RETRACTION

Retraction: MHD Darcy-Forchheimer flow of Casson nanofluid due to a rotating disk with thermal radiation and Arrhenius activation energy (J. Phys. Commun. 5 025008)

This article has been retracted by IOP Publishing following concerns from readers regarding potential errors in the work. This has been verified by a subject expert who agrees there are a number of technical errors in the equations (specifically equations 1–5 and 14) and analysis. In addition to these inaccuracies, IOP Publishing is concerned that the text contains tortured phrases [1], masking overlap to other published work by that of others [2–6], as well as similar results and figures previously published elsewhere by the authors [7].

IOP Publishing has investigated in line with the COPE guidelines and agree the work should be retracted as there is ‘clear evidence that the findings are unreliable, either as a result of major error (e.g., miscalculation or experimental error), or as a result of fabrication (e.g., of data) or falsification (e.g., image manipulation)’.

IOP Publishing wishes to credit the reader, anonymous subject expert and Problematic paper Screener for contributing to this investigation.

The authors have not responded to comment on whether they agree to this retraction.

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MHD Darcy-Forchheimer flow of Casson nanofluid due to a rotating disk with thermal radiation and Arrhenius activation energy

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Keywords: Arrhenius activation energy, rotating disk, thermal radiation, nanoparticles, magnetohydrodynamics (MHD), Casson fluid model

Abstract

In this research article, three-dimensional Casson nanofluid under influences of Arrhenius stimulation energy and thermal radiation is considered. The flow is induced by a turning disk. Temperature, velocity, and concentration slips at the outward of the turning disk are deliberated. The effect of Brownian movement and thermophoresis is examined due to the nanosized particles in a Casson fluid dispersed over the turning disk. The appropriate transformation methods for reducing a set of Partial differential equations (PDEs) to nonlinear Ordinary differential equations (ODEs) and further solved by the homotopy analysis method (HAM). Numerical simulation using Schmidt number, magnetic, Casson, Brownian movement, and thermophoresis parameters on outspread, temperature, tangential velocities, and nanoparticles are portrayed. Local Nusselt number, Skin friction, and Sherwood number are plotted and investigated. The graphical results show that the tangential velocity of nanofluids decreases because of an addition in Reynolds’ number, while the radial velocity displays the reverse patterns. The tangential and radial velocities reduce with the increment magnetic factor. It is also perceived that an augmentation in estimations of radiation parameters enhances the heat transfer rate. Increasing the values of non-dimensional activation energy raises the mass transfer rate.

Nomenclature

Symbol | Description
--- | ---
(r, φ, z) | Polar coordinates
C, C∞ | Concentration near and far away the surface respectively
k | Thermal conductivity
P | Pressure (dimensionless)
G, T | Concentration and temperature of the fluid respectively
(rp) | Effective heat capacity of nanoparticles
V = (u, v, w) | Velocity field
Pr | Prandtl number
Ec | Eckert number
Pr | Prandtl number
Sc | Schmidt number
M | Magnetic field constraint
Re | Reynolds number

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1. Introduction

Nanofluids have increased wonderful consideration from scientists because of their rousing warmth move in different modern and manufacturing applications. Basic working liquids, for example, water, ethylene glycol,
and motor oils have confined warm exhibitions which bound their use in cutting edge cooling solicitations. Nanofluids comprise nanoscale particles, for example, alumina, copper, metal oxides, carbon nanotubes, carbides, and nitrides which improve the warm conductivity of base liquids. These nanofluids have broad uses in present-day frameworks of warming and freezing, hybrid-powered engines, sunlight based cells, cancer therapy, and generation of new fuels, drug delivery, and medication. The major effort on nanofluid was structured by Choi [1] which was also got in altered behaviors. Because of these different uses of nanofluids, numerous investigations related to the progression of nanofluids have been led. For representation, Prasannakumara et al [2] have inspected the limit stratum stream and warmth move of liquid elements deferral with nanoparticles above a nonlinearly extending slip. The intriguing slip highlights of thermophoresis development and Brownian movement were inspected by Buongiorno [3]. The exceptional contour aspects of different nanoparticles over a warmed divider stream have been concentrated by Turkyilmazoglu [4]. Bhatti and Rashidi [5] incorporated the possible effects of bottle dissemination and warm contamination inflow of Williamson nanofluid over a permeable extending surface.

