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Analysis of Self-Gravitational Instability of Hall Plasma in the Presence Suspended Particles Under the Effect finite Electron Inertia.

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Abstract:-

The problem of self-gravitational instability of Hall plasma in the presence of suspended particles and incorporating viscosity, thermal-conductivity and the effect of finite electron-inertia. The equation of the problems and stated and a general dispersion relation is obtained using normal mode analysis with the help of relevant linearized perturbation equations of the problem. This general dispersion relation is discussed when axis of rotation parallel and perpendicular to the direction of magnetic field for longitudinal mode of propagation and transverse mode of propagation and it is further reduced the cases.

Key words: Thermal conductivity, Hall-Effect, Finite Electron-Inertia, Suspended Particles, Rotation, Magnetic Field.

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1.Introduction :-

The self-gravitational instability of a gaseous plasma is important for understanding various astrophysical problems. It plays an important role in cloud collapse and the formation of stars. The self-gravitational instability was discovered by Jeans (1). These has been great interest in analyzing the onset of self-gravitational instabilities is rotating, magnetized or turbulent media and these are studied by Chandrasekhar (2). In this connection, many authors have studied the self-gravitational instability of a homogeneous plasma considering the effects of various parameters [Chhajlani, R.K.

and Sangvi(3), R.K. , Chhajlani, R.K. and Vyas, M.K.(4) , Lima J.A.S., Silva R. and Santos J.(5) , Bhatia P.K. and Chhonkar R.P.S.(6) , Shaikh S., Khan A. and Bhatia P.K. (7), Sharma, R.C., Gupta, U.(9), Gupta, U., Kumar, V.(11), Sharma, R.C., Aggarwal, A.K.(12), Kumar, P., Singh, G.J., Lal, R.(13), Gupta, U., Sharma, G.(14),]. Recently prajapati et al.(15) have discussed the self-gravitational instability of rotating viscous Hall plasma with arbitrary radiative heat loss functions and electron inertia. Pensia et al.(16) have discussed the effect of quantum correction on disturbances propagating in the gaseous plasma having fine dust particles. In the light of above studies we find that suspended particles and electron inertia are two important parameters to discuss the self-gravitational of gaseous plasma incorporating the effect of Hall current, thermal-conductivity, viscosity and rotation and magnetic field. Thus is the present work we want to study the effect of suspended particles, finite electron inertia, Hall current on the self-gravitational instability of infinite homogeneous gaseous plasma under the influence of corolios force, viscosity and thermal-conductivity in the presence of transverse magnetic field. The result of the present study well help to understand the astrophysical problems.

2. Linearized Perturbation Equations:-

We consider an infinite homogeneous, viscous, Self-gravitating, rotating, ionized plasma composed of gas and the fine dust particles (suspended particles) incorporating thermal conducting and finite electron inertia.

Linearized Perturbation Equations of the Problem are,

$$\frac{\delta\vec{v}}{\delta t} = -\frac{\vec{\nabla}\delta P}{\rho} + \vec{\nabla}\delta\phi + \frac{KN}{\rho}(\vec{u}-\vec{v}) + \vartheta\nabla^2\vec{v} + \frac{1}{4\pi\rho}(\vec{\nabla}\times\vec{b})\times\vec{B} + 2(\vec{v}\times\vec{\Omega}) \quad (1)$$

$$\frac{\partial\delta\rho}{\partial t} = -\rho\vec{\nabla}.\vec{v} \quad (2)$$

$$\delta P = C^2\delta P \quad (3)$$

$$\nabla^2\delta\phi = -4\pi G\delta\rho \quad (4)$$

$$\left(\tau\frac{\partial}{\partial t}+1\right)\vec{u} = \vec{v} \quad (5)$$

$$\lambda\nabla^2\delta T = \rho C_p\frac{\partial\delta t}{\partial t} - \frac{\partial\delta P}{\partial t} \quad (6)$$

$$\frac{\delta P}{P} = \frac{\delta T}{T} + \frac{\delta\rho}{\rho} \quad (7)$$

$$\frac{\partial\vec{b}}{\partial t} = (\vec{\mathrm{B}}.\vec{\nabla})\vec{v} - (\vec{v}.\vec{\nabla})\vec{B} + \frac{C^2}{\omega_{pe}^2}\frac{\partial}{\partial t}\nabla^2\vec{b} - \frac{C}{4\pi Ne}\vec{\nabla}\times[(\vec{\nabla}\times\vec{b})\times\vec{B}] \quad (8)$$

