*33rd EPS Conference on Plasma Phys. Rome, 19 - 23 June 2006 ECA Vol.**30I**, P-4.040 (2006)*

Dusty plasma expansion in the presence of multi-ions species

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abstract

We studied the dusty plasma expansion in a spherical and cylindrical con£guration. The species present in the plasma are electrons, spherical dust grains, positive and negative ions. The grain ¤uid is modelled using ¤uid equations, the other species are in thermal equilibrium. The set of non-linear differential equations are solved numerically using the self similar method in the case of quasi-neutral assumption. We found that the densities pro£le depends on the positive to negative density ratio and the expansion ends for £nite value of the self similar parameter ($\xi \approx 9$). It is also found that the pro£le depends on the dust grain initial values parameters.

I- Introduction:

The investigation of dusty plasma in the presence of multi ions species is a growing research area. Due to electrons attachment it is possible to have negative ions as well as positive ones in dusty plasmas. This is the case of most space and laboratory plasmas such as the earth's mesosphere where negative ions are often present. When the number of electrons density becomes small, the negative ions contribution to collective effect can be signi£cant, such as the changes in plasma frequencies[1]. It was also shown that the solitons structures can exist in the presence of negative ions[2], there density can lower the limits of Mach number by reducing the total Debye shielding[3]. The negative ions play an important role in the charging process where they affect the grain surface potential and give rise to changes in dust charge pro£le[4]. This effect has been also introduced to study the role of dust charge ¤uctuation on different situations[5−6]. Previously, we investigated this effect on dusty plasma expansion in spherical con£guration and showed that the dust charge pro£le during expansion depended on negative to positive density ratio and the dust charge initial value for which there existed a critical value[7]. In this work we will extend our study to investigate the densities pro£les in spherical and cylindrical geometries.

II- Formulation

We consider plasma with a spherical dust grains of radius a with the presence of electrons, positive and negative ions. To model the expansion of dusty plasma into vacuum we use the set ¤uid equations given by,

$$n_e = n_{eo} \exp\left\{\frac{e\phi}{T_e}\right\}, \tag{1}$$

$$n_i = n_{io} \exp\left\{-\frac{e\phi}{T_i}\right\}, \tag{2}$$

$$n_n = n_{no} \exp\left\{\frac{e\phi}{T_n}\right\}, \tag{3}$$

$$\frac{\partial n_d}{\partial t} + \frac{1}{r^{\nu-1}}\frac{\partial}{\partial r}[r^{\nu-1} n_d v_d] = 0, \tag{4}$$

$$\frac{\partial v_d}{\partial t} + v_d \frac{\partial v_d}{\partial r} = -\frac{q}{m_d}\frac{\partial \phi}{\partial r} - \frac{1}{m_d n_d}\frac{\partial p_d}{\partial r}, \tag{5}$$

$$\frac{\partial q}{\partial t} + v_d \frac{\partial q}{\partial r} = a_e e n_e + a_i e n_i + a_n e n_n, \tag{6}$$

Here $\nu = 2$ and 3 corresponds, respectively, to cylindrical and spherical expansion geometries. We have considered ions with charge number $Z = 1$. The current coef£cient a_j ($j = e$ for electrons, i for positive ions and n for negative ions) ¤owing onto the grain surface are given by

$$a_j = -\pi r_o^2 \sqrt{\frac{8K_B T_j}{\pi m_j}} \exp\left(\frac{e\phi}{K_B T_j}\right), \tag{7}$$

$$a_i = \pi r_o^2 \sqrt{\frac{8K_B T_i}{\pi m_i}} \exp\left(1 - \frac{e\phi}{K_B T_i}\right), \tag{8}$$

where n_j, m_j, T_j are respectively, the density, the mass and the temperature, v_d is the dust velocity. The dust pressure is given by $p_d = T_d n_d$ for isothermal case. The spherical dust grains with a radius r_o and a charge $q = eZ_d$ ($Z_d < 0$). To calculate the electrostatic potential $\phi = q/r_o$, we have considered quasi-neutrality assumption without charge separation effect. The relevant equation used to £nd the electrostatic potential is:

$$Z_i n_i + Z_d n_d = n_e + Z_n n_n, \tag{9}$$

Using the self similar variable $\xi = r/c_{ds}t$ and normalized physical quantities as in Ref.[8] we solved the set of nonlinear differential equations (1 - 9).

III-Numerical results and conclusion

We take as initial values for our background plasma, which contains O_2^+ and O_2^- as positive and negative ions, the following set of parameters: dust massic density $\rho = 0.4\ g.cm^{-3}$, grain radius $a = 0.1\mu m$, positive ions density $n_o = 10^9 cm^{-3}$, negative to positive density ratio 0.8, dust density $10^{-4} n_o$ and dust initial charge $Z_o = -100$. We have plot the densities, dust charge and dust normalized velocity versus the self similar parameters ξ for two initial values of dust normalized velocity $V = 10$ and $V = 15$. Figure (1) shows that the dust expansion ends for a £nite value of the self similar variable in the spherical geometry case as found in previous papers for both plasma and dusty plasma expansion[8]. However due to the presence of negative ions the expansion ends earlier ($\xi \sim 9$), the electrostatic potential responsible of dust acceleration is in this case reduced. This effect is clearly shown in the case of cylindrical geometry where the dust are weakly accelerated after leaving the source plasma region (Figure 6). In the case of cylindrical geometry the expansion goes beyond this critical parameter. The dust initial velocity has no signi£cant effect on dust expansion. From Figs 2, 4 and 5 we see that there are two stages of electrons, positive and negative ions expansion. At the £rst stage positive ions increasing instead of electrons and negative ions depletion. Close to the plasma source region there is more dust grains which attach more negative particle as show by the dust charge evolution during expansion (Figure 3). Beyond this region as the dust charge is reaching its equilibrium value, there is more attachment of positive ions before the end of expansion. The ef£ciency of attachment of both species is more important in cylindrical geometry.

