Engineering and Scientific International Journal (ESIJ)
Volume 3, Issue 3, July– September 2016
ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

Self-Similar Cylindrical Ionizing Shock Waves in a Non-uniform Gas with Radiation Heat-Flux

Arvind Kumar Singh
Department of Mathematics, St.Andrew's College, Gorakhpur-273001, India
arvind_st.math@yahoo.com

Abstract**—** Self-similar flows in the background, a gas-ionizing cylindrical shock wave, associated with radiation heat-flux, in an ideal gas are considered. The ionizing shock is considered to be propagating in a medium at rest with variable density permeated by an azimuthal magnetic meadow. The electrical conductivity of the gas is never-ending behind shock and zero ahead of it. Effect of radiation flux and the variation of initial density and the rate of energy input from the inner contact surface on the flow-field behind the shock and on the shock proliferation are investigated.

Keywords— Ionizing Shock Wave; Ideal Gas; Similarity Solution; Heat Transfer Effects; Variable Energy; Variable Initial Density; Variable Magnetic Field; Radiation Heat-Flux.

1. Introduction

The power of radiation on a shock wave and on the flow-field following the shock obverse has always been of great interest, for instance, in the meadow of nuclear power and space study. Consequently, similarity replicas for classical blast wave troubles have been extended by taking radiation in to account (Elliott [1], Wang [2], Helliwell [3], Nicastro [4], Ghoniem et al.[5]) considered the explosion problem by initiating the radiation flux in its diffusion estimation. Wang [2] explained the piston dilemma with radioactive heat transmit in the thin and thick limits and also in the general case with idealized two path approximately. Ghoniem et al. [5] gets a self-similar result for spherical blast taking into account the effects of both conduction and radiation in the two confines of Rosseland radiative diffusion and Plank radiative emission.

Since at elevated temperatures that overcome in the difficulty associated with shock waves a gas is partly ionized, electromagnetic effects may also be important. A complete analysis of such problem should therefore the study on the gas dynamic flow and the electromagnetic radiation fields simultaneously. Also, the results of the study of shock waves propagating in a non-uniform medium are more applicable to skocksfomed in the stars (Sedov[6],Sakurai[7],Rogers[8],Summer's[9]).

The purpose of this study is, there to obtain self-similar solutions for the propagation of a cylindrical shock wave in a non-uniform gas with radiation heat-flux. The initial density of gas and initial azimuthal magnetic field are to vary some powers of distance. The problem of line explosion with time needy energy discharge and radiation in the charisma of an azimuthal magnetic field is measured due to its significance to the experiments on pinch effect and explosion wires. A gas-ionizing cylindrical shock wave, generated by line bang, is propagating in an ideal gas. The counter pressure is taken into account. The radiation pressure and radiation energy are considered very little in comparison to material pressure and energy, correspondingly, and therefore only radiation fluctuation is taken into account. A dispersal model for an optically thick grey gas is assumed. The piston velocity is considered to vary as a few power of time and the initial density of the gas and the initial azimuthal magnetic field is assumed to be varying as some power of the distance from the axis of symmetry. Also, the rate of energy contribution to the flow behind shock, the radiation fluctuation and the idealness of the gas are found to have important effects on the proliferation of the shock as well as the flow-field behind it.

2. Basic Equations and Boundary Conditions

The basic equations governing the unsteady and cylindrically symmetric motion of aninviscid, perfectly conducting and idyllic gas in with the effects of radiation fluctuation and azimuthal magnetic field may be noteworthy, can be written as (Christer and Helliwell[10];Vishwakarma and Pandey [11], Gretler and Wehle[12]):

$$\frac{d\rho}{dt}+\frac{\rho}{r}\frac{\partial}{\partial r}(ru)=0, \tag{2.1}$$

$$\frac{du}{dt}+\frac{1}{\rho}\frac{\partial p}{\partial r}+\frac{h}{\rho r}\frac{\partial}{\partial r}(rh)=0, \tag{2.2}$$

$$\frac{dh}{dt}+h\frac{\partial u}{\partial r}=0, \tag{2.3}$$

$$\frac{de}{dt}+p\frac{d}{dt}\left(\frac{1}{\rho}\right)+\frac{1}{\rho r}\frac{\partial}{\partial r}(rq)=0, \tag{2.4}$$

