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Time-dependent non-planar DIA shock waves in non-extensive dusty plasma

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Abstract. The propagation of dust ion-acoustic shock waves (DIASHWs) in an unmagnetized dissipative dusty plasma system consisting of inertial ions, non-inertial, non-extensive q-distributed electrons, and negatively charged stationary dust is investigated in bounded non-planar (cylindrical and spherical) geometry. A modified Burgers equation is derived and its numerical solution is obtained. It is found that the basic features of DIASHWs are significantly modified by the effects of electron non-extensivity and ion kinematic viscosity in bounded geometry. It is also shown that the propagation characteristics of non-planar DIASHWs in a non-extensive plasma are qualitatively different from those of planar ones.

1. Introduction

From the very beginning to the present, there has been a phenomenal growth in research activities in dusty plasmas as highlighted in recent reviews (Goertz 1989; Shukla and Silin 1992; Mendis and Rosenberg 1994; Verheest 2000; Shukla and Mamun 2002; Shukla and Eliasson 2009). It is clear that when dust grains (Asaduzzaman and Mamun 2012a, b, e; Asaduzzaman et al. 2011; Pervin et al. 2012c; Masud et al. 2012d; Yasmin et al. 2012f) are incorporated into usual two-component, i.e. electron–ion plasma, the response to the latter changes significantly. Shukla and Silin (1992) were the first to report theoretically the existence of dust-ion-acoustic (DIA) waves. In a DIA wave, the restoring force mainly comes from the electron pressure, and inertia comes from the ion mass. The theoretical prediction of Shukla and Silin (1992) has been conclusively verified by a number of laboratory experiments (Barkan et al. 1996; Nakamura et al. 1999; Merlino and Goree 2004). Nonlinear waves associated with DIA waves, particularly the DIA solitary waves (SWs) (Moslem et al. 2005; Alinejad 2010; Alinejad 2011a, b; El-Taibany et al. 2011; Rahman and Mamun 2011; Das et al. 2012; El-Labany et al. 2012a; Yasmin et al. 2012b) and dust ion-acoustic shock waves (DIASHWs) (Luo et al. 1999; Nakamura et al. 1999; Popel et al. 2000; Nakamura and Sharma 2001; Mamun and Shukla 2002; Shukla and Mamun 2003; Eliasson and Shukla 2005; Alinejad 2010; Mamun and Tasnim 2010; El-Labany et al. 2012b), have received a baronial interest in space and laboratory dusty plasmas. By deriving the Korteweg-de-Vries (K-dV) equation, the behavior of DIA SWs has been analyzed. These SWs are formed due to the delicate balance of nonlinearity and dispersion. However, for a plasma medium with significant dissipative properties, supports the formation of shock structures. The Landau damping, kinematic viscosity among plasma species, and collision between ion-neutral, dust-neutral, etc. are the major causes for rise of dissipation, which is responsible for the formation of shock waves in plasma system. The DIASHWs have been investigated by a number of authors (Luo et al. 1999; Nakamura et al. 1999; Popel et al. 2000; Nakamura and Sharma 2001; Mamun and Shukla 2002; Shukla and Mamun 2003; Eliasson and Shukla 2005; Alinejad 2010; Mamun and Tasnim 2010; El-Labany et al. 2012b). All of these theoretical investigations (Luo et al. 1999; Nakamura et al. 1999; Popel et al. 2000; Nakamura and Sharma 2001; Mamun and Shukla 2002; Shukla and Mamun 2003; Eliasson and Shukla 2005; Alinejad 2010; Mamun and Tasnim 2010; El-Labany et al. 2012b) are valid for equilibrium plasma states, and these investigations cannot provide any explanation for non-equilibrium stationary states (Plastino and Plastino 1993; Nobre and Tsallis 1995; Ferro et al. 2004; Sakagami and Taruya 2004) such as correlation or long-range interactions among plasma constituents where non-extensivity plays significant roles.

