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Effect of negative charge dust on ion-acoustic dressed solitons in plasmas

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ABSTRACT

Propagation of an ion-acoustic soliton in a plasma consisting of negative charge dust is considered the reductive perturbation method (RPM). The well-known RPM has been used to derive the KdV equation. This exact solution reduces to the dressed soliton solution when mach number is expanded in terms of soliton velocity. Variation of amplitude and width for the KdV soliton, core structure, dressed soliton and exact soliton are graphically represented to different values of negative ions and mach number.

The present study of this paper may be helpful in space and astrophysical plasma system where negative charge dust ions are present.

Key words: Soliton, RPM, Negative ion, KdV

INTRODUCTION

In recent years, interest in study of dusty plasmas has arisen because of its occurrence in space and astrophysics. Vladimirov et al. [1] studied the ion acoustic waves in complex laboratory plasmas containing dust grains and negative ions, where effects of relevant processes were considered. Mamun and Shukla [2] used two models for negative ion distributions, i.e., Boltzmannian and the streaming, and found that the negative ion number density and streaming velocity could greatly affect the dust surface potential, and therefore the dust charge. Baluku et al. [3] investigated dust ion acoustic solitons in an unmagnetized dusty plasma comprising cold dust particles, adiabatic fluid ions, and electrons satisfying a kappa distribution using both small amplitude and arbitrary amplitude techniques. A theoretical investigation of dusty plasma consisting of ion fluid, non-thermal electrons and fluctuating immobile dust particles has been made by Alinejad [4]. Saini et al. [5] studied dust-acoustic waves in magnetized dusty plasma with Maxwellian electrons.

Ichikawa et al. [6] and Sugimoto and Kakutani [7] have been studied the dressed soliton in plasmas. Ion acoustic dressed soliton in EPI [8-9], ion beam [10] and dusty [11] plasmas have been studied using sagdeev potential technique and RPM. They discuss the characteristics of the soliton such as amplitude, width and velocity. Chatterjee et al. [12] and Roy and Chatterjee [13] have been studied the dressed soliton in quantum plasmas and dusty pair-ion plasma. Effect of the quantum parameters and characteristics of soliton such as amplitude and width.

Tiwari [9] studied only the effect of fractional concentration on amplitude and width the soliton. The aim of this research paper have been studied the propagation of ion-acoustic dressed soliton in nonthermal electrons in plasmas by considering the RBM, the first and second coupled evolution equation, namely the KdV equations is derived. Through elimination of the secular terms, the KdV soliton, core structure, dressed soliton and exact soliton are determined.

The paper is organized in the following fashion. In section 2 and 3, we use the RPM to derive the KdV equation. Section 4 investigates the dependence negative charge dust on ion-acoustic dressed soliton in plasma and we summarize our results in the same section. Conclusions are present in last section.

BASIC EQUATIONS

We consider a collisionless unmagnetized plasma consisting of ions, positrons and nonthermal electrons. The dynamics of the plasma is given by following set of normalized fluid equation:

$$\frac{\partial N_i}{\partial t} + \frac{\partial (N_i V_i)}{\partial x} = 0 \tag{1}$$

$$\frac{\partial V_i}{\partial t} + V_i \frac{\partial V_i}{\partial x} = -\frac{\partial \phi}{\partial x} \tag{2}$$

$$\frac{\partial N_d}{\partial t} + \frac{\partial (N_d V_d)}{\partial x} = 0 \tag{3}$$

$$\frac{\partial V_d}{\partial t} + V_d \frac{\partial V_d}{\partial x} = \beta \frac{\partial \phi}{\partial x} \tag{4}$$

$$\frac{\partial^2 \phi}{\partial x^2} = (1-\gamma)e^{\phi} + \gamma N_d - N_i \tag{5}$$

