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MHD VISCOUS CHEMICALLY REACTED MARANGONI CONVECTIVE NANOFLUID FLOW OVER A FLAT PLATE WITH SUCTION/INJECTION

D.R.V.S.R.K. Sastry
Department of Mathematics, SASTRA University,
Thanjavur-613401, Tamil Nadu, India

M. Srinivasu
Department of Mathematics, Aditya College of Engineering,
Surampalem-533437, Andhra Pradesh, India

A V S N Murty, M. N. Srinivas
Department of Mathematics, VIT University,
Vellore – 632014, Tamilnadu, India

ABSTRACT

Analysis is carried out in a two dimensional marangoni convection boundary layer flow over a flat plate with uniform porosity. The fluid is a mixture of three nanoparticles (Copper, Silver, Alumina) with base fluid water. The combined effects of suction with various parameters over fluid physical properties are studied. Navier-Stoke's equations are transformed to a set of coupled nonlinear differential equations by means of similarity transformation. The higher order differentials are reduced to a set of first order differentials and solved then by using 'bvp4c' routine programme.

Key word: Marangoni Convection, Viscous Dissipation, Nanofluid, Heat and Mass Transfer, Magnetic Field.

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1. INTRODUCTION

High thermal conductivity and stability uniquely brought the nanofluids into many engineering applications. When a common fluid is experienced the suspension of nanoparticles results in nanofluid. Water is used as common fluid with Prandtl number 6.785. Many research papers are published on numerical studies over modeling heat and mass transfer in nanofluids (Ghasemi et al. , Ho et al. , Das et al.)[1, 2, 3]. Thermophoresis and Brownian diffusion in nanofluids are studied by (Buongiorno)[4]. In recent years, marangoni convection attains a great interest in the study of crystal growth melts and in the process of semiconductors. The gradient in the surface tension causes marangoni convection. (Pop et al.)[5] Focused on effect of marangoni convection in a flow over a permeable surface. Many researchers study effects on heat and mass transfer over a marangoni convection in a fluid flow over a permeable surface (Hamid et al., Sastry et al.)[6, 7].

The fluid flow over a permeable surface with suction/injection affects the flow characteristics. So we proposed to study these effects over a nanofluid flow effected by suction parameter and Hartmann number.

2. MATHEMATICAL FORMULATION

Consider a nanofluid laminar flow over a permeable flat plate having constant porosity. The flow is assumed to be two-dimensional, incompressible and steady. Two nano sized particles Copper and Silver are submerged in base fluid Water. Further assume that fluid is experiencing a uniform transverse magnetic field and nano particles are in thermal equilibrium. A Cartesian coordinate system (x, y), where x and y are the coordinates measured along the plate and perpendicular to it, respectively. The Boussinesq flow which takes place at $y \geq 0$ has boundary layer equations as follows.

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

$$\rho_{nf}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=\mu_{nf}\frac{\partial^2 u}{\partial y^2}-\sigma^* {H_0}^2 u \tag{2}$$

$$(\rho C_p)_{nf}\left(u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k_{nf}\frac{\partial^2 T}{\partial y^2}-\mu_{nf}\left(\frac{\partial u}{\partial y}\right)^2 \tag{3}$$

$$u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D\frac{\partial^2 C}{\partial y^2}+D^*\frac{\partial^2 T}{\partial y^2}-K^*(C-C_\infty) \tag{4}$$

with valid boundary conditions:

$$v=v_w, T=T_\infty+ax^2, C=C_\infty+bx^2, \mu_{nf}\frac{\partial u}{\partial y}=\gamma\frac{\partial T}{\partial x}+\gamma^*\frac{\partial C}{\partial x} \text{ at } y=0 \text{ and}$$

