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Heat Transfer of SWCNT-MWCNT Based Hybrid Nanofluid Boundary Layer Flow with Modified Thermal Conductivity Model

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ABSTRACT

Thermal conductivity is one of the important thermophysical property of nanofluid in enhancing heat transfer. To analyse heat transfer in boundary layer problems thermal diffusivity coefficient along with embedded nano particle thermophysical values will be used via various thermal conductivity models. Many thermal conductivity models are being utilised for theoretical analysis of heat transfer behaviour such as Maxwell model, Hamilton crosser model etc. In this current communication we are analysing the thermal properties of carbon nanotubes by embedding modified Xue thermal conductivity model. Momentum, energy and nano particle volume fraction equations are turned into differential equation of single variable by using appropriate similarity transformation and solved by numerical scheme shooting method. Skin friction, Nusselt numbers for mono particle nanofluid, hybrid nanofluid are computed for distinct physical parameters and it is observed that heat transfer rate is improved with SWCNT-MWCNT as compared to SWCNT.

1.Introduction

Over the past few years effective heat transfer has become challenging in many mechanical industries, chemical processing units and microelectronic chips etc. Although conventional fluids such as oils, water etc are relevant for many convective heat transfer applications but not suitable for the current advanced technological applications where heat transfer rate has to be very high. The term nanofluid is widely used in thermal domain which is basically colloidal suspensions of nano sized (1nm-100nm) particles into regular fluids. This idea of revamping thermo physical characteristics of conventional fluids is initially demonstrated by Choi and Eastman [2]. Later many researchers performed experimentations to understand these engineered fluids.

Lee *et al.,* [3] performed experimental study on oxide nano particles and come out with an interesting results that thermal conductivity of base fluid enhances by suspending oxide nano particles thereby improves overall heat exchange rate. Xuan and Yimin [4] discussed about size, shape and dimension factors on thermal conductivity copper. Besides this mono particle nanofluid another

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idea of combining two distinct nano materials for efficient nano coolants drawn the attention of thermal engineers and chemists which is known as hybrid nanofluid. Suresh *et al.,* [5] explored thermal transport mechanism in copper-alumina hybrid nanofluid and concluded that hybrid nanofluid is better alternative with low nano particle volume fraction.

Study of fluid flow and heat transfer in boundary layer is important due its broad range application in many manufacturing, aerospace, chemical and food processing industries. Sakiadis [6] introduced the notion of viscous fluid flow and its nature near the surface boundary of a moving surface in his series of works on distinct geometries. The same work was later extended by Crane [7] over a stretching plate. These two theoretical studies are benchmarks for analysing momentum, energy characteristics in boundary layer. Later many mathematics researchers extended these models including various effects such as magnetic field, suction-injection, partial slip etc. The main aim of the current article is to discuss to thermal properties of nano particles particularly hybrid nanofluid, so we are concentrating literature survey pertained to hybrid nanofluid flow over stretching shrinking surfaces. Devi *et al.,* [8] presented hydromagnetic flow of copper-alumina hybrid nanofluid flow over a stretching sheet with suction/blowing effect. Impact of Brownian motion and thermophoresis on time dependent hybrid nanofluid is investigated by Sulochana and Aparna [9]. Lund *et al.,* [10] investigated the impact iron oxide nano particle over a nonlinear stretching shrinking sheet and observed that dual solutions exist for shrinking surface hybrid nanofluid flow case. Loan pop *et al.,* [11] reported convective boundary condition effect on hydromagnetic hybrid nanofluid flow over an exponentially stretching-shrinking moving surface and found dual solutions for suction parameter. Prasad *et al.,* [12] discussed influence of variable thermal properties of nanofluid using Keller box numerical scheme. Partial slip micropolar hybrid nanofluid flow over a stretching surface was simulated by Faizal *et al.,* [13] and this study says that micropolar fluid angular velocity increases with slip parameter. Recently Albeshri *et al.,* [14] investigated steady mixed convective hybrid nanofluid containing silver-Titanium oxide nano particle in concentric annulus. Waini *et al.,* [15] considered Gluert problem in hybrid nano fluid model and concludes that the presence of nano particle increases drag friction and Nusselt number under the influence of magnetic field strength. Apart from the oxide nano particle carbon nanotubes also proven to be good nano coolants for heat transfer applications. Hayat *et al.,* [16] examined carbon nanotubes based stagnation point flow over a nonlinear stretching sheet and their results shows that MWCNT is producing dominating heat transport behaviour as compared SWCNT. In another numerical study carried out by Nadeem *et al.,* [17] over a convectively heated stretching surface also reconfirm that carbon nanotubes produces better heat transfer rate as compared regular fluids. Apart from water based hybrid nanofluid flows of carbon nanotubes hybrid base fluid is considered in the study by Gholinia [18] in which base fluid taken as 50% water and 50% ethylene glycol.