Recently, non-extensive (Renyi 1955; Tsallis 1988) plasma has become a research topic of current interest due its wide relevance in astrophysical and cosmological scenarios such as stellar polytropes (Plastino and Plastino 1993), hadronic matter and quark-gluon plasma (Gervino et al. 2012), protoneutron stars (Lavagno and Pigato 2011), dark-matter halos (Feron and Hjorth 2008), etc. as well as its laboratory applications in nano-materials, micro-devices, micro-structures (Vladimirov and Ostrikov 2004), etc. The non-extensive q-entropies, formerly proposed by Renyi (1955), and subsequently

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proposed by Tsallis (1988), have been successfully employed in plasma physics (Liu and Goree 2008; Liu et al. 2009; Amour and Tribeche 2010; Pakzad and Tribeche 2011). Following the class of Tsallis's (1988) velocity distribution, it has been established that for a collisionless unmagnetized thermal plasma the electrostatic plane wave propagation is dominated by non-extensive q-parameter smaller than unity (Lima et al. 2000). The value of q for Maxwellian distribution is found just by putting $q = 1$ whereas non-Maxwellian Tsallis's (1988) velocity distribution follows $q \neq 1$, and that it follows a power law distribution. The underlying physics behind a thermodynamics system, which is characterized by the non-extensive parameter q, is obviously different from the system observed in extensive limit, $q = 1$. It is believed that such thermodynamical systems are the systems for which the entropy of the whole system is different from the sum of the entropies of the respective parts. This is due to the long-range interactions of the self-gravitating body and the non-local, non-Markovian, or global correlations within the systems, and each particle is constantly feeling the influences by all other particles in the system (Sahu 2012). In this case, the total energy of the particle is non-extensive.

Most of the investigations described above are concerned with DIASHWs (Luo et al. 1999; Nakamura et al. 1999; Popel et al. 2000; Nakamura and Sharma 2001; Mamun and Shukla 2002; Shukla and Mamun 2003; Eliasson and Shukla 2005; Alinejad 2010; Mamun and Tasnim 2010; El-Labany et al. 2012b) in one-dimensional (1D) planar geometry, which may not be a realistic situation in space and laboratory devices, since the waves observed in space (laboratory devices) are certainly not infinite (bounded) in one dimension. Therefore, we have considered a plasma system in a bounded time-dependent non-planar (cylindrical and spherical) geometry. Examples of bounded geometries are of great importance, and in practical interest, some examples are shock tubes, supernovae explosion, capsule implosion, star formation, etc (Sahu and Tribeche 2012). It may be noted here that very recently, Sahu and Tribeche (2012) and Sahu (2012) have investigated the possible formation of shock excitations in a non-planar geometry. Sahu and Tribeche (2012) have discussed the effects of ion non-extensivity and dust kinematic viscosity on the basic features of dust-acoustic shock waves in cylindrical and spherical geometry. In absence of heavier charged dust considering ion kinematic viscosities, Sahu (2012) derived the cylindrical and spherical K-dV Burgers (KdVB) equation for ion-acoustic shock waves and found both compressive- and rarefactive-type shock waves depending on parameter q associated with electron non-extensivity. The theoretical surveys of Sahu and Tribeche (2012) and Sahu (2012) are appropriate for a plasma situation where the effects of stationary charged dust are being ignored. But it is important to take into account the effects of charged dust grains, considered to be immovable due to their heavy mass (Shukla and Silin 1992), into shock waves in cylindrical and spherical geometry since unbounded planar geometry is not a realistic situation in space and laboratory environments. Therefore, we considered electron non-extensivity and ion kinematic viscosities in presence of stationary negatively charged dust and studied the basic features of DIASHWs by deriving the modified Burgers equation using the reductive perturbation method (Washimi and Taniuti 1966) in a non-planar geometry. The paper is organized as follows. The governing equations are provided in Sec. 2. The modified Burgers equation is derived and numerically solved in Sec. 3. Finally, a brief discussion is given in Sec. 4.

