RESEARCH ARTICLE

Three-Dimensional Nanofluid Flow with Convective and Slip Condition with Thermal Radiation Effect via Stretching/Shrinking Surface

Nainaru Tarakaramu[1,*], **Motamari Madhu**[2] and **G. YuvaRoopa Lakshmi**[3]

[1] Department of Mathematics, School of Liberal Arts and Sciences, Mohan Babu University, Sree Sainath Nagar, Tirupati, Andhra Pradesh 517502, India
[2] Department of Mathematics, University College, Palamuru University, Mahabubnagar, Telangana 509001, India
[3] Department of Mathematics, Government Degree College for Women, Wanaparthy, Nandi Hills, Wanaparthy, Telangana 509103, India

Abstract

A numerical technique for the nonlinear thermal radiation effect on 3D ("Three Dimensional") nanofluid (NFs) motion through shrinking or stretching surface with convective boundary condition is examined. In this investigation we use the convective and velocity slip conditions. The governing equations were converted into a set of couple non-linear ODE's by suitable similarity transformations. The converted nonlinear equations are obtained by applying R-K-F ("Range-Kutta-Fehlberg") procedure along with shooting technique. The physical parameters are explained graphically on velocity, temperature and concentration. Moreover, we found the coefficient of skin friction, rate of heat transfer with various nanofluid parameters. It is very good agreement when compared with previous study.

Submitted: 16 July 2025
Accepted: 30 July 2025
Published: 22 August 2025

Vol. 1, **No.** 1, 2025.
10.62762/IJTSSE.2025.456595

***Corresponding author:**
Nainaru Tarakaramu
nainaru143@gmail.com

Keywords: nanofluid, Magnetohydrodynamics, Shrinking/stretching surface, velocity slip, nonlinear thermal radiation.

1 Introduction

In most of the investigation, developed the no-slip condition is established Kn ("Knudson Number"), but in some circumstances such as suspensions, emulsions, foams and polymer solutions [1–4], the no-slip condition is not acceptable for the slip flow range $0{:}01 Kn 0{:}1$, still the basic equations of energy and Navier-Stokes can be used by taking into account velocity slip and temperature jump. It has a lot of importance in physics. The stagnation point flow of NFs via surface with different slip conditions examined by [5–8]. Wang et al. [9] introduce boundary layer slip with microscale gas motion. Magnetohydrodynamic (MHD) slip motion over a sheet/wall was investigated by Mahabaleshwar et al. [10] for hybrid nanofluid flow with Navier's slip, Aziz and Jamshed [11] for non-Newtonian nanofluid

Citation
Tarakaramu, N., Madhu, M., & Lakshmi, G. Y. R. (2025). Three-Dimensional Nanofluid Flow with Convective and Slip Condition with Thermal Radiation Effect via Stretching/Shrinking Surface. *International Journal of Thermo-Fluid Systems and Sustainable Energy*, 1(1), 30–38.

with temperature-dependent conductivity, and Abbas and Sheikh [12] for ferrofluid with nonlinear slip conditions. Nojoomizadeh et al. [13] studied permeability effects on slip velocity in microchannels, while Farooq et al. [14] explored second-order slip in Sisko nanomaterial flow. Abd El-Aziz and Afify [15] analyzed MHD stagnation-point flow with induced magnetic fields, and Majeed et al. [16] investigated nanoparticle magnetic properties under momentum slip in aqueous media. Nayak et al. [17] and Sharma et al. [18] examined MHD slip flow with porous media and heat transfer. Ahmad et al. [19] noticed that the solid volume fraction diminutions the velocity and enhances the temperature distribution. Three dimensional couple stress casson liquid motion via bidirectional surface was created Tarakaramu et al. [20]. Noor et al. [21] finding that wall shear stress and fluid velocity increase as the plates approaching each other.

The word NFs is created Choi [22, 23] which define the size of base fluids ("like water, oil kerosene and ethylene glycol"). These fluids have addition of NPs, the properties of the fluids can be rapidly enhanced. It has a lot of demand placed upon them in terms of growing or declining energy release to systems and their effects depend on thermal conductivity, heat capacity and other physical properties in manufacturing presses [24–26]. The heat and mass transfer on 3D ("Three-Dimensional") MHD ("Magnetohydrodynamic") motion of Maxwell NFs via stretching sheet was discover Sreedevi and Sudarsana Reddy [27]. Eid et al. [28] found that the increase of Fe_3O_4 ("nanoparticle") NPs concentration enhances heat transfer rate of hybrid NFs in a shrinkable case and opposite happens in a stretchable state. Satya Narayana et al. [29] finding reviled that the thermal and species boundary layer thickness is enhanced due to rising values of thermal radiation.

Moreover, the boundary layer flow through a shrinking/stretching sheet has a motivate work in fluid dynamic. Some of the practical situations of shrinking sheets ("like shrinking spring, shrinking balloon, and shrinking plastic"). Which is very useful in packaging of bulk products. The shrinking/stretching sheet has many tremendous applications ("crystal growing, extraction of polymer and rubber sheet, like glass-fibre production, paper production, annealing and tinning of copper wires, wire drawing, metal and polymer processing and many others") in manufacturing industries and technological process. Jat et al. [30] developed the 3D boundary layer flow due to shrining sheet. Recently, some of the scientists [31–34] working on stagnation point flow towards a shrinking/stretching sheet. The 2D ("Two Dimensional") stagnation point flow of NFs via stretching sheet was presented Najib et al. [35]. Khan et al. [36] discussed analytical and numerical analysis for the viscous and heat transfer flow over a nonlinear stretching sheet. Murtaza et al. [37] explored the biomagnetic fluid flow and heat transfer in 3D unsteady shrinking/stretching sheet. Jusoh et al. [38] analysed the 3D rotating and heat transfer flow of ferrofluid over exponential permeable shrinking/stretching sheet with suction effect. 3D flow of nanofluid passing through an exponential stretching sheet. Further, the boundary layer flow via stretching or shrinking sheet was examined [39–46].