To conclude we have investigated the dusty plasma expansion in the presence of positive and negative ions in spherical and cylindrical geometries. As a result of the presence of negative ions the dust expansion ends earlier for £nite value of self similar parameter. The effect of the the presence of negative ions is more important on ions densities in the spherical case.

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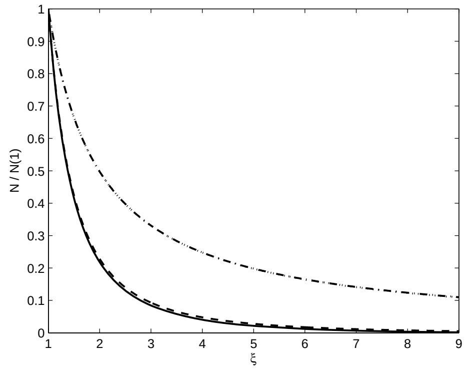

Figure 1: Normalized dust density for spherical case with $V_o = 10$(—), $V_o = 15$(− − −) and cylindrical case $V_o = 10$(· · ·), $V_o = 15$(− · −·)

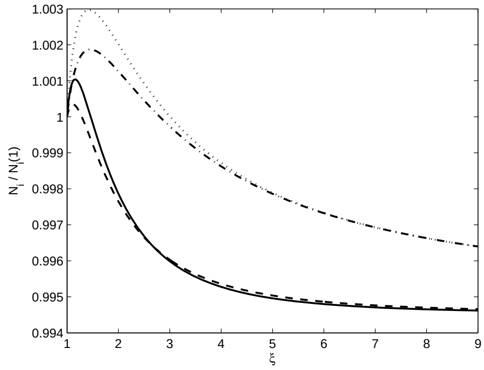

Figure 4: Normalized positive ions density for spherical case with $V_o = 10$(—), $V_o = 15$(−−) and cylindrical case $V_o = 10$(· · ·), $V_o = 15$(− · −·)

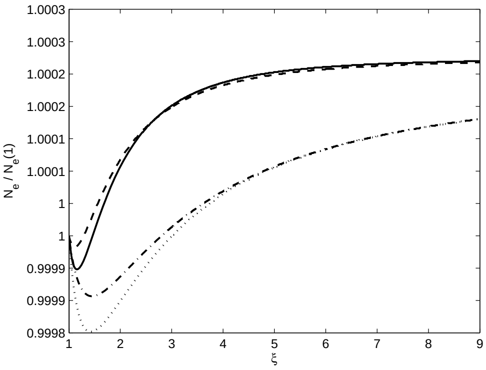

Figure 2: The same as Figure 2 but for electrons density

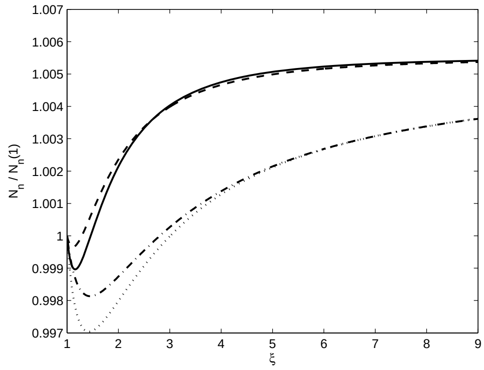

Figure 5: The same as Figure 2 but for negative ions density

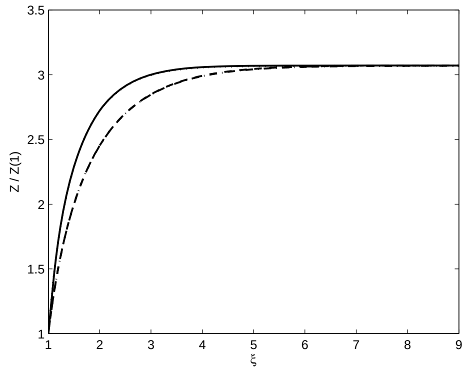

Figure 3: Dust charge

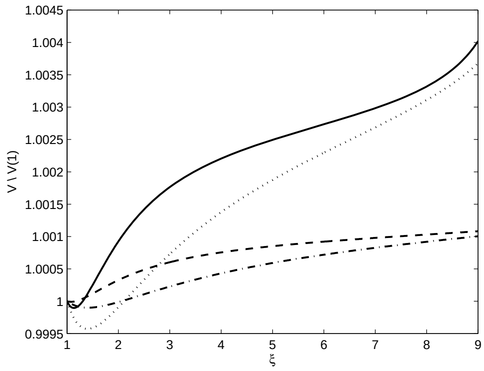

Figure 6: Dust velocity