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Multimedia Feature for Unsteady Fluid Flow over a Non-Uniform Heat Source Stretching Sheet with Magnetic Radiation Physical Effects

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Abstract: Multimedia feature for a steady two-dimensional forced convection with magnetic hydrodynamic flow (MHD) and with radiation effect of an incompressible fluid over an unsteady thermal forming non-uniform heat source stretching sheet have been studied. The parameters M and R which are used to represent the dominance of the magnetic effect and radiation effect which have been presented in governing equations. The similar transformation and an implicit finite-difference method have been used to analyze the present problem. The numerical solutions of the flow velocity distributions, temperature profiles, the wall unknown values of $f''(0)$ and $\theta'(0)$ for calculating the heat transfer of the similar boundary-layer flow are carried out as functions of the unsteadiness parameter (S), the Prandtl number (Pr), the radiation parameter (R), the non-uniform source parameters (A, B) and the magnetic parameter (M). The effects of these parameters have also discussed. At the results, it will produce greater heat transfer effect with a larger Pr, R and S but a larger parameters M, A, B will reduce momentum and heat transfer effects.

Keywords: Finite-difference method, Multimedia feature, Non-uniform heat source, Radiation, Heat transfer, Unsteady Stretching Sheet, MHD, Forced convection.

1. Introduction

Multimedia feature for boundary layer flow and heat transfer in fluid driven by a continuous thermal forming non-uniform heat source stretching sheet with magnetic and radiation effects are significance in a number of industrial engineering processes, such as the drawing of a polymer sheet or filaments extruded continuously from a die, the cooling of a metallic plate in a bath, the extrusion of a polymer sheet from a die or in the drawing of plastic films, annealing and tinning of copper wires, the wire and fiber coating, etc. During the processes, mechanical properties are greatly dependent upon the rate of cooling.

Sakiadis [1] was the first study in the boundary layer flow generated by a continuous stretching surface moving with a constant velocity. Several authors [2–5] investigated the heat transfer problem in a stretching sheet with a linear or non-linear surface velocity and a uniform or different surface temperature conditions. Abo–Eldahab and Aziz [6] extended the problem to involve a space-dependent exponentially decaying with internal heat generation or absorption. Abel et al. [7] and Bataller [8] presented the effects of non-uniform heat source on viscoelastic fluid flow and heat transfer over a stretching sheet. Moreover, Mukhopadhyay et al. [9], Pantokratoras [10] and Mukhopadhyay and Layek [11] extended to consider the effects of variable fluid properties or specific dimensionless parameters on the flow over a stretching sheet. The related boundary layer flow in the non-linear mechanics were studied by Rajagopal et al [12,13]. In all these above studies, the flow and temperature fields have been considered to be at steady state.

Some authors [14–17] studied the problem for unsteady stretching surface condition by using a similarity method to transform governing time-dependent boundary layer equations into a set of nonlinear ordinary differential equations. Some methods have been used to analysis the related unsteady stretching sheet problems, such as Sajid et al. [18], Mehmood et al. [19] and Liu and Andersson [20] that have used series solution method, homotopy analysis method, respectively. Recently, most authors [21-24] toward the second grade or viscoelastic fluids over an unsteady stretching sheet with heat transfer or others related effects by similar and non-similar analysis methods with numerical solution methods to solve such kinds of problems. Most recently, Tsai et al. [25] have studied fluid flow and heat transfer over an unsteady stretching surface with non-uniform heat source by using similarity method and solved numerically by Chebyshev finite difference method (ChFD), but not consider the magnetic effect.

From above, provide the motivation for the present analysis to study the multimedia feature about flow and heat transfer in an incompressible fluid caused by forced convection with magnetic effect and radiation effect on a thermal forming non-uniform heat source stretching sheet. It is a point of view to examining the influence of flow and heat transfer characteristics phenomena. The magnetic force, the non-uniform heat source and radiation effect are important in the present problem due to the difference among the previous studies. A similar derivation technique has been used and the resulting non-linear similar equations were solved by using the finite-difference method. The paper is an extension work for Hsiao [40], in this study increasing some new effects than before, to study the multimedia feature about flow on a thermal forming non-uniform heat source stretching sheet, all the results are also increasing the different effects.

