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EXPERIMENTAL RESEARCH OF HYDRODYNAMICS OF FLOWS WITH A VARIABLE ALONG THE LENGTH MASS

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Abstract

The paper analyzes the results of experiments on the research of the flow of viscous fluids in nozzles in the presence of discrete selection. The results of the experiments confirmed the assumption that the flow is not stabilized, i.e. there are inertia forces from convective acceleration except viscous friction forces. Conclusions about the impact of the curvilinear pipeline on the hydraulic losses are made. Using the results of the research, the recommendations for the design of nozzles and sprinklers with the same loss coefficients are offered.

Keywords: fluid flow, hydraulic resistance, viscosity, fluid losses, water current, convective acceleration.

INTRODUCTION

The existing method of stationary flows research requires significant correction, particularly for liquids which are used in fire engineering and exhibit viscosity anomalies. These clarifications and correction in calculations are connected with the manifestations of destabilizing of the continuous flow or with discrete fluid selection along the channel through which the liquid is supplied. Under such conditions substantial change of hydraulic resistance is possible in the central line, in the supply line and in nozzles arranged along the line. In turn, these changes affect the nature, dimensions and parameters of created flows.

EXPOSITION

Experimental studies of these flows were carried out by many authors. They are presented in the work by Fedorets A.A. and Malanchuk S.M. [1]. Unfortunately, the experiments were carried out only with a steady selection of fluid along the length of the pipeline. Researches of Kravchuk A.M. are considered thorough and profound [2]. The author examines several schemes of pipelines where the working fluid is water. The equations that describe the hydraulic system are presented and criteria that characterize the movement of water in the channel with a variable along the length consumption are developed. Using the obtained criteria the author offered formulas for the calculation of relative flow with a relative difference in pressure.

However, experimental research in this field is not enough to obtain the correct conclusions about the factors that affect the nature of fluid flow along the channel, especially when it comes to cases with its discrete selection and usage of abnormally viscous liquids.

Taking into account all the information mentioned above, there is a need for physical modeling of fluid flow hydrodynamics to correct the researches of stationary flows. The present work is devoted to the solution of this problem.

The experimental stand for research of fluid flow. To make the research full it was necessary to create several stands. They made it possible to carry out research of flow hydrodynamics both in the nozzles installed in the distributing pipe along the flow and in the pipe itself.

Fig. 1. *The appearance of the stand and its elements*

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The stand allows carrying out research related to the viscous fluids flow in nozzles of various types and in fire barrels. The main element of the stand is a pump unit, which includes an asynchronous three-phase electric motor having the power of 18 kW and a centrifugal liquid pump, which can provide consumption of up to 800 l/min with a pressure of up to 100 m and allows carrying out research both under laminar and turbulent flow regimes. The pump unit via hydraulic system (a flowmeter, pressure sensor, pressure pipe lines) is connected with flow forming nozzles (fire barrels) that can be set at different angles of inclination using a tripod.

Fig. 2. *The working part of the stand, which allows simulating the flow of viscous and abnormally viscous liquids with a variable along the flow mass*

The next part of the stand is an installation, the working part of which is the pipeline, which allows simulating the flow of viscous or abnormally viscous liquids with the variable along the flow mass. The installation consists of the system of plastic pipe lines with drenching sprinklers placed on it. The water supply to the sprinklers is provided by a centrifugal pump from the tank with the capacity of 1 m^3 (Fig.1). Water is supplied into the ring network with sprinklers installed on it.

Consumption of liquid from nozzles (sprinklers) is measured by the volumetric method, and manometers installed in front of them provide an opportunity to build dependencies of pressure changes in nozzles from the fixed consumption from them along the pipeline and to calculate their characteristics. Similar to straight pipelines, such researches can be carried out in curved pipelines (Fig. 2).

Thus, experiments carried out with the following installations presented data on all the main characteristics of the flow (under given geometric parameters), namely: consumption Q in the line, consumption q in the nozzles, pressure P in various points of the system, the data of calculating of changes in the average flow velocity along the distributing pipeline Uav and, as a consequence, the velocity gradient γ, which is extremely important for the Newtonian medium.