$$u\to 0, T\to T_\infty, C\to C_\infty \quad \text{as } y\to\infty \tag{5}$$

Here u and v are the components of velocity along the x and y axes, respectively. ρ is the fluid density, T is the temperature, C is the concentration, C_∞ is the concentration of the fluid far from the surface, C_p is the specific heat at constant pressure, D is the species diffusivity, $D^*$is the coefficient that signifies the contribution to mass flux through temperature gradient and K^* is the chemical reaction parameter. $\sigma^*$is the electric conductivity and a, b are the coefficients of temperature and concentration gradients respectively. Let ϕ be solid particles volume fraction of nanoparticles, then the following

$$\mu_{nf} = \frac{\mu_f}{(1-\phi)^{2.5}} \quad (6)$$

$$\rho_{nf} = (1-\phi)\rho_f + \phi\rho_s \quad (7)$$

$$\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}} \quad (8)$$

$$(\rho C_p)_{nf} = (1-\phi)(\rho C_p)_f + \phi(\rho C_p)_s \quad (9)$$

$$k_{nf} = k_f\left(\frac{k_s+2k_f-2\phi(k_f-k_s)}{k_s+2k_f+\phi(k_f-k_s)}\right) \quad (10)$$

Describe effective quantities like viscosity, density, thermal diffusivity, and the heat capacitance of the nanofluid respectively.

In equations (6) - (10), the subscripts *nf*, *f* and *s* denote the thermo physical properties of the nanofluid, base fluid and nano-solid particles respectively. By the virtue of fluid flow one can introduce a similarity variable η and stream function $\psi(x, y)$ satisfying$u = \frac{\partial\psi}{\partial x}$, $v = -\frac{\partial\psi}{\partial x}$ in such a way that

$$\psi = C_1 x f(\eta), \quad \eta = C_2 y \quad (11)$$

where the constants C_1 *and* C_2 are given by

$$C_1 = \left(\frac{\frac{d\sigma}{dT}\Big|_C a\mu_f}{\rho_f^2}\right)^{1/3}, \quad C_2 = \left(\frac{\frac{d\sigma}{dT}\Big|_C a\rho_f}{\mu_f^2}\right)^{1/3} \quad (12)$$

Further non-dimensional temperature and concentration are defined as

$$\theta(\eta) = \frac{T-T_\infty}{ax^2} \quad h(\eta) = \frac{C-C_\infty}{bx^2} \quad (13)$$

By the influence of dimensionless quantities given by (11)-(13), the governing flow equations (2) -(4) along with boundary conditions (5) are transformed to non-dimensional equations as follows.

$$f''' = (1-\phi)^{2.5}[(1-\phi) + \phi\frac{\rho_s}{\rho_f}](f'^2 - ff'') + M^2 \ (1-\phi)^{2.5} f' \quad (14)$$

$$\theta'' = \frac{\Pr k_f}{k_{nf}}\left(1-\phi+\phi\frac{(\rho C_p)_s}{(\rho C_p)_f}\right)(2f'\theta - f\theta') + \frac{Ecf'^2}{(1-\phi)^{2.5}\left(1-\phi+\phi\frac{(\rho C_p)_s}{(\rho C_p)_f}\right)} \quad (15)$$

$$h'' = Sc(2hf' - fh' + K^* h) - Sr\theta'' \quad (16)$$

Boundary conditions are

$f(0) = f_0, \theta(0) = h(0) = 1, \frac{1}{(1-\phi)^{2.5}} f''(0) = -2(1+\varepsilon)$ at y = 0 and

$$f'(\infty) = 0, \theta(\infty) = h(\infty) = 0 \text{ as } y \to \infty \quad (17)$$

where $M = \dfrac{\sigma_c^{1/2} H_0 \mu^{1/6}}{\rho^{1/3}\left(\left.\dfrac{d\sigma}{dT}\right|_C\right)^{1/3} a^{1/3}}$, $K^* = \dfrac{K_0 \mu_f^{1/3} \rho_f^{1/3}}{\left(\left.\dfrac{d\sigma}{dT}\right|_C\right)^{2/3} a^{2/3}}$, $\varepsilon = \dfrac{\Delta C \left.\dfrac{d\sigma}{dC}\right|_C}{\Delta T \left.\dfrac{d\sigma}{dT}\right|_C}$ $\Pr = \dfrac{\upsilon_f (\rho C_p)_f}{k_f}$,