2. Problem formulation

It was consider multimedia feature that unsteady two-dimensional magneto-hydrodynamic (MHD) laminar flow of an incompressible fluid over a non-uniform heat source thermal forming with radiation effect stretching sheet. A constant magnetic field of strength B_0 and q_r is applied perpendicular to the thermal forming stretching sheet, which is a valid assumption on a laboratory scale under the assumption of small magnetic Reynolds number. Under the usual boundary layer assumptions and in the absence of pressure gradient, the unsteady basic boundary layer equations governing the MHD flow of fluid. Let us consider the unsteady, incompressible, two-dimensional MHD flow of a thin liquid film of uniform thickness h(t) over the horizontal thermal forming stretching sheet with radiation effect. A non-uniform heat source exists at the boundary layer flow. The fluid motion within the film is due to stretching of sheet. The geometry of the problem is shown in Figure 1.

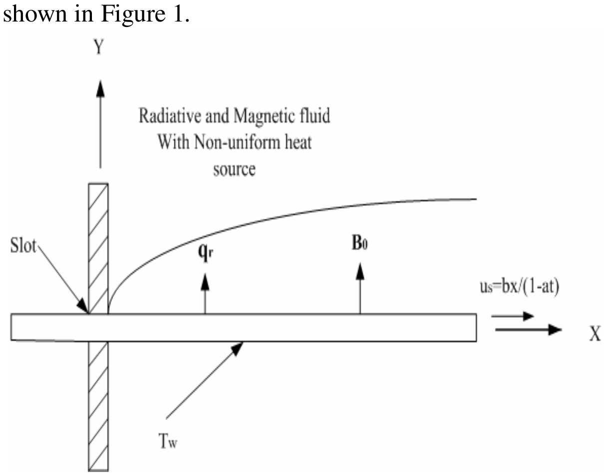

Figure 1. A sketch of the physical model for multimedia feature unsteady forced convection flow with magnetic and radiation effects of an incompressible fluid over a thermal forming non-uniform heat source stretching sheet

The conducting fluid is permeated by an imposed uniform magnetic field $B=(0,B_0,0)$ which acts in the positive y-direction. The magnetic Reynold number is assumed small enough so that the induced magnetic field can be neglected. The magnetic force $\mathbf{J}\times\mathbf{B}$ under these assumptions becomes $\sigma(\mathbf{V}\times\mathbf{B})\times\mathbf{B}=-\sigma B_0^2\mathbf{V}$. The fluid flow is modeled as an unsteady, two dimensional, incompressible viscous laminar flow on a horizontal thin elastic sheet that issues from a narrow slot at the origin and is continuous stretching with a velocity $u_s=bx/(1-at)$ [14] (where a and b are positive constants, and t<1/a) in the positive x-direction. The fluid is considered as a Newtonian liquid with constant properties at temperature T_∞. The thermal forming stretching sheet is assumed to have a non-uniform internal heat generation/absorption and the sheet temperature varies with the coordinate x and time t. The governing conservation equations of mass, momentum and energy at unsteady state can be expressed as

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0, \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}-\frac{\sigma B_0^2}{\rho}u \tag{2}$$

$$\rho c_p\left[\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]$$
$$=k\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}+(\frac{ku_s}{x\nu}) \tag{3}$$
$$[A(T_w-T_\infty)e^{-\eta}+B(T-T_\infty)]$$

