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ONE-DIMENSIONAL STUDY OF SHOCK WAVE PROPAGATION IN A ROTATING DUSTY NON-IDEAL GAS

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Abstract- **Strength of overtaking waves on the freely propagating strong spherical converging shock waves in the dusty gaseous non-uniform medium has been investigated. The non-uniformity of the medium arises due to solid body rotation of the mixture and the flow behind the shock. It is assumed that the medium in which shock propagates, is a suspension of inert dust particles and non-ideal gas. The particles are of small spherical uniform size and uniformly distributed in the medium. It is also assumed that the condition of equilibrium flow is maintained. Neglecting the Coriolis forces, the analytical expressions for the shock velocity and shock strength for freely propagation as well as under the influence of flow behind the shock front have been derived using CCW method. The non-dimensional expressions for pressure and particle velocity are also obtained. The variations of all flow variables with propagation distance(r), angular velocity (Ω), and mass concentration of dust particles in the medium (k_p) are shown through figures. The results reported here are compared with those for dusty perfect gas[26]. It is observed that the presence of non-idealness in the gaseous medium has significant effects on flow variables of shock propagation.**

Keywords- ***Dusty shock, strong, non-ideal gas, effect of overtaking disturbances.***

I INTRODUCTION

Propagation of shock wave in non-uniform medium is influenced both by the non-uniformity ahead of the shock and also by a wave which overtakes the shock. Yousaf [1] has estimated the effect of overtaking disturbance on the motion of shock wave in non-uniform medium by using similarity method. Chisnell and Yousaf[2] investigated the strength of overtaking waves on the propagation of strong shock wave in a medium having exponentially verifying density. Assuming the propagation of both C_+ and C_- disturbances in medium, Yadav[3] has developed a method to calculate the strength of of overtaking waves(EOD) on freely propagation of shock wave in an ideal gas. Using CCW method, Yadav and Tripathi[4] studied the effect of flow behind the shock(EOD) on motion of shock wave in a self-gravitating ideal pure gas. Yadav and Gangwar[5],[6] discussed theoretically the problem of the motion of spherical converging strong and weak shock wave in non-uniform gaseous medium under EOD.

In most of the problems associated with the explosion waves, the assumption of the gas to be an ideal gas is not practically true. Anisimov and Spiner[7] simplified the equation of state for non-ideal(real) gas and studied the problem of shock explosion. Rnga Rao and Purohit[8], Ojha[9], Vishwakarma and Nath[10] and Singh *et. al.*[11] have also considered the problem of shock wave explosion for non-ideal gases. Assuming constant initial density distribution Vishwakarma and Patel[12] have used similarity method to explore the problem of diverging cylindrical shock wave in a low conducting non-ideal gas under the influence of axial and azimuthal components of magnetic induction.

The propagation of shock wave in dusty atmosphere has many applications in engineering and geophysical science. The problem of dusty shock dynamics has been tackled by Several scientist like Carrier[13], Kriebel[14], Rudinger[15], Taylor[16], Sedov[17], Marble[18], Pai [19], Miura and Glass[20] and Igra and Ben-Dor[21]. Using Chester[22]- Chisnell[23]-Whitham[24] (CCW) theory Singh and Pandey[25], have investigated the motion of magnetogasdynamics shock waves in a self-gravitating and rotating gas. Neglecting the EOD, Yadav et. al. [26] have investigated the effect of magnetic fields on the behaviour of weak shock waves in the suspension of a perfect gas and dust particles. Singh and Gogoi [27] have used the similarity method to study isothermal and adiabatic motion of strong shock wave in the mixture of non-ideal gas and small solid dust particles. They discussed the effects of variation of the parameter of non-idealness of the gas in the mixture.

Recently, Gangwar [28] has consider the problem of strong shock wave propagation in dusty real gaseous non-uniform medium, for freely under EOD and found that shock is strengthened as the EOD is taken in to account. The effect of self-gravitational forces on the motion of strong imploding shock waves in dusty real gas has also reported by Gangwar[29] by using CCW theory.

In the present study, we have estimated the strength of overtaking disturbances on the freely propagating strong spherical converging shock in the dusty gaseous non-uniform medium by using Yadav technique[3]. The non-uniformity of the medium arises due to solid body rotation of the mixture and the flow behind the shock. It is assumed that the medium in which shock propagates, is a suspension of dust particles and non-ideal gas. The particles are small spherical uniform size and uniformly distributed in the medium. It is also assumed that the condition of equilibrium flow is maintained. Neglecting the Coriolis forces, the analytical expressions for the modified shock velocity and shock strength under the EOD have been derived using CCW method. The non-dimensional expressions for pressure and particle velocity are also obtained. The variation of all flow variables with propagation distance(r), angular velocity (Ω), and mass concentration of dust particles in the medium (k_p) have shown through figures. The results reported here are compared with those for dusty perfect gas[26]. It is observed that the presence of non-idealness in the gaseous medium has significant effects on flow variables of shock propagation.

II GOVERNING EQUATION, BOUNDARY CONDITIONS AND ANALYTICAL EXPRESSIONS.

The basic equations for the spherical symmetrical flow of dusty gas can be written as [3],[19]

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+\frac{1}{\rho}\frac{\partial p}{\partial r}-\frac{v^2}{r}=0 \tag{1}$$

$$\frac{\partial \rho}{\partial t}+u\frac{\partial \rho}{\partial r}+\rho\frac{\partial u}{\partial r}+\frac{2\rho u}{r}=0 \tag{2}$$

$$\frac{\partial \varepsilon}{\partial t}+u\frac{\partial \varepsilon}{\partial r}+\frac{p}{\rho^2}\left(\frac{\partial \rho}{\partial t}+u\frac{\partial \rho}{\partial r}\right)=0 \tag{3}$$

where u, p, and ρ are the particle velocity, the pressure and density at a distance 'r' from the center of explosion at time 't'. ε is the internal energy and v is the angular velocity of mixture.

