VISCOSITY OF LIQUIDS IN A NONSTATIONARY TEMPERATURE FIELD

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In this paper, we've got the law of variation of dynamic viscosity in the nonstationary regime, i.e. directly in the process of performing technological operations on the basis of input and output information. A formula that establishes a relationship between the viscosity in the nonstationary and stationary regime is also obtained.

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INTRODUCTION

A large number of theoretical and experimental studies have been devoted to the investigation of fundamental thermophysical parameters of liquids [1-3]. Interest in researching the thermophysical properties of liquids is due to the fact that by controlling these properties with the help of various physical fields it is possible to increase the efficiency of technological processes.

Taking into account that the thermophysical parameters of the liquids are very sensitive to the conditions for their determination, in order to increase the accuracy of the measurements, the laboratory experimental setups have become more and more complicated all the time and it was still impossible to completely simulate the real conditions.

It should be noted that in nature all real processes are nonstationary and therefore methods for determining the thermophysical parameters of liquids based on stationarity of processes have limits of applicability. Thermophysical parameters of liquids, determined on the basis of stationarity of processes, are constant and do not change with time. And in the case of non-stationary processes, the thermophysical properties of liquids vary with time, i.e. the relaxation of the parameters takes place, and the relaxation time of these parameters is different. In this connection, in order to determine thermophysical parameters in the nonstationary regime, a method is proposed that would make it possible to establish a relationship between stationary and nonstationary properties of liquids.

THEORETICAL STUDIES AND DISCUSSIONS

One of the important thermophysical parameters of liquids, as is known, is the dynamic viscosity. In non-stationary mode, the pressure drop, as well as the fluid flow rate varies with time. Then it is obvious that the formula for determining the viscosity coefficient derived for the case of constant pressure and flow of liquids will differ from the formula for the variable pressure and the flow rate of the liquid.

The laminar stationary motion of a viscous liquid in a capillary tube is described by the equation:

$$\eta\left(\frac{d^2\upsilon}{dr^2}+\frac{1}{r}\frac{d\upsilon}{dr}\right)+\frac{\Delta p}{\ell}=0 \qquad (1)$$

The amount of fluid flowing through the cross section of the pipe per unit time, i.e. flow rate is determined by the formula:

$$Q=\int_0^R 2\pi r\upsilon(r)dr=const \qquad (2)$$

From the solution of equation (1) under the conditions $\upsilon(R)=0$, $\upsilon(0)\neq\infty$ and using Eq. (2) to determine the viscosity coefficient, the formula

$$\eta=\frac{\pi R^4\Delta p_\infty}{8\ell Q_\infty} \qquad (3)$$

Where the index «∞» corresponds to the stationary motion, i.e. $t\to\infty$. Formula (3) determines the viscosity in a stationary state. In the nonstationary regime, the viscosity $\eta(t)$ as well as the stationary one is theoretically determined by solving the inverse problem for the Navier-Stokes equation. From the solution of this equation, one can find the relationship between viscosity in the nonstationary $\eta(t)$ and stationary regime η.

The nonstationary laminar motion of a viscous incompressible fluid in a capillary tube is described by a differential equation:

$$\rho\frac{\partial\upsilon}{\partial t}=\eta(t)\left(\frac{\partial^2\upsilon}{\partial r^2}+\frac{\partial\upsilon}{\partial r}\right)+\frac{\Delta p(t)}{\ell} \qquad (4)$$

To solve the differential equation (4), the averaging method [4] is applied. Following [4], we introduce the function $\varphi(t)$

$$\varphi(t)=\frac{1}{R}\int_0^R\frac{\partial\upsilon}{\partial t}(r,t)dr \qquad (5)$$

Taking into account (5), the differential equation (4) is written as follows

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$$\frac{1}{r}\frac{d}{dr}\left(r\frac{d\upsilon}{dr}\right)=\frac{\varphi(t)}{\upsilon(t)}-\frac{\Delta p(t)}{\rho\ell\upsilon(t)} \qquad (6)$$

The solution of this equation under the conditions noted above has the form:

$$\upsilon(r,t)=\frac{1}{4}\left(r^2-R^2\right)\left[\frac{\varphi(t)}{\upsilon(t)}-\frac{\Delta p(t)}{\rho\ell\upsilon(t)}\right] \qquad (7)$$

The flow rate through the pipe cross-section is determined by the formula

$$Q(t)=\frac{\pi R^4}{8\upsilon(t)}\left[-\varphi(t)+\frac{\Delta p(t)}{\rho\ell}\right] \qquad (8)$$

To determine $\varphi(t)$ let's put the value $\upsilon(r,t)$ from (7) into (5), then we have

$$\varphi(t)=-\frac{R^2}{6}\left[\frac{\varphi(t)}{\upsilon(t)}-\frac{\Delta p(t)}{\rho\ell\upsilon(t)}\right]' \qquad (9)$$

Performing differentiation in (9), we obtain the following equation for determining $\varphi(t)$

$$\frac{d\varphi}{dt}+\left(\frac{6\upsilon}{R^2}-\frac{\upsilon'}{\upsilon}\right)\varphi=\frac{\Delta}{\rho\ell}-\frac{\Delta p}{\rho\ell\upsilon} \qquad (10)$$

The solution of this equation is expressed by the formula

$$\varphi(t)=e^{-\Phi(t)}\int_0^t\left(\frac{\Delta p'}{\rho\ell}-\frac{\Delta p\upsilon'}{\rho\ell\upsilon}\right)e^{\Phi(t)}dt \qquad (11)$$

whereas $\Phi(t)=\int_0^t\left(\frac{6\upsilon}{R^2}-\frac{\upsilon'}{\upsilon}\right)dt.$ from joint solution (8) and (11) we get an equation for determining the viscosity coefficient for the nonstationary motion of a viscous liquid in a capillary tube:

$$\frac{8\upsilon(t)Q(t)}{\pi R^4}-\frac{\Delta p(t)}{\rho\ell}=e^{-\Phi(t)}\int_0^t\left(\frac{\Delta p'}{\rho\ell}-\frac{\Delta p\upsilon''}{\rho\ell\upsilon}\right)e^{\Phi(t)}dt \qquad (12)$$

Solving equation (12) we obtain the following formula for determining the non-stationary viscosity

$$\eta(t)=\frac{\pi R^4\Delta p(t)}{8Q(t)\ell}-\frac{\rho R^2}{6Q(t)}Q' \qquad (13)$$

Obviously, if $\Delta p=const$ $Q=const$ then formula (13) coincides with formula (3) for the stationary case. From a comparison of (3) and (13) we have

$$\frac{\eta(t)}{\eta_\infty}=\frac{Q_\infty}{Q(t)}\left[\frac{\Delta p(t)}{\Delta p_\infty}-\frac{4\rho\ell}{3\pi R^2\Delta\rho_\infty}\frac{dQ}{dt}\right] \qquad (14)$$

Formula (14) establishes the relationship between stationary and non-stationary viscosities of liquids.

CONCLUSION

Application of formula (14) does not require the creation of a special laboratory installation. To use formula (14), it is sufficient to know the flow rate and the pressure drop over time in a certain section of a pipe of length *l*. The proposed formula (13) makes it possible to determine the law of viscosity change with time in the region of the nonstationary field and can be used as the basis for creating an automated system for continuous measurement of thermophysical parameters of liquids.

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