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COMPARISON OF SPHERICAL AND CYLINDRICAL WEAK SHOCK WAVES IN HIGHLY VISCOUS MEDIUM

Dr. Praveen Kumar

Department of Physics, V.R.A.L.Govt Girls Degree College, Bareilly (U.P)

Prof. (Dr.) Neeraj Rathore

Department of Physics, Bareilly College, Bareilly (U.P.)

Abstract

The propagation of weak spherical and cylindrical shock waves in highly viscous uniform medium has been investigated by Chester - Chisnell - Whitham method. The analytical expressions for the shock velocity decreases as shock advances for low viscous region of a medium to the high viscous region. The pressure and particle velocity behind weak shock decreases with adiabatic index and Small decreasement in the pressure and particle velocity is found with the increase in viscosity coefficient. It is shown that applications of the Chester - Chisnell - Whitham method.

Key words- shock wave, Chester - Chisnell - Whitham method and viscosity.

Inroduction:

The theory of shock waves has a rich history beginning with the fundamental contributions by Riemann in the mid of the 19th century. In fact, all natural fluids admit some compressibility and therefore support shock waves. Shock waves can only develop in a medium which behaves like a fluid. Shock waves may be produced in fluids such as sea water by a variety of natural and artificial mechanisms. The flow parameters such as pressure, density, temperature, particle velocity and entropy change very rapidly in the thin transition layer, through which the gas passes from its initial state of thermodynamic equilibrium into its final, also equilibrium state. Here, the thermodynamic equilibrium inside this region is called the shock front and it can be substantially disturbed. Therefore, in studying the internal structure of a shock front it is necessary to consider the dissipative processes due to viscosity (internal friction) and thermal conduction. The study of the internal structure of shock front has its importance for many reasons. At first this problem attracted attention as purely a theoretical one, the solution of which describes the physical mechanism of shock compression, as a truly remarkable phenomenon in gas dynamics and also in understanding the various processes which take place in gases at high temperatures, as for example, vibrational excitation in molecules, molecular dissociation, chemical reactions, ionization, and radiation. Obviously, the theoretical consideration of the structure of shock front permits one to deduce from the experimental data a good deal of valuable information about the rates of these processes.

Sakurai [1958] refined the Mott-Smith method on the basis of a hard sphere model for the molecular interaction, and predicted that the thickness of shock front approaches a finite limit as the strength of shock wave tends to infinity. Zel'dovich and Raizer [2002] studied the entropy production due to the propagation of plane shock waves in a viscous gaseous medium. The propagation of plane, cylindrical and spherical shock waves in a viscous medium was investigated by Yadav and Anand [2011]. Recently,Anand and Yadav [2014] have studied the structure of MHD shock waves in a viscous non-ideal gas. Elizarova et al. [2005] calculated the structure of shock wave for argon and helium using NS approach and compared the results with experimental data.

The aim of the present part is to study the propagation of weak spherical and cylindrical shock waves propagating in a uniform medium. When shock moves freely. The shock strength, shock velocity, pressure and particle velocity both decreases as spherical and cylindrical shock. The effect of overtaking disturbances is to inhance the values. The results obtained here are compared with those Yadav et al (2015).

Basic Equations:

The general equations of exploding shock waves in presence of uniform viscous medium

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+\frac{1}{\rho}\frac{\partial P}{\partial r}-\frac{4}{3}\mu\frac{\partial u}{\partial r}=0$$

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

$$\frac{\partial P}{\partial t}+u\frac{\partial P}{\partial r}-a^2\left[\frac{\partial r}{\partial t}+u\frac{\partial \rho}{\partial r}\right]=0$$

$$\frac{\partial P}{\partial t}+u\frac{\partial P}{\partial r}+a^2\rho\left[\frac{\partial r}{\partial t}+\frac{\alpha u}{r}\right]=0$$

Where, u (r, t), P (r,t) and ρ (r,t) denote particle velocity, pressure, density at a distance r from the origin at time t, γ is the adiabatic index of gas, μ is the coefficient of viscosity and $\alpha = 2, 1$ for spherical and cylindrical shock waves.

Boundary Conditions:

Let P_0 and ρ_0 denotes the unperturbed values of pressure and density in front-

$$P = a_0^2\rho_0\left[\frac{2M^2}{(\gamma+1)} - \frac{(\gamma-1)}{(\gamma+1)}\right]$$

$$\rho = \rho_0\left[\frac{(\gamma+1)M^2}{(\gamma-1)M^2+2}\right].$$

$$U = \frac{2a_0}{(\gamma+1)}\left[M - \frac{1}{M}\right]$$

$$a = a_0\sqrt{\frac{[2\gamma M^2-(\gamma-1)][(\gamma-1)M^2+2]}{(\gamma+1)}}$$

Where, $M = \frac{U}{a_0}$ is Mach number, U is the shock velocity, a and a_0 are the sound velocity in disturbed and undisturbed medium respectively.

