Certain Solutions Of Shock-Waves In Non-Ideal Gases

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ABSTRACT. In present paper non similar solutions for plane, cylindrical and spherical unsteady flows of non-ideal gas behind shock wave of arbitrary strength initiated by the instantaneous release of finite energy and propagating in a non-ideal gas is investigated. Asymptotic analysis is applied to obtain a solution up to second order. Solution for numerical calculation Runga-Kutta method of fourth order is applied and is concluded that for non-ideal case there is a decrease in velocity, pressure and density for 0th and II-nd order in comparison to ideal gas but a increasing tendency in velocity, pressure and density for Ist order in comparison to ideal gas. The energy of explosion *J0* for ideal gas is greater in comparison to non-ideal gas for plane, cylindrical and spherical waves.

1. Introduction. The assumption that the medium is an ideal gas is no more valid when the flow takes place in extreme conditions. Anisimov & Spiner [1] studied a problem of point explosion in low density non ideal gas by taking the equation of state in a simplified form which describes the behaviour of medium satisfactorily. Robert's & Wu [2] studied the gas that obeys a simplified Vander Waal's equation of state.

Vishwakarma et al. [3] have investigated the one dimensional unsteady self-similar flow behind a strong shock, driven out by a cylindrical or spherical piston in a medium which is assumed to be non-ideal and which obey the simplified Vander-Waal's equation of state as considered by Robert's & Wu [2]. However, they have assumed that the piston is moving with time according to law given by Steiner & Hirschler [4]. Madhumita & Sharma [5] have considered the model equation for a low density gas, which describes the behavior of the medium satisfactorily for implosion problems where the temperature for implosion problems were the temperature attained by the gas motion in the strong shock limit is very high. Pandey & Pathak [6] have discussed growth and decay of sonic waves in non-ideal gases. In present paper using asymptotic expansion an attempt is made to obtain non-self similar solution of shock-waves in non-ideal gas. For numerical calculation Runge Kutta method is applied .In preparation of graphs Origin 7.5 is used.

2. Basic Equations

The basic equations describing a cylindrically symmetric (α= 1) or a spherically symmetric (α = 2) motion of a non-ideal gas can be written as:

$$\frac{\partial\rho}{\partial t}+\frac{\partial(u\rho)}{\partial r}+\frac{u\alpha\rho}{r}=0, \tag{2.1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+\frac{1}{\rho}\frac{\partial p}{\partial r}=0, \tag{2.2}$$

$$\frac{\partial(r^{\alpha}E)}{\partial t}+\frac{\partial\{r^{\alpha}u(E+p)\}}{\partial r}=0, \tag{2.3}$$

where ρ is the gas density, u is the fluid velocity, p is the pressure and

$$E = \rho e + \frac{\rho u^2}{2}, \tag{2.4}$$

is the total energy density with e being the internal energy density, the independent variables are the space co-ordinate r and time t: The equation of state characterizing the non-ideal medium is taken to be of the form

$$p = \frac{\rho RT}{(1-b\rho)},$$

where b is the internal volume of the gas molecules which is known in terms of the molecular interaction potential in high temperature gases, it is a constant with $b\,\rho << 1$. The gas constant R and the temperature T are assumed to obey the thermodynamic relations $R = C_p - C_V$ and $e = C_V T$, where $C_V = \frac{R}{(\gamma - 1)}$ is the specific heat at constant volume and γ is the ratio of specific heats. Thus in view of these thermodynamic relations, the equation of state can be written as

$$p = \frac{\rho e(\gamma - 1)}{(1-b\rho)}. \tag{2.5}$$

Expression for E, in view of equation (2.5) assumes the form

$$E = \frac{p(1-b\rho)}{(\gamma-1)} + \frac{\rho u^2}{2}.$$

Using above value of E in equation (2.3), we have

$$\frac{\partial p}{\partial t} + u\frac{\partial p}{\partial r} + \frac{p\gamma}{(1-b\rho)}\left(\frac{\partial u}{\partial r} + \frac{\alpha u}{r}\right) = 0. \tag{2.6}$$

Here α=0,1,2 corresponds to planar, cylindrical and spherical geometries respectively. The assumption of the instantaneous release of constant energy E_0 at time t = 0 yields the energy balance equation:

$$E_0 = K_\alpha \int_0^S \left(\frac{u^2}{2} + \frac{1}{(\gamma-1)}\left\{\frac{p(1-b\rho)}{\rho} - \frac{p_0(1-b\rho_0)}{\rho_0}\right\} \right)\rho r^\alpha dr,$$

where $K\alpha$= 2, 2π, 4 π for α= 0, 1, 2 and S represents the shock radius which is assumed to be zero at $t = 0$.

From Lagrangian equation of continuity we have $\int_0^S \frac{\rho}{\rho_0} r^\alpha dr = \frac{S^{\alpha+1}}{(\alpha+1)}$. Thus energy balance equation transform into:

$$E_0 = K_\alpha \left(\int_0^S \left(\frac{u^2}{2} + \frac{p(1-b\rho)}{\rho(\gamma-1)} \right) \rho r^\alpha dr \right) - \frac{K_\alpha S^{\alpha+1} p_0 (1-b\rho_0)}{(\alpha+1)(\gamma-1)}. \quad (2.7)$$

The conservation relations across the shock for the present problem can be written as:

$$\rho_0 U = \rho_1 (U - u_1), \quad (2.8)$$

$$p_0 + \rho_0 U^2 = p_1 + \rho_1 (U - u_1)^2, \quad (2.9)$$

$$\frac{p_0}{\rho_0} + \frac{p_0(1-b\rho_0)}{\rho_0(\gamma-1)} + \frac{U^2}{2} = \frac{p_1}{\rho_1} + \frac{p_1(1-b\rho_1)}{\rho_1(\gamma-1)} + \frac{(U-u_1)^2}{2}, \quad (2.10)$$

where subscripts 1 and 0 refer to values immediately behind and ahead of the shock respectively and represents the shock velocity.

$$U = \frac{dS}{dt},$$

In following section we introduce the dimension less variables.

3. Transformation of Fundamental Equations in Non-Dimensional Form

To transform fundamental equations, we consider principal of similarity & introduces new variables x and y in place of r and t as defined by *Sakurai*[7]

$$x = \frac{r}{S} \quad (3.1)$$

$$\frac{\Lambda_0^2}{U^2} = y, \quad (3.2)$$

$$u = Uf(x, y), \quad (3.3)$$

$$p = \frac{\rho_0 U^2}{\gamma}(1-b\rho_0) g(x,y), \quad (3.4)$$

$$\rho = \rho_0 h(x,y), \quad (3.5)$$

where

$$\Lambda_0^2 = \frac{\gamma p_0}{\rho_0(1-b\rho_0)}, \ r = Sx \Rightarrow dr = Sdx. \tag{3.6}$$

Thus

$$\frac{\partial}{\partial r} = \frac{1}{S}\frac{\partial}{\partial x}, \tag{3.7}$$

$$\frac{D}{Dt} = \frac{U}{S}\left((f-x)\frac{\partial}{\partial x} + \lambda y\frac{\partial}{\partial y}\right), \tag{3.8}$$

where

$$\lambda = S\left(\frac{\frac{dy}{dS}}{y}\right) \tag{3.9}$$

and λ is a function of y alone.

