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MHD Mixed Convective Heat Transfer of Cu-Al_2O_3 Water Hybrid Nanofluid over a Stretching Wedge with Ohmic Heating

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ABSTRACT

The main purpose of the current article is present exploration scrutinizes a numerical simulation for the magneto-mixed convection flows of hybrid nanofluid over a stretching wedge with Ohmic heating applying Tiwari and Das model. Proper dimensionless variables are applied the governing PDEs which are solved numerically using Matlab program. The obtained results of velocity and temperature profiles for several key parameters are portrayed and construed in detail. It has been observed that the amount of skin friction coefficient and the Nusselt number of the hybrid liquid nano improve and increase with the increase of the nanoparticle size fraction, magnetic field, mixed load, and wedge angle while it decreases when we increase the velocity ratio and increases with the increase of the Nusselt number.

1. INTRODUCTION

Mixed convection flow occurs when natural convection and forced convection technique work with each other to transfer heat. The study of the flow and heat transfer has great practical applications in the field of technology and science. Mixed convection flow over a stretching surface is one of these studies that play an important role in engineering, petroleum and agriculture industries like ion exchange columns, heat-treated materials operating between rolls or on a conveyor belt, materials production by extrusion processes, distillation towers, solar power absorbers and subterranean chemical waste migration etc. [1-9] are some of the studies that concentrate on the mixed convective flow over a perpendicular stretching surface in various cases. The study of the magnetic properties and behavior of electrically conducting fluids is called "Magnetohydrodynamics". This word has come from magneto which means magnetic field, hydro- which means water, and dynamics which mean movement. Saltwater, plasmas, liquid metals and electrolytes are examples of such magnetofluids. Alfvén [10] who is starting MHD. Mahdy and Nabwey [11] reported a numerical analysis of buoyancy-driven nanoliquid flow of gyrotactic time-mixed bioconvection heat transfer in stagnation domain of an impulsively revolving sphere due to convective boundary condition. Ahmed and Mahdy [12] delignated the case of mixed convection flow through an isothermal vertical wedge submersed in saturated porous medium using Buongiorno's nanofluid.

Magnetic fields are vastly utilized in modern metallurgical and metal-working processes like MHD power generators, the cooling of reactors, flow meters and MHD pumps etc. Magnetohydrodynamic debates the induced magnetic features of the electrical conductive fluids. In general, its impact on the stream and heat transfer knows as Lorentz force and Joule heating. Actually, exerting the magnetic field provides the resistance in the stream course and reduce the fluid motion. MHD mixed convective flow over a perpendicular stretching surface has been checked by Kumari and Nath [13] and Ishak et al. [14]. MHD mixed convection flow in an upper sided lid-driven cavity heated by a corner heater which was considered by Oztop et al. [15]. The number of studies associated with mixed convection flow over a wedge is very limited. The numerical results for mixed convection flow over a wedge with variable surface temperature were given by Hossain et al. [16]. The MHD mixed convective mass and heat transfer over a permeable wedge in the existence of a chemical reaction was checked by Muhaimin et al. [17]. MHD mixed convective mass and heat transfer past a permeable wedge was studied by Kandasamy et al. [18] and took into the effects of chemical reaction, thermophoresis, and variable viscosity.

A fluid which contains nanoparticles like (oxides, metals, carbon nanotubes or carbides) suspended in a base fluid like (oil, ethylene glycol, and water) is defined as nanofluid. This technique improves the effective conductivity of the resulting fluid comparing to the base fluid Choi [19] considered the first one introduce nanofluids. This increasing on the nanofluid conductivity depends on various parameters such as volume concentration of nanoparticles, shape, size, and material of nanoparticles, working temperature, and the material of base fluid. Recently, Momin [20] and Suresh et al. [21] have made a new experimental work on reinforcing the thermal conductivity of the prime fluid. it observed a new type called hybrid nanofluid by adding two various types or more of nanoparticles in a base fluid which improve the rate of heat transfer and thermal conductivity of the prime fluid better than nanofluids. For example, Al_2O_3 seems more chemical stagnation and stabilization than metallic nano particles, so metallic nanoparticles like zinc, aluminum and copper have high thermal conductivities. Hybrid nanofluid have many applications in different engineering fields like micro fluidics, nuclear safety, manufacturing, military, transportation, pharmaceutical, acoustics, naval structures, buildings or cooling of flush-mounted electronic heaters in supercomputers and modern electronic devices. So, due to these benefits of hybrid nanofluid, a lot of researchers are interested to use hybrid nanofluid for developing nanotechnology. Mourad et al. [22] presented a numerical contribution for heat transmit and magneto-hydrodynamic in a fined cold wavy-walled porous cavity with a hot elliptic inner cylinder occupied by hybrid Fe_3O_4-MWCNT /water nanofluid. Alwawi et al. [23] concerned with natural convection of ethylene glycol-based non-Newtonian nanoliquid and it is affected by a magnetic field along a horizontal circular cylinder. Niihara [24] shown that the thermal and mechanical properties can be significantly enhancement by adding nanoparticles to materials. The advantage of using the nanofluid in the liquid block is greater than pure water this is which was explored by Mehdi Bahiraei et al. [25]. The heat capacity of a fluid increased by single and hybrid nano-additives as show in the works of many researchers [26-28]. The aim of this article is discussing the effect of some parameters on Cu- Al_2O_3 water hybrid nanofluid flow over a stretching wedge with ohmic heating in the existence of a magnetic field.

