# Magnetic and Viscous Dissipation Effects on Convection-Radiation in Corrugated Channel with Porous Medium and Uniform Heat Flux

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Abstract: This manuscript investigates the influence of Ohmic heating and viscous dissipation on steady free convective MHD fluid flow through a wavy channel; with porous medium in presence of heat generation, bounded by adiabatic-isoflux walls. The fluid is an optically thick non-gray gas. The dimensionless governing coupled nonlinear differential equations obtained; using suitable nondimensional variables, are linearized by perturbation technique and then solved numerically by the mid-point method with Richardson Extrapolation (MMRE) using the software MAPLE. The velocity, temperature, skin-friction coefficient and the rate of heat transfer for meaningful values of some selected parameters are depicted graphically and discussed. It is noticed that increasing of magnetic parameter increases the temperature and decreases the velocity. It is also observed that the velocity/temperature profile is decreasing/increasing with the increasing values of Eckert number while Ohmic heating exhibits the opposite behavior.

Keywords: Joule heating, Adiabatic-isoflux walls, Wavy channel, Temperature dependent heat source and Porous medium

#### 1. Nomenclature

A Permeability parameter

 $B_0$  Intensity of the applied magnetic field  $q_r$  Radiative heat flux

- $C_p$  Specific heat at constant pressure R Radiation parameter
- W Distance between the walls S Heat source/sink parameter
- $E_c$  Eckert number
- $J_{\rho}$  Ohmic heating
- g Acceleration due to gravity
- $G_r$  Grashof number

M magnetic field parameter  $\beta_T$  Thermal expansion coefficient

- $T_{e}$  Temperature in the equilibrium state
- (u, v) Dimensionless velocity components
- $\theta$  Dimensionless fluid temperature

 $\sigma_{e}$  Electrical conductivity

(x, y) dimensional coordinate

- $\rho_e$  Density of the fluid in the equilibrium state
- $k_w$  Wave number
- $\alpha_{\scriptscriptstyle{\lambda e}}$  Mean absorption coefficient  $\lambda$  Wavelength

 $B_{\lambda e}$  Planck's function

#### 2. Introduction

Although the usefulness of corrugated wall(s) components in enhancing heat transfer and, therefore, in reducing the heat exchanger size has been generally understood for some times, but many of its important impacts have been given thoughtful study only in recent times. Its potential applications to physical and engineering devices is mentioned by Vajravelu and Sastri [17]. Vajravelu and Sastri [17] may be considered as the origin of the modern research on the effect of heat transfer on free convection flow in a viscous incompressible fluid. The geometry considered consists of two finitely long (compared to width of the channel) vertical isothermalisothermal walls; one of which is sinusoidally corrugated, and the other being smooth. Many scholars have shown interest, incorporating various parameters of physical interest (see cf. [1], [5], [6], [7], [8], [9], [10], [11], [16]), for different thermal or thermal and species diffusion conditions, where the flow and transfer processes are caused by buoyancy effect of thermal diffusion only or convection and transfer processes governed by buoyancy mechanisms arising from both thermal and species diffusion.

Of the ten papers, only Taneja and Jain [16] examined slip and constant heat flux (Isothermal-isoflux walls) boundary conditions at the flat wall in presence of temperature dependent heat generation or absorption. Other authors have taken constant heat source or sink into consideration under no-slip condition. Overall, the above papers ignored the modelling of thermal boundary conditions which will be significant when we are concerned with the designing of engineering walls/surfaces for their heat transfer. In a given process, engineer must design materials which will economically remove or added as much heat as possible, while in other cases, the converse is desirable; that is, economically preventing heat from being transferred. Insulators are used in multilayers as a more effective prevention against heat loss, thus made the storage of cryogenic material possible. Thermal insulation is the most effective way of improving comfort and save energy. A study of magnetic hydrodynamic free convective flow past an infinite vertical porous plate with constant heat flux has been considered by Amenya et al. [2]. In all these investigations the problem of the frictional and Joule heating has been omitted.