Here $N_{i,d}$ and $V_{i,d}$ are the normalized density and fluid velocity of the plasma ions and dust particles respectively. ϕ is the electric potential. $\beta = Z_d / M_d$. Charge multiplicity (Z_d) and mass ratio of dust grains with plasma ions (M_d). Dust concentration $(\alpha = N_{d0} / N_{i0})$, and $\gamma = Z_d \alpha$. These quantities have been rendered dimensionless in terms of equilibrium plasma density (n_0), ion sound speed $(T_e / m_i)^{1/2}$ and characteristic potential (T_e / e), respectively. The space coordinate speed (x) has been normalized in terms of Debye length speed $\lambda_D = (\varepsilon_0 T_e / n_0 e^2)^{1/2}$ and time coordinates by the inverse of ion plasma frequency.

STATIONARY SOLUTION

We introduce the usual transformation in equation (1) – (5) and obtain stationary soliton solution

$$\eta = x - Mt \tag{6}$$

Where M is the Mach number of soliton. Integrating Eqs. (1) - (5) and using the necessary boundary conditions ($N_{i,d} \to 1$, and $V_{i,d} \to 0$ as $\eta \to \pm\infty$) for a soliton structure, gives

$$N_i = M\left(M^2 - 2\phi\right)^{-1/2} \tag{7}$$

$$N_d = M\left(M^2 + 2\beta\phi\right)^{-1/2} \tag{8}$$

Integrating the value of η in (5), multiplying both side by $d\phi / d\eta$, integrating once and using the necessary boundary conditions ($N_{i,d} \to 1$, and $V_{i,d} \to 0$ as $\eta \to \pm\infty$) we get the following relation

$$\frac{1}{2}\left(\frac{d\phi}{d\eta}\right)^{1/2} + V(\phi) = 0 \tag{9}$$

where the Sagdeev potential $V(\phi)$ is given by

$$V(\phi) = (1-\gamma)(1-e^{\phi}) + \frac{\lambda M^2}{\beta}\left[1-\left(1+\frac{2\beta\phi}{M^2}\right)^{1/2}\right] + M^2\left[1-\left(1-\frac{2\phi}{M^2}\right)^{1/2}\right] \quad (10)$$

We expand the value of $e^{\phi} = 1+\phi+\frac{\phi^2}{2}+\frac{\phi^3}{6}+...$ and using this Taylor series expansion in (10) and include also the effect of fourth-order nonlinearities of electric potential (ϕ). The equation (10) reduces to

$$\left(\frac{d\phi}{d\eta}\right)^2 = \alpha_1\phi^2 - \alpha_2\phi^3 + \alpha_3\phi^4 \quad (11)$$

Where

$$\alpha_1 = \left[(1-\gamma) - \frac{\gamma\beta}{M^2} - \frac{1}{M^2}\right] \quad (12)$$

$$\alpha_2 = \left[\frac{1}{M^4} - \frac{\beta^2\gamma}{M^4} - \frac{(1-\gamma)}{3}\right] \quad (13)$$

$$\alpha_3 = \left[\frac{(1-\gamma)}{12} - \frac{5\gamma\beta^3}{4M^6} - \frac{5}{4M^6}\right] \quad (14)$$

Integrating of eq. (11) with respect to η and using the boundary conditions ($d\phi/d\eta \to 0,\ \phi \to 0$ as $\eta \to \pm\infty$) gives stationary exact soliton solution as

$$\phi = \frac{2(\gamma_1/\gamma_2)}{\left(1-\frac{4\gamma_1\gamma_3}{\gamma_2^2}\right)^{1/2}\left(2\cosh^2(A\eta)-1\right)+1} \quad (15)$$

Where

$$A = \left(\frac{\alpha_1}{4}\right)^{1/2} \quad (16)$$

We denote (15) as small amplitude as compared with the KdV soliton, because its expansion in small amplitude limit can give rises to the KdV soliton and dressed soliton solution when the RPM is used for the analysis.

