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# Convective Flow of Nanofluids Using Blasius-Rayleigh-Stoke Variable with Slip Effect

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***Abstract :*** *This theoretical analysis investigates the unsteady convective flow of nanofluid using Blasius-Rayleigh-Stokes variable with slip effect. The non-Newtonian fluid problem is examined mathematically via a system of governing partial differential equations to determine the effect of moving slot parameter, thermal Grashof number and mass Grashof number on the flow. A suitable similarity variable is employed to transform these equations into the corresponding ordinary differential equations and then solved using the method of Newton's Finite differences adopted from MAPLE 18.0 software. From the graphical representations derived, an overview of the effects of some physical parameters on the velocity, temperature and the concentration profiles is then presented.*

***Keywords –*** *Blasius-Rayleigh-Stokes variable, moving slot, thermal Grashof number, slip velocity, mass Grashof number.*

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## I. Introduction

The Study of particles less than 100nm diffused into base fluids has received substantial attention in recent decades due to its copious technological and biological applications. Such applications are distinguishable in flows in proximal tube, raw petroleum generation, glass blowing, design of toxic waste storage, electronic chips, filaments and wires, cooling of metallic sheet, crystal growing, artificial fibers, metallurgical processes, tinning of copper wires, paper production and many other industrial applications as stated in Pop and Ingham [1] and Vafai [2].

Previous researchers have perused into fluid with nanoparticles; Sobamowo *et al*. [3] presented thermo-magneto-solutal squeezing flow of nanofluid between two parallel disks embedded in a porous medium and a report on the effects of nanoparticles geometry slip and temperature jump conditions was stated. Sravan *et al.* [4] scrutinized the effect of homogeneous-heterogeneous reactions in magnetohydrodynamic stagnation point nanofluid flow toward a cylinder with non-uniform heat source or sink . Hayat *et al.* [5] considered the unsteady flow of nanofluid through porous medium with variable characteristics. In the recent time, Dianchen *et al.* [6] viewed the analysis of unsteady flow and heat transfer of nanofluid using Blasius-Rayleigh-Stokes variable. Shamshuddin *et al.* [7] considered the numerical study of heat transfer and viscous flow in a double rotating stretchable disk system with a non-Fourier heat flux model. Hayat *et al.* [8] considered a flow between two stretchable rotating disks with Cattaneo-Christov heat flux model.Recent progress about nanofluid can be mentioned through references [9-20]. The conjugate mixed convective flow of nanofluid with radiation was examined by Hsiao [21] .The stability analysis on the flow and heat transfer of nanofluid past a stretching/shrinking cylinder with suction effect was reported by Abubakar *et al.* [22]. Reported on the flow between two stretchable disks with exact solution of Navier-Stokes equations was done by Fang and Zhang [23]. Fang *et al.* [24] investigated a new cluster of unsteady boundary layers over a stretching surface. Ramesh *et al.* [25] analyzed the Heat Transfer in MHD Dusty Boundary Layer Flow over an Inclined Stretching Sheet with Non-Uniform Heat Source or Sink. Todd [26] reported a family of laminar boundary layers along a semi-infinite flat plate. Musa [27] examined the unsteady magnetohydrodynamic Flow of Nano-fluid with Variable Properties past a Stretching Sheet with Thermal Radiation and Chemical Reaction.

The objective of the current research is to examine the development of the unsteady convective flow of nanofluid employing Blasius-Rayleigh-Stoke variable with slip effect. The velocity, thermal and concentration fields were taken into consideration. The systems of governing non-linear partial differential equations were modified into their ordinary differential equation equivalents and the resulting equations were solved numerically by Newton's Finite difference technique subjected to appropriate boundary conditions.

