35th EPS Conference on Plasma Phys. Hersonissos, 9 - 13 June 2008 ECA Vol.**32D**, P-1.156 (2008)

Dust motion in flowing magnetized plasma

B.P. Pandey[1,2], A. Samarian[2], S. V. Vladimirov[2]

[1] *Department of Physics, Macquarie University, Sydney, NSW 2109, Australia*

[2] *School of Physics, University of Sydney, NSW 2006, Australia*

Plasma flows occur in almost every laboratory device and interactions of flowing plasmas with near-wall impurities and/or dust significantly affects the efficiency and lifetime of such devices [1]. As an example, the Hall thruster, also known as closed-drift thruster, lacks an adequate physical model to describe the critical regions of a plasma dynamics in a self-consistent fashion [2-3]. This is important as the choice of thruster sizes requires an optimum selection between efficiency and lifetime. Another example is the fusion devices where the impact of the dust grain near the first wall is not well understood. On the other hand, the dynamics of dust particles near tokamak walls may significantly modify the plasma transport properties [4].

The drag on the dust inside the sheath consists of the forces caused by the flowing plasmas as well as the electrostatic field near the plasma–wall boundary. The charged dust placed in the path of plasma flows experiences the drag force and resulting dust dynamics is controlled by the strength of this force. Ion drag is the force applied to charged particle by flowing ions. It occurs from two processes: some ions are deflected by Coulomb attraction of a negatively charged dust particle, producing so called orbit force (or Coulomb collision), while others collide straight with particle, producingâĂăso called collection force (or charged collision).

The primary motivation of this work is to examine the motion of the dust particles in non-uniform flowing plasma (which reflects near wall region of plasma devices) by self-consistently calculating the charge and forces on the grain. We believe that such an investigation will complement the ongoing study of the plasma sheath characteristics by using fine dust probes [5-6]. We extend our previous work [7] by studying the dust dynamics in the presence of plasma flow in a magnetized sheath.

Two-component plasma consisting of electrons and singly charged ions is considered in the presence of a magnetic field that is parallel to the wall. A stationary magnetized planer plasma sheath boundary is located at $z = 0$ with the plasma filling the half space $z < 0$. The basic set of equations and boundary condition for a magnetized sheath is described in Ref. [7]. The dynamics of the dust grain is determined by numerically solving following set of equations

$$\frac{dz}{dt} = v_d\,, \quad m_d\,\frac{dv_d}{dt} = F_{\mathrm{coll.}}(a, v_d) + F_{\mathrm{CD}}(y, a, v_d) + F_E\,, \tag{1}$$

where collisional and Coulomb drag (CD) forces are both due to electrons and ions. We find

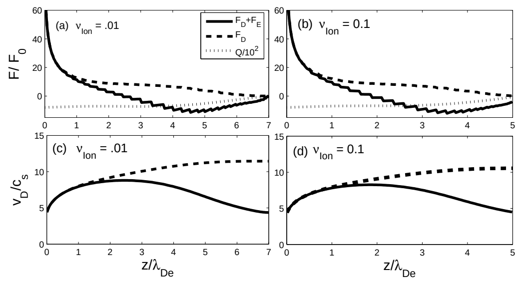

Figure 1: In Fig. 1(a)-1(d) the profile of drag and drag plus electrostatic forces inside the sheath are shown along with the charge distribution of grain charge in the unit of $10^2 e$ is given for $\beta_i = 0.01$, $\beta_e = 0.1$, $\nu_{en} = \nu_{in} = 0.1$ and changing ν_I.