2. MATHEMATICAL FORMULATION

Table 1. Thermo-physical properties of Copper and Alumina [29, 30]

Property	Water	Copper Cu	Alumina Al_2O_3
ρ	997.1	8933	3970
C_p	4179	385	765
k	0.613	401	40
β	$21x10^{-5}$	$1.67x10^{-5}$	$0.85x10^{-5}$
σ	0.05	$5.96x10^{7}$	$1x10^{-10}$
μ	$8.9x10^{-4}$	--	--

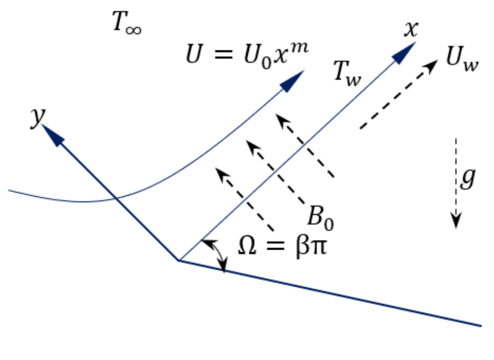

Figure 1. Flow model

Consider the problem of steady 2D magneto-hydrodynamic mixed convection flow of hybrid nanofluid Cu-Al_2O_3 water and heat transfer over a stretching wedge in an animated viscous, incompressible and electrically conducting fluid. As shown from Figure 1, the x-axis is been selected to be the along the wedge surface, and the normal to it is the y-axis. $U = U_0x^m$ is the velocity of the stream flow far away from the wedge. $U_w = UR$ is the velocity of the stretching of the wedge, were $(R \geq 0)$. $B(x) = B_0x^{(m-1)/2}$ is the magnetic field and applied in the y-direction. The induced magnetic field is neglected due to the assuming that the magnetic Reynolds number is small. The temperature in the external side of the temperature boundary layer is T_∞. The stretching wedge surface temperature is $T_w = T_\infty + bx^{2m}$.$\beta = 2m/(m+1)$, is the angle parameter of the wedge and $\Omega = \beta\pi$ for an overall angle of the wedge. $\beta = 0$ in the case of the wall is horizontal and $\beta = 1$ in the case of the wall is perpendicular. Table 1 shows the properties of thermophysical of the nanoparticles and base fluid [29, 30]. By these assumptions, the equations governing can be written as:

Continuity equation

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad (1)$$

Momentum equation

$$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = U\frac{dU}{dx} + \upsilon_{hnf}\left(\frac{\partial^2 u}{\partial y^2}\right) + g\beta_{hnf}(T - T_\infty)sin\frac{\Omega}{2} - \frac{\sigma_{hnf}B^2}{\rho_{hnf}}(u - U) \quad (2)$$

Energy equation

$$(\rho C_p)_{hnf}\left(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}\right) = -\rho_{hnf}u\left(U\frac{dU}{dx} + \frac{\sigma_{hnf}}{\rho_{hnf}}{B_0}^2U\right) + \alpha_{hnf}\left(\frac{\partial^2 T}{\partial y^2}\right) + \sigma_{hnf}B^2u^2 \quad (3)$$

with the boundary conditions

$$\left.\begin{array}{c} y = 0\text{: } u(x,y) = U_w, v(x,y) = 0, \\ T = T_w(x) = T_\infty + bx^{2m}, \\ y \to \infty\text{: } u(x,y) = U(x), T(x,y) = T_\infty, \end{array}\right\} \quad (4)$$

where, u is the component of the velocity along x-direction and v is the component of the velocity along the y-direction. T is the temperature, g is the gravity field, β_{hnf} is the thermal expansion coefficient, $(\rho c_p)_{hnf}$ is the specific heat at a fixed pressure, μ_{hnf} is the viscosity of the hybrid nanofluid, α_{hnf} is the thermal conductivity of the hybrid nanofluid, $\upsilon_{hnf} = \mu_{hnf}/\rho_{hnf}$ is the kinematics viscosity of the hybrid nanofluid.

