CONVECTIVE HEAT TRANSFER FLOW OF CUO-WATER NANO FLUID IN A WAVY PIPE WITH THERMAL RADIATON

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Abstract: We analyze the effect of thermal radiation on mixed heat transfer flow of nanofluid fluid in a non-uniformly heated corrugated pipe in the presence of a constant heat source. The non-linear governing equations have been solved by using perturbation with the slope δ of the boundary of the pipe as perturbation parameter. The effect of thermal radiation and waviness of the boundary on all flow characteristics are discussed graphically. The stress and Nusselt number on the boundary have been evaluated numerically for different variation. It is found that higher the amplitude of the non-uniform boundary temperature reduces the Axial velocity and enhances the secondary and axial temperature. Higher the dilation of the boundary larger the velocity and temperature.

Keywords: Non-Uniform Temperature, Wavy Pipe, Heat Source, Nanoparticle Concentration, Thermal Radiation.

Introduction: Present days, researchers are more concentrating on enhancement of heat transfer. The low thermal conductivity of conventional heat transfer fluids, such as water, is considered a primary limitation in enhancing the heat transfer performance. Maxwell's review [6] demonstrated the possibility of increasing the thermal conductivity of fluid-solid particles. Subsequently, the particles with micrometer or considerably millimeter measurements were utilized. Those particles caused several problems such as abrasion, clogging and pressure losses. During the past decade the technology of producing particles in nanometer dimensions was improved and a new kind of solid-liquid mixture that is called nanofluid was established by Choi [4]. The dispersion of a small amount of solid nanoparticle in conventional fluids such as water or Ethylene glycol changes their thermal conductivity remarkably. In general, in most recent research areas, heat transfer enhancement in forced convection is desirable [2],[3] but there is still a debate on the effect of nano-particles on heat transfer enhancement in natural convection applications. Natural convection of Al_2O_3-water and CuO-water nanofluid inside a cylindrical enclosure heat from one side and cooled from the other side was studied by Putra et al., [7]. They found that the natural convection heat transfer coefficient was lower than that of pure water. Wen and Ding [8] investigated the natural convection of TiO_2-water in a vessel composed of two discs. Their results showed that the natural convection decreases by increasing the volume fraction of nanoparticle. Jou and Tzeng [5] conducted a numerical study of natural convection heat transfer in rectangular enclosure filled with the stream function-vorticity formulation. They investigated the effects of Rayleigh number, the aspect ratio of the enclosure, and the volume fraction of the nanoparticle on the heat transfer inside the enclosures.

In this paper we analyse the effect of thermal radiation on combined heat transfer of nanofluid fluid in a non-uniformly heated corrugated pipe in the presence of a constant heat source. A non –uniform temperature is maintained on the boundary. Taking the slope δ of the boundary of the pipe as perturbation parameter, the equations governing the flow , heat transfer and magnetic induction have been solved. The effect of the various governing parameters on flow, heat transfer has been exhibited through various profiles of velocity, temperature distributions.

Formulation of the Problem: We consider the steady axisymmetric flow of an incompressible ,viscous nanofluid in a vertical pipe of variable cross section maintained at non-uniform temperature $\gamma(\delta x/a)$.The Boussinesq approximation is used so that the density variations will be retained only in the buoyancy force. The viscous dissipation is neglected in comparison to the heat flow by convection. The concentration on these walls is taken to be constant. The cylindrical polar system(r,x) is chosen with x-axis along the axis of the pipe.

The boundary of the pipe is assumed to be $r = af(\delta x / a)$ where 'a ' is characteristic radial length, f is twice differentiable and 'δ'is a small parameter proportional to the boundary slope. The flow is maintained by a constant flow for which a characteristic velocity U is defined as

$$U = (\frac{2}{a^2})\int_0^{af(\delta x/a)} urdr \tag{1}$$

The momentum and energy equations are

$$\rho_{nf}(\bar{\varsigma} x \bar{q}) = -\nabla p + \mu_{nf}\nabla^2 \bar{q} + (\rho\beta)_{nf}\bar{g}(T - T_e) \tag{2}$$

$$\nabla.\bar{q} = 0 \tag{3}$$

$$(\rho C_p)_{nf}(\bar{q}.\nabla)T = k_{nf}\nabla^2 T + Q - \frac{1}{r}\frac{\partial(rq_R)}{\partial r} \tag{4}$$