Magneto hydrodynamic flow is a division of fluid dynamics which handles the magnetic properties of electrically conducting fluids. Usage of magnetic fields in boundary layer flows causes boundary layer separation purpose. Many researchers embedded impact of external magnetic field effect in hybrid nanofluid boundary layer flow problems. Daniel [19] discussed impact of magnetic field on nonlinear stretching sheet and proved that magnetic field increases skin friction at the boundary of the surface and diminishes Nusselt number. Ali *et al.,* [20] examined peristaltic titanium oxide and copper hybrid nanofluid flow under the presence of magnetic field and their results shows that magnetic parameter slows down the flow near the channel and improves in the central region of the channel. Recently Yashkun *et al.,* [21] reported copper-alumina hybrid nanofluid flow over permeable elongating /shrinking surface and proves that dual solution exist for stretching case. Mabood *et al.,* [22] simulated nonlinear radiation effect in presence of magnetic field utilising Iron oxide-Graphene oxide nano particles and their outcomes shows that nano particle volume fraction plays Sandeep *et* *al.,* [23] reported three dimensional hybrid nanofluid flow over variable thickness stretching sheet and in this study authors considered cupric oxide-magnesium oxide nanoparticles.

Close observation on above cited hybrid nanofluid literature survey reveals that majority authors embedded Hamilton Crosser model [24] which does not takes size and shape of non-spherical nano tubes. This current investigation focuses on heat transfer behaviour with Xue thermal conductivity model [25] with carbon nanotubes based hybrid nanofluid. Many theoretical analysis are carried out by authors using carbon nanotubes, but hybrid nanofluid with Xue model are not done with best of our knowledge. Hence this study will be useful in making decisions on heat transfer with carbon nanotubes based hybrid nanofluid.

2. Problem Statement

Let us consider two-dimensional steady incompressible hybrid nanofluid flow induced by stretching of a surface with exponential velocity $u_w(x) = ce^{\frac{x}{2L}}$ where c is constant indicates stretching parameter. Flow directions and boundary layer formation is illustrated geometrically in Figure 1 in which coordinate system is chosen such that x-axis is along the stretching sheet and y-axis is perpendicular to the surface. Transverse magnetic field $B(x) = B_0 e^{\frac{x}{2L}}$ is applied in y axis direction. As the current fluid flow scenario comes into low Reynold's flow model so induced magnetic field effect is neglected. It is assumed that suspended nano particles and base fluids are in thermally equilibrium condition and no slip occurs between them.