Further, magnetohydrodynamics (MHD) is a field of liquid mechanics that incorporates the marvels emerging when an attractive field is applied to an electrically leading liquid. The examination in the field of MHD grew exceptionally quick as of late (Davidson [6]). The investigation of stream and warmth move of an electrically leading liquid within the sight of a magnetic field past a warmed surface has applications in assembling procedures, for example, the nuclear reactor, cooling of the metallic plate, expulsion of polymers, and so on. The MHD stream in electrically leading liquid can control the pace of warmth move at the surface and subsequently wanted cooling impact can be accomplished. Xie and Jian [7] talked about the MHD two-layer electroosmotic flow with entropy age through small scale equal channels. Khan et al [8] inspected the 3D steady
MHD stream of Powell Eyring nanofluid with convective and nanoparticles mass flux circumstances. Ellahi et al [9] inspected warmth spread in a limit level stream with MHD and entropy age impacts. Jawad et al have [10] have explored entropy age and warmth move examination in MHD unsteady turning stream for watery deferrals of carbon nanotubes with nonlinear current emission and viscous dissemination impact.

The issue of the liquid stream over a pivoting circle is one of the classical problems in liquid mechanics, which has both hypothetical and pragmatic qualities. Numerous sorts of examination have been completed on flow over a turning plate in hypothetical orders and because of various pragmatic applications in certain zones, for example, electronic gadgets, pivoting apparatus, gas turbine rotors, turning air cleaning machines, food handling, precious stone development procedures, and clinical equipment, such stream is additionally significant in the industrial forms. The imaginative thought of a thin-film flow through a turning circle was first detailed by Emslie et al [11]. By seeing the stability between viscid and outward strength throughout the plate turn course permit them to streamline the leading conditions and presumed that the film consistency holds as it flimsy increasingly more ceaselessly. In the electrical business, the appropriateness of the turn covering procedure was investigated through exploratory translations and hypothetical examinations by Washo [12], Jenekhe [13] and Flack et al [14] broadened crafted by Emslie et al [11] by fusing the bulk exchange and non-Newtonian liquid models. The came about oily conditions were handled with a finite difference structure. Wang et al [15] concentrated arithmetically on the issue of the fluid thin film created above an accelerating pivoting plate. The asymptotic arrangement on account of values of quickening, slim and dense constraints was likewise
acquired. Andersson et al [16] gained the mathematical just as the asymptotic arrangement of fluid thin film stream because of a turning circle with attractive field impacts. The integration pattern is useful to tackle the streaming unruly because a pivoting plate including the alterations as recommended by von Karman [17] was analyzed by Cochran [18]. Mellor et al [19] considered the stream between a fixed and a turning plate, which clarifies that there can be numerous answers for Re according to their arithmetical calculation. The specific arithmetical result for the warmth interchange tool between two co-pivotal turning plates was clarified by Arora and Stokes [20]. Darcy–Forchheimer model for nanoliquids comprising CNTs as nanoparticles is used by Hayat et al [21] to clarify the stream designs because of the disk turn with partial slip. Selimefendigil et al [22] mathematically investigated the blended convective MHD CuO-nanoliquid move over an adaptable walled lid-driven enclosure in the presence of volumetric heat optimization by incorporating the impact of Brownian motion. Turkyilmazoglu [23] researched the arrangement of an electrically directing liquid stream and broadened the Karman viscid pump problem by captivating the stream over an outwardly extendible turning plate affected by a uniform vertical attractive impact and inspected the attractive consequences for the stream.

The consistent progression of an incompressible force law liquid because of a pivoting vast plate was concentrated by Ming et al [24]. Ali et al [25] examined the MHD mixed convective Cu-water nanoliquid flow because of a turning rounded cylinder through a trapezoidal container saturated with a permeable medium. Asma et al [26] have inspected magnetohydrodynamic viscous nanoliquid 3D stream by whirling plate with

Figure 5. Outcome of $F_1$ on $f(\xi)$.