Where ρ_{nf} is the density of the nanofluid,fluid in the equilibrium state, $\bar{q}$ is the velocity,ζ is the viscosity p is the pressure. T is the temperature in the flow region,ρ is the density of the fluid ,k is the coefficient of permeability, Q is the strength of the heat source ,μ is the coefficient of viscosity, Cp is the specific heat at constant pressure, k_{nf} is the coefficient of thermal conductivity,β_1 is the coefficient of volume expansion,

The effective density of the nanofluid is given by $\rho_{nf} = (1-\varphi)\rho_f + \varphi\rho_s$ (5)

Where ϕ is the solid volume fraction of nanoparticles

Thermal diffusivity of the nanofluid is $\alpha_{nf} = \frac{k_{nf}}{(\rho C_p)_{nf}}$ (6)

Where the heat capacitance C_p of the nanofluid is obtaine as $(\rho C_p)_{nf} = (1-\varphi)(\rho C_p)_f + \varphi(\rho C_p)_s$ (7)

And the thermal conductivity of the nanofluid k_{nf} for spherical nanoparticles can be written as

$$\frac{k_{nf}}{k_f} = \frac{(k_s + 2k_f) - 2\phi(k_f - k_s)}{(k_s + 2k_f) + \phi(k_f - k_s)} \tag{8}$$

The thermal expansion coefficient of nanofluid can determine by $(\rho\beta)_{nf} = (1-\varphi)(\rho\beta)_f + \varphi(\rho\beta)_s$ (9)

Also the effective dynamic viscosity of the nanofluid given by $\mu_{nf} = \frac{\mu_f}{(1-\varphi)^{2.5}}$ (10)

Where the subscripts nf, f and s represent the thermo physical properties of the nanofluid, base fluid and the nanosolid particles respectively and ϕ is the solid volume fraction of the nanoparticles. The thermo physical properties of the nanofluid are given in Table 1.

Table - 1

Physical properties	Fluid phase	CuO (Copper)	Al_2O_3 (Alumina)	TiO_2 (Titanium dioxide)
C_p(j/kg K)	4179	385	765	686.2
ρ(kg m^3)	997.1	8933	3970	4250
k(W/m K)	0.613	400	40	8.9538
$\beta x10^{-5}$ 1/k)	21	1.67	0.63	0.85

Invoking Rosseland approximation the radiative heat flux is given by $q_R = -\frac{4\sigma^\bullet}{\beta_R}\frac{\partial(T'^4)}{\partial r}$ (11)

and expanding T'^4 by Taylor's expansion after neglecting higher order terms we get

$$T'^4 \cong 4T_e^3 T' - 3T_e^4 \tag{12}$$

Introducing the non-dimensional variables

$$\bar{q}^* = q/U, p^* = p/\rho U^2, \quad \theta = \frac{T - T_e}{\Delta T_e}, \gamma^* = \gamma/\Delta T \ , \quad \Delta T_e = T_e(0) - T_e(a) \tag{13}$$

The equations (2)-(4) after using (11)-(13) reduce to (on dropping the asterisks)

$$A_1A_3R_e(\bar{\zeta}x\bar{q}) = A_1\nabla(p+\frac{1}{2q^2})+\nabla^2 q + GA_1A_4(\theta) \quad (14)$$

$$\nabla.\bar{q} = 0 \quad (15)$$

$$A_5P_e(\bar{q}.\nabla)\theta = A_2(\frac{\partial^2\theta}{\partial r^2}+\frac{1}{r}\frac{\partial\theta}{\partial r}+\frac{\partial^2\theta}{\partial x^2}+\frac{4}{3N_1}(\frac{\partial^2\theta}{\partial r^2}+\frac{1}{r}\frac{\partial\theta}{\partial r})+\alpha \quad (16)$$

Where $R_e = \frac{Ua}{\nu}$ (Reynolds number), $M = aB_0(\frac{\sigma}{\rho\nu})^{1/2}$ (Hartmann number)

$G = \frac{\beta_1 g\Delta T_e a^3}{\nu^2}$ (Grashof number), $P_e = \frac{\mu_e UC_p a}{\lambda\nu}$ (the Peclet number)

$N_1 = \frac{\beta_R T_e^3}{4\sigma^{\bullet}}$ (Radiation parameter) $\alpha = \frac{Qa^2}{\lambda C_p}$ (Heat source parameter)