The equation of state of the mixture of non-ideal gas and small dust particles is given by [7],[8],[19] and [27]

$$p=\frac{\left(1-k_p\right)}{1-Z}\left[1+b\rho\left(1-k_p\right)\right]\rho R^{*}T \tag{4}$$

where R^* is the gas constant, T the temperature, Z and k_p are the volume fraction of solid particles in the mixture and mass concentration of solid particles in the mixture, respectively.

The mass concentration of the dust particles in the mixture (k_p) is as follows [19]

$$k_p=\sigma Z \tag{5}$$

where $\sigma=\rho_{sp}/\rho$ is the ratio of density to solid particle to the specific density of a non-ideal gas(dust loading parameter) ρ_{sp} is the species density of dust particles. The range of σ is form σ=1 to ∞. The fundamental parameters of Pai medel[19] are k_p and σ. The internal energy is given by[19]

$$\varepsilon=p(1-Z)\Big/\left[\rho(\Gamma-1)\left\{1+b\rho\left(1-k_p\right)\right\}\right] \tag{6}$$

Initial volume fraction is given by[19],[30]

$$Z_o=k_p\Big/\left[\sigma\left(1-k_p\right)+k_p\right] \tag{7}$$

At equilibrium two phase flows for an isentropic change of state of the mixture, the speed of sound is given by [13]

$$a^2=\frac{p\left[\Gamma+(\Gamma-Z)b\rho\left(1-k_p\right)\right]}{\rho(1-Z)} \tag{8}$$

At the equilibrium, state of the gas is assumed to be specified by the condition

$$u=0=\partial/\partial t \text{ and } v_0=r\Omega_0$$

where v_0 is the rotational velocity and Ω_0 is the initial angular velocity of rotating gas. Therefore from equation (1), the equilibrium condition prevailing the front of the shock may be written as

$$\frac{1}{\rho_o}\frac{dp_o}{dr}-r\Omega_o^2=0 \tag{9}$$

On solving the above equation becomes

$$p_o=\frac{1}{2}\rho_o r^2\Omega_o^2 \tag{10}$$

Hence from equation (8) speed of sound in undisturbed medium a_0 is given by

$$a_0^2=\left[\frac{\Gamma+\left(\Gamma-Z_o\right)\bar{b}\left(1-k_p\right)}{2\left(1-Z_o\right)}\right]r^2\,\Omega_0^2 \tag{11}$$

The jump conditions across the strong shock are given by[12],[14] and [23]

$$u=(1-\beta)U \tag{12}$$

$$\rho=\rho_o/\beta \tag{13}$$

$$p=(1-\beta)\rho_o^2U^2 \tag{14}$$

$$Z=Z_0/\beta \tag{15}$$

The quantity $\beta(0<\beta<1)$ is obtained by the relation

$$\frac{2(\beta-Z)\beta}{\rho(\Gamma-1)\left[\beta+\bar{b}\left(1-k_p\right)\right]}+\beta-\left[1+\frac{2\left(F_2-F_1\right)}{pU}\right]=0 \tag{16}$$

where the suffix "$_0$" represents the values at front of shock and $\bar{b}=b\rho_o$ is the parameter of non-idealness of the mixture.

For strong shock, it is assumed that F_1-F_2 is negligible in the comparison to the product of U and p[14], therefore equation (17) may be written as

$$\beta^2(\Gamma+1)+\beta\left[\left\{\bar{b}(1-k_P)-1\right\}(\Gamma-1)-2Z_o\right] -(\Gamma-1)\bar{b}(1-k_P)=0 \tag{17}$$

where β is shock density ratio.

Using jump conditions the speed of sound behind the spherical strong shock is given by

$$a^2=U^2\frac{(1-\beta)\left\{\Gamma\beta^2+(\Gamma\beta-Z_o)\bar{b}(1-k_P)\right\}}{(\beta-Z_o)} \tag{18}$$

(a) Freely propagation

For spherical converging shocks, the characteristic form of the system of basic equations (1)-(3) is

$$dp-\rho a du+\frac{2\rho a^2 u}{(u-a)}\frac{dr}{r}+\frac{\rho a}{(u-a)}v^2\frac{dr}{r}=0 \tag{19}$$

Substituting the values of respective quantities from boundary conditions(12)-(18) , At constant initial density distribution (ρ_o= constant and $v_0=r\Omega_0$), after simplifying, we have

$$\frac{dU^2}{dr}+M\frac{U^2}{r}=Nr\Omega_o^2 \tag{20}$$

where

$$M=\frac{4}{\eta-\mu+1}=M\left(\Gamma,\beta,Z_o,\bar{b},k_P\right)$$

$$N=\frac{2(\beta-Z_o)(1+\beta)}{(1-\beta)^2\mu(\mu-\eta-1)}=N\left(\Gamma,\beta,Z_o,\bar{b},k_P\right)$$

$$\eta=\frac{4\beta(\beta-Z_o)}{\left\{\Gamma\beta^2+(\Gamma\beta-Z_o)\bar{b}(1-k_P)\right\}}$$

$$\mu^2=\frac{(1+\beta)^2(\beta-Z_o)}{(1-\beta)\left\{\Gamma\beta^2+(\Gamma\beta-Z_o)\bar{b}(1-k_P)\right\}}$$

