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Entropy generation in thermal radiative oscillatory MHD couette flow in the influence of heat source

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Abstract. Entropy generation and their minimization for magnetohydrodynamic oscillatory couette flow through a vertical channel, soaked with a porous medium in the existence of heat source and thermal radiation has been deliberated. In the present analysis, flow governing equations are elucidated and extricated with the help of analytical technique for the fluid velocity profile, temperature field, irreversibility distribution and Bejan number. Also, the numerical value of dimensionless shearing stress and heat transfer coefficient are obtained and presented through tables with reference to flow governing parameters. It has noticed that entropy generation can be regulated or minimized with the change in the applied magnetic field and thermal radiation, and this result is useful in several thermodynamic industries and engineering field for attaining the high performance of devices with minimum heat loss.

Keywords: Entropy Generation, Bejan number, Heat Source, MHD, Thermal Radiation, Heat Source, Couette Flow

1. Introduction

The Entropy generation in convective Magnetohydrodynamic Couette flows through the porous material has a wide range of applications in numerous disciplines, like cooling of electronic components of heat-generating devices, ground hydrology, storage of nuclear wastes, polymer industries, petroleum industries, purification of crude oil, and many more. Katagiri [1], Drake [2], Gupta and Arora [3], Singh and Ram [4] are the few researchers who made significant contributions in this area. Sengupta and Ray [5] considered the oscillatory Couette flow through the rotating channel in the impact of the magnetic field.

Magnetohydrodynamic oscillatory flow through a horizontal channel was discussed by Makinde and Mhone [6] by considering the heat source effect. Further, Singh and Okwoya [7] examined the effect of the uniform magnetic field during the flow-through channel. The effect of radiation due to natural convective couette flow through a parallel plate channel was discussed by Narhari [8]. Later, Raju and Verma [9] expanded the work with periodic wall temperature. In the recent years, Chand et al. [10], Pal and Talukdar [11], Devika et al. [12], Gul et al. [13], Jha et al. [14], Sharma and Choudhary [15] are the few researchers who have also extended the earlier research work and explored the oscillatory flow with different geometrical conditions. In the same time, Narayana et. al. [16] explained the MHD oscillatory flow in asymmetry channel with the heat source and mass transfer effect. Falade et. al. [17] considered the MHD oscillatory flow through the vertical channel with suction and injection.



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In the literature, we have noticed that MHD oscillatory flow through the porous material occupied channel has been discussed extensively by several researchers due to its useful practical applications in medical (arterial blood flow) and industrial fields.

In the present study, we have made an attempt to fill the literature gap and analyze the MHD free convective, oscillatory couette flow through a vertical channel with the impact of thermal radiation, heat source and strong magnetic field, and also explored the total entropy generation/ irreversibility and their minimization with reference to the flow parameters. The main concern of the present analysis is to find the suitable parameters that can optimize the irreversibilities in the specified flow conditions.

2. Mathematical Formulation and Physical Model

In the present paper, we have considered the time-dependent natural convective oscillatory flow due to viscous incompressible electrically and thermally conducting fluid through a channel.

This channel is occupied with a saturated porous material and bounded by non-conducting vertical plates of infinite length in the existence of heat source and magnetic field. The magnetic field B_0 is working in the normal direction of the flow. Suppose, the plate at $y^* = 0$ starts suddenly with the velocity: $U^*(t^*) = U_0(1 + \varepsilon e^{i\omega^*t^*}),$ (1) and its

temperature fluctuates with time which is denoted by T_m . Where U_0 is the mean velocity, $\varepsilon \ll 1$ is the amplitude of the velocity variation, ω^* represents the frequency of oscillations and t^* is given for time.



Figure 1. Geometry Configuration

The plate lying in the plane $y^* = d$ is considered stationary with the temperature $T^* = T_s$ as displayed in Fig. 1. In the present flow scheme, the flow variables do not depend on x^* , therefore the derivative $\frac{d(\cdot)}{dx^*} = 0$.