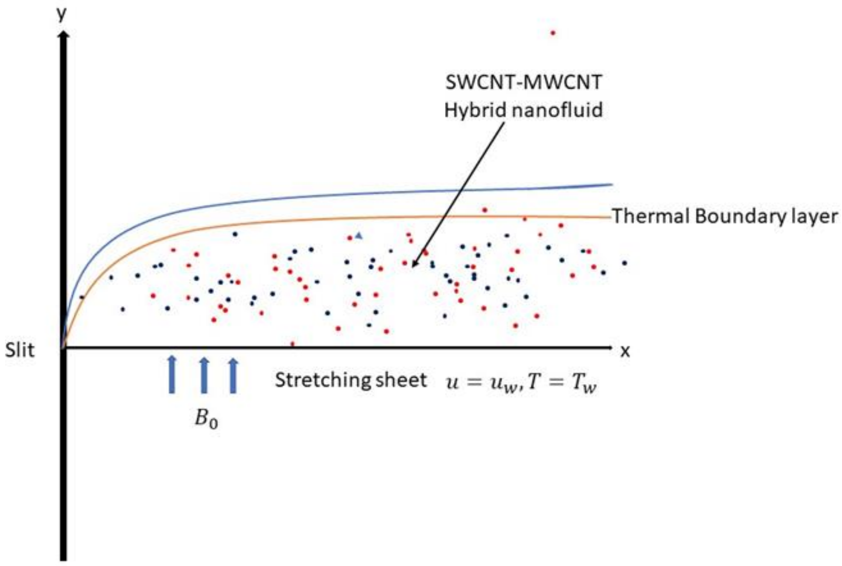

Fig. 1. Physical model of the problem

With these assumption boundary layer approximations for momentum, energy and nano particle volume fraction equations can be expresses as follows

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

$$\rho_{hnf}\left\{u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}\right\} = \mu_{hnf}\left\{\frac{\partial^2 u}{\partial x^2}\right\} - \sigma_{hnf}B_0^2(x)u \tag{2}$$

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

Boundary conditions are

$$At\ y=0:u=u_w,v=0,T=T_w\ and\ at\ y=\infty:u=0,T=T_\infty \tag{4}$$

and skin friction coefficient, Nusselt number are defined as $C_f=\frac{\tau_w}{\rho_{f u_w}{}^2}$, $Nu_x=\frac{2Lq_w}{k_f(T_w-T_f)}$

Using the following similarity variables (See [26]) Eq. (2)-(4) can be written as equations of single variable.

$$\psi=\sqrt{2U_0\nu_f L}f(\zeta)e^{\frac{x}{2L}},T=T_\infty+(T_w-T_\infty)\theta(\zeta)\text{ and }\zeta=ye^{\frac{x}{2L}}\sqrt{\frac{U_0}{2L\nu_f}} \tag{5}$$

here ψ being stream function and velocity components (u, v) can be computed using relations

$$u=\frac{\partial\psi}{\partial y}\text{ and }v=-\frac{\partial\psi}{\partial x}$$

Now the governing Eq. (2)-(5) are expressed in single variable ξ as shown below.

$$\frac{A_1}{A_2}f'''(\zeta)+f(\zeta)f''(\zeta)-2f'(\zeta)^2-\frac{A_3}{A_2}Mf'(\zeta)=0 \tag{6}$$

$$\left[\frac{k_{hnf}}{k_f}+\frac{4R}{3}\right]\theta''(\zeta)+A_3Prf(\zeta)\theta(\zeta)-f'(\zeta)\theta(\zeta)+Q\theta(\zeta)=0 \tag{7}$$

Subject to the boundary conditions

$$f(0)=0,f'(0)=1,\theta(0)=1,f'(\infty)=0\ and\ \theta(\infty)=0 \tag{8}$$

Also non dimensional form of skin friction, Nusselt number are given by,

$$\sqrt{Re_x}C_f=A_1f'(0),\frac{Nu_x}{\sqrt{Re_x}}=\left(\frac{k_{hnf}}{k_f}+\frac{4R}{3}\right)\theta'(0)$$

3. Numerical Algorithm

The system of non-dimensional governing Eq. (6)-(7) are solved along with relevant boundary conditions specified in Eq. (8) using shooting method. In this algorithm equations are supplied as system of first order differential equations. We must provide some initial guesses for unknown boundary conditions and compute the most accurate values for missing boundary conditions.

Let us assume that $f(\zeta)=p$, $f'(\zeta)=q$,$f''(\zeta)=r$,$\theta(\zeta)=s$, $\theta'(\zeta)=t$ and $\theta''(\zeta)=w$then system of Eq. (6)-(8) can be written in first order as follows

$$p'(\zeta)=q$$

$q'(\zeta) = r$

$\frac{A_1}{A_2} r'(\zeta) = 2q(\zeta)\, q(\zeta) + \frac{A_3}{A_2} Mq(\zeta) - p(\zeta)\, r(\zeta)$