The accuracy of measurements was determined according to the measuring instruments. Thus, for example, using a rotational viscometer «Rheotest-2", which measures the viscosity in the range of 10^{-2} to 10^{3} poise at shear rates of $0.2\ s^{-1} \leq \gamma \leq 1.8 \cdot 10^{3}\ s^{-1}$ the error was 3-4%. According to the analysis the following measurement errors were obtained: consumption - 4-7%; determination of the mixture viscosity - 4%; determination of pressure - 3-4%.

Planning of the experiment. Planning of the experiment, connected with the research of viscous medium flow in currents with variable mass, was carried out on the basis of presented studies [3-7]. When conducting experimental studies the main task is to identify the dependencies between the pressure P and liquid consumption Q in different parts of the pipeline. These values depend on a number of parameters: the geometric characteristics of channels, the rheological and thermal properties of liquids and solutions, nozzle consumption. According to [3] multivariate experiment makes it possible to suggest that the optimization parameter in this case depends on three independent variables. Using these data we can draw a conclusion about the influence of factors on optimization parameters.

Method of forecasting the experimental characteristics of flow with the variable along the length liquid mass. The results of the experiments can be predicted on the basis of a simplified flow diagram shown in Fig. 3 and described in the works of M. Zhuk (d - channel diameter, Q_0 - the initial flow rate, q1, q2, q3 - sprinklers consumption, l - the distance between them, x - direction of flow along the channel).

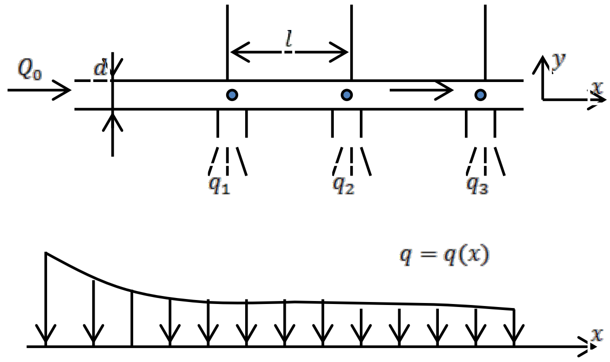

Fig. 3. *Flow prediction scheme in the current with variable mass*

Looking at the flow shown in Fig. 3, we can see that the change in value of q(x) in length has a nonlinear character. V.M. Zhuk offers to use the following dependencies for calculation:

$$q(x) = \mu S \sqrt{2gH(x)}\,;$$

$$Q(x) = \frac{1}{e}\int_0^x q(x)\,dx$$

then, according to the Darcy-Weisbach law for the pressure we obtain

$$dH = \frac{8\lambda Q^2(x)}{\pi^2 q d^5}\,dx$$

Further, the author gives a numerical analysis, which allows choosing the results relating to the reduction of consumption in separate sectors. However, this approach can only be used at the first approximation. The presence of polymer impurities can significantly affect the results of the experiments. In addition, the phenomenon of the anomalies of fluid viscosity may be displayed differently in laminar and turbulent flow regimes.

The studies were conducted under the simplified scheme using the installation with the main pipeline with the diameter of 27.2 mm and the length of 5 m. The nozzles were located at a distance of 0.7 m from each other with diameters ranging from 3 mm to 6 mm. The results are shown in Fig. 4. As a liquid, aqueous glycerin solution was used with the density of 1112 kg/m^3 at T=23.5°C, and a solution of carboxymethylcellulose (CMC) had the density of 1200 kg/m^3 at T=20°C.

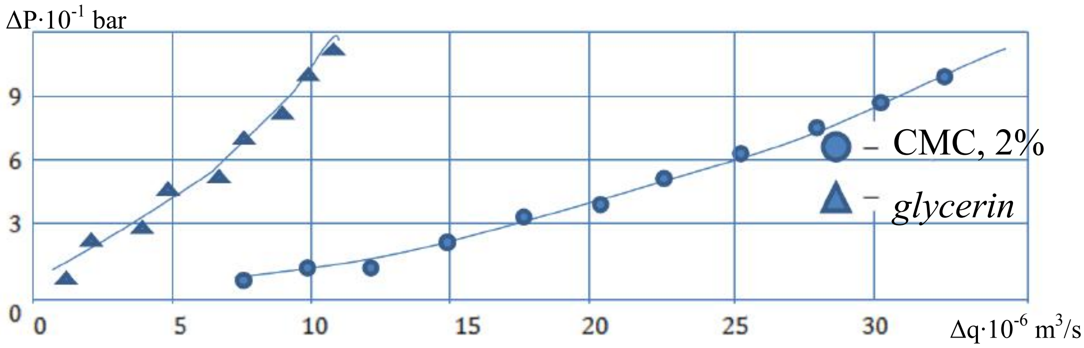

Fig. 4. The results of studies on the straight pipeline with a 2% aqueous solution of CMC and glycerin