## II. Mathematical Formulation

Considering the unsteady duo- dimensional boundary layer convective flows and heat transfer of an incompressible viscous-based nanofluid over a heated moving semi-infinite plate, the surface emerges along the x-axis from a moving slot. Under the usual boundary layer approximation, the governing equation for the flow, heat and mass transfer are expressed as follows:

Nomenclature

$C$: Concentration ($kg/m^3$)
$C_w$: Wall nanoparticles concentration
$C_\infty$: Ambient nanoparticles concentration
$C_p$ : Specific heat at constant pressure
$D_1$: Thermal slip factor
$D_B$: Brownian motion coefficient ($m^2/s$)
$D_T$: Thermophoretic diffusion coefficient ($m^2/s$)
$f$: Velocity profile
$g$: Acceleration due to gravity
$Gr$ : Thermal Grashof number
$Gm$ : Mass Grashof number
$k$: Thermal conductivity
$k_0$: permeability constant
$L_1$: Velocity slip factor
$Le$: Lewis number
$N_b$: Brownian motion parameter
$N_t$: Thermoporesis parameter
$Pr$ : Prandtl's number
$Re$: Local Reynolds number
$t$: Time
$T$: Fluid temperature
$T_w$: Wall temperature
$T_\infty$ : Ambient temperature
$u$: Velocity component in x direction
$v$: Velocity component in y direction
$U_w$: Plate velocity

Greek symbols
$\eta$ : Similarity variable
$\nu$: Kinematic viscosity
$\beta$ : Permeable parameter
$\mu$ : Dynamic viscosity
$\psi$: Stream function
$\rho$ : Density
$\sigma$: Thermal diffusivity of the fluid
$\varepsilon$: Ratio of the heat capacities of the nano-particles
$\theta$: Dimensionless temperature variable
$\alpha$ : Moving slot parameter
$\gamma$ : Velocity slip parameter
$\tau$: Thermal slip parameter
$\phi$: Dimensionless nanoconcentration parameter
$\boldsymbol{\nu}_f$: Fluid viscosity
$\beta_T$: Thermal expansion coefficient
$\beta_C$: Mass expansion coefficient

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

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=v\frac{\partial^2 u}{\partial y^2}+g\beta_T(T-T_\infty)+g\beta_C(C-C_\infty) \tag{2}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\sigma\left(\frac{\partial^2 T}{\partial y^2}\right)+\varepsilon\left(D_B\frac{\partial T}{\partial y}\frac{\partial C}{\partial y}+\frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right) \tag{3}$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_B\frac{\partial^2 C}{\partial y^2}+\frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \tag{4}$$

the associated boundary conditions are given by

$$\left.\begin{array}{ll} U=L_1\left(\frac{\partial u}{\partial y}\right), V=0, T=T_w+D_1\left(\frac{\partial t}{\partial y}\right), C=C_W & \text{at y=0} \\ U\to U_\infty, T\to T_\infty, C\to C_\infty & \text{as } y\to\infty \end{array}\right\} \tag{5}$$

where $L_1$ and $D_1$ are velocity slip factor and thermal slip factor respectively

## III. Similarity Transformations

Introducing the following similarity variables into equations (1) - (4) with the boundary conditions (5):

$$\left.\begin{array}{l} \eta=\dfrac{y}{\sqrt{(\cos\alpha)\upsilon t+(\sin\alpha)\upsilon x/U_W}},\ \psi(x,y,t)=U_W\sqrt{(\cos\alpha)\upsilon t+(\sin\alpha)\upsilon x/U_W}*f(\eta) \\ \theta(\eta)=\dfrac{T-T_\infty}{T_W-T_\infty},\ \phi(\eta)=\dfrac{C-C_\infty}{C_W-C_\infty} \end{array}\right\} \tag{6}$$

Where the stream functions $\psi$ are define in the usual way as $u=\frac{\partial\psi}{\partial y}, v=-\frac{\partial\psi}{\partial x}$.