2 Mathematical Analysis

The nonlinear effect on 3D NFs motion over a shrinking or stretching sheet with velocity slip in the presence of magnetohydrodynamic is considered. The physical model of the coordinate system is explored in Figure 1. It is considered that the surface is stretched or shrink in the x^*y^* surface with velocity slip. The z^* direction is orthogonally to stretching $b_1 > 0$ or shrinking surface $b_1 < 0$. The nanofluid flow occupies the region $z^* > 0$. The velocity components of the surface trough x^* and y^* directions are $u_w^*(x) = a_q x^*$ and $v_w^*(y^*) = b_1 y^*$, respectively. The liquid is electrically conducting under the effect of uniform magnetic field B_0. Moreover, the velocity mass flux is $w_1 = w_0$, where $w_0 < 0$ then it is called suction and $w_0 > 0$ then it is known as injection. Under these considerations, the basic governing equations are:

$$\frac{\partial u_1^*}{\partial x^*} + \frac{\partial v_1^*}{\partial y^*} + \frac{\partial w_1^*}{\partial z^*} = 0 \tag{1}$$

$$u_1 \frac{\partial u_1}{\partial x^*} + v_1 \frac{\partial u_1}{\partial y^*} + w_1 \frac{\partial u_1}{\partial z^*} = \nu_1 \frac{\partial^2 u_1}{\partial (z^*)^2} - \frac{\sigma_1 B_0^2}{\rho_f} u_1 \tag{2}$$

$$u_1 \frac{\partial v_1}{\partial x^*} + v_1 \frac{\partial v_1}{\partial y^*} + w_1 \frac{\partial v_1}{\partial z^*} = \nu_1 \frac{\partial^2 v_1}{\partial (z^*)^2} - \frac{\sigma_1 B_0^2}{\rho_f} v_1 \tag{3}$$

$$u_1 \frac{\partial T^*}{\partial x^*} + v_1 \frac{\partial T^*}{\partial y^*} + w_1 \frac{\partial T^*}{\partial z^*} = \alpha_m \left(\frac{\partial^2 T^*}{\partial (z^*)^2} \right) - \frac{1}{(\rho c_p)_f} \left(\frac{\partial q_r}{\partial z^*} \right) + \tau \left\{ D_B \left(\frac{\partial C^*}{\partial z^*} \frac{\partial T^*}{\partial z^*} \right) + \frac{D_{T^*}}{T_\infty^*} \left(\frac{\partial T^*}{\partial z^*} \right)^2 \right\} \tag{4}$$

$$u_1 \frac{\partial C^*}{\partial x^*} + v_1 \frac{\partial C^*}{\partial y^*} + w_1 \frac{\partial C^*}{\partial z^*} = D_B \left(\frac{\partial^2 C^*}{\partial (z^*)^2} \right) + \frac{D_T^*}{T_\infty^*} \left(\frac{\partial^2 T^*}{\partial (z^*)^2} \right) \tag{5}$$

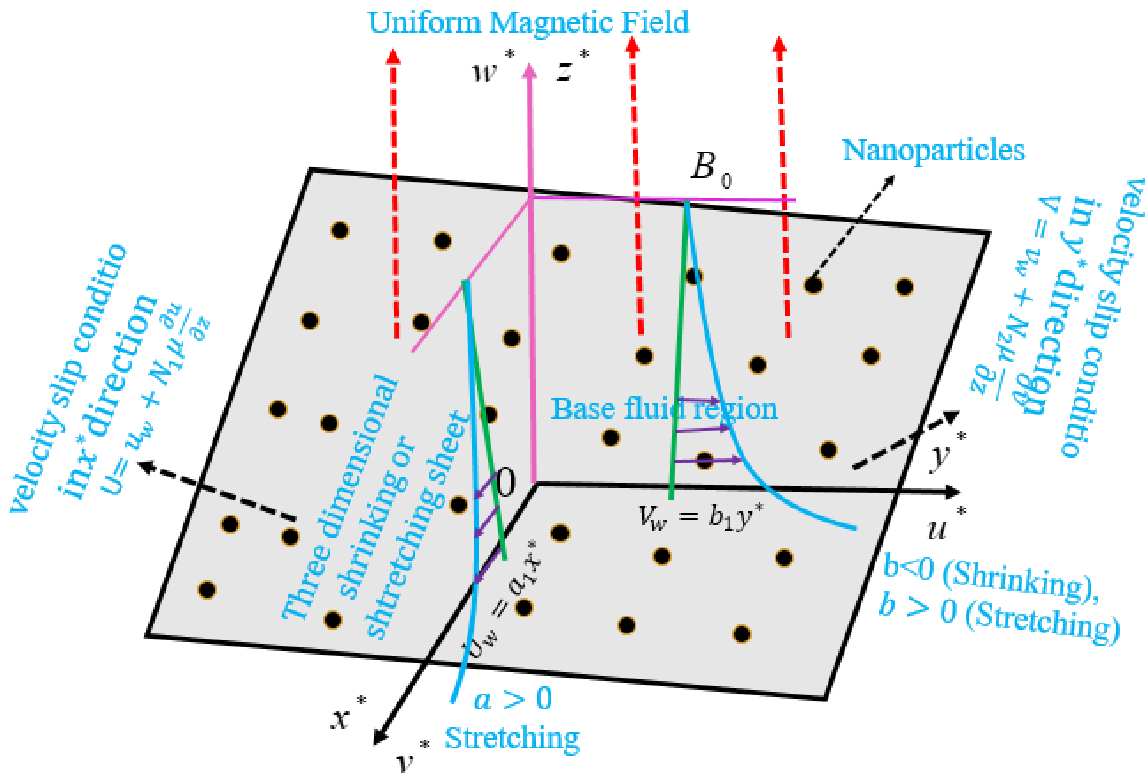


Figure 1. Physical model of the problem.