Under the discussed conditions, the governing equations for present fluid flow configurations are defined as:

$$\frac{\partial u^*}{\partial t^*} = \frac{\partial U^*}{\partial t^*} + \upsilon \frac{\partial^2 u^*}{\partial y^{*2}} + g \beta \left(T^* - T_s\right) - \left(\frac{\upsilon}{K^*}\right) \left(u^* - U^*\right) - \frac{\sigma B_0^2}{\rho} \left(u^* - U^*\right), \tag{2}$$

$$\frac{\partial T^*}{\partial t^*} = \frac{\kappa}{\rho C_p} \left(\frac{\partial^2 T^*}{\partial y^{*2}} \right) + \frac{\mu}{\rho C_p} \left(\frac{\partial u^*}{\partial y^*} \right)^2 + \frac{Q^*}{\rho C_p} \left(T^* - T_s \right) - \frac{1}{\rho C_p} \left(\frac{\partial q_r^*}{\partial y^*} \right) + \frac{\sigma B_0^2}{\rho C_p} \left(u^* - U^* \right)^2, \tag{3}$$

The consistent boundary conditions are:

$$y^{*} = 0: \quad u^{*} = U^{*}(t^{*}) = U_{0}\left(1 + \varepsilon e^{i\omega^{*}t^{*}}\right), \quad T^{*} = T_{m} + \varepsilon \left(T_{m} - T_{s}\right) e^{i\omega^{*}t^{*}}; \\ y^{*} = d: \quad u^{*} = 0, \quad T^{*} = T_{s};$$

$$(4)$$

The flux of radiative heat is defined by Cogley et. al. [18], which is written as

$$\frac{\partial q_r^*}{\partial y^*} = 4 \left(T^* - T_s \right) \int_0^\infty K_{\lambda w} \left(\frac{\partial e_{b\lambda}}{\partial T} \right)_w d\lambda = 4 I^* \left(T^* - T_s \right),$$
(5)
where
$$I^* = \int_0^\infty K_{\lambda w} \left(\frac{\partial e_{b\lambda}}{\partial T} \right)_w d\lambda \cdot$$

In the above-discussed relations, u^* represent velocity component in the x^* direction. β denotes the thermal expansion, g for the gravity T^* represents fluid temperature, T_m is the temperature of moving plate, T_s denotes the temperature of stationary plate, ρ stands for fluid density, υ denotes the kinematic viscosity, K^* defines the permeability parameter, σ and κ show the thermal and electrical conductivity, and Q^* explain heat source.

3. Method and Solution

The dimensionless parameters are listed as:

$$y = \frac{y^{*}}{d}, \ u = \frac{u^{*}}{U_{0}}, \ t = \frac{\upsilon t^{*}}{d^{2}}, \ \omega = \frac{\omega^{*} d^{2}}{\upsilon}, \ U = \frac{U^{*}}{U_{0}}, \ M = \frac{\sigma B_{0}^{2} d^{2}}{\rho \upsilon}, \ T = \frac{T^{*} - T_{s}}{T_{m} - T_{s}}, \ \Pr = \frac{\mu C_{p}}{\kappa},$$

$$Gr = \frac{g\beta d^{2} (T_{m} - T_{s})}{\upsilon U_{0}}, \ K = \frac{K^{*}}{d^{2}}, \ Ec = \frac{U_{0}^{2}}{C_{p} (T_{m} - T_{s})}, \ Q = \frac{Q^{*} d^{2}}{\mu C_{p}}, \ R = \frac{4I^{*} d^{2}}{\mu C_{p}},$$
(6)

Using (6), the equations (2) and (3) are reduced to:

$$\frac{\partial u}{\partial t} = \frac{dU}{dt} + \frac{\partial^2 u}{\partial y^2} + GrT - \left(M + \frac{1}{K}\right) \left(u - U\right),\tag{7}$$

$$\frac{\partial T}{\partial t} = \frac{1}{\Pr} \frac{\partial^2 T}{\partial y^2} + Ec \left(\frac{\partial u}{\partial y}\right)^2 + \left(Q - R\right)T + EcM\left(u - U\right)^2,\tag{8}$$

The dimensionless boundary conditions are:

$$\begin{array}{l} at: \ y = 0; \ u = U = 1 + \varepsilon e^{i\omega t}, \ T = 1 + \varepsilon e^{i\omega t} \\ at: \ y = 1; \ u = 0, \ T = 0; \end{array} \right\},$$

$$(9)$$

Where Gr stand for buoyancy force, M shows the magnetic field, Ec for the dissipation parameter, K represents the permeability, Pr the Prandtl number, u represents the dimensional velocity, U stand for the velocity of moving plate, Q is the heat source and R explains the thermal radiation.

