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Magnetohydrodynamic Mixed Convection on Cu-nanofluid Over a Cone in a Suspension of Different Water Temperatures

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Abstract: Nanofluids are Nanoscale colloidal suspensions containing condensed nanomaterials. These fluids enhanced the thermal and physical properties in many areas. With this intention, we study the magnetohydrodynamic mixed convection flow over a cone in the presence of non-uniform heat source/sink and thermal radiation. In this study, we consider Cu-water nanofluid at 50°C and 10°C temperature variations. The model; used for the nanofluid is one which includes the Brownian motion and thermophoresis effects. The self-similarity transformed governing equations are solved by using Runge-Kutta technique. The physical characteristics namely, the friction factor coefficient, the rate of heat and mass transfer coefficients , velocity, temperature and concentration fields are discussed and analyzed through graphs and tables. Results indicate that the Cu-water nanofluid enhanced the temperature profiles at 50°C when comparison with 10°C for all flow parameters. Also, found that the heat transfer rate is higher at 10°C temperature when compared with the temperature at 50°C.

Keywords: Mixed convection, MHD, Brownian motion and thermophoresis parameters, Copper nanoparticles, Non-uniform heat source/sink, Thermal radiation

I. INTRODUCTION

Common base fluids include water, ethylene glycol and oil. Nanofluids have novel properties that make them potentially useful in many applications in heat transfer including microelectronics, fuel cells, pharmaceutical processes, and hybrid-powered engines, engine cooling/vehicle thermal management, domestic refrigerator, chiller, heat exchanger, in grinding, machining and in boiler flue gas temperature reduction. They exhibit enhanced thermal conductivity and the convective heat transfer coefficient compared to the base fluid. The word nanofluid was initiated by Choi [1]. He explained that the nanoparticles increases the thermal conductivity of base fluids and therefore substantially enhances the heat transfer characteristics of the nanofluid. Later, Eastman et al. [2], Xie et al. [3] and Jana et al. [4] showed that higher thermal conductivity can be achieved in thermal systems utilizing nanofluids.

The phenomenon of mixed convection occurs in many technical and industrial problems like electronic devices cooled by fans, nuclear reactor cooled during emergency shutdown, heat exchanger placed in a low velocity environment, solar central receiver to wind current etc. Few other studies on mixed convection and nanofluids are given in [5-15]. Bakier et al. [16] studied the melting effect on MHD mixed convection flow from radiate vertical plate embedded in a saturated porous medium. They observed that the stream function, velocity and the rate of heat transfer at the plate surface increases with increase of radiation parameter, mixed convection parameter and magnetic field.

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Magnetohydrodynamic mixed convection boundary layer flow of a nanofluid near the stagnation-point on a vertical permeable plate with prescribed external flow and surface temperature is investigated by Tamim [17].

The study of flow over cone-shaped bodies is often encountered in many engineering applications. Unsteady flow of a rotating nanofluid in a rotating cone in the presence of magnetic field is studied by Nadeem [18]. The effects of temperature-dependent viscosity and thermal conductivity on the flow and heat transfer characteristics of a viscous fluid over a rotating vertical cone is investigated by Malik [19]. The similarity solution of the mixed convection from a rotating vertical cone in an ambient fluid was obtained Himasekhar et al. [20]. The laminar natural convection from a non-isothermal cone was analyzed by Hering [21] and Roy [22]. Nadeem [23] examined the unsteady mixed convection flow of magnetohydrodynamic flow on a rotating cone in a rotating frame. Mixed convection nanofluid flow over a vertical cone embedded in a porous medium with thermal radiation is studied by Chamkha [24]. Singh [25] analyzed the development of unsteady mixed convection flow over a vertical cone when the fluid in the external stream is set into motion impulsively, and at the same time the surface temperature is suddenly changed from its ambient temperature. Mixed convection flow over a vertical cone in the presence of suction/injection is studied by Ravindran [26] and concluded that the suction parameter and the axial distance steepen both the velocity and temperature profiles.

Now a days, because of the numerous applications of nanofluids in science and technology, a comprehensive study on magnetohydrodynamic mixed convection flow over a cone with cu-water nanofluid at 10°C and 50°C temperature varying in the presence of Brownian motion, thermophoresis, non-uniform heat source/sink and radiation. The resulting set of equations is solved by using MATLAB package and the impact of various flow parameters on velocity, temperature and concentration as well as the friction factor coefficient and the rate of heat and mass transfer coefficients are derived and analyzed through graphs and tables.