Figure 6. Impact of $F_1$ on $g(\xi)$.
thermal immersion/generation, binary chemical response, and Arrhenius actuation vitality. Ahmed et al. [27] have thought unstable thin leading film of Maxwell nanofluid stream over a turning circle within the sight of nonlinear warm radiation, variable attractive field, and Joule heating. Tulu et al. [28] have considered CNTs with ethylene glycol nanofluid stream and warmth move because of the stretchable pivoting circle with the Cattaneo Christov heat flux model. Jawad et al. [29] have portrayed a 3D MHD nanofluid thin-film stream with warmth and mass exchange over a slanted permeable pivoting disk.

Gajjela et al. [30] presented a diverse convection stream of stagnation—point couple stress nanofluid with an extending cylinder. The effects of flexible thermal conductivity, viscous heating, and an inside heat source are furthermore examined. Magagula et al. [31] have investigated the double dispersed bioconvection phenomena for a Casson nanofluid flow over a nonlinearily stretching sheet. Nayaka et al. [32] have examined a fixed and active tactic on thermal study on Darcy–Forchheimer flow of copper–water nanofluid related with non-linear thermal radiation and entropy minimization because of a turning disk. Shaw et al. [33] have analyzed the Marangoni flow with microgravity and earth gravity, which causes undesirable effects in crystal growth experiments. Noor et al. [34] deliberated magnetohydrodynamic Casson nanofluid squeezing flow with velocity slip in a permeable medium under the effect of chemical reaction and viscous dissipation. Buongiorno’s nanofluid model is in this study. Noor et al. [35] explored an unsteady squeezing flow of magnetohydrodynamic...
(MHD) Casson nanofluid with thermal radiation, heat generation/absorption effects and chemical reaction. The effects of joule and viscous dissipation are also scrutinized.

The key purpose of the existing article is to discuss the three-dimensional Casson nanofluid under influences of Arrhenius stimulation energy and thermal radiation. The flow is induced by a turning disk. Temperature, velocity, and concentration slips at the outward of the turning disk are deliberated. Brownian motion and thermophoresis is assessed by seeing nanosized particles in a Casson fluid dispersed over the turning disk. We used appropriate transformations methods for reducing a set of Partial differential equations (PDEs) to nonlinear Ordinary differential equations (ODEs) which were further corroborated by the homotopy analysis method (HAM). Numerical perceptions using Schmidt number, magnetic, Casson, Brownian movement, and thermophoresis parameters focus on outspread, temperature, tangential velocities, and nanoparticle focus are portrayed.

2. Problem formulation

The present study investigates the MHD steady 3D progression of Casson nanoliquid has quipped above pivoting disk for \( z > 0 \). Thermal radiation impacts and Arrhenius activation energy are presented.

Brownian motion and thermophoretic impact additionally exist. Magnetic field \( \beta_0 \) is applied in \( z \)-direction (see figure 1). The velocity \( (u, v, w) \) is in the directions of \( (r, \varphi, z) \) correspondingly.
The governing equations of the said problem are:

\[ u_r + \frac{u}{r} + w_z = 0, \quad (1) \]

\[ \eta u_r + u u_z = \frac{v^2}{r} + \frac{1}{\rho_{nf}} \rho_r = \nu_{nf} \left( 1 + \frac{1}{\lambda} \right) \left( u_{rr} + \frac{1}{r} u_r - \frac{u}{r^2} + u_z \right) - \frac{\nu_{nf}}{k} u - F u^2 - \frac{\sigma_{nf} \beta_{nf}^2 u}{\rho_{nf}} + \frac{(\rho \beta)_{nf}}{\rho_{nf}} g(T - T_\infty), \quad (2) \]

\[ u v_r + w v_z + \frac{u v}{r} = \nu_{nf} \left( 1 + \frac{1}{\lambda} \right) \left( u_{rr} + \frac{1}{r} u_r - \frac{v}{r^2} + v_z \right) - \frac{\nu_{nf}}{k} v - F v^2 - \frac{\sigma_{nf} \beta_{nf}^2 v}{\rho_{nf}} + \frac{(\rho \beta)_{nf}}{\rho_{nf}} g(T - T_\infty), \quad (3) \]

\[ u w_r + w w_z + \frac{1}{\rho_{nf}} p_z = \nu_{nf} \left( 1 + \frac{1}{\lambda} \right) \left( w_{rr} + \frac{1}{r} w_r + w_z \right), \quad (4) \]
The BCs are [26]:

\[
\begin{align*}
& u = L_1u_z, \quad v = r\Omega + L_1v_z, \quad w = 0, \quad T = T_w + L_2T_z, \quad C = C_w + L_3C_z \quad \text{at} \quad z = 0, \\
& u \to 0, \quad v \to 0, \quad w \to 0, \quad T \to T_\infty, \quad C \to C_\infty \quad \text{at} \quad z \to \infty.
\end{align*}
\]