We expand the Mach number (M) of soliton velocity (λ) as $M = 1+\lambda$ in (12) – (14), and retaining terms up to λ^2 in α_1, and terms up to λ in α_2, and keeping α_3, independent of λ such that each terms on R.H.S. of (8) is of fourth order in combined nonlinearities of λ and ϕ. we find out

$$\alpha_1 = -\gamma(1+\beta) - (1+\beta\gamma)(-2\lambda+3\lambda^2) \quad (17)$$

$$\alpha_2 = [R-4\lambda] \quad (18)$$

$$\alpha_3 = \left[\frac{(1-\gamma)}{12} - \frac{5}{4}\left(1+\gamma\beta^3\right) \right] \tag{19}$$

where

$$R = \frac{3\left(1-\beta^2\gamma\right)-(1-\gamma)}{3\left(1-\beta^2\gamma\right)} \tag{20}$$

We using (17) – (19) and retain terms up to the order of λ^2 in (15)

$$\frac{\alpha_1}{\alpha_2} = \left[k + k_1\lambda + k_2\lambda^2\right] \tag{21}$$

$$\frac{\alpha_3}{\alpha_2} = k_3\left(1+\frac{4\lambda}{R}\right) \tag{22}$$

$$\left(1-4\frac{\gamma_1\gamma_3}{\gamma_2}\right)^{1/2} = \left[1-2\left(kk_3 + k_1k_3\lambda + \frac{4kk_3\lambda}{R}\right)+\ldots\right] \tag{23}$$

where

$$k = \frac{(1-\gamma)-(1+\beta\gamma)}{R} \tag{24}$$

$$k_1 = \frac{1}{R^2}\left[4(1-\gamma)+(4-2R)(1+\beta\gamma)\right] \tag{25}$$

and

$$k_2 = \frac{1}{R^3}\left[16(1-\gamma)-(1+\beta\gamma)\left(3R^2-8R+16\right)\right] \tag{26}$$

Substituting (21) - (23) in (15) and retain terms up to the order of λ^2 in the expansion, we can write the dressed soliton solution as

$$\phi = P\sec h^2\tilde{A}\eta + Q\sec h^2\tilde{A}\eta\tanh^2\tilde{A}\eta \tag{27}$$

where

$$P = \left(\left(k+2k^2k_3\right)+\lambda\left(k_1+2kk_1k_3-k_1^2k_3+8\frac{k^2k_3}{R}-\frac{4k^2k_3}{R}\right)+\lambda^2\left(k_2+2kk_2k_3+2k_1^2k_3+\frac{4kk_1k_3}{R}\right)\right) \tag{28}$$

and

$$Q = \left(k^2k_3+\lambda\left(2kk_1k_3+\frac{4k^2k_3}{R}\right)+\lambda^2\left(kk_2k_3+k_1^2k_3+\frac{4kk_1k_3}{R}\right)\right) \tag{29}$$

Including the contribution of λ^2 term in (16), we can expressed $\tilde{A}$ as

$$\tilde{A} = \left(\frac{\alpha_1}{4}\right)^{1/2} = \left[\frac{(1-\gamma)}{2}\left\{\frac{1}{2} + \frac{(1+\beta\gamma)}{(1-\gamma)}\left(\lambda - \frac{3}{2}\lambda^2 - \frac{1}{2}\right)\right\}\right]^{1/2} \tag{30}$$

Keeping terms of order λ only soliton solution (28) reduces to the KdV soliton

$$\phi = \lambda\left(k_1 + 2kk_1k_3 - k_1^2k_3 + 8\frac{k^2k_3}{R} - 4\frac{k^2k_3}{R}\right)\mathrm{sec}h^2 A\eta \tag{31}$$

where

$$A = \left(\frac{(1+\beta\gamma)}{2}\right)^{1/2} \tag{32}$$

Equation (27) is following first (core structure) and second terms (cloud structure)

$$\phi_{core} = P\,\mathrm{sec}h^2\tilde{A}\eta \tag{33}$$

$$\phi_{cloud} = Q\,\mathrm{sec}h^2\tilde{A}\eta\tanh^2\tilde{A}\eta \tag{34}$$

DISCUSSION AND RESULTS

We present the effect of charged dust grains (Zd) and Mach number present in a plasma on velocity, amplitude, width and product of amplitude and square of width (P = amplitude × Width^2), we plot the variation of the KdV soliton $\{\phi_k\}$, core structure $\{\phi_c\}$, cloud structure $\{\phi_{cl}\}$, dressed soliton $\{\phi_d\}$, and the small amplitude exact soliton solution $\{\phi_s\}$, with different parameters of plasma.