We can define some of the similarity transformations as:

$$\left.\begin{array}{c} \psi(x,\eta) = \sqrt{Ux\upsilon_f}f(\eta) \\ \eta = y\sqrt{\frac{U}{\upsilon_f x}}, \theta(x,\eta) = \frac{T - T_\infty}{T_w - T_\infty} \end{array}\right\} \quad (5)$$

where, θ is the dimensionless temperature, $f' = u/U$ is the dimensionless velocity.

By substituting from Eq. (5) into Eq. (1:3) we get:

$$f''' = \frac{\sigma_{hnf}}{\sigma_f}(1-\varphi)^{2.5}\,\mathrm{M}(f'-1) - \frac{\rho_{hnf}}{\rho_f}(1-\varphi)^{2.5}\left(\frac{m+1}{2}ff'' + m(1-f'^2) + \frac{\beta_{hnf}}{\beta_f}\gamma\left(sin\frac{\Omega}{2}\right)\theta\right) \tag{6}$$

$$\theta'' = Pr\left(\frac{k_{hnf}}{k_f}\frac{(\rho C_p)_f}{(\rho C_p)_{hnf}}\right)^{-1}\left(\frac{(\rho C_p)_{hnf}}{(\rho C_p)_f}\left(-\frac{m+1}{2}f\theta' + 2mf'\theta\right) - Ec\left(M\frac{\sigma_{hnf}}{\sigma_f}f'^2 - \left(m\frac{\rho_{hnf}}{\rho_f} + \frac{\sigma_{hnf}}{\sigma_f}M\right)f'\right)\right) \tag{7}$$

The factors appeared are $\gamma = \frac{Gr_x}{Re^2{}_x}$, $\mathrm{M} = \frac{\sigma_f B_0{}^2}{\rho_f U_0}$, $Pr = \frac{\mu_f (C_p)_f}{k_f}$, $Re_x = \frac{Ux}{\upsilon_f}$, $Ec = \frac{U^2}{(C_p)_f (T_w - T_\infty)}$, $Gr_x = \frac{g\,\beta_{0f}\,(T_w - T_\infty)x^3}{\upsilon_f{}^2}$.
where, γ is the mixed convection parameter that refers to the effect of the thermal buoyancy force on the field of the flow, Pr is the Prandtl number, Ec is Eckert number, M is the magnetic parameter, Gr_x is local Grashof number, Re_x is local Reynolds number.

The boundary conditions which defined in Eq. (4), after transformations become:

$$\left.\begin{array}{c} f(0) = 0, f'(0) = R, f'(\infty) = 1, \\ \theta(0) = 1, \theta(\infty) = 0, \end{array}\right\} \tag{8}$$

where, R is the velocity ratio, when $\mathrm{R} > 1$ the wedge stretching is faster, when $\mathrm{R} < 1$ the wedge stretching slower. The prime refers to the derivative with respect to η. The physical quantities of interest, local Nusselt number and local skin friction coefficient are defined as:

Skin friction coefficient and Nusselt number are

$$C_f = \frac{\mu_{hnf}\left(\frac{\partial u}{\partial y}\right)_{y=0}}{\rho_f\,U_w^2}$$

$$Nu_x = -\frac{x\,k_{hnf}\left(\frac{\partial T}{\partial y}\right)_{y=0}}{k_f\,(T_w - T_\infty)}$$

Hence

$$Re_x{}^{1/2}C_f = \frac{f''(0)}{(1-\varphi)^{2.5}}$$
$$Re_x{}^{-1/2}Nu_x = -\frac{k_{hnf}}{k_f}\theta'(0) \tag{9}$$

3. THERMO-PHYSICAL PROPERTIES OF REGULAR NANOFLUIDS AND HYBRID NANOFLUIDS

The equation of density in nanofluid is:

$$\rho_{nf} = (1-\varphi)\rho_f + \varphi\,\rho s\rho_{nf} = (1-\varphi)\rho_f + \varphi\,\rho_s$$