$Sr = \dfrac{D^*(T - T_\infty)}{D(C - C_\infty)}, Sc = \dfrac{\upsilon_f}{D},\ Ec = \dfrac{1}{Cp_f}\left\{\dfrac{a\left.\dfrac{d\sigma}{dt}\right|_C^4}{\rho_f^2 \mu_f^2}\right\}^{1/3}$

Heat and mass transfer rates are measured with Nusselt and Sherwood numbers respectively. They are defined as $Nu_x = \dfrac{xq_w}{k(T - T_\infty)}$, $Sh_x = \dfrac{xq_s}{D(C - C_\infty)}$ where $q_w = -k_{nf}\left(\dfrac{\partial T}{\partial y}\right)_{y=0}$ and $q_s = -D\left(\dfrac{\partial C}{\partial y}\right)_{y=0}$

In dimensionless form Nusselt and Sherwood numbers are obtained as:

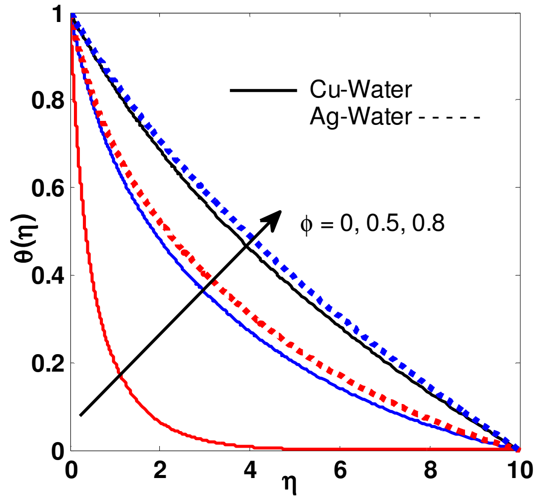
$\dfrac{Nu_x}{C_2 x}\left(\dfrac{k_f}{k_{nf}}\right) = -\theta'(0)$ and $\dfrac{Sh_x}{C_2 x} = -h'(0)$

where $C_2 x$ is dimensionless quantity.

2. GRAPHICAL ILLUSTRATION AND RESULT ANALYSIS

The physics of the problem is explained through Graphs. The set of coupled boundary layer equations presented in (14)-(16) followed by boundary conditions (17) does not possess a closed form solution. So, we carried out a numerical approach to get an approximate solution. We applied a semi numerical method 'bvp4c' solver in MATLAB to obtain a solution of governing equations of motion. Results are carried out at the following parametric values: $M = Nr = Sr = 2, Sc = 0.6, \emptyset = \epsilon = K^* = Ec = 0.2, f_0 = 1$.

It is observed that from fig.1, when the nanoparticles volume fraction increases, temperature also increases within the boundary layer. It is also observed that, the temperature is higher for Cu-water nanofluid particles than that of Ag-water particles. This is due to the high solutal conductivity of Copper (Fig.3). In addition to this, when the volume fraction of the nano particles increases, the thermal conductivity increases, and the thermal boundary layer increases. Also temperature distribution is more in Ag-water than Cu-water, since Silver is more thermal conductive material. With increasing nano particles volume fraction, the thermal boundary layer thickness increases. From fig.2 and fig.5, it is noticed that when a magnetic field is applied within the boundary layer, it produces a resistive type force, known as Lorentz force which acts to retard the fluid motion along the surface and simultaneously increase temperature and concentration profiles. From fig.3, it is observed that temperature decreases as Eckert number increases. Fig.4 witnesses that thermosolutal surface tension ratio significantly decreases the fluid temperature. This finding is obtained due to the increase in the values of ε demand the increase in the marangoni convection which produces more induced flows within the boundary layer. As a consequence, the resulting flows will propagate within the boundary layers causing the maximum velocity obtained at the wall which reduces the temperature boundary layer Also it is found from Fig.6 that increase in Eckert number enhances the species concentration. Fig.7 depicts the effect of Soret number on the species concentration of the nano particles. It is noticed that increase in Soret number enhances the concentration of the nanofluid particles. This increase is more in Cu-water nanofluid particles. Fig.8 and fig.9 show that temperature and concentration are decreased with increase in suction parameter. Fig.10 – Fig.12 witness that when suction parameter increases velocity temperature and concentration profiles are decreasing and this is more effective in Alumina species.