The correspondence boundary conditions are

$$u=u_s(x,t),\ \ v=0,\ \ T=T_w(x,t),\ \text{at}\ \ y=0 \tag{4}$$

$$T=T_s\ \text{at}\ \ y=0;\ \frac{\partial T}{\partial y}=0\ \text{at}\ \ y=h. \tag{5}$$

where u_s and T_w are the velocity and temperature of the stretching sheet at the surface y = 0, A is the space-dependent parameter, B is temperature-dependent parameter, q_r is the radiation heat flux, respectively. The flow is induced due to stretching at y = 0 which moves in the x-direction with the velocity

$$u_s=\frac{bx}{1-at}, \tag{6}$$

in which a and b are positive constants with dimension $(\text{time})^{-1}$. It can be noted from Eq. (6) that the effective stretching rate $b/(1-at)$ increases with time since a > 0. The surface temperature T_w of the sheet is

$$T_w = T_0 - T_{ref}\left[\frac{bx^2}{2\nu}\right](1-at)^{-3/2}, \qquad (7)$$

where T_0 and T_{ref} are the temperature at the slit and reference temperature respectively. Expression (7) reflects that the sheet temperature decreases from T_0 at the slot in proportion to x^2 and temperature reduction increases with an increase in $(1-at)$. But it should be noticed that Eqs. (6) and (7), which are responsible for the whole analysis, are valid only for time $t < 1/a$. The following dimensionless parameters are introduced

$$\eta = \sqrt{\frac{b}{\nu}}(1-at)^{-\frac{1}{2}}y,\ \psi = \sqrt{b\nu}\,x(1-at)^{-\frac{1}{2}}f(\eta), \qquad (8)$$

and the stream function $\psi(x, y)$ through

$$u = \frac{\partial\psi}{\partial y} = \frac{bx}{1-at}f'(\eta), \qquad (9)$$

$$u = -\frac{\partial\psi}{\partial x} = -\sqrt{\frac{b\nu}{1-at}}f'(\eta), \qquad (10)$$

By using Rosseland approximation [26] the radiation heat flux. is given by $q_r = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$; Where σ^* and k^* respectively, the Stephan-Boltzmann constant and the mean absorption coefficient. Further we assume that the temperature difference within the flow is such that T^4 may be expanded in a Taylor series. Hence, expanding T^4 about T_∞ and neglecting higher order terms we get $T^4 \cong 4T_\infty^3 T - 3T_\infty^4$; the continuity equation (1) is identically satisfied and dimensionless problems of flow and temperature [27] are

$$f''' - f'^2 + ff'' - S\left(f' + \frac{1}{2}\eta f''\right) - M^2 f' = 0, \qquad (11)$$

$$(3R+4)\theta'' + 3RP_r\left[-\frac{1}{2}S(3\theta + \eta\theta') - 2f'\theta + f\theta'\right] \qquad (12)$$
$$+[Af' + B\theta] = 0$$

And the associated with boundary conditions become

$$f'(0) = 1,\quad f(0) = 0,\quad \theta(0) = 1 \qquad (13)$$

$$f'(\infty) = 0,\quad \theta(\infty) = 0 \qquad (14)$$

Here $S = a/b$ is the unsteadiness parameter, $M^2 = \sigma B_0^2(1-at)/\rho b$ is the dimensionless and magnetic parameters, $R = \frac{16\sigma^* T_\infty^3}{3k^* k}$ is the radiation parameter, A is the space-dependent parameter, B is temperature-dependent parameter, respectively. Here primes indicate the differentiation with respect to η. The skin-friction coefficient C_f and the Nusselt number Nu are defined as

$$C_f = \frac{\tau_w}{\frac{1}{2}\rho u_s^2} = -2\,\mathrm{Re}_x^{-1/2} f''(0), \qquad (15)$$

$$Nu = \frac{hx}{k} = -\mathrm{Re}_x^{1/2}\theta'(0), \qquad (16)$$

where Re_x is the local Reynold number and C_f is the skin-friction coefficient.

