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Variation of Temperature Due to Converging Shock Wave in Self – Gravitating Gas having Intense Dust Particles

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Abstract: Temperature variation of self-gravitating gas having intense dust particles perturbed by strong spherical shock waves has been investigated by Chester-Chisnell-Whitham method. Analytical relation for shock velocity and shock strength have been derived and used for temperature variation of medium having density distribution of $\rho_o = \rho' r^{-\omega}$ ***Where*** ω ***is density parameter, depends on medium. It is found that the variation of temperature of the gas atmosphere is significant and depends on the strength of the shock perturbing the medium.***
Keywords: Shock waves, converging, temperature variation.

I. INTRODUCTION

The variation of self gravitating gas atmosphere having intense dust particle perturbed by spherical shock wave, is investigated by Chester-Chisnell-Whitham method.

The dusty gas is assumed to be a mixture of small solid particles and perfect gas . The solid particles are continuously distributed in the perfect gas. In order to get some essential features of shock propagation, the solid particles are considered as a pseudo-fluid and it is assumed that the equilibrium flow condition is maintained in the flow-field. The viscous stress and heat conduction of the mixture are negligible. The presence of small solid particles affects the medium in two ways. The volume fraction of solid particles lowers the compressibility of the mixture and on the other hand, the particles load increases the inertia of the mixture. It is found that if the density of the solid particles and that of the perfect gas are equal, by an increase in the mass fraction of solid particles in the mixture, the strength of the shock is decreases and its distance from the inner expanding surface is increased. Also, by an increase in the ratio of density of solid particles and that of the perfect gas in the mixture, the strength of the shock is increased and its distance from the inner surface is decreased. Further, an increase in the rate of energy input increases the shock velocity and decreases the distance between the shock front and inner surface (Vishwakarma and Pandey[1]).

The study of high speed flow of a mixture of gas and small solid particles is of great interest in several branches of engineering and science (Pai et al.[2]). The propagation of strong shock wave produced on account of sudden explosion in a medium where the density varies as some power of the distance from the point of explosion, has been studied by (Chester and Halliwell[3]). Ray and Bhowmick[4], Vishwakarma[5] have studied the propagation of plane shock wave in a medium where density increases exponentially. The thermal conductivity and the absorption coefficient are assumed to vary with temperature and density, and the total energy of the wave to vary with time (Vishwakarma and Singh[6]). Anand and Yadav[7] have studied the thickness of shock front decreases with increasing value of the coefficient of viscosity and Mack number. The initial density of the medium obeys a power law. The total energy of the flow field behind the shock is not constant, assumed to be increasing due to time dependent energy input (Vishwakarma et al.[8]).

The CCW (Chester-Chisnell-Whitham) method is used for variation of temperature of self-gravitating gas having intense dust particle. In this paper we discussed the variation of shock velocity, shock strength and pressure in dusty medium with temperature.

It is found that the temperature decreases with propagation distance *r*, density parameter □, initial volume fraction β and increases with specific density G' in case of converging shock.

II. BASIC EQUATIONS AND BOUNDRY CONDITIONS

The basic equations for the flow behind the shock under the influence of its own gravitation are written as –

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + \frac{1}{\rho}\frac{\partial p}{\partial r} + \frac{Gm}{r^2} = 0 \quad (1)$$

$$\frac{\partial \rho}{\partial t} + u\frac{\partial \rho}{\partial r} + \rho\left\{\frac{\partial u}{\partial r} + \alpha\frac{u}{r}\right\} = 0 \quad (2)$$

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

$$\frac{\partial m}{\partial r} = 4\pi r^2 \rho$$

where, r is the radial coordinate u,p and ρ are the particle velocity, the pressure and the density of gas respectively. m denotes the mass inside a sphere of radius r / cylinder of radius r and of unit length. $c_\alpha = 2\pi \ or \ 4\pi$, according to α =1 or 2 respectively for cylindrical or spherical flow.

Let p_0 ,a_0 and ρ_0 denote the undisturbed values of pressure, sound velocity and density in front of the shock , and u, p and ρ be the respective values of the particle velocity, the pressure and the density at any point immediately after the passes of the shock. The Rankine-Hugoniot conditions are-

$$u = (1-\beta)U$$

$$\rho = \rho_0 \backslash \beta \quad (4)$$

$$p = (1-\beta)\rho_0 U^2$$

$$a_0 = \sqrt{\frac{\gamma p_0}{\rho_0(1-z)}}$$

Where $\beta = \frac{\gamma+2z-1}{\gamma+1}$,is known as initial volume fraction, depends on no. of solid particles z. In general z is not constant but the value occupied by the solid particles is very small because the density of solid particle is much larger than of the gas. Hence, z may be assumed as a small constant, expressed as-

$$z = \frac{k_p}{G'(1-k_p)+k_p}$$

Where, the mass concentration $k_p = \frac{z\rho_{sp}}{\rho}$ and specific density $G' = \frac{\rho_{sp}}{\rho}$

For converging shock waves the characteristic form of system of flow equations (1)-(4) is

$$dp - \rho a du + \frac{\rho a^2 \alpha u}{u-a}\frac{\partial r}{r} - \frac{Gm\rho a}{u-a}\frac{\partial r}{r^2} = 0 \quad (5)$$