The solution of equations (7) and (8) are not possible at this stage, due to non-linear and coupled nature. For the solution of these equations, we have taken the velocity and temperature distribution in the vicinity of the plate (Raju and Verma, [9]) as:

$$F(y,t) = F_0(y) + \varepsilon e^{i\omega t} F_1(y) + O(\varepsilon^2), \qquad (10)$$

Where F stand for the u and T respectively. Substituting (10) in the equations (7) to (9) and comparing the like terms, the succeeding differential equations with the reduced boundary conditions are obtained as:

$$\frac{d^2 u_0}{dy^2} - \left(M + \frac{1}{K}\right) u_0 = -GrT_0 - \left(M + \frac{1}{K}\right),\tag{11}$$

$$\frac{1}{\Pr} \frac{d^2 T_0}{dy^2} + (Q - R)T_0 = -Ec \left(\frac{du_0}{dy}\right)^2 - EcM(1 - u_0)^2,$$
(12)

3.2. First-order equations $\frac{d^2 u_1}{dy^2} - \left(M + \frac{1}{K} + i\omega\right)u_1 = -GrT_1 - \left(M + \frac{1}{K} + i\omega\right),$ (13)

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$$\frac{1}{\Pr}\frac{d^2T_1}{dy^2} + \left(Q - R - i\omega\right)T_1 = -2Ec\left(\frac{du_0}{dy}\right)\left(\frac{du_1}{dy}\right) - 2EcM\left(1 + u_0u_1 - u_0 - u_1\right),\tag{14}$$

The reduced form of boundary conditions are:

$$y = 0; \ u_0 = 1, \ u_1 = 1, \ T_0 = 1, \ T_1 = 1;$$

$$y = 1; \ u_0 = 0, \ u_1 = 0, \ T_0 = 0, \ T_1 = 0;$$
(15)

The equations (11) to (14) are still coupled ordinary second-order differential equations. Since Eckert number $Ec \ll 1$ for the incompressible fluid flow, therefore, u_0, u_1, T_0, T_1 can be expressed as:

$$F_{0}(y) = F_{00}(y) + Ec F_{01}(y) + O(Ec)^{2}$$

$$F_{1}(y) = F_{10}(y) + Ec F_{11}(y) + O(Ec)^{2}$$
(16)

Now, substituting (16) into (11) to (14) and comparing the coefficient of Eckert number Ec and deserting the term of $O(Ec)^2$, we have:

3.3. Zeroth order equations

$$\frac{d^2 u_{00}}{dy^2} - \left(M + \frac{1}{K}\right) u_{00} = -GrT_{00} - \left(M + \frac{1}{K}\right),\tag{17}$$

$$\frac{d^2 u_{10}}{dy^2} - \left(M + \frac{1}{K} + i\omega\right) u_{10} = -GrT_{10} - \left(M + \frac{1}{K} + i\omega\right),\tag{18}$$

$$\frac{1}{\Pr} \frac{d^2 T_{00}}{dy^2} + (Q - R)T_{00} = 0,$$
(19)

$$\frac{1}{\Pr}\frac{d^2T_{10}}{dy^2} + (Q - R - i\omega)T_{10} = 0,$$
(20)