Preliminary conclusion. Thus, the possibility of physical modeling of viscous liquids flow in pipelines with variable in length mass is considered. The stands, which allow the modeling of flow in the stream forming equipment (barrels), are presented. The stand with a pipeline in the form of curved channel with a radius of curvature of R_k=420 mm is also presented. Subsequently, it becomes possible to analyze the effect of the channel curvature on hydraulic resistance along the length of the flow.

Influence of changes in the mass of liquid flow along the length on its destabilization. Experimental studies conducted on the basis of installations presented above make it possible to get an idea of hydrodynamics of non-stabilized flows in currents in the presence of a discrete selection of liquid through the nozzles. The aim of further research was processing and synthesis of the results, which would make it possible to obtain dependencies characterizing the hydraulic losses in such channels, peculiarities of liquid outflow through the nozzles when the pressure along the length changes, and to develop recommendations that will help to predict the characteristics of such flows.

The destabilization of the flow due to changes in consumption along the length. On the basis of experimental studies, it has been found out that, depending on the distance between the nozzles mounted along the pipeline, the flow and pressure change respectively. Rate of change of these quantities is dependent on consumption from the main flow and the liquid flow regime, that is the Reynolds number. Thus, the experiments demonstrated how the quantity $\frac{dQ}{dx}$ changes along length of the pipeline, and thus the quantity $\frac{\partial U_x}{\partial x}$. Changing this value leads to destabilization of the flow behind the nozzle. The research results presented in Fig. 5-7 were obtained by photographing, and showed that the structure of the flow with high Reynolds numbers (Re>1500) varies greatly, especially in the turbulent flow regime.

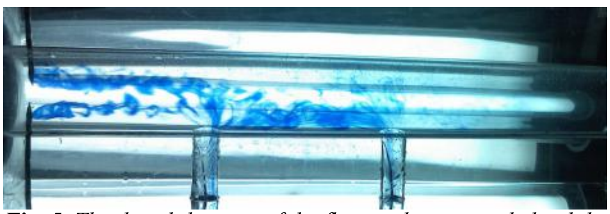

Fig. 5. The destabilization of the flow in the current behind the nozzle with a minimum consumption from the nozzle

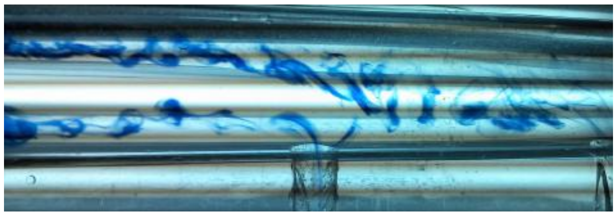

Fig. 6 The destabilization of the flow in the current behind the nozzle at Reynolds numbers Re>1500

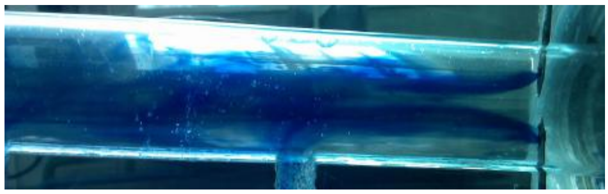

Fig. 7. The destabilization of the flow in the current behind the nozzle in the turbulent regime

Consequently, the flow in the pipeline in the sectors between the nozzles in some cases can be described from the point of hydrodynamic initial section, that is, assuming that behind the fluid selection sector velocity curve differs from the parabolic one, if the flow regime is laminar. Then the process of converting the curve to a form that corresponds to the stabilized flow is taking place.