Substituting equations (3.1) to (3.8) in to fundamental equations (2.1), (2.2), (2.6), (2.7) and boundary conditions (2.8, 2.9, 2.10), equations (2.1), (2.2), (2.6) become

$$(f-x)\frac{\partial h}{\partial x} + \lambda y\frac{\partial h}{\partial y} = -h\left(\frac{\partial f}{\partial x} + \frac{\alpha f}{x}\right), \tag{3.10}$$

$$h\left((f-x)\frac{\partial f}{\partial x} + \lambda y\frac{\partial f}{\partial y} - \frac{\lambda f}{2}\right) = -\frac{(1-b\rho_0)}{\gamma}\frac{\partial g}{\partial x}, \tag{3.11}$$

$$-\lambda g + (f-x)\frac{\partial g}{\partial x} + \lambda y\frac{\partial g}{\partial y} = \frac{-\gamma g}{(1-b\rho_0 h)}\left(\frac{\partial f}{\partial x} + \frac{\alpha f}{x}\right). \tag{3.12}$$

Equation (2.7) now become

$$y\left(\frac{S_0}{S}\right)^{\alpha+1} = \int_0^1\left[\frac{hf^2}{2} + \frac{g(1-b\rho_0 h)(1-b\rho_0)}{\gamma(\gamma-1)}\right]x^\alpha dx - \frac{(1-b\rho_0)^2 y}{\gamma(\gamma-1)(\alpha+1)}, \tag{3.13}$$

where

$$S_0 = \left(\frac{E_0}{\rho_0 K_\alpha \Lambda_0^2}\right)^{\frac{1}{\alpha+1}}. \tag{3.14}$$

Equations (2.8), (2.9), (2.10) now become as

$$h(1,y)=\frac{\gamma+1}{\gamma-1+2b\rho_0-2y(1-b\rho_0)}, \tag{3.15}$$

$$f(1,y)=\frac{h(1,y)-1}{h(1,y)}, \tag{3.16}$$

$$g(1,y)=\frac{\gamma}{(1-b\rho_0)}\left(\frac{(1-b\rho_0)y}{\gamma}+f(1,y)\right). \tag{3.17}$$

Differentiating equation (3.11) with respect to y and using expression,

$$\int_0^1\left[\frac{hf^2}{2}+\frac{g(1-b\rho_0h)(1-b\rho_0)}{\gamma(\gamma-1)}\right]x^{\alpha}dx=J, \tag{3.18}$$

λ defined in equation (3.9) is given by

$$\lambda=\frac{\gamma J(\alpha+1)-\dfrac{(1-b\rho_0)^2 y}{(\gamma-1)}}{\gamma J-\gamma y\dfrac{dJ}{dy}}. \tag{3.19}$$

4. Construction of Solution in Power series of y. While the shock waves are strong, the velocity U is large and y can be considered as small there, so that the quantities f; g; h can be expanded in rapidly convergent series of powers of y in following manner:

$$f=f^{(0)}+yf^{(1)}+y^2f^{(2)}+.......... \tag{4.1}$$

$$g=g^{(0)}+yg^{(1)}+y^2g^{(2)}+.......... \tag{4.2}$$

$$h=h^{(0)}+yh^{(1)}+y^2h^{(2)}+......... \tag{4.3}$$

where $f^{(i)}$, $g^{(i)}$, $h^{(i)}$, $(i = 0,1, 2,.........)$ are all functions of x only . Inserting equations (4.1, 4.2, 4.3) in the expression (3.18), we have

$$J=J_0\left(1+y\sigma_1+y\ \sigma_2+.....\right), \tag{4.4}$$

where

$$J_0 = \int_0^1 \left(\frac{h^{(0)} f^{(0)^2}}{2} + \frac{(1-b\rho_0)g^{(0)}}{\gamma(\gamma-1)} - \frac{(1-b\rho_0)b\rho_0 h^{(0)} g^{(0)}}{\gamma(\gamma-1)} \right) x^\alpha dx, \tag{4.5}$$

$$\sigma_1 J_0 = \int_0^1 \left(h^{(0)} f^{(0)} f^{(1)} + \frac{h^{(1)} f^{(0)}}{2} + \frac{g^{(1)}(1-b\rho_0)}{\gamma(\gamma-1)} - \frac{b\rho_0 h^{(0)} g^{(1)}(1-b\rho_0)}{\gamma(\gamma-1)} - \frac{b\rho_0 h^{(1)} g^{(0)}(1-b\rho_0)}{\gamma(\gamma-1)} \right) x^\alpha dx \tag{4.6}$$

$$\sigma_2 J_0 = \int_0^1 [\frac{1}{2}\left(2h^{(0)} f^{(0)} f^{(2)} + h^{(0)} f^{(1)^2} + 2f^{(0)} f^{(1)} h^{(1)} + f^{(0)^2} h^{(2)}\right) + \frac{(1-b\rho_0\ )}{\gamma(\gamma-1)}\left(g^{(2)} - b\rho_0 h^{(0)} g^{(2)} - b\rho_0 g^{(1)} h^{(1)} - b\rho_0 g^{(0)} h^{(2)}\right)] x^\alpha dx \tag{4.7}$$

Using equation (4.4),the equation (3.13)becomes

$$y\left(\frac{S_0}{S}\right)^{\alpha+1} = J_0 \left[1 + \left\{ \sigma_1 - \frac{(1-b\rho_0)^2}{\gamma(\gamma-1)(\alpha+1)J_0} \right\} y + \sigma_2 y^2 + ... \right], \tag{4.8}$$

Or in view of (3.1)

$$\left(\frac{\Lambda_0}{U}\right)^2 \left(\frac{S_0}{S}\right)^{\alpha+1} = J_0 \left[1 + \left\{ \sigma_1 - \frac{(1-b\rho_0)^2}{\gamma(\gamma-1)(\alpha+1)J_0} \right\} \left(\frac{\Lambda_0}{U}\right)^2 + \sigma_2 \left(\frac{\Lambda_0}{U}\right)^4 + ... \right]. \tag{4.9}$$

Equation (4.9) is in form of power series in $\left(\frac{\Lambda_0}{U}\right)^2$, which gives a relation between propagation velocity U and the position of shock front S. If J_0 and σ_i are known λ can be expanded in following form

$$\lambda = (\alpha+1)\left[1 + y\left\{ \sigma_1 - \frac{(1-b\rho_0)^2}{\gamma J_0(\gamma-1)(\alpha+1)} \right\} + 2\sigma_2 y^2 + ... \right]. \tag{4.10}$$

If we use, for simplicity , the expressions

$$\sigma_1 - \frac{(1-b\rho_0)^2}{\gamma J_0(\gamma-1)(\alpha+1)} = \lambda_1, \tag{4.11}$$

$$2\sigma_2 = \lambda_2. \tag{4.12}$$

Equation(4.10)can be written as

$$\lambda = (\alpha+1)(1 + \lambda_1 y + \lambda_2 y^2 + ...). \tag{4.13}$$

Now, substituting equations (4.1, 4.2. 4.3) and (4.13) in equation (3.10, 3.11, 3.12) and Comparing the Coefficients of the same powers of y on both sides of (3.10), (3.11), (3.12) we get the following system in equations:

For zero-th power of y (Ist Approximation)

$$h^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(0)}(f^{(0)}-x)+\left(\frac{\partial g}{\partial x}\right)^{(0)}\frac{(1-b\rho_0)}{\gamma}=\frac{(\alpha+1)}{2}f^{(0)}h^{(0)}, \tag{4.14}$$

$$h^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(0)}+(f^{(0)}-x)\left(\frac{\partial h}{\partial x}\right)^{(0)}=-\frac{\alpha}{x}f^{(0)}h^{(0)}, \tag{4.15}$$

$$\gamma g^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(0)}+(f^{(0)}-x)\left(\frac{\partial g}{\partial x}\right)^{(0)}(1-b\rho_0 h^{(0)})+(\alpha+1)b\rho_0 g^{(0)}h^{(0)}=(\alpha+1)g^{(0)}-\frac{\alpha\gamma}{x}f^{(0)}g^{(0)}, \tag{4.16}$$

For the first power of y (IInd Approximation)

$$(f^{(0)}-x)h^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+\left(\frac{\partial g}{\partial x}\right)^{(1)}\frac{(1-b\rho_0)}{\gamma}=-\left[\frac{(\alpha+1)}{2}+\left(\frac{\partial f}{\partial x}\right)^{(0)}\right]h^{(0)}f^{(1)}+\left[\frac{(\alpha+1)}{2}f^{(0)}-(f^{(0)}-x)\left(\frac{\partial f}{\partial x}\right)^{(0)}\right]h^{(1)}+\frac{(\alpha+1)}{2}f^{(0)}h^{(0)}\lambda_1, \tag{4.17}$$

$$h^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+(f^{(0)}-x)\left(\frac{\partial h}{\partial x}\right)^{(1)}=-\left[\left(\frac{\partial h}{\partial x}\right)^{(0)}+\frac{\alpha h^{(0)}}{x}\right]f^{(1)}-\left[\left(\frac{\partial f}{\partial x}\right)^{(0)}+\frac{\alpha f^{(0)}}{x}+(\alpha+1)\right]h^{(1)}, \tag{4.18}$$

$$-(\alpha+1)\lambda_1 g^{(0)}+\left(\frac{\partial g}{\partial x}\right)^{(1)}(f^{(0)}-x)+f^{(1)}\left(\frac{\partial g}{\partial x}\right)^{(0)}=\frac{1}{(1-b\rho_0 h^{(0)})}\left[-\gamma g^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(1)}-\gamma g^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-\frac{\gamma\alpha g^{(0)}f^{(1)}}{x}-\frac{\gamma\alpha f^{(0)}g^{(1)}}{x}+\left(\frac{\partial g}{\partial x}\right)^{(0)}(f^{(0)}-x)b\rho_0 h^{(1)}-(\alpha+1)b\rho_0 g^{(0)}h^{(1)}\right]$$

$$h^{(0)}f^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(2)}+h^{(0)}f^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+h^{(0)^2}f^{(2)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-h^{(0)}x\left(\frac{\partial f}{\partial x}\right)^{(2)}+h^{(1)}f^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+h^{(1)}f^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-h^{(2)}f^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-h^{(2)}x\left(\frac{\partial f}{\partial x}\right)^{(0)}-h^{(1)}x\left(\frac{\partial f}{\partial x}\right)^{(1)}+ \tag{4.19}$$

$$2(\alpha+1)f^{(2)}h^{(0)}+\lambda_1(\alpha+1)f^{(1)}h^{(0)}+(\alpha+1)f^{(1)}h^{(1)}-\frac{(\alpha+1)}{2}h^{(0)}f^{(2)}-\frac{(\alpha+1)}{2}h^{(1)}f^{(1)}-\frac{(\alpha+1)}{2}h^{(2)}f^{(0)}=\frac{(1-b\rho_0)}{\gamma}\left(\frac{\partial g}{\partial x}\right)^{(2)}$$

For the second power of y (IIIrd Approximation)

$$h^{(0)}f^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(2)}+h^{(0)}f^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+h^{(0)^2}f^{(2)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-h^{(0)}x\left(\frac{\partial f}{\partial x}\right)^{(2)}+h^{(1)}f^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(1)}+h^{(1)}f^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-$$

$$h^{(2)}x\left(\frac{\partial f}{\partial x}\right)^{(0)}+2(\alpha+1)f^{(2)}h^{(0)}+\lambda_1(\alpha+1)f^{(1)}h^{(0)}+(\alpha+1)f^{(1)}h^{(1)}-\frac{(\alpha+1)}{2}f^{(2)}h^{(0)}-\frac{(\alpha+1)}{2}f^{(1)}h^{(1)} \quad , \tag{4.20}$$

$$-\frac{(\alpha+1)}{2}f^{(0)}h^{(2)}=-\frac{(1-b\rho_0)}{\gamma}\left(\frac{\partial g}{\partial x}\right)^{(2)}$$

$$f^{(0)}\left(\frac{\partial h}{\partial x}\right)^{(2)}+f^{(1)}\left(\frac{\partial h}{\partial x}\right)^{(1)}+f^{(2)}\left(\frac{\partial h}{\partial x}\right)^{(0)}-x\left(\frac{\partial h}{\partial x}\right)^{(2)}+2(\alpha+1)h^{(2)}+(\alpha+1)\lambda_1 h^{(1)}=-h^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(2)}$$

$$-h^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(1)}-h^{(2)}\left(\frac{\partial f}{\partial x}\right)^{(0)}-\frac{\alpha h^{(0)}f^{(2)}}{x}-\frac{\alpha h^{(1)}f^{(1)}}{2}-\frac{\alpha h^{(2)}f^{(0)}}{x} \quad , \tag{4.21}$$

$$-b\rho_0 f^{(0)}h^{(2)}\left(\frac{\partial g}{\partial x}\right)^{(0)} - b\rho_0 f^{(0)}h^{(1)}\left(\frac{\partial g}{\partial x}\right)^{(1)} - b\rho_0 f^{(1)}h^{(1)}\left(\frac{\partial g}{\partial x}\right)^{(0)} + b\rho_0 x h^{(2)}\left(\frac{\partial g}{\partial x}\right)^{(0)} + f^{(0)}\left(\frac{\partial g}{\partial x}\right)^{(2)}$$

$$-x^2\left(\frac{\partial g}{\partial x}\right)^{(2)} + b\rho_0(\alpha+1)h^{(2)} + b\rho_0(\alpha+1)h^{(1)}g^{(1)} + b\rho_0(\alpha+1)\lambda_1 h^{(1)}g^{(0)} - b\rho_0(\alpha+1)h^{(1)}g^{(1)} + 2(\alpha+1)g^{(2)} \quad (4.22)$$

$$+\lambda_1(\alpha+1)g^{(1)} = -\gamma g^{(0)}\left(\frac{\partial f}{\partial x}\right)^{(2)} - \gamma g^{(1)}\left(\frac{\partial f}{\partial x}\right)^{(1)} - \gamma g^{(2)}\left(\frac{\partial f}{\partial x}\right)^{(0)}$$

In similar manner substituting equations (4.1, 4.2, 4.3) into equations (3.15, 3.16, 3.17), we have

$$f^{(0)}(1) = \frac{2(1-b\rho_0)}{\gamma+1}, \quad g^{(0)}(1) = \frac{2\gamma}{\gamma+1}, \quad h^{(0)}(1) = \frac{\gamma+1}{\gamma-1+2b\rho_0}, \quad (4.23)$$

$$f^{(1)}(1) = \frac{2(1-b\rho_0)}{\gamma+1}, \quad g^{(1)}(1) = \frac{1-\gamma}{\gamma+1}, \quad h^{(1)}(1) = \frac{-2(\gamma+1)(1-b\rho_0)}{(\gamma-1+2b\rho_0)^2}, \quad (4.24)$$

$$f^{(2)}(1) = 0, \quad g^{(2)}(1) = 0, \quad h^{(2)}(1) = \frac{4(\gamma+1)(1-b\rho_0)^2}{(\gamma-1+2b\rho_0)^3}, \quad (4.25)$$

If we take b=0, equations (4.14 – 4.16) with condition (4.23) coincides with the results obtained by Sakurai [7].