3.4. First-order equations

$$\frac{d^2 u_{01}}{dy^2} - \left(M + \frac{1}{K}\right) u_{01} = -GrT_{01},$$
(21)

$$\frac{d^2 u_{11}}{dy^2} - \left(M + \frac{1}{K} + i\omega\right) u_{11} = -GrT_{11},$$
(22)

$$\frac{1}{\Pr} \frac{d^2 T_{01}}{dy^2} + (Q - R)T_{01} = -\left(\frac{du_{00}}{dy}\right)^2 - M\left(1 - u_{00}\right)^2,$$
(23)

$$\frac{1}{\Pr} \frac{d^2 T_{11}}{dy^2} + \left(Q - R - i\omega\right) T_{11} = -2\left(\frac{du_{00}}{dy}\right) \left(\frac{du_{10}}{dy}\right) - 2M\left(1 + u_{00}u_{10} - u_{00} - u_{10}\right),\tag{24}$$

The reduced form of boundary conditions are:

 $y = 0; \ u_{00} = 1, \ u_{01} = 0, \ u_{10} = 1, \ u_{11} = 0, \ T_{00} = 1, \ T_{01} = 0, \ T_{10} = 1, \ T_{11} = 0; \\ y = 1; \ u_{00} = 0, \ u_{01} = 0, \ u_{10} = 0, \ u_{11} = 0, \ T_{00} = 0, \ T_{01} = 0, \ T_{10} = 0, \ T_{11} = 0; \}.$ (25)

Equations (17) to (24) are the set of second-order coupled differential equations. These equations are solved by the usual algebraic method with the help of boundary conditions (25).

4. Coefficient of Skin Friction

The dimensionless form of the coefficient of skin friction at both the plates of the channel is given as:

4.1. Coefficient of skin friction at the moving plate for y = 0

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$$C_{f_0} = \left(\frac{\tau_{\omega}}{\underline{\rho U_0^2}}\right)_{y^*=0} = \frac{2}{\operatorname{Re}} \left(\frac{\partial u}{\partial y}\right)_{y=0} = \frac{2}{\operatorname{Re}} \left\{ \left(\frac{\partial u_0}{\partial y}\right)_{y=0} + \varepsilon e^{i\omega t} \left(\frac{\partial u_1}{\partial y}\right)_{y=0} \right\},\tag{26}$$

4.2. Coefficient of skin friction at the stationary plate for y = 1

$$C_{f_{1}} = \left| \frac{\tau_{\omega}}{\frac{\rho U_{0}^{2}}{2}} \right|_{y^{*}=d} = \frac{2}{\operatorname{Re}} \left\{ \left(\frac{\partial u}{\partial y} \right)_{y=1} = \frac{2}{\operatorname{Re}} \left\{ \left(\frac{\partial u_{0}}{\partial y} \right)_{y=1} + \varepsilon e^{i\omega t} \left(\frac{\partial u_{1}}{\partial y} \right)_{y=1} \right\},$$
(27)

Where shear stress τ_{ω} at the wall of plates (Moving and Stationery) are presented by $\tau_{\omega} = \mu \left(\frac{\partial u^*}{\partial y^*}\right)_{y^*=0}$

and
$$\tau_{\omega} = \mu \left(\frac{\partial u^*}{\partial y^*} \right)_{y^*=d}$$
 respectively.

5. Nusselt Number/ Coefficient of Heat Transfer

The rate of heat transfer at the wall of the plates of the channel is given as:

5.1. Coefficient of heat transfer (Nusselt number) at the moving plate for y = 0

$$Nu_{0} = \left(\frac{dq_{(x)}}{\kappa(T_{m} - T_{s})}\right) = -\left(\frac{\partial T}{\partial y}\right)_{y=0} = -\left\{\left(\frac{\partial T_{0}}{\partial y}\right)_{y=0} + \varepsilon e^{i\omega t} \left(\frac{\partial T_{1}}{\partial y}\right)_{y=0}\right\},$$
(28)

5.2. Coefficient of heat transfer (Nusselt number) at the stationary plate for y = 1

$$Nu_{1} = \left(\frac{dq_{(x)}}{\kappa(T_{m} - T_{s})}\right) = -\left(\frac{\partial T}{\partial y}\right)_{y=1} = -\left\{\left(\frac{\partial T_{0}}{\partial y}\right)_{y=1} + \varepsilon e^{i\omega t}\left(\frac{\partial T_{1}}{\partial y}\right)_{y=1}\right\},$$
(29)

Where $q_{(x)} = -\kappa \left(\frac{\partial T^*}{\partial y^*}\right)_{y^*=0}$ and $q_{(x)} = -\kappa \left(\frac{\partial T^*}{\partial y^*}\right)_{y^*=d}$ are the coefficient of heat transfer for both the plates

respectively.