And in Hybrid nanofluid is:

$$\rho_{\,hnf} = \left(1 - (\varphi_{s1} + \varphi_{s2})\right)\rho_f + \varphi_{s1}\rho_{s1} + \varphi_{s2}\rho_{s2}$$

The effective dynamic viscosity of the nanofluid according to the Brinkman model [31] is given by

$$\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$$

where, μ_f is the viscosity of the fluid fraction, so the effective dynamic viscosity of hybrid nanofluid is

$$\mu_{hnf} = \frac{\mu_{bf}}{\left(1 - (\varphi_{s1} + \varphi_{s2})\right)^{2.5}}$$

The equation of heat capacity in nanofluid is

$$(\rho c_p)_{nf} = (1-\varphi)(\rho c_p)_f + \varphi(\rho c_p)_s$$

The equation of heat capacity in hybrid nanofluid is:

$$(\rho_{Cp})_{hnf} = (1-\varphi)\left(\rho c_p\right)_f + \varphi_{s1}\left(\rho c_p\right)_{s1} + \varphi_{s2}(\rho c_p)_{s2}$$

The equation of thermal conductivity in nanofluid for spherical nanoparticles and according to the Maxwell-Garnetts model [28] is defined as:

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\varphi(k_f - k_s)}{(k_s + 2k_f) + \varphi(k_f - k_s)}$$

From this, the thermal diffusivity of nanofluid defined as:

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

The equation of thermal conductivity in hybrid nanofluid if thermal conductivity is defined as according to the Maxwell-Garnetts model should give by

$$\frac{k_{hnf}}{k_f} = \frac{\frac{\varphi_{s1}k_{s1} + \varphi_{s2}k_{s2}}{\varphi} + 2k_f + 2(\varphi_{s1}k_{s1} + \varphi_{s2}k_{s2}) - 2\varphi k_f}{\frac{\varphi_{s1}k_{s1} + \varphi_{s2}k_{s2}}{\varphi} + 2k_f - (\varphi_{s1}k_{s1} + \varphi_{s2}k_{s2}) + \varphi k_f}$$

So, the thermal diffusivity of hybrid nanofluid given by

$$\alpha_{hnf} = \frac{k_{hnf}}{(\rho C_p)_{hnf}}$$

The thermal expansion coefficient of the nanofluid can be determined by:

$$(\rho\beta)_{nf} = \varphi(\rho\beta)_s + (1-\varphi)(\rho\beta)_f$$

where, β_f is the coefficient of thermal expansion of the fluid and β_s for the solid fractions.

For a hybrid nanofluid, the thermal expansion can be defined as follows:

$$(\rho\beta)_{hnf} = \varphi_{s1}(\rho\beta)_{s1} + \varphi_{s2}(\rho\beta)_{s2} + (1-\varphi)(\rho\beta)_f$$

The effective electrical conductivity of the nanofluid was given by Maxwell [32] as:

$$\frac{\sigma_{nf}}{\sigma_f} = 1 + \frac{3\left(\frac{\sigma_s}{\sigma_f} - 1\right)\varphi}{\left(\frac{\sigma_s}{\sigma_f} + 2\right) - \left(\frac{\sigma_s}{\sigma_f} - 1\right)\varphi}$$

where, $\varphi = \varphi_{s1} + \varphi_{s2}$, and for hybrid nanofluid is given by

$$\frac{\sigma_{hnf}}{\sigma_f} = 1 + \frac{3\left(\frac{\varphi_{s1}\sigma_{s1} + \varphi_{s2}\sigma_{s2}}{\sigma_{bf}} - \varphi\right)}{\left(\frac{\varphi_{s1}\sigma_{s1} + \varphi_{s2}\sigma_{s2}}{\varphi\sigma_f} + 2\right) - \left(\frac{\varphi_{s1}\sigma_{s1} + \varphi_{s2}\sigma_{s2}}{\sigma_f} - \varphi\right)}$$

4. RESULTS AND DISCUSSION

Table 2. Comparison of numerical values of $f''(0)$ and $\theta'(0)$

M	R	$f''(0)$ Su et al. [33]	$f''(0)$ Present study
0.0	0.1	1.024909003	1.0249090030
	2	-1.122862620	-1.122862620
3.0	0.1	1.991260941	1.9912609410
	2	-2.144131581	-2.1441330609