2. Governing equations

We consider cylindrical and spherical geometry, and study the propagation of DIASHWs in an unmagnetized, collisionless, quasi-neutral dusty plasma consisting of negatively charged stationary dust, inertial ions, and non-inertial electrons following q-non-extensive distribution. We use ion continuity and momentum equations, supplemented by the Tsallis (1988) velocity distribution of electrons along with stationary, negatively charged dust, to derive the modified Burgers equation. Our assumption of stationary charged dust is valid since the time scale of DIA waves is much faster than the dust plasma period. The charge of stationary dust usually depends on local plasma parameters. It should be mentioned here that in the case of local plasma parameters, where the characteristic time scale of DIA waves, τ, is not comparable to the dust charging time period, τ_{ch}, one can neglect the effect of dust charge fluctuation, i.e. dust charge Z_d being constant. Therefore, we have neglected the role of dust charge fluctuation, since the time period (which is a fraction of a second (Shukla and Mamun 2002)) of DIA waves under consideration is much larger than the dust charging time (which is the order of few microseconds (Shukla and Mamun 2002)). Our main interest here is to examine the effect of the non-extensive electron distribution on small but finite amplitude nonlinear electrostatic structure-shock waves satisfying $\tau_{ch} \gg \tau$ or $\tau_{ch} \ll \tau$. We note that this appropriate approximation (constant dust charge) has been used by many authors to study the propagation of DIASHWs (Samsonov et al. 2002; Shukla and Mamun 2002; Xue 2003; Eliasson and Shukla 2005; Rahman et al. 2007; Abderrezak and Tribeche 2009; Adhikary 2012; Yasmin et al. 2012a; El-Labany et al. 2012b). Thus, at equilibrium we have $n_{i0} = n_{e0} + Z_d n_{d0}$, where n_{i0} (n_{e0}) is the equilibrium ion (electron) number density and n_{d0} is the equilibrium of dust density. The dynamics of DIASHWs, whose phase speed is much smaller (larger) than the electron (ion) thermal speed in a non-planar geometry, is governed by

$$\frac{\partial n_i}{\partial t} + \frac{1}{r^\nu}\frac{\partial}{\partial r}(r^\nu n_i u_i) = 0, \tag{2.1}$$

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$$\frac{\partial u_i}{\partial t} + u_i \frac{\partial u_i}{\partial r} = -\frac{\partial \phi}{\partial r} + \eta \frac{1}{r^v} \frac{\partial}{\partial r} \left(r^v \frac{\partial u_i}{\partial r} \right), \quad (2.2)$$

$$\frac{1}{r^v} \frac{\partial}{\partial r} \left(r^v \frac{\partial \phi}{\partial r} \right) = -n_i + (1-\mu) q_0 + \mu, \quad (2.3)$$

$$q_0 = [1 + (q-1)\phi]^{1+q/2(q-1)}, \quad (2.4)$$

where $v = 0$ for 1D planar geometry, and $v = 1$ (2) for a non-planar cylindrical (spherical) geometry, n_i is the ion number density normalized by its equilibrium value n_{i0}, u_i is the ion fluid speed normalized by $C_i = (T_e/m_i)^{1/2}$, ϕ is the electrostatic wave potential normalized by T_e/e, Z_d (normalized by its equilibrium value Z_{d0}) is the number of electrons residing on the stationary dust grain surface, $\mu = Z_d n_{d0}/n_{i0}$, η is the viscosity coefficient normalized by $m_i n_{io} \omega pi \lambda_{Dm}^2$, T_e is the electron temperature in energy units, t is the time variable normalized by the ion plasma period $\omega_{pi}^{-1} = (m_i/4\pi n_{io} e^2)^{1/2}$, and r is the radial space variable normalized by $\lambda_{Dm} = (T_e/4\pi n_{io} e^2)^{1/2}$.

We note here that the effect of background neutral component in ion momentum equation has been neglected. The assumption which has been used by many authors (Luo et al. 1999; Nakamura et al. 1999; Popel et al. 2000; Shukla 2000; Shukla and Mamun 2001; Nakamura 2002; Eliasson and Shukla 2005; Sayeed and Mamun 2007) is valid as long as the ion-neutral collision frequency (ν_{in}) is less than the DIA wave frequency (ω) as considered in the present paper. However, the presence of neutral components or ion-neutral collision frequency and dust charge fluctuation effect is only important for those waves whose period is comparable to dust grain charging period, and the omission of neutral components or ion-neutral collision frequency is valid as long as the DIA wave frequency is not comparable with the ion-neutral collision frequency. For this reason, the presence of neutral components is not considered in our model, and our model could be suitably applicable to laboratory conditions.