## International Journal of Science and Research (IJSR) ISSN: 2319-7064 Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296

The viscous dissipation, which appears as a source term in the fluid flow generates appreciable temperature, gives the rate at which mechanical energy is converted into heat in a viscous fluid per unit volume. This effect is of particular importance in natural convection in various devices that are subjected to large variation of gravitational force or that operate at high rotational speeds (see Gebhat [12]). The study of Ohmic heating describes the process where the energy of an electric current converted into heat as it flows through a resistance. Ohmic heating is pertinent to an electrical device's design. This is relevant in terms of electrical systems components, such as conductors in electronics, electric heaters, and fuses. The heating of these structures can cause them to degenerate or even melt. Now engineers can add convection cooling into the design to prevent the components and devices from overheating.

The combined action of viscous and magnetic dissipation on MHD convection flow of heat or heat and mass transfer has received considerable attentions in recent years for its application on heat exchanger designs, and in nuclear engineering in connection with the cooling of reactors. Another vital applications is in various devices which are subjected to large variations of gravitational force. This has been the important subject of many recent research articles, for instance, see Jaber [13], Jabir [14], Loganathan and Sivapoornaprnapriya [15] and Balamurugan [3] studied the problem on different geometries, respectively, stretching plate, stretching porous sheet, vertical plate and moving inclined porous plate, for different thermal or thermal and species diffusion conditions. Yet, the preceding literature survey shows that combined influence of viscous and magnetic dissipations on free convection heat transfer in electrically conducting radiating fluid flowing through a porous medium bounded by thermally insulated wavy wall and isoflux flat wall in the presence of temperature dependent heat source or sink has not being investigated and the present work illustrate the issue. The investigation is based on perturbation of the dimensionless basic equations, wherein the amplitude  $\mathcal{E}$ ; characterizing the roughness of the wall assumed small, hence the perturbation parameter. The numerical solutions are then obtained using the software MAPLE. Results are presented graphically and discussed quantitatively for parameter values of practical interest from physical point of view.

## 3. Formulation of the Problem

Here, we consider the steady  $(\frac{\partial()}{\partial t'}=0)$ , two-dimensional  $(\vec{u} = (u', v', 0))$ , laminar free convection flow of a viscous incompressible and electrically conducting fluid through a porous medium bounded by finitely long vertical walls. The channel is characterized by a sinusoidal wavy wall (represented by  $y' = \varepsilon^* \cos k_w x', |\varepsilon^*| < 1$ ), and an opposite wall being flat (represented by y' = W). The wavy wall is considered adiabatic and the constant heat flux is mounted on the flat wall. The x' - axis is taken vertically upwards and parallel to the flat wall and the y' - axis is normal to it.

Properties of the fluid are assumed constant except that density change with temperature that brings about the buoyancy forces in a manner corresponding to the equation

of state: 
$$\frac{\rho - \rho_e}{\rho_e} = \beta_T (T - T_e)$$
. There is no applied

magnetic field in the y'-direction and magnetic Reynold's number is much less than unit, so that Hall, ions slip current and induced magnetic fields are ignored.  $\nabla \vec{B} \oplus$  (Gauss's law of magnetism) gives  $B_y = \text{constant} = B_0$  in the

flow, thus 
$$\vec{B} = (0, B_0, 0)$$
 and Lorentz  
force  $\vec{F} = \vec{J} \times \vec{B} = \sigma_e (\vec{u} \times \vec{B}) \times \vec{B} = -\sigma_e B^2 u$ ,  
 $\nabla \times \vec{B} = \vec{J}$ ,  $\nabla \cdot \vec{E} = 0$  and  $\vec{J} = \sigma_e \vec{u} \times \vec{B}$  (Ohm's law).

Maxwell currents displacement and free charges are neglected. The volumetric heat sources/sink term in the energy equation is assumed to be proportional to the high temperature differences of the form  $Q(T - T_e)$ . The Cogley et al. [4] model; showing that the relation  $\frac{\partial q_r}{\partial r} = 4I(T - T_e)$ 

where 
$$I = \int_0^\infty \alpha_{\lambda_e} \left( \frac{\partial B_{\lambda_p}}{\partial T} \right)_e d\lambda$$
, evaluated at the