Where, $\frac{d}{dt}=\frac{\partial}{\partial t}+u\frac{\partial}{\partial r}$

Here, ρ is the density, p the force, u the radial velocity, h the azimuthal magnetic field, q the radiation temperature fluctuation, t the time, r the distance from the axis of symmetry and e the interior energy. The magnetic permeability of the medium is taken to be concord. In most of the cases the proliferation of shock waves arise in tremendous conditions under which the assumption that the gas is an ideal a sufficiently accurate description. The system of equations could be supplemented with an equation of state. An ideal gas behaviour of the medium is assumed, so that

$$p = \Gamma \rho T, \tag{2.5}$$

$$e = \frac{p}{\rho(\gamma - 1)}, \tag{2.6}$$

Where, Γ is the gas constant and γ is the ratio of specific heats. For an isentropic change of state of the ideal gas, we may calculate the so called speed of sound in the ideal gas as follows

$$a = \left(\frac{dp}{d\rho}\right)_s^{\frac{1}{2}} = \left(\frac{\gamma p}{\rho}\right)^{\frac{1}{2}}, \tag{2.7}$$

Where, subscript 'S' refers to the course of stable entropy. Assuming local thermodynamic equilibrium and a diffusion model for an optically thick grey gas (Pomraning[13]), the differential approximation of the radiation transport equation can be written in the following form

$$q = -\frac{c\mu}{3}\frac{\partial}{\partial r}\left(\sigma T^4\right), \tag{2.8}$$

Where, $q = \frac{1}{4}\sigma c$ is the Stefan-Boltzmann constant and c the velocity of light andμ is the Rosseland mean free path for radiation. The assumption of an optically thick grey gas is physically reliable with the neglect of radiation force and radiation power in the equation system (2.1) to (2.4) (Ni-Castro [4]).

The Wang [2], we take $\mu = \mu_0 \rho^{\alpha} T^{\chi}$, (2.9)

Where, μ_0, α and χ are the constants. It will be seen afterward that the exponents α and χ must gratify the resemblance necessities. The self-similarity state puts no restraints on requirement of the density trust of μ.

We presume that a cylindrical shock is circulating in the medium and the flow variables immediately ahead of the shock front are,

$u = 0,\quad \rho = \rho_1 = AR^d,\quad h = h_1 = BR^n$ (n<0) (Rosenou [14]),

$p = p_1 = -\frac{(n+1)}{2n}B^2R^{2n},\quad q = q_1 = 0$ (Laumbach and Probstein [15]), (2.10)

Where, R is the shock radius, and A, B, d and n are constants. A cylindrical shock is hypothetical to be propagating in the uninterrupted ideal gas with changeable density and due to get ahead of the shock, the gas is tremendously ionized and its electrical conductivity turn into infinitely large. The circumstances across such a gas-ionizing shock are (Singh and Srivastava [16], Vishwakarma and Pandey [11])

$$\rho_2(V - u_2) = \rho_1 V = m_s,$$

$$p_2 - p_1 = m_s u_2, \tag{2.11}$$

$$e_2 + \frac{p_2}{\rho_2} + \frac{1}{2}(V - u_2)^2 - \frac{q_2}{m_s} = e_1 + \frac{p_1}{\rho_1} + \frac{1}{2}V^2,$$

$$h_2 = h_1,$$

Where, subscripts 2 and 1 are for the regions that behind and ahead of the shock surface correspondingly, and V indicates the shock velocity. The shock front is assumed to be obscure and it does not obtain any temperature fluctuation from exterior sources. Therefore, the temperature fluctuation q_2 is the heat fluctuation swapped between the flow-field and the shock front. The jumps circumstances (2.11) are not adequate to decide all the stream variables at the shock front. Hence, one variable resides irresolute there. This complexity is detached by pretentious the shock front to isothermal that is, $T_2 = T_1$ (Zel'dovich and Raizer [17], Rosenau and Frankenthal [18], Singh and Mishra [19]). The shock conditions (2.11) may be written as