On integrating the equation(20), we have

$$U=\left\{r^2\Omega_o^2\frac{N}{M+2}+Kr^{-M}\right\}^{1/2} \tag{21}$$

This equation represents the expression for the shock velocity just behind the shock for freely propagation. Using equation (11), (14) and (12), the analytical expressions for shock strength(U/a_0), non-dimensional pressure(p/p_0) and particle velocity(u/a_0) for freely propagation of spherical converging shock in dusty non-ideal gas may be written as, respectively

$$\frac{U}{a_o}=\left[\frac{2(1-Z_o)}{\left\{\Gamma+(\Gamma-Z_o)\bar{b}(1-k_P)\right\}}\left\{\frac{N}{M+2}+\frac{Kr^{-M-2}}{\Omega_o^2}\right\}\right]^{1/2} \tag{22}$$

$$\frac{p}{p_o}=\frac{2(1-\beta)}{(1-Z_o)}\left\{\frac{N}{M+2}+K\frac{r^{-M-2}}{\Omega_o^2}\right\} \tag{23}$$

$$\frac{u}{a_o}=\left[\frac{2(1-Z_o)(1-\beta)}{\left\{\Gamma+(\Gamma-Z_o)\bar{b}(1-k_P)\right\}}\left\{\frac{N}{M+2}+\frac{Kr^{-M-2}}{\Omega_o^2}\right\}\right]^{1/2} \tag{24}$$

(b) Effect of overtaking disturbances

It is assumed that shock propagates along C_- characteristic and produces velocity increment du, whereas overtaking wave propagate along C_+ characteristic create velocity increment du_+. For C_- disturbance, the fluid velocity increments form the equation (12) [3]

$$du_-=(1-\beta)dU \tag{25}$$

Now substituting the value of dU from equation(20) , we get

$$du_-=\frac{(1-\beta)}{2U}\left\{Nr\Omega_o^2-M\frac{U^2}{r}\right\}dr \tag{26}$$

To estimate the strength of overtaking disturbance an independent C_+ disturbances is considered. The characteristics equation for the C_+ disturbances is given by

$$dp+\rho a du+\frac{2\rho a^2 u}{(u+a)}\frac{dr}{r}-\frac{\rho a v^2}{(u+a)}\frac{dr}{r}=0 \tag{27}$$

Substituting the values from equations (11)-(21) in equation (27), and after simplifying equation we get the velocity increment for C_+ disturbance

$$du_+=\frac{(1-\beta)}{2U}\left\{N_+r\Omega_o^2-M_+\frac{U^2}{r}\right\}dr \tag{28}$$

where

$$M_+=\frac{4}{\eta+\mu+1}=M_+\left(\Gamma,\beta,Z_o,\bar{b},k_P\right)$$

$$N_+=\frac{2(\beta-Z_o)(1+\beta)}{(1-\beta)^2\mu(\mu-\eta-1)}=N_+\left(\Gamma,\beta,Z_o,\bar{b},k_P\right)$$

Therefore, the net velocity increment [3]

$$du_--du_+=(1-\beta)dU^* \tag{29}$$

Here U^* has been used in place of U to differentiate the shock velocity with overtaking disturbances.

On putting the values from (26) and (28) into above equation, we have

$$\frac{dU^{2*}}{dr} = N^* r\Omega_o^2 - M^* \frac{U^2}{r} \tag{30}$$

where $N^* = N - N_+$ and $M^* = M - M_+$

On solving the equation (30), we get the modified expression for the shock velocity(U^*) for spherical converging strong shock under the influence of overtaking disturbances.

$$U^* = \left\{ r^2\Omega_o^2 \frac{N^*}{M^*+2} + Kr^{-M^*} \right\}^{1/2} \tag{31}$$

Using equation (11) and equation (31), modified shock strength(U^*/a_0) just behind the shock under the effect of overtaking disturbances may be written as

$$\frac{U^*}{a_o} = \left[\frac{2(1-Z_o)}{\left\{\Gamma + (\Gamma - Z_o)\bar{b}(1-k_p)\right\}} \left\{ \frac{N^*}{M^*+2} + \frac{Kr^{-M^*-2}}{\Omega_o^2} \right\} \right]^{1/2} \tag{32}$$

The expression for non-dimensional pressure(p/p_0) and flow velocity in the region behind the shock modified by overtaking disturbances is given by, respectively

$$\frac{p^*}{p_o} = \frac{2(1-\beta)}{(1-Z_o)} \left\{ \frac{N^*}{M^*+2} + K\frac{r^{-M^*-2}}{\Omega_o^2} \right\} \tag{33}$$

The expression for non-dimensional particle velocity(U/a_0) in the region behind the shock is given by

$$\frac{u^*}{a_o} = \left[\frac{2(1-Z_o)(1-\beta)}{\left\{\Gamma + (\Gamma - Z_o)\bar{b}(1-k_p)\right\}} \left\{ \frac{N^*}{M^*+2} + \frac{Kr^{-M^*-2}}{\Omega_o^2} \right\} \right]^{1/2} \tag{34}$$

III RESULTS AND DISCUSSION

Analytical expressions (21)-(24) and (31)-(34) represent the shock velocity, shock strength, pressure and particle velocity just behind the spherical converging strong shock in a dusty non-ideal gaseous medium having solid body rotating initial density distribution both for freely propagation and under effect of overtaking disturbances.

