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# Analytical Study of MHD Thermoconvective Waves through its Propagation

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**Abstract**

Following is the analytical study on the propagation of undamped thermoconvective waves, an electrically conducting viscous fluid is hypothesized which has the property of uniform horizontal magnetic field in heating the uniform vertical concentration gradient for a solute. It has seen that undamped thermoconvective waves propagation in a specific order, whereas the heating of fluid, is based on the solute concentration, this decreased vertically or show vertical pattern. If the heating of fluid takes place in upward manner the propagation of waves is highly effected, the above aspect proves hypothetically and has shown that its laboratory demonstration is also possible.

## 1. Introduction

Many scientists has worked on the hypothesis of thermoconvective waves with MHD. The condition $k_\theta > \eta$ ($k_\theta = 4.5 \times 10^{-2} cm^2 sec^{-1} and\ \eta = 7.6 \times 10^{-3} cm^2 sec^{-1}$),does not exist in hydromagnetic stability has been studied by 'Chandrasekhar' (1961). 'Luikov and Berkovsky' (1970) observed that phenomenon of BENARD convection does not exist for MHD or the propagation of waves showed decreased manner. The waves having this character are known as TCW, which are effected by nature of fluid and gravitational field. The moving property of TCW specially in fluid which have the property of electrical condition shows the propagation of the waves uniformly in horizontally magnetic field was investigated by 'Takashima' (1972). 'Bhattacharyya and Gupta' (1985) studied the mechanism of propagation of TCW in the binary mixture situation. The propagation of the damped MHD thermoconvective waves depend on the temperature and heat the waves also shows the relationship between thermal and magnetic diffusivity ($k_\theta > \eta$) where $k_\theta$ and $\eta$ represent thermal and diffusivity of the fluid, this situation is possible in astrophysical condition.

The present study is based on a solute with uniform vertical concentration gradient for the study of propagation of undamped MHD thermoconvective waves for viscous fluid. The whole study is the indication for a certain condition of undamped propagation of TCW ($k_\theta > \eta$).

## 2. Formulation and Solution of the problem

The concerned equations of undamped MHD thermoconvective waves can be represented in the form as given below:

$$\mathrm{div}\,\vec{v} = 0, \tag{2.1}$$

$$\mathrm{div}\,\vec{H} = 0, \tag{2.2}$$

$$\rho \frac{d\vec{v}}{dt} = -\,\mathrm{grad}\,Q + \mu_e \vec{H}.\mathrm{grad}\vec{H} + \mu\nabla^2\vec{v} + \rho\vec{g}, \tag{2.3}$$

$$\frac{d\vec{H}}{dt} = \vec{H}.\mathrm{grad}\vec{v} + \eta\nabla^2\vec{H}, \tag{2.4}$$

$$\frac{d\theta}{dt} = k_\theta \nabla^2\theta, \tag{2.5}$$

$$\frac{dC}{dt} = k_\rho \nabla^2 C. \tag{2.6}$$

Where

$$\frac{d}{dt} = \frac{\partial}{\partial t} + \vec{v}.\vec{\nabla}$$

The equation of state

$$\text{(i.e.) } \rho = \rho_0[1-\alpha(\theta-\theta_0)-\alpha'(C-C_0)] \tag{2.7}$$

Reduces to

$$\rho = \rho_0 + (\vec{\nabla}\rho)_\theta + (\vec{\nabla}\rho)_p \,. \tag{2.8}$$

Here, $(\vec{\nabla}\rho)_\theta$and$(\vec{\nabla}\rho)_p$ are the change in the density variation due to the variation of temperature and concentration respectively. Fluid velocity, density, magnetic permeability, coefficient of dynamic viscosity magnetic field, temperature, concentration of solute and acceleration due to gravitational are denoted by $\vec{v}, \rho, \mu_e, \mu, \vec{H}\, \theta, C,$ and $\vec{g}$ respectively. As described earlier that the magnetic diffusivity indicated by $\eta\,.\sigma$ is the fluid' electrical conductivity in the equation (2.3), the pressure of the fluid indicated by Q where as $\frac{\mu_e H^2}{2}$ denotes the magnetic pressure. When temperature increamentation takes place the density of the fluid decreased, whereas if the density increases, the solute concentration will also be increased.