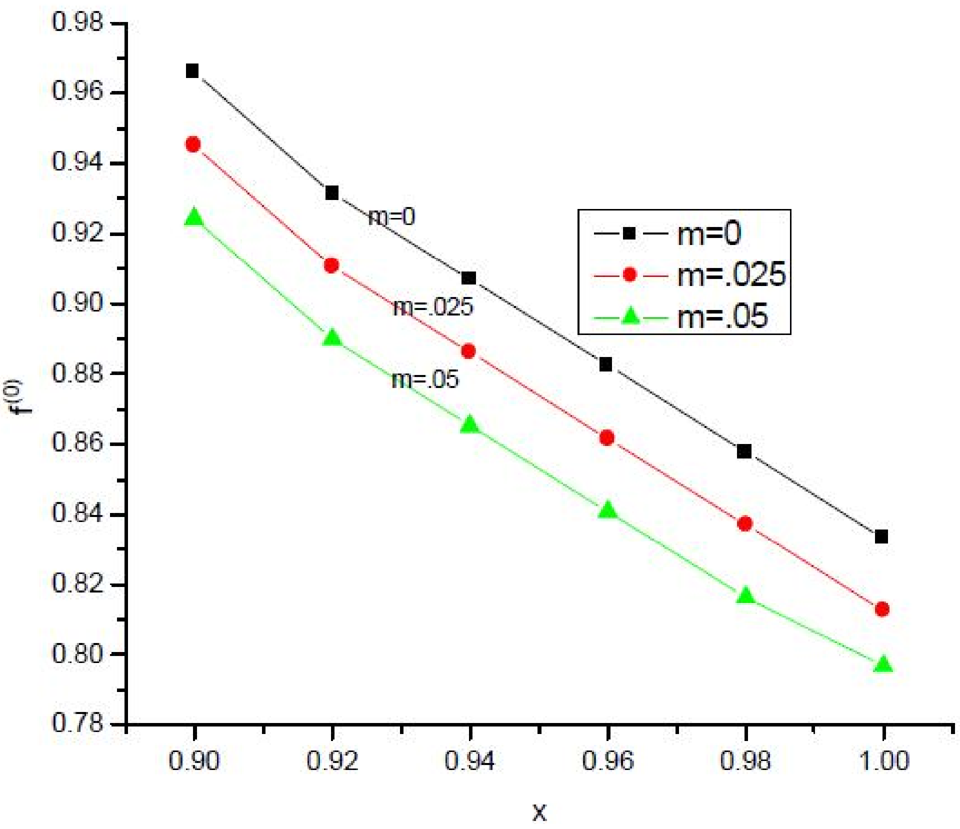

Fig. 1. Variation of velocity for zeroth order solution (plane wave)

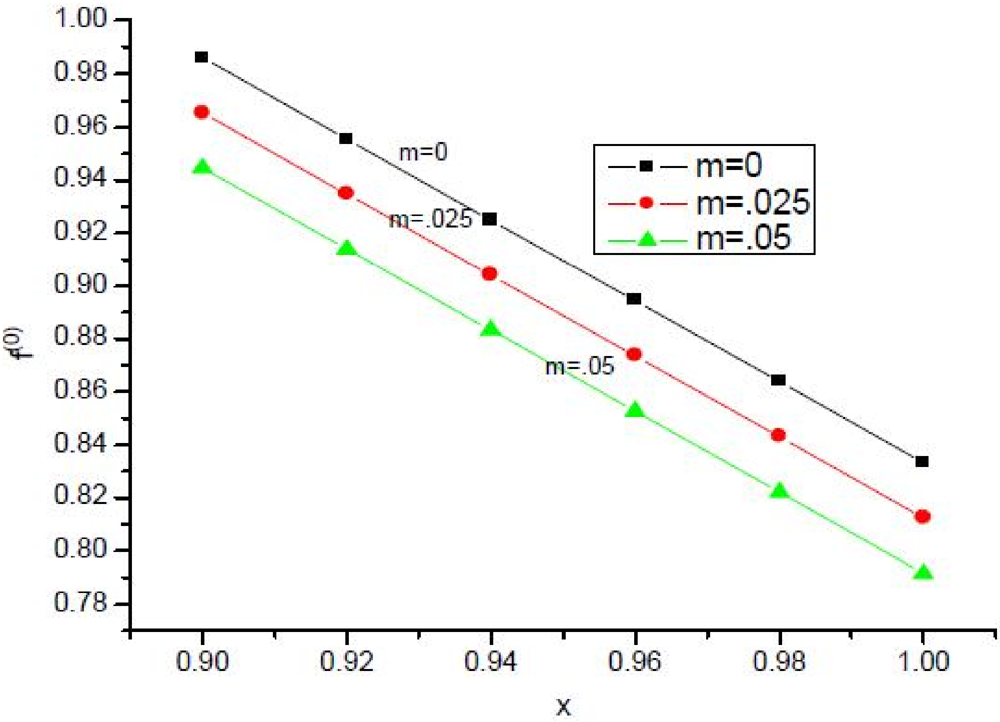

Fig. 2. Variation of velocity for zeroth order solution (cylindrical case)