Corresponding B.Cs are

$$\left.\begin{array}{r} u_1 = u_w^*(x) = U_w(x) + N_1\gamma_0 \dfrac{\partial u_1}{\partial z^*}, \\ v_1 = v_w^*(x) = V_w(x) + N_2\gamma_0 \dfrac{\partial v^*}{\partial z^*}, \\ w_1 = w_0, \quad T^* = T_w^*, \\ -k\dfrac{\partial C^*}{\partial z^*} = h_1(T_f - T^*) \end{array}\right\} \text{at} \quad z^* = 0 \\ u_1 \to 0, v_1 \to 0, T^* \to T_\infty^*, C^* \to C_\infty^* \quad \text{as } Z^* \to \infty \tag{6}$$

According to the Roseland's approximation [47] the non-linear radiative heat flux q_r as given by

$$q_r = \frac{-4\sigma_1}{3k^*}\frac{\partial T^{*4}}{\partial z^*} = \frac{-16\sigma_1 T^{*3}}{3k^*}\frac{\partial T^*}{\partial z^*} \tag{7}$$

Differentiate above the heat flux equation, we get

$$\frac{\partial q_r}{\partial z} = \frac{-16\sigma_1}{3k^*}\frac{\partial}{\partial z}\left(T^{*3}\frac{\partial T^*}{\partial z}\right) \tag{8}$$

Eq. (4) is transfer by utilizing above Eq. (6), we get

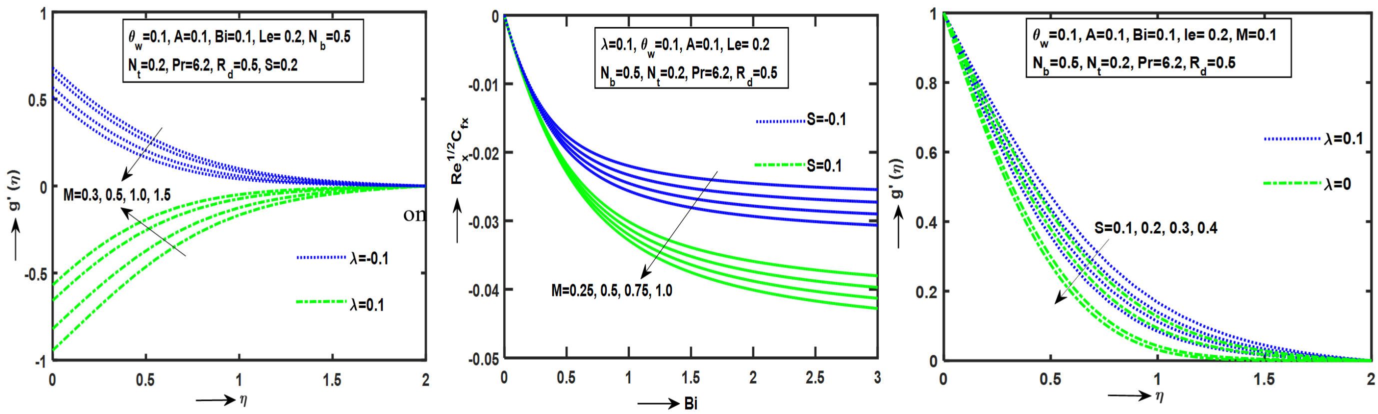
$$u_1\frac{\partial T^*}{\partial x^*} + v_1\frac{\partial T^*}{\partial y^*} + w_1\frac{\partial T^*}{\partial z} = \alpha_m^*\left(\frac{\partial^2 T^*}{\partial z^{*2}}\right) \\ + \frac{1}{(\rho C)_f}\left[\frac{16\sigma_1}{3K^*}\frac{\partial}{\partial z^*}\left(T^{*3}\frac{\partial T^*}{\partial z^*}\right)\right] \\ + \tau\left\{D_B\left(\frac{\partial C^*}{\partial z^*}\frac{\partial T^*}{\partial z^*}\right) + \frac{D_T}{T_\infty^*}\left(\frac{\partial T^*}{\partial z^*}\right)^2\right\} \tag{9}$$

The following dimensionless functions and the similarity variables are:

$$\left.\begin{array}{r} \eta = z\sqrt{\dfrac{a_1}{\nu_f}}, \quad u_1 = a_1 x^* f'(\eta), \\ v_1 = a_1 y^* g'(\eta) \\ w_1 = -\sqrt{a_1\nu_f}\left(f'(\eta) + g(\eta)\right), \\ \theta(\eta) = \dfrac{T^* - T_\infty^*}{T_w^* - T_\infty^*}, \\ \varphi(\eta) = \dfrac{C^* - C_\infty^*}{C_w^* - C_\infty^*} \end{array}\right\} \tag{10}$$

Utilizing the above dimensions, Eq. (1) is identically satisfied and translate Eqs. (2)-(4) and Eq. (9) becomes:

$$f''' + ff''(f+g) - (f')^2 - Mf' + 1 = 0 \tag{11}$$



(a) Influence of M on $g'(\eta)$ **(b)** Influence of M on $Re_x^{1/2}C_{fx}$ **(c)** Influence of M on $g'(\eta)$

Figure 2. Effect of M on fluid motion and skin friction coefficient.

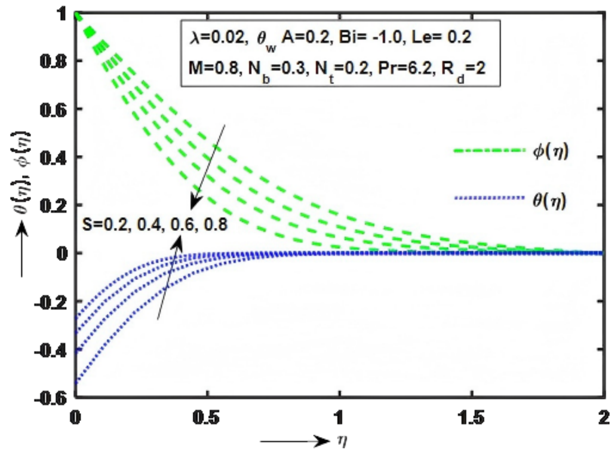


Figure 3. Influence S of on $\theta(\eta)$,$\phi(\eta)$.