The boundary conditions relevant to the problem are $v(r,x) = 0, \frac{\partial v}{\partial r} = 0, \frac{\partial\theta}{\partial r} = 0$ on $r = 0$

$$u(r,x) = 0, T - T_e = \gamma(\delta x) \quad on\ r = a \quad (17)$$

Equations (14)-(16) constitute a system of three equations for the three unknowns u,v and θ. These may be reduced to three equations for the Stoker's stream function ψ(r,x) is given by

$$u = -\frac{1}{r}\frac{\partial\psi}{\partial r} \ , \ v = \frac{1}{r}\frac{\partial\psi}{\partial x}$$

Taking the curl of the former to eliminate the pressure, we get

$$A_1A_3R_e((\frac{1}{r}\frac{\partial\psi}{\partial x}\frac{\partial(E^2\psi)}{\partial r}-\frac{1}{r}\frac{\partial\psi}{\partial r}\frac{\partial(E^2\psi)}{\partial x}-\frac{2}{r^2}\frac{\partial\psi}{\partial x}E^2\psi) = E^2(E^2\psi) + \quad -(GA_1A_5/R_e)(r(\frac{\partial\theta}{\partial r})) \quad (18)$$

The energy equation is $A_5P_1(\theta_r\psi_x - \theta_x\varphi_r) = (A_2+\frac{4}{3N_1})(\theta_{rr}+1/r)\theta_r + A_2N_2\theta_{xx}+\alpha$ (19)

These coupled equations (18)-(19) are to be solved subject to non dimensional boundary conditions.

$$\psi(r,x) = 0, \ \frac{\partial}{\partial r}((1/r)\frac{\partial\psi}{\partial r} = 0 \quad (20) \ , \ \frac{\partial\theta}{\partial r} = 0 \quad on\ r = 0 \quad (21)$$

$$\psi(r,x) = -1/2, \ \frac{\partial\psi}{\partial r} = 0 \quad (22), \ \theta(r,x) = \gamma(\delta x) \quad on\ r = f \quad (23)$$

The value of ψ on the boundary assures the constant volumetric flow in consistence with the hypothesis (1) and conditions (22) & (23) corresponds to axial symmetry of the flow.

Analysis of the Flow:

Introducing the transformations $\bar{x} = \delta x$ we assume $\frac{\partial}{\partial x} \approx O(\delta)$ such that $\frac{\partial}{\partial\bar{x}} \approx O(1)$ for small values of δ ,the flow develops slowly along the axial direction with gradient $O(\delta)$.Making use of the above transformation the equations(18)-(19) reduce to

$$(A_1A_3\delta R_e)((\frac{1}{r}\frac{\partial\psi}{\partial\bar{x}}\frac{\partial(E_1^2\psi)}{\partial r}-\frac{1}{r}\frac{\partial\psi}{\partial r}\frac{\partial(E_1^2\psi)}{\partial\bar{x}}-\frac{2}{r^2}\frac{\partial\psi}{\partial\bar{x}}E_1^2\psi)-E_1^4\psi - -(GA_1A_4/R_e)(r(\frac{\partial\theta}{\partial r})) \quad (24)$$

$$(A_5\delta P_1)(\theta_r\psi_{\bar{x}} - \theta_x\varphi_r) = (A_2+\frac{4}{3N_1})(\theta_{rr}+(1/r)\theta_r)+\delta^2A_2\theta_{xx}+\alpha \quad (25)$$

Where $E_1^2 = r\frac{\partial}{\partial r}(\frac{1}{r}\frac{\partial}{\partial r})+\delta^2\frac{\partial^2}{\partial\bar{x}^2}$ Taking the transformation $\eta = \frac{r}{f(\bar{x})}$

the above equations reduce to

$$(A_1A_3\delta\, f\, R_e)((\frac{1}{\eta}\frac{\partial\psi}{\partial\bar{x}}\frac{\partial(F^2\psi)-}{\partial\eta}\frac{1}{\eta}\frac{\partial\psi}{\partial\eta}\frac{\partial(F^2\psi)}{\partial\bar{x}}-\frac{2}{\eta^2}\frac{\partial\psi}{\partial\bar{x}}F^2\psi)-F^4\psi--(Gf^4A_1A_4/R_e)(\eta(\frac{\partial\theta}{\partial\eta})) \quad (26)$$

$$(A_5\delta\, f\, P_1)(\theta_\eta\psi_{\bar{x}}-\theta_x\varphi_\eta)=(A_2+\frac{4}{3N_1})\theta_{\eta\eta}+(1/\eta)\theta_\eta+\delta^2f^2A_2\theta_{xx}+\alpha f^2 \quad (27)$$