Temperature  $T_e$ , is used to stimulate the effects of thermal radiation. Under these assumptions, the governing equations in dimensionless form are:

$$u_x + u_y = 0 \tag{1}$$

$$uu_{x} + vu_{y} = -(P - P_{e})_{x} + u_{xx} + u_{yy} - (M + \frac{1}{A})u + G_{r}\theta$$
(2)

$$uv_{x} + vv_{y} = -P_{y} + v_{xx} + v_{yy} - \frac{1}{A}v$$
(3)

$$P_{r}(u\theta_{x} + v\theta_{y}) = \theta_{xx} + \theta_{yy} - (R - S)\theta + J_{e}E_{c}u^{2}$$
(4)  
+
$$P_{r}E_{c}\left[u_{y}^{2} + v_{x}^{2} + 2u_{y}v_{x} - 4u_{x}v_{y}\right]$$

Where

$$(x, y) = \frac{1}{W}(x', y'), (u, v) = \frac{W}{\upsilon}(u', v'), T_w > T$$

$$M = \frac{\sigma_e B_0^2 W^2}{\rho \upsilon}, G_r = \frac{\beta_T g q_W W^4}{K \upsilon^2}, P_r = \frac{\mu C_p}{K},$$

$$S = \frac{Q W^2}{K}, J_e = \frac{\sigma_e B_0^2 W^2 C_p}{K}, E_c = \frac{\upsilon^2 K}{C_p W^3 q_w}$$

$$A = \frac{k'}{W^2}, R = \frac{4IW^2}{K}, \theta = \frac{K(T - T_e)}{q_w W}$$

$$P = \frac{p' W^2}{\rho \upsilon^2}, P_e = \frac{p'_e W^2}{\rho \upsilon^2}, \lambda = k_w W, \varepsilon = \frac{\varepsilon^*}{W}$$
The boundary conditions are:

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(5)

$$u = 0, v = 0, \frac{\partial \theta}{\partial y} = 0 \text{ at } y = \cos \lambda x$$
  
 $u = 0, v = 0, \frac{\partial \theta}{\partial y} = -1 \text{ at } y = 1$ 

#### 4. Method of Solution

Since the roughness of the wavy wall is assumed small, we seek a perturbation solution for small  $\mathcal{E}$ , where the limit  $\mathcal{E}=0$  is, of course, the limit of a smooth flat wall. We now take the flow field and the temperature to be:

$$u(x, y) = u_0(y) + \varepsilon u_1(x, y), v(x, y) = \varepsilon v_1(x, y)$$

$$P(x, y) = P_0(x) + \varepsilon P_1(x, y),$$

$$\theta(x, y) = \theta_0(y) + \varepsilon \theta_1(x, y)$$
(6)

Put (6) in (1)-(5), equating  $\varepsilon^0, \varepsilon^1$  and neglecting  $0(\varepsilon^2)$ , zeroth- and perturbed quantities denoted by the subscripts 0 and 1, respectively, obtained. Eliminate dimensionless  $P_1$  and

employ stream function  $\Psi_1$  defined by

 $. u_1$ 

$$. u_1(x, y) = -\Psi_{1,y}, v_1(x, y) = \Psi_{1,x}$$
 (7)  
Assume wave-like solutions:

$$\Psi_1(x, y) = \varepsilon e^{i\lambda x} \psi(\lambda, y), \theta_1(x, y) = \varepsilon e^{i\lambda x} \phi(\lambda, y)$$
(8)

(7) becomes  $u_1 = -\varepsilon e^{i\lambda x} \psi'(y), v_1 = \varepsilon i e^{i\lambda x} \psi(y)$ In term of stream function, perturbed quantities reduce to

$$\psi^{i\nu} + \lambda^2 (\frac{\psi}{A} - 2\psi^{"}) - \frac{\psi}{A} - M\psi^{"} - G_r \phi^{'}$$
$$= i\lambda (u_0 \psi^{"} - u_o^{"} \psi)$$
(9)

$$\phi'' - R\phi + S\phi + 2J_e E_c u_0 \psi' - \lambda^2 \phi$$

$$2P_r E_c u_0 (-\psi'' - \lambda^2 \psi = i\lambda P_r (u_0 \phi + \theta_0 \psi) \quad (10)$$

i is the complex unit.

