Dust Acoustic Shocks in Viscous Dusty Plasma with Polarization Force

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Abstract. In present paper, the propagation of dust acoustic shocks are investigated in viscous dusty plasma including the effect of polarization force. The considered three fluid model is dealing with electrons, ions and negatively charged dust grains. In the governing model equations, the non-thermal ions distribution, Maxwell Boltzmann electrons and dust polarization force modified by the presence of nonthermal ion population are considered. Using the reductive perturbation method, Burger equation is obtained to study the characteristics of modified dust acoustic shocks analytically and graphically. The viscous and nonthermal polarization force significantly affects the propagation of dust acoustic shocks.

INTRODUCTION

The discovery of the occurrence of dust particulates in space plasma, astro-plasma as well as in laboratory plasmabrought forth a new avenue in the direction of rapidly growing field of plasma [1]. The presence of dust grains makesit of great importance since it modifies the properties of plasma. In dusty plasma, the dust particulates influence and modify various kinds of modes. It is observed that the plasma pressure and dust inertia balance originates dust acoustic mode in dusty plasma [2], later various studies have been done in this direction [3-5].Several researchers considered the Maxwell distribution of ions whereas many other included the non-thermal ion population after its appearance in Earth's bow-shock region, upper ionosphere of Mars, planetary region etc. [6,7]. Using pseudo-potential method, the effect of nonthermal ion on dust acoustic solitary wave propagation has been analysed by Pakzad [8]. Annou and Annou [9] have considered the nonthermal ion to study the dust acoustic solitary waves. In collisional nonthermal dusty plasma, ion acoustic solitary wave propagation is studied by Sultana [10] including the effect of magnetic field and κ-distributed electrons.

In the field of dusty plasma, Hamaguchi and Farouki [11] introducedtheideaof dust polarization force. The influence of polarization force on dust acoustic mode propagation in dusty plasma has been observed including the effect of various other parameters. Recently, Khrapak et al. [12] have investigated the role of polarization force on dust acoustic waves. Pervin et al. [13] have studied the dust acoustic shock waves considering nonthermal ion and polarization force in dusty plasma with strongly coupled dust grains. Bentabet and Tribeche [14] have explored that the presence of nonthermal ion population modifies the polarization force and this modified polarization force significantly affects the dust acoustic solitary waves. Khrapak and Khrapak [15] have studied the influence of charge gradient force on the propagation of dust acoustic wave including polarization force in dusty plasma. Thus, looking towards the all previous works mentioned in the paper we studied the effect of modified polarization force due to the presence of non-thermal ion population on the dust acoustic shocks in dusty plasma considering Maxwellian distributed electrons.

BASIC EQUATIONS

The three fluid model is considered to describe the dust acoustic wave propagation in dissipative dusty plasma. The set of equations are written accounting Maxwellian distribution of electrons, non-thermal distribution of ions and modified dust polarization force with non-thermal ions. Thus, the non-thermal distribution of ions is

$$n_i = \mu_i \left(1 + \beta\phi + \beta\phi^2\right) e^{-\phi} \quad (1)$$

and Maxwellian distribution of electrons is

$$n_e = \mu_e e^{\sigma\phi} \quad (2)$$

where n_i, n_e and ϕ is number density of ion, number density of electron and electrostatic potential respectively. The symbol $\beta = 4\alpha/(1+3\alpha)$ is ratio of non-thermal ion population (α), $\mu_e = n_{e0}/Z_d n_{d0}$ is ratio of electron number density to the product of dust surface charge number (Z_d) and dust number density (n_{d0}), $\mu_i = n_{i0}/Z_d n_{d0}$ is ratio of ion number density to the product of surface charge number and number density of dust and $\sigma = T_i/T_e$ shows the ratio of ion temperature to the electron temperature.

The dust force balance equation including the dust non-thermal polarization force and dissipative effect is given as

$$\frac{\partial u_d}{\partial t} + u_d \frac{\partial u_d}{\partial x} = \frac{\partial \phi}{\partial x} - \frac{\Gamma \beta^* e^{(-\phi/2)}}{\left(1 + \beta\phi + \beta\phi^2\right)^{1/2}} \frac{\partial \phi}{\partial x} + \eta \frac{\partial^2 u_d}{\partial x^2} \quad (3)$$

The dust fluid velocity and coefficient of viscosity are represented by u_d and η respectively. The symbol Γ stands as a measure of polarization force and $\beta^* = 1 - \beta\left(1 + e\phi/T_i - (e\phi/T_i)^2\right)$.