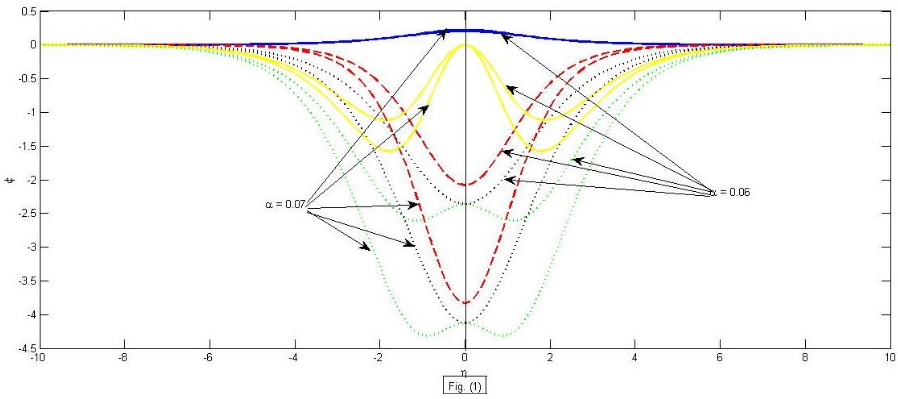

Fig. 1 Variation of ϕ_S (solid blue color line), ϕ_{KdV} (dashed red color line), ϕ_{core} (dotted black color line), ϕ_{dS} (dotted green color line) and ϕ_{cloud} (solid yellow color line) vs η for different value of α = 0.006 and 0.007 at the Md = 10000, Zd= -100, and M = 1.2.

Figure (1) shows the **v**ariation of ϕ_S (solid blue color line), ϕ_{KdV} (dashed red color line), ϕ_{core} (dotted black color line), ϕ_{dS} (dotted green color line) and ϕ_{cloud} (solid yellow color line) is plotted against η for different value of α = 0.006 and 0.007 at the Md = 10000, Zd= -100, and M = 1.2. Here we find that as finite dust concentration (α) increases, the small amplitude of ϕ_S, ϕ_{KdV}, ϕ_{core}, ϕ_{dS} and ϕ_{cloud} corresponding to η also increases but the potential of the ϕ_{cloud} is constant.