Where $F^2=\eta\frac{\partial}{\partial\eta}(\frac{1}{\eta}\frac{\partial}{\partial\eta})$

We use the asymptotic expansions

$$\psi(\eta,\bar{x})=\psi_0(\eta,\bar{x})+\delta\psi_1(\eta,\bar{x})+\delta^2\psi_2(\eta,\bar{x})+\ldots\ldots\ldots\ldots$$

$$\theta(\eta,\bar{x})=\theta_0(\eta,\bar{x})+\delta\theta_1(\eta,\bar{x})+\delta^2\theta_2(\eta,\bar{x})+\ldots\ldots\ldots\ldots$$

$$\phi(\eta,\bar{x})=\phi_0(\eta,\bar{x})+\delta\phi_1(\eta,\bar{x})+\delta^2\phi_2(\eta,\bar{x})+\ldots\ldots\ldots\ldots \quad (28)$$

Substituting (28) in equations(26)&(27) and separating the like powers of δ ,the equations corresponding to the zeroth order are $(A_2+\frac{4}{3N_1})(\theta_{0,\eta\eta}+\frac{1}{\eta}\theta_{0,\eta})+\alpha f^2=0$ (29)

$$F^4\psi_0-h^2F^2\psi_0+\frac{GA_1A_4f^4}{R_e}(\eta(\theta_{0,\eta}+NC_{0,\eta}))=0 \quad (30)$$

The corresponding conditions on ψ_o, θo , and ϕ_o are

$$\psi_0(1,\bar{x})=-1/2,\qquad (\psi_{0,\eta})_{\eta=1}=0\ (\eta\psi_{0,\eta\eta}-\psi_{0,\eta})_{\eta=0}=0,\qquad \psi_0(0,\bar{x})=0 \quad (30a)$$

$$\theta_0(1,\bar{x})=\gamma(\bar{x}),\qquad (\theta_{0,\eta})_{\eta=0}=0 \quad (30b)$$

$$\phi_{0,x}(0,\bar{x})=0,\quad \lim_{r\to\infty}(\frac{1}{\eta}\phi_{0,\eta})=-1 \quad (30d)$$

The equations to the first order are $(A_2+\frac{4}{3N_1})(\eta\theta_{1.,\eta\eta}\ +\theta_{1,\eta})=P_1A_5(\psi_{0,\bar{x}}\theta_{0,\eta}-\psi_{0,\eta}\theta_{0,\bar{x}})$ (31)

$$F^2(F^2-h^2)\psi_1=A_1A_3f^4R_e(\psi_{0,\bar{x}}(F^2\psi_0)_\eta-\psi_{0,\eta}(F^2\psi_0)_{\bar{x}}-$$
$$-(\frac{2}{r^2})\psi_{0,\bar{x}}(F^2\psi_0))+\frac{GA_1A_4f^4}{R_e}(\eta(\theta_{1,\eta})) \quad (32)$$

The corresponding conditions on ψ_1, θ_1 are $\psi_1(1,\bar{x})=-0$, $(\psi_{1,\eta})_{\eta=1}=0$

$$(\eta\psi_{1,\eta\eta}-\psi_{1,\eta})_{\eta=0}=0,\qquad \psi_1(0,\bar{x})=0 \quad (33)$$

$$\theta_1(1,\bar{x})=\gamma(\bar{x}),\qquad (\theta_{1,\eta})_{\eta=0}=0 \quad (34)$$

We can get the second order equations

Solution of the Problem: Solving the coupled equations (29)&(30) subject to the corresponding boundary conditions (30a)-(30d),we get the expressions for zeroth order

$\theta_0(\bar{x},\eta)=\gamma(\bar{x})+\alpha_1 f^2(1-\eta^2)/4$ $\qquad \psi_0=\frac{a_4}{2}\eta^2+\frac{a_3}{16}\eta^4+\frac{a_2}{192}\eta^6$ Solving the coupled equations (31)&(32) subject to the corresponding conditions(33)-(34),we get the solution for θ_1,ψ_1 *and* ϕ_1 .