Formulation of the Problem

In this study, we devoted the Brownian motion and thermophoresis effects on radiative MHD nanofluid flow over a cone in the presence of non-uniform heat source/sink. The cone is of radius r and half angle is γ. The origin is placed at the vertex of full cone, where x is the coordinate measured from the origin along the surface of the full cone and y-axis is the normal to the surface of the cone. The distance from the edge of the cone to origin is x. It is assumed that the variable magneticfield $B(x) = B_0/x(\mathrm{Gr})^{-1/4}$ is applied along the x-direction as displayed in Fig. 1. The induced magneticfield is neglected in this study. T_w, T_∞ and C_w, C_∞ are indicates the temperature and concentrations near and far away from the cone. $u_w(x) = (v/x)(Gr)^{1/2}$ is the at the wall velocity. According to assumptions the governing boundary layer equations are as follows:

Fig. 1. Physical model of flow configuration.

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Flow Analysis

(1)

$$\rho_{nf}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\left(\mu_{nf}\frac{\partial^2 u}{\partial y^2}+g(\rho\beta_T)_{nf}(T-T_\infty)\cos(\gamma)+g(\rho\beta_c)_{nf}(C-C_\infty)\cos(\gamma)-\sigma B^2 u\right) \quad (2)$$

With the boundary conditions

$$u=u_w(x)=(v/x)(Gr)^{1/2}, v=0,\ \text{at}\ y=0,\ u\to 0, \text{as}\ y\to\infty,\} \quad (3)$$

Where u, v are the velocity components along the x, y directions respectively ρ_{nf} is the density of the nanofluid, μ_{nf} is the viscosity coefficient, g is the acceleration due to gravity, $(\rho\beta)_{nf}$ is the thermal expansion coefficient due to temperature difference, $\sigma$is the electric conductivity, $\boldsymbol{v}$ is the kinematic viscosity.
The nanofluid constants are given by

(4)

To convert the non-linear coupled partial differential equations for velocity, we introduce the self-similarity transformations are given by: (5)

$$\left.\begin{aligned}&u=\frac{v_f}{x}(Gr)^{1/2}f'(\eta), v=\frac{v_f}{x}(Gr)^{1/4}\left(\frac{\eta}{4}f'(\eta)-\frac{1}{2}f(\eta)\right), \eta=\frac{y}{x}(Gr)^{1/4}\\&T=T_\infty+(T_w-T_\infty)\theta(\eta), C=C_\infty+(C_w-C_\infty)\phi(\eta), Gr=\frac{\rho g x^3\beta_T\cos(\gamma)(T_w-T_\infty)}{v^2}\end{aligned}\right\}$$

Here in Equation (5) u and v are automatically satisfying the continuity equation and by using equation (5), the equations (1) to (2) transformed equations are given by:

$$\left(\frac{1}{(1-\phi)^{2.5}}\right)f'''+\left(\frac{ff''}{4}-\frac{f'^2}{2}\right)\left((1-\phi)+\phi\frac{\rho_s}{\rho_f}\right)-Mf'+\left((1-\phi)+\phi\frac{(\rho\beta)_s}{(\rho\beta)_f}\right)(\lambda\theta+\phi)=0 \quad (6)$$

The transformed boundary conditions are:

(7)

Here ϕ is the volume fraction of Ferro nanoparticle, M is the magnetic field parameter, γ is the half angle, ρ_f, ρ_s are the densities of the fluid and solids respectively, λ is the buoyancy parameter, is for assisting flow(heated cone) and (T_w-T_∞) 0 is for opposing flow(cooled cone).

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Heat Transfer Analysis

The boundary layer energy equation with non-uniform heat source/sink, heat source parameter, Brownian motion and thermophoretic parameters are given by:

(8)

With the corresponding boundary conditions are:

(9)

Where $(\rho c_p)_{nf}$ is the heat capacitance of the nanofluid, T is the fluid temperature, T_w, T_∞ are the near the fluid temperature and the far away from the fluid temperature, k_{nf} is the thermal conductivity of the nanofluid, c_p is the specific heat capacitance at constant pressure, c_s is the concentration susceptibility, σ^* is the Stefan-Boltzmann constant, k^* is the mean absorption coefficient and the time dependent non-uniform heat source/sink parameter is q'''defined as:

(10)

In the above equation $A^*>0$, $B^*<0$ corresponds to internal heat generation and $A^*>0$, $B^*<0$ corresponds to heat absorption coefficients respectively.
By using self-similarity transformations of (4), (9), (10) and equation (8) reduced to

$$\left(\frac{k_{nf}}{k_f}+\frac{4}{3}R\right)\theta''+\frac{\Pr}{2}f\theta'\left((1-\phi)+\phi\frac{(\rho c_p)_s}{(\rho c_p)_f}\right)+\Pr Nt\theta'^2+\Pr Nb\theta'\phi'+A^*f'+B^*\theta=0$$
(11)

With the transformed boundary conditions are:

$$\theta(0)=1,\ \theta(\infty)=0 \qquad (12)$$

Where Pr is the Prandtl number, A^*, $B^*$are the time dependent heat source/sink parameters, R is the radiation parameter which are given by:

(13)

Mass Transfer Analysis

The boundary layer equation of mass diffusion equation in the presence of chemical reactions is given by:

(18)

The corresponding boundary conditions are:

(19)

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Where D_B is the Brownian diffusion coefficient, D_T is the thermophoretic coefficient.

(20)

The corresponding boundary conditions are:

(21)

Where $Le = \nu_f / D_B$ is the Lewis number.

For physical quantities of interest the friction factor coefficient, the rate of heat transfer and the rate of mass transfer are given by:

(22)

Where is the Reynolds number.

II. Results And Discussion

The set of coupled non-linear equations (6), (11) and (20) subjected to the boundary conditions (7), (12) and (21) are solved numerically by using Runge-Kutta method. The impact of various flow parameters on velocity, temperature and concentration as well as the friction factor coefficient and the rate of heat and mass transfer coefficients at 10°C and 50°C are discussed through graphs and tables. For numerical computation we fixed the values as K = 0.3, M = 1, λ = 0.1, ϕ = 0.01, Nb = 0.1, Nt = 0.1, A^* = 1, B^* = -0.1, R = 0.5.The thermo physical properties are shown in Tables 1 and 2 shows the validation of results with the existing results.

Fig. 2. Effect of M on $f'(\eta)$.

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Fig. 3. Effect of *M* on θ(η).

Fig. 4. Effect of *M* on ϕ(η).

Fig. 5. Effect of λ on f'(η).

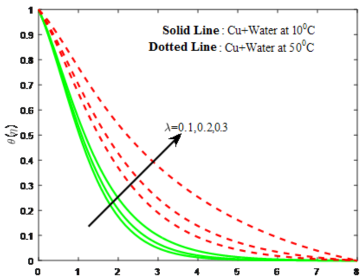

Fig. 6. Effect of λ on θ(η).

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with the rising values of M in both cases. This is due to the fact that an increasing transverse magnetic field on the electrically conducting fluid gives rise to a resistive type force called Lorentz force which is similar to drag force and upon increasing the value of M, increases the drag force which has the tendency to slow down the fluid velocity. The resistance offered to the flow is responsible in enhancing the temperature and concentration fields. It is interesting to notice that the hike in fluid temperature is due to the enhancement in temperature from 10°C to 50°C.

Figs. 5-7 demonstrates the behavior of mixed convection parameter λ on velocity, temperature and concentration distributions for cu-water nanofluid with different temperatures. It is clear that the mixed convection parameter shows the reduction in velocity filed for both temperatures. Physically $\lambda>0$ means heating of the fluid, $\lambda<0$ means cooling of the fluid, and$\lambda = 0$ means the absence of free convection currents. From the Fig. 5 it is seen that an increase in λ leads to a decrease in the normal velocity. Also, the rising values of λ leads to an enhance in the temperature difference (T_W-T_∞). This leads to reduce the velocity profile due to the enhanced convection and thus decreases the velocity boundary layer thickness. The reverse tendency is observed on temperature and concentration profiles (Figs. 6 and 7). Here the temperature profiles of Cu-water nanofluid at 50°C temperature showed better enhancement in thermal boundary layer thickness compared with 10°C temperature while the opposite trend is observed on concentration profiles.

M	λ	ϕ	Nb	Nt	A^*	B^*	R	Friction factor coefficient		Nusselt number		Sherwood number	
								Water at 10°C	Water at 50°C	Water at 10°C	Water at 50°C	Water at 10°C	Water at 50°C
1								-1.23917	-1.24963	0.414359	0.255967	0.91072	0.945516
2								-1.42164	-1.42965	0.397712	0.23474	0.860077	0.906935
2								-1.58145	-1.58771	0.382272	0.217942	0.819007	0.87587
	0							-1.85784	-1.86263	0.355356	0.170669	0.748733	0.818497
	0							-1.93661	-1.9463	0.342373	0.14978	0.714762	0.789701
	0							-2.01912	-2.03363	0.324723	0.123405	0.672404	0.755344
		0						-1.85784	-1.86263	0.355356	0.170669	0.748733	0.818497
		0						-1.67355	-1.68346	0.341986	0.154861	0.733069	0.804994
		0						-1.45029	-1.464	0.318083	0.139328	0.716693	0.787218
			0					-1.85989	-1.86318	0.595105	0.383267	0.444322	0.580111
			0					-1.85694	-1.86072	0.436456	0.331227	0.714417	0.736054
			0					-1.85725	-1.86041	0.312037	0.2847	0.792242	0.785291
				0				-1.85694	-1.86072	0.436456	0.331227	0.714417	0.736054
				0				-1.86159	-1.86384	0.375157	0.308685	0.613664	0.63636
				0				-1.86561	-1.86675	0.326439	0.288651	0.535851	0.546564
					1			-1.85816	-1.86185	0.267449	0.135951	0.788307	0.833583
					2			-1.85976	-1.86382	0.056291	-0.11263	0.87701	0.938271
					3			-1.86134	-1.86576	-0.1559	-0.35995	0.966294	1.042532
						0		-1.85688	-1.86024	0.435621	0.335782	0.717768	0.749502
						0		-1.85608	-1.85866	0.507203	0.455033	0.689787	0.701069
						-1		-1.85539	-1.85747	0.572552	0.552477	0.663949	0.661826
							1	-1.85694	-1.86061	0.436379	0.331996	0.714703	0.73914
							1	-1.85806	-1.86152	0.409648	0.296282	0.718181	0.751585
							2	-1.85896	-1.86214	0.382301	0.270129	0.724242	0.761935

Table 3. The physical parameter values of skin friction coefficient, Nusselt number and Sherwood number values with different values of M = 2, λ = 0.1, A^* = 0.1, B^* = 0.1, Ra = 0.5, ϕ = 0.1, Nb = Nt = 0.3, Le = 0.1, Pr = 2 different temperatures of base fluid with copper nanofluid flow over a cone.

Figs. 8-10 depict the effect of volume fraction parameter ϕ on $f'(\eta)$, $\theta(\eta)$ and $\phi(\eta)$ in different temperatures with cu-water nanofluid. Ii is found that the velocity decreases with the increase of the volume fraction of the nanoparticles. This is due to the fact that, as the nanoparticle volume fraction increases, the reaction becomes increasingly confined to a relatively narrow region far from the wall. In addition to this, when the volume fraction of the nanoparticle increases, the thermal conductivity increases, and the thermal boundary layer increases. Moreover, the concentration profiles are

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III. CONCLUSION

In the present study, we studied the magnetohydrodynamic mixed convection flow of nanofluid over a cone with Cu-water nanofluid at 10°C and 50°C temperature variations. The governing partial differential equations are transformed into ordinary differential equations by using suitable similarity transformations and then solved numerically by using Runge-Kutta method. The effects of flow parameters are discussed through graphs and tables.

The main conclusions are as follows

- Thermal and concentration boundary layers are enhanced by the volume fraction parameter and mixed convection parameter.
- The Cu-water nanofluid at 10°C has high heat transfer rate when compared with the temperature variation at 50°C. As a result Cu-water nanofluid at 10°C improves the thermal performance more than the Cu-water nanofluid at 50°C temperature.
- The space dependent heat source/sink parameter ($A^{*}>0$) reduces the friction factor coefficient and improves the heat transfer rate. But an opposite trend is observed on temperature dependent heat source/sink parameter ($B^{*}<0$).
- The heat transfer rate is higher at 10°C when compared with the temperature at 50°C.

The rising value of thermophoresis parameter enhances the species concentration.

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