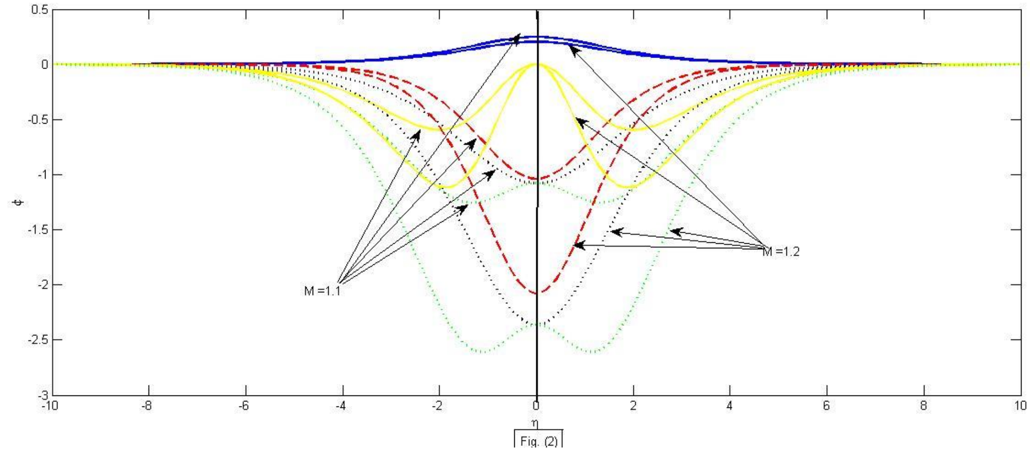

Fig. 2 Variation of ϕ_S (solid blue color line), ϕ_{KdV} (dashed red color line), ϕ_{core} (dotted black color line), ϕ_{dS} (dotted green color line) and ϕ_{cloud} (solid yellow color line) vs η for different value of M = 1.1 and 1.2, at the Md = 10000, Zd= -100, α = 0.006.

In figure (2) shows the variation of ϕ_S (solid blue color line), ϕ_{KdV} (dashed red color line), ϕ_{core} (dotted black color line), ϕ_{dS} (dotted green color line) and ϕ_{cloud} (solid yellow color line) is plotted against the η for different values of Mach number (M) = 1.1 and 1.2, at the Md = 10000, Zd= -100, α = 0.006. Here we find that as finite Mach number (M) increases, the small amplitude of ϕ_{KdV} , ϕ_{core}, ϕ_{dS} and ϕ_{KdV} (ϕ_S) corresponding to η also increases (decreases) but the potential of the ϕ_{cloud} is constant.

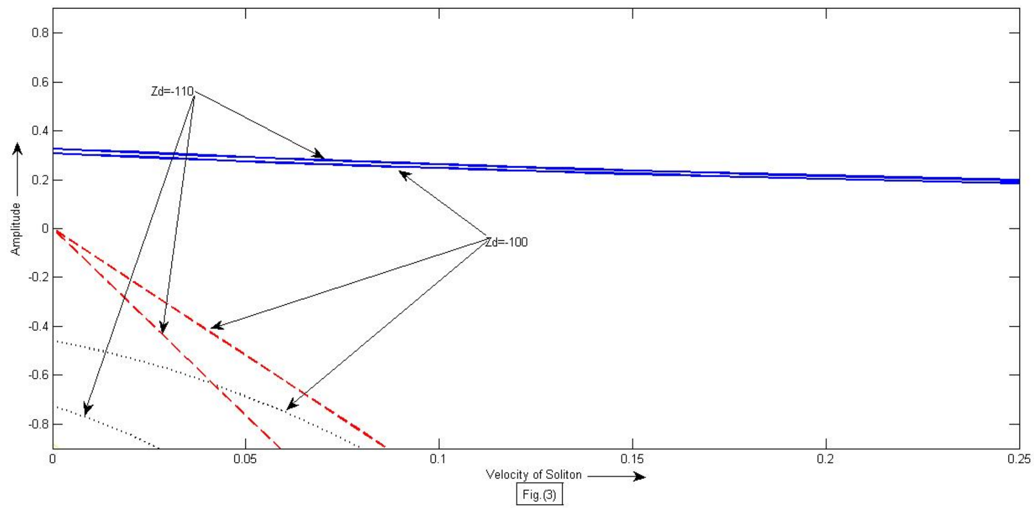

Fig. 3 Variation of soliton amplitude (solid blue color line), KdV amplitude (dashed red color line) and core amplitude (dotted black color line) vs λ for different value of Zd= -100 and -110 at the Md = 10000, and α = 0.006.

From figure (3) **v**ariation of soliton amplitude (solid blue color line), KdV amplitude (dashed red color line) and core amplitude (dotted black color line) versus soliton velocity (λ) for different value of Zd = -100 and -110 at the Md = 10000, and α = 0.006. Here we find that as finite Zd increases the amplitude of KdV soliton and core structure (exact soliton) decreases (increases) correspond soliton velocity (λ) also decreases.