Where,

$\vec{v}(v_x,v_y,v_z),\vec{u}(u_x,u_y,u_z),N,\rho,P,\phi,\vec{B}(0,0,B),\vec{\Omega}(\Omega_x,0,\Omega_z),T,G,\vartheta,C_p,\lambda,R,$ $m,\rho_s,\omega_{pe},K_s(6\pi\rho r)$ *and* $\vec{b}(b_x,b_y,b_z)$ denote respectively, the gas velocity, the particle velocity, the number density of the particle, density of the gas, pressure of the gas, Gravitational potential, magnetic field, rotation, temperature, Gravitational constant, kinematic viscosity, specific heat at constant pressure, thermal conductivity, gas constant, mass per unit volume of the particles its density, plasma frequency of electron, the constant is the stokes drag formula and the perturbation in magnetic field.

3. Dispersion Relation:-

We analyse these perturbations with normal oscillation technique, we find solution of equation (1)-(8). In a uniform system we can find a plane-wave solution with all variables varying as,

$$exp\{i(k_x, k_z, \omega t)\} \tag{9}$$

Where k_x, k_z are the wave numbers of perturbation along the x and z-axis so that $k_x^2 + k_z^2 = k^2$ and the frequency of harmonic disturbances, Using (2)-(9) in (1), we obtain the following algebraic equations for the components.

$$M_1 v_x - \left(\frac{K_z^2 V^2 K^2 A_3}{A_2} + 2\Omega_z\right) v_y + \frac{ik_x}{k^2}\Omega_T^2 s = 0 \tag{10}$$

$$\left(\frac{K_z^2 K^2 V^2 A_3}{A_2} + 2\Omega_z\right) v_x + M_2 v_y - 2\Omega_z v_z = 0 \tag{11}$$

$$2\Omega_x u_y + d_1 v_z + \frac{ik_z}{k^2}\Omega_T^2 s = 0 \tag{12}$$

The divergence of (1) with the aid of (2)-(9) gives

$$\frac{ik_x k^2 V^2 A_1}{A_2} v_x - \left\{\frac{iK_x K_z^2 V^2 K^2 A_3}{A_2} + 2i(k_x\Omega_z - \Omega_x k_z)\right\} v_y - M_3 s = 0 \tag{13}$$

Where$s = \frac{\delta\rho}{\rho}$is the condensation of the medium

$\gamma = \frac{C_p}{C_v} = \frac{C^2}{C'^2}$ ratio of the specific heat, $V = \frac{B}{\sqrt{4\pi\rho}}$is the Alfven velocity,

$A = \frac{KN}{\rho}$ has the dimension of frequency, $\tau = \frac{m}{K_s}$ is the relaxation time,

τA $= \frac{\rho_s}{\rho}$ is the mass conservation, $\sigma = i\omega$ is the growth rate of perturbation,

$\Omega_\vartheta = \vartheta K^2, A_1 = \sigma f, f = \left(1 + \frac{C^2K^2}{\omega_{pe}^2}\right), \theta_k = \frac{\lambda}{\rho C_p}$ is the thermometric Conductivity, C and C' is the adiabatic and isothermal velocities of sound.