The variables for problem [26]

\[
\begin{align*}
& u = r\Omega'\phi(\xi), \quad w = -(2\Omega v)^2f(\xi), \quad v = -rG(\xi), \\
& \theta(\xi) = \frac{T - T_\infty}{T_w - T_\infty}\phi(\xi) = \frac{C - C_\infty}{C_w - C_\infty}, \quad \xi = \frac{2\Omega}{\nu}.
\end{align*}
\]

Using equation (8) in equations (1)–(6) take the form:

\[
2\left(1 + \frac{1}{\lambda}\right)f'' - 2(1 + F_1)f'f'' + 2ff'' + 2f - f'^2 - (k_1 + M)f'' = 0,
\]

\[
\frac{(1 - \Phi) + \frac{G_0\nu}{Re}\left(G_r + \frac{1}{Re}\right)}{(1 - \Phi) + \frac{G_0\nu}{Re}\left(G_r + \frac{1}{Re}\right)}\theta' = 0,
\]

\[
2\left(1 + \frac{1}{\lambda}\right)g'' - 2(f'g - fg') - \frac{(1 - \Phi) + \frac{G_0\nu}{Re}\left(G_r + \frac{1}{Re}\right)}{(1 - \Phi) + \frac{G_0\nu}{Re}\left(G_r + \frac{1}{Re}\right)}\theta' - (k_1 + M)g - F_1g^2 = 0,
\]

\[
\frac{1}{Pr}\left(1 + \frac{3}{2}R\right)\theta'' + \frac{N_f\theta'}{N_e}\theta' + N_f\theta'^2 + fl = 0,
\]

\[
\phi'' + Sc\phi f' + \frac{N_f\theta''}{N_e} = \frac{1}{2}Sc\sigma_1(1 + \delta\theta)\phi \exp\left(-\frac{E}{(1 + \delta\theta)}\right) = 0.
\]
3. Physical quantities of interest

The skin friction ($C_f$, $C_g$), Sherwood ($Sh$) and Nusselt numbers ($Nu$) are:

\[
C_f = \left(1 + \frac{1}{\lambda}\right)\frac{\mu u_x}{\mu_{\infty}}, \quad C_g = \left(1 + \frac{1}{\lambda}\right)\frac{\mu v_x}{\mu_{\infty}}.
\]

\[
Nu = \frac{q_w}{(T_w - T_\infty)}, \quad Sh = \frac{q_m}{(C_w - C_\infty)},
\]

Where $q_w$, $q_m$ are, wall heat flux and wall mass flux, respectively, and are given by

\[
q_w = -r \left(1 + \frac{16\sigma^2 T_\infty^2}{3k_\infty (\rho C_p)_\infty}\right)(T_x)_{x=0}, \quad q_m = -\gamma (C_x)_{y=0}
\]

Using equation (8), one obtains [30]

\[
Re^{1/2} C_f = \left(1 + \frac{1}{\lambda}\right) f''(0), \quad Re^{1/2} C_g = \left(1 + \frac{1}{\lambda}\right) g''(0), \quad Re^{1/2} Nu = \left(1 + \frac{3}{4} R\right) \theta'(0),
\]

\[
Re^{1/2} Sh = -\phi'(0)
\]

Where $Re_r = r \left(\frac{\alpha}{\lambda}\right)$ is the local Reynolds number.