$s'(\zeta) = t(\zeta)$

$\left[\frac{k_{hnf}}{k_f} + \frac{4R}{3}\right] w'(\zeta) = q(\zeta)\, s(\zeta) - A_3\, Pr. p(\zeta)\, s(\zeta)$

and boundary condition can be written as

$p(0) = 0$, $q(0) = 1$, $s(0) = 1$, $q(\infty) = 0$ and $s(\infty) = 0$

4. Results and Discussions

This segment explores significance of distinct physical parameters on momentum, temperature distribution. The hybrid nano fluid containing SWCNT-MWCNT is used in this theoretical study by considering SWCNT as ϕ_1=0.01 and then MWCNT is added with volume fraction in the range $0.01 \le \phi_2 \le 0.04$ .It is important to note that when nano particle volume fraction is more than 5% the nanofluid behaves like non-Newtonian fluid. Thus, we have taken nano particle volume fraction ranges less than 4%. In numerical simulation the range for various physical parameters must be chosen properly so that the required boundary conditions satisfy correctly. Since the base fluid of this study is water Prandtl number is fixed as 6.2 and remaining physical parameters are taken as : $0 \le M \le 5,\ 0 \le R \le 3,\ 0.01 \le \phi_1 \le 0.1,\ 0.01 \le \phi_2 \le 0.04$ .The boundary layer thickness is taken as $\zeta_\infty = 4$ which asymptotically satisfies all boundary conditions. The thermophysical properties of nano materials and base fluid are mentioned Table 1 and Table 2. The velocity distribution is shown in Figure 2, from this plot momentum get diminishes with higher magnetic field strength. The physics behind this behaviour could be applied Lorentz force which acts as resistive force fluid flow on stretching sheet (see Table 3). Figure 3 shows the impact of magnetic field strength on temperature distribution, and it is observed that temperature profile accelerated in nanofluid, hybrid nanofluid models' Thermal radiation effect on temperature distribution is portrayed in Figure 4 in which we can observe that temperature is increasing for higher radiation parameter values. Skin friction coefficient and Nusselt numbers are significant for any fluid flow problem to decide friction at the surface and heat transport phenomena between ambient fluid and surface. Figure 5 shows the influence of magnetic field strength on skin friction. It is evident from this picture that absolute value of skin friction increases with nano particle volume fraction.

Table 1
Thermophysical properties [27]

Property	Hybrid Nanofluid
Viscosity (μ)	$\dfrac{\mu_f}{(1-\emptyset_1)^{2.5}(1-\emptyset_2)^{2.5}}$
Density (ρ)	$(1-\emptyset_2)\{(1-\emptyset_1)\rho_f+\emptyset_1\rho_{s1}\}+\emptyset_2\rho_{s2}$
Heat Capacity (ρc_p)	$(1-\emptyset_2)\{(1-\emptyset_1)(\rho c_p)_f+\emptyset_1(\rho c_p)_s\}+\emptyset_2(\rho c_p)_{s2}$
Thermal conductivity (k)	$\dfrac{k_{hnf}}{k_f}=\dfrac{1-\phi_2+2\phi_2(\frac{k_{s2}}{k_{s_2}-k_{nf}})\log(\frac{k_{s_2}+k_{nf}}{2k_{nf}})}{1-\phi_2+2\phi_2(\frac{k_{nf}}{k_{s_2}-k_{nf}})\log(\frac{k_{s_2}+k_{nf}}{2k_{nf}})}$ where $\dfrac{k_{nf}}{k_f}=\dfrac{1-\phi_1+2\phi_1(\frac{k_{s_1}}{k_{s_1}-k_f})\log(\frac{k_{s_1}+k_f}{2k_f})}{1-\phi_1+2\phi_1(\frac{k_f}{k_{s_1}-k_f})\log(\frac{k_{s_1}+k_f}{2k_f})}$

Table 2
Thermophysical properties of nano particles and base fluid at 25^oC [28]

Type of particle	$\rho(kg/m^3)$	$C_p(J/kgK)$	K(W/mK)	$\sigma(S/m)$
SWCNT	2600	425	6600	5.96×10^7
MWCNT	1600	796	3000	2.38×6
H_2O	997.1	4179	0.613	0.05

Table 3
Comparison of $-\theta'(0)$ when M=0,R=0 , $\phi_1=0,\phi_2=0$ for stretching case

Pr	Waini *et al.,* [26]	Ishak *et al.,* [29]	Present results
0.5	0.59443	---	0.59234
1	0.95478	0.9548	0.95488
3	1.86913	1.8691	1.86911
5	2.50013	2.5001	2.50012