The dust continuity equation is written as

$$\frac{\partial n_d}{\partial t} + \frac{\partial}{\partial x}\left(n_d u_d\right) = 0 \quad (4)$$

The Poisson's equation is

$$\frac{\partial^2 \phi}{\partial x^2} = \mu_e e^{\sigma\phi} - \mu_i \left(1 + \beta\phi + \beta\phi^2\right) e^{-\phi} + n_d \quad (5)$$

In above equations the distance and time are normalized by $\lambda_{pd} = \left(T_i/4\pi z_d n_{d0} e^2\right)^{1/2}$ and $\omega_{pd}^{-1} = \left(m_d/4\pi n_{d0} Z_d^2 e^2\right)^{1/2}$ respectively. The velocity is normalized by $c_d = \left(Z_d T_i/m_d\right)^{1/2}$, the dust number density is normalized by n_{d0} and electrostatic potential is normalized by (T_i/e).

DUST ACOUSTIC SHOCKS

In order to derive the Burger equation, we first insert the stretched coordinates of the form $\xi = \varepsilon(x - V_A t)$ and $\tau = \varepsilon^2 t$, where V_A and ε show phase velocity and small parameter respectively.The expansion of the perturbed quantities u_d, n_d, and ϕ are written in form of power series of ε as

$$u_d = 0 + \varepsilon u_{d1} + \varepsilon^2 u_{d2} + \dots\dots\dots\dots$$
$$n_d = 1 + \varepsilon n_{d1} + \varepsilon^2 n_{d2} + \dots\dots\dots\dots \quad (6)$$
$$\phi = 0 + \varepsilon \phi_1 + \varepsilon^2 \phi_2 + \dots\dots\dots\dots$$

Introducing stretched coordinates and using Eq. (6) in Eqs. (3)-(5), the coefficients of lowest power of ε from Eqs. (3)-(5) can be given as

$$V_p \frac{\partial u_{d1}}{\partial \xi} = \Gamma(1-\beta)\frac{\partial \phi_1}{\partial \xi} - \frac{\partial \phi_1}{\partial \xi} \quad (7)$$

$$\frac{\partial u_{d1}}{\partial \xi} = V_p \frac{\partial n_{d1}}{\partial \xi} \quad (8)$$

$$n_{d1} + \mu_e \sigma \phi_1 - \mu_i (1-\beta)\phi_1 = 0 \quad (9)$$

The expression for the wave phase velocity from Eqs. (7)-(9) can be obtained as

$$V_A = \left(\frac{1-\Gamma(1-\beta)}{\mu_e \sigma - \mu_i (1-\beta)} \right)^{1/2} \quad (10)$$

Now the collection of next higher order coefficients of ε from Eqs. (3)-(5) yield

$$-V_p \frac{\partial u_{d2}}{\partial \xi} + \frac{\partial v_{d1}}{\partial \tau} + u_{d1}\frac{\partial u_{d1}}{\partial \xi} - \frac{\partial \phi_2}{\partial \xi} + \Gamma(1-\beta)\phi_2 + \frac{\Gamma}{2}(1-\beta)^2 = \eta \frac{\partial^2 u_{d1}}{\partial \xi^2} \quad (11)$$

$$-V_p \frac{\partial n_{d2}}{\partial \xi} + \frac{\partial n_{d1}}{\partial \tau} + n_{d1}\frac{\partial u_{d1}}{\partial \xi} + u_{d1}\frac{\partial n_{d1}}{\partial \xi} + \frac{\partial u_{d2}}{\partial \xi} = 0 \quad (12)$$

$$n_{d2} + \mu_e \sigma \phi_2 + \frac{\mu_e \sigma^2}{2}\phi_1^2 + \mu_i (1-\beta)\phi_2 - \frac{\mu_i}{2}\phi_1^2 = 0 \quad (13)$$