If  $\lambda$  is much less than unity or  $(k_w \ll 1)$ , we write

$$\psi(\lambda, y) = \sum_{j=0}^{\infty} \lambda^{j} \psi_{j}, \phi(\lambda, y) = \sum_{j=0}^{\infty} \lambda^{j} \phi_{j}, (j = 0, 1, 2, ...)$$
(11)

Putting (11) into (9) and (10) in terms of  $\psi_j$ , comparing the

like-power terms of  $\lambda$  to the order of  $\lambda^2$ , overall set of coupled nonlinear set of ordinary differential equations and the boundary conditions for this work:

$$u_0^{"} - (M + \frac{1}{A})u_0 = -G_r\theta_0$$
(12)

$$\theta_0^{"} - (R - S)\theta_0 + J_e E_c u_0^2 + P_r E_c (u_0)^2 = 0$$
(13)

$$\psi_0^{iv} - (M + \frac{1}{A})\psi_0^{"} = G_r\phi_0^{'}$$
 (14)

$$\phi_0^{"} - (R - S)\phi_0 + 2J_e E_c u_0 \psi_0 - 2P_r E_c u_0 \psi_0^{"} = 0$$
(15)

$$\psi_1^{i\nu} - (M + \frac{1}{A})\psi_1^{"} = G_r \phi_1^{'} + u_0 \psi_0^{"} - u_0^{'} \psi_0 \qquad (16)$$

$$\phi_{1}^{"} - (R - S)\phi_{1} + 2J_{e}E_{c}u_{0}\psi_{1} - u_{0}\phi_{0} = 2P_{r}E_{c}u_{0}\psi_{1}^{"} + \psi_{0}\theta_{0}$$
(17)

$$\psi_{2}^{i\nu} - (M + \frac{1}{A})\psi_{2}^{"} + \frac{\psi_{0}}{A} = 2\psi_{0}^{"} + G_{r}\phi_{2}^{'}$$
$$-u_{0}\psi_{1}^{"} + u_{0}^{"}\psi_{1} \qquad (18)$$

$$\phi_{2}^{"} - (R - S)\phi_{2} + 2J_{e}E_{c}u_{0}\psi_{2} - \phi_{0} + u_{0}\phi_{1} = 2P_{r}E_{c}u_{0}\psi_{2}^{"} + 2P_{r}E_{c}u_{0}\psi_{0} + \psi_{1}\theta_{0}$$
(19)

and

$$u_{0} = 0, \theta_{0} = 0 \text{ at } y = 0, \ u_{0} = 0, \theta_{0} = -1 \text{ at } y = 1$$
  

$$\psi_{0} = u_{0}, \psi_{0} = 0, \phi_{0}^{1} = -\theta_{0}^{"} \text{ at } y = 0$$
  

$$\psi_{0} = 0, \psi_{0} = 0, \phi_{0}^{1} = 0 \text{ at } y = 1$$
  

$$\psi_{1} = 0, \psi_{1} = 0, \phi_{1}^{1} = 0 \text{ at } y = 1$$
  

$$\psi_{1} = 0, \psi_{1} = 0, \phi_{1}^{1} = 0 \text{ at } y = 1$$
  

$$\psi_{2} = 0, \psi_{2} = 0, \phi_{2}^{1} = 0 \text{ at } y = 1$$
  

$$\psi_{2} = 0, \psi_{2} = 0, \phi_{2}^{1} = 0 \text{ at } y = 1$$

## 5. Results and Discussion

The numerical solutions for the velocity u, temperature  $\theta$ , skin friction coefficient  $C_f$  and the rate of heat transfer  $N_u$ are computed for physical parameters  $E_{a}, J_{a}, S, A, M$  and R. The Prandtl  $P_r = 0.71$ corresponds to the air at temperature  $20^{\circ}C$  and one atmospheric pressure. The values of A, M and R are chosen arbitrarily.  $G_r$  and  $E_c$  take negative values, which corresponds to heating of the wall (heat flux, that is, transferred heat from the wall to the fluid). *S* =-1 corresponds to heat absorption and we have S = 0 in the absence of heat generation while S = 1, 2 give heat generation. Geometric parameters characterizing the roughness of wall; amplitude  $\mathcal{E} = 0.025$  (characteristic of dilated channel), wavelength  $\lambda = 0.01$  and  $\lambda x = \frac{\pi}{2}$ . The default parameter used throughout the numerical computations, M = 2.5, R = 3,  $E_c = -1.5$ , S = 2, A = 0.3,

 $G_r = -2$ ,  $J_e = -1.5$ . Fig. 1, Fig. 2 and Fig. 3 gives velocity profiles at varying values of  $E_c$ , R, and M, respectively. It is observed that velocity decreases with increasing values of  $E_c$ , R, and M. Increase in  $J_e$ , S and A increases the velocity of the fluid throughout the channel as observed in Fig. 4 to Fig. 6, respectively. Fig. 3 asserts that as *M* increases the velocity of the fluid decrease; attributed to the presence of the transverse magnetic field normal to the walls which gives rise to Lorentz force which is resistive to the flow hence decelerating the flow of the fluid.