M	R	$-\theta'(0)$ Su et al.[33]	$-\theta'(0)$ Present study
0.0	0.1	0.626473534	0.626473534
	2.0	0.878136319	0.878136342
3.0	0.1	0.786144878	0.786144878
	2.0	0.407961083	0.407966998

Table 3. Numerical values of skin-friction coefficient and Nusselt number for different parameters when $Pr = 1$

φ	M	R	γ	β	$Re_x^{1/2}C_f$	$Re_x^{-1/2}Nu_x$
1%	2.0	0.1	1.0	1.0	2.00055	2.39129
5%					2.36538	2.58523
10%					2.90624	2.83484
5%	0				1.74447	2.42940
	1.0				2.08025	2.51840
	2.0				2.58523	2.58523
	2.0	0.1			2.58523	2.58523
		0.5			1.45502	3.36365
		2.0			-2.82672	5.58771
		0.1	-2.0		1.66258	2.43215
			-1.0		1.90339	2.48678
			0		2.13736	2.53762
			1.0		2.36538	2.58524
			2.0		2.58814	2.63010
			1.0	0	1.60072	1.03198
				2/3	2.12664	2.00331
				1.0	2.36538	2.58524

The numerical solutions are obtained for many values of physical parameters. Skin friction and Nusselt number coefficients. The ranges of the magnitude of the nanoparticles volume fraction φ, mixed convection γ, the angle of the wedge β the magnetic field M, and the ratio of the velocity R, used in this study are $\varphi = [0,1], \gamma = [-2,2], \beta = [0,1], M = [0,2], R = [0.1,2]$ respectively. Table 2 shows the obtained outcomes of our study in the case of ($\varphi_{s1} = 0$ and $\varphi_{s2} = 0$) and notice that our outcomes are excellent agreement with the last published results of Su et al. [33].

From Table 3 we notice that the quantity of skin friction coefficient of hybrid nanofluid is improved with increasing of nanoparticle volume fraction, magnetic field, mixed convection, and the angle of the wedge whereas decreases when we increase the ratio of the velocity. Also observed the Nusselt number increase with increasing nanoparticle volume fraction, magnetic field, mixed convection, the angle of the wedge, and the ratio of the velocity.

Figure 2 shows the effect of γ on f' in the case of existence and absence the magnetic field. It shows that f' increases as γ increases. It can be seen that related boundary layer thickness and the fluid velocity is improved due to increment in values of γ. This is because of the fact that an improvement in γ means an improvement in the buoyancy force through which the fluid velocity is improved. The effect of γ on θ is depicted in Figure 3 in the case of existence or absence the magnetic field. It refers that the profile θ decreases with increasing in the values of γ, so the thickness of the thermal boundary layer is decreased. The mixed convection does not exist in the energy equation explicitly; this explains the low reliance of the heat transfer at the surface. Figure 4 shows the impact of m on the velocity profile f'. It is observed that an increase in the values m leads to that the thickness of the fluid layer and f' are decreased.

Figure 5 shows the impact of m on the temperature profile. It is observed that an increase in m leads to a decrease in the temperature profile. Because the angle parameter of the wedge is reliant over the gradient of the pressure, which its values can be negative or positive.