Shear Stress, Nusselt Number: The stress tensor for the motion on the pipe

$$\sigma_{ij}=-p\delta_{ij}+2\rho\nu e_{ij}\quad \text{where}\quad e_{xx}=\frac{\partial u}{\partial x},e_{rr}=\frac{\partial v}{\partial r},e_{rx}=0.5(\frac{\partial u}{\partial r}+\frac{\partial v}{\partial x})$$

The shear stress on the pipe r=f(x),in the non-dimensional form is given by

$$\tau=(\sigma_{rx}(1-f'^2)+(\sigma_{rr}-\sigma_{xx})f'/(1+f'^2)$$

In terms of non-dimensional variables, we obtain the non-dimensional shear stress

The local rate of heat transfer coefficient(Nusselt number) on the boundary of the pipe is calculated using the formula $Nu = \frac{1}{f(\theta_m - \theta_w)}(\frac{\partial \theta}{\partial \eta})_{\eta=1}$

Where $\theta_m = 2\int_0^1 \theta d\eta$ and the corresponding expression is $Nu = \frac{B_5 + \delta B_6}{f(B_3 + \delta B_4 - \gamma(\bar{x}))}$

Discussion of the Numerical Results: From (fig. 1&5) we find that the axial and the secondary velocities enhance with increase in 'β.Thus higher the dilation of the wavy pipe larger the velocity components. The influence of the non-uniform temperature shows that |u| decreases with increase in the amplitude of the boundary temperature (fig. 2) while |v| enhances with α_1 (fig. 6). The variation of u and v with radiation parameter N_1 is shown in (fig. 3 & 7). An increase in N_1 enhances u and reduces v in the entire flow region. (Figs.4 &8)represent u and v with nanoparticle volume fraction parameter ϕ.It can be seen from the profiles that u reduces and v enhances with increase in ϕ in the entire flow region.

The temperature distribution (θ) is exhibited is figures (9-12)for different variations in governing parameters N_1,α_1, β, ϕ. It is found that θ is positive for all variations. The profile for 'θ' gradually falls from its maximum at the mid region to attain its prescribed value on the boundary η = 1. We find from (fig. 10) that the axial temperature experiences an enhancement with increase in the amplitude α_1 of the boundary temperature. An increase in N_1 leads to an enhancement in the axial temperature in the entire flow region (fig. 11). From (fig.12) we infer that the axial temperature reduces with increase in nanoparticle volume fraction ϕ.

The stress (τ) at the boundary of the pipe η = 1 is evaluated for different values of β, α_1, N_1, ϕ and is shown in (table 2).. The variation of 'τ' with β shows that the stress enhances with increase in β. Thus greater the dilation of the pipe larger the stress . An increase in the amplitude α_1 of the boundary temperature results in an enhancement in stress. The variation of 'τ' with radiation parameter N_1 shows that the stress depreciates with increase in radiation parameter N1.The variation of stress with nanoparticle volume faction ϕ shows that the stress experiences an enhancement with increase in ϕ. The average Nusselt number (Nu) which measures the rate of heat transfer at the boundary is exhibited for different parametric values. From (Table 2). The variation of Nu with β shows that greater the dilation of the pipe, larger |Nu| . Also an increase in the amplitude 'α1'of the boundary temperature leads to an enhancement in the rate of heat transfer . From(table 2) we find that an increase in the radiation parameter N_1 increases the rate of heat transfer at boundary .