Initial volume fraction of solid particles in medium(Z_o) depends on mass concentration of solid particles in the mixture(k_p) and ratio of the density of solid particle to the density of gas. Values of initial volume fraction Z_o for some values of k_p and σ are calculated from the equation(13). Initially taking $U/a_o=15$ for strong shock at r=1.1 for $k_p=0.1$, $\sigma=50$, $\bar{b}=0.02$, $Z_o=0.00222$, $\beta=0.16$, $\gamma=1.4$ and $\Gamma=1.36$ the variation of shock velocity, shock strength, non-dimensional pressure and non-dimensional particle velocity with propagation distance (r) have been calculated and displayed through figures(1-4). It is found from figure (1-4) that all the flow variables increase as strong shock converges dusty non-ideal gas. The dotted line(….) shows the increment in the values of all flow variables, when effect of overtaking taken is into account. The similar variation of all flow variables with propagation distance have been reported by [28] for the case of uniform density distribution. It is also observed from figures (1-4) that strength of the strong spherical converging shock increases as the realness of the gaseous phase of the mixture increase($\bar{b}$=0, 0.01 and 0.02). The variation of all flow variables with concentration of dust particles in the mixture (k_p) are shown in the figures(5-9) and it is found that as K_p increases, the values of all flow variables increase. The similar results have also been obtained by [29] in case of self-gravitating dusty gas. It may be concluded from the general observation of these figures that the consideration of non-idealness of the gas has significant role on the variation of all flow variables [cf Fig (1-8)].

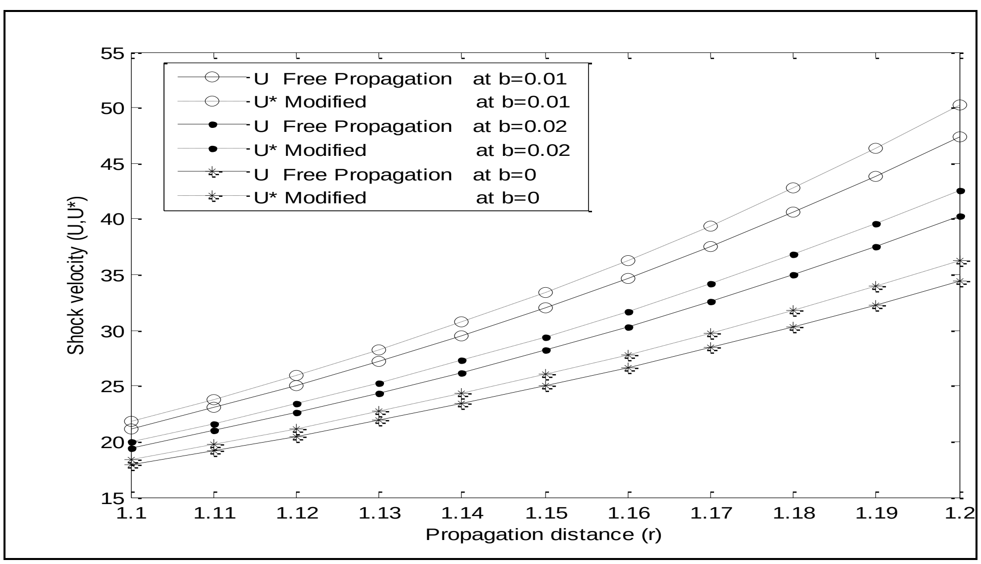

Figure 1 Variation of Shock velocity with propagation distance (r)

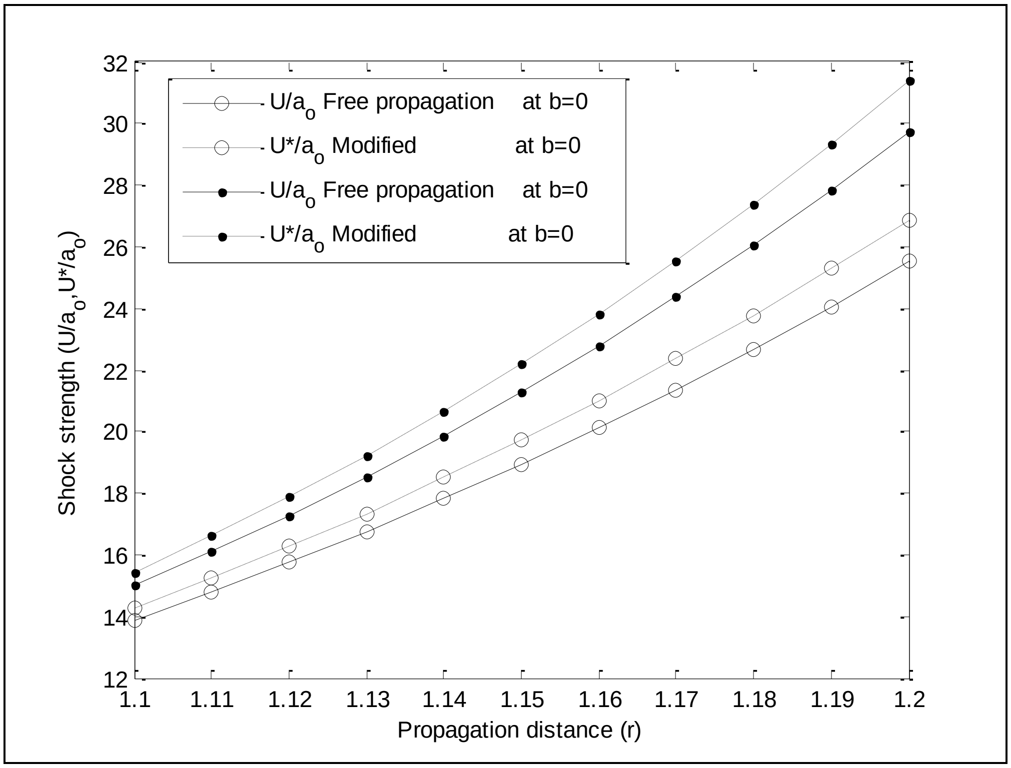

Figure 2 Variation of shock strength with propagation distance (r)

