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Research of the dependence of the hydraulic friction coefficient of the liquid (λ) on the reinolds number (Re) applicable to the hydraulic drive

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Annotation. Experimental studies of the dependence of the coefficient of hydraulic friction λ on the Reynolds number Re at the stand "Hydraulics" in relation to the hydraulic drive. The formula for determining the coefficient of hydraulic friction for a turbulent regime of fluid motion is refined. Based on the results of studies, a graph of the dependence of the coefficient of hydraulic friction λ on the Reynolds number Re with an analysis of the four zones of this dependence is constructed.

Introduction

It is known that in the laminar regime of fluid motion, energy (pressure) losses along the flow are explained by the resistance of internal friction forces and, therefore, depend on the viscosity of the fluid. The coefficient of friction resistance along the length λ during laminar motion is a function of only the Reynolds criterion, and the material and the state of the surface of the walls surrounding the flow are independent. A different situation is observed with turbulent motion. As the experiments show, the coefficient of friction resistance λ along the flow length, taking into account the hydraulic flow conditions under the turbulent regime, depends not only on the viscosity of the liquid, but also on the roughness of the walls Δ / d, i.e. Re, $\lambda = f(\mathrm{Re}, \Delta/d)$. Therefore, the reliability of the calculation of energy losses during turbulent motion largely depends on the correct determination of the coefficient of friction resistance along the length λ.

Pipe resistance research has been the subject of many works in Russia and abroad [1–8]. However, until now, due to the complexity of the turbulent flow [9–20], there is no general theoretical method for determining λ for hydraulic pipes.

There are many empirical formulas for determining λ [2, 4]. Each of these formulas is valid only for those conditions for which it is obtained. This practically complicates the choice of the optimal value of λ for each specific system of the pipeline system of hydraulic drives. The complexity and variety of factors that determine the movement of fluid, in most cases, does not allow to be limited to a strictly theoretical solution for a particular case of fluid motion. The obtained solutions need correction coefficients, which are determined as a result of experimental work. This is confirmed by our studies of the dependence of the coefficient of hydraulic friction λ on the Reynolds number at the experimental stand "Hydraulics", created in relation to the hydraulic drive. The stand includes a gear pump, piping systems and instrumentation. The initial data of the hydraulic system: the length of the studied section is ℓ_{ab} = 0.43 m, the internal diameter of the pipeline is d_{in} = 6 mm, the density of mineral oil is ≈900 kg / m3. Measured parameters: pressure at the boundaries of the pipeline section with pressure gauges, the time taken to pass the given volume of fluid is measured using an electronic stopwatch, and the volume of fluid passed through is measured using a flow meter, and the temperature of the working fluid is also measured. The variables of flow rate Q, velocity U, pressure P, kinematic viscosity coefficient ν were varied by changing the temperature during operation of the hydraulic system of the experimental bench [4–5],[9–13].

Methods

Based on the experimental data determined on the bench in the temperature range 18–40 ° C, the hydraulic friction coefficients λ and Reynolds number using previously conducted theoretical and experimental studies. The hydraulic coefficient of friction was determined using the Darcy formula [1–4].

$$h_e = \lambda \frac{l}{d}\frac{U^2}{2g} \ (1)$$

$$\lambda = \frac{2gd}{l}\frac{h_e}{U^2} = 0.274\frac{h_e}{U^2} \ (2)$$

$$U = \frac{Q}{S} \ (3)$$

whereP_1, P_2— liquid pressure according to manometers MH1 and MH2, Pa; ρ— fluid density, 900kg / m3; Q — the volume of fluid traversed during time t. The Reynolds number was determined based on the solution of the system of equations:

- for the laminar regime of fluid motion

$$\begin{cases} \lambda_{on} = 0{,}274\dfrac{h_e}{U^2} \\ \lambda = \dfrac{A}{Re} \end{cases} \ (4)$$

where A — is a value depending on the state of pipelines, the type of liquid (water, oil), etc.

For oil pipelines and hydraulic pipelines, it is usually taken [4]. ThenRe_{lam}= 75/λ_{op}, and$\lambda_{op.cr}$= = 75/2320 = 0,0323 —friction coefficient for Re_{cr}.

- for the turbulent regime of fluid motion

$$\begin{cases} \lambda_{on} = 0{,}274\dfrac{h_e}{U^2} \\ \lambda = B\left(\dfrac{\Delta_e}{d} + \dfrac{75}{Re}\right)^{0{,}25} \end{cases} \ (5)$$

Where Δ_e = 0,002 mm —vivalent roughness; B— coefficient determined at Re = Re_{cr}, $\lambda_{op.cr}$ = 0.0323.

$$B = \frac{\lambda_{kr}}{\left(\frac{\Delta_e}{d} + \frac{75}{2320}\right)^{0{,}25}} \ (6)$$

For the conditions of the experimental stand "Hydraulics" B = 0.0763.