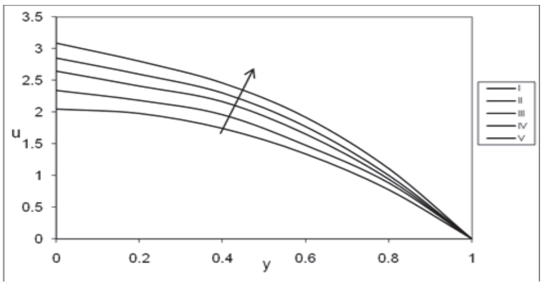

Fig. 1: Variation of u With B

	I	II	III	IV	V
β	0.3	0.5	0.7	0.9	1.20

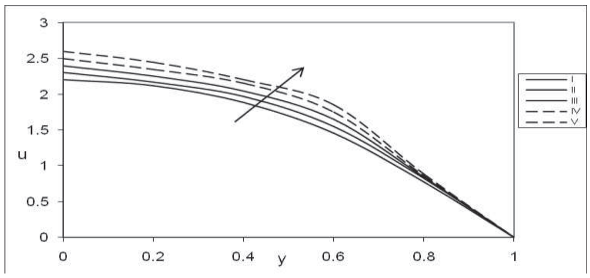

Fig. 3: Variation of u with N1

	I	II	III	IV
N1	0.5	1.5	3.5	5

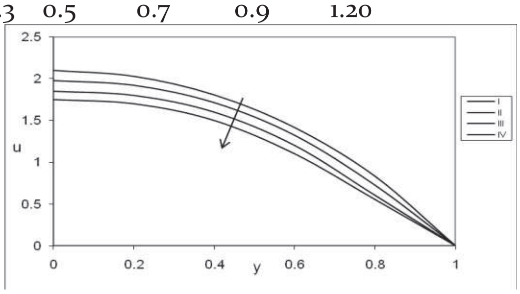

Fig. 2. Variation of u with α1

	I	II	III	IV
α1	0.3	0.5	0.7	0.9

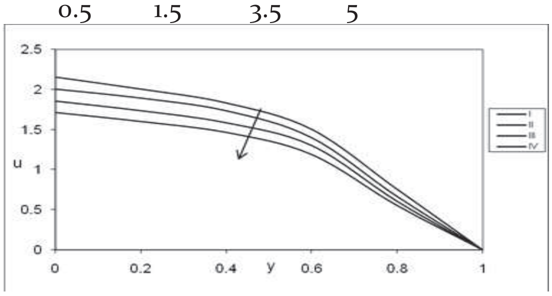

Fig. 4. Variation of u with ϕ

	I	II	III	IV	V
ϕ	0.1	0.3	0.5	0.7	0.9

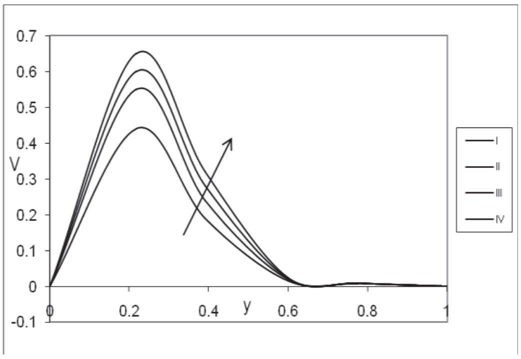

Fig. 5. Variation of V with β

	I	II	III	IV	V
β	0.3	0.5	0.7	0.9	1.20

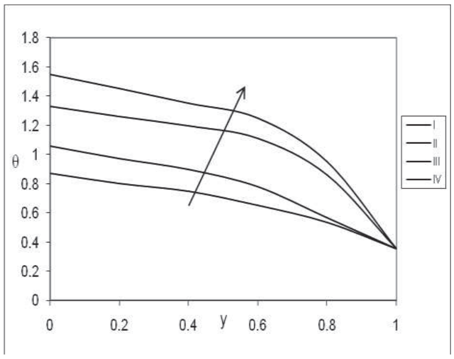

Fig.9. Variation of θ with β

	I	II	III	IV	V
β	0.3	0.5	0.7	0.9	1.20

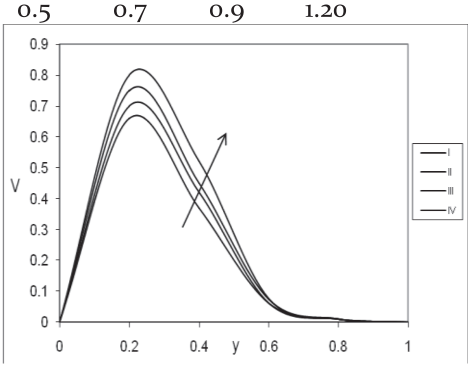

Fig. 6. Variation of V with α1

	I	II	III	IV
α1	0.3	0.5	0.7	0.9

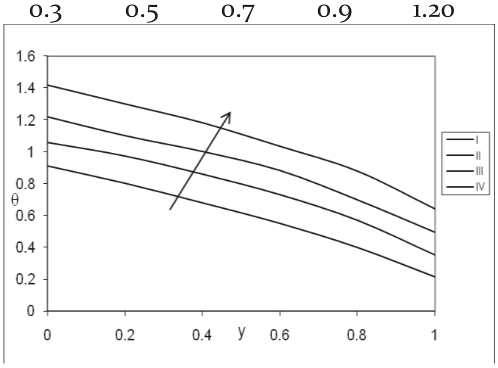

Fig. 10. Variation of θ with α1

	I	II	III	IV
α1	0.3	0.5	0.7	0.9

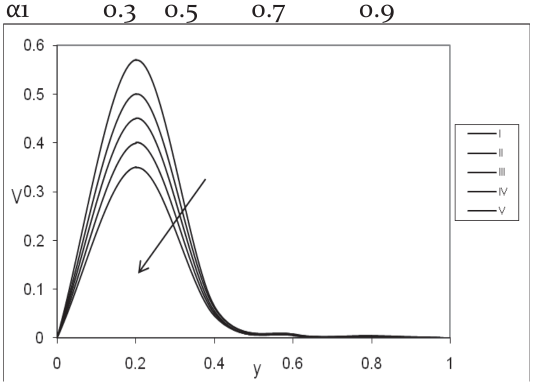