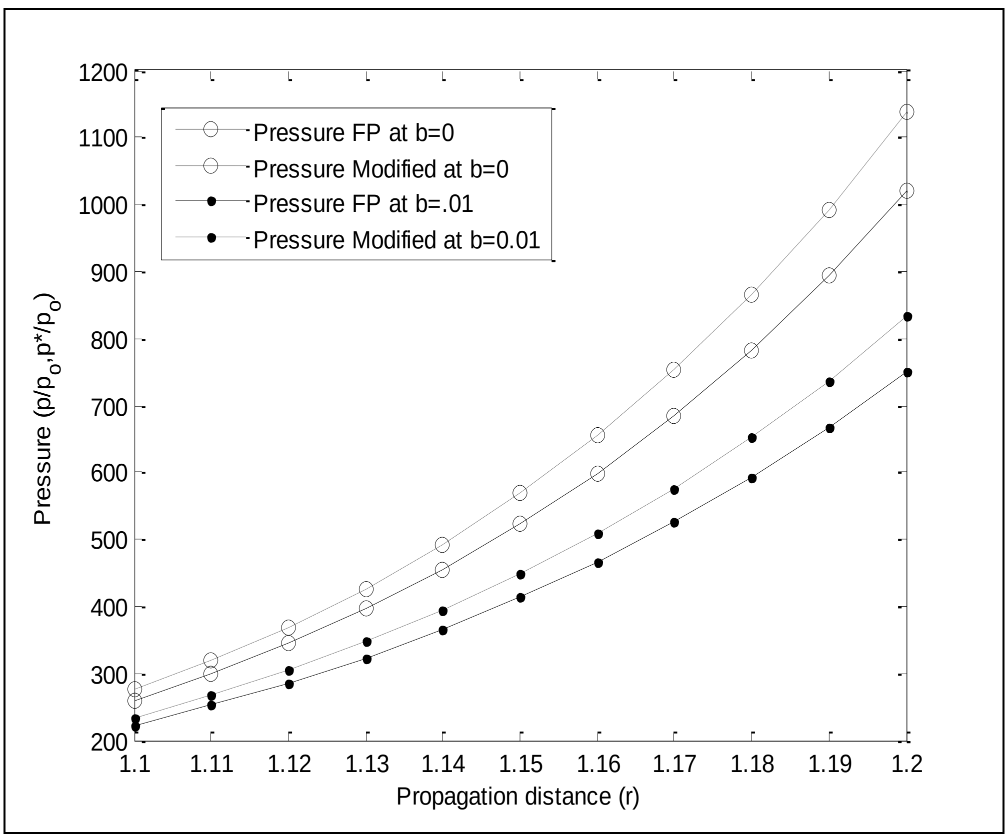

Figure 3 Variation of pressure with propagation distance (r)

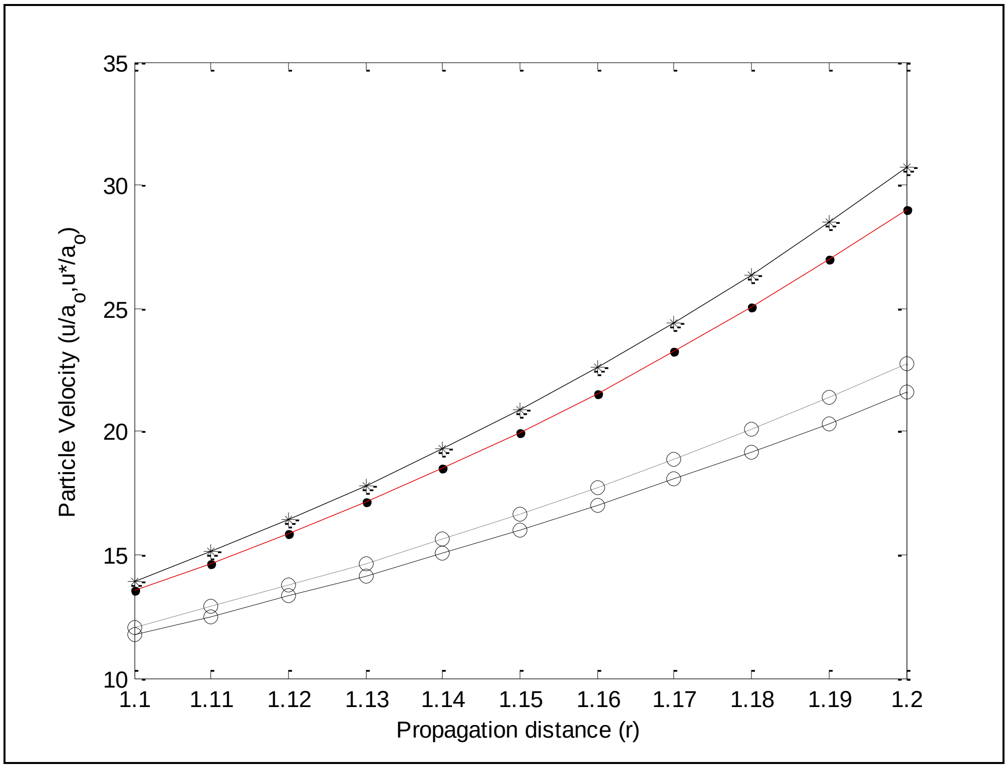

Figure 4: Variation of particle velocity with r(··· for EOD and O for $\bar{b}$=0, * for EOD at $\bar{b}$=0.02)