3. Shock waves

In order to derive a dynamical equation for electrostatic DIA shock waves from our basic equations (2.1)–(2.4), we employ the reductive perturbation technique (Washimi and Taniuti 1966). We first introduce stretched coordinates (Maxon and Viecelli 1974; Mamun and Shukla 2009)

$$\xi = -\epsilon(r + V_p t), \qquad \tau = \epsilon^2 t, \quad (3.1)$$

where ϵ is the smallness parameter measuring the weakness of dispersion, and V_p is the phase speed of the perturbation mode. We also expand the perturbed quantities of n_i, u_i, and ϕ asymtotically about their equilibrium values in power series of ϵ as

$$n_i = 1 + \epsilon n_i^{(1)} + \epsilon^2 n_i^{(2)} + \epsilon^3 n_i^{(3)} \cdots, \quad (3.2)$$

$$u_i = 0 + \epsilon u_i^{(1)} + \epsilon^2 u_i^{(2)} + \epsilon^3 u_i^{(3)} \cdots, \quad (3.3)$$

$$\phi = 0 + \epsilon \phi^{(1)} + \epsilon^2 \phi^{(2)} + \epsilon^3 \phi^{(3)} \cdots, \quad (3.4)$$

and develop equations in various powers of ϵ. Substituting (3.1)–(3.4) into (2.1)–(2.4), we obtain from the lowest order in ϵ as

$$u_i^{(1)} = -\frac{\phi^{(1)}}{V_p}, \quad n_i^{(1)} = \frac{\phi^{(1)}}{V_p^2}, \quad (3.5)$$

$$V_p = \sqrt{\frac{2}{(q+1)(1-\mu)}}. \quad (3.6)$$

Equation (3.6) represents the linear dispersion relation for DIA waves significantly modified by electron non-extensivity following q-distribution (Silva et al. 1998) in a non-extensive dusty plasma system where ion mass provides inertia and electron thermal pressure provides restoring force. The stationary charged dust plays a crucial role because its mass and charge are very large even variable in contrast to ions and electrons. To the next higher order of ϵ, i.e. taking the coefficients of ϵ^3 from both sides of (2.1) and (2.2), and ϵ^2 from both sides of (2.3) and (2.4), one may obtain another set of simultaneous equations for $n_i^{(2)}$, $u_i^{(2)}$, and $\phi^{(2)}$. Invoking this different set of equations, which contains coupled set of parameters, viz. as the first- and second-order perturbed quantities of ion density, as well as ion fluid speed and characterizing wave potential, we finally deduce the cylindrical and spherical modified Burgers equation for the propagation of DIASHWs in non-extensive plasma as

$$\frac{\partial \psi}{\partial \tau} + \frac{v}{2\tau}\psi + A\psi \frac{\partial \psi}{\partial \xi} = C \frac{\partial^2 \psi}{\partial \xi^2}, \quad (3.7)$$

where $\phi^{(1)} = \psi$, A is the nonlinear coefficient, and C is the dissipative coefficient, and are given by

$$A = \frac{V_p^3}{2} \left[\frac{3}{V_p^4} + (1-\mu) \frac{(q+1)(q-3)}{4} \right], \quad (3.8)$$

$$C = \frac{\eta}{2}. \quad (3.9)$$

Equation (3.7) is the Burgers equation modified by an extra term $(v/2\tau)\psi$ arising due to the effect of the non-planar cylindrical ($v = 1$) or spherical ($v = 2$) geometry. It is obvious from (3.7) that Burgers equation includes the effects of electron non-extensivity and kinematic viscosity. An exact analytic solution of (3.7) is not possible. Therefore, we have numerically solved (3.7), and have studied the effects of cylindrical ($v = 1$) and spherical ($v = 2$) geometry on time-dependent DIASHWs in presence of non-extensive electrons.