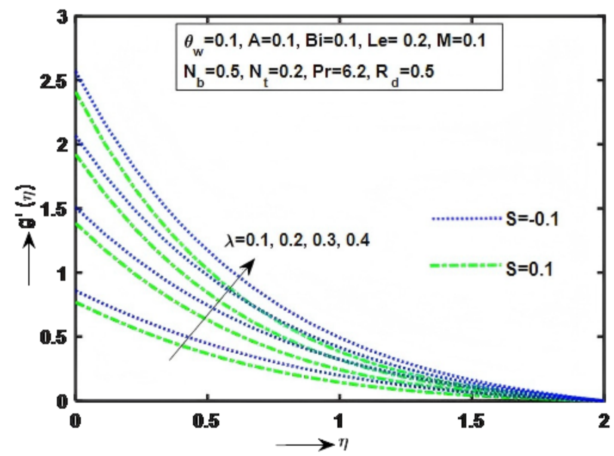


Figure 4. Influence of λ on $g'(\eta)$.

$$g''' + gg''(f+g) - (g')^2 - Mg' + 1 = 0 \tag{12}$$

$$\left(\left(1 + R_d\left(1 + (\theta_w - 1)\theta\right)^3\theta\right)\right)' + \Pr\left((f+g)\theta' + N_b\theta'\varphi' + N_t\theta'^2\right) \tag{13}$$

$$\varphi'' + Le\Pr(f+g)\varphi' + \left(\frac{N_t}{N_b}\right)\theta'' = 0 \tag{14}$$

With subject to the boundary conditions are:

$$\left.\begin{array}{l} f(0) = S, g(0) = 0, f'(0) = 1 + Af''(0), g'(0) = \lambda + Bg''(0) \\ \varphi(0) = 1, \theta'(0) + Bi(1 - \theta(0)) = 0 \\ f'(\eta) \to 0, g'(\eta) \to 0, \theta(\eta) \to 0, \varphi(\eta) \to 0 \quad \text{as } \eta \to \infty \end{array}\right\} \tag{15}$$

The physical quantities of practical interest are the

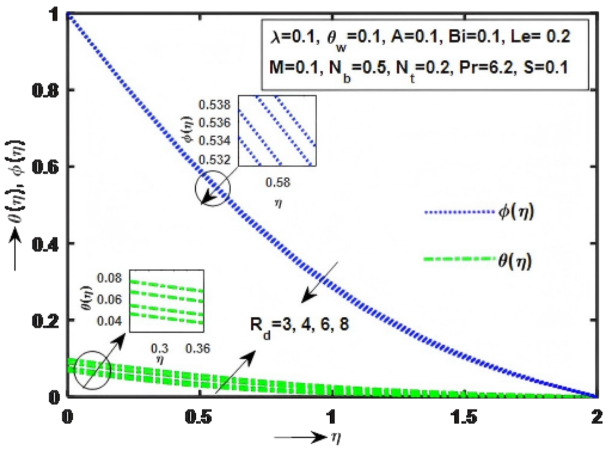


Figure 5. Influence R_b of on $\theta(\eta)$,$\phi(\eta)$.

local skin friction coefficient C_{fx} and C_{fy}, and Nusselt number Nu_x; it is defined as

$$Nu_x = \frac{x^* q_x}{k^*(T_w^* - T_\infty^*)} \tag{16}$$

Defines the skin friction or shear stresses along x^*, y^* direction, heat flux q_w and mass flux q_m from surface of the sheet are

$$q_w = -k^*\left(\frac{\partial T^*}{\partial z^*}\right)_{z^*=0} \tag{17}$$

Substituting the u_1, v_1, T^* from the Eq. (7) onto Eq. (15) and using Eq. (14), we getting

$$Nu_x Re_x^{-1/2} = -\theta'(0) \tag{18}$$

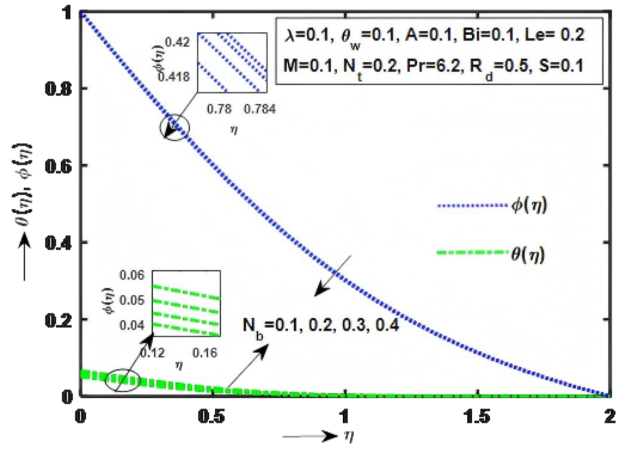


Figure 6. Influence N_t of on $\theta(\eta)$,$\phi(\eta)$.

where $Re_x = \frac{U_w x^*}{\nu}$ and $Re_y = \frac{U_w y^*}{\nu}$ are the local Reynolds number.

3 Results and Discussion

The physical effect of M ("Magnetic Parameter") on fluid motion component $g'(\eta)$ for the cases of sheet is stretching ($\lambda > 0$) and shrink ($\lambda < 0$), $Re_x^{1/2} C_f$ (coefficient of skin friction) for the cases of suction ($S > 0$) and injection ($S < 0$) is predicted on Figures 2 (a)-2(b). It is clear that the nanofluid flow velocity is slowing down along y-direction when the sheet is stretching ($\lambda > 0$) while opposite motion displays when sheet is shrink ($\lambda < 0$) with various growth numerical values of M as illustrated in Figure 2(a). Moreover, the coefficient of skin friction along x^*-direction for both cases of suction ($S > 0$) and injection ($S < 0$) as explored in Figure 2(b). Physically, a drag force like resistive type force (Lorentz force) is created disturbance by the fluid particles of the vertical magnetic field to the electrically conducting fluid. This force has to reduce the motion of the fluid over a stretching surface.

