



e-ISSN: 2319-8753 | p-ISSN: 2320-6710

# IJRSET

International Journal of Innovative Research in  
**SCIENCE | ENGINEERING | TECHNOLOGY**



# INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

**Volume 9, Issue 10, October 2020**

**ISSN** INTERNATIONAL  
STANDARD  
SERIAL  
NUMBER  
INDIA

**Impact Factor: 7.512**



9940 572 462



6381 907 438



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# Variation of Temperature Due To Diverging 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  $\rho_0 = \rho' r^{-\omega}$  Where  $\omega$  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, diverging, 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**<sup>1</sup>).

The study of highspeed flow of a mixture of gas and small solid particles is of great interest in several branches of engineering and science (**Pai et al.**<sup>2</sup>). 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**<sup>3</sup>). **Ray and Bhowmick**<sup>4</sup>, **Vishwakarma**<sup>5</sup> 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**<sup>6</sup>). **Anand and Yadav**<sup>7</sup> 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.**<sup>8</sup>).

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 increase with the variation of propagation distance  $r$ , density parameter  $\omega$  and specific density  $G'$  while it is decreases with initial volume fraction  $\beta$  in case of diverging 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 –

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

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

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

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

where,  $r$  is the radial coordinate  $u, p$  and  $\rho$  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  $\alpha = 1$  or  $2$  respectively for cylindrical or spherical flow.

Let  $p_0, a_0$  and  $\rho_0$  denote the undisturbed values of pressure, sound velocity and density in front of the shock, and  $u, p$  and  $\rho$  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-

$$u = (1 - \beta)U \tag{4}$$

$$\rho = \rho_0 \beta$$

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

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

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  $G' = \frac{\rho_{sp}}{\rho}$

The characteristic form of system of flow equation (1)-(3) is

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

Assuming that shock waves move in the non - uniform medium. Substituting the conditions (4) in equation (5) and after solving, we get shock velocity -

$$\frac{U}{\sqrt{G\rho'}} = \left\{ \frac{Kr^{-A}}{G\rho'} - \frac{Br^{2-\omega}}{(A-\omega+2)} \right\}^{\frac{1}{2}} \tag{6}$$



where,  $K/G\rho'$  is constant of integration and  $A$  and  $B$  are constant given by –

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

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

The sound velocity-

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

The shock strength can be expressed as-

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

### III. TEMPERATURE

Expression for temperature can be given as-

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

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

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

### IV. RESULTS AND DISCUSSION

For strong shock, initially taking  $U/a_0 = 20$ , at  $r = 2$ ,  $\gamma = 1.4$   $\alpha = 2$   $\omega = 2.1$ ,  $\beta = 0.5$ ,  $k_p = 0.1$  and  $z = 0.00222$ , 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 increases in case of diverging shock as spherical shock advances in the self-gravitating gas having intense dust particles. The temperature varies from 11.65497 to 12.44290 as strong spherical shock moves from 0.90 to 1.00.



$r$	$T/T_0$ (diverging)
0.90	11.65497
0.91	11.73484
0.92	11.81446
0.93	11.89383
0.94	11.97297
0.95	12.05187
0.96	12.13053
0.97	12.20896
0.98	12.28717
0.99	12.36515
1.00	12.44290

Table-1

$\omega$	$T/T_0$ (diverging)
1.1	9.748534
1.2	13.75091
1.3	14.82251
1.4	15.63520

Table-2

$\beta$	$T/T_0$ (diverging)
0.050	8.762076
0.055	8.567175
0.600	8.504015

Table-3

$G'$	$T/T_0$ (diverging)
50	3.878078
100	3.878301
200	3.878415

Table-4

The variation of temperature  $T/T_0$  with propagation distance  $r$  (table-1), density parameter  $\omega$  (table-2), initial volume fraction  $\beta$  (table-3) and specific density  $G'$  (table-4) for diverging shock.

The variation of temperature with density parameter with  $\omega$  is shown in table (2).

It is concluded that temperature increases in diverging shock with  $\omega$ . Temperature varies from 9.748534 to 15.63520 s with the variation of  $\omega$  from 1.1 to 1.4.

The variation of temperature with initial volume fraction  $\beta$  is shown in table (3).

Temperature decreases from 8.762076 to 8.504015 for diverging spherical shock waves with the variation of initial volume fraction  $\beta$  from 0.050 to 0.600.

The variation of temperature with specific density  $G'$ , is shown in table (4).

Temperature decreases from 3.878078 to 3.878415 for diverging 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<sup>9</sup>).

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