$$d_1 = \left(\sigma + \Omega_\vartheta + \frac{\beta\sigma}{\sigma\tau + 1}\right), d_2 = \left(\frac{K_z^2 K^2 V^2 A_3}{A_2} + 2\Omega_z\right), d_3 = \left(\frac{iK_x K_z^2 K^2 V^2 A_3}{A_2} + 2iM_4\right),$$

$$\Omega_{j'}^2 = (C'^2K^2 - 4\pi G\rho), \Omega_j^2 = (C^2K^2 - 4\pi G\rho)\ \Omega_T^2 = \left(\frac{\sigma\Omega_j^2 + \gamma_k\Omega_{j'}^2}{\sigma + \gamma_k}\right),$$

$$M_1 = \left(d_1 + \frac{V^2K^2}{A_1}\right), M_2 = \left(d_1 + \frac{V^2K_z^2}{A_1}\right), M_3 = \left(\sigma d_1 + \Omega_T^2\right),$$

$M_4 = (k_x\Omega_z - \Omega_x k_z), A_2 = (A_1^2 + A_3^2 K_z^2 K^2), A_3 = \left(\frac{CH}{4\pi Ne}\right),$

The nontrivial solution of the determinant of the matrix obtained from (11)-(13) with $(v_x, v_y, v_z,)$ having various coefficients, that should vanish is to give the following dispersion relation.

$$(\sigma d_1 + \Omega_T^2)(M_1 M_2 d_1 + 4\Omega_x^2 M_1 + d_1 d_2^2) - \frac{K_x^2 V^2 A_1}{A_2}\Omega_T^2(M_2 d_1 + 4\Omega_x^2) - 2\Omega_x k_z \Omega_T^2\left(\frac{iM_1 d_3}{K^2} + \frac{K_x A_1 d_2}{A_2}\right) + \frac{iK_x}{K^2} d_1 d_2 d_3 \Omega_T^2 = 0 \qquad (14)$$

The dispersion relation (14) shows the combined influence of fine dust particles thermal conductivity, finite electron inertia, magnetic field, viscosity and rotation of the self-gravitational instability of a homogeneous plasma. If we ignore the effect of finite electron inertia then (14) reduces to Chhajlani and Vyas (4). The present results are also similar to those of Chhajlani and Sanghvi (3) in the absence of rotation and finite electron inertia neglecting the contribution of finite Larmor radius (FLR) connection and Hall parameter in that case. In the absence of finite fine dust particles (14) give similar result as are obtained by prajapati et al.(5) excluding the effects of arbitrary radiative heat-loss functions , permeability ,electrical resistivity and Hall-effect in that case.

Thus with these correlations we find that the dispersion relation (14) is modified due to the combined effects of finite dust particles, finite electron inertia, rotation , magnetic field, viscosity and thermal conductivity. This dispersion relation well be able to predict the complete information about the a caustic wave, Alfven wave and Jeans gravitational instability of the gaseous plasmas considered. The above dispersion relation is very lengthy and to analysis the effects of each parameter we now reduce the dispersion relation (14) for two modes of propagation.

4. Analysis of the Dispersion Relation:-

Now we shall discuss the dispersion relation given by equation (14) for different cases of rotation and propagation as follows.

4.1. Axis of rotation parallel to the magnetic field($\Omega \parallel \boldsymbol{B}$):-

Axis of rotation along the magnetic field i.e. $\Omega_x = 0$ and $\Omega_z = \Omega$. for the convenience equations (14) reduces to

$$(\sigma d_1 + \Omega_T^2)\left\{M_1 M_2 d_1 + d_1\left(\frac{K_z^2 K^2 V^2 A_3}{A_2} + 2\Omega\right)^2\right\} - \frac{K_x^2 V^2 A_1}{A_2}\Omega_T^2 d_1 M_2 + \frac{iK_x}{K^2} d_1\left(\frac{K_z^2 K^2 V^2 A_3}{A_2} + 2\Omega\right)\left(\frac{iK_x K_z^2 K^2 V^2 A_3}{A_2} + 2iK_x\Omega\right)\Omega_T^2 = 0 \qquad (15)$$