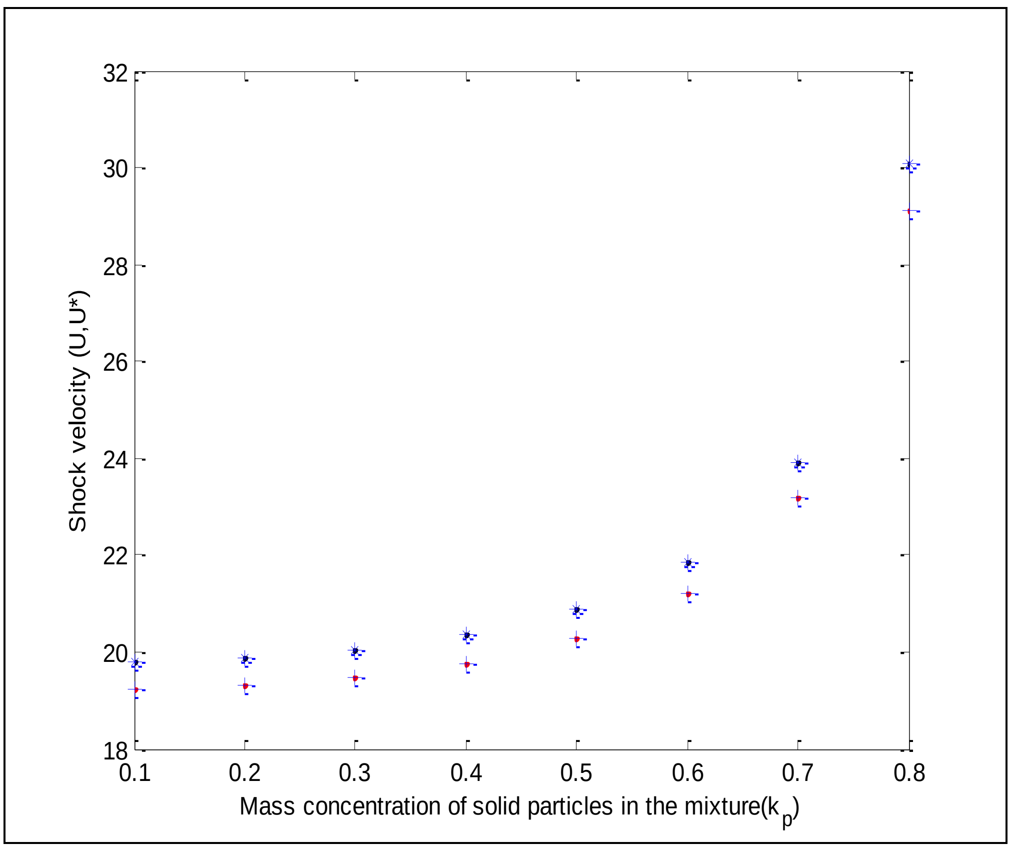

Figure 5: Variation of shock velocity with k_p at $\bar{b}$=0.01(* for EOD and + for FP)

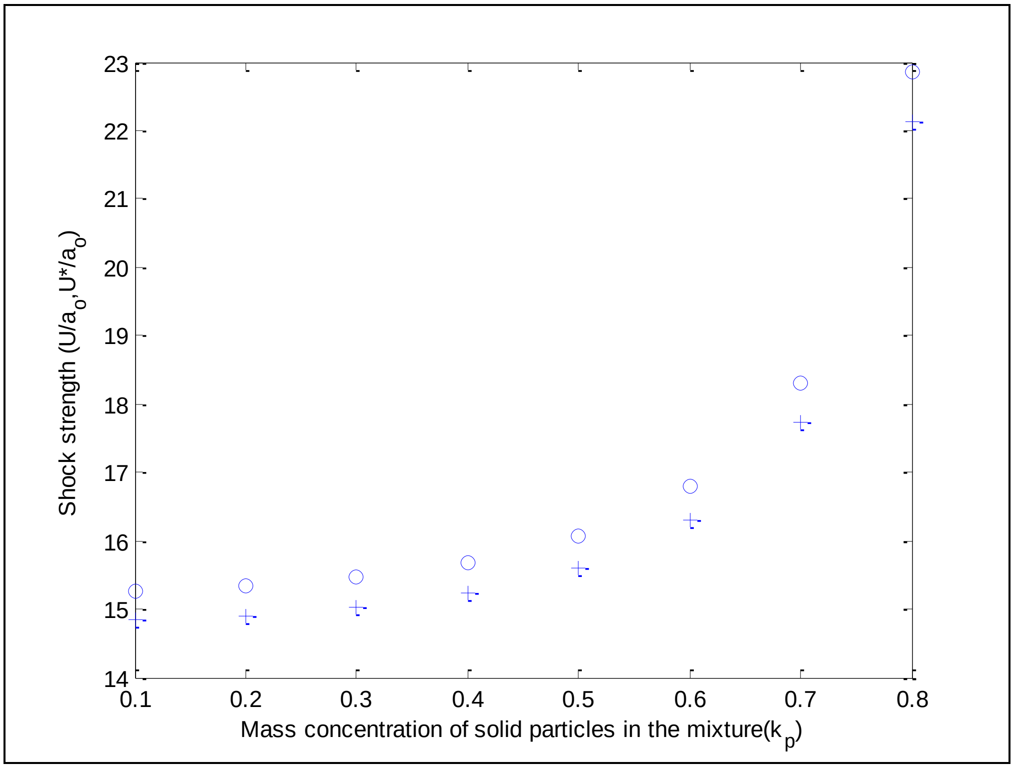

Figure 6: Variation of shock Strength with k_p at $\bar{b}$=0.01(O for EOD and + for FP).

