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ScienceDirect

Procedia Engineering 150 (2016) 626 – 634

Procedia Engineering

www.elsevier.com/locate/procedia

International Conference on Industrial Engineering, ICIE 2016

Inertial Method of Viscosity Measurement of the Complex Rheology Medium

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Abstract

Modern lubricants have a complex content and complex rheological properties: the viscosity of oils depends on the shear rate, pressure and temperature. Strange as it is, the complication of the rheological properties of the studied medium requires the simplification of thermomechanical testing conditions. It is due to the necessity of development of the homogeneous distribution of the thermomechanical values and the flow conditions with the known type of the stress-strain state. The authors offer a theoretical justification of a new method of the viscosity measurement of the complex rheology medium which combines the advantages of known rotational and capillary methods. The medium under study moves in the torus-shaped channel under the influence of the inertial forces, during this movement the friction torque is measured and the viscosity is calculated. The problem of a non-stationary and non-isothermal movement of the complex rheology medium in the torus-shaped channel has been studied. Based on the similarity theory and the analysis of the equability of the dimensions, the conditions were determined, under which the strain rate tensor has the simplest form, on the surface of the torus the distributions of the thermomechanical values are homogeneous, and pressure and temperature are homogeneous across the whole object. Based on the movement equation projected on one of the axis in the toroidal coordinates, the method of viscosity calculation was developed. Moreover, the prototype of the test rig and the data acquisition and measurement system were developed which allow to apply the automated experimental study on the subject.

Peer-review under responsibility of the organizing committee of ICIE 2016

Keywords: Rheology; viscosity; viscometer; non-Newtonian fluid; hydrodynamics.

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Peer-review under responsibility of the organizing committee of ICIE 2016
doi:10.1016/j.proeng.2016.07.056

1. Introduction

The majority of precise viscometers can be either capillary or rotational viscometers [1]. The theoretical base for them are the Poiseuille flow and the Couette flow accordingly [2-4]. Other types [5], including orifice viscometers, falling ball viscometers [6], vibrational viscometers [7] and ultrasonic viscometers [8] – are simple in application but have some significant assumptions made in the theory and methods, so their application to the medium of complex rheology is inconvenient. The application of capillary or rotational viscometers to the complex rheology medium is also a number of challenges. First of all, it has to be remembered that viscosity by definition is a proportional coefficient in a generalized Newton's law, connecting the stress tensor and the shear rate tensor. So when going from the acquired integral values of flow and friction force torque to the differential values of shear rate or shear stress, during the experiment it is advised to have a homogeneous distribution of the latter. Secondly, the measurement of one physical value, which characterizes only the stressed or only deformed state of the medium under experiment, causes the change in the number of unknown values and requires the use of additional continuum mechanics equations; and when studying the non-Newtonian medium it also requires the a priori knowledge of the rheological models [9].

The main goal of the present work is a theoretical justification of the new method of viscosity measurement, which provides the homogeneous distribution of the thermomechanical values and allows measuring the viscosity of the medium with complex rheological properties, depending on the shear rate, temperature and pressure. Note that the pressure factor gains more and more important in the research of the fluids with hard additives [10].

2. Conceptual model of inertial method of viscosity measurement

The goal can be achieved with the combination of advantages and eliminated disadvantages of the capillary and inertial viscometers. It is suggested that the torus-shaped closed channel is used as a flow area of the medium under research, where the flow will be provided by the action of inertial and friction forces. Such cannel is, in fact, the capillary free from the disadvantage of the capillary viscometers – heterogeneity of the stress distribution. Indeed, in capillary viscometers the medium pumping is provided by the pressure drop on the ends of the capillary, in the inertial viscometer the pressure along the channel is equal from the symmetry condition, and the driving force is the inertial force. Here the advantage of the capillary viscometer is saved – homogeneity of the strain distribution on the surface of the capillary. More than that, it is easier to put the medium under high pressure in the closed channel. The advantage of the rotational viscometers is the continuous measurement of the friction torque in some range of velocities, and the disadvantage is the influence of the related friction force torques in the bearings and in the drive. So, the friction torque measurement after a full stop of torus rotation but during the continuing inertial motion of the medium inside also provides the continuity of advantages and elimination of disadvantages.

The suggested inertial viscometer is a torus [11,12], characterized by the channel radius r and the distance between the symmetry center and the center of the channel R, see Fig.1.

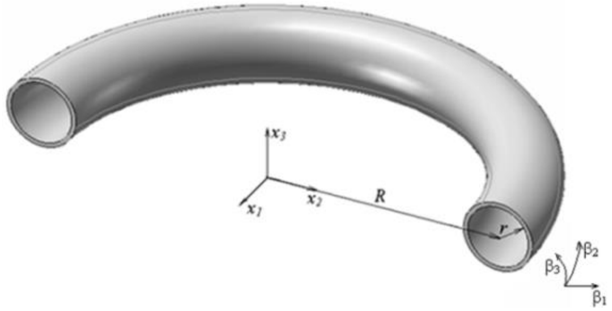

Fig. 1. Section of the toroidal flow area.