4.1.1. Longitudinal mode of propagation ($\boldsymbol{K} \parallel \boldsymbol{B}$):-

For this case we assume that all the perturbations and longitudinal to the direction of

the magnetic field($i.e.\ K_x = 0\,, K_z = K$).
Thus the dispersion relation (15) reduces in the simple from to give

$$d_1\left[M_1^2 + \left(2\Omega + \frac{K^4V^2A_3}{A_2}\right)^2\right]\left(\sigma d_1 + \Omega_T^2\right) = 0 \tag{16}$$

The equation (16) shows the dispersion relation which has tree functions. we discuss them separately. In the above dispersion relation first factor equated to zero gives,

$$d_1 = 0$$

$$\tau\sigma^2 + \sigma\{1 + \tau(A + \vartheta_k)\} + \vartheta_k = 0 \tag{17}$$

The first factor of this dispersion relation represent stable mode.
The second factor equated to zero gives,

$$M_1^2 + \left(2\Omega + \frac{K^4V^2A_3}{A_2}\right)^2 = 0$$

$$\sigma^8\tau^2f^4 + A_7\sigma^7 + A_6\sigma^6 + A_5\sigma^5 + A_4\sigma^4 + A_3\sigma^3 + A_2\sigma^2 + A_1\sigma + A_0 = 0 \tag{18}$$

This is Eight degree polynomial equations and shows the combined influence of fine dust particles, viscosity, Hall-Effect, rotations, magnetic field, thermal-conductivity in the transverse mode of propagation when axis of rotation is parallel to the direction of magnetic field.
Where the coefficients are very lengthy and emitted constant term are $A_0 = K^8\vartheta_k^2A_3^4 + 4\Omega^2K^8A_3^4 + 4\Omega\, K^8V^2A_3^3 + K^8V^4A_3^2$
The third factor equated to zero gives,

$$\left(\sigma d_1 + \Omega_T^2\right) = 0$$

$$\sigma^4\tau + \sigma^3\{1 + \tau(A + \vartheta_k)\} + \sigma^2\left[(\vartheta_k + \Omega_k) + \tau\left\{\Omega_j^2 + \Omega_k(A + \vartheta_k)\right\}\right] + \sigma\left(\Omega_j^2 + \vartheta_k\Omega_k + \tau\Omega_k\Omega_{j\prime}^2\right) + \Omega_k\Omega_{j\prime}^2 = 0 \tag{19}$$

This is four degree polynomial equations and shows the combined influence of fine dust particles, viscosity, rotations, magnetic field, thermal-conductivity in the transverse mode of propagation when axis of rotation is parallel to the direction of magnetic field.

4.1.2.Transverse Mode of Propagation ($\boldsymbol{K}\perp \boldsymbol{B}$):-

For this case we assume all the perturbations transverse to the direction of the magnetic field($i.e. K_x = K, K_z = 0$). Thus the dispersion relation (15) reduces in the simple from to gives,

$$d_1^2\left[\sigma d_1^2 + d_1\left(\Omega_T^2 + \frac{\sigma K^2V^2}{A_1}\right) + 4\Omega^2\sigma\right] = 0 \tag{20}$$

This dispersion relation is the product of two independent factors. These factors show the mode of propagations incorporating different parameters as discussed below. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (20) simplification written as