The mass conservation law equation (1) is identically satisfied. The mathematical problem defined through equation (2) - (4) and the boundary conditions on equation (5) were transformed into the following set of ordinary differential equations:

$$f'''+\frac{\eta}{2}(\cos\alpha)f''+\frac{1}{2}(\sin\alpha)ff''+Gr\,\theta+Gm\,\phi=0 \tag{7}$$

$$\theta''+\frac{\Pr}{2}((\cos\alpha)\eta+(\sin\alpha)f)\theta'+N_b\theta'\phi'+N_t\theta'^2=0 \tag{8}$$

$$\phi''+\frac{Le}{2}((\cos\alpha)\eta+(\sin\alpha)f)\phi'+\frac{N_t}{N_b}\theta''=0 \tag{9}$$

Subjected to the boundary conditions

$$\left.\begin{array}{l} f(0)=0,\ f'(0)=\gamma f''(0), \theta(0)=1+\tau\theta'(0), \phi(0)=1 \\ f'(\infty)=0, \theta(\infty)=0, \phi(\infty)=0 \end{array}\right\} \tag{10}$$

Where the prime depicts an ordinary differentiation with respect to η, $\alpha$ is the moving slot parameter, $Gr=\frac{g\beta_T(T_W-T_\infty)}{\upsilon U_W\left((\cos\alpha)\upsilon t+(\sin\alpha)\upsilon x/U_W\right)^{-1}}$ the thermal Grashof number, $Gm=\frac{g\beta_C(C_W-C_\infty)}{\upsilon U_W\left((\cos\alpha)\upsilon t+(\sin\alpha)\upsilon x/U_W\right)^{-1}}$ is the mass Grashof number, $\Pr=\frac{\upsilon}{\sigma}$ is the Prandtl number, $N_b=\frac{\varepsilon D_B(C_W-C_\infty)}{\sigma}$ is the Brownian diffusion parameter, $N_T = \frac{\varepsilon D_T (T_W - T_\infty)}{T_\infty \sigma}$ is the Thermophoresis diffusion parameter, $Le = \frac{\upsilon}{D_B}$ is Lewis number, $\gamma$ is the velocity slip parameter and $\tau$ is the thermal slip parameter.

## IV. Results And Discussion

Equations (7) - (9) along with the associated boundary conditions (10) were solved numerically via Newton's finite difference method with the help of Maple 18.0 software. This investigation analyzed the convective flow of nanofluid using Blasius-Rayleigh-Stoke variable, the effect of flow parameters were obtained from the solution. This section interprets the graphical description of sundry variables such as moving slot parameter ($\alpha$), thermal Grashof number (Gr), mass Grashof number (Gm), Prandtl number (Pr), Lewis number (Le), Brownian motion parameter ($N_b$), Thermophoresis parameter ($N_t$), velocity slip parameter ($\gamma$) and thermal slip parameter (τ) on velocities profile $f'(\eta)$, thermal field θ (η) and the concentration field φ (η). Table.1 describes the behavior of the skin friction coefficient f'' (0), local Nusselt number -θ' (0) and local Sherwood number -φ' (0) with different values of the moving slot parameter ($\alpha$). Figure.1 and figure.2 highlighted the impacts of moving slot parameter ($\alpha$) on f'(η) and θ (η) respectively. It is clearly observed that φ (η) and θ (η) possesses same trend, they both increase with increases in the moving slot parameter but later falls when the angle reaches $90^0$. Figure.3 elaborates the role of ($\alpha$) on φ (η). It shows that an increment in ($\alpha$) leads to a decrement in the concentration profile but later increases when the angle reaches $90^0$. Figure.4 elaborates the characteristics of thermal Grashof number (Gr) on f'(η). Here velocities profile f' (η) is higher for (Gr). Figure.5 displayed the behavior of (Gr) on the thermal field θ (η). Higher (Gr) leads to stronger θ (η). The role of (Gr) on φ (η) is elaborated in figure.6. The concentration φ (η) is a decreasing function of (Gr). Characteristics of (Gm) on velocity and thermal profiles f'(η) and θ (η) are portrayed in figure.7 and figure.8 respectively. Same trend on the profiles are noted i.e. both are higher for increasing (Gm). Figure.9 is sketched to scrutinize the behavior of φ (η) through (Gm), an enhancement in φ (η) is observed through lower (Gm). Figure.10 and figure.11 witnessed that Brownian motion parameter ($N_b$) increases the thermal field θ (η) and concentration field φ (η) respectively. Figure.12 displayed behavior of thermal field θ (η) against Thermophoresis parameter ($N_t$). Clearly higher estimation of ($N_t$) increases the thermal field θ (η). Figure.13 sketched the attributes of φ (η) for ($N_t$). Reduction in φ (η) is seen through higher ($N_t$). Outcome of ($\gamma$) on the velocity profile f' (η) and thermal field θ (η) are plotted in figure.14 and figure.15 respectively. Clearly higher ($\gamma$) strengthen both profiles. Plot of φ (η) against velocity slip parameter ($\gamma$) is illustrated in figure.16, clearly φ (η) is reduced for higher ($\gamma$). Figure.17 and figure.18 analyzed that higher estimations of thermal slip parameter (τ) lowers the velocity profile f' (η) and thermal field θ (η) respectively. Behavior of velocity slip parameter ($\gamma$) on φ (η) is addressed in figure.19. Higher ($\gamma$) yields more concentration profile φ (η).