3. Numerical analysis

In the present problem, the set of similar equations from (11) to (14) are solved by a finite difference method. These ordinary differential equations are discretized by a second-order accurate central difference method [28], and a computer program has been developed to solve these equations. Vajravelu [29-31] and Hsiao et al. [33-38] are also using analytical and numerical solutions to solve the related problems. So, some numerical technique methods will be applied to the same area in the future. In this study, the program to compute finite difference approximations of derivatives for equal spaced discrete data. The code employ centered differences of O(h^2) for the interior points and forward and backward differences of O(h) for the first and last points, respectively. See Chapra and Canale, Numerical Methods for Engineers [32]. To ensure the convergence of the numerical solution to exact solution, the step sizes $\Delta\eta$ and have been optimized and the results presented here are independent of the step sizes at least up to the fourth decimal place. The convergence criteria based on the relative difference between the current and previous iteration values of the velocity and temperature gradients at wall are employed. When the difference reaches less than 10^{-6} for the flow fields, the solution is assumed to have converged and the iterative process is terminated. The sequence of equations of above was expressed in difference form using central difference scheme in η-direction. In each iteration step, the equations were then reduced to a system of linear algebraic equations.

4. Results and Discussion

The objective of the present analysis is to study the heat transfer of fluid cooled or heated by a high or low Prandtl-number fluid with various parameters. An extension of previous works has then performed to investigate the heat transfer of fluid pass a thermal forming stretching sheet with magnetic effect and radiation effect, are included. The model for fluid has been used in the momentum equations. Effects of dimensionless parameters, the unsteadiness parameter (S), the Prandtl number (Pr), the radiation parameter (R), the non-uniform heat source parameters (A, B) and the magnetic parameter (M) are mainly interests of the study. Flow and temperature fields of the fluid flow have analyzed by utilizing the boundary layer concept to obtain a set of coupled momentum equations and energy equations. A similarity transformation has then used to convert the nonlinear, coupled partial differential equations to a set of nonlinear, coupled ordinary differential equations. A generalized derivation is used to analyze an unsteady flow has been studied. A second-order accurate finite difference method used to obtain solutions of these equations. Comparing $-\theta'(0)$ to results of [39] for an unsteady fluid flow (A=0, B=0, R～0, M=0) showed a good agreement and these values have listed in Table 1.

Table 1.A comparison of $-\theta'(0)$ for an unsteady fluid flow (A=0, B=0, M=0, R～0)

S	Pr	$-\theta'(0)$ Ref.[39]	Present Solution	Errors
0.8	1	0.6348	0.6334	0.0014
1.2	1	0.9491	0.9533	0.0042
2.0	1	1.4086	1.4564	0.0478

The main contribution of this study considers the heat transfer magnetic and radiation effects in a forced convection for fluid flow past a thermal forming non-uniform heat source stretching sheet hybrid heat transfer system. From the figures provide more physical insights, as follow:

Figure 2 is shown dimensionless velocity gradient f' vs. η as S=0.1, Pr=1, R=0.1, A=0.1, B=0.1, M = 0.1, 1, 5, 10, 20. It is represent the fluid flow phenomenon toward the flow filed. The numerical calculation results are satisfied the boundary layer conditions at the figure. The momentum was interacting with each other and the figure curves are all having a strong varies with η along the boundary layer for different magnetic parameter M. When the M value is larger and the dimensionless velocity gradient f' is larger, so that the magnetic effect will increase the momentum force and the flow will move quickly with the whole flow field. On the other hand, when the M value is lower and the dimensionless velocity gradient f' is also lower too, so that the momentum force is not good for a lower magnetic parameter M.

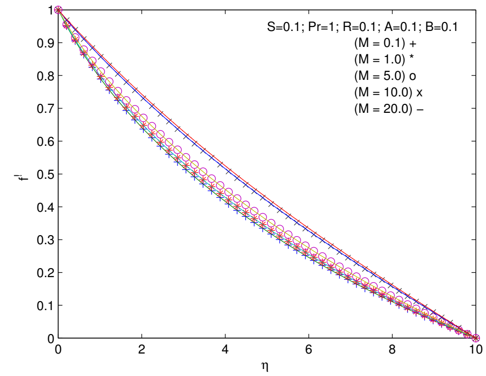

Figure 2 dimensionless velocity gradient f' vs. η as S=0.1, Pr=1, R=0.1, A=0.1, B=0.1, M = 0.1, 1, 5,10, 20