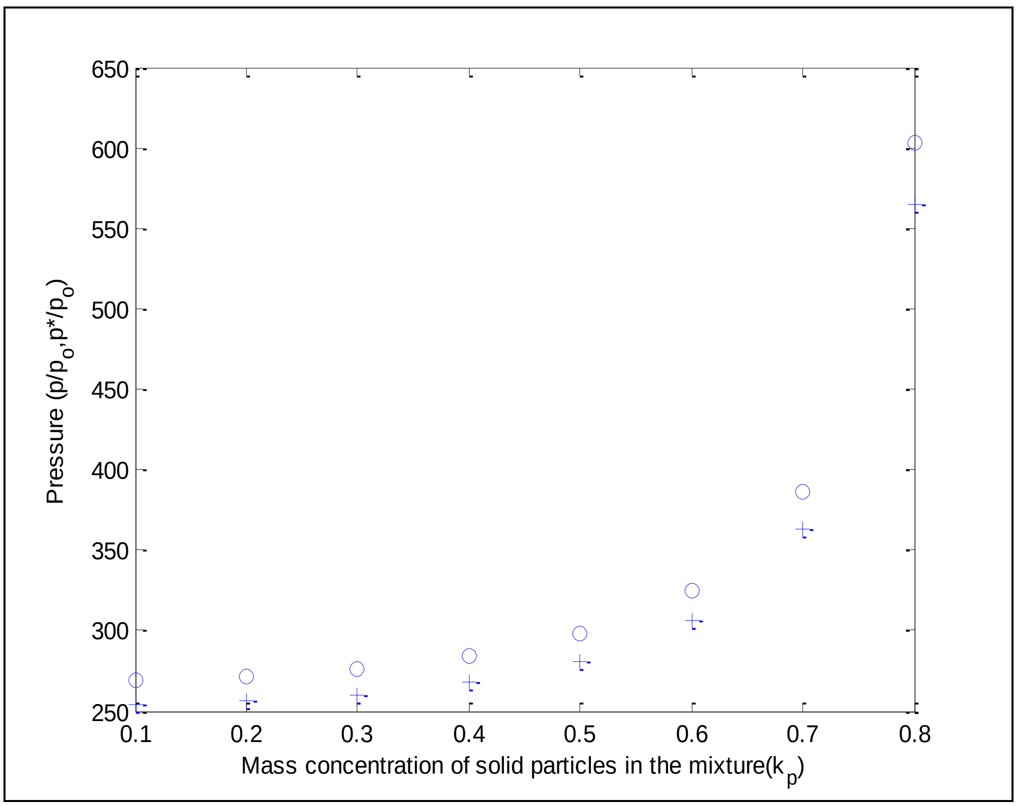

Figure 7: Variation of pressure(p/p_0) with k_p at $\bar{b}$=0.01(O for EOD and + for FP)

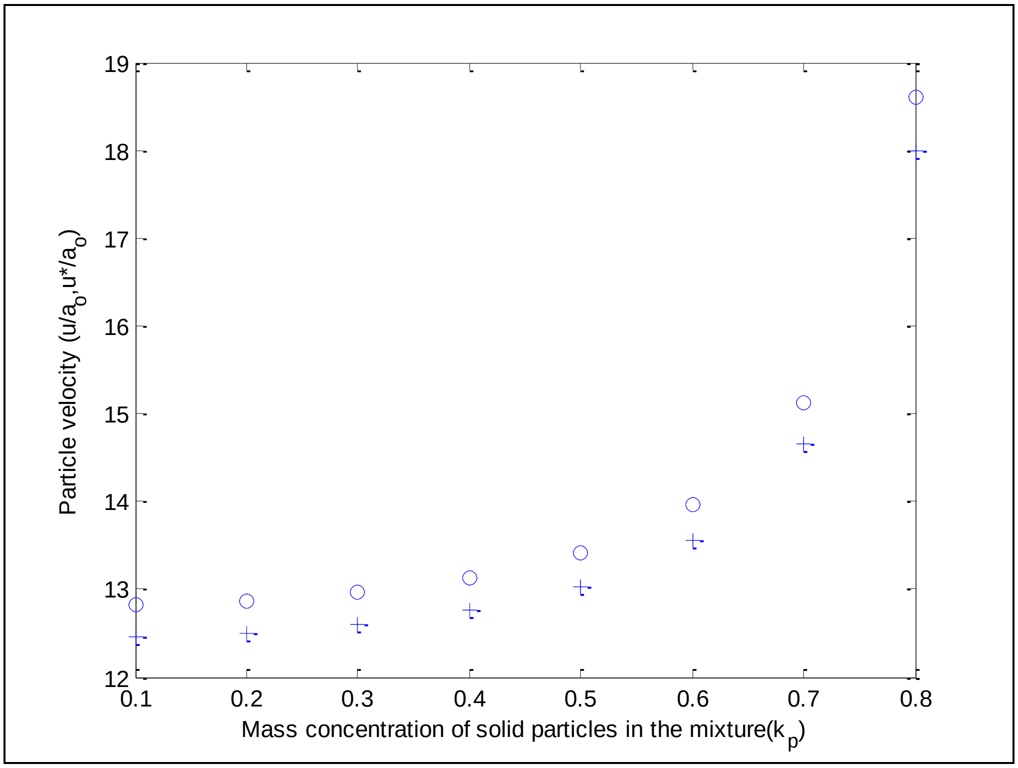

Figure 8: Variation of particle velocity with k_p at $\bar{b}$=0.01(O for EOD and + for FP)

REFERENCE

[1] M. Yousaf, "The effect of overtaking disturbances on the motion of converging shock wave", *J. Fluid Mech.*, vol. 66, no.3, pp. 577-591, 1974.

[2] R. F. Chisnell and M. Yousaf, "The effect of the overtaking disturbance on a shock wave moving in a non-uniform medium," *J. Fluid Mech.*, vol. 120, pp.523-533, 1982.