If we consider the mass transfer equation as described in equation (2.6), the Fick's law is used, according to which , diffusion flux is proportional to concentration gradient, actually diffusion flux is the total amount of solute which is transported by diffusion through a single unit area with a single unit time, the diffusion flux $\hat{\imath}$ showed correlation variance with $\Delta C$ and $\Delta\theta$ . If we consider the heat flux $\vec{v}$, this is also depends on $\Delta C$ and $\Delta\theta$ .

We have the equation

$$\hat{\imath} = -\rho k_p\left[\vec{\nabla}C + \left(\frac{k_D}{\theta}\right)\vec{\nabla}\theta\right]. \tag{2.9}$$

Which indicates the Fick's law with the addition of mass transfer due to the change in correlation gradient, the temperature gradient is also responsible for the mass transfer as described above. This is associated with soret effect and denotes the thermal diffusivity in the equation (2.9) ,where the coefficient $k_D$ is the ratio of thermal diffusion. There is also the phenomenon of heat transfer with the variation in concentration gradient is highly effected in a binary mixture, in addition to heat transfer due to temperature gradient. This another heat transfer due to $\Delta C$ is defined as "diffusion-thermo effect" or 'Dufour'. In the present paper study soret and Dofour effect are not considered due to neglectivity of these laws are important for mixture of the gas (incompressible binary mixture in the studies). The density variation$(\vec{\nabla}\rho)_p$ denotes in the L.H.S. of the equation (2.3). Here is displaced by equation (2.8) and is negligible. The equation (2.7) and (2.8) represent the concentration in the basic state, there is the variation $\vec{v}, \rho, \vec{H}, \theta, Q,$ and$C$ can be represented in the following manner when the state is undisturbed.

$$\vec{v} = 0 \quad Q = Q_B(x), \qquad \rho = \rho_B(x), \tag{2.10}$$

$$\theta = \theta_0 - \beta x, \qquad C = C_0 - \beta' x, \qquad \vec{H} = \vec{H}_0$$

Where $\beta$ and $\beta'$ may be either positive or negative. Comparing equations (2.1) to (2.8),we have

$$\frac{d\bar{Q}_B}{dx} + \rho_B\bar{g} = 0, \quad \rho_B = \rho_0(1+\alpha\beta x + \alpha'\beta' x). \tag{2.11}$$

Where the transverse plane waves are considered for propagation along y-axis, the variables are considered as :

$$\vec{v} = (v_1, 0) \;\; Q = Q_B(x) + Q_1, \quad \rho = \rho_B(x) + \rho_1, \tag{2.12}$$

$$\vec{H} = (h, \vec{H}_0) \;\; \theta = \theta_0 - \beta x + \theta_1, \quad C = C_0 - \beta' x + \phi_1 \tag{2.13}$$

The functions of y and t are variable with perturbation quantities $v_1$ , $Q_1, \rho_1$ , $h, \theta_1, \phi_1$. $\vec{H}$and h both arise due to the expansion of the undisturbed horizontal magnetic line of forces with the vertical movability of by propagation of waves.

Equations (2.1) and (2.2) elaborate the condition of magnetic solenoidel and equation of continuity, these are identical with reference to $\vec{v}$ and $\vec{H}$ as shown in equations (2.12) and (2.13). By using equations (2.12) and (2.13) in equations (2.3) to (2.6) and taking the help of equations (2.7),(2.8),(2.10) and (2.11),we get the following equations:

$$\vec{\nabla}_v v_1 - \vec{g}(\alpha\theta_1 + \alpha'\phi_1) - \frac{\mu_e \vec{H}_0}{\rho_0}\frac{\partial h}{\partial y} = 0, \tag{2.14}$$

$$\vec{\nabla}_\eta h - \vec{H}_0\frac{\partial v_1}{\partial x} = 0, \tag{2.15}$$

$$\vec{\nabla}_{k_\theta}\theta_1 - \beta v_1 = 0, \tag{2.16}$$

$$\vec{\nabla}\phi_1 - \beta' v_1 = 0, \tag{2.17}$$

Where

$$\nu = \frac{\mu}{\rho_0}, \qquad \vec{\nabla}_x \equiv \frac{\partial}{\partial t} - x\frac{\partial^2}{\partial y^2}.$$