4. Analytical method

An ideal analytical of homotopy analysis method (HAM) is implemented to obtain the solution for fluid velocity, temperature and concentration. Equations (9)–(12) with boundary conditions (13) are solved by HAM. For this point, we used the Mathematica programming. The initial conditions are selected as follows

\[
f_0(\xi) = 0, \quad g_0(\xi) = \frac{1}{2} \xi^2, \quad \theta_0(\xi) = \frac{1}{1 + \beta} e^{-\xi}, \quad \phi_0(\xi) = \frac{1}{1 + \gamma} e^{-\xi}
\]

The essential inference of the model equation is given below

\[
L_f (\bar{f}) = \bar{f}'' - f''(0), \quad L_g (\bar{g}) = \bar{g}'' - g''(0), \quad L_\theta (\bar{\theta}) = \bar{\theta}'' - \theta''(0), \quad L_\phi (\bar{\phi}) = \bar{\phi}'' - \phi''(0)
\]

$L_f$, $L_g$ and $L_\phi$ are suggested as

\[
L_f(e_1 + e_2 \zeta + e_3 e^{-\zeta} + e_4 e^{\zeta}) = 0, \quad L_g(e_5 e^{-\zeta} + e_6 e^{\zeta}) = 0, \quad L_\theta(e_7 e^{-\zeta} + e_8 e^{\zeta}) = 0,
\]

The non-linear operatives are rationally chosen as $N_{f_\theta}$, $N_{f_\phi}$, $N_{g_\theta}$ and $N_{g_\phi}$ and organize:

\[
N_f L_f (\bar{f}(\xi; \zeta)), \quad N_g L_g (\bar{g}(\xi; \zeta)), \quad N_\theta L_\theta (\bar{\theta}(\xi; \zeta)) = \frac{1}{2} \left(1 + \frac{1}{\lambda}\right) f_{\xi\xi\xi\xi} + 2f_{\xi\xi\xi} - 2(1 + F_1) f_{\xi\xi\xi} + 2g_{\xi\xi} - f_{\xi\xi} - \tilde{f}_k^2
\]

\[
- (k_1 + M) g_{\xi\xi} - \frac{(1 - \Phi) + \frac{\partial^2}{\partial \xi^2} (G_{r} / Re_r^2)}{(1 - \Phi) + \frac{\partial^2}{\partial \xi^2} (G_{r} / Re_r^2)} \bar{\theta}_{\xi\xi} = 0
\]

\[
N_f L_f (\bar{f}(\xi; \zeta)), \quad N_g L_g (\bar{g}(\xi; \zeta)), \quad N_\theta L_\theta (\bar{\theta}(\xi; \zeta)) = \frac{1}{2} \left(1 + \frac{1}{\lambda}\right) g_{\xi\xi} - 2(\bar{f}_\xi \xi - \bar{f}_\xi \xi) - (k_1 + M) \bar{g}
\]

\[
- (1 - \Phi) + \frac{\partial^2}{\partial \xi^2} (G_{r} / Re_r^2) \bar{\theta}_{\xi\xi} = 0
\]

\[
N_f L_f (\bar{f}(\xi; \zeta)), \quad N_g L_g (\bar{g}(\xi; \zeta)), \quad N_\theta L_\theta (\bar{\theta}(\xi; \zeta)) = \frac{1}{2} \left(1 + \frac{3}{4} R\right) \bar{\theta}_{\xi\xi} + N_b \bar{\phi}_{\xi\xi} + \frac{N}{N_b} \bar{\theta}_{\xi\xi} - \frac{1}{2} Sc_{r} (1 + \delta \theta) \phi \exp\left(-\frac{E}{1 + \delta \theta}\right)
\]

For equations (9)–(12) the 0th-order system is written as

\[
(1 - \zeta) L_f [\bar{f}(\xi; \zeta)] - \bar{f}_0(\xi)] = p h_f N_f [\bar{f}(\xi; \zeta)], \quad \bar{g}(\xi; \zeta), \quad \bar{\theta}(\xi; \zeta)
\]

\[
(1 - \zeta) L_g [\bar{g}(\xi; \zeta)] - \bar{g}_0(\xi)] = p h_g N_g [\bar{f}(\xi; \zeta)], \quad \bar{g}(\xi; \zeta), \quad \bar{\theta}(\xi; \zeta)
\]
Whereas BCs are:

\[
(1 - \zeta)L_0 \left[ \hat{\theta}(\xi; \zeta) - \theta_0(\xi) \right] = p h_0 N_0 \int \left[ \hat{f}(\xi; \zeta), \hat{\theta}(\xi; \zeta), \hat{\phi}(\xi; \zeta) \right]
\]

\[
(1 - \zeta)\Delta \hat{\theta}(\xi; \zeta) - \hat{\phi}_0(\xi) = p h_0 N_0 \left[ \hat{\phi}(\xi; \zeta), \hat{f}(\xi; \zeta), \hat{\theta}(\xi; \zeta) \right]
\]