Weak Shock Waves:

For weak shock waves i.e. ($U<<a_0$) the boundary conditions, $M = 1+\varepsilon$ reduce to-

$$P = \frac{\gamma P_0}{(\gamma+1)}\left[\frac{(\gamma+1)}{\gamma} + 4\varepsilon\right]$$

$$\rho = \rho_0\left[1 + \frac{4\varepsilon}{(\gamma+1)}\right]$$

$$U = a_0[1+\varepsilon]$$

$$u = \frac{4a_0\varepsilon}{(\gamma+1)}$$

Characteristic Equation for Freely Propagation of Shock Wave:

The characteristic equation for exploding shock is given as-

$$dP + \rho a\, du + \frac{\alpha\rho a^2 u}{r}\frac{dr}{(u+a)} - \frac{4}{3}\frac{\mu\rho a\, du}{(u+a)} = 0$$

Solving, this equation-

$$\varepsilon = k\, r^{-\frac{\alpha}{\left[2-\frac{4}{3}\frac{\mu}{a_0}\right]}}$$

The expression for shock velocity may be written as-

$$U = a_0\left[1 + k\, r^{-\frac{\alpha}{\left[2-\frac{4}{3}\frac{\mu}{a_0}\right]}}\right] \quad (1)$$

The expression for shock strength may be written as-

$$M = \frac{U}{a_0} = \left[1 + k\, r^{-\frac{\alpha}{\left[2-\frac{4}{3}\frac{\mu}{a_0}\right]}}\right] \quad (2)$$

Results and Discussion:

Weak Spherical and cylindrical Shock Waves:

Expression (1) and (2) represents the shock strength and shock velocity for the freely propagation of weak shock, in uniform medium. Shock strength is a function of propagation distance r, adiabatic index γ, shock symmetry parameter μ and viscosity coefficient μ.

Table 1: Variation of variable with propagation distance for weak spherical shock wave

$$(r = 10, \mu = 0.000172, \alpha = 2\ and \rho = 1.29)$$

R	U	M	P	U
10.0	1.3201	1.3001	1.3597	0.5231
10.2	1.3141	1.2941	1.3563	0.5129
10.4	1.3084	1.2885	1.3530	0.5029
10.6	1.3028	1.2831	1.3449	0.4935
10.8	1.2975	1.2778	1.3469	0.4843
11.0	1.2924	1.2728	1.3440	0.4755

Table 2: Variation of variable with adiabatic index for weak spherical shock wave

γ	U	M	P	U
1.33	1.30509	1.300048	1.3972	0.5231
1.40	1.35437	1.300052	1.4084	0.5307
1.66	1.47033	1.300057	1.5916	0.5393
1.69	1.48364	1.300061	1.6144	0.5393
1.75	1.51423	1.300069	1.6682	0.5591

Table 3: Variation of variable with viscosity coefficient for weak spherical shock wave

□	U	M	P	U
0.0000172	1.3201	1.3001	1.3597	0.5231
0.0001720	1.3169	1.2873	1.3564	0.4929
0.0017200	1.3029	1.9177	1.3439	0.4417
0.0172000	1.4275	1.8765	1.3352	0.4039
0.1720000	1.2427	1.8196	1.3161	0.3902

Table 4: Variation of variable with propagation distance for weak cylindrical shock wave

$$(r = 10, \mu = 0.000172, \alpha = 1\ and \rho = 1.29)$$

R	U	M	P	U
10.0	1.9789	1.9489	1.7300	1.6541
10.2	1.9694	1.9395	1.7246	1.6378
10.4	1.9602	1.9304	1.7195	1.6219
10.6	1.9512	1.9216	1.7144	1.6066
10.8	1.9425	1.9130	1.7095	1.5917
11.0	1.9341	1.9047	1.7048	1.5771

Table 5: Variation of variable with adiabatic index for weak cylindrical shock wave

γ	U	M	P	U
1.33	1.9789	1.948911	1.7300	1.6541
1.40	2.0303	1.948912	1.7868	1.6950
1.66	2.2041	1.948913	1.9123	1.7715
1.69	2.2240	1.948914	2.0211	1.8532
1.75	2.2699	1.948915	2.0811	1.9917

Table 6: Variation of variable with viscosity coefficient for weak cylindrical shock wave

□	U	M	P	U
0.0000172	1.9789	1.9489	1.7300	1.6541
0.0001720	1.9587	1.9283	1.7199	1.6329
0.0017200	1.9377	1.9177	1.6993	1.6127
0.0172000	1.8963	1.8765	1.6729	1.5326
0.1720000	1.8475	1.8196	1.6562	1.4287

Conclusions:

It is concluded that shock strength, shock velocity, pressure and particle velocity decrease with propagation distance and viscosity coefficient. These parameter increases with adiabatic index. But similar results are found for strong shock propagating in non- uniform medium.

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