$$u_2 = \left(1 - \frac{1}{\gamma M^2}\right)V,\qquad \rho_2 = \gamma M^2 \rho_1,\qquad p_2 = \rho_1 V^2,$$

$$q_2 = \frac{1}{2}\rho_1 V^3\left(\frac{1}{\gamma^2 M^2} - 1\right),\qquad h_2 = h_1 \tag{2.12}$$

Here, $M = \left(\frac{\rho_1 V^2}{\gamma p_1}\right)^{1/2}$ is the shock Mach-number referred to the frozen speed of sound $\left(\frac{\gamma p_1}{\rho_1}\right)^{1/2}$ and $M_A = \left(\frac{\rho_1 V^2}{h_1^2}\right)^{1/2}$ is the Alfven-Mach number.

The total energy of the flow-field behind the shock is not constant, but implied to be time dependent and subjective as (Rogers[20], Freeman [21]) $E = E_0 t^w$, w≥0 (2.13) where, E_0 and 'w' are the constants. The positive morals of 'w' match to the class in that the total power boosts with time. This improve of power may be realized by the pressure used on the fluid by mounting surface. This surface might be, actually, the exterior of the stellar corona or the strong explosives or the diaphragm contains very high force driver gas. By unexpected growth of the stellar corana or the ignition harvest or the driver gas into the ambient gas, a shock is formed in the ambient gas. The shocked gas is alienated from this mounting surface which is a contact discontinuity. This contact facade takes action as a 'piston' for the shock wave. Thus the flow is headed by a shock front and has a mounting surface as the inner border. A condition very much of the same type may triumph during the configuration of a cylindrical spark channel from explosion wires. In addition, in the common cases of flash break down, time-dependent energy input is a more pragmatic assumption than instantaneous energy input (Freeman and Cragges [22], Director and Dabora [23]). The expression for the total energy of an ideal gas behind the shock is given by

$$E = 2\pi \int_{r_p}^{R} \left[\frac{1}{2}\rho u^2 + \frac{p}{\gamma - 1} + \frac{h^2}{2} \right] r\, dr = E_0 t^w, \tag{2.14}$$

Where, r_p is the position of inner contact surface.

3. Similarity Solutions

For self- similar motions, the structure of partial discrepancy equations (2.1) – (2.4), (2.8) reduces to a system of usual differential equations in new unidentified functions of the similarity variable $\eta = \frac{r}{R}$. Let us obtain these equations. To accomplish this we symbolize the solution of the partial differential equations (2.1) – (2.4), (2.8) in terms of the products of scale functions and the novel unknown functions of the resemblance variable $\eta = \frac{r}{R}$, R=R(t). The pressure, density, velocity, magnetic field, radiation heat flux and length scales are not all free of each other. If we decide R and ρ_1 as essential scales, then quantity $V = \dot{R}$ can provide as the velocity scale, $\rho_1 V^2$ as the pressure scale, $\rho_1^{1/2} V$ as the magnetic pasture scale, and $\rho_1 V^3$ as the radiation fluctuation scale. This does not edge the generality of the result, as the scale is only defined to within an arithmetic coefficient which can always be incorporated in the new unidentified purpose. We request a result of the form (Ghoniem et al. [5], Abdel-Raouf and Gretler [24], and Vishwakarma and Singh [25]).

$$u = VU(\eta), \quad \rho = \rho_1 D(\eta), \quad p = V^2 \rho_1 P(\eta), \quad h = \rho_1^{1/2} V H(\eta), \quad q = V^3 \rho_1 Q(\eta). \tag{3.1}$$

Where, U, D, P, Q and H are the functions of the non-dimensional changeable (similarity variable) η only. Pertain the resemblance transformations (3.1) to the relation (2.14), we find that the motion of the shock front is given by the equation

$$R^{d+2} V^2 = \frac{E_0 t^w}{2\pi A J}, \tag{3.2}$$

Where,

$$J = \int_{\eta_p}^{1} \left[\frac{1}{2} D U^2 + \frac{P}{\gamma - 1} + \frac{H^2}{2} \right] \eta\, d\eta. \tag{3.3}$$

Where, η_p being the value of η at the inner expanding surface.

Equation (3.2) can be written as

$$V = \frac{dR}{dt} = \left(\frac{E_0}{2\pi A J} \right)^{1/2} t^{w/2} R^{-\frac{1}{2}(d+2)}. \tag{3.4}$$

Which is on integration, gives

$$R = \left(\frac{d+4}{w+2} \right)^{\frac{2}{d+4}} \left(\frac{E_0}{2\pi A J} \right)^{\frac{1}{d+4}} t^{\frac{w+2}{d+4}}. \tag{3.5}$$

From (3.5), we get the shock velocity

$$V = \frac{dR}{dt} = \left(\frac{w+2}{d+4} \right) \frac{R}{t} = K R^{\frac{w-d-2}{w+2}} \tag{3.6}$$

$$\text{Where, } K = \left(\frac{w+2}{d+4} \right)^{\frac{w}{w+2}} \left(\frac{E_0}{2\pi A J} \right)^{\frac{1}{w+2}}. \tag{3.7}$$

Since M and M_A are constants for similarity solutions, we have

$$n = \frac{d}{2} + \frac{w-d-2}{w+2}, \tag{3.8}$$

The conservation equations (2.1) to (2.4) can be transformed into following system of ordinary differential equations with respect to η

$$D' = \frac{(U + \eta d + \eta U')D}{\eta(\eta - U)}, \tag{3.9}$$

$$H' = \frac{(n + U')H}{\eta - U}, \tag{3.10}$$

$$P' = \left[D\left\{ (\eta - U)U' - U\left(\frac{w-d-2}{w+2} \right) \right\} - H^2 \left(\frac{1}{\eta} + \frac{H'}{H} \right) \right] \tag{3.11}$$

$$Q' = \left[\left(\frac{\eta - U}{\gamma - 1} \right) P' + \frac{\gamma P(U - \eta) D'}{D(\gamma - 1)} - \left(\frac{w-d-2}{w+2} \right) \frac{2P}{\gamma - 1} - \frac{Q}{\eta} + dP \right]. \tag{3.12}$$

Where, primed denotes the differentiation with respect to η .

By using equations (2.5), and (2.9) in (2.8), we get

$$q = -\frac{4}{3} \frac{\mu_0 \sigma c \rho^{\alpha} p^{\chi+3}}{\Gamma^{\chi+3} \rho^{\chi+3}} \frac{\partial T}{\partial r}. \tag{3.13}$$

Again, Using equations (2.5) in (3.13), and then the similarity transformations (3.1) we get

$$Q = -\frac{4}{3} \frac{\mu_0 \sigma c A^{\alpha-1} K^{2\chi+5}}{\Gamma^{\chi+4}} D^{\alpha-\chi-4} P^{\chi+4} R^{\left[d(\alpha-1) - 1 + (2\chi+5)\left(\frac{w-d-2}{w+2} \right) \right]} \left[\frac{P'}{P} - \frac{D'}{D} \right]. \tag{3.14}$$

Equation (3.14) shows that the similarity solution of the present problem exists only when

$$\chi = \frac{(w+2)[1 - d(\alpha - 1)]}{2(w - d - 2)} - \frac{5}{2}, \tag{3.15}$$

Therefore, equation (3.14) becomes:

$$Q = -N D^{\alpha-\chi-4} P^{\chi+4} \left[\frac{P'}{P} - \frac{D'}{D} \right], \tag{3.16}$$

$$\text{Where, } N = \frac{4}{3} \frac{\mu_0 \sigma c A^{\alpha-1} K^{2\chi+5}}{\Gamma^{\chi+4}}, \tag{3.17}$$

is a non-dimensional radiation parameters. N depends on the mean free path of radiation. By using (3.9) and (3.11) in (3.16), we get

$$U' = \frac{(\eta - U)P}{[D(\eta - U)^2 - H^2 - P]} \left[\frac{DU}{P}\left(\frac{w-d-2}{w+2} \right) + \frac{H^2}{\eta P} + \frac{nH^2}{P(\eta - U)} + \frac{U}{\eta(\eta - U)} + \frac{d}{(\eta - U)} - \frac{Q}{N D^{\alpha-\chi-4} P^{\chi+4}} \right]. \tag{3.18}$$

Using the self-similarity transformations (3.1), equations (2.12), can be rewritten as:

$$U(1)=1-\frac{1}{\gamma M^2},\ D(1)=\gamma M^2,\ P(1)=1,\ H(1)=\frac{1}{M_A},\ Q(1)=\frac{1}{2}\left(\frac{1}{\gamma^2 M^4}-1\right). \quad (3.19)$$

In addition to the shock conditions (3.19), the condition to be satisfied at the inner bounbary surface is that the velocity of the fluid is equivalent to the velocity of inner frontier itself. The kinematic condition, from the equations (3.1) and (3.6), can be written as:

$$U(\eta_p)=\eta_p. \quad (3.20)$$

Where, η_p is the value of η at the inner expanding surface. Now, the equations (3.9) to (3.12) and (3.18) may be integrated, with the boundary conditions (3.19) and the appropriated, values of the constant parameters γ, d, α, w, M^2, M_A^2 and N to obtain D, H, P, Q and U. To exhibit the numerical solutions, it is convenient to write the flow-variables in the following non- dimensional form as $\frac{u}{u_2}=\frac{U(\eta)}{U(1)}, \frac{\rho}{\rho_2}=\frac{D(\eta)}{D(1)}, \frac{p}{p_2}=\frac{P(\eta)}{P(1)}, \frac{h}{h_2}=\frac{H(\eta)}{H(1)}, \frac{q}{q_2}=\frac{Q(\eta)}{Q(1)}$. (3.21)

4. Results and Discussion

Non-dimensionally flowing variables $\frac{u}{u_2}, \frac{\rho}{\rho_2}, \frac{h}{h_2}, \frac{p}{p_2}$ and $\frac{q}{q_2}$ are obtained by numerical integration of the equations (3.9) to (3.12) and (3.18) with the boundary conditions (3.19).For the purpose of numerical calculations, the values of the constant parameters are taken as(Elliott [1], Singh and Mishra [19], Rosenau [14], Vishwakarma and Singh [25])γ=1.4; α= -2;M=5; $M_A^2=20$; d=0.25, 0.50; w=1, 1.2; N=10, 100 .Figures 1(a) to 1(e) show the variation of the flow variables $\frac{u}{u_2}, \frac{\rho}{\rho_2}, \frac{h}{h_2}, \frac{p}{p_2}$ and $\frac{q}{q_2}$ with η at various values of parameters w, d, N. It is shown that, as we move inward from the shock front to the contact surface in inner, the reduced magnetic field $\frac{h}{h_2}$ and the reduced pressure $\frac{p}{p_2}$ increase and the reduced density $\frac{\rho}{\rho_2}$,and the reduced total heat flux $\frac{q}{q_2}$ decreases. Similarly, move inwards from the shock surface reduced fluid velocity $\frac{u}{u_2}$ increases. The effects of an increase in the density variation exponent'd' are (from figures 1 (a), (b), (c), (d), (e) and table 1)

(i) to increase the velocity $\frac{u}{u_2}$, magnetic field $\frac{h}{h_2}$ and pressure $\frac{p}{p_2}$ at any point in the flow-field behind the shock; and

(ii) to decrease the density $\frac{\rho}{\rho_2}$ and radiation heat flux $\frac{q}{q_2}$;

(iii) to decrease the distance of the inner growing surface from the shock front(see tables 1);

(iv) to increase the slope of profiles of velocity, magnetic field and pressure; and to decrease the slope of density and radiation heat flux.

The effects of an increase in the value of exponent in the law for energy input 'w' (or the exponent in the law for early magnetic field 'n') are (from figures 1(a-e) and table 1)

(i) to increase the velocity $\frac{u}{u_2}$, magnetic field $\frac{h}{h_2}$ and pressure $\frac{p}{p_2}$ at any point in the flow-field behind the shock; and to decrease these quantities for the value of d=0.25, N=10; and

(ii) to decrease the density $\frac{\rho}{\rho_2}$ and radiation heat flux $\frac{q}{q_2}$; and to increase these quantities for the value of d=0.25, N=10; and

(iii) to decrease the length of the inner expanding surface from the shock front(see tables 1);

(iv) to increase the slope of profiles of velocity, magnetic field and pressure; and to decrease the slope of density and radiation heat flux; and

(v) to decrease the slope of profiles of velocity, magnetic field and pressure; and to increase the slope of density and radiation heat flux for the value of d=0.25, N=10.

The effects of an increase in the value of the radiation heat transfer parameter N are (from figures 1(a) to 1(e) and table 1):

(i) to decrease the reduced velocity $\frac{u}{u_2}$, the reduced magnetic field $\frac{h}{h_2}$ and the reduced pressure $\frac{p}{p_2}$; and to increase the reduced density $\frac{\rho}{\rho_2}$ and the

ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

reduced radiation heat flux $\frac{q}{q_2}$ at any point in the flow-field behind the shock; and

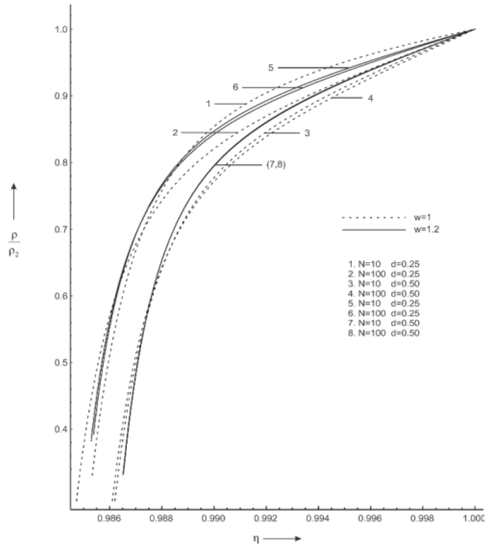
(ii) To increase the distance of the inner expanding surface from the shock front(see table 1); and

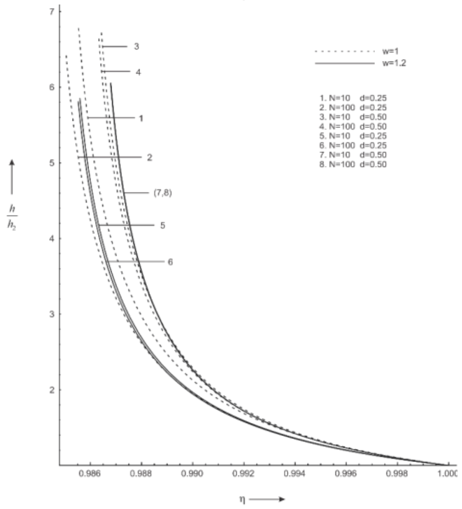
(iii) To decrease the slope of profiles of velocity, magnetic field and pressure; and to increase the slope of density and radiation heat flux, in general.

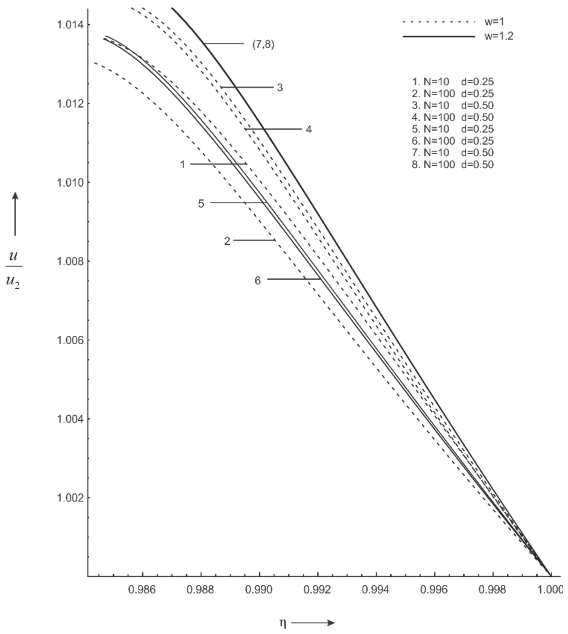
The effect of an increase in the radiation parameter N, the effect is small for the values of w=1.2, d=0.50, N=10,100.

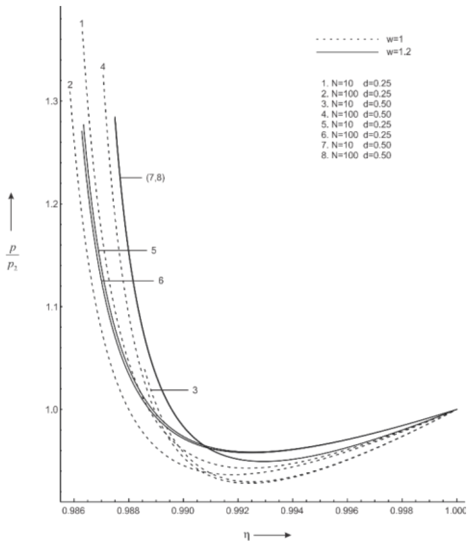
Table 1: Position of the inner boundary surface $\bar{\eta}$ for the various values γ=1.4, α= -2, M=5, $M_A^2 = 20$, d=0.25, 0.50, w=1, 1.2 and N=10, 100.

w	d	N	$\bar{\eta}$
1	0.25	10	0.984685
		100	0.984140
	0.50	10	0.985595
		100	0.985485
1.2	0.25	10	0.984747
		100	0.984673
	0.50	10	0.986012
		100	0.985997









ISSN 2394-7187(Online)
ISSN 2394 - 7179 (Print)

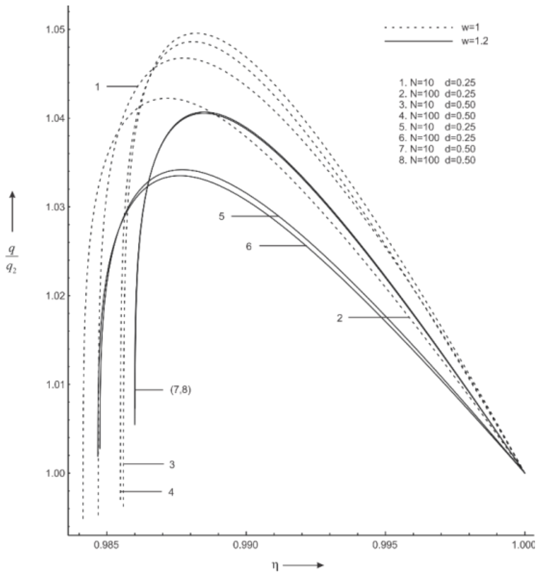


Fig. 1 (a), (b), (c), (d), (e) : Variation of reduced velocity, density, magnetic field, pressure and radiation heat flux

References

[1] Elliott L.A., Similarity methods in radiation hydrodynamics, Proc. Roy.Soc. Lond. A, 258(1960), pp. 287-301.

[2] Wang K.C., The "piston problem" with thermal radiation, J. Fluid Mech., 20(1964), pp. 447-455.