Figures 3 and 4 presented the S ("Mass Flux Parameter") on base fluid flow component $g'(\eta)$, y^*-direction for the cases of sheet is stretching ($\lambda > 0$), shrink ($\lambda < 0$) and $\theta(\eta)$, $\varphi(\eta)$. It is clear the fluid velocity motion, $\varphi(\eta)$ is slow reduction through a stretching and shrinking sheet while reverse behaviour shows temperature various enlarge values of S. Physically, the larger values of mass flux effect in fluid particles and the fluid resistance slow down then its fluid flow boundary layer thickness is reducing.

The impact of λ ("Stretching/shrinking Parameter") on velocity component $g'(\eta)$ along y^*-direction is explored through in Figure 5 for the cases of suction ($S > 0$) and injection ($S < 0$). It is clear the fluid motion is monotonically decrease over a stretching surface with various enlarge values of λ. Because, the fluid flow convergent to surface area very fast then the surface is injection case.

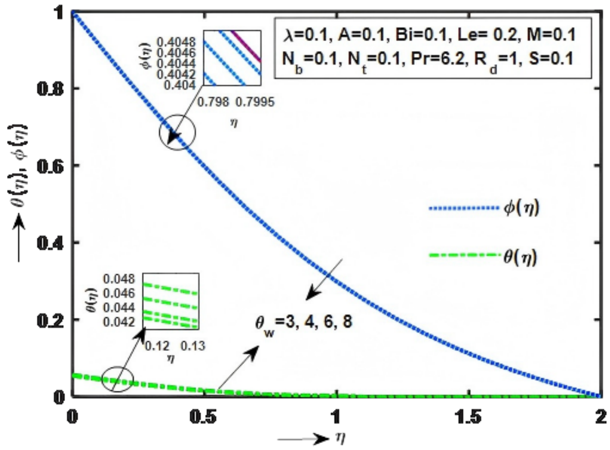


Figure 7. Influence θ_w of on $\theta(\eta)$,$\phi(\eta)$.

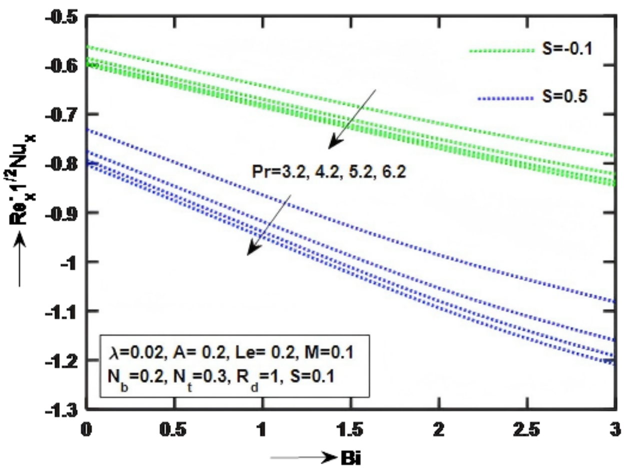


Figure 8. Influence Pr of on $Re_x^{-1/2} N_x$.

The significant effect of R_d ("Nonlinear thermal radiation") on $\theta(\eta)$, $\varphi(\eta)$ as discussed in Figure 6. It is noticed that fluid $\theta(\eta)$ flow enhances, while opposite direction of $\varphi(\eta)$ with higher enlarge values of R_d. Physically, nonlinear thermal radiation is inversely proportional to the thermal conductivity. In this fact the weaker thermal conductivity of the nanofluid flow and large values of R_d than that it has produce more heat on surface.

Figure 7 depicts the physical parameter N_t ("Thermophoresis Parameter") on $\theta(\eta)$, $\varphi(\eta)$. It is noticed that $\theta(\eta)$ of the nanofluid flow enhances over the surface while opposite motion of fluid $\varphi(\eta)$ with higher values of N_t. Physically, when huge amount of temperature variance exists, then the

Table 1. Evaluation of Skin friction coefficient $-f''(0)$ for $A = B = Bi = R_d = 0$.

M	Present study	Sarah et al. [48]	Nadeem et al. [49]	Gupta et al. [50]	Ahmad et al. [51]
0.0	1.000000	1.00000	1.0004	1.0003181	1.0042
10	3.316624	3.31662	3.3165	3.3165824	3.3165
100	10.04987	10.04987	10.049	10.049864	10.049

Table 2. Comparison of Skin friction coefficient $-f''(\infty)$ for $A = B = Bi = R_d = 0$.

M	Present study	Nadeem et al. [49]
0.0	1.173719	–
10	3.367222224	3.3667
100	10.06646642	10.066

suspended particles tends to move more closer to the surface to reduce the concentration and subsequently enhances the heat somewhere, far from the cold area surface. This force produces the effect called "thermophoresis force".

Figure 8 displays the heat transfer of Pr ("Prandtl Number") for both stretching and shrinking sheet. It is observed that the $Re_x^{-1/2}N_x$ ("Heat Transfer rate") boundary layer decreases for both present and absents of suction and injection cases. Here, the boundary layer of heat transfer rate is weaker when absents of suction case while comparing to injection case, because of the higher thermal conductivity of nanofluid flow with enlarge values of Pr and associate boundary layer thickness is very less.

Table 1 shows the evaluation of the skin friction coefficient $-f''(0)$ for $A = B = Bi = R_d = 0$, comparing the results from the present study with those of Sarah et al. [48], Nadeem et al. [49], Gupta and Sharma [50], and Ahmad et al. [51].

Table 2 presents a comparison of the skin friction coefficient $-f''(\infty)$ for $A = B = Bi = R_d = 0$, comparing the results from the present study with those of Nadeem et al. [49].