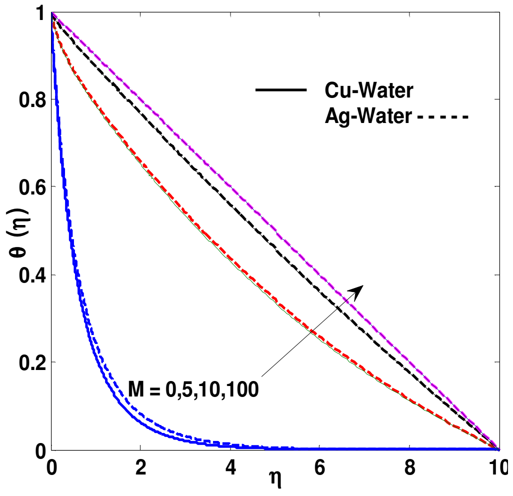
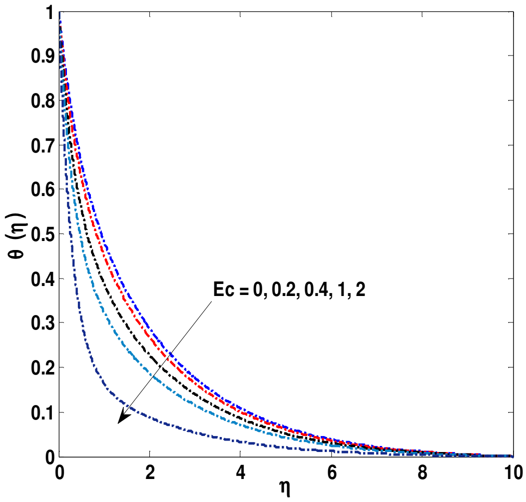


Figure 1 Temperature profiles for different volume fraction` **Figure 2** Temperature profiles for different Hartmann number



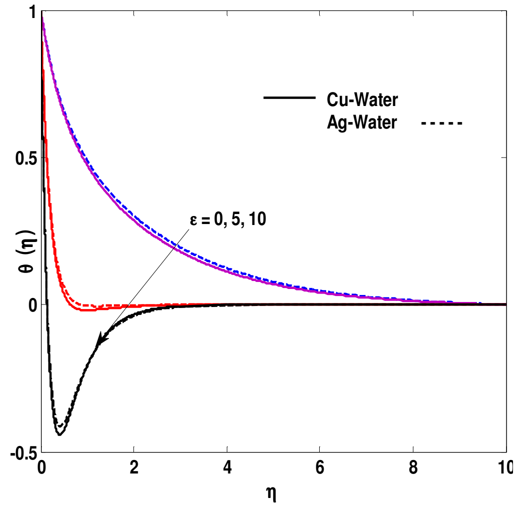


Figure 3 Temperature profiles for different viscous parameter **Figure 4** Temperature profiles for marangoni number