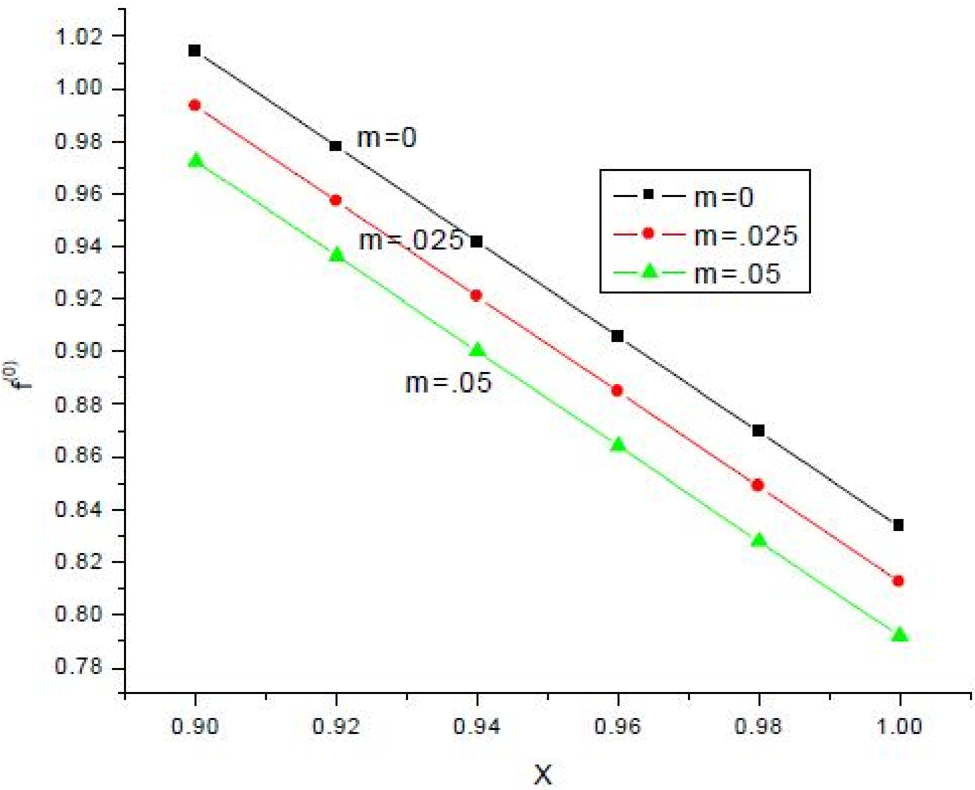

Fig. 3. Variation of velocity for zeroth order (Spherical case)

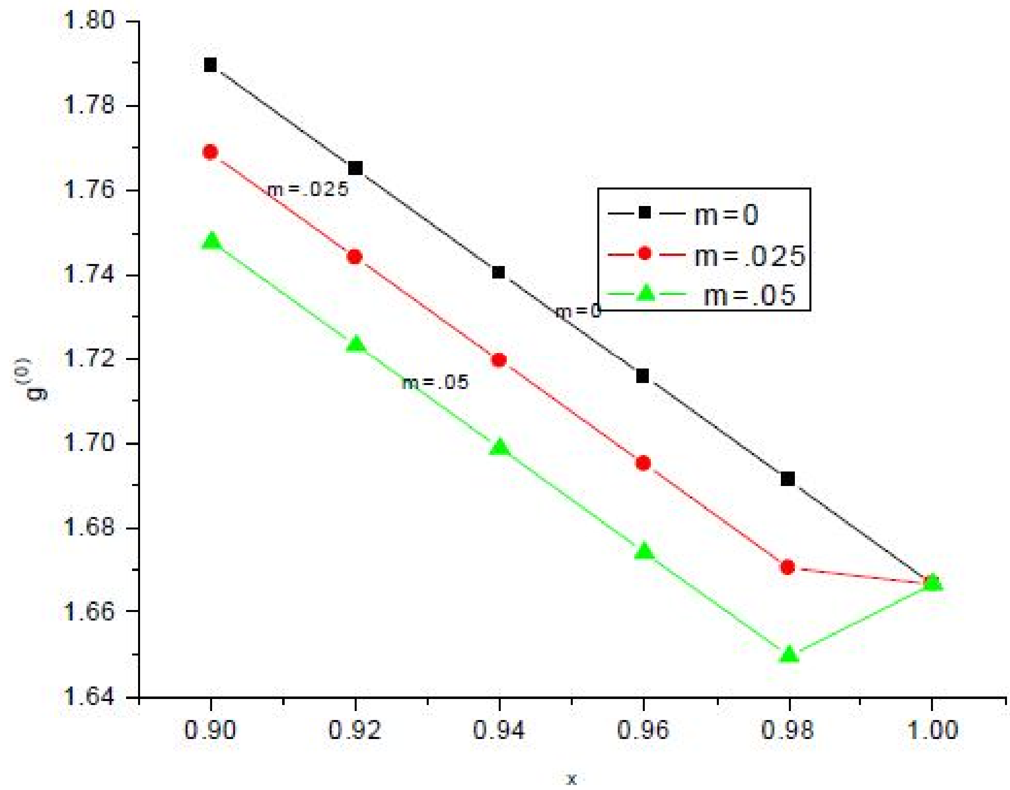

Fig. 4. Variation of pressure for zeroth order solution (plane case)

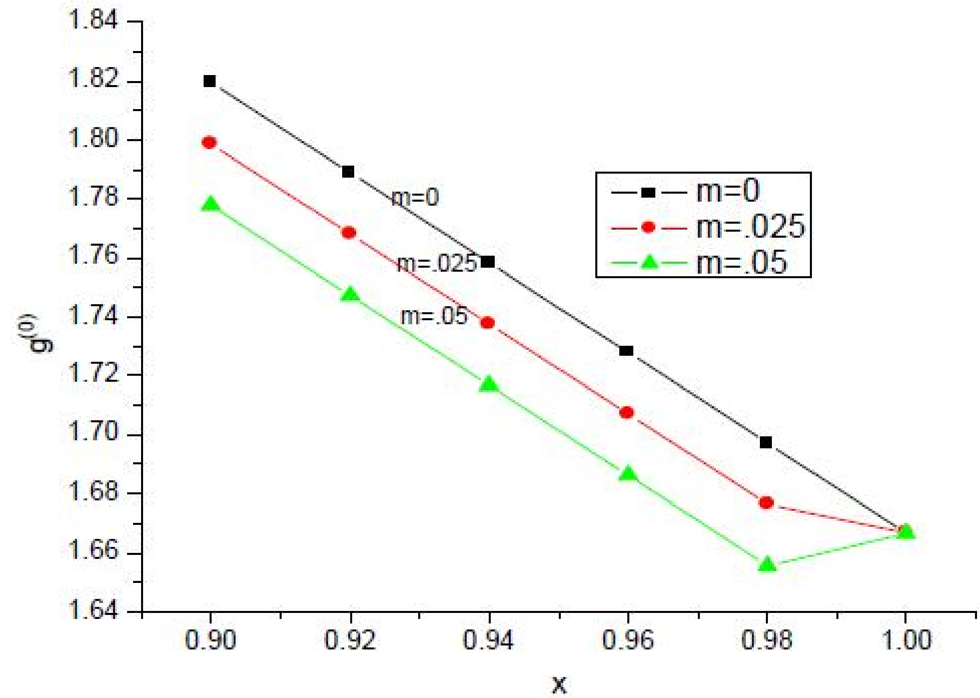

Fig. 5. Variation of pressure for zeroth order solution (cylindrical case)