[3] Hilliwell, J.B., Self-similar piston problem with thermal radiation, J. Fluid Mech., 37(1969),pp. 497-512.

[4] Nicastro J.R., Similarity analysis of the radiative gas dynamics equations with spherical symmetry, Phys.Fluids, 13(1970), pp. 2000-2006.

[5] Ghoniem A.F., Kamel M.M., Berger S.A. and Oppenheim A.K., Effects of internal heat transfer on the structure of self-similar blast waves, J. Fluid Mech., 117(1982), pp. 473-491.

[6] Sedov L. I., Similarity and Dimensional Methods in Mechanics, Academic Press, New York (1959).

[7] Sakurai A., Propagation of spherical shock waves in stars, J. Fluid Mech., 1(1956), pp. 436-453.

[8] Rogers M.H., Analytic solutions for the blast-waves problem with an atmosphere of varying density, Astrophys. J., 125(1957) pp. 478-493.

[9] Summers D., An idealized model of a magneto hydrodynamic spherical blast wave applied to a flare produced shock in the solar wind, Astron Astrophys., 45(1975),pp. 151-158.

[10] Christer, A.H. and Helliwell, J.B., Cylindrical shock and detonation waves in magnetogasdynamics, J. Fluid Mech. 39(1969), pp.705-725.

[11] Vishwakarma, J.P. and Pandey, S.N., Converging cylindrical shock waves in a non-ideal gas with an axial magnetic field, Def. Sci. J., 56(2004), pp. 721-731.

[12] Gretler, W. and Wehle, P., Propagation of blast waves with exponential heat release and internal heat conduction and thermal radiation, Shock Wave, 3(1993), pp. 95-104.

[13] Pomraning G.C., The equations of Radiation Hydrodynamic, Int. Ser. Monographs in Natural Philosophy Pergaman Press, Oxford, (1973), 54.

[14] Rosenau P., Equatorial propagation of axisymmetric magnetohy drodynamic shocks II Phys. Fluids, 20(1977), pp. 1097-1103.

[15] Laumbach D.D. and Probstein R.F., A point explosion in a cold exponential atmosphere Part 2, Radiating flow, J.Fluid Mech., 40(1970), pp. 833-858.

[16] Singh J.B. and Srivastava S.K., Cylindrical ionizing shock waves in non-ideal gas, J.P.A.S. Jaunpur, 2(1991), pp.39-46.

[17] Zel'dovichYa. B. andRaizerYu.P., Physics of Shock Waves and High Temperature Hydrodynamic Phenomena, Vol.2 (Translated from 2nd Russian Edn.) Academic Press, New York, (1967).

[18] Rosenau P. and Frankenthal S., Shock disturbances in a thermally conducting solar wind, Astrophys. J., 208(1976), pp. 633-637.

[19] Singh, J.B. and Mishra, S.K., Modelling of self-similar cylindrical shock wave in radiation- magnetogasdynamics, Astrophys. Space Sci., 127(1986),pp.33-43.

[20] Rogers M.H., Similarity flows behind strong shock waves, Quart. J. Mech. Appl. Math., 11(1958), pp. 411-422.

[21] Freeman, R.A., Variable-energy blast waves, Brit. J. Appl. Phys. (J. Pyhs. D), 1(1968), pp. 1697-1710.

[22] Freeman, R.A. and Cargges, J.D., Problem of spark channel formations, Brit. J. Appl. Phys. (J. Pyhs. D), 2(1969), pp. 421-427.

[23] Director M.N. and Dabora E.K., An experimental investigation of variable energy blast waves, ActaAstronautica, 4(1977),pp.391-407.

[24] Abdel-Raouf A.M. and Gretler W., Quasi-similar solutions for blast wave with internal heat transfer effect, Fluid Dyn. Res., 8(1991),pp. 273-285.

[25] Vishwakarma, J. P. and Singh, A. K., Magneto gas dynamic shock waves in a non-uniform gas with heat conduction and radiation heat flux, Int. J. of Applied Mechanics and Engi., 13(2008), 797-815.