that for the micron-sized grains, the collisional drag force dominates the Coulomb drag force. The electrostatic force $F_E = Q\mathbf{E}$ becomes important closer to the wall and may modify the dust trajectory considerably. The expressions for the collisional and Coulombic drag forces are

$$F\mathrm{drag}(i,e) = 2\pi a^2 T_{i,e} n_{i,e} G_0(s_{i,e}) \,, F_{\mathrm{CD}}(y,a,v_d) = 2\pi a^2 T_{i,e} n_{i,e} y^2 \log(\Lambda_{i,e}) G_2(s_{i,e}) \,, \quad (2)$$

where the difference between the plasma and the grain surface potential $y(z, v_p) = \Phi_p - \Phi_s$ determines the grain charge Q and

$$s_{i,e} = \sqrt{\frac{m_{i,e}\left(v_f - v_d\right)^2}{2T_{i,e}}}, \quad \Lambda_{i,e} = \frac{3\lambda_{De,i}}{e|y|a\left(1+\frac{a}{\lambda_s}\right)}, \quad (3)$$

with v_f as the plasma flow velocities and

$$G_0(s) = \frac{8s}{3\sqrt{\pi}}\left(1+\frac{9\pi}{64}s^2\right)^{1/2}, \quad G_0(s) = s\left(\frac{3\sqrt{\pi}}{4}+s^3\right)^{-1}. \quad (4)$$

For the given conditions, the sheath width $\lambda_s \gg a$ and the correction a/λ_s in Eq. (3) is unimportant. Only when grains are really large, i.e. $a \leq$ cm this correction could modify $\Lambda_{i,e}$. In the present case, we deal with the micron-sized grains and hence the correction $\sim a/\lambda_s$ will be neglected. The results are given for F/F_0 where $F_0 = m_d c_s \omega_{pi}$. For $T_e = 1eV$, for argon ions $c_s = 2.36\times10^5$cm/s and with reference density $n_0 = 10^8\,\mathrm{cm}^{-3}$, the ion plasma frequency is $\omega_{pi} = 3.1\times10^6\,\mathrm{s}^{-1}$. Thus for a micron-sized grain $a = 10^{-4}$cm, we get $F_0 = 3\,10^{-5}$N. We have assumed that the grains are spherical with radius a in these estimates. We shall define $\beta_j = \frac{eB}{m_j c \nu_{jn}}$ as the ratio of plasma-cyclotron to the plasma-collision frequencies and discuss the dust dynamics inside the sheath by changing β_j.

In Fig. 1(a)-(d) the forces and corresponding velocity profiles are given for the parameters $\beta_i = 0.01$, $\beta_e = 0.1$, $\nu_{en} = \nu_{in} = 0.1$ and varying ionization frequency ν_I. With increasing ionization frequency, the sheath width decreases. The sheath potential for the increased ionization

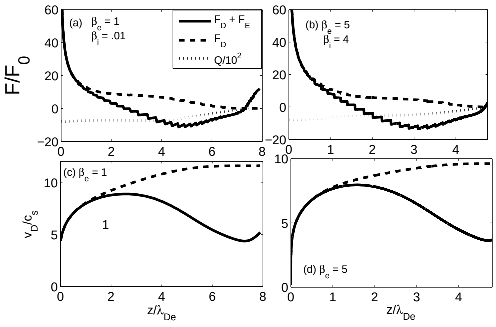

Figure 2: Same as Fig. 2 with $\nu_I = 0.001\,, \nu_{en} = \nu_{in} = 0.1\,, \beta_i = 0.01$ and $\beta_e = 1$. Fig. 4(b) and 4(d) with $\nu_I = 0.001\,, \nu_{en} = \nu_{in} = 0.1\,, \beta_i = 4$ and $\beta_e = 5$.