4 Conclusion

A numerical analysis has been executed for the nonlinear thermal radiation effect on 3D MHD (“Magnetohydrodynamic”) nanofluid flow via stretching/shrinking sheet with slip velocity. The main out comes of the present study are mentioned below:

- The nanofluid temperature enhances with enlarge values of nonlinear thermal radiation while opposite trend in concentration of the fluid flow.
- The heat transfer rate decline with increasing values of for both suction and injection cases because of higher thermal conduction in the flow of nanofluid on stretching/shirking surfaces.

Nomenclature
(x^*, y^*) Cartesian coordinate's
u_1, v_1, w_1 velocity components along x^*, y^*, z^*-axis
A Velocity slip along x-axes $\sqrt{\alpha\gamma_0}N_1$
B Velocity slip along y-axes $\sqrt{\alpha\gamma_0}N_2$
C^* Concentration
C_f^* Skin friction coefficient
C_p^* Specific heat
C_∞^* Uniform ambient concentration
D_B Brownian diffusion
D_T Thermophoresis diffusion
f Dimensionless stream function
f' Dimensionless velocity
S Constant mass flux parameter $w_0/\sqrt{\alpha_1\gamma_0}$
k^* Thermal conductivity
Le Lewis number $= \frac{\alpha_m^*}{D_B}$
M Magnetic field parameter $= \frac{\sigma_1 B_0^2}{a_1\rho_f}$
N_t Thermophoresis parameter $= \tau D_T\frac{T_w^*-T_\infty^*}{\alpha_m^* T_\infty^*}$
N_b Brownian motion coefficient $= D_B\tau\frac{(C_w^*-C_\infty^*)}{v_f}$
Pr Prandtl number $= \frac{v_1}{\alpha_m^*}$
q_r Radiative heat flux
Re_x Reynolds number
R_d Radiation parameter $= \frac{16\sigma^* T^{*3}}{3\alpha_m^* k k^*}$
T^* Temperature of the fluid
T_∞^* fluid temperature far away from the surface
T_w^* Constant fluid temperature of the wall
U_w Stretching velocity
U_∞ Free stream velocity
Greek symbols
ρ Density
φ Dimensionless concentration
σ_1 Boltzmann constant
λ Constant stretching/shrinking parameter $\frac{b_1}{a_1}$
τ Ratio of the nanoparticle to the fluid $\frac{(\rho c)_p}{(\rho c)_f}$
v_1 Kinematic viscosity of the fluid
σ^* Electrical conductivity
θ Dimensionless temperature
α_m^* Thermal diffusivity $= \frac{k}{(\rho c_p)_f}$
$(\rho c_p)_f$ Heat capacity of the fluid
$(\rho c_p)_p$ Heat capacity of the nanoparticle to the fluid
ρ_f Fluid density
Subscripts
∞ condition at free stream

Data Availability Statement

Data will be made available on request.

Funding

This work was supported without any funding.

Conflicts of Interest

The authors declare no conflicts of interest.

Ethical Approval and Consent to Participate

Not applicable.

References

[1] Day, E. A. (1990). The no-slip condition of fluid dynamics. *Erkenntnis, 33*, 285–296. [CrossRef]

[2] Beavers, G. S., & Joseph, D. D. (1967). Boundary conditions at a numerically permeable wall. *Journal of Mechanics, 30*, 197–207. [CrossRef]

[3] Thompson, P. A., & Troian, S. M. A. (1997). A general boundary condition for liquid flow at solid surfaces. *Nature, 389*, 360–362. [CrossRef]

[4] Madasu, K. P., Kaur, M., & Bucha, T. (2021). Slow motion past a spheroid implanted in a Brinkman medium: slip condition. *International Journal of Applied and Computational Mathematics, 7*(4), 162. [CrossRef]

[5] Abbas, S. Z., Farooq, S., Chu, Y. M., Chammam, W., Khan, W. A., Riachi, A., Rebei, H. A., & Zaway, M. (2021). Numerical study of nanofluid transport subjected to the collective approach of generalized slip condition and radiative phenomenon. *Arabian Journal for Science and Engineering, 46*, 6049–6059. [CrossRef]

[6] Malkin, A. Y., Patlazhan, S. A., & Kulichikhin, V. G. (2019). Physicochemical phenomena leading to slip of a fluid along a solid surface. *Russian Chemical Reviews, 88*(3), 319. [CrossRef]

[7] Besthapu, P., Haq, R. U., Bandari, S., & Al-Mdallal, Q. M. (2019). Thermal radiation and slip effects on MHD stagnation point flow of non-Newtonian nanofluid over a convective stretching surface. *Neural Computing and Applications, 31*(1), 207-217. [CrossRef]

[8] Nadeem, S., Ahmad, S., & Khan, M. N. (2020). Mixed convection flow of hybrid nanoparticle along a Riga surface with Thomson and Troian slip condition. *Journal of Thermal Analysis and Calorimetry, 143*, 2099–2109. [CrossRef]

[9] Wang, K., Chai, Z., Hou, G., Chen, W., & Xu, S. (2018). Slip boundary condition for lattice Boltzmann modeling of liquid flows. *Computers & Fluids, 161*, 60–73. [CrossRef]

[10] Mahabaleshwar, U. S., Anusha, T., Bég, O. A., Yadav, D., & Botmart, T. (2022). Impact of Navier's slip and chemical reaction on the hydromagnetic hybrid nanofluid flow and mass transfer due to porous stretching sheet. *Scientific Reports, 12*(1), 10451. [CrossRef]

[11] Aziz, A., & Jamshed, W. (2017). Unsteady MHD slip flow of non Newtonian power-law nanofluid over a moving surface with temperature dependent thermal conductivity. *Discrete and Continuous Dynamical Systems-S, 11*(4), 617-630. [CrossRef]

[12] Abbas, Z., & Sheikh, M. (2017). Numerical study of homogeneous–heterogeneous reactions on stagnation point flow of ferrofluid with non-linear slip condition. *Chinese Journal of Chemical Engineering, 25*, 11–17. [CrossRef]