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## www.ijsr.net

#### International Journal of Science and Research (IJSR) ISSN: 2319-7064 Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296





Figure 6: u vs. y with A

0.6

0.8

0.4

0.2

The velocity of the fluid decreases or increases as one moves away from the walls at a given values of governing parameters making the velocity of the fluid to be maximum at the Centre of the channel. This satisfies the natural situation since fluids flow in such a way that the velocity is maximum at the Centre position of the channel. This is due to the interaction of fluid molecules with wall molecules hence reducing its velocity near the walls.



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DOI: 10.21275/ART20191312

## International Journal of Science and Research (IJSR) ISSN: 2319-7064 Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296





**Figure 12:**  $\theta$  vs. y with A

Fig. 13 to Fig. 18 demonstrate the effect of values of stated relevant parameters on the skin friction  $C_f$ . The effects of  $E_c$ , R and M are displayed in Fig. 13, Fig. 14 and Fig. 15, respectively. For the growth of  $E_c$ , R and M, the shearing stress experiences a declination to the position y = 0.5 and then becomes constant for all values of  $E_c$ , R and M, that is, the value of skin friction coefficient decreases but as from this point to the heated flat wall accelerating upward and increases. The influence of  $J_e$ , S and A is shown in Fig. 16, Fig. 17 and Fig. 18, respectfully. However, the skin friction shows opposite pattern due to the change of  $J_{e}$ , S and A as depicted in Fig. 16 to Fig. 18. It is being observed that increasing the embedded parameters cause reversal flow towards the heated wall, that is, skin friction becomes negative near the heated flat wall while it remains positive near the insulated wavy wall.

**Figure 10:**  $\theta$  vs. y with  $J_e$ 

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# DOI: 10.21275/ART20191312

International Journal of Science and Research (IJSR) ISSN: 2319-7064 Index Copernicus Value (2016): 79.57 | Impact Factor (2017): 7.296





Figure 18:  $C_f$  vs. y with A

The Nusselt number  $N_u$  which measures the rate of heat transfer is shown in Fig. 19 to Fig. 24. It becomes negative as a result of the heating of the flat wall. The Nusselt number slow down significantly (Fig. 19) for higher values of  $E_c$  to the position y = 0.5, where it becomes constant, then accelerated upward and increases.  $E_c$  exert stronger effect on the rate of heat transfer in comparison with Joule heating (Fig. 22). Fig. 20 reveals an increasing trend of the rate of heat transfer with the enhancement of the radiation parameter but the Fig. 23 exhibits an opposite trend of rate of heat transfer with increase in heat source parameter, for heated wall ( $G_r < 0$ ). Fig. 21 and Fig. 24 revealed that Nusselt number against М exhibits the opposite behavior against A.



Figure 19:  $N_u$  vs. y with  $E_c$ 

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#### 6. Conclusions

An analysis of steady MHD free convective flow with heat transfer through porous medium bounded by thermally insulated wavy wall and uniformly heated flat wall in presence of Ohmic heating and viscous dissipation has been presented for different values of Eckert number  $E_c$ , Ohmic heating  $J_e$  in combination of other flow parameters.

The investigation create the circumstances to make the following results:

- Enhancement in  $E_c$ , R and M cause the fluid temperature to rise while fall in the fluid temperature observed with an increase in  $J_e$ , S and A, towards the heated flat wall.
- Velocity decreases with increasing values of E<sub>c</sub>, R and M while velocity increases as



 $J_e$ , S and A increase.

- Damping of the velocity noted in increasing the magnetic field strength is the Hartmann result.
- With the enhancement of  $E_c$ , R and M, skin friction shows a diminishing trend and exhibits opposite trend for  $J_e$ , S and A.
- The Nusselt number diminishes with the increasing values of Eckert number.