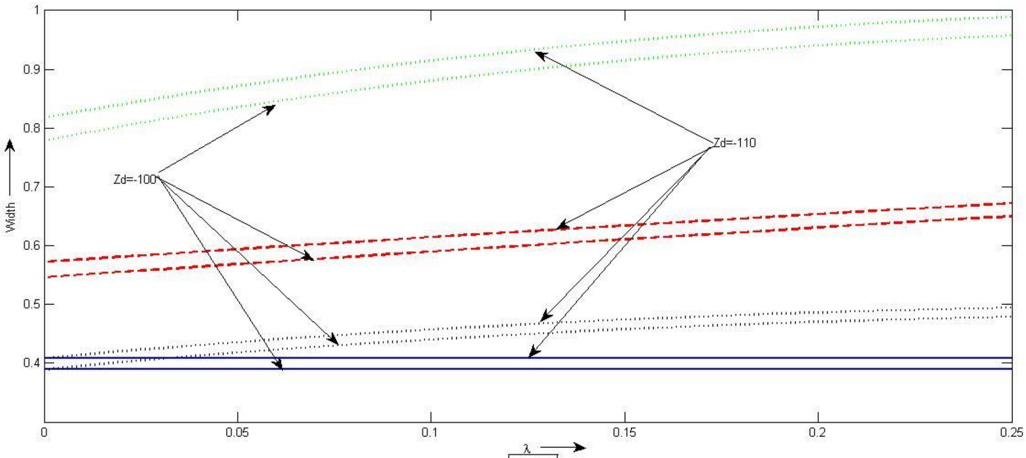

Fig. 4 Variation of $W_{soliton}$ (solid blue color line), W_{KdV} (dashed red color line), W_{core} (dotted black color line), and $W_{dressed\ soliton}$ (dotted green color line) vs λ for different value of Zd= -100 and -110 at the Md = 10000, and α = 0.006.

From figure (4) **v**ariation of soliton width (solid blue color line), KdV width (dashed red color line), core width (dotted black color line), and dressed soliton width (dotted green color line) versus soliton velocity (λ) for different value of Zd= -100 and -110 at the Md = 10000, and α = 0.006. Here we find that as finite Zd increases the width of exact soliton, KdV soliton, core structure and dressed soliton increases correspond soliton velocity (λ) also increases but the exact soliton width is constant.

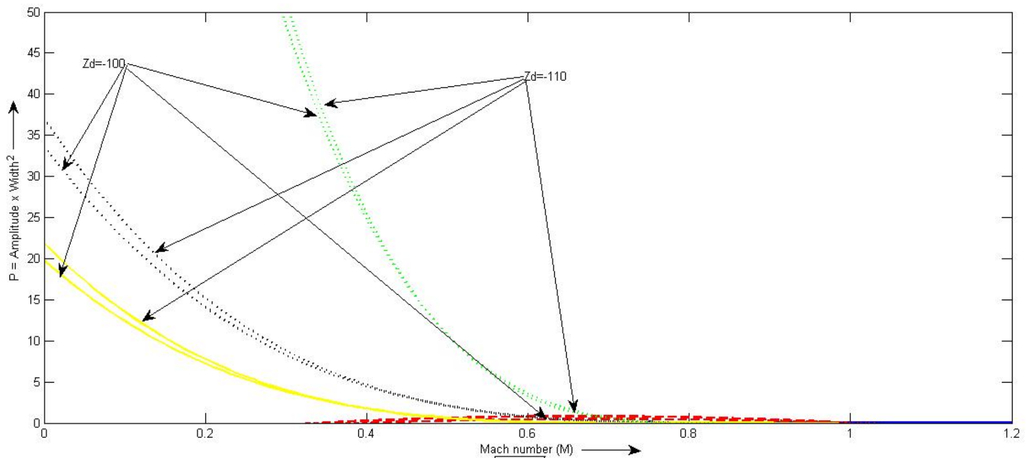

Fig. 5 P = amplitude × Width^2 for the soliton (solid blue line), KdV (dashed red color line), core (dotted black color line), cloud (solid yellow line) and dressed soliton (dotted green line) vs M for different value of Zd= -100 and -110 at the Md = 10000, and α = 0.006.