Substituting the value of n_{d1}, u_{d1} from Eqs. (7)-(9) and $\partial u_{d2}/\partial \xi$ from Eq. (12) into Eq. (11), and then using the value of $\partial n_{d2}/\partial \xi$ after differentiating Eq. (13) with respect to ξ, the Burgers equation can be derived as

$$\frac{\partial \phi_1}{\partial \tau} + P\phi_1 \frac{\partial \phi_1}{\partial \xi} = Q\frac{\partial^2 \phi_1}{\partial \xi^2} \quad (14)$$

where

$$P = \frac{-V_p^3 (\mu_e \sigma^2 - \mu_i)}{2(1-\Gamma+\Gamma\beta)} - \frac{\Gamma V_p (1-\beta)^2}{4(1-\Gamma+\Gamma\beta)} - \frac{3(1-\Gamma+\Gamma\beta)}{2V_p}$$

and

$$Q = \frac{\eta}{2}$$

The stationary localized solution of Burgers equation can be obtained by introducing co-moving coordinate system and transforming ξ to $\zeta = \xi - U_0 \tau$, where U_0 represents shock wave speed. Further, applying the boundary conditions i.e., at $\delta \to \pm\infty$: $\phi_1 = d\phi_1/d\zeta = d^2\phi_1/d\zeta^2 \to 0$. Thus, from Eq. (14), the solution can written as $\phi_1 = \phi_m [1-\tanh(\zeta/\Delta)]$ wherethe width of shock wave is represented by $\Delta = 2Q/U_0$ and amplitude by $\phi_m = U_0/P$.

In order to analyze the effect of modified polarization force quantitatively, the numerical data are chosen for typical complex plasma i.e., $r_d = 1\mu m$, $n_{e0} = 1.48\times 10^8 cm^{-3}$, $n_{i0} = 1.6\times 10^8 cm^{-3}$, $\eta = 0.5$, $Z = 1000$, $T_i = 0.03eV$ and $T_e = 3eV$ [14, 16].Figure 1 illustrates the variation of shock electrostatic potential for three different value of polarization force corresponding to three different value of non-thermal population (for $\alpha = 0.2$, $\Gamma = 0.084$; $\alpha = 0.15$, $\Gamma = 0.091$ and $\alpha = 0.1$, $\Gamma = 0.099$). It is observed that the shock potential decreases with the increasing value of modified polarization force.

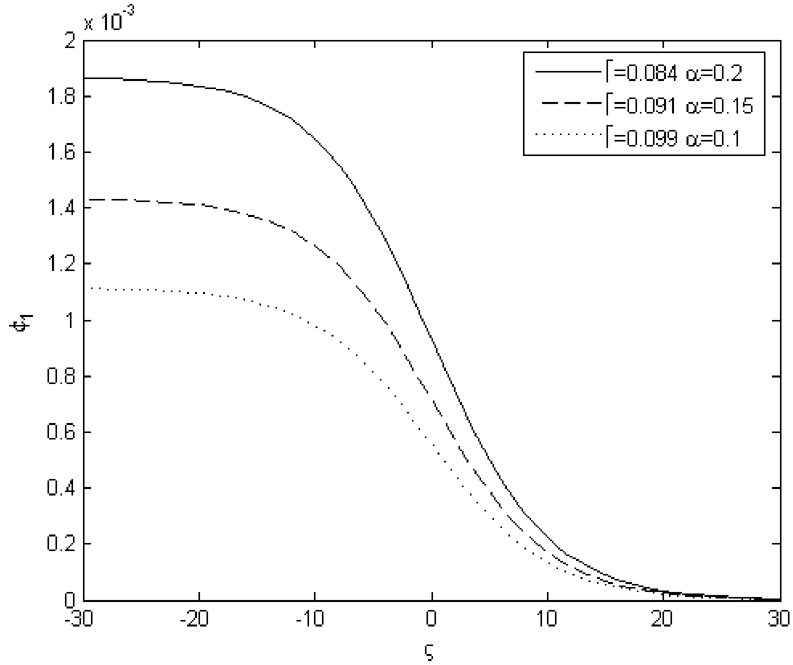

FIGURE 1. The variation of electrostatic potential of dust acoustic shock wave for three values of non-thermal polarization force

CONCLUSIONS

It can be concluded that the presence of non-thermal polarization force significantly affect the dust acoustic shocks in dusty plasma consisting of non-thermal distribution of ion and Maxwellian distribution of electrons. Numerically it is found that electrostatic potential for shock reduces with modified polarization force.

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