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Viscosity Properties of Dusty Plasma Liquid

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The investigation of the transport of momentum in dusty component of plasma is attracting more and more attention due to new information that it is able to give about macroparticle interaction in strongly nonideal plasma. Some works dealt with viscous properties of systems with screened Coulomb potential via computer modeling [1,2]. In addition to it some experimental works have been carried out dealing with measurement of shear viscosity coefficient of dusty component in two- and three-dimensional cases [3, 4]. Note that the results of the works [3] and [4] differ violently. This distinction might be explained different number of dimension of the studied objects. Besides one must bear in mind sufficient difference in the conditions under which the dusty structures were formed in these researches. At first place it is about background gas pressure. In the work [3] dust was trapped in plasma under pressure ~ *1 Pa*. As for the work [4] it amounted *35 Pa*. In view of this it is of particular interest to study the dependence of shear viscosity coefficient on background gas pressure. Moreover, in the work [4] one can find some facts pointing to anomalous character of current of dusty plasma liquid: the formation of stream channel which is larger than the one of external action and threshold character of current. The first fact is evidence of existence of critical shear tension. The latter is the tension bellow which there is no current, this being confirmed by the experiment. As soon as the power of external action is less than *10 mW* under the conditions in question there was no current. The facts above show the non-newtonian type of dusty plasma liquid current. That is why we fulfilled the research of shear viscosity coefficient dependence on the value of external action.

This work is also devoted to experimental studying of dusty plasma liquid shear viscosity coefficient dependence on value of outer influence resulting in flow of dusty plasma liquid. The results of experimental studying of dusty plasma shear viscosity for different values of background gas are also presented here.

Experiments with a variation of parameters RF-discharge (RF-power (3-15 W) and gas pressure (15- 35 Pa) were carried out. As a background gas we used argon. In experiment we use monodisperse plastic particles of 1,9 μm diameter. The structures formed by dust particles in RF-discharge are levitated above lower electrode. Directed moving of macroparticles in dusty plasma liquid was caused by laser radiation (Ar+ 514 nm). The diameter of zone within which dusty plasma liquid was affected by laser beam was equal in each of four cases and amounted 3 mm.

During experimental data processing the parameters of non-perturbed media (e.g. dusty plasma structure without external influence) were obtained: macroparticles concentration, range of order (pair correlation functions and nonideality parameter Γ) and kinetic temperature of dusty subsystem. According to the results mentioned the state of dusty structure must be treated as liquid.

In the course of processing of video images obtained in experiments for each value of external influence power (0 – 400mW) and each value of plasma making gas pressure the trajectories of dusty particles were regained. The analysis of them confirmed that in all cases there was laminar flow of dusty liquid. One is able to plot velocity distributions *V(r)* along the radius of argon laser beam.

It was found that under the influence of sufficiently large laser radiation power and relatively high pressures of background gas (overall radiation power ≥ 300 mW, P ~ 35Pa) stream velocity profile can be drawn as trapezium, as it was done in [4]. In that case the viscosity can be evaluated using the classical definition on the basis of momentum balance. However if laser radiation power and pressure of background gas are decreased stream velocity profile deviates from the trapeziform and tends to be like velocity profile of viscous flow of the classical liquid, described by Navier–Stocks equation. In view of this in the present work the determination of the dusty liquid viscosity coefficient was fulfilled via comparison of empirical velocity profile with the profile for viscous laminar flow of liquid in a cylindrically symmetrical tube of radius R_V under the effect of bulk force *F(r)* (*r* – radial distance) (*F(r)* was measured during the experiment).

We have a cylindrical symmetrical problem to solve. Let us treat dusty plasma liquid as incompressible. The Navier–Stocks equation thus transforms to:

$$\eta \cdot \frac{1}{r} \cdot \frac{\partial}{\partial r}\left(\frac{\partial V}{\partial r}\right) = -F(r) \qquad (1)$$

Bear in mind that the diameter of the tube (inside which we study the flow of dusty liquid) was chosen according to experimental velocity profiles in the way for liquid velocity to be zero at tube's boundary.

Numerical solution of Eq. (1) with zero boundary conditions allows one to obtain the dependence of stream velocity for dusty liquid on *r*. Via the comparison of this distribution with empirical one we were seeking the optimal value of shear viscosity coefficient in Navier–Stocks equation to make them coincide as much as possible. The value of η that ensures the best coincidence was treated as the viscosity of dusty plasma liquid. Thus for each value of laser radiation power and background gas pressure the values of shear viscosity coefficients were obtained. (fig. 1.)

The dependencies obtained allows one to state confidently that the viscosity of dusty plasma liquid decreases with decreasing background gas pressure. Today there is no fine interpretation for this fact. However, by analogy with other systems containing disperse phase and demonstrating anomalous behaviour of shear viscosity one can make some hypothesis about the mechanism of such a behaviour. Particularly this effect can be evidence of attraction between macroparticles. Let us presume that along with screened Coulomb potential there is some attraction potential (see for instance [5]). In view of this two macroparticles can form coupled state if the velocity of their mutual movement is low. Indeed, under comparatively low pressures the friction due to background gas is negligible and a macroparticle, because of low dissipation, possesses sufficient kinetic energy and does not "fill" small potential hole, and domain of localization is determined by neighbours repulsion. On the contrary if the background gas pressure is high the friction "calm" the macroparticle and it can be trapped by the potential hole. In that case any displacement of a neighbour causes the displacement of the particle. In other words, with attraction in interparticle potential viscosity increases with increasing background gas pressure. We can't help mentioning that the dependence of liquid viscosity on pressure was discussed in early works of Frenkel [6]. It's obvious that the speculation about pressure influence upon viscosity of common liquids can't be applied for dusty plasma medium. At the same time the approach based on the concept of "free volume" and empirical formula of Bachinskij [7] (according to which viscosity is inversely dependent on free volume) can be valuable in the case of dusty plasma. It means that with background gas pressure increasing and arising of crystal-like clusters the free volume in dusty plasma is sufficiently decreasing. According to Bachinskij formula viscosity must increase, the latter being observed experimentally.

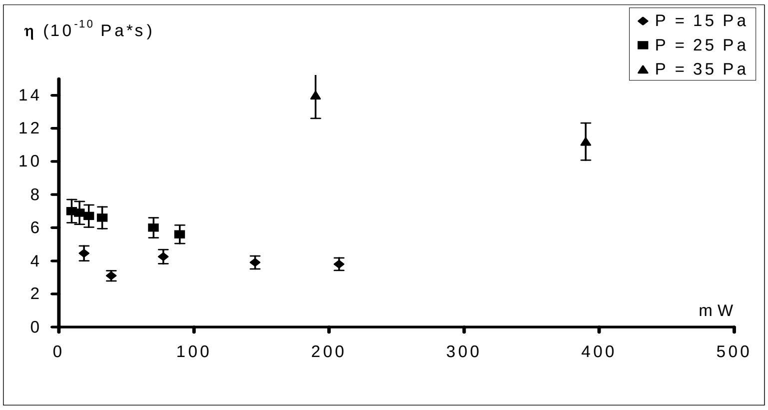

Fig.1. The power of laser action dependence of shear viscosity coefficient for various pressures of background gas.

One more interesting fact is the dependence of the viscosity on the value of the external action. The experimental data obtained (fog. 4) show that increase of laser radiation power (e.g. the value of external action) results in decrease of shear viscosity. Such a dependence is the property of so called Bingham liquids. [8,9].

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