We first consider that $v = 0$ corresponds to 1D planar geometry, and examine the basic features (polarity, amplitude, width, etc.) of the DIASHW solution of (3.7). The initial condition that we have used in our numerical analysis is in the form of the stationary solution of (3.7)

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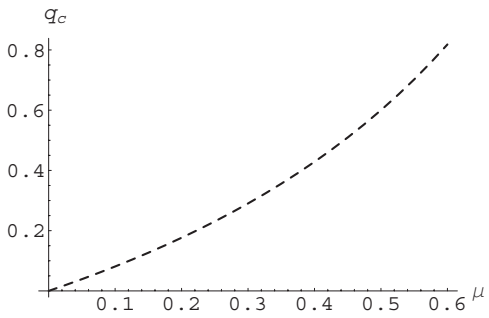


Figure 1. Variation of q_c [obtained from $A(q = q_c) = 0$] with μ.

without the term $(v/2\tau)\psi$, i.e.

$$\psi(v = 0) = \psi_m \left[1 - \tanh\left(\frac{\xi - u_0\tau}{\Delta}\right)\right], \quad (3.10)$$

where $\psi_m = u_0/A$ is the shock amplitude and $\Delta = 2C/u_0$ is the shock width. We choose our initial pulse at $\tau = 15$, and observed that for a large value of time $\tau = 30$, the cylindrical and spherical DIA shock waves are similar to 1D shock waves. The parametric regimes for the existence of compressive and rarefactive shock waves are shown in Fig. 1. It is clear from (3.8)–(3.10), and Fig. 1 that the formation of DIASHWs is due to kinematic viscosity of ions with stationary negatively charged dust, and the basic properties of shock waves are significantly modified by the non-extensive behavior of electrons. We note that DIASHWs are associated with negative (positive) potential, i.e. with the rarefaction (compression) of the ion number density if $A < 0$ ($A > 0$). The shock profile associated with $A < 0$ or $A > 0$ is graphically shown in Figs. 3–6. The regions of compressive and rarefactive shock structures are obtained by plotting $A = 0$ curve, which separates these into two regimes: the parametric regime above (below) the curve corresponds to $A > 0$ ($A < 0$) (shown in Fig. 1). Figure 1 shows the minimum or critical value of q for which its above (below) value is responsible for the formation of compressive (rarefactive) shock structures. It has been concluded that for a small amount depletion of electron number density, i.e. for a lower amount of dust, the value of q_c is significantly decreased. For $\mu = 0$, the value of q_c is 0. Figure 1 also illustrates that due to the non-extensive behavior of electron, we have found both compressive and rarefactive types of shock structures. These findings are represented in Figs. 3–6. For a typical value of μ, say $\mu = 0.5$, the minimum number of q for which the shock structures transit from positive to negative potential shock wave is $q_c = 0.6$. It has also been shown that for $q = 0.58$, which is below the minimum value of q, i.e. $A < 0$, we get rarefactive shock wave. This behavior of electron non-extensivity which significantly affects the propagation of DIASHWs in cylindrical (spherical) geometry is shown in Fig. 3. We note that for $q > q_c$, say $q = 0.64$, we have observed compressive shock waves, and this effect of electron non-extensivity on shock profile has been displayed in cylindrical (spherical) geometry in Fig. 4.

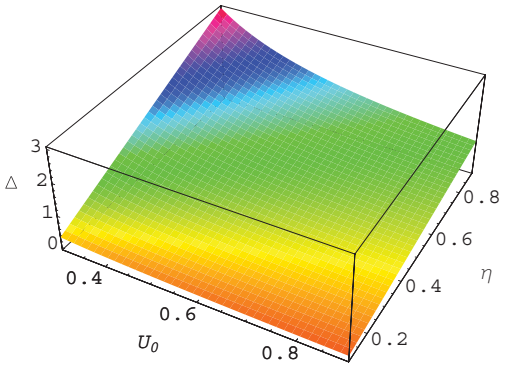


Figure 2. (Colour online) Variation of width of shock structure with U_0 and η for $\mu = 0.5$ and $q = 0.7$.

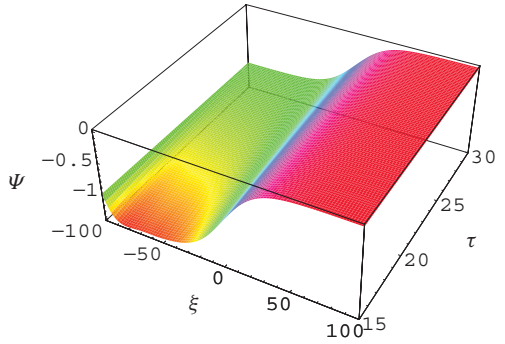


Figure 3. (Colour online) Time evolution of cylindrical ($v = 1$) rarefactive DIASHWs for $A < 0$, i.e. $q = 0.58$, $\mu = 0.5$, $\eta = 0.5$, and $U_0 = 0.01$. We choose our initial pulse at $\tau = 15$.