The equations (2.14) to (2.17) represent the phenomenon of natural convection with the help of equations (2.7) and (2.8),we can find the approximation of Oberneck- Boussinesq, when the small oscillation takes place. Here we can explain a specific force for a single fluid pressure can be denoted by p ,{ $\rho = \rho(\theta, p)$ . An algebraic equation of state is connected with $\rho, \theta$ and p can be integrodifferential equation as below:

$$d\rho = \left(\frac{\partial\rho}{\partial\theta}\right)_p d\theta + \left(\frac{\partial\rho}{\partial p}\right)_\theta dp, \tag{2.18}$$

this equation is the derivative extended part of $\alpha = -\frac{1}{\rho}\left(\frac{\partial\rho}{\partial\theta}\right)_p$ *and* $\beta_\theta = \frac{1}{\rho}\left(\frac{\partial\rho}{\partial p}\right)_\theta$.Equation for $\rho$ with density distribution $\rho_0$ can be solved at equilibrium state as below:

$$\rho = \rho_0\left[1 - \alpha(\theta - \theta_0) + \beta_\theta(p - p_0)\right] \tag{2.19}$$

if we consider horizontal temperature difference for a gravitational field and is no forced convection $p - p_0 = 0$, the value of $p - p_0$based on solution for vertical temperature differences, this cannot be shown as priori. The natural convection can be shown slow motion with minute rates of deformation, if pressure of all particles can assumed as hydrostatic in nature. So we can take $p - p_0 \sim \rho g L$ ,here L is the vertical length ,then the equation (2.19) takes of the form

$$\frac{\text{density variation due to compressibility}}{\text{density variation due to thermal expansion}} \sim \frac{\beta_\theta \rho g L}{\alpha \Delta\theta} \tag{2.20}$$

Here $\Delta\theta = \theta - \theta_0$, if L=2m and $\Delta\theta \sim 20^0$C for water , the ratio can be $2.5\text{x}10^{-3}$.Here effect of pressure on density variation can be neglected. According to 'Arpaci'and Larsen'for atmospheric air L=2cm and $\Delta\theta \sim 20^0$C,the ratio should be $23.5\text{x}10^{-3}$.Here in the effect of compressibility on density change can be ignored or neglected . In equation (2.20) the effect of compressibility on density change can be ignored for thick layer ($\vec{H}$) and temperature difference is small. So the equation of state (2.19) can be summarized in the form of equation

$$\rho = \rho_0\left[1 - \alpha(\theta - \theta_0)\right] \tag{2.21}$$

The phenomenon of compressibility effect on density change has proved in the above equation. $\alpha$, the volume expansion coefficient having the range of $10^{-3}$ to$10^{-4}$for most of the fluid ,the variations in the density are 1% at $20^0$C for small variation in the temperature, here density is constant in terms of natural convection except in the buoyancy force $\rho_0\vec{g}\alpha\Delta\theta$ ,which is proved by equation (2.21), the Oberbeck-Boussinesq approximation has proved by mathematical justification if the following conditions are governed:

i) Movement is buoyancy- driven and no forced convection is seen.
ii) The thickness of layer is not large when natural convection takes place.
iii) $\theta$ is small compared with fluid layer.

From above statement the Oberbeck- Boussinesq approximation has proved in two situations found from above statement:

i) The magnitude of $\alpha'$in the modified form of equations (2.7) and (2.8), is very small ($\alpha' < 0$).
ii) C which is variation in the concentration throughout the fluid layer is minutely compared with Q itself.

The Oberbeck- Boussinesq approximation has proved by buoyancy force $\vec{g}(\alpha\theta_1 + \alpha'\phi_1)$in the equation (2.14) i.e. momentum equation. The thickness of the layer in which natural convection takes place is not too large in our opinion the length of the tank containing the binary mixture can be compared with height of tank

$$(v_1, \theta_1, \phi_1, h) = (V, \xi, \phi, G)e^{i(\omega t - ky)} \tag{2.22}$$

Where $V, \xi, \phi$ *and* $G$ are constant,$\omega$ is real and wave number is k. Subscription of the equation (2.22) in equations (2.14) to (2.17) and elimination of $V, \xi, \phi$ *and* $G$, thus we get the dispersion relation in the form of non dimensionless condition of the equation in the following manner :

$$\left(a_1+\frac{\ell_1^2}{P}\right)\left(a_1+\frac{\ell_1^2}{R_m}\right)\left[(a_1+\ell_1^2)\left(a_1+\frac{\ell_1^2}{R}\right)-\gamma_1\right]-\left(a_1+\frac{\ell_1^2}{R}\right)\left[\gamma'\left(a_1+\frac{\ell_1^2}{R_m}\right)-M\ell_1^2\left(a_1+\frac{\ell_1^2}{P}\right)\right]=0, \qquad (2.23)$$

