The maximum reduction in resistance for the tube with artificial roughness reached 59% at a metaupone concentration \( C = 0.6\% \) and \( Re = 6500 \), while for the naturally rough tube the maximum reduction was 68% at the same concentration and \( Re = 12,000 \). With further increase in velocity there is a quite sharp increase in friction coefficient, i.e., a decrease in the reduction of hydrodynamic resistance. This is evidently related to destruction of the mycelial structures of the surface-active substance in the Reynolds number range above the threshold value.

It follows from the experimental studies performed that addition of polyacrylamide and metaupone decrease hydrodynamic resistance in turbulent flow of liquids in rough tubes: in practice the resistance reduction begins in the region of transition from laminar to turbulent flow: the resistance reduction in metaupone solutions is found over a limited range of change of Reynolds number, which range enlarges with increase in metaupone concentration. Comparison of the results obtained with experimental data for smooth tubes [1, 5] shows that to obtain the same resistance reduction effect a larger concentration of the additive is necessary in rough tubes.

**NOTATION**

- \( d \), inner diameter of tube;
- \( R \), radius;
- \( s \), screw pitch;
- \( k \), height of roughness projection;
- \( b_1 \), distance between projections;
- \( h \), effective height of projections;
- \( k_s \), roughness value equivalent to sand roughness;
- \( l \), length of tube section over which pressure drop was measured;
- \( \lambda \), friction resistance coefficient;
- \( Re \), Reynolds number, calculated from solution viscosity;
- \( C \), concentration of solute;
- \( \tau_w \), threshold shear stress on tube wall;
- \( b \), width of roughness projections.

**LITERATURE CITED**


**A GENERALIZED HYDRAULIC RESISTANCE COEFFICIENT**

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A generalization of the resistance law for rheologically stationary liquids is considered for flow in tubes and channels of various geometry.

In hydrodynamic calculations the necessity often develops of determining hydraulic losses in motion of liquid in tubes and channels of various cross sections.

The present study will consider the possibility of generalizing the resistance law for rheologically stationary liquids for flow in media of various geometries.

It has been discovered [1] by processing of experimental data on the flow of various non-Newtonian systems that in the case of laminar flow, in the consistent variables chosen, rheometric data for media of various geometries form a single curve. According to Bingham, consistency is defined by complete relationships between force factors and flow characteristics. For the force factor the mean over the perimeter of the shear stress \( \tau_w \) was chosen, while for the flow characteristic the mean velocity gradient \( \dot{\gamma}_w \) was selected. The quantity \( \tau_w \) is determined from the equilibrium of pressure and friction forces acting on a certain volume of liquid, limited by two sections separated by a distance \( l \), i.e.,

The choice of the parameter $\tau_w$ was based on the analogy between laminar flow of a liquid and the twisting of a prism of the same cross section (the Boussinesq analogy). An approximate formula for liquid flow rate then has the form

$$Q = \Delta PF/16\pi^2 l.$$

After elementary transformations, Eq. (2) becomes

$$\tau_w = \frac{4\pi i_0}{x} u_m R_h / \xi = u_m R_h.$$  

From Eq. (3), together with Newton's law, written in the consistent variables $\tau_w$ and $\chi_w$, we obtain

$$\chi_w = \frac{4\pi i_0}{x} u_m / R_h.$$  

The geometric quantity $\xi = (4\pi i_0 / x)^2$ depends solely on the form of the cross section and is termed the form coefficient. The exact value of $\xi$ may be determined by writing the formulas for flow rates for various cross sections in consistent variables. The values of $\xi$ for media of various geometries are presented in [1].

Thus, a generalized relationship

$$\tau_w = \xi u_m / R_h$$

is obtained.

Equation (5), which relates integral values (pressure drop and flow rate) for media of various geometries, can be considered as applicable to non-Newtonian liquids as well. However, in the case of a non-Newtonian liquid the quantity $\mu$ does not remain constant, but is some function of the velocity gradient (shear stress). The form of the function $\mu = f(\chi_w)$ is determined from the condition of best approximation of the actual flow curves. It has been found by processing of experimental data that the generalized model of Shul'man [2] is the most reliable, describing the rheological curves of non-Newtonian liquids over a quite wide range. In consistent variables the Shul'man model is written as

$$\tau_w^{1/n} = \tau_0^{1/n} + (\eta \chi_w)^{1/m}.$$  

From Eq. (6) and the Darcy–Weisbachite equation, written in the form

$$\tau_w = \frac{1}{8} \lambda u_m^2,$$

we obtain

$$\lambda = 8i \left\{ \frac{\rho u_m^2 - i R_h^i}{\xi i^i \eta^i} \right\} \left( 1 + \left( \frac{\tau_0 R_h^i}{\xi i^i \eta^i u_m^i} \right)^n \right).$$  

If we employ the notation

$$\frac{\rho u_m^2 - i R_h^i}{\xi i^i \eta^i} = \text{Re}^i, \quad \frac{\tau_0 R_h^i}{\xi i^i \eta^i u_m^i} = \Pi, \quad \frac{\text{Re}^i}{(1 + \Pi^{i, n})^{1/n}} = \text{Re}^*,$$

then from Eq. (8) we have

$$\lambda = 8 \text{Re}^*.$$

As follows from Eq. (9), for laminar flow of a non-Newtonian liquid the criterial equation is written in the form $\lambda = f(\text{Re}^i, \Pi)$, i.e., there are two similarity criteria: the