Figure 3 is shown dimensionless velocity gradient f' vs. η as Pr=1, R=0.1, A=0.1, B=0.1, M = 0.1, S = 0.01, 0.1, 0.7, 1.3, 2.0. It is represent the fluid flow phenomenon toward the flow filed. The numerical calculation results are satisfied the boundary layer conditions at the figure. The momentum was interacting with each other and the figure curves are all having a strong varies with η along the boundary layer for different unsteadiness parameter S. When the S value is larger and the dimensionless velocity gradient f' is lower, so that the unsteadiness effect will decrease the momentum force and the flow will move slowly with the whole flow field. On the other hand, when the S value is lower and the dimensionless velocity gradient f' is larger, so that the unsteadiness effect is not good for a larger unsteadiness parameter S. For discussing the result for figures 4, 5, 6 and 7 some numerical calculations have carried out for dimensionless temperature profiles for different values of Pr, R, S and M.

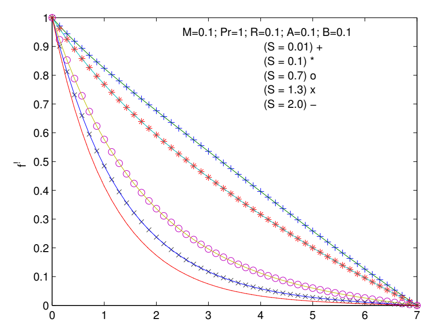

Figure 3 dimensionless velocity gradient f' vs. η as Pr=1,R=0.1, A=0.1,B=0.1,M = 0.1, S = 0.01,0.1, 0.7,1.3,2.0

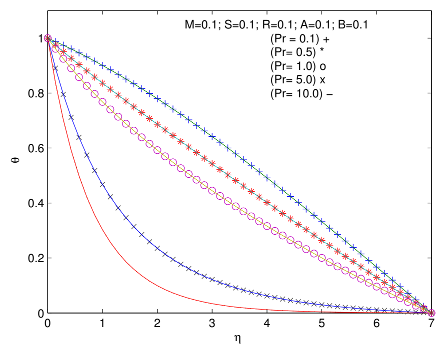

Figure 4 dimensionless temperature profiles θ vs. η as M=0.1,S=0.1,R=0.1, A=0.1, B=0.1 and Pr=0.1, 0.5, 1,5,10.

Figure 4 is shown dimensionless temperature profiles θ vs. η as M=0.1, S=0.1, R=0.1, A=0.1, B=0.1 and Pr=0.1, 0.5, 1, 5, 10. The dimensionless temperature profiles are a parabolic type curve satisfied with the boundary conditions. The Prandtl number is larger, when the dimensionless temperature profile is lower. So that, the Prandtl number can remove the heat from the fluid and its effect is good for a higher Prandtl number.

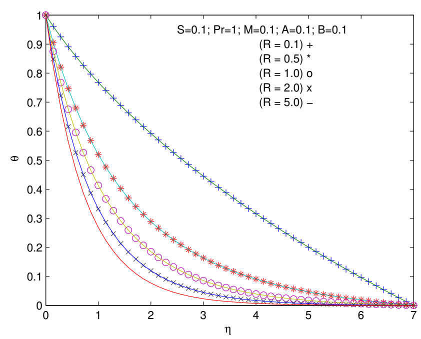

Figure 5 dimensionless temperature profiles θ vs. η as S=0.1, M=0.1, Pr=1, A=0.1, B=0.1 and R=0.1, 0.5, 1, 2, 5.

Figure 5 is shown dimensionless temperature profiles θ vs. η as S=0.1, M=0.1, Pr=1, A=0.1, B=0.1 and R=0.1, 0.5, 1, 2, 5. The dimensionless temperature profiles are a parabolic type curve satisfied with the boundary conditions. The radiation parameter is larger, when the dimensionless temperature profile is lower. So that, the radiation parameter can remove the heat from the fluid and its effect is good for a higher radiation parameter.