Where

$$\omega_1=\left(\frac{v}{g^2}\right)^{\frac{1}{3}}\omega\ , \qquad \ell_1=\left(\frac{v}{g^2}\right)^{\frac{1}{3}}\ell\ , \quad R=\frac{\nu}{k_\theta},\quad P=\frac{\nu}{k_P},$$

$$\gamma_1=\left(\frac{v^2}{g}\right)^{\frac{1}{3}}\alpha\beta,\quad R_m=\frac{v}{\eta}\ ,\ \gamma_1'=\left(\frac{v^2}{g}\right)^{\frac{1}{3}}\alpha'\beta'\ ,\ M=\frac{\mu_e H_0^2}{\rho_0(\nu g)^{2/3}},\quad a_1=i\omega_1. \qquad (2.24)$$

If there is no presence of magnetic field (M=0) and there is neither any type of temperature gradient nor any concentration of solute gradient ($\gamma_1=\gamma_1'=0$). Equation (2.23) paired in four first order equation of $\ell_1^2$ and explain pure viscous diffusion waves ($\nu$-waves), pure mass diffusion waves ($k_p-$ waves), pure thermal diffusion waves ($k_\theta-$ waves) and pure magnetic waves ($\eta-$ waves). This is known very well that amplitude of waves described by a specific factor of $\exp(2\pi)\simeq 540$ times per wave lenth. These type of waves are very strongly damped. In the following situation $M\neq 0, \gamma_1\neq 0, \gamma_1'\neq 0$, the pure waves joined to produce four type of mode's like modified $k_\theta-$ waves , modified $k_p-$ waves, modified $\nu$-waves and modified $\eta-$ waves .This waves shows possibilities of undamped TCW. The value of $\ell_1$should be actual for undamped propagation of TCW, here the speed of dimensionless phase shows $\frac{\omega_1}{\ell_1}$ position. When we solve the imaginary part of equation (2.23) ,we can find the equations (2.25) and (2.26) for $\omega_1\neq 0$ and $\ell_1\neq 0$ as given below:

$$\omega_1^4-\left[\left\{\frac{1}{RR_m}+\frac{1}{P}+\left(\frac{1}{p}+1\right)\left(\frac{1}{R}+\frac{1}{R_m}\right)\right\}\ell_1^4+M\ell_1^2-\gamma_1-\gamma_1'\right]\omega_1^2+\frac{\ell_1^8}{RPR_m}+\frac{M\ell_1^6}{RP}-\frac{\ell_1^4}{R_m}\left(\frac{\gamma_1'}{R}+\frac{\gamma_1}{P}\right)=0 \qquad (2.25)$$

And

$$\omega_1^2\left(\frac{1}{R_m}+\frac{1}{R}+\frac{1}{P}+1\right)=\frac{\ell_1^4}{RP}\left(\frac{1}{R_m}+1\right)+\ell_1^2\left(\frac{1}{R}+\frac{1}{P}\right)\left(\frac{\ell_1^2}{R_m}+M\right)-\left[\gamma_1\left(\frac{1}{R_m}+\frac{1}{P}\right)+\gamma_1'\left(\frac{1}{R}+\frac{1}{R_m}\right)\right] \qquad (2.26)$$

Equation 2.26 can be written as

$$\omega_1^2=B_1\ell_1^4+B_2\ell_1^2+B_3 \qquad (2.27)$$

Where

$$B_3=-\left[\frac{\gamma_1\left(\frac{1}{R_m}+\frac{1}{P}\right)+\gamma_1'\left(\frac{1}{R}+\frac{1}{R_m}\right)}{\left(\frac{1}{R_m}+\frac{1}{R}+\frac{1}{P}+1\right)}\right] \qquad (2.28)$$

In the consequences of equations (2.27)and (2.25) takes the form

$$\begin{aligned}&\ell_1^8\left[B_1^2-B_1\left\{\frac{1}{RR_m}+\frac{1}{P}+\left(\frac{1}{P}+1\right)\left(\frac{1}{R}+\frac{1}{R_m}\right)+\frac{1}{RPR_m}\right\}\right]\\&+\ell_1^6\left[2B_1B_2-B_1M-B_2\left\{\frac{1}{RR_m}+\frac{1}{P}+\left(\frac{1}{P}+1\right)\left(\frac{1}{R}+\frac{1}{R_m}\right)\right\}+\frac{M}{RP}\right]\\&+\ell_1^4\left[2B_1B_3+B_2^2+B_1(\gamma_1+\gamma_1')-B_3\left\{\frac{1}{RR_m}+\frac{1}{P}+\left(\frac{1}{P}+1\right)\left(\frac{1}{R}+\frac{1}{R_m}\right)\right\}-MB_2-\frac{1}{R_m}\left(\frac{\gamma_1}{R}+\frac{\gamma_1'}{P}\right)\right]\\&+\ell_1^2[2B_2B_3+B_2(\gamma_1+\gamma_1')-B_3M]+B_3^2+B_3(\gamma_1+\gamma_1')=0\end{aligned} \qquad (2.29)$$