6. Entropy Generation

The work efficiency of the thermal systems or devices needs to be maintained in all the thermal industries, where entropy generation is encountered due to friction and heat transfer. In the thermodynamics, entropy generation is referred to as irreversibility distribution. In the present case, the volumetric rate of entropy generation is given due to the magnetic field, thermal radiation and friction. Following Wood [19] and Bejan [20], the entropy generation is given as :

$$S_{gen}^{*} = \frac{\kappa}{\left(T_{0}^{*}\right)^{2}} \left(\frac{\partial T^{*}}{\partial y^{*}}\right)^{2} + \frac{\mu}{\left(T_{0}^{*}\right)} \left[\left(\frac{\partial u^{*}}{\partial y^{*}}\right)^{2} + \frac{\left(u^{*} - U^{*}\right)^{2}}{K^{*}} \right] + \frac{\sigma B_{0}^{2} \left(u^{*} - U^{*}\right)^{2}}{\left(T_{0}^{*}\right)^{2}}, \qquad (30)$$

Where T_0^* denotes the reference temperature and S_{gen}^* the dimensional entropy generation term. Using (30), the entropy generation in dimensionless form as:

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$$Ns = \frac{S_{gen}}{S_0^{"}} = \left[\left(\frac{dT}{dy} \right)^2 + \Pr EcT_0 \left\{ \left(\frac{du}{dy} \right)^2 + \frac{\left(u - U \right)^2}{K} \right\} + \Pr EcT_0 M \left(u - U \right)^2 \right], \tag{31}$$

Where $T_0 = \frac{T_0^*}{(T_m - T_c)}$ is the dimensionless temperature and $S_0^* = \frac{\kappa}{T_0^2 d^2}$.

In equation (31), the irreversibility due to friction, magnetic field and heat transfer has been obtained and presented as:

$$N_H = \left(\frac{dT}{dy}\right)^2,\tag{32}$$

$$N_F = \Pr EcT_0 \left[\left(\frac{du}{dy} \right)^2 + \frac{\left(u - U \right)^2}{K} \right], \tag{33}$$

$$N_{M} = \Pr EcT_{0}M\left(u-U\right)^{2},$$
(34)

The Bejan number is also defined for the stated flow configuration, and it is expressed as $Be = \frac{N_{H}}{Ns} = \frac{Entropy \ generation \ due \ to \ heat \ transfer}{Total \ entropy \ generation \ (friction + heat \ transfer + magnetic \ field)}$

7. Results and Discussion

The fluid velocity profile, temperature field, entropy generation and Bejan number are obtained for the distinct flow parameters by using MATLAB software. The positive values of buoyancy force parameter (Gr>0) represent the cooling of plates while negative values (Gr<0) stand for heating of plates.

Velocity distribution profiles

The velocity distribution profiles for the various physical parameter are shown in Figure. 2 to Figure, 8. Figure 2 depicts that the cooling of plates accelerates the fluid motion, and increase in the magnetic field enhance the fluid motion when the plates are hot as noticed from Figure 3.

Figure 4 reflects that an upsurge in the Eckert number promotes the fluid flow for (Gr < 0), whereas adverse behavior is seen for the cooling of plates (Gr > 0). Figure 5 depicts the effect of permeability parameter with fluid velocity, and it is observed that fluid flow reduces with the improvement in the permeability parameter.

The rise in the Prandtl number, heat source, and thermal radiation, deaccelerates the fluid flow when plates are taken hot for (Gr < 0), and boosts the fluid motion when plates are cool (Gr > 0) as presented through Figures 6, 7 and 8.