[3] R. P. Yadav, "Effect of overtaking disturbances on the propagation of strong cylindrical shock in a rotating gas", *Mod. Meas. & Cont., B, AMSE Press*, vol. 46, no. 4, pp. 1-11,1992.

[4] R. P. Yadav and S. Tripathi, "Effect of overtaking disturbances on the propagation of spherical shock through self-gravitating gas," *Astrophy. Space.Sci., J.*, vol. 225, pp.67-88, 1995.

[5] R. P. Yadav, and P.K. Gangwar "Effect of overtaking disturbances on strong spherical converging shock in non uniform medium," *Proc. 2nd International, (29th National) Conf. Fluid Mechanics and Fluid Power (FMFP-2002), IIT Roorke*, vol. 1, pp.161-168. 2002.

[6] R. P. Yadav, and P.K. Gangwar, "Strong spherical converging shock in a rotating gas," *Proc. Int. Conf., Mod. & Sim. Tech. Social Sci., MS 2002, Spain*, pp.635-641, 2002.

[7] S. I. Anisimov and O.M. Spiner, "Motion of an almost ideal gas in the presence of a strong point explosion." *J Appl. Math. Mech.* vol.36, pp 883–887, 1972.

[8] M. P. Ranga Rao, and B.V. Ramana, " Unsteady flow of a gas behind an exponential shock." *J. Math. Phy. Sci.*,vol. 10, pp. 465-476. 1976.

[9] S. N. Ojha, "Shock waves in non-ideal fluid, Internet." *J. applied. Mech. Eng.*vol. 17, pp. 445-464, 2002.

[10] J.P. Vishwkarma and G. Nath, "Similiraty solution for the flow behind an exponential shock in a non-ideal gas, *Meccanica*, vol. 42, pp. 331-339. 2007.

[11] L. P. Singh, D.B. Singh and Subedar Ram "Propagation of weak shock wave in a non-ideal gas, *Cent. Eur. J Eng.*, vol. 1, no.3, pp.287-294, 2011.

[12] J.P. Vishwkarma and N. Patel, " Cylendrical shock wave in a low conducting non-ideal gas in presence of axial and azimuthal components of magnetic induction, *J. Raj. Acd. Phy. Sci*. vol. 12, no.3, pp.301-316.2013

[13] G.F. Carrier, "Shock waves in a dusty gas" *J. Fluid Mech.*, vol. 4, pp.376-382, 1958.

[14] A. R. Kriebel, " Analysis of normal shock waves in a particle laden gas, *Trans. ASME J Basic Eng.* Vol. 86, pp. 655-665,1964.

[15] G. Rudinger, "Some properties of shock relaxation in gas flow carrying small particles, *Phys. Fluids*, vol.7, pp.658-663, 1964.

[16] G.I. Taylor, "The formation of a blast wave by a very intense explosion. I. Theoretical discussion" *Proc. Roy. Soc.* vol. 201 no.1065, pp. 159-174, 1950.

[17] L. I. Sedov, "Similarity and Dimensional methods in mechanics" (acadmic Press New Yark) pp. 166, 1959.

[18] F. E. Marble, "Dynamics of dusty gases," *Annu. Rev. Fluid Mech.* vol.2, pp.397–446, 1970.

[19] S. I. Pai, "Two phase flows, Vieweg Tracts in Pure and Appl. Phys, Chapter-V, vol 3. Vieweg Verlag Braunschweig, 1977.

[20] H. Miura and I. I. Glass, "On the passage of a shock wave through a dusty gas layer". *Proc. R Soc Lond.*, vol. A no. 385, pp. 85–105, 1983.

[21] O. Igra and G. Ben-Dor, "Dusty shock waves, Appl. Mech. Rev. vol. 41, no.11, pp.379-437, 1988.

[22] W. Chester, "The diffraction and reflection of shock wave", Quar." *J. Mech. Appl. Math.*, vol. 7, pp. 57–82, 1954.

[23] R. F. Chisnell, "The Normal Motion of a Shock Wave through a Non-Uniform One-Dimensional Medium", *Proc Roy Soc. London*, vol. A no. 232, pp. 350-370, 1955.

[24] G. B. Whitham,"On the propagation of shock waves through regions of non-uniform area or flow", *J. Fluid Mech.,* vol. 4, pp. 337- 360. 1958.

[25] J. B. Singh and S.K. Pandey ," Analytical solution of magnetogasdynamics cylindrical shock waves in self-gravitating and rotating gas, II," *Astrophy. Space Sci.*, vol. 148, no.2, pp.221-227, 1988.

[26] R.P. Yadav, A. Sharma, R. P. Vats and P.S. Rawat, "Effect of axial magnetic field on weak cylindrical shock in a dusty gas." *Ultra sciences*, vol. 19 no.2, pp331, 2007.

[27] K. K. Singh and S. Gogoi, "Self-similar flow of a dusty gas behind an exponential shock with heat conduction and radiation heat flux". *J. Raj. Acad. Phy. Sci.* vol.12 no.4, pp. 419-440, 2013.

[28] P. K. Gangwar, "Behavior of Dusty Real Gas on Adiabatic Propagation of Cylindrical Imploding Strong Shock Waves, , *International conference on condense matter and applied Physics ICC-2017-Bikaner, 24-25 Nov, 2017, AIP conference proceedings (accepted).*

[29] P. K. Gangwar,"Cylindrical imploding shock waves in a dusty real gas and effect of overtaking disturbances, National symposium on shock waves NSSW-5 TBRL Chandigarh, 26-28, Feb 2018. *(accepted)*

[30] G. N. Naidu, K. Venkatanandam and M.P. Ranga Rao, "Approximate analytical solutions for self-similar flows of a dusty gas with variable energy" *Int. J. Eng. Sci.*, vol. 23, pp.39-49, 1985.