Assuming shock waves move in the non - uniform medium. Substitute conditions (4) in equation (10) and after solving, we get shock velocity -

$$\frac{U}{\sqrt{G\rho'}} = \left\{\frac{Kr^{-c}}{G\rho'} + \frac{Dr^{2-\omega}}{(c-\omega+2)}\right\}^{\frac{1}{2}} \quad (6)$$

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where, $K/G\rho'$ is constant of integration and *C* and *D* are constants, defined as -

$$C = \left[\frac{(1-\beta)\alpha}{(1-z)}\left\{\frac{1}{(1-\beta)-\sqrt{\frac{(1-\beta)\beta}{(1-z)}}}\right\}-\omega\right]\left\{\frac{2}{2-\sqrt{\frac{(1-\beta)}{(1-z)\beta}}}\right\} \qquad (7)$$

$$D = \frac{4\pi}{(1-\omega)(1-\beta)\beta}\left\{\frac{\sqrt{(1-\beta)\beta/(1-z)}}{(1-\beta)-\sqrt{\frac{(1-\beta)\beta}{(1-z)}}}\right\}\left\{\frac{2}{2-\sqrt{\frac{(1-\beta)}{(1-z)\beta}}}\right\}$$

The sound velocity-

$$\frac{a_0}{\sqrt{G\rho'}} = \left\{\frac{3\pi r^{2-\omega}}{(3-\omega)(\omega-1)(1-z)}\right\}^{\frac{1}{2}} \qquad (8)$$

The shock strength can be expressed as-

$$M = \frac{\left\{\frac{Kr^{-C}}{G\rho'}+\frac{Dr^{2-\omega}}{(C-\omega+2)}\right\}^{\frac{1}{2}}}{\left\{\frac{3\pi r^{2-\omega}}{(3-\omega)(\omega-1)(1-z)}\right\}^{\frac{1}{2}}} \qquad (9)$$

III. TEMPERATURE

Expression for temperature can be given as-

$$\frac{T}{T_0} = \frac{\{2\gamma M^2-(\gamma-1)\}\{2+(\gamma-1)M^2\}}{(\gamma-1)^2 M^2} \qquad (10)$$

In case of converging shock, putting the shock strength from eq.(9) in eq.(10),the temperature –

$$\frac{T}{T_0} = \frac{\left[2\gamma\frac{\left\{\frac{Kr^{-C}}{G\rho'}+\frac{Dr^{2-\omega}}{(C-\omega+2)}\right\}}{\left\{\frac{3\pi r^{2-\omega}}{(3-\omega)(\omega-1)(1-z)}\right\}}-(\gamma-1)\right]\left[2+(\gamma-1)\frac{\left\{\frac{Kr^{-C}}{G\rho'}+\frac{Dr^{2-\omega}}{(C-\omega+2)}\right\}}{\left\{\frac{3\pi r^{2-\omega}}{(3-\omega)(\omega-1)(1-z)}\right\}}\right]}{(\gamma-1)^2\frac{\left\{\frac{Kr^{-C}}{G\rho'}+\frac{Dr^{2-\omega}}{(C-\omega+2)}\right\}}{\left\{\frac{3\pi r^{2-\omega}}{(3-\omega)(\omega-1)(1-z)}\right\}}}$$

IV. RESULTS AND DISCUSSION:

For strong shock, initially taking U/a_0 =20, at *r* =2,γ=1.4 α=2 **ω**=2.1,β=0.5, k_p=0.1and z=0.00222, the constant of integration $K/\rho'G$ is calculated using equation (9) . The variation of temperature with propagation distance *r* is shown in table (1). It is found that temperature decreases in case of converging shock as spherical shock advances in the self-gravitating gas having intense dust particles. The temperature decrease from 121.809896 to 12.6531577 as strong spherical shock moves from 0.90 to 1.00.

r	T/T_0 (converging)
0.90	121.809896
0.91	95.0491384
0.92	74.4579315
0.93	58.5686818
0.94	46.2734486
0.95	36.7332699
0.96	29.3109749
0.97	23.5212419
0.98	18.9933578
0.99	15.4433634
1.00	12.6531577

Table-1

ω	T/T_0 (converging)
1.1	6.1453E+18
1.2	6.0397E+18
1.3	5.2034E+18
1.4	4.0781E+18

Table-2

β	T/T_0 (converging)
0.050	8.411874
0.055	7.734476
0.600	1.662611

Table-3

G'	T/T_0 (converging)
50	1.636223
100	1.639940
200	1.641810

Table-4

The variation of temperature T/T_0 with propagation distance r (Table-1), density parameter ω (Table-2),initial volume fraction β (Table-3) and specific density G' (Table-4)for diverging and converging shock.
The variation of temperature with density parameter with ω is shown in table (2).
It is concluded that temperature decreases from 6.1453E+18 to 4.0781E+18 with the variation of ω from 1.1 to 1.4.
The variation of temperature with initial volume fraction β is shown in table (3).
Temperature decreases with initial volume fraction β. Temperature varies from 8.411874 to 1.662611 converging spherical shock waves with the variation of initial volume fraction β from 0.050 to 0 .0600.
The variation of temperature with specific density G', is shown in table (4).It is concluded that temperature increases in case of converging shock with Specific density G' . Temperature varies from 1.636223 to 1.641810 for converging spherical shock waves with the variation of Specific density G' from 50 to 200.
Therefore it may be concluded that temperature variation of the perturbed medium is of the order of 1000 times and above of its initial values, the formation of plasma take place (**S.N.Sen**[9]).

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