ON NONLINEAR RHEOLOGY OF DENSE SUSPENSIONS

A.Yu. Zubarev[1], L.Yu. Iskakova[1], I.A. Bashkirtseva[1], L.B. Ryashko[1], S.P. Fedotov[2]

1 - Urals State University
2 - Manchester University

andrey.zubarev@usu.ru

Many experiments with concentrated suspensions, polymers, oils, and other complex fluids demonstrate strong shear thickening effects, (increase of viscosity with the shear rate $\dot{\gamma}$ or imposed stress σ by several times or even orders of magnitude), S-like dependences of σ on $\dot{\gamma}$, instabilities of the fluid steady flow, regular and chaotic self oscillations of the flow. These effects have been observed in suspensions with particles of various shape (spherical, disks, rods, etc.) and compositions (metallic, plastic, glass, etc), various polymer solutions, micelle solutions, emulsions, etc. Therefore, these phenomena have a general character. The microscopical, internal nature of these strong effects is still none understood.

We propose a microscopical model of the non linear rheological behavior of concentrated suspensions. This model is based on the idea that the shear thickening effects and S-like shape of the function $\sigma(\dot{\gamma})$ can be explained by contact friction between the suspended particles. Indeed, in real suspensions particles are seldom perfectly smooth; some microroughnesses are inevitable in principle. Sufficiently strong hydrodynamic shear stress can approach particles to such an extent that a spot of physical interparticle contact arises. Therefore, a rise in the shear stress may enhance the interconnection of the rough regions, thus enlarging the contact spot, where the interparticle friction manifests itself. The enlargement of the contact spot must cause an increase in the friction force, which, in its turn, may noticeably enhance the viscosity of a medium and even decelerate its flow. Note that the hypothesis on the contact friction cause of the shear thickening and S-effects is supported by experiments which demonstrate that roughening of the particle surface strongly increases the effective viscosity of suspensions. Computer simulations also suggest a great contribution of the contact friction to the development of the viscosity of concentrated suspensions.

The decreasing part of the S- dependence corresponds to negative sign of differential viscosity of the suspension. Steady flow of a fluid with the negative differential viscosity can not be stable. Our analysis shows that experimentally observed oscillations of the suspension flow can be caused by combination of negativity of this viscosity with viscoelasticity of the system. We propose a model of viscoelastic liquid with S-like dependence of σ on $\dot{\gamma}$. This model leads to self-oscillations of the flow, which, in principal points, coincide with those, observed in experiments. Amplitude and shape of these oscillations depend significantly on the imposed shear stress/shear rate.

We have studied effects of external noise on the self-oscillations. This noise can be induced by small vibrations of the system, irregular distribution of the particles in suspension, etc. Analysis shows that the noise can change significantly character of the self oscillations and even induce these oscillations in the region of flow which is stable in the noiseless system.

In conclusions, the proposed microscopical model explains shear thickening phenomena in dense suspensions, experimentally observed S-like dependence of σ on $\dot{\gamma}$ and appearance of the rheological self-oscillations of the suspension flow.

ACKNOWLEDGEMENT: This work has been supported by grants of Russian Agency of Education 2.1.1/2571 and 2.1.1/1535, grant of Russian Federal Target Program, grants 02.740.11.0202, 02-740-11-5172 and NK-43P(4), grants RFFI 10-02-00034, 10-01-96002-Ural and 10-02-96001- Ural .