frequency decreases almost by half [7], although this is not reflected in the Fig. 1(a) - 1(b), as in both cases $F_D + F_E$ curve is similar. The respective velocity profiles Fig. 1(c) - 1(d) are very similar as well. The reason, as has been noted above lies in the grain charging. Since the charge distribution is similar for $\nu_{Ion} = 0.01\,\omega_{pi}$ and $\nu_{Ion} = 0.1\,\omega_{pi}$, the magnitude of electric force acting upon the charged grain is very similar. This explains why in both case, force and velocity profiles are similar. In Fig. 2(a) and 2(c) the parameters $\beta_i = 0.01\,, \nu_{en} = \nu_{in} = 0.1\,, \nu_I = 0.001$ and $\beta_e = 1$. It is known that the sheath potential is not very sensitive to the electron magnetization and only when electron-cyclotron frequency dominates the electron-neutral collision, the sheath characteristics displays significant change [7]. The total force $F_D + F_E$ on the grain, like in Fig. 2(a) and 2(b) twice changes sign, once in the middle of the sheath and again very close to the wall. Clearly, the insensitivity of the sheath characteristics when $\beta_e = 1$ is seen in the similarity of Fig. 1(b) and Fig. 2(a). Only when electron-cyclotron frequency dominates the electron-neutral collision, i.e. $\beta_e \gg 1$ the sheath characteristics will change. Thus, when $\beta_e = 5$ and $\beta_i = 4$, the increased electron and ion magnetization inhibits the free flow of electrons to the wall and this will result in decreased sheath width. One may conclude that the change in the sheath potential is slightly more sensitive to the β_i than to the β_e. The velocity profile in this case, Fig. 2(d) shows somewhat smaller dust density closer to the wall than in the previous case [Fig. 2(c)]. The reason can be traced to the charging of the grain inside the sheath. Once ion flow is inhibited (due to large β_i) grains charge will more negative than when ions were weakly magnetized. Thus grains feel stronger negative force (as there is larger negative dip in $F_D + F_E$ curve in Fig. 2(b)) and thus, its velocity is somewhat smaller than when ions are weakly magnetized. In addition, the decreased sheath potential due to strong magnetization decreases the sheath field resulting in smaller grain charge. Thus only when electron-cyclotron frequency dominates the electron-neutral collision, there is significant change in the sheath characteristics. For $\beta_e = 0.1$, i.e. when $\omega_{ce} = 0.1\,\nu_{en}$, sheath potential $\phi_W = -5.4V$ and sheath width is $0.52\,\mathrm{cm}$ whereas for $\beta_e = 10$, $\phi_W = -1.9V$ and sheath width is $0.27\,\mathrm{cm}$. This could have been anticipated on the ground that electron magnetization inhibits the free flow of electrons to the wall and thus sheath width decreases. The decrease in the sheath width is not as large as in the sheath potential. Plasma number densities, Fig. 2(b), shows the effect of the changing electron magnetization. The decrease in the electron density, Fig. 2(b), is very pronounced when electron-cyclotron frequency is twenty times the ion-neutral collision frequency. The plasma velocity [Fig. 2(c) – 2(d)] is consistent with the number density profiles.

To summarize, the drag force acting on the charged dust grain inside the sheath is dependent upon the sheath plasma parameters and the dust dynamics is dictated by the local sheath characteristics. The net drag force, i.e. collisional and Coulomb drag on the grain, in the absence of sheath electric force acts in the direction of the wall and this force gradually diminishes towards the wall. However, in the presence of the self-consistent sheath field the total force, which is a sum of collisional and Coulomb drag forces and electrostatic force due to sheath field, changes sign approximately in the middle of the sheath and slowly approaches zero thereafter. The change of sign of the total force implies that the charged grains are accelerated near the plasma–sheath boundary and decelerated from approximately middle of the sheath.

References

[1] S.V. Vladimirov, K. Ostrikov and A.A. Samarian, Physics and Applications of Complex Plasmas (Imperial Press, London, 2005).

[2] S. Roy and B. P. Pandey, J. Plasma Phys., **68**, 305 (2002).

[3] S. Roy and B. P. Pandey, J. Propulsion and Power, **19**, 964 (2003).

[4] S. I. Krasheninnikov, T. K. Soboleva, Y. Tomita, R. D. Smirnov and R. K. Janev, J. Nuclear Mat., **337**, 65 (2005).

[5] A. A. Samarian and B. W. James, Phys. Letters, **A 287**, 125 (2001).

[6] A. A. Samarian and B. W. James, Plasma Phys. and contr. Fusion, **47**, 1 (2005).

[7] B. P. Pandey, A. Samarian and S. V. Vladimirov, Phys. Plasmas, **14**, 1 (2007).