[13] Nojoomizadeh, M., D'Orazio, A., Karimipour, A., Afrand, M., & Goodarzi, M. (2018). Investigation of permeability effect on slip velocity and temperature jump boundary conditions for FMWNT/Water nanofluid flow and heat transfer inside a microchannel filled by a porous media. *Physica E: Low-Dimensional Systems and Nanostructures, 97*, 226–238. [CrossRef]

[14] Farooq, S., Hayat, T., Alsaedi, A., & Ahmad, B. (2017). Numerically framing the features of second order velocity slip in mixed convective flow of Sisko nanomaterial considering gyrotactic microorganisms. *International Journal of Heat and Mass Transfer, 112*, 521–532. [CrossRef]

[15] Abd El-Aziz, M., & Afify, A. A. (2018). Influences of slip velocity and induced magnetic field on MHD stagnation-point flow and heat transfer of Casson fluid over a stretching sheet. *Mathematical Problems in Engineering, 2018*(1), 9402836. [CrossRef]

[16] Majeed, A., Zeeshan, A., & Hayat, T. (2019). Analysis of magnetic properties of nanoparticles due to applied magnetic dipole in aqueous medium with momentum slip condition. *Neural Computing and Applications, 31*(1), 189-197. [CrossRef]

[17] Nayak, M. K., Shaw, S., Pandey, V. S., & Chamkha, A. J. (2018). Combined effects of slip and convective boundary condition on MHD 3D stretched flow of nanofluid through porous media inspired by non-linear thermal radiation. *Indian Journal of Physics, 92*(8), 1017–1028. [CrossRef]

[18] Sharma, P. R., Choudhary, S., & Makinde, O. D. (2017). MHD slip flow and heat transfer over an exponentially stretching permeable sheet embedded in a porous medium with heat source. *Frontiers in Heat and Mass Transfer, 9*(18), 1–7.

[19] Ahmad, S., & Nadeem, S. (2021). Flow analysis by Cattaneo-Christov heat flux in the presence of Thomson and Troian slip condition. *Applied Nanoscience, 10*, 4673–4687. [CrossRef]

[20] Tarakaramu, N., Satya Narayana, P. V., Sivajothi, R., Bhagya Lakshmi, K., Harish Babu, D., & Venkateswarlu, B. (2022). Three-dimensional non-Newtonian couple stress fluid flow over a

permeable stretching surface with nonlinear thermal radiation and heat source effects. *Heat Transfer, 51*(6), 5348-5367. [CrossRef]

[21] Noor, N. A. M., Shafie, S., & Admon, M. A. (2021). Impacts of chemical reaction on squeeze flow of MHD Jeffrey fluid in horizontal porous channel with slip condition. *Physica Scripta, 96*(3), 035216. [CrossRef]

[22] Choi, S. U. S. (1995). Enhancing thermal conductivity of fluids with nanoparticles. In D. A. Singer & H. P. Wang (Eds.), *Developments and applications of non-Newtonian flows* (Vol. 231, pp. 99–105). American Society of Mechanical Engineers.

[23] Jagadeesh, S., krishna Reddy, M. C., Tarakaramu, N., Sivakumar, N., & Sivajothi, R. (2022). Nonlinear thermal radiation effect on 3D nanofluid flow with convective and slip condition via stretching/shrinking surface. [CrossRef]

[24] de Faoite, D., Browne, D. J., Chang-Díaz, F. R., & Stanton, K. T. (2012). A review of the processing, composition, and temperature-dependent mechanical and thermal properties of dielectric technical ceramics. *Journal of Materials Science, 47*(10), 4211-4235. [CrossRef]

[25] Hussain, A. R. J., Alahyari, A. A., Eastman, S. A., Thibaud-Erkey, C., Johnston, S., & Sobkowicz, M. J. (2017). Review of polymers for heat exchanger applications: Factors concerning thermal conductivity. *Applied Thermal Engineering, 113*, 1118-1127. [CrossRef]

[26] Choi, S. U. S., Zhang, Z. G., Yu, W., Lockwood, F. E., & Grulke, E. A. (2001). Anomalous thermal conductivity enhancement in nanotube suspensions. *Applied Physics Letters, 79*(14), 2252–2254. [CrossRef]

[27] Sreedevi, P., & Reddy, P. S. (2020). Combined influence of Brownian motion and thermophoresis on Maxwell three-dimensional nanofluid flow over stretching sheet with chemical reaction and thermal radiation. *Journal of Porous Media, 23*(4). [CrossRef]

[28] Eid, M. R., & Nafe, M. A. (2022). Thermal conductivity variation and heat generation effects on magneto-hybrid nanofluid flow in a porous medium with slip condition. *Waves in random and complex media, 32*(3), 1103-1127. [CrossRef]

[29] Satya Narayana, P. V., Tarakaramu, N., & Harish Babu, D. (2022). Influence of chemical reaction on MHD couple stress nanoliquid flow over a bidirectional stretched sheet. *International Journal of Ambient Energy, 43*(1), 4928-4938. [CrossRef]

[30] Jat, N., & Rajotia, D. (2014). Three-dimensional viscous flow and heat transfer due to a permeable shrinking sheet with heat generation/absorption. *Indian Journal of Pure and Applied Physics, 52*, 79–86.

[31] Bachok, N., Ishak, A., & Pop, I. (2010). Unsteady three-dimensional boundary layer flow due to a permeable shrinking sheet. *Applied Mathematics and Mechanics (English Edition), 31*(11), 1421–1428. [CrossRef]

[32] Yao, S., Fang, T., & Zhong, Y. (2011). Heat transfer of a generalized stretching/shrinking wall problem with convective boundary conditions. *Communications in Nonlinear Science and Numerical Simulation, 16*(2), 752–760. [CrossRef]

[33] Bachok, N., Ishak, A., & Pop, I. (2012). Unsteady boundary-layer flow and heat transfer of a nanofluid over a permeable stretching/shrinking sheet. *International Journal of Heat and Mass Transfer, 55*(7–8), 2102–2109. [CrossRef]

[34] Bhattacharyya, K., Uddin, M. S., & Layek, G. C. (2016). Exact solution for thermal boundary layer in Casson fluid flow over permeable shrinking sheet with variable wall temperature and thermal radiation. *Alexandria Engineering Journal, 55*(2), 1703–1712. [CrossRef]