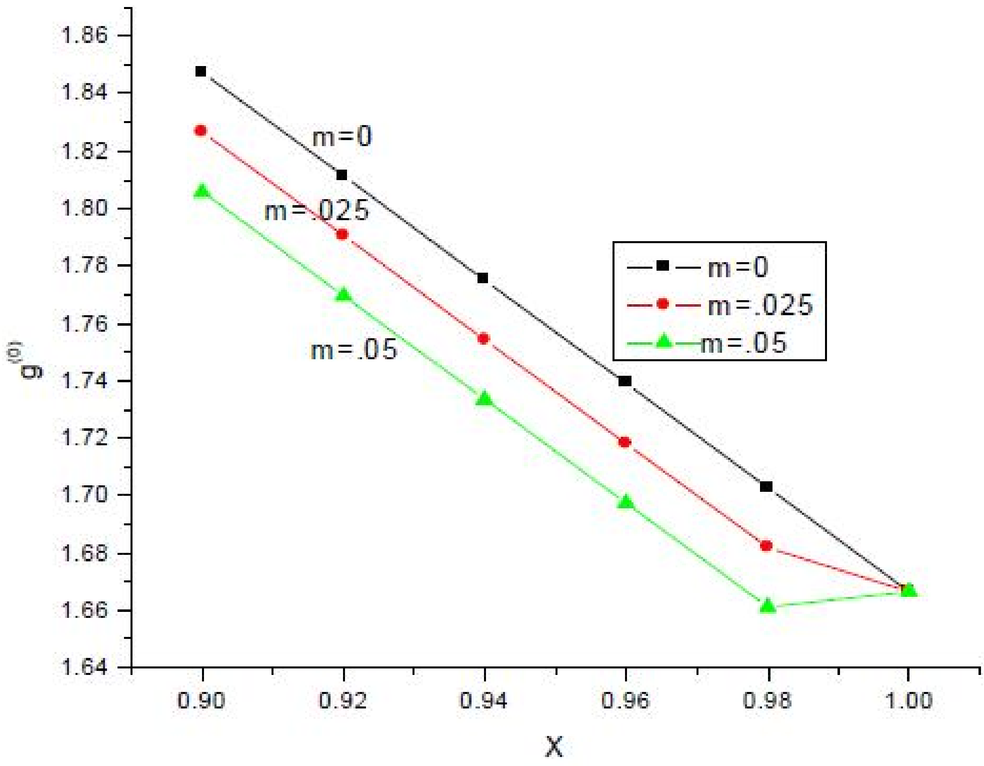

Fig. 6. Variation of pressure for zeroth order (spherical case)

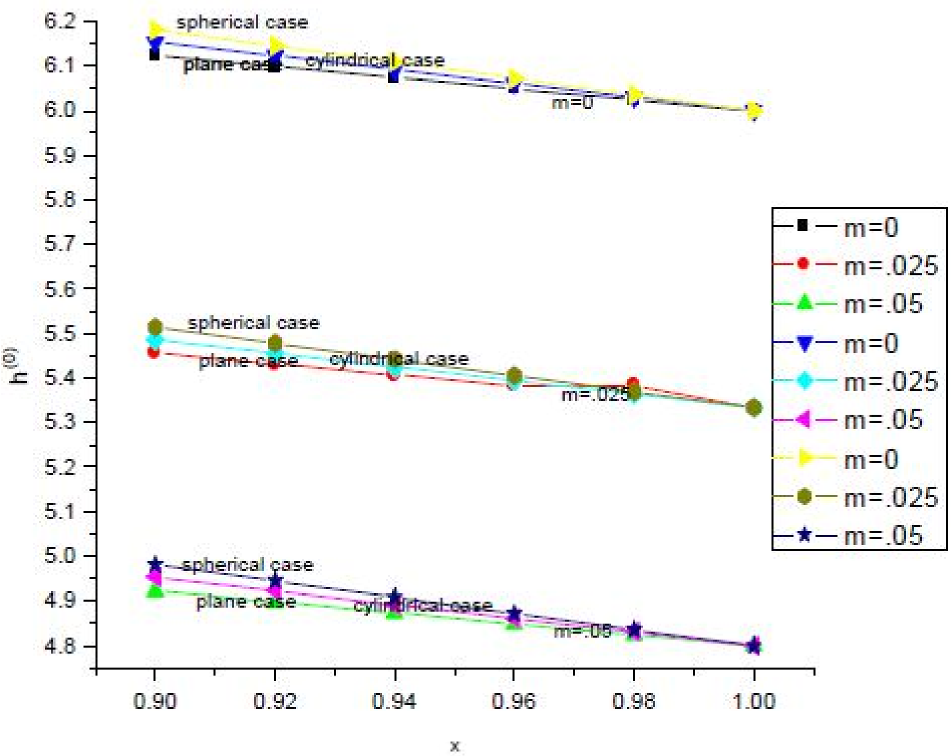

Fig. 7. Variation of density for zeroth order

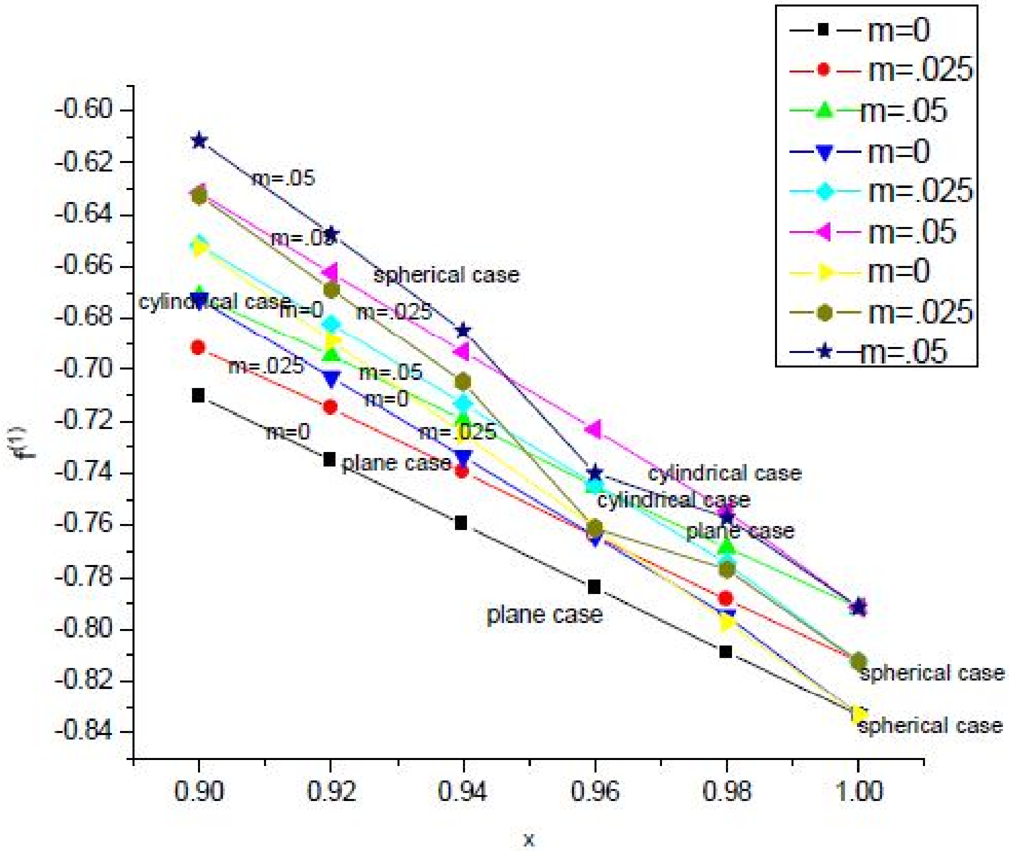

Fig. 8. Variation of velocity for the first order solution

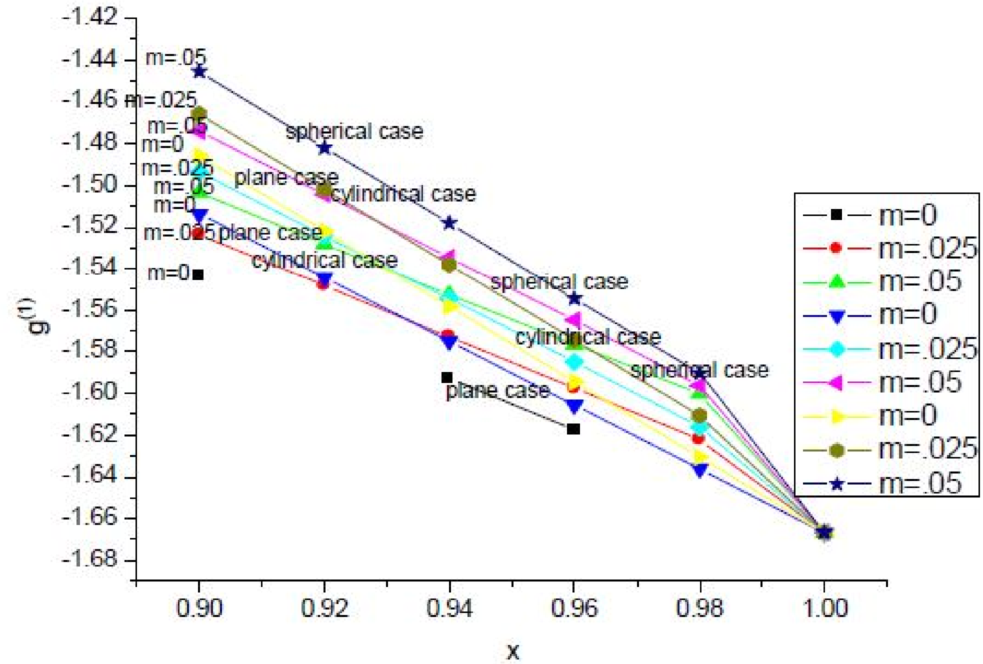

Fig. 9. Variation of pressure for the first order solution

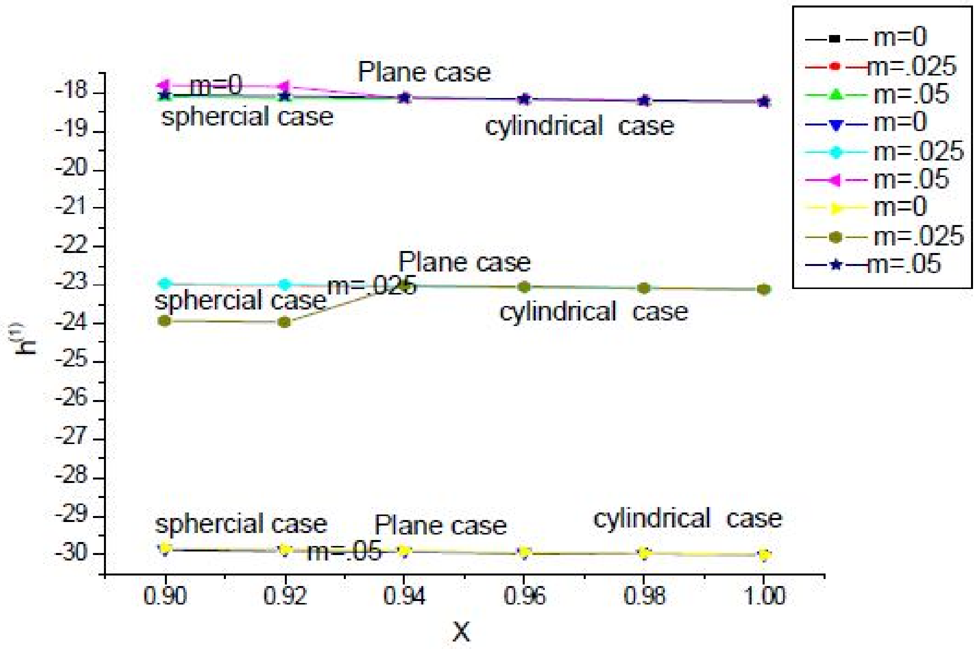

Fig. 10. Variation of density for the first order solution

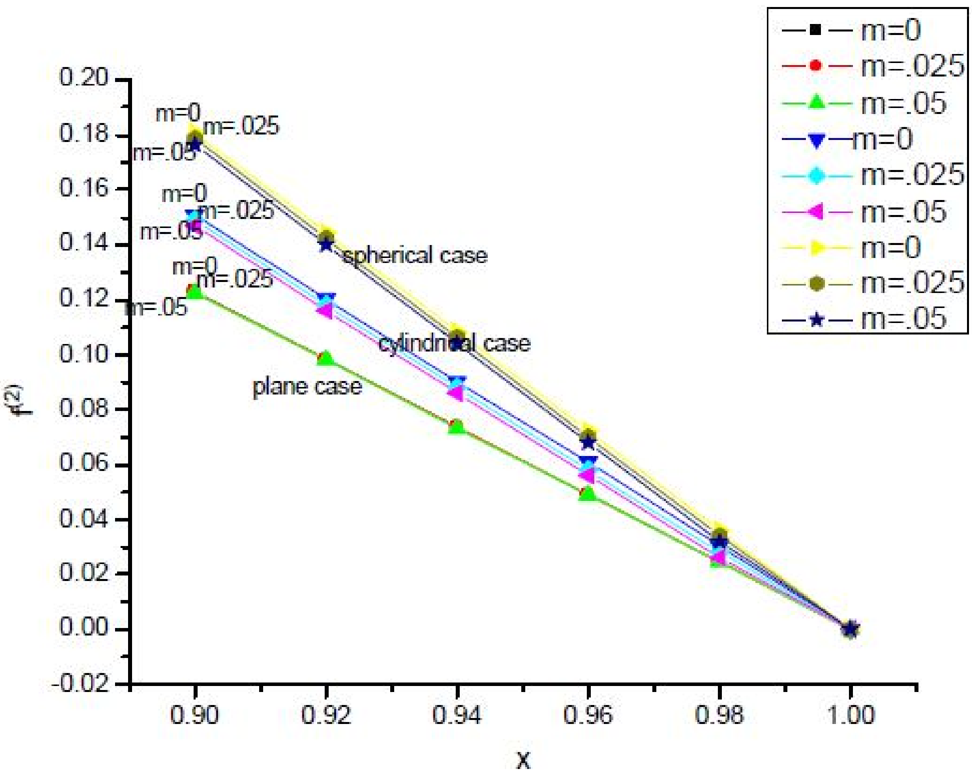

Fig. 11. Variation of velocity for the second order solution

5. Result and Conclusion

1. For constant solutions, velocity, pressure and density varies linearly and for non-ideal case there is a decrease in comparison to ideal gas.

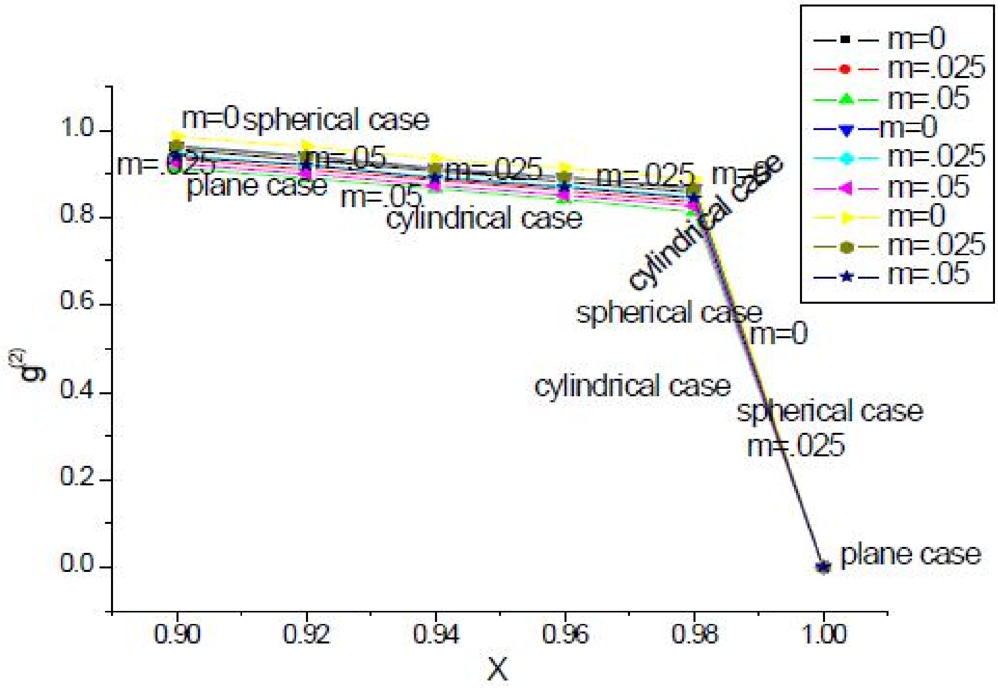

Fig. 12. Variation of pressure for the second order solution

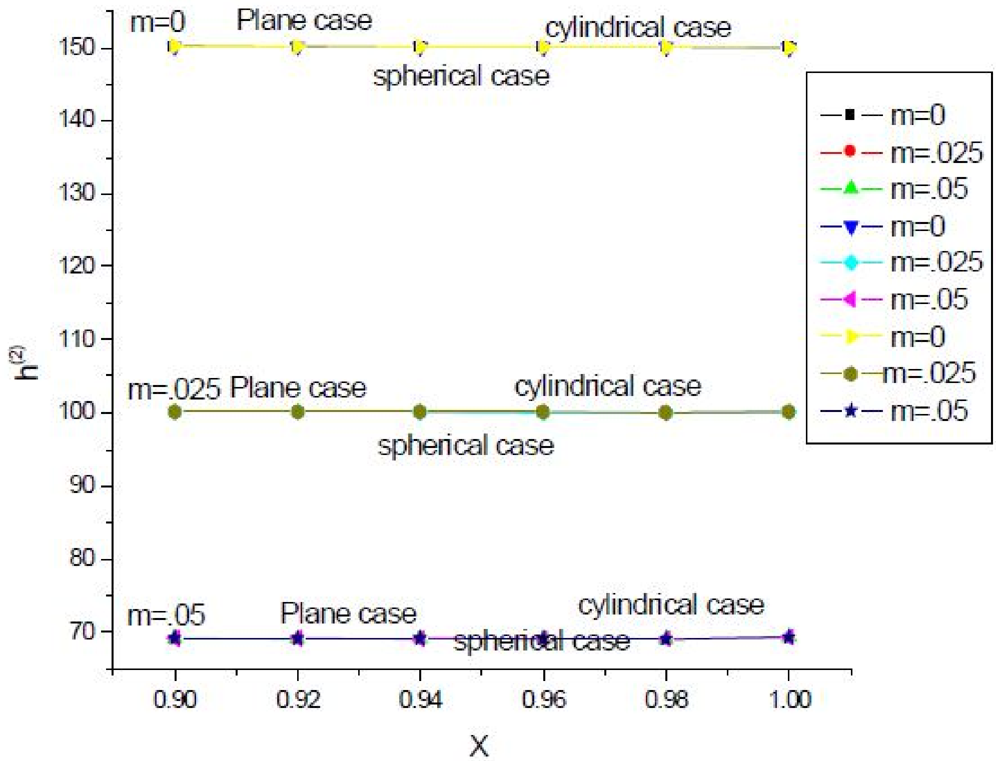

Fig. 13. Variation of density for the second order solution

2. For first order solution velocity, pressure density all varies linearly, but as value of m (= $b\rho_0$) increases they are increasing in comparison to ideal gas.

3. For second order solution variation of velocity is linear. In plane case it is same for ideal as well as non-ideal case but as m increases there is a slight decrease for cylindrical and spherical case.

4. The energy of explosion J0 for ideal gas is greater in comparison to non ideal gas for plane, cylindrical and spherical wave.

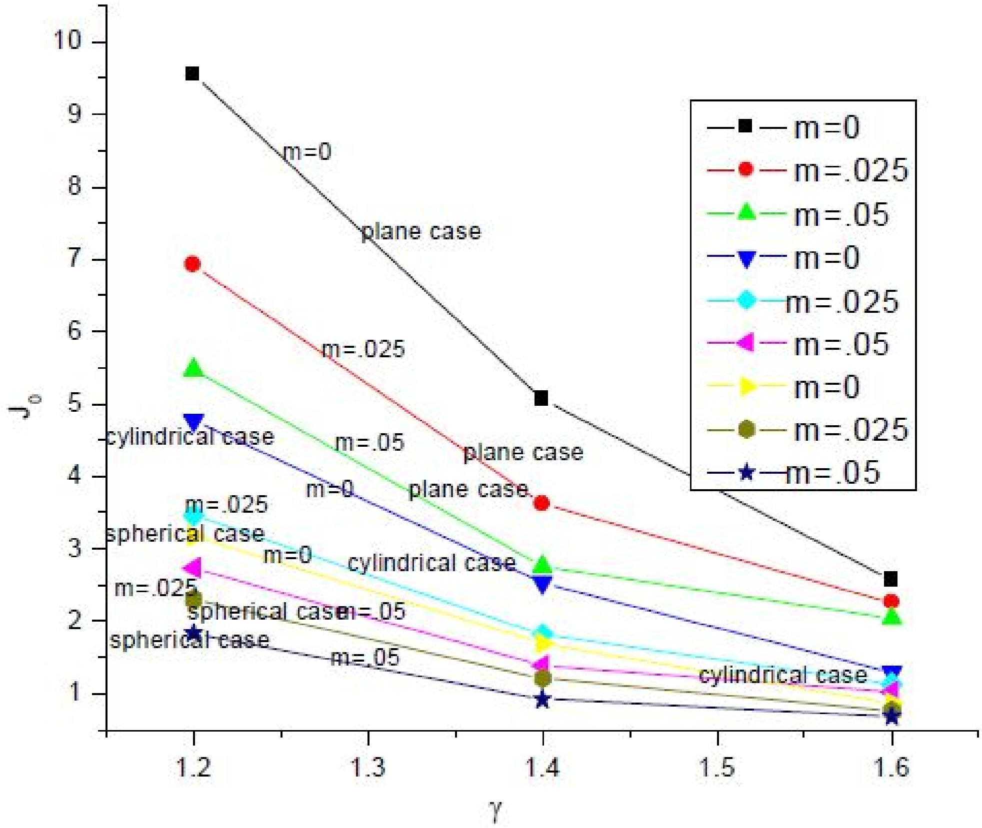

Fig. 14. Variation of energy of explosion

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