Figure 2. Velocity distribution profile for M = 2.0, Ec = 0.01, K = 0.5,

















Figure 8. Velocity distribution profile for M = 2.0, Ec = 0.01,

K = 0.5, Pr = 1.0, and Q = 0.5

Temperature distribution profiles

The temperature distribution profiles for the various physical parameter are shown in Figures 9 to 15. In Figures 9 to 11, we have noticed that fluid temperature declines, due to escalation in the buoyancy force, magnetic field and Eckert number, whereas fluid temperature props up with the increment in the permeability, Prandtl number, heat source and thermal radiation as reported from Figures 12 to 15.



Figure 9. Temperature distribution profile for M = 2.0, Ec = 0.01, K = 0.5, Pr = 4.0, Q = 0.5, and R = 1.0



Figure 10. Temperature distribution profile for Ec = 0.01, K = 0.5, Pr = 4.0, Q = 0.5, and R = 1.0







Figure 12. Temperature distribution profile for M = 2.0, Ec = 0.01, Pr = 4.0, Q = 0.5, and R = 1.0







Figure 14. Temperature distribution profile for M = 2.0, Ec = 0.01, K = 0.5, Pr = 4.0, and R = 1.0





Entropy generation profiles

The irreversibility distributions in terms of entropy generations profiles are presented from Figures 16 to 23 for various flow governing parameters. From Figures 16 to 19, it is noticed that total entropy generation declines near the moving plate when the intensity of the applied magnetic field, heat source, thermal radiation and Prandtl number increase, although it props up with the increase of permeability and Eckert number as observed from Figure 20 and 21. The reverse effect is seen near the stationary plate as compared to the moving plate. It is also depicted that the rate of entropy generation near the moving plate for the heating case (Gr < 0) is higher than the cooling case (Gr > 0), while the adverse

phenomenon is reported near the stationary plate as shown in Figure 22 and 23. In the analysis of entropy generation profiles, it is found that external applied magnetic field and thermal radiation play an important role for regulating the entropy generation in the fluid slow system.



Figure 16. Ns distribution profile for Ec = 0.10, K = 0.5, Pr = 0.71, Q = 1.0, and R = 0.5







Pr = 0.71, R = 0.5, M = 2.0, and Q = 1.0



Figure 23. Ns distribution profile for K = 0.5, Pr = 0.71, R = 0.5, M = 2.0, Q = 1.0, and Ec = 0.10

Bejan number profiles

In addition, the effect of the Bejan number is also illustrated from Figures 24 to 31. Figure 24 explains the effect of uniform magnetic with Bejan number, and it is seen that the improvement in the intensity of magnetic field gains the irreversibility ratio Bejan number in the vicinity of the moving plate, and shows the opposite effect at the stationary plate of the channel. The Bejan number profile declines with the improvement in the Prandtl number and radiation as depicted from Figure 25 and 26 for the value of Gr > 0, while the contrary effect is for Gr < 0.

In the continuation, it is also found from Figure 27 and 28 that escalation in the heat source and permeability props up the Bejan number, although an increase in the Eckert number shows the reverse effect as noticed from Figure 29. The Bejan number rises with the value of Gr < 0 and it reduces when Gr > 0 as observed from Figure 30 and 31. The result is relatively accurate when the Bejan number, Be lies from 0 to 1. It is noticed that the irreversibility due to heat transfer amplifies when Bejan number Be < 0.50, whereas viscous dissipation influences the irreversibility when Bejan number Be < 0.50 and equal contribution of entropy distribution defines when Be = 0.50. The results of this analysis are in accordance with the results discussed by Butt and Ali [21].





Figure 28. Be distribution profile for Q = 1.0, M = 2.0, R = 0.5, Pr = 1.0, and Ec = 0.10



Figure 31. Be distribution profile for Q = 1.0, M = 2.0, R = 0.5, Pr = 1.0, K = 0.5, and Ec = 0.10

The coefficient of skin friction

The coefficient of skin friction is calculated at the wall of moving and fixed plates with the aid of MATLAB software, and their values are reported from Table 1. It is noticed that rise in the radiation,

buoyance force, heat source and magnetic field upsurges the skin friction at the wall of moving plate, whereas it declines with the rise in the viscous dissipation

Table 1. Coefficient of Skin friction at both plates with different physical parameter values when $\omega = 10$ and $\omega t = \frac{\pi}{2}$.