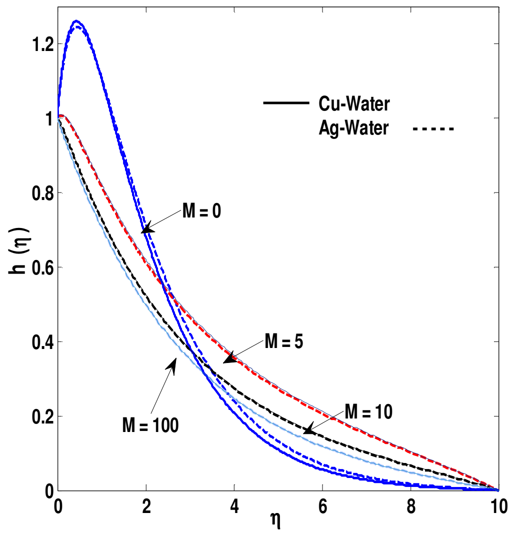


Figure 5 Concentration profiles for different Magnetic parameter

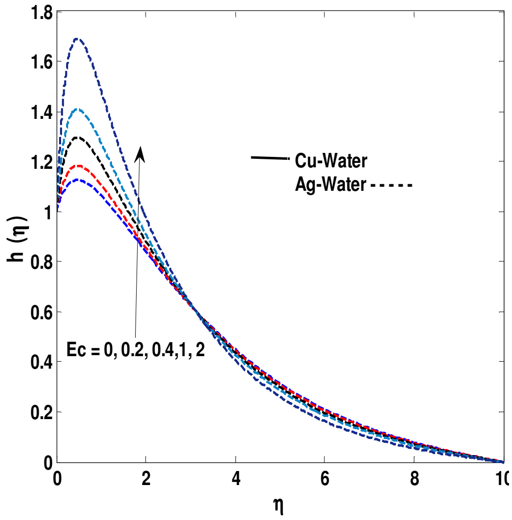
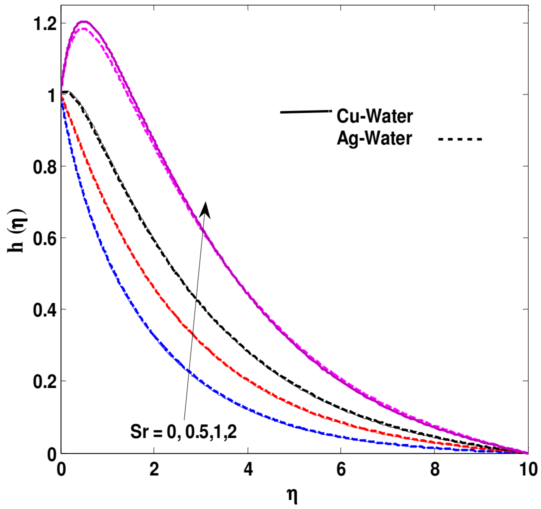


Figure 6 Concentration profiles for different Eckert number



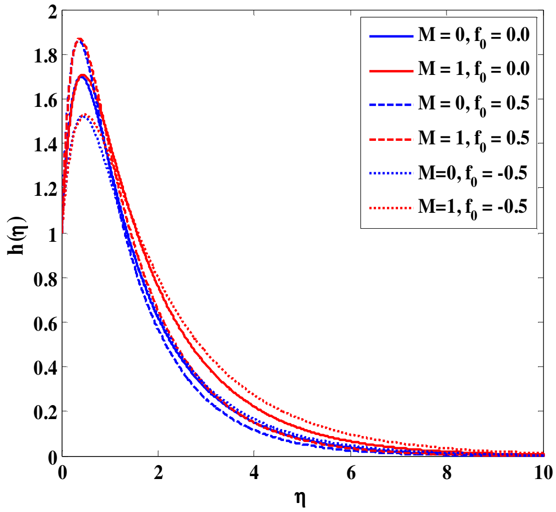


Figure 7 Concentration profiles for different Soret number **Figure 8** Concentration profiles for different Suction and magnetic parameters