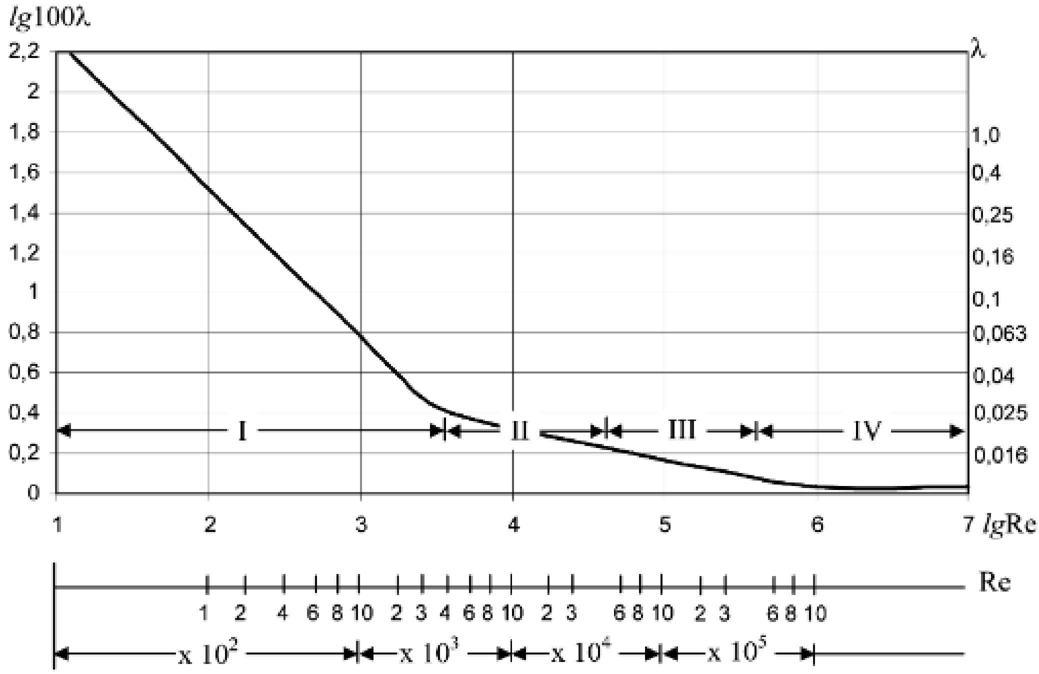
$$Returb = \frac{75}{\left(\left(\frac{\lambda}{B}\right)^4 - \frac{\Delta_e}{d}\right)} \ (7)$$

It should be noted that formulas (5); (7) are valid for all turbulent motion zones. So, at the boundaries of zone III, this formula is transformed, which corresponds well to the experimental conditions, the dependences for λ: for hydraulically smooth pipes, it turns into the Blasius formula, for a zone of completely rough pipes (self-similar region) into the Shifrinson formula, with only one condition: instead of the coefficient 0.11, the coefficient B is used, determined by the formula (6).

Based on the obtained experimental data by the above-described method, a graph was plotted of the dependence of the Darcy coefficient λ on the Reynolds number Re (figure).

Analyzing this graph, we see that in the laminar mode of motion all the experimental points (λ values) lie on the same line. In logarithmic coordinates, this is line I, described by equation (3)

In turbulent mode of motion and hydraulically smooth pipes, all points are also described on one straight line II.



Graph of the Darcy coefficient (λ) versus the Reynolds number (Re)

As can be seen from the graph, in the turbulent regime of motion between the zones of smooth and quite rough pipes (zone IV), there is another (transitional) zone III, in which λ depends both on Re and Δ / d. A smooth decrease in λ with increasing Re in this zone obtained good convergence with the calculated data of the coefficient of hydraulic friction according to the recommended formula.

Results

Conducted experimental studies established the following:

1. Based on the research results (experimental data), we plotted the dependence λ = f (Re) and Δ / d = const, in the temperature range T = 18–40 °, which revealed four zones of dependence λ = f (Re, Δ / d): one for laminar motion and three for turbulent.
2. An improved formula is proposed for determining the coefficient of hydraulic friction for a turbulent regime of fluid motion (3)
3. In the regime of fluid motion between the zones of smooth and completely rough pipes (transition zone III), the curve λ = f (Re, Δ / d) has a smooth decrease in λ with increasing Re and agrees with high accuracy with the calculated data of the hydraulic friction coefficient according to the recommended formula (3)
4. The proposed methodology for determining the coefficient of hydraulic friction is recommended to be used in the calculation of oil pipelines of hydraulic pipelines.

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