Equation (2.29) is a biquadratic equation in $\ell_1^2$ with real coefficients. When we consider the product of $\ell_1^2, \ell_2^2, \ell_3^2$and $\ell_4^2$ assume as four roots as a negative, the equation (2.29) represent at least one positive root. Using the values of $B_1$, $B_2$and $B_3$ from equations(2.26)to (2.28) in equation (2.29), we get

$$(\ell_1\ell_2\ell_3\ell_4)^2=\frac{C}{D} \qquad (2.30)$$

Where

$$C=\frac{-\left[\gamma_1\left(\frac{1}{R_m}+\frac{1}{P}\right)+\gamma_1'\left(\frac{1}{R}+\frac{1}{R_m}\right)\right]\left[\gamma_1\left(\frac{1}{R}+1\right)+\gamma_1'\left(\frac{1}{P}+1\right)\right]}{\left(\frac{1}{R_m}+\frac{1}{R}+\frac{1}{P}+1\right)^2} \qquad (2.31)$$

$$D = \frac{-\begin{bmatrix} P\left(\frac{1}{R_m}+\frac{1}{R}\right)\left(\frac{1}{R_m}+1\right)\left(\frac{1}{R}+1\right)+\frac{2}{R_m}\left(\frac{3}{R}+\frac{1}{R_m}\right)+2+R\left(\frac{1}{R_m}+\frac{1}{P}\right)\left(\frac{1}{R_m}+1\right)\left(\frac{1}{P}+1\right) \\ +R_m\left(\frac{1}{R}+\frac{1}{P}\right)\left(\frac{1}{R}+1\right)\left(\frac{1}{P}+1\right) \\ +\left(\frac{1}{R}+\frac{1}{P}\right)\left\{6+\frac{1}{RP}+\frac{1}{R_m}+\frac{1}{R_m^2}\right\}+\left(\frac{1}{R}+\frac{1}{P}\right)^2+\frac{4}{R_m}\left(\frac{1}{P}+1\right) \end{bmatrix}}{\left(\frac{1}{R_m}+\frac{1}{R}+\frac{1}{P}+1\right)^2 RPR_m} \tag{2.32}$$

Since $R_m$ ,R and P all are positive, therefore from above equation D < 0

Let us consider

$$\gamma_1\left(\frac{1}{R_m}+\frac{1}{P}\right)+\gamma_1'\left(\frac{1}{R_m}+\frac{1}{R}\right) < 0. \tag{2.33}$$

$$\gamma_1\left(\frac{1}{R}+1\right)+\gamma_1'\left(\frac{1}{P}+1\right) > 0. \tag{2.34}$$

In the above case, equation (2.31) follows that C > 0 and equation (2.30) shows the product of the four roots of the equation (2.29) is negative. In this way equation (2.29) allow to enter one root $\ell_1^2$ , which is positive that $\ell_1$ is real . From equation (2.27), we find $\omega_1^2 > 0$ , here $\omega_1$ is real and the values of $B_1$ and $B_2$ are positive and $B_3 > 0$ with reference to the equation (2.28) and inequality (2.33). When we consider the inequalities (2.33) and (2.34) the undamped TCW can propagate till both $\omega_1$ and $\ell_1$ are real. The following cases may be considered.

i. If $k_\theta > k_p$ (or $R < P$)
   The undamped TCW can propagate in the hatched region A of $\gamma_1 - \gamma_1'$ parameter plane (Fig. 1) from above situation such a region exists when $\gamma_1 > 0$ *and* $\gamma_1' < 0$.
ii. If $k_\theta < k_p$ (or $R > P$) The undamped TCW indicate hatched area B of $\gamma_1 - \gamma_1'$ parameter plane (Fig. 2) from above situation such a zone exists when $\gamma_1 < 0$ *and* $\gamma_1' > 0$.
iii. If $k_\theta = k_p$ (or R = P) The undamped TCW indicate unsatisfactory answer, it means undamped TCWcan not exist. This have no more physical interest.