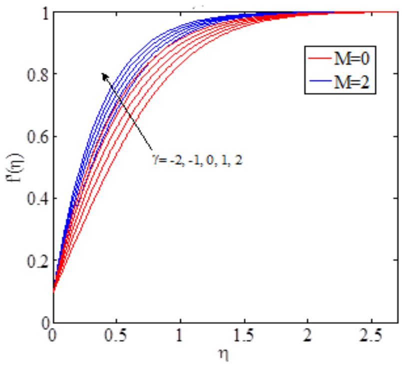

Figure 2. Velocity distributions versus M and γ

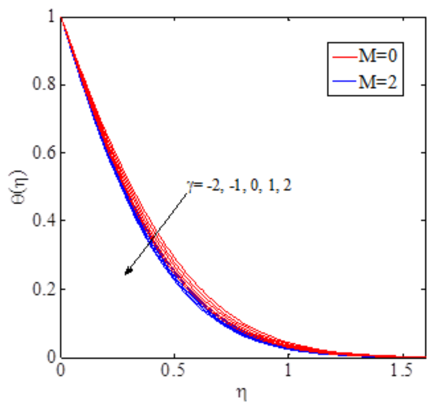

Figure 3. Temperature distributions versus M and γ

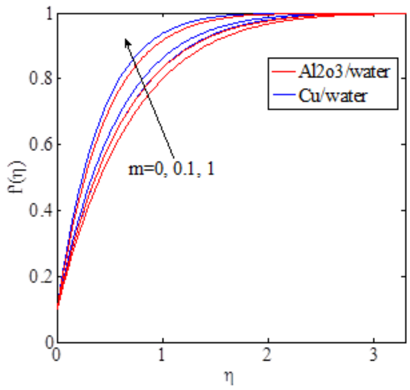

Figure 4. Velocity distributions versus *m*

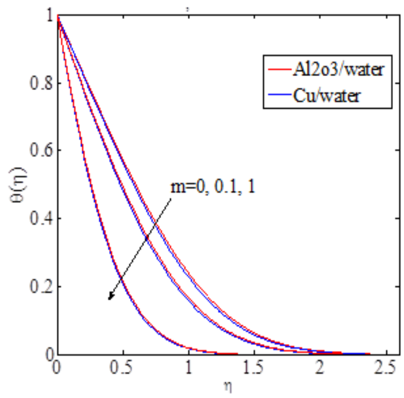

Figure 5. Temperature distribution versus *m*

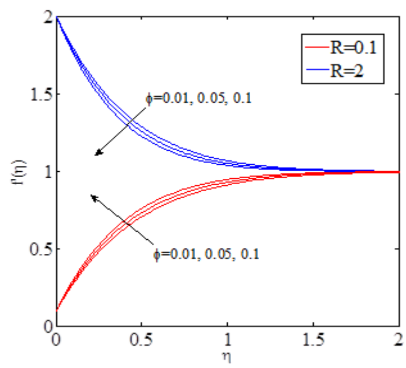

Figure 6. Velocity distribution versus *φ*

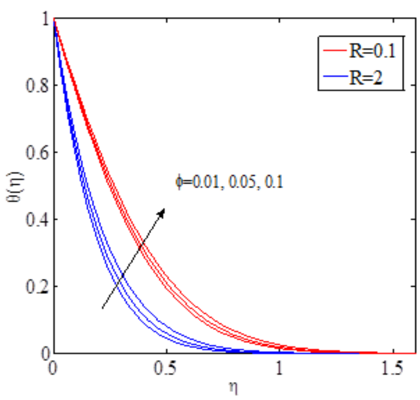

Figure 7. Temperature distributions versus *φ*

Figures 4 and 5 show that the thickness of the velocity and temperature boundary layer in the Cu-water case is less than that in Al_2O_3-water. Figure 6 shows the effect of volume fraction on the velocity profile as R=0.1 or R=2. It is observed that an increase in the volume fractions leads to that a thickness of the velocity boundary layer is decreased when R=0.1 or R=2. Physically, a varied velocity line is generated by the occurrence of divergent collisions between adjacent particles during fluid diffusion. Moreover, it is found that an increase in the concentration of the nanoparticle improved the resistance among the neighboring layers of moving fluid, which leads to reduce the velocity profile.

Further, Figure 7 Shows the effect of volume fraction on the temperature profile as R=0.1 or R=2. It is observed that an increase in the volume fractions leads to an increase in the temperature profile. This is due to that the exchange of thermal energy in the layer of fluid is enhanced by the dispersion of nanoparticles, that is neighboring to the surface and next neighboring-fluid layers dispersion of nanoparticles. So, results expect that the utilize of nanoparticles can aid to enhance the heat distribution in heat transfer particular equipment and can store energy through the chemical process.

5. CONCLUSIONS

The problem of heat transfer by MHD mixed convection of Cu-Al_2O_3-water hybrid anofluid past over a stretching wedge with Ohmic heating is studied. The governing equations were converted into a similar form. The obtained equations were solved numerically by using the Matlab bvp4c method. The numerical results very agree with the last work. The effects of the different parameters namely magnetic parameter, mixed convection, the angle of the wedge parameter, the ratio of the velocity, the nanoparticles volume fraction, the velocity, temperature profiles as well as the local Nusselt number and the local skin friction coefficients are discussed and shown graphically. From the obtained outcomes of the problem, it was noticed that a rising of the values of the nanoparticles volume fraction, magnetic field, mixed convection and the angle of the wedge parameters resulted in increases in the skin-friction coefficient, local Nusselt numbers whereas the skin-friction coefficient decrease and local Nusselt numbers increase as the ratio of the velocity is an increase.

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