[35] Najib, N., Bachok, N., Arifin, N. M., & Ali, F. M. (2018). Stability analysis of stagnation-point flow in a nanofluid over a stretching/shrinking sheet with second-order slip, soret and dufour effects: A revised model. *Applied Sciences, 8*(4), 642. [CrossRef]

[36] Khan, J. A., Mustafa, M., Hayat, T., & Alsaedi, A. (2014). On three-dimensional flow and heat transfer over a non-linearly stretching sheet: analytical and numerical solutions. *PloS one, 9*(9), e107287. [CrossRef]

[37] Murtaza, M. G., Tzirtzilakis, E. E., & Ferdows, M. (2018). Numerical solution of three dimensional unsteady biomagnetic flow and heat transfer through stretching/shrinking sheet using temperature dependent magnetization. *Archives of Mechanics, 70*(2), 161–185.

[38] Jusoh, R., Nazar, R., & Pop, I. (2018). Magnetohydrodynamic rotating flow and heat transfer of ferrofluid due to an exponentially permeable stretching/shrinking sheet. *Journal of Magnetism and Magnetic Materials, 465*, 365–374. [CrossRef]

[39] Wang, C. Y. (2008). Stagnation flow towards a shrinking sheet. *International Journal of Non-Linear Mechanics, 43*(5), 377–382. [CrossRef]

[40] Bachok, N., Ishak, A., & Pop, I. (2012). Boundary layer stagnation-point flow and heat transfer over an exponentially stretching/shrinking sheet in a nanofluid. *International Journal of Heat and Mass Transfer, 55*(25-26), 8122-8128. [CrossRef]

[41] Zangooee, M. R., Hosseinzadeh, K., & Ganj, D. D. (2022). Investigation of three-dimensional hybrid nanofluid flow affected by nonuniform MHD over exponential stretching/shrinking plate. *Nonlinear Engineering, 11*(1), 143-155. [CrossRef]

[42] Rahman, M. M., Roşca, A. V., & Pop, I. (2014). Boundary layer flow of a nanofluid past a permeable exponentially shrinking/stretching surface with second order slip using Buongiorno's model.

International Journal of Heat and Mass Transfer, 77, 1133-1143. [CrossRef]

[43] Bachok, N., Ishak, A., & Pop, I. (2011). Stagnation-point flow over a stretching/shrinking sheet in a nanofluid. *Nanoscale Research Letters, 6*(623), 1–10.

[44] Rehman, F. U., Nadeem, S., Rehman, H. U., & Haq, R. U. (2018). Thermophysical analysis for three-dimensional MHD stagnation-point flow of nano-material influenced by an exponential stretching surface. *Results in Physics, 8*, 316–323. [CrossRef]

[45] Thumma, T., Bég, O. A., & Kadir, A. (2017). Numerical study of heat source/sink effects on dissipative magnetic nanofluid flow from a non-linear inclined stretching/shrinking sheet. *Journal of Molecular Liquids, 232*, 159–173. [CrossRef]

[46] Nayak, M. K., Akbar, N. S., Tripathi, D., & Pandey, V. S. (2017). Three dimensional MHD flow of nanofluid over an exponential porous stretching sheet with convective boundary conditions. *Thermal Science and Engineering Progress, 3*, 133–140. [CrossRef]

[47] Brewster, M. Q. (1972). *Thermal radiative transfer properties*. Wiley.

[48] Sarah, I., Mondal, S., & Sibanda, P. (2015). Unsteady Casson nanofluid flow over a stretching sheet with thermal radiation, convective and slip boundary conditions. *Alexandria Engineering Journal, 55*(2), 1025–1035. [CrossRef]

[49] Nadeem, S., Haq, R. U., & Akbar, N. S. (2014). MHD three-dimensional boundary layer flow of Casson nanofluid past a linearly stretching sheet with convective boundary condition. *IEEE Transactions on Nanotechnology, 13*(1), 109–115. [CrossRef]

[50] Gupta, S., & Sharma, K. (2017). Numerical simulation for magnetohydrodynamic three dimensional flow of Casson nanofluid with convective boundary conditions and thermal radiation. *Engineering Computations, 34*(8), 2698–2722. [CrossRef]

[51] Ahmad, K., & Nazar, R. (2011). Magnetohydrodynamic three-dimensional flow and heat transfer over a stretching surface in a viscoelastic fluid is discussed. *Journal of Science and Technology, 3*(1), 1–14.

Nainaru Tarakaramu (Assistant Professor, Mohan Babu University) received the Ph.D. degree in Mathematics from Vellore Institute of Technology, Vellore, India. He is currently an Assistant Professor in the Department of Freshman, School of Liberal Arts and Sciences, Mohan Babu University, Sree Sainath Nagar, Tirupati, Andhra Pradesh 517102, India. His research interests include magnetohydrodynamic (MHD) flow, non-Newtonian fluid flows, and nanofluid dynamics. (Email: nainaru143@gmail.com)

Motamari Madhu (Assistant Professor, Palamuru University) received the Ph.D. degree in Mathematics from Mahatma Gandhi University, Nalgonda, India, in 2024. He is currently an Assistant Professor in the Department of Mathematics, University College, Palamuru University, Mahabubnagar, Telangana 509001, India. His research focuses on three-dimensional nanofluid flow, Casson fluid dynamics, and heat and mass transfer with thermal radiation. (Email: madhu.palamuru@gmail.com)

G. YuvaRoopa Lakshmi (Assistant Professor, Government Degree College for Women) received the Ph.D. degree in Mathematics from a recognized university in India. She is currently an Assistant Professor in the Department of Mathematics, Government Degree College for Women, Wanaparthy, Nandi Hills, Wanaparthy, Telangana 509103, India. Her research interests include intuitionistic Pythagorean fuzzy graphs and their applications in decision-making. (Email: yuvaroopalakshmi21@gmail.com)