$$\begin{aligned}
&\sigma^6\tau^2 f + \sigma^5\tau f\{2 + \tau(2A + 2\vartheta_k + \Omega_k)\}\\
&\quad + \sigma^4\left[\tau^2 f\{\Omega_j^2 + A\Omega_k + (A + \vartheta_k)(A + \vartheta_k + \Omega_k)\}\right.\\
&\quad \left.+ 2\tau f\{1 + (A + 2\vartheta_k + \vartheta_k)\}\right]\\
&\quad + \sigma^3\left[\tau^2 f\{(A + \vartheta_k)\Omega_j^2 + \vartheta_k^2 + \Omega_k(\Omega_{j'}^2 + A^2)\}\right.\\
&\quad + \tau\{\Omega_k(2f\Omega_{j'}^2 + K^2V^2 + 4\Omega^2 f) + (A + \vartheta_k)(f\Omega_j^2 + K^2V^2)\\
&\quad \left.+ f\vartheta_k(\Omega_j^2 + \vartheta_k\Omega_k + \Omega_k)\} + f(2\vartheta_k + \Omega_k)\right]\\
&\quad + \sigma^2\left[\tau^2(A + \vartheta_k)(f\Omega_k\Omega_{j'}^2)\right.\\
&\quad + \tau\{\Omega_k(2f\Omega_{j'}^2 + K^2V^2 + 4\Omega^2 f)\\
&\quad + (A + \vartheta_k)(f\Omega_j^2 + K^2V^2 + \vartheta_k + \Omega_k) + \vartheta_k f(\Omega_j^2 + \vartheta_k\Omega_k)\}\\
&\quad \left.+ (f\Omega_j^2 + K^2V^2 + \vartheta_k + \Omega_k) + f\vartheta_k(\vartheta_k + 2\Omega_k)\right]\\
&\quad + \sigma\left[\tau\{(A + \vartheta_k)\Omega_k(\Omega_{j'}^2 + K^2V^2) + \vartheta_k\Omega_k f\Omega_{j'}^2\}\right.\\
&\quad \left.+ \Omega_k(f\Omega_{j'}^2 + K^2V^2 + 4\Omega^2 f) + \vartheta_k(f\Omega_j^2 + K^2V^2 + f\vartheta_k\Omega_k)\right]\\
&\quad + \vartheta_k\Omega_k(f\Omega_{j'}^2 + K^2V^2) = 0 \qquad (21)
\end{aligned}$$

This is Six degree polynomial equations and shows the combined influence of fine dust particles, viscosity, rotations, magnetic field, thermal-conductivity in the transverse mode of propagation when axis of rotation is perpendicular to the direction of magnetic field.

5. Axis of rotation perpendicular to the magnetic field$(\Omega \perp \boldsymbol{B})$:-

In the case of a rotation axis perpendicular to the magnetic field, we put $\Omega_x = \Omega \; and \; \Omega_z = 0$ in the dispersion relation (14) and this gives,

$$\begin{aligned}
&(\sigma d_1 + \Omega_T^2)\left\{M_1 M_2 d_1 + 4\Omega^2 M_1 + d_1\left(\frac{K_z^2 K^2 V^2 A_3}{A_2}\right)^2\right\} - \frac{K_x^2 V^2 A_1}{A_2}\Omega_T^2(d_1 M_2 + 4\Omega^2)\\
&\quad - 2\Omega\, k_z\, \Omega_T^2\left\{\frac{iM_1}{K^2}\left(\frac{iK_x K_z^2 K^2 V^2 A_3}{A_2} - 2i\Omega\, k_z\right) + \frac{K_x A_1}{A_2}\left(\frac{K_z^2 K^2 V^2 A_3}{A_2}\right)\right\}\\
&\quad + \frac{iK_x}{K^2} d_1\left(\frac{K_z^2 K^2 V^2 A_3}{A_2}\right)\left(\frac{iK_x K_z^2 K^2 V^2 A_3}{A_2} - 2i\Omega\, k_z\right)\Omega_T^2 = 0 \qquad (22)
\end{aligned}$$

5.1.1. Longitudinal mode of propagation

For this case we assume that all the perturbations and longitudinal to the direction of the magnetic field$(i.e.\ K_x = 0\,, K_z = K)$.