## References

[1] N. Ahmed, K. Sarma, H. Deka, "Soret and Dufour effects on an MHD free convective flow through a

<u>www.ijsr.net</u> Licensed Under Creative Commons Attribution CC BY channel bounded by a long wavy wall and a parallel flat wall," Turkish Journal of Physics, 38, pp. 50-63, 2014. doi:10.3906/fiz-1210-10

- [2] R.O. Amenya, J.K. Sigey, J.A. Okele, J.M. Okwoye, "MHD free convection flow past a vertical infinite porous plate in the presence of transverse magnetic field with constant heat flux," International Journal of Science and Research (IJSR), 2(10), pp. 217-222, 2013. Paper ID: 02013344 www.ijsr.net
- [3] K.S. Balamurugan, J.L. Ramaprasad, D. Gurram, V.V.C. Raju, "Influence of radiation absorption, viscous and Joule dissipation on MHD free convection chemically reactive and radiative flow in a moving inclined porous plate with temperature dependent heat source," International Refereed Journal of Engineering and Science, 5(12), pp. 20-31, 2016. www.irjes.com
- [4] A.C. Cogley, W.G. Vinceti, S.E. Giles, "Differential approximation for radiative transfer in a non-gray gas near equilibrium," AIAAJ, 6(3), pp. 551 - 556, 1968.
- [5] U.J. Das, "Soret and Dufour effects on steady free convective MHD viscoelastic fluid flow confined between a long vertical wavy wall and parallel flat wall," Thammasat International Journal of Science and Technology, 19((2), pp. 9-21, 2014.
- [6] U.N. Das, N. Ahmed, "Free convective MHD flow and heat transfer in a viscous incompressible fluid confined between a long vertical wavy wall and a parallel flat wall," Indian Journal of Pure and Applied Mathematics, 23(4), pp. 299-304, 1992.
- [7] B. Devika, P.V.S. Narayana, S. Venkataramana, "Chemical reaction effects on MHD free convection flow in an irregular channel with porous medium," International Journal of Mathematical Archive, 4(4), pp. 282-295, 2013. Available Online through www.ijma.info
- [8] P.F. Fasogbon, "MHD flows in corrugated channel", International Journal of Pure and Applied Mathematics, 20(2), pp. 137-147, 2007.
- [9] P.F. Fasogbon and J.O. Omolehin, "Radiation effect on natural convection in spirally enhanced channel", Electronic Journal of Engineering International Mathematics. Theory and Application (IeJEMTA), Vol. 3, No. 1, pp.1-28, 2008.
- [10] P.F. Fasogbon, "Analytical studies of heat and mass transfer by free convection in a two-dimensional irregular channel," International Journal of Applied Mathematics and Mechanics, 6(4), pp. 17-37, 2010.
- [11] J.A. Gbadevan, T.L. Ovekunle, P.F. Fasogbon, J.U. Abubakar, "Soret and Dufour effects on heat and mass transfer in chemically reacting MHD flow through a wavy channel," Journal of Taibah university for Science, https://doi.org/10.1080/16583655.2018.1492221, 2018.
- [12] B. Gebhart, "Effects of viscous dissipation in natural convection," Journal of Fluid Mechanics, 14, pp. 225-235, 1962.
- [13]K.K. Jaber, "Effects of viscous dissipation and Joule heating on MHD flow of a fluid with variable properties past a stretching vertical plate," European Scientific Journal, 10(33), pp. 383-393, 2014.
- [14]K.K. Jaber, "Joule heating and viscous dissipation effects on MHD flow over a stretching porous sheet subjected to power law heat flux in presence of heat

source," Open Journal of Fluid Dynamics, 6, pp. 156-165, 2016. http://www.scirp.org/journal/ojfd

- [15] P. Loganathan, C. Sivapoornapriya, "Ohmic heating and viscous dissipation effects over a vertical plate in the presence of porous medium," Journal of Applied Fluid Mechanics, 9(1), pp. 225-232, 2016. Available online at www.jafmonline.net
- [16] R. Taneja, N.C. Jain, "MHD flow with slip effects and temperature-dependent heat source in a ciscous incompressible fluid confined between a long vertical wavy wall and a parallel flat wall," Defence Science Journal, 54(1), pp. 21-29, 2004.
- [17] K. Vajravelu, K.S. Sastri, "Free convective heat transfer in a viscous incompressible fluid confined between a long vertical wavy wall and a parallel flat wall," Journal of Fluid Mechanics, 86(2), pp. 365-383, 1978.

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