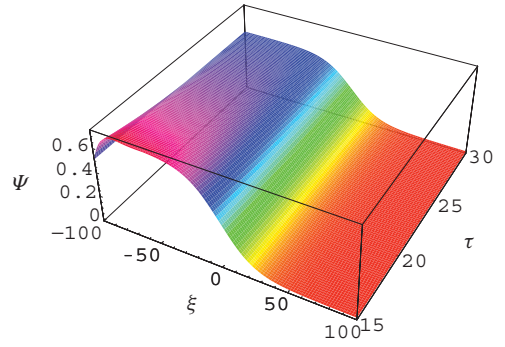


Figure 4. (Colour online) Time evolution of cylindrical ($v = 1$) compressive DIASHWs for $A > 0$, i.e. $q = 0.64$, $\mu = 0.5$, $\eta = 0.5$, and $U_0 = 0.01$. We choose our initial pulse at $\tau = 15$.

We revisit (3.7) with the term $(v/2\tau)\psi$ to imply that this only happened due to the effect of non-planar-bounded geometry. It is observed that as the magnitude of time increases, the shock structures (both compressive and rarefactive) behave like those for 1D DIA shock structures. However, as the value of time decreases, the term $(v/2\tau)\psi$ becomes dominant, and both cylindrical and spherical compressive and rarefactive DIASHWs qualitatively differ from the planar DIASHWs. It is evident from the Figs. 2–5 that the amplitude of shock waves in spherical geometry is larger than that of cylindrical geometry, and in spherical geometry the shock wave travels faster than in cylindrical geometry.

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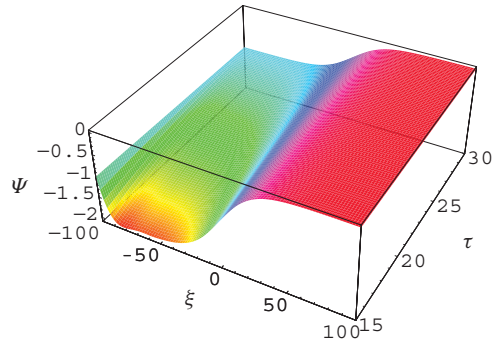


Figure 5. (Colour online) Time evolution of spherical ($v = 2$) rarefactive DIASHWs for $A < 0$, i.e. $q = 0.58$, $\mu = 0.5$, $\eta = 0.5$, and $U_0 = 0.01$. We choose our initial pulse at $\tau = 15$.

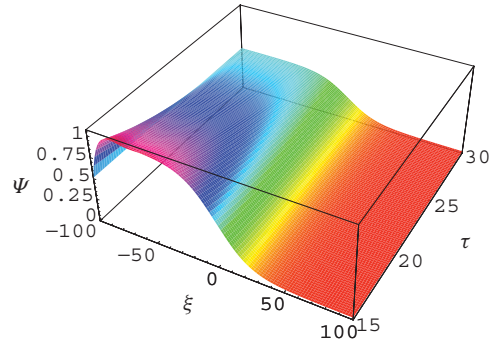


Figure 6. (Colour online) Time evolution of spherical ($v = 2$) compressive DIASHWs for $A > 0$, i.e. $q = 0.64$, $\mu = 0.5$, $\eta = 0.5$, and $U_0 = 0.01$. We choose our initial pulse at $\tau = 15$.