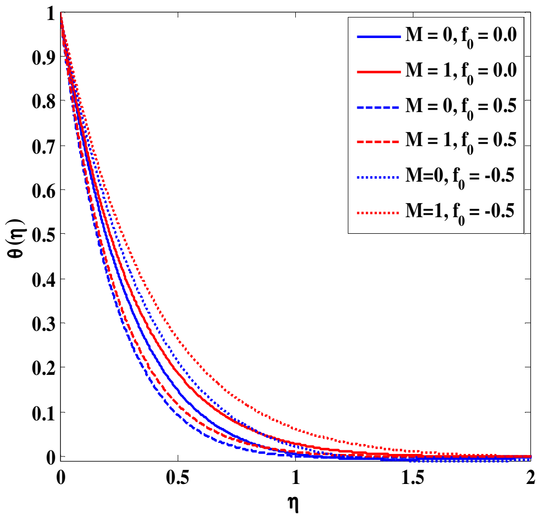


Fig 9 Temperature profiles for different Suction and magnetic parameters

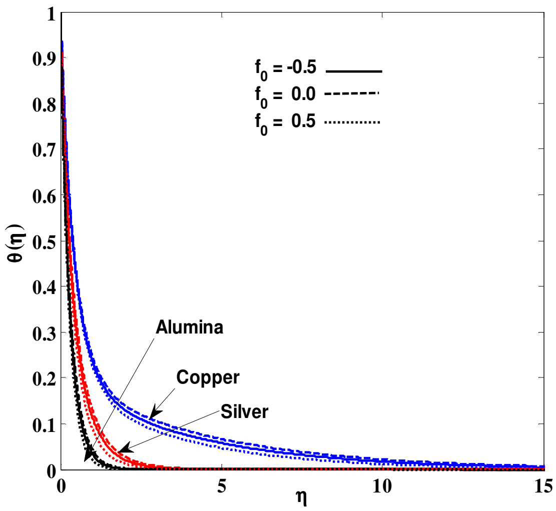


Fig 10 Temperature profiles for different Suction parameter

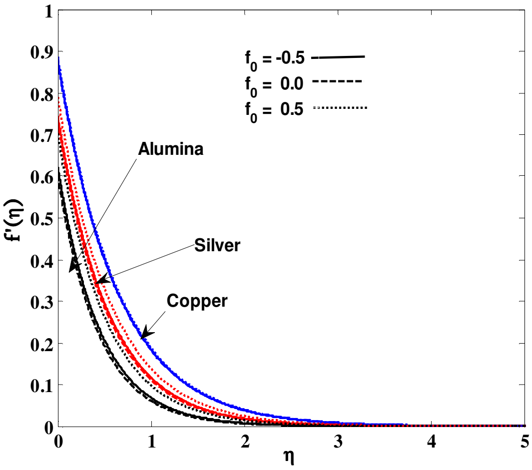


Fig 11 Velocity profiles for different Suction parameters

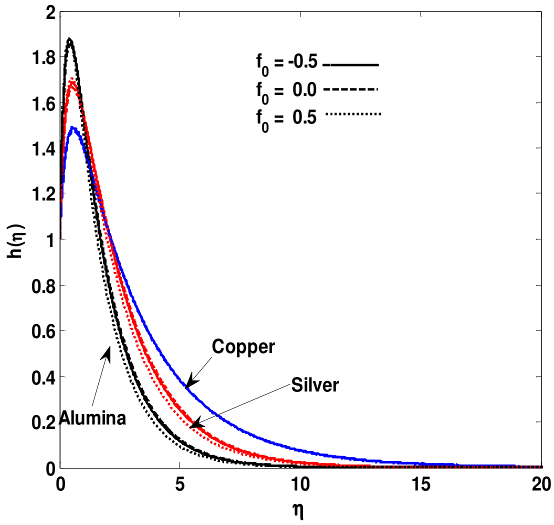


Fig 12 Concentration profiles for different Suction parameters

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