Thus the dispersion relation (22) reduces in the simple from to give

$$d_1\left[M_1(\sigma d_1 + \Omega_T^2)M_1 + 4\Omega^2\sigma + \frac{K^8 V^4 A_3^2}{A_2^2}(\sigma d_1 + \Omega_T^2)\right] = 0 \qquad (23)$$

This dispersion relation is the product of two independent factors. These factors show the mode of propagations incorporating different parameters as discussed below. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (23) simplification written as

$$\sigma^{12}\tau^3 f^4 + A_{11}\sigma^{11} + A_{10}\sigma^{10} + A_9\sigma^9 + A_8\sigma^8 + A_7\sigma^7 + A_6\sigma^6 + A_5\sigma^5 + A_4\sigma^4 + A_3\sigma^3 + A_2\sigma^2 + A_1\sigma + A_0 = 0 \quad (24)$$

This is twelve degree polynomial equations and shows the combined influence of fine dust particles, viscosity, rotations, magnetic field, thermal-conductivity, electron inertia and Hall-effect in the transverse mode of propagation when axis of rotation is parallel to the magnetic field.

Where the coefficients are very lengthy and emitted constant term are, $A_0 = K^8 A_3^4 \vartheta_k^2 \Omega_k \Omega_{j'}^2 + K^8 V^4 A_3^2 \Omega_k \Omega_{j'}^2$

5.1.2. Transverse Mode of Propagation $(K \perp B)$:-

For this case we assume all the perturbations transverse to the direction of the magnetic field$(i.e. K_x = K, K_z = 0)$. Thus the dispersion relation (22) reduces in the simple from to gives,

$$d_1\left(d_1^2 + 4\Omega^2\right)\left(M_1\sigma + \Omega_T^2\right) = 0 \quad (25)$$

The equation (25) shows the dispersion relation which has tree functions. we discuss them separately. The first factor of this dispersion relation is stable mode as discussed in the previous case and the second factor of the dispersion relations (25) simplification written as

$$\sigma^4\tau^2 + 2\sigma^3\tau\{1 + \tau(A + \vartheta_k)\} + \sigma^2\left[\{1 + \tau(A + \vartheta_k)\}^2 + \tau\left(2\vartheta_k + \tau 4\Omega^2\right)\right] + \sigma\left[2\vartheta_k\{1 + \tau(A + \vartheta_k)\} + \tau 8\Omega^2\right] + \vartheta_k^2 + 4\Omega^2 = 0 \quad (26)$$

This is four degree polynomial equations and shows the combined influence of fine dust particles, viscosity, rotations, magnetic field, thermal-conductivity in the transverse mode of propagation when axis of rotation is perpendicular to the direction of magnetic field.

The third factor equated to zero gives,

$$\sigma^4\tau f + \sigma^3 f\{1 + \tau(A + \vartheta_k + \Omega_k)\} + \sigma^2\left[f(\vartheta_k + \Omega_k) + \tau\left(f\Omega_j^2 + K^2V^2 + f\Omega_k(A + \vartheta_k)\right)\right] + \sigma\left(\Omega_j^2 + K^2V^2 + f\Omega_k\vartheta_k\right) + \tau\Omega_k\left(f\Omega_{j'}^2 + K^2V^2\right) + \Omega_k\left(f\Omega_{j'}^2 + K^2V^2\right) = 0 \quad (27)$$

This is four degree polynomial equation and show the combined influence of various parameters, fine dust particles, viscosity, rotations, magnetic field, thermal conductivity in the transverse mode of propagation when axis of rotation perpendicular to the magnetic field.

6. Conclusions:-

In the present research work, we have studied the problem of self-gravitational instability of infinite homogeneous gaseous viscous plasma in the presence of suspended particles and transverse magnetic field under the influence of Hall-current, thermal-conductivity and finite electron inertia. The general dispersion relation is obtained, which is modified due to the presence of all parameters. This dispersion relations is discussed for longitudinal and transverse modes of propagation, which are further discussed for axes of rotation parallel and perpendicular to the direction of the magnetic field. The viscosity has stabilizing effect on the instability. The rotation and magnetic field have their influence in only in the transverse mode of propagation. It can be observed from the various dispersion relation that an infinitely conducting medium the condition of Jeans instability of self-gravitating media is modified due to the presence of a magnetic field and finite electron inertia and it is understating of Hall current and suspended particles.

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