AUTOMATED SYSTEM FOR CHECKING THE VISCOSITY-TEMPERATURE CHARACTERISTICS OF LIQUIDS

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A description is presented of an automated monitoring system that makes it possible to measure all of the viscosity-temperature characteristics of polymers, lacquers, sulfur, oils, and other petroleum products. The system checks the quality of the products in real time during the production process.

Increasing the production of polymers, lacquers, paints, sulfur, lubricating oils, and other petroleum products, improving the quality of those products, conserving raw materials and energy, and improving working conditions for employees are the most acute problems facing petrochemical plants today. All of these problems can be resolved by automating process measurements and automating control of the production process on the basis of those measurements while simultaneously broadening the range of parameters that are checked.

The quality of polymers, lacquers, paints, sulfur, lubricating oils, and other petroleum products is determined by their molecule structure, which is in turn characterized by the energy of the intermolecular bonds and viscosity at a prescribed temperature (either the viscosity at two prescribed characteristic temperatures or viscosity at a single prescribed characteristic temperature and the viscosity index). The energy of the intermolecular bonds is determined in scientific laboratories with the use of special equipment. Only viscosity and the viscosity index are determined under factory conditions. Direct measurements of viscosity at prescribed characteristic temperatures are made only on laboratory viscometers, while the viscosity index is determined by calculation. These are the testing methods used at factories in the nations of the CIS (Commonwealth of Independent States). However, it takes from 3 to 5 h to perform a lab analysis of one sample of a product taken from a pipeline. This time period is too long to allow real-time correction of the production process. In addition, obtaining samples of polymer melts (at temperatures up to 300°C and pressures up to 10^7 Pa) is a complicated operation that is potentially dangerous for production workers.

The industrial viscometers made by the leading companies (HAAKE (Germany), HOECHST (Germany), BROOKFIELD (U.S.)) allow real-time measurement only of viscosity and only at the working temperature. Values of viscosity at the prescribed characteristic temperatures are calculated from formulas that describe the temperature dependence of the viscosity of a product which conforms to the corresponding specifications. Here, it is assumed that the parameters in these formulas are known constants. However, the dimensions of molecules and their structural bonds change during the production process, so there are also changes in the values of the parameters that describe the functional dependence of viscosity on temperature. Since the latter changes are not accounted for by existing industrial viscometers, these instruments cannot provide a high degree of accuracy in monitoring and control operations.

To resolve the above problems, we have developed a system that is unique in world practice [1, 2]. The system makes it possible to measure all of the viscosity-temperature characteristics (viscosity corrected for prescribed characteristic temperatures; viscosity index; intermolecular bond energy, and other parameters characterizing the functional dependence of viscosity on temperature of polymers, lacquers, paints, sulfur, oils, and other petroleum products in real time.

The liquid being tested is moved by a pump (see Fig. 1) with a regulable productivity through a measured section of a pipeline, the MS is heated by a heater of regulable power, and pump productivity and heater power are varied in the course of the test. At different moments of time, different values of pump productivity, and different values of heater power established by means of a controller respectively measure running values of the pressure gradient in the MS, the power of the heater, pressure in the pipeline after the pump, the speed of the pump rotor, the tempera-

Fig. 1. Diagram of an automated system for monitoring the viscosity-temperature characteristics of liquids.

ture of the walls of the pipeline inside the heater, and the temperature of the walls of the pipeline before the heater. The output signals of the transducers are sent to the controller 6, which calculates the running values of the viscosity-temperature characteristics of the test liquid on the basis of a mathematical model of the system.

The mathematical model of the system was obtained from the equation that describes the laminar flow of viscous fluids and the equations that describe heat exchange between the walls of the MS and the flow of the test liquid [3]:

\[ G = -\frac{x}{2} \frac{dP}{dx} \int_{0}^{R} \frac{r^3}{\sqrt{r^2}} \, dr \]  

(1)

\[ \frac{c_{p}v \frac{\partial T}{\partial x}}{2} = \frac{\partial}{\partial x} \frac{\partial T}{\partial r} + \frac{\partial}{\partial r} \left( \lambda \frac{\partial T}{\partial r} \right) . \]  

(2)

where \( G \) is the mass rate of liquid flow through the MS; \( p \) is pressure in the MS; \( x \) is the axial coordinate, which coincides with the direction of the flow; \( r \) is the radial coordinate; \( \nu(T) \) is the kinematic viscosity of the liquid at the temperature \( T \); \( c \) is the heat capacity of the liquid; \( \rho \) is the density of the liquid; \( v \) is the velocity of the flow; \( \lambda \) is the thermal conductivity of the liquid. The following approximate expressions were used:

\[ \frac{1}{\nu(T)} = \frac{1}{f(T_1, a_1, a_2, ..., a_n)} \]  

(3)

\[ G = c_1 \omega - \frac{\omega_1 \rho p}{f(T_1, a_1, a_2, ..., a_n)} \]  

(4)

\[ \frac{d\rho}{dx} = -\frac{\Delta \rho}{L} ; \]  

(5)

\[ T_1 = \frac{2}{R^2} \int_{0}^{R} r T \, dr ; \]  

(6)

\[ \left( \lambda \frac{\partial T}{\partial r} \right)_{r=R} = \frac{W}{\delta} ; \]  

(7)

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