Figure 2 fairly reveals that how shock width is modified by the effect of kinematic viscosity. Shock width is linearly or proportionally increased with the increase of η. This scenario can be justified from the formulation of shock width $\Delta = \eta/u_0$. Figures 7 and 8 represent the effect of viscosity variation on the generation of cylindrical shock waves. We plot the compressive shock structure (i.e. $A > 0$ for $q > q_c$, $q = 0.64$) for cylindrical geometry (shown in Figs. 7 and 8) for several values of τ. It is found that the strength of shock wave increases as we decrease τ. It should be noted that if the value of τ increases, the non-planar geometries would approach the planar geometry, i.e. for a large value of time ($\tau = 30$), the planar and non-planar shock waves are identical. Conspicuously, the amplitude of shock waves decreases with increase of time. The phenomenal growth of shock structures for different values of time $\tau = 15$, 25, and 30along with the effect of viscosity variation is depicted in Figs. 7 and 8. It is obvious that for a large value of kinematic viscosity, taking other parameters constant, the width of shock waves increases. This is physically correct and feasible from the width expression: $\Delta = 2C/u_0$, where $C = \eta/2$, and η is the kinematic viscosity. Figure 7 is plotted against $\eta = 0.2$, and Fig. 8 is plotted against $\eta = 0.5$. It may be inferred that with increase of dissipation, shock waves become smoother and weak. On the other hand, Figs. 9 and 10 show the generation of spherical compressive shock structures for several values of τ

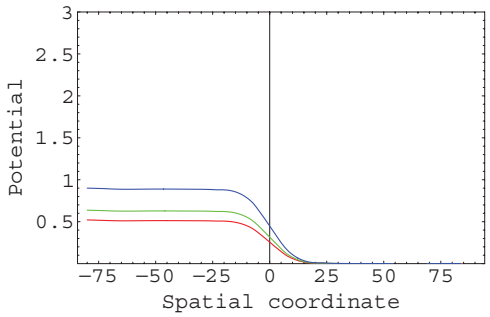


Figure 7. (Colour online) Compressive cylindrical ($v = 1$) shock profile at times $\tau = 30$ (red curve), $\tau = 25$ (green curve), and $\tau = 15$ (blue curve) for $q = 0.64$, $\mu = 0.5$, $U_0 = 0.01$, and $\eta = 0.2$. We choose our initial pulse at $\tau = 15$.

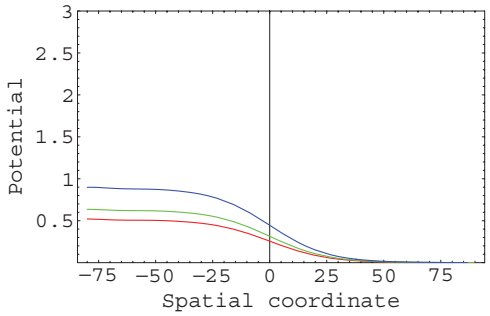


Figure 8. (Colour online) Compressive cylindrical ($v = 1$) shock profile at times $\tau = 30$ (red curve), $\tau = 25$ (green curve), and $\tau = 15$ (blue curve) for $q = 0.64$, $\mu = 0.5$, $U_0 = 0.01$, and $\eta = 0.5$. We choose our initial pulse at $\tau = 15$.

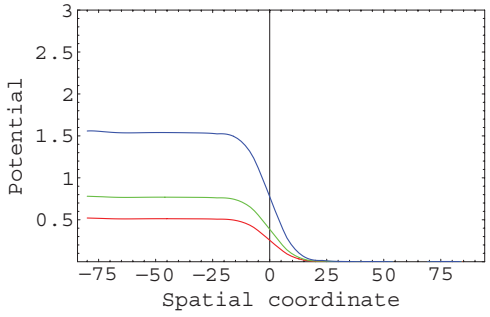


Figure 9. (Colour online) Compressive spherical ($v = 2$) shock profile at times $\tau = 30$ (red curve), $\tau = 25$ (green curve), and $\tau = 15$ (blue curve) for $q = 0.64$, $\mu = 0.5$, $U_0 = 0.01$, and $\eta = 0.2$. We choose our initial pulse at $\tau = 15$.

and for different values of η. We have observed that the amplitude of compressive cylindrical DIASHWs is almost half of that compressive spherical DIASHWs. So the effect of viscosity variation is more pronounced in spherical geometry than it is in cylindrical geometry. It is observed that the shape of developed compressive shock wave changes appreciably with increase in η, say $\eta = 0.2$–0.5. Also, it is concluded from Figs. 9 and 10 that as we increase the value of kinematic viscosity η, the width of waves also increases. Similar paradigm can be available for rarefactive shock structures ($A < 0$) for $q < q_c$, i.e. $q = 0.58$, which is not shown in figure.