**Table 1:** The values of f''(0), -θ'(0) and -φ'(0) for different values of $\alpha$ and Pr when the values of the parameters are Gr=Gm=0, $N_b$=$N_t$=0.01, Le=1.0 and $\gamma$=τ=1.0.

| $\alpha$ | Pr | $N_b$ | $N_t$ | Le | $\gamma$ | τ | -φ'(0) | -θ'(0) | f''(0) |
|---|---|---|---|---|---|---|---|---|---|
| 90 | 1 | 0.01 | 0.01 | 1.0 | 1.0 | 1.0 | 1.008477 | 0.500470 | 0.502344 |
| 60 | - | - | - | - | - | - | 0.958801 | 0.473526 | 0.475464 |
| 30 | - | - | - | - | - | - | 0.985325 | 0.488512 | 0.490415 |
| 90 | 2 | - | - | - | - | - | 1.003826 | 0.502799 | 0.502344 |
| 60 | - | - | - | - | - | - | 1.010849 | 0.447101 | 0.475464 |
| 30 | - | - | - | - | - | - | 1.005191 | 0.478551 | 0.490415 |
| 90 | 3 | - | - | - | - | - | 0.999231 | 0.505100 | 0.502344 |
| 60 | - | - | - | - | - | - | 1.065957 | 0.419023 | 0.475464 |
| 30 | - | - | - | - | - | - | 1.025697 | 0.468265 | 0.490415 |
| 0 | 4 | - | - | - | - | - | 0.941587 | 0.570934 | 0.520139 |
| -30 | - | - | - | - | - | - | 0.952078 | 0.556929 | 0.5159911 |
| -90 | - | - | - | - | - | - | 1.106756 | 0.404698 | 0.4787712 |
| 0 | 5 | - | - | - | - | - | 0.911603 | 0.585953 | 0.5201393 |
| -30 | - | - | - | - | - | - | 0.927040 | 0.569475 | 0.5159911 |
| -90 | - | - | - | - | - | - | 1.158490 | 0.378319 | 0.4787712 |
| 0 | 6 | - | - | - | - | - | 0.883939 | 0.599833 | 0.5201393 |
| -30 | - | - | - | - | - | - | 0.903602 | 0.581234 | 0.5159911 |
| -90 | - | - | - | - | - | - | 1.211693 | 0.351107 | 0.4787712 |

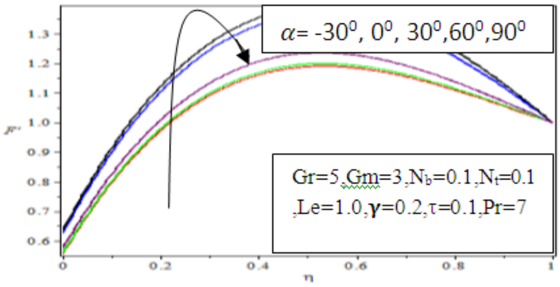


Fig. 1 Impact of $\alpha$ on the velocity profiles.

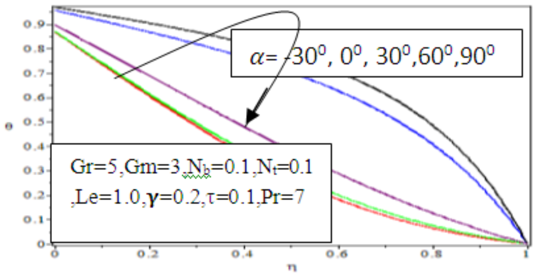


Fig. 2 Impact of $\alpha$ on the temperature profiles.

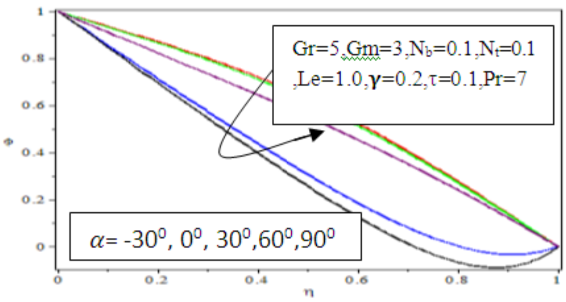


Fig. 3 Impact of $\alpha$ on the concentration profiles.

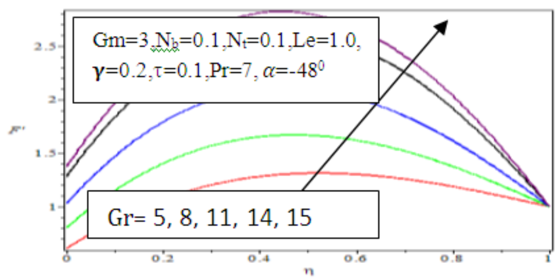


Fig. 4 Impact of Gr on the velocity profiles.

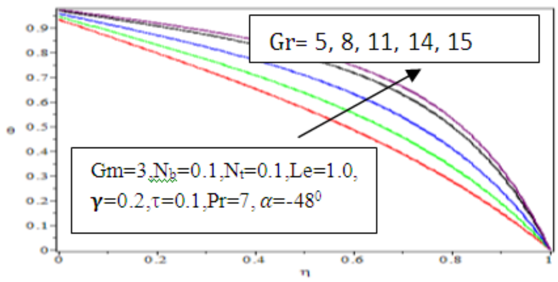


Fig. 5 Impact of Gr on the Temperature profiles.

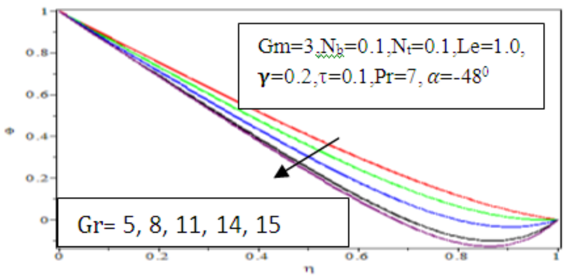


Fig. 6 Impact of Gr on Concentration profile

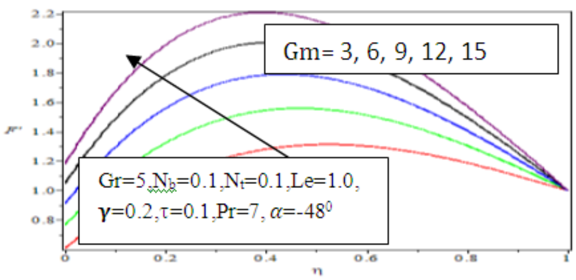


Fig. 7 Impact of Gm on the Velocity profiles.

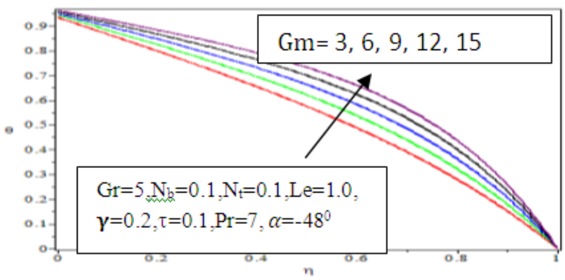


Fig. 8 Impact of Gm on Temperature profiles.

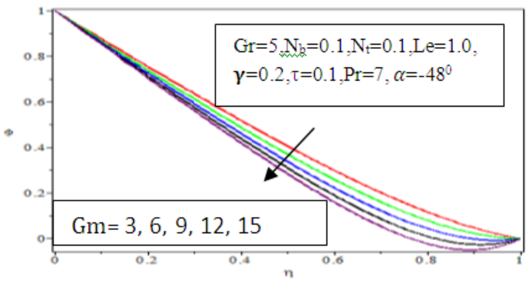


Fig. 9 Impact of Gm on Concentration profiles.

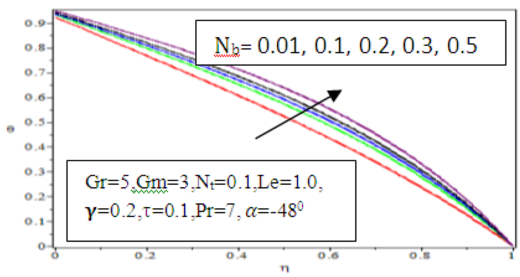


Fig. 10 Impact of $N_b$ on Temperature profiles.

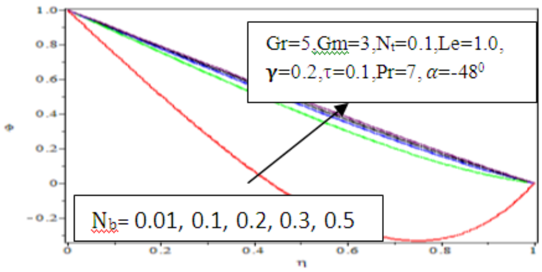


Fig. 11 Impact of $N_b$ on Concentration profiles.

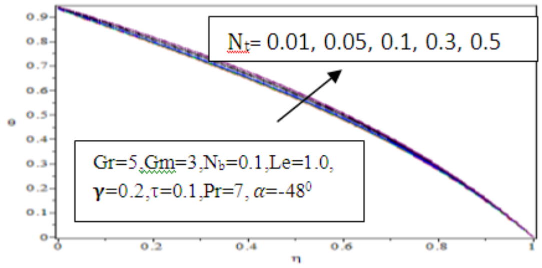


Fig. 12 Impact of $N_t$ on Temperature profiles.

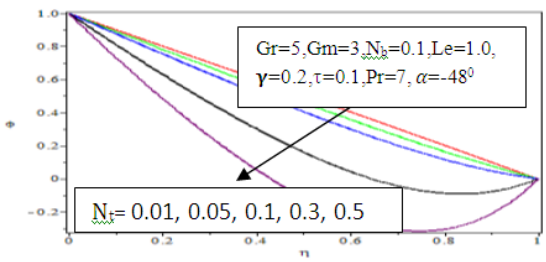


Fig. 13 Impact of $N_t$ on Concentration profiles.

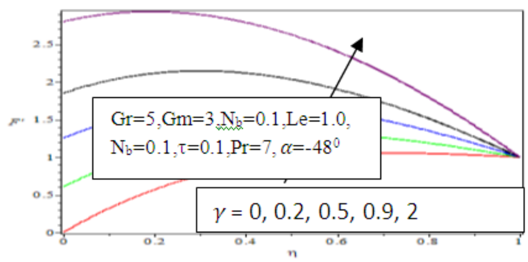


Fig. 14 Impact of $\gamma$ on Velocity profiles.

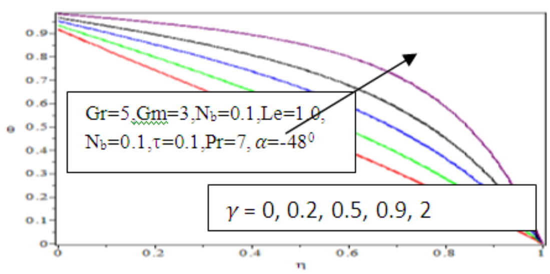


Fig. 15 Impact of $\gamma$ on Temperature profiles.

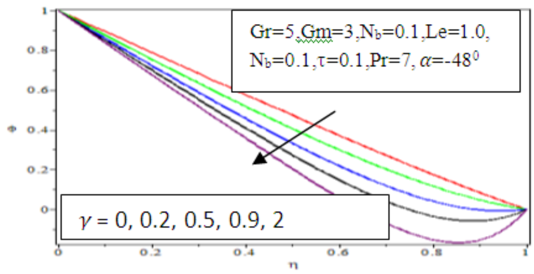


Fig. 16 Impact of $\gamma$ on Concentration profiles.

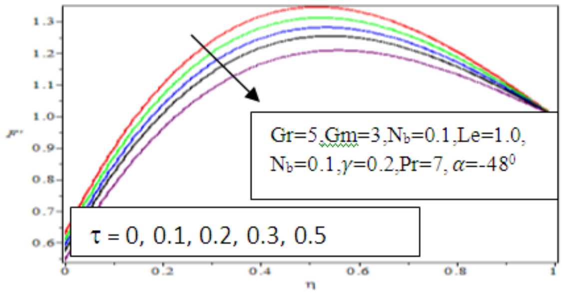


Fig. 17 Impact of τ on Velocity profiles.

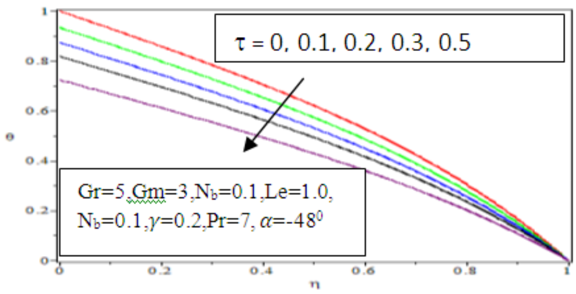


Fig. 18 Impact of τ on Temperature profiles.

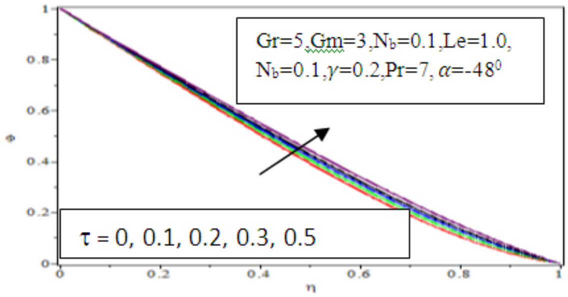


Fig. 19 Impact of τ on Concentration profiles.

## V. Conclusion

This research has studied the effect of moving slot parameter, thermal Grashof number and mass Grashof number on the unsteady convective flow and heat transfer of nanofluid using Blasius-Rayleigh-Stoke variable. The numerical solutions were obtained using the Newton's Finite difference method.The influence of other flow parameters such as Lewis number, Prandtl number, velocity slip parameter, thermal slip parameter, Brownian diffusion parameter and the Thermophoresis diffusion parameter on the velocity profile, thermal field and concentration profile were examined. It was discovered that adding particles less than 100nm to the basefluid positively influences the thermal conductivity of the medium and thus, the following remarks were made.

1) As the moving slot parameter increases, the velocity component and the temperature profile increases significantly but later decelerate when the angle reaches $90^0$ while the concentration component decreases and later accelerate when the angle reaches $90^0$.

2) The velocity component and the thermal profile increase with an increase in the thermal Grashof number but decreases on the concentration profile.

3) As the Thermophoresis parameter increases, the thermal field increases. A reverse case is recorded on the concentration profile.

4) Increasing the Brownian motion parameter evokes a corresponding increase in the thermal field and the concentration distribution and also, increasing the thermal velocity slip parameter, increases the velocity and thermal field but retardation occurs on the concentration profile.

5) Increase in the value of the thermal slip parameter, increases the concentration distribution notably, while it decelerates rapidly on the velocity and the thermal field.

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