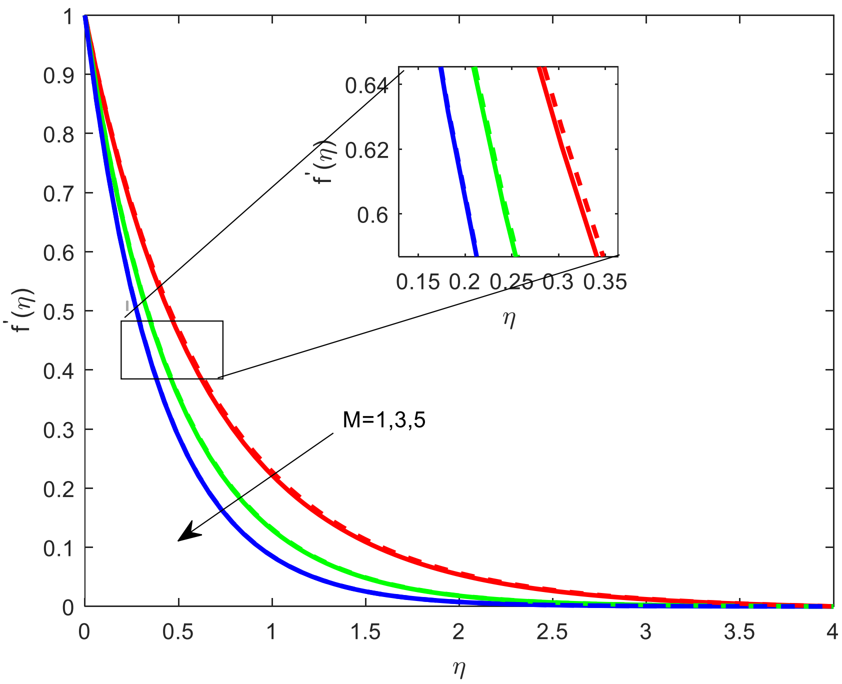

Fig. 2. Momentum behaviour for magnetic field parameter

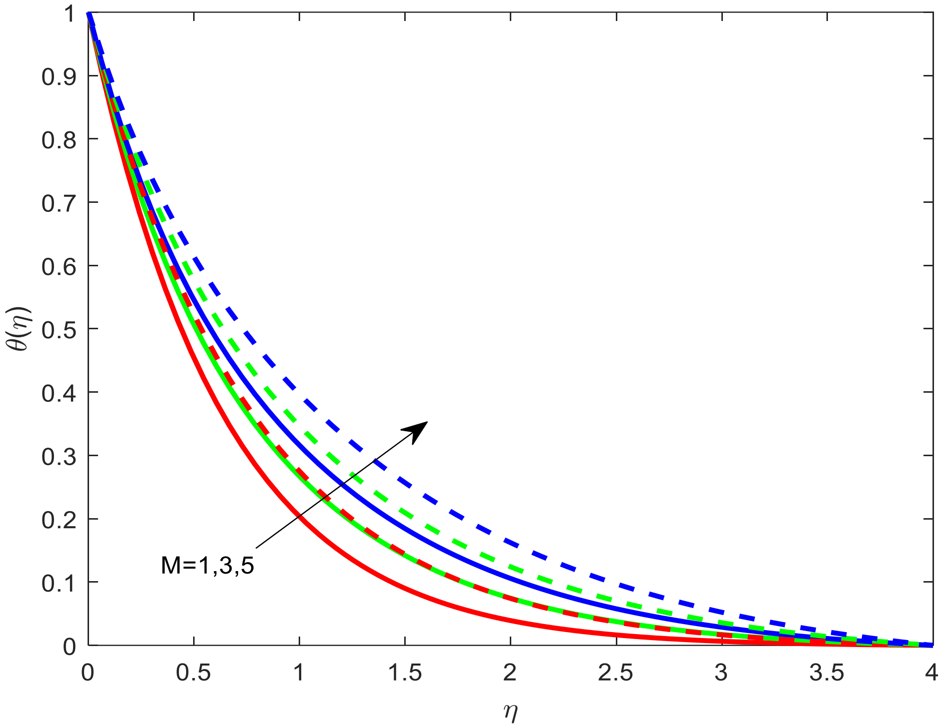

Fig. 3. Thermal behaviour for magnetic field parameter

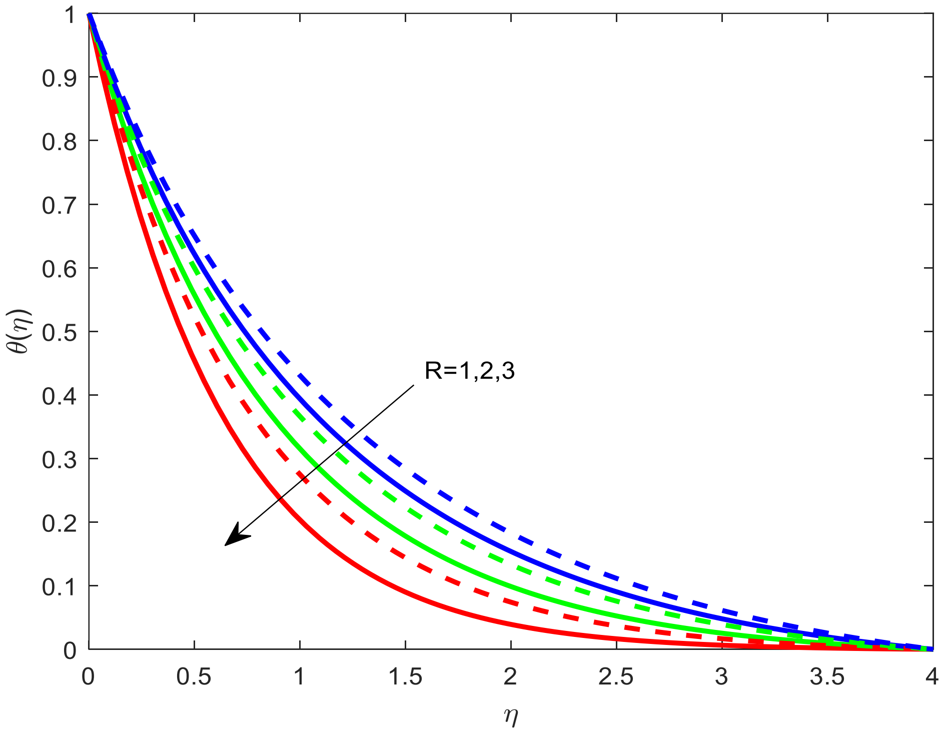

Fig. 4. Thermal behaviour for radiation parameter

It is also observed that skin friction of SWCNT-MWCNT is more than that SWCNT. By raising by nano particle volume fraction from $\phi_1 = 0.01$ to $\phi_1 = 0.1$ It is noticed that absolute value of skin friction increases in both nano fluid and hybrid nanofluid models. Impact of magnetic field parameter on Nusselt number is shown in Figure 6 which portrays that with the increase of nano particle volume fraction Nusselt number is raising. Radiation parameter is increasing Nusselt number which can be seen in Figure 7. It is observed that Nusselt number for SWCNT-MWCNT hybrid nanofluid is more than that of SWCNT nanofluid. It is also noticed that with higher nanoparticle volume fraction Nusselt number is increasing for radiation parameter. Table 4 shows the heat transfer rate comparison between nanofluid and hybrid nanofluid, it is noticed that 13% improved heat transfer rate in hybrid nanofluid as compared to nanofluid. Table 5 shows the Nusselt number and skin friction values for different flow parameters.

Table 4
Comparison of heat transfer rate between nanofluid and hybrid nanofluid

Nano particle volume fraction	Nano fluid	Hybrid nanofluid	Increment (%)
0.01	4.28867	4.82682	13%
0.02	4.40709	4.99193	14%
0.03	4.52020	5.09893	13%
0.04	4.62902	5.20410	13%

