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MATHEMATICAL MODELING OF STRUCTURAL TRANSFORMATION OF SUSPENSION INTO ANISOTROPIC COMPOSITE WITH OPTIMAL STRUCTURE

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ABSTRACT

The flow is associated usually with an irreversible destruction of macrostructure of flowing structured liquid medium. Nevertheless, we unexpectedly detected that dilute suspension of axially symmetric elongated particles with anisotropic carrier fluid acquires the optimal stable anisotropic structure in gradient flows. The optimizing factor of this phenomenon is the anisotropy of the suspended carrier fluid. Thanks to it, gradient flows form the anisotropic composite in suspension, suspended particles of which was initially randomly oriented. It facilitates the reinforcement of anisotropic matrix with the help of uniformly oriented elongated undeformable particles.

In the first part of our study presented in this contribution, we obtain the constitutive equations defining the rotary dynamics of suspended axially symmetric undeformable particles in arbitrary gradient flows of dilute suspension with anisotropic carrier fluid under the action of hydrodynamic forces, and also obtain the constitutive equations which allow to study the stress arising in such a suspension. These equations are derived within the frames of the structure-phenomenological approach proposed for the first time in [1]. The Ericksen anisotropic fluid [2] and a symmetric triaxial dumbbell [3] are used as a rheological model of the suspension carrier fluid and a hydrodynamic model of suspended particles respectively.

Our investigations in the second part of the paper demonstrate that the anisotropy of viscosity of the Ericksen carrier fluid of the considered suspension arising in gradient flows is the cause of the anisotropy of hydrodynamic interaction of suspended particles with surrounding medium. This leads to the existence of stable stationary solutions of the dynamical set of ordinary differential equations describing the particles rotary motion in a steady-state Couette flow of the suspension. Particular emphasis has been placed on the investigation of stability of the obtained stationary solutions by the use of the first method of Lyapunov [4]. By this is meant that suspended elongated particles may be oriented stationary in gradient flows of suspension with anisotropic carrier fluid under the action of forces, which usually destroy macrostructures of flowing liquid media. In such a manner, biaxial anisotropic liquid-crystalline structures arise in the considered suspension. They are formed by the stationary orientation of the unit director

of the Ericksen anisotropic carrier fluid and by the uniform stationary orientation of suspended particles.

A comparison between the results obtained in the present paper with the results obtained by Einstein [5] and Jeffery [6] shows that the dilute suspension of rigid particles with anisotropic carrier fluid can behave in gradient flows radically differently than the corresponding dilute suspensions with the Newtonian carrier fluid. So, the employment of the constitutive equation for stress arising in gradient flows of the dilute suspension with anisotropic carrier fluid obtained in the present paper shows that the structural optimization of the suspension induced by gradient flows changes the properties of the suspension in such a way that it behaves as a viscoelastic quasi-Newtonian liquid medium. Its shear effective viscosity does not depend on a shear rate of gradient flows but it depends on the parameters characterizing considered suspension and the stationary biaxial anisotropy established in the suspension. The elastic properties of the suspension in this case are characterizing by manifestation of the Weissenberg effect, that is, by the presence of non-zero differences of normal stresses in a steady-state Couette flow of the suspension.

The mathematical model of the structural optimization of the suspension presented in this paper is proposed as a theoretical model of forming the composite materials through the reinforcement of liquid-crystalline matrices with elongated undeformable uniformly oriented particles.

The hydrodynamic orientation of suspended particles is of great importance in the case when suspended particles are electrically (magnetically) neutral and orientation of the suspended particles under the action of electrical (magnetic) fields is impossible. Also obtained results can be used in developing the hydrodynamic theory of formation of liquid crystals on the base of self-consistent field theory.

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