From figure (5) variation of product (P) = amplitude × Width^2 for the soliton (solid blue color line), KdV (dashed red color line), core (dotted black color line), cloud (solid yellow color line) and dressed soliton (dotted green color line) versus Mach number (M) for different value of Zd= -100 and -110 at the Md = 10000, and α = 0.006. Here we find that as finite Zd increases the product (P) of exact soliton, KdV soliton, core and cloud structure and dressed soliton increases correspond soliton Mach number (M) also increases.

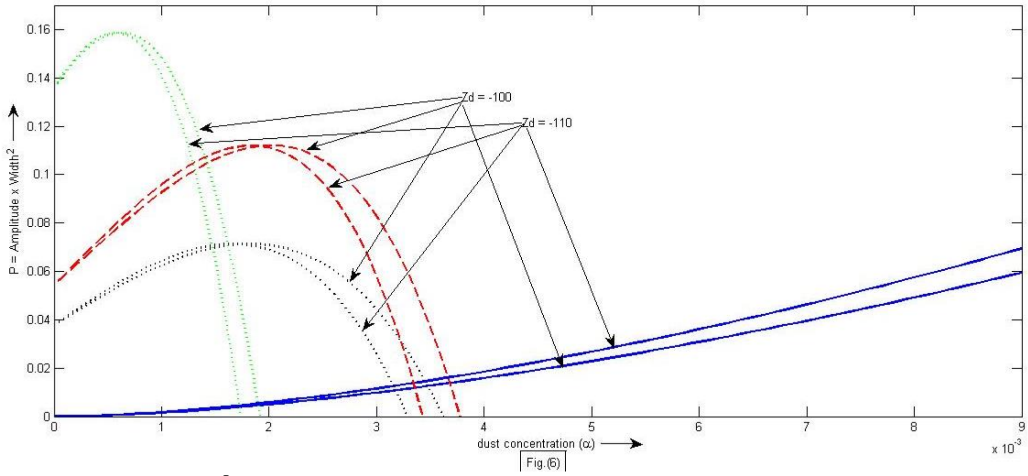

Fig. 6 P = amplitude × Width^2 for the soliton (solid blue line), KdV (dashed red color line), core (dotted black color line), cloud (solid yellow line) and dressed soliton (dotted green line) vs α for different value of Zd= -100 and -110 at the Md = 10000, and M = 1.2.

From figure (6) variation of product (P) = amplitude × Width^2 for the soliton (solid blue line), KdV (dashed red color line), core (dotted black color line), cloud (solid yellow line) and dressed soliton (dotted green line) versus dust concentration (α) for different values of Zd = -100 and -110 at the Md = 10000, and M = 1.2. Here we find that as finite Zd increases the product (P) of exact soliton, KdV soliton, core and cloud structure and dressed soliton increases correspond soliton dust concentration (α) also increases.

CONCLUSIONS

The main conclusions of this paper are the following

(1) For a given value of soliton velocity, the amplitude of KdV soliton and core structure decreases but the amplitude of exact soliton increases as dust concentration increases.
(2) For a given value of soliton velocity, the width of exact soliton, KdV soliton, core structure and dressed soliton increases dust concentration increases.
(3) Amplitude of KdV soliton, core structure and exact soliton decreases as soliton velocity increases.
(4) Width of KdV soliton, core structure and dressed soliton increases as soliton velocity increases but width of exact soliton is constant.
(5) The charge multiplicity (Zd) increases the product (P) of exact soliton, KdV soliton, core and cloud structure and dressed soliton increases correspond soliton Mach number (M) also decreases.
(6) The charge multiplicity (Zd) increases the product (P) of exact soliton, KdV soliton, core and cloud structure and dressed soliton increases correspond soliton dust concentration (α) also increases

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