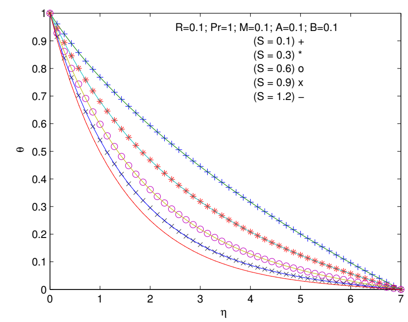

Figure 6 dimensionless temperature profiles θ vs. η as R=0.1, M=0.1, Pr=1, A=0.1, B=0.1 and S=0.1, 0.3, 0.6, 0.9, 1, 2

Figure 6 is shown dimensionless temperature profiles θ vs. η as R=0.1, M=0.1, Pr=1, A=0.1, B=0.1 and S=0.1, 0.3, 0.6, 0.9, 1, 2. The dimensionless temperature profiles are a parabolic type curve satisfied with the boundary conditions. The unsteadiness parameter is larger, when the dimensionless temperature profile is higher. So that, the unsteadiness force can not remove the heat from the fluid and its effect is not good for a higher magnetic parameter. Figure 7 is shown dimensionless temperature profiles θ vs. η as R=0.1, Pr=1, S=0.1, A=0.1, B=0.1 and M=0.1, 0.5, 1, 2, 5. The dimensionless temperature profiles are a parabolic type curve satisfied with the boundary conditions. The magnetic parameter is larger, when the dimensionless temperature profile is higher. So that, the magnetic force can not remove the heat from the fluid and its effect is not good for a higher magnetic parameter.

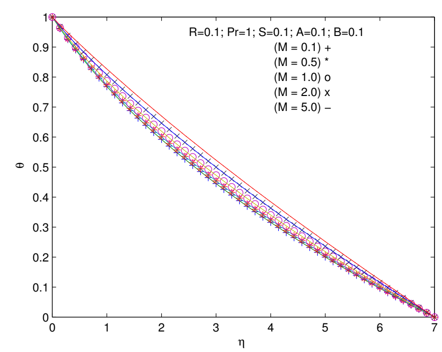

Figure 7 dimensionless temperature profiles θ vs. η as R=0.1, Pr=1, S=0.1, A=0.1, B=0.1 and M=0.1, 0.5,1,2,5.

Figure 8 is shown dimensionless temperature profiles θ vs. η as R=0.1, Pr=1, S=0.1, M=0.1 and A, B=1, 2, 3, 4, 5. The dimensionless temperature profiles are a parabolic type curve satisfied with the boundary conditions. The non-uniform heat source parameters are larger, when the dimensionless temperature profiles are higher. So that, the non-uniform heat source parameters can not remove the heat from the fluid and their effects are not good for a higher magnetic parameter.

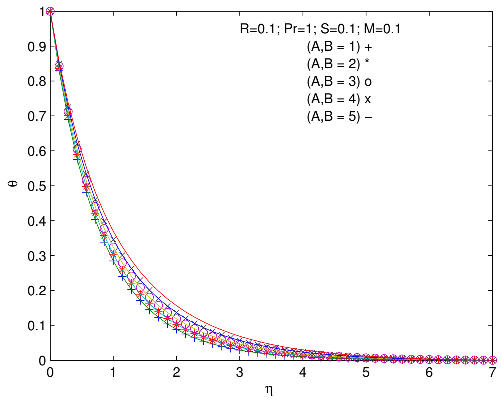

Figure 8 dimensionless temperature profiles θ vs. η as R=0.1, Pr=1, S=0.1, M=0.1 and A, B=1, 2, 3, 4, 5

5. Conclusion

A steady two-dimensional forced convection of an incompressible fluid flow adjacent to a thermal forming stretching sheet has been studied. A similar solution obtained and results indicate that the magnetic force can reduce the fluid speed in the boundary layer and reduce the heat transfer performance. The variation of the magnitude of dimensionless wall shear stress important factor $f''(0)$ depends on relative quantities of S and M. Dimensionless heat transfer important factor $-\theta'(0)$ increases with increasing values of Pr, R, S and $-\theta'(0)$ is decreases with increasing M, A, B so that, the values of M, S, Pr, R parameters are important factors in this study. It concluded that Pr, R, S are important factors that result in greater heat transfer effect, but parameters M, A, B will reduce heat transfer effect.

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