As shown in works [8-10], the pressure drop in the initial part, taking into account the inertia forces from the convective acceleration, can be presented as the sum of two terms: the term corresponding to the stabilized flow $(\frac{\partial P}{\partial x})_{stub}$, which can be determined from the Darcy - Weisbach formula, and additional pressure drop which reflects the acceleration forces when the liquid particles move from the outer edge inwardly by smoothing the differences between $(U_{ave})^2$ and $(U^2)_{ave}$.

Analysis of the results of the experiments conducted in the curved lines. Conducting research we measured: total consumption; pressure; liquid consumption, selected through the nozzles along the flow at given viscosity, density and temperature of the liquid.

Thus, the liquid selection was discrete (through the nozzles installed at a distance of 4 m from each other), then graphically Q(x) function is represented as a step characteristics. However, processing the data, the solid line of function Q(x) and not the step one is constructed (Fig. 8). The error of this approximation does not exceed 10%, which makes it possible to assess the system of destabilization of the flow due to the variable along the length mass of current. Fig. 8 shows the character of this dependence for various values of consumption Q.

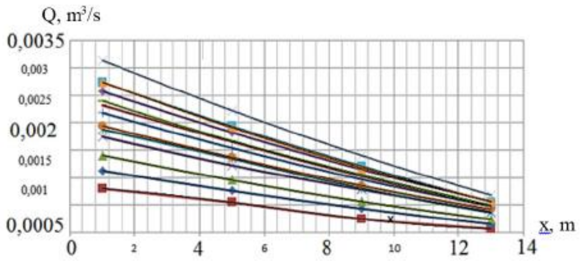

Fig. 8. *Character of change of the discrete selection of a viscous liquid through the nozzle along the length of the curved pipeline*

Character of change of the discrete selection of viscous liquid through the nozzles along the length of the curved pipeline for the case where the liquid is 0.5%, 1%, 2.5%, 5% aqueous solution of a foaming agent, will look similar to the one shown in Fig. 7.

Experiments have shown that changes in consumption Q (x) led to the change in pressure along the length of the pipeline and were nonlinear. Fig. 8 shows the character of this dependence in the case of the flow of water.

Character of change in pressure of viscous liquid through the nozzles along the length of the curved pipeline when the liquid is 0.5%, 1%, 2.5%, 5% aqueous solution of a foaming agent, will look similar to the one shown in Fig. 9. The non-linearity of the function F(x) is due to the fact that the local selection of liquid through the nozzles results in some destabilization of the flow, because of the influence of the inertia forces from convective acceleration. Thus, there is a difference between the pressure drop ΔP_{stab} of stabilized flow, where the function ΔP(x) is linear, and the flow being considered.

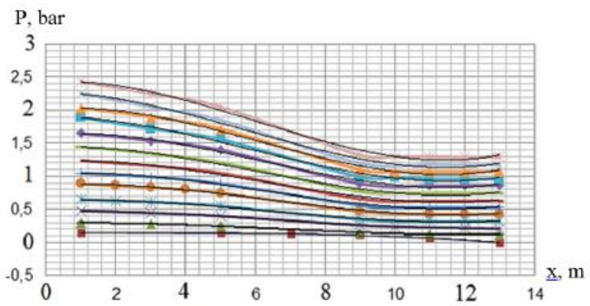

Fig. 9. *Character of change in pressure of viscous liquid through the nozzles along the length of the curved pipeline (for water)*

CONCLUSION

The analysis of the results of experiments investigating the flow of viscous liquids in the nozzles in the presence of discrete selection is presented in the article. The results of the experiments confirmed the assumption that flow in the currents described above is nonstabilized, i.e. in addition to viscous friction there are inertia forces from convective acceleration. Therefore, the energy losses in the current differ from losses for the stabilized current that must be taken into account in hydraulic calculations. Discrete liquid selection also leads to the fact that the calculation of nozzles arranged along the pipeline has specific characteristics. It is possible to offer recommendations in design of nozzles and sprinklers with the same consumption coefficients. The experimental results also allow drawing definite conclusions on the impact of the curved pipelines on hydraulic losses. The data obtained may be useful in the development of methods and algorithms for the calculation of this type of flows, for example, in the design of automatic fire extinguishing systems or agricultural irrigation systems.

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