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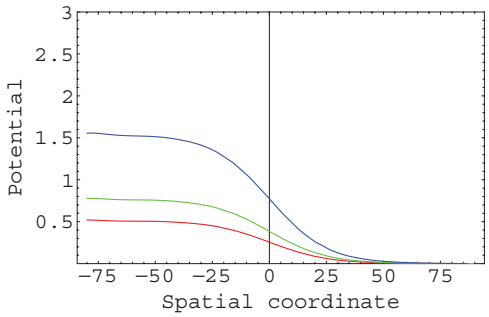


Figure 10. (Colour online) Compressive spherical ($v = 2$) shock profile at times $\tau = 30$ (red curve), $\tau = 25$ (green curve), and $\tau = 15$ (blue curve) for $q = 0.64$, $\mu = 0.5$, $U_0 = 0.01$, and $\eta = 0.5$. We choose our initial pulse at $\tau = 15$.

Comparing with 1D planar structures, it is concluded that the amplitude of cylindrical shock waves is larger than that of 1D planar shock waves, but smaller than that of spherical waves. Interestingly, it is found that the amplitude of compressive shock wave decreases with increase of non-extensivity of electrons characterized by parameter q. In case of rarefactive shock structures, the amplitude of shock wave behaves surprisingly different from the compressive shock wave. The amplitude of rarefactive shock wave increases with increase of electron non-extensivity. These scenarios (effects of non-extensivity of plasma species) are very important for different astrophysical and cosmological environments (Plastino and Plastino 1993; Ferro et al. 2004; Feron and Hjorth 2008; Vergou 2009; Lavagno and Pigato 2011; Gervino et al. 2012) and are relevant to that very recent observation of shock structures (Sahu 2012; Sahu and Tribeche 2012) by including (Sahu and Tribeche 2012) or excluding (Sahu 2012) dust dynamics.

4. Discussion

We have studied the effects of electron non-extensivity and ion kinematic viscosity in presence of charged dust on the propagation of DIASHWs in a dusty plasma consisting of inertial ions, non-inertial electrons showing non-extensive behavior, and stationary negatively charged dust in non-planar cylindrical ($v = 1$) and spherical ($v = 2$) geometries. The dynamics of cylindrical and spherical DIASHWs is governed by the modified Burgers equation. It has been shown that the basic properties of DIASHWs change appreciably due to the effect of electron non-extensivity in both cylindrical and spherical geometries. It may be concluded that time evolution of cylindrical and spherical DIASHWs qualitatively differs from the 1D planar DIASHWs. The amplitude of both cylindrical and spherical DIASHWs increases with decrease of time. Our numerical analysis shows that due to non-extensive electrons, the effect of spherical geometry is more pronounced in comparison with cylindrical geometry. We have found both compressive and rarefactive DIA shock structures. It has been seen that depending on the non-extensivity of electrons, i.e. for the value of q which is above (below) the minimal value of q, the DIA shock structures exhibit compression (rarefaction). The amplitude of the compressive (rarefactive) shock waves decreases (increases) with increase of non-extensive parameter q. In conclusion, we hope that the results predicted in this paper considering non-extensive behavior of electrons may be useful to understand the salient features of the cylindrical and spherical DIASHWs that may arise due to a delicate balance between nonlinearity and dissipation. It may also be noted here that the results of this investigation should be useful for understanding the nonlinear features of electrostatic disturbances in laboratory plasmas since the observation of DIASHWS are more easier than the observation of DASHWs in such a plasma environment. Our investigations may also be useful to study the non-extensive effect of electrons in a dissipative plasma, i.e. interstellar and space plasmas (Ferro et al. 2004; Vergou 2009), stellar polytropes (Plastino and Plastino 1993), hadronic matter and quark-gluon plasma (Gervino et al. 2012), protoneutron stars (Lavagno and Pigato 2011), dark-matter halos (Feron and Hjorth 2008), etc., where the effects of non-extensivity of different plasma species may be observed by incorporating magnetic field (Shukla 2005). Finally, it has been suggested that a new experiment can be designed to observe electron non-extensivity concerning DIASHWs in laboratory environment.

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