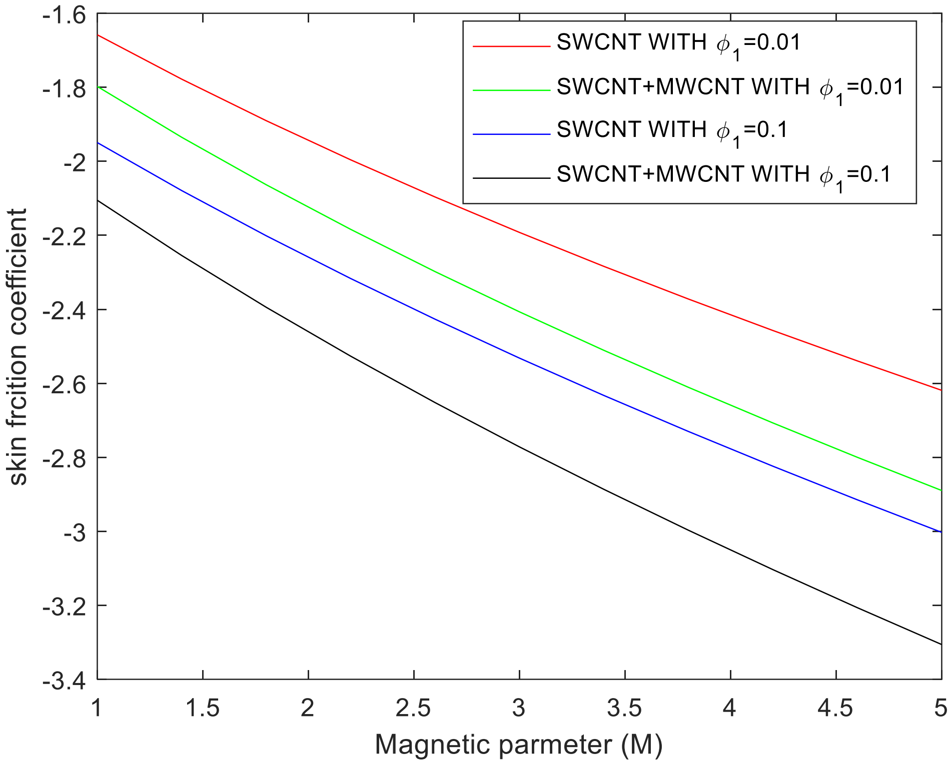

Fig. 5. Skin friction coefficient for magnetic parameter

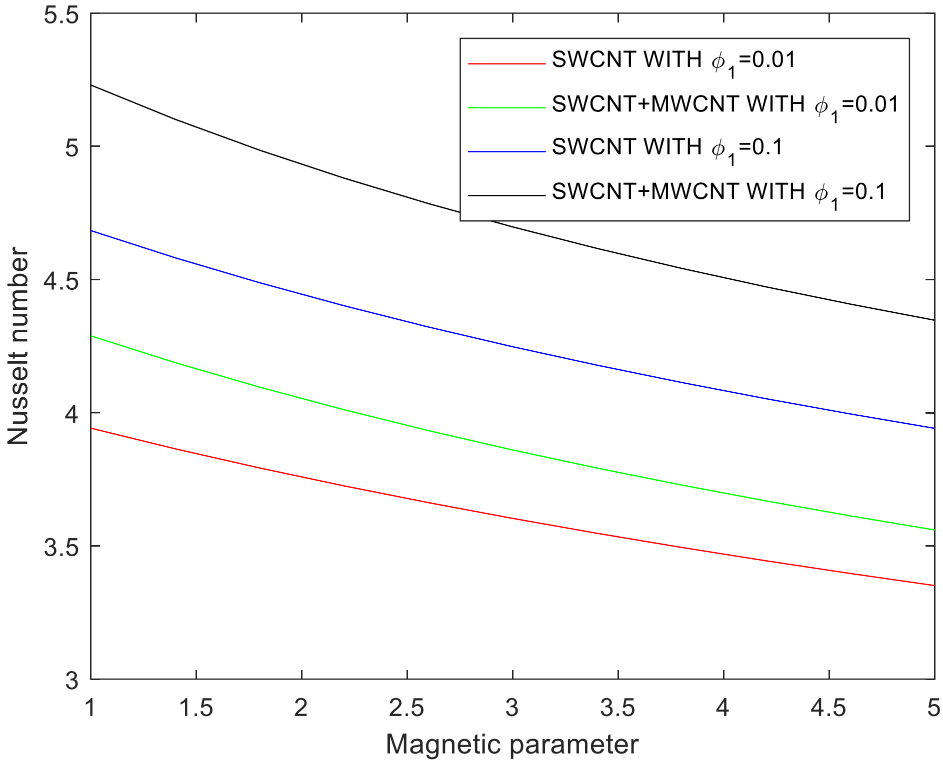

Fig. 6. Nusselt number for magnetic parameter

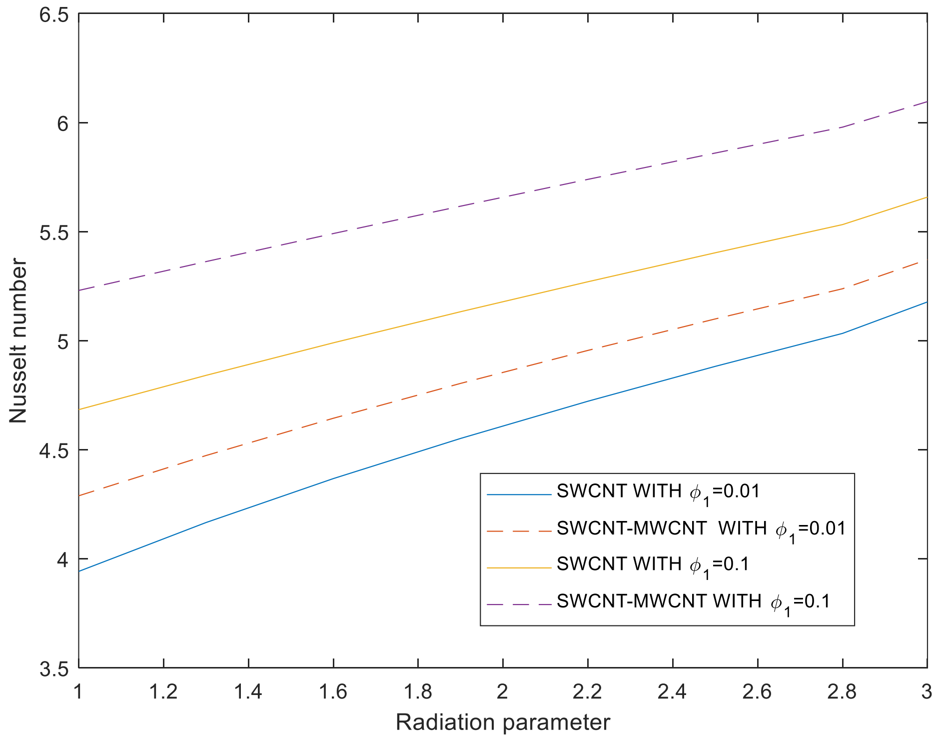

Fig. 7. Nusselt number for radiation parameter

Table-5
Nusselt number and skin friction values for different flow parameters

M	R	ϕ_1	ϕ_2	$C_f Re_x^{\frac{-1}{2}}$		$N_u Re_x^{\frac{-1}{2}}$	
				Nanofluid	Hybrid Nanofluid	Nanofluid	Hybrid Nanofluid
1				-1.658143	-1.797707	3.942062	4.288679
2				-2.192262	-2.406896	3.603290	3.860216
3				-2.618987	-2.889750	3.351176	3.559924
	0.1			-1.658143	-1.797707	3.942062	4.286790
	0.2			-1.658143	-1.797707	4.609935	4.855372
	0.3			-1.658143	-1.797707	5.130144	5.327537
		0.005		-1.64364	------	3.899475	------
		0.01		-1.65843	------	3.942062	------
		0.1		-1.94945	------	4.683690	------
			0.01	------	-1.676962	------	3.982779
			0.02	------	-1.711700	------	4.067248
			0.03	------	-1.746308	------	4.148570
			0.04	------	-1.782415	------	4.227114

5. Conclusions

This article simulates boundary layer flow of carbon nanotubes-based hybrid nanofluid over an exponential velocity moving surface. Heat transfer characteristics of mono particle nanofluid and hybrid nanofluid are analysed with respect to different nanoparticle volume fractions. Some of the important key observations of this investigation are

i. Magnetic field strength diminishes Nusselt number.
ii. Nusselt number increases with nano particle volume fraction and also radiation parameter improves Nusselt number.
iii. Temperature profile accelerates for magnetic parameter, radiation parameter.
iv. Nano particle volume fraction increases heat transfer rate.

Conflicts of interests

No conflict of interests.

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