Fig. 7. Variation of V with N1

	I	II	III	IV	V
N1	0.5	1.5	3.5	5	10

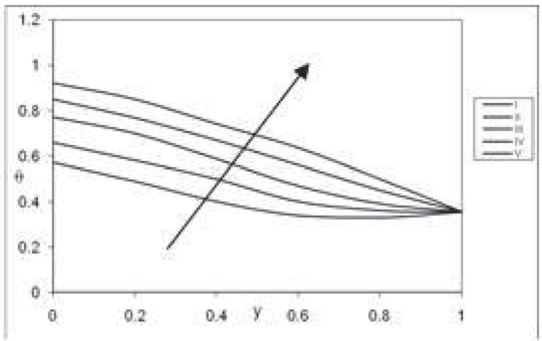

Fig. 11. Variation of θ with N1

	I	II	III	IV	V
N1	0.5	1.5	3.5	5	10

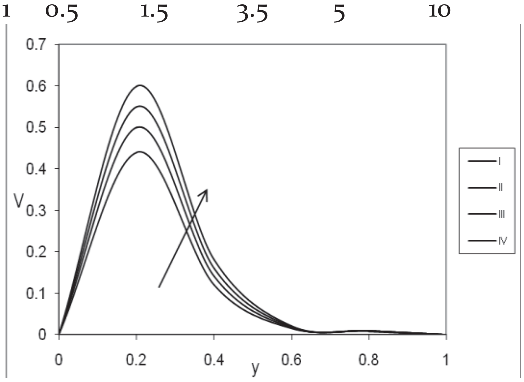

Fig. 8. Variation of V with ϕ

	I	II	III	IV	V
ϕ	0.1	0.3	0.5	0.7	0.9

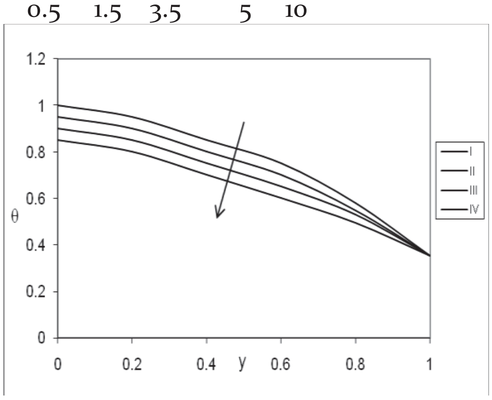

Fig.12. Variation of θ with ϕ

	I	II	III	IV	V
ϕ	0.1	0.3	0.5	0.7	0.9

Table-2:
Skinfriction(τ),NusselNumber(Nu) on r=1

α 1	β	N1	ϕ	τ(1)	Nu(1)
0.3	0.3	0.5	0.1	-1.44101	3.29455
0.5	0.3	0.5	0.1	-0.8024	0.61349
0.7	0.3	0.5	0.1	-1.2791	0.67612
0.3	0.5	0.5	0.1	-0.6155	0.60497
0.3	0.7	0.5	0.1	-0.5091	1.12305
0.3	0.9	0.5	0.1	-0.7885	1.54375
0.3	0.3	1.5	0.1	-0.5456	-0.6266
0.3	0.3	5.0	0.1	-0.1132	-0.883
0.3	0.3	0.5	0.3	-0.8062	0.26486
1	0.3	0.5	0.5	-0.8647	0.46052
1	0.3	0.5	0.1	-0.8029	0.89851
1	0.3	0.5	0.1	-0.8026	0.44472

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