amount of hydraulic pressure losses in pipelines can be influenced by various parameters, which is what some modern studies are devoted to.

It is often necessary to pump heated liquids, for example, liquids used as a coolant in heating networks. The temperature of the liquid affects the amount of hydraulic losses, since the basic physical properties such as density, dynamic and kinematic viscosities depend on the temperature value.

A scientific hydraulic study was conducted and mathematical calculations were performed, which showed that with an increase in the temperature of the coolant, the specific pressure loss increases, which is associated with an increase in the velocity of the coolant and the Reynolds criterion [14]. This circumstance is explained by the fact that with an increase in the temperature of the liquid, its density decreases, and with an increase in temperature, the kinematic viscosity decreases.

Some design parameters, such as the diameter of the pipeline and the roughness of its walls, may change over time during the operation of pipelines. Both of these parameters have an impact on the amount of hydraulic losses, so it is necessary to take into account their changes.

The oil and gas industry occupies an important position in the economy of our country, and the transportation of hydrocarbons is of great importance. The main economic and energy costs during transportation are associated with the operation of pumps and compressors. Therefore, the conducted studies [15] are relevant, the purpose of which was to determine hydraulic losses during the movement of paraffin oil in the pipeline and to identify the influence of temperature on losses. As a result of the study, it was concluded that the hydraulic pressure losses in the oil pipeline depend on the temperature and speed of the pumped liquid. The amount of losses is also influenced by the geometric parameters of pipelines, its length, diameter and surface roughness. A comparative analysis of hydraulic pressure losses at a constant oil velocity was carried out for several temperature values and for several diameter values in the range from 0.3 to 0.7 m, which showed that at an oil temperature of 7 ° C, with an increase in diameter, losses decrease by 5 times, at a temperature of 20 ° C, hydraulic losses decrease by 2.7, and with a further increase in temperature, with an increase in the diameter of the pipeline, there are no significant changes in pressure losses.

The value of the equivalent roughness of the inner surface of pipelines affects the value of hydraulic losses, therefore, there are methods that reduce roughness, these include the use of polypropylene pipes, the use of smooth coatings and the addition of special additives [16].

In 1948, the English chemist Toms found that when a polymer additive is added to water, there is a significant decrease in friction between the pipeline and the turbulent flow. Anti-turbulent additives added to pumped liquids make it possible to reduce the amount of hydraulic losses and increase the throughput of main oil pipelines without increasing the diameter and increasing the number and capacity of main pumping units in operation. The hydraulic losses calculated according to the Darcy Weisbach formula can be reduced by reducing the coefficient of hydraulic friction, and polymer solutions can reduce the Darcy coefficient. The coefficient λ for ordinary Newtonian fluids is a function of the Reynolds number and the relative roughness of the inner surface of the pipeline.

In Russia, research on the use of polymer additives to reduce the Darcy coefficient was conducted at the Department of Hydraulics of the Ministry of Agriculture and the Gubkin State Enterprise in 1964. In experimental studies on water, a decrease in the coefficient of hydraulic friction by 15-20 percent was observed at various Reynolds numbers.

Currently, there are studies proving that the presence of anti-turbulent polymer additives in a liquid affects the amount of losses, since the coefficient of hydraulic friction begins to depend not only on the roughness and Reynolds number, but also on the concentration and type of polymer. The concentration of several millionths of a polymer liquid significantly reduces flow turbulence and hydraulic resistance. But at the same time, the effect of reducing hydraulic losses due to the damping of turbulent pulsations in the wall area of pipelines is observed when homogeneous liquids move, since when oil moves, representing a complex physico-chemical system, the entire amount of flocculant polymers is spent on the formation of agglomerates from colloidal and fine impurities of natural oil.

4 Conclusion

Modern research aimed at determining the magnitude of hydraulic losses complements the previously obtained results. In addition to the well-known Blasius formulas, etc., the formulas derived in Oregon and Princeton can be used in hydraulic calculations. Studies aimed at identifying factors that reduce hydraulic resistance are of not only theoretical but also practical importance.

To understand the results of the study, S.V. Terebilova et al. according to the effect of liquid temperature on the value of hydraulic resistances, a more complete additional description of the experimental conditions is desirable. Thus, although the basic formulas for determining linear hydraulic resistances and hydraulic friction coefficients have been derived for a long time, work in this direction is promising and continues.

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