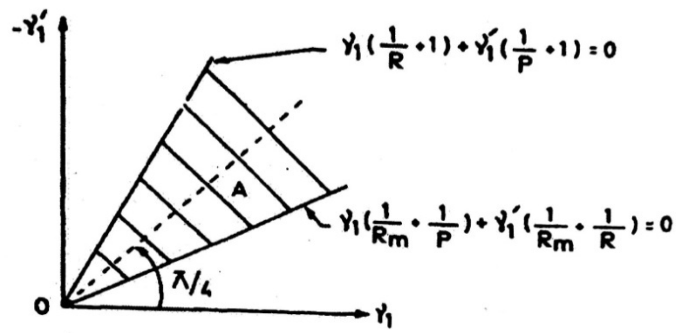


**Fig. 1 : Zone of undamped TCW for $k_\theta > k_p$.**

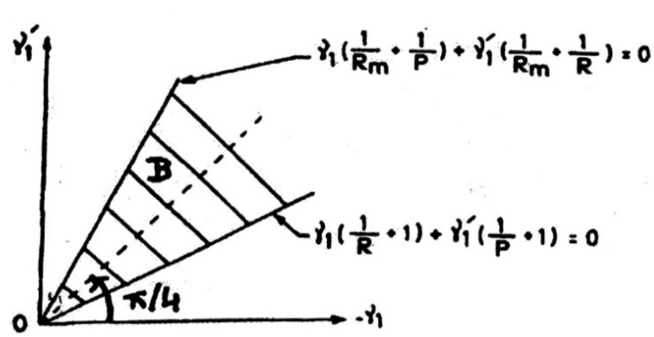


**Fig.2: Zone of undamped TCW for $k_\theta < k_p$**

It is very much interesting phenomenon of propagation of MHD thermoconvective waves in presence of magnetic field which is parallel to the gravitational direction. Another interesting phenomenon is that thermoconvective waves possibilities appear in the binary fluid layer due to heating effect from below or above in the presence of solute, the waves propagation will not be affected by the magnetic field. During the propagation of transverse waves, fluid particles shows movement to upward and downward in a verticle direction, it is also the property of MHD flow that there is no electromagnetic force which initiates in the fluid due to the direction of the fluid flow parallel to the magnetic field. So we can say that the propagation of TCW has not affected by the magnetic field or electric current which is initiated in the flow of propagation.

## 3. Discussion

The inequalities (2.33) and (2.34) implies that the presence of undamped TCW have few physical valuable significance. The conditions of inequalities (2.33)and (2.34)and the conditions used in manetic prandtl number $R_m\left(\frac{v}{\eta}\right)$ do not represent the restriction of $k_\theta$ and $\eta$ (Takashima). Above described condition does not depend on the strength of the magnetic field (M),which are reverse with the result of 'Takashima'. The presence of undamped waves based on the power of magnetic field. Conditions are satisfactory in the two cases $k_\theta > k_p$ and $k_\theta < k_p$where $\gamma_1$and $\gamma_1{}'$ so reserve sign $\alpha > 0$ *and* $\alpha' < 0$ in equation (2.24)which shows $\beta$ and $\beta'$ both positive or both negative. We can find very interesting result on BENARD convection ,if fluid is heated from below ($\beta > 0$) the BENARD convection does not appear. In this condition the solute concentration decrease vertically $\beta' > 0$ ,the propagation of undamped TCW shows $k_\theta > k_p$ $\gamma_1$and $\gamma_1{}'$ behind in the region of A (Fig.1).The result of $k_\theta < k_p$ that undamped TCW can propagate if the layer is heated above $\beta < 0$ which provide that solute concentration increases vertically upward $\beta' < 0$ $\gamma_1$and $\gamma_1{}'$ behind in the zone B (Fig.2).if we consider that a small drop of fluid is displaced downward in the new condition of the drop at higher temperature with higher concentration of solute shows some variation in the condition of variation in k suppose $k_\theta < k_p$. The diffusion of mass should be faster than the heat from the drop for the surrounding area, the drop become less dominant in solute but it is hotter the surrounding associated region, so it increases again. The downward and upward motion is responsible of TCW. In both the cases of k,(i.e.) $k_\theta > k_p$and $k_\theta < k_p$, relationship between potential energy and density appears. This indicates the propagation with viscous and destriction of energy.

At last, we can say that the inequalities (2.33) and (2.34) do not put any relationship with M, the effect is possible for the demonstration of TCW in the laboratory is possible for outer magnetic field.

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