Е	Gr	М	Ec	K	Pr	Q	R	Re	Cf_0	Cf_1
0.00	5.0	2.0	0.01	0.2	0.71	0.5	1.0	2.0	0.8900	-4.0075
0.01	5.0	2.0	0.01	0.2	0.71	0.5	1.0	2.0	0.8950	-4.0135
0.01	10.0	2.0	0.01	0.2	0.71	0.5	1.0	2.0	2.1214	-10.2318
0.01	5.0	4.0	0.01	0.2	0.71	0.5	1.0	2.0	0.8915	-5.9969
0.01	5.0	2.0	0.04	0.2	0.71	0.5	1.0	2.0	0.5741	-6.4844
0.01	5.0	2.0	0.01	0.5	0.71	0.5	1.0	2.0	0.8804	-2.7945
0.01	5.0	2.0	0.01	0.2	1.0	0.5	1.0	2.0	0.9298	-4.4298
0.01	5.0	2.0	0.01	0.2	0.71	1.0	1.0	2.0	0.9260	-4.0730
0.01	5.0	2.0	0.01	0.2	0.71	0.5	3.0	2.0	1.0343	-4.1179
0.01	5.0	2.0	0.01	0.2	0.71	0.5	1.0	4.0	0.4475	-2.0068

The Rate of heat transfer/ Nusselt number

The rate of heat transfer at the wall of plates is calculated and displayed from Table 2. It is observed that magnitude of Nusselt number increases at the wall of the moving plate when the value of buoyance force, permeability, viscous dissipation and magnetic field rise, and the boost in the heat source and radiation decline the Nusselt number. In addition, the rise in the magnitude of the buoyance force, uniform magnetic field, viscous dissipation and permeability reduce the heat transfer at the wall of the fixed plate, whereas Nusselt number upsurges with the escalation in the radiation and heat source.

Table 2. Heat transfer / Nusselt number at both plates with different physical parameter values when $\omega = 10$ and $\omega t = \frac{\pi}{2}$.

Е	Gr	М	Ec	K	Pr	Q	R	Nu ₀	Nu ₁
0.00	5.0	2.0	0.01	0.2	0.71	0.5	1.0	0.6381	1.1557
0.01	5.0	2.0	0.01	0.2	0.71	0.5	1.0	0.6436	1.1473
0.01	10.0	2.0	0.01	0.2	0.71	0.5	1.0	0.7146	0.9695
0.01	5.0	4.0	0.01	0.2	0.71	0.5	1.0	0.6407	1.1509
0.01	5.0	2.0	0.04	0.2	0.71	0.5	1.0	0.7074	1.0048
0.01	5.0	2.0	0.01	0.5	0.71	0.5	1.0	0.6526	1.1362
0.01	5.0	2.0	0.01	0.2	1.0	0.5	1.0	0.4762	1.2309
0.01	5.0	2.0	0.01	0.2	0.71	1.0	1.0	0.5012	1.2371
0.01	5.0	2.0	0.01	0.2	0.71	0.5	3.0	0.0118	1.5474

8. Conclusions

In this paper, irreversibility distribution for MHD free convective oscillatory couette flow through a porous material occupied vertical channel in the existence of thermal radiation, heat source, and the strong magnetic field is examined with the suitable analytical scheme. It is observed that:

- 1. The fluid motion deaccelerates with increment in the magnetic field, and it is only possible due to the existence of the Lorentz forces.
- 2. Due to the increase in thermal radiation, heat releases within the system, which subsequently causes the development of fluid velocity and thermal boundary layer thickness.

- 3. The fluid temperature goes down as buoyancy force and intensity of the magnetic field are amplified; whereas it props up with the increase of heat source.
- 4. The total entropy generation decreases with the enhancement in the thermal radiation, magnetic strength, and heat source.
- 5. Magnetic field and thermal radiation play an important role to regulate the total irreversibility. It is concluded that the irreversibility distributions in terms of entropy generation can be reduced by a suitable change in these parameters. This result is useful for achieving the thermodynamic performance of the devices in the field of manufacturing and designing industries.

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