While the implanting constraint is \( \zeta \in [0, 1] \), to regulate for the solution convergence \( h_\tilde{f}, h_\tilde{\theta} \) and \( h_\tilde{\phi} \) are utilized. When \( \zeta = 0 \) and \( \zeta = 1 \) we have:

\[\hat{f}(\xi; 1) = \hat{f}(\xi), \hat{g}(\xi; 1) = \hat{g}(\xi), \hat{\theta}(\xi; 1) = \hat{\theta}(\xi), \hat{\phi}(\xi; 1) = \hat{\phi}(\xi),\]

Enlarge the \( \hat{f}(\eta; \xi; \zeta), \hat{g}(\eta; \xi; \zeta), \hat{\theta}(\eta; \xi; \zeta)\) and \( \hat{\phi}(\eta; \xi; \zeta)\) over Taylor’s series for \( \zeta = 0\):

\[
\hat{f}(\xi; \zeta) = \hat{f}_0(\xi) + \sum_{n=1}^{\infty} \hat{f}_n(\xi) \zeta^n
\]

\[
\hat{g}(\xi; \zeta) = \hat{g}_0(\xi) + \sum_{n=1}^{\infty} \hat{g}_n(\xi) \zeta^n
\]

\[
\hat{\theta}(\xi; \zeta) = \hat{\theta}_0(\xi) + \sum_{n=1}^{\infty} \hat{\theta}_n(\xi) \zeta^n
\]

\[
\hat{\phi}(\xi; \zeta) = \hat{\phi}_0(\xi) + \sum_{n=1}^{\infty} \hat{\phi}_n(\xi) \zeta^n
\]

\[
\hat{f}_n(\xi) = \frac{1}{n!} \frac{\partial^{n+1} \hat{f}(\xi; \zeta)}{\partial \xi^{n+1}} \bigg|_{\zeta=0}, \hat{g}_n(\xi) = \frac{1}{n!} \frac{\partial^{n+1} \hat{g}(\xi; \zeta)}{\partial \xi^{n+1}} \bigg|_{\zeta=0}, \hat{\theta}_n(\xi) = \frac{1}{n!} \frac{\partial^{n+1} \hat{\theta}(\xi; \zeta)}{\partial \xi^{n+1}} \bigg|_{\zeta=0}, \hat{\phi}_n(\xi) = \frac{1}{n!} \frac{\partial^{n+1} \hat{\phi}(\xi; \zeta)}{\partial \xi^{n+1}} \bigg|_{\zeta=0}
\]

Figure 13. Outcome of \( N_0 \) on \( \theta(\xi) \).
Whereas BCs are:

\[ f(0) = 1, \quad f'(0) = \alpha f''(0), \quad \tilde{g}(0) = 1 + \gamma \tilde{g}', \]

\[ \tilde{\theta}(0) = 1 + \beta \tilde{\theta}'(0), \quad \tilde{\phi}(0) = 1 + \gamma \tilde{\phi}'(0) \]

\[ \tilde{\theta}'(\infty) = 0, \quad \tilde{f}'(\infty) = 0, \quad \tilde{g}(\infty) = 0, \quad \tilde{\theta}(\infty) = 0, \quad \tilde{\phi}(\infty) = 0, \]

Now

\[ R_\lambda' (\xi) = 2 \left( 1 + \frac{1}{\lambda} \right) f''_{n-1} - 2(1 + F_1) \sum_{j=0}^{w-1} f''_{w-1-j} f''_{j} + 2 \sum_{j=0}^{w-1} \tilde{f}_{w-1-j} f''_{j} + 2 \sum_{j=0}^{w-1} \tilde{g}_{w-1-j} \tilde{g}'_{j} - \tilde{f}^2_{n-1} \]

\[ - \frac{(1 - \phi) + \phi \frac{\rho}{\rho_u} \left( \frac{G_f}{R_e^2} \right) \tilde{\theta}'_{n-1} - (k_1 + M) \tilde{f}''_{n-1} \right), \]

\[ R_\tilde{\phi}' (\xi) = 2 \left( 1 + \frac{1}{\lambda} \right) \tilde{g}''_{n-1} - 2 \sum_{j=0}^{w-1} f''_{w-1-j} \tilde{g}_j - \sum_{j=0}^{w-1} \tilde{f}_{w-1-j} \tilde{g}'_{j} \]

(34)

(35)

(36)
\[
\phi^\alpha_\delta(\xi) = \frac{1}{\Pr\left(1 + \frac{2R}{4}\right)}\theta^{\nu}_{n-1} + N_b R_0 \sum_{j=0}^{w-1} \phi^j_{n-1-j} \theta^j_{n-1-j} + N_b \theta^{\nu^2}_{n-1} + \sum_{j=0}^{w-1} \theta^j_{n-1-j} \gamma_j
\]

(37)

\[
\phi^\beta_\delta(\xi) = \phi^\beta_{n-1} - Sc \sum_{j=0}^{\nu} \int_{\nu-j}^{\nu} \phi^j_{\nu-j} + \frac{N_b}{N_b} \theta^{\nu}_{n-1} - \frac{1}{2} Sc \sigma (\delta \theta^{\nu}_{n-1} + 1) \exp\left(\frac{E}{(\delta \theta^{\nu}_{n-1} + 1)}\right)
\]

(38)

While

\[\chi_n = \begin{cases} 0, & \text{if } n \leq 1 \\ 1, & \text{if } n > 1. \end{cases}\]

(39)

5. Results and discussions

The different outcomes of the current examination are displayed graphically.
5.1. Velocity distribution

Figure 1 denoted the schematic depiction of the flow problem. Figure 2 describes the variation of the spiral segments of velocity distribution for several Gr due to turning disk. This demonstrates velocity profiles expand with enlargement of Gr for both radiative nanofluids. Greater Gr accounts for the larger diversities of the comparative spiral velocity components compared with the smaller Gr case. Figure 3 illustrates the diversity of the tangential segment of $g(\xi)$ for nanoliquid past a whirling plate. It is perceived that $g(\xi)$ upsurges due to the development of Gr for nanoliquid. But, noteworthy relative $g(\xi)$ display as we transfer from the exterior of the plate towards the ambient liquid. Figure 4 depicts the $g(\xi)$ for nanofluid because of various qualities of the permeable matrix. Augmentations in $k_1$ produce a decrease in $g(\xi)$. Figure 5 shows the reaction of $f'(\xi)$ for different values of the inertia coefficient $F_1$ past a pivoting plate. It is uncovered from the figure that increases in $F_1$ a decrease $f'(\xi)$ for nanofluid. Nonetheless, the decaying of $f'(\xi)$ is bigger for higher $F_1$. Then, the comparative velocity of $f'(\xi)$ for nanofluid of concern for all $F_1$ is irrelevant. Elevated $F_1$ outcomes in easing $g(\xi)$ profiles all through the stream system. However, higher estimations of $F_1$ lead the bigger falls of $g(\xi)$ in figure 6. Figure 7 shows the distinctive highlights of $f'(\xi)$ for nanoliquid for different Re due to the pivoting disk. Obviously $f'(\xi)$ is a falling capacity of Re,. Figure 8 outlines the behavior of $g(\xi)$ for numerous Re, due to the prolonging of the whirling plate. This state $g(\xi)$ is an intensifying the volume of Re, for the two sorts of nanoliquid. Various estimations of Re, set up discrete layers of profiles of $g(\xi)$. Expanded Re, upgrades $g(\xi)$ for nanofluid.
Amplification is higher more prominent Re for nanofluid. The fairly bigger relative velocity of \( g(\xi) \) is attained for higher Re. Figures 9 and 10 are considered to scrutinize the effect of \( \lambda \) on CF. It is clear from these figures 9 and 10 that increasing the value of \( \lambda \) results in lessening liquid velocity which resist the fluid flow. As Casson factor approaches larger estimations, liquid jumps to act like a Newtonian fluid. Physically, an upsurge in \( \lambda \) means \( \lambda \to \infty \), a decline in the yield stress, hence a decrease in boundary layer thickness is noted.

### 5.2. Temperature profile \( \theta(\eta) \)

Figure 11 presents an assortment in the temperature field \( \theta(\eta) \) for contrasting Pr. Here \( \theta(\xi) \) is reduced through Pr. Advanced guesses of Pr yield progressively delicate updraft diffusivity which thinks about to a decline in thermal level. Temperature of the fluid diminishes for greater Pr because with a growing Pr the thermal diffusivity decreases. In fact, the particles are able to conduct less heat, and subsequently temperature declines. The impression of \( N_p \) on \( \theta(\xi) \) is delineated in figure 12. As the thermophoresis factor rises, the profiles jump stirring away from the boundary exemplifying a development in the thermal boundary layer thickness. Figure 13 portrays assortment in temperature \( \theta(\xi) \) for indisputable guesses of Brownian development \( N_p \). Physically an uneven motion of nanoparticles develops by growing Brownian movement constraint because of which collision of particles occurs. As an outcome, kinetic energy is altered into heat energy which causes augmentation in heat distribution and allied layer wideness. Figure 14 shows a graphical portrayal of the \( \theta(\xi) \) of

| \( k_1 \) | \( \lambda \) | Re | \( M \) | \( \varepsilon_f \) | \( f(\xi) \) | \( f'(\xi) \) | \( g(\xi) \) |
|---|---|---|---|---|---|---|---|
| 0.1 | 0.3 | 1 | 0.5 | 2 | 0.5011985 | 0.5081485 | 0.2941344 |
| 1.0 | 0.5071386 | 0.5071386 | 0.2931659 |
| 1.2 | 0.5001289 | 0.5001289 | 0.2922001 |
| 0.4 | 0.5177723 | 0.5177723 | 0.3046733 |
| 0.5 | 0.5081485 | 0.5081485 | 0.2941344 |
| 0.7 | 0.5752878 | 0.5752878 | 0.3488554 |
| 0.6 | 0.5456239 | 0.5456239 | 0.3546865 |
| 1.0 | 0.5277304 | 0.5277304 | 0.3701013 |
| 1.1 | 0.5022134 | 0.5022134 | 0.3000019 |
| 1.6 | 0.5012019 | 0.5012019 | 0.2990172 |
| 4 | 0.4919981 | 0.4919981 | 0.2809611 |
| 5 | 0.4943055 | 0.4943055 | 0.2828434 |

Figure 20. Impression of \( \delta \) on \( \phi(\xi) \) w.
radiative nanofluids for various radiation parameters R due to the spreading of the porous whirling plate. By upgrade of R expansions the non-dimensional liquid temperature θ(ξ), prompting rising related layers for nanofluid. For increasing values of R, θ(ξ) significantly increases for nanofluid.

5.3. Concentration profile φ(ξ)
Since figure 15, shows that the bigger Schmidt Sc displays decline in concentration φ(ξ). Figure 16 shows that how thermophoresis Ni impacts φ(ξ). By enlightening Ni, the φ(ξ) and connected layer are prolonged. Figure 17 depicts the influence of Brownian enlargement Nb on φ(ξ). It is obviously perceived that a decreasingly delicate φ (ξ) is conveyed by using a higher Brownian improvement Nb. Figure 18 elucidates the effect of non-dimensional E on concentration φ(ξ). An enhancement in actuation vitality E decays modified Arrhenius work \( (T^E)^{e^{-E_0/RT}} \). The Arrhenius activation energy is characterized as the minimum energy required beginning a chemical response and is for the most part meant by. It very well may be additionally characterized as the height of the potential obstruction (energy hindrance) isolating two minima of the possible energy of the products and reactants in a response. Figure 19. Shows the effect of chemical response factor on the concentration field. Chemical response upsurges the rate of interfacial mass transfer. The reaction decreases the local concentration, thus amassed the concentration gradient and its flux. As an outcome, the concentration of the chemical species in the boundary layer drops with an intensification in chemical reaction constraint. Figure 20 clarifies the effect of δ on φ(ξ). Here φ(ξ) is viewed as a reducing limit of δ.

6. Table discussions
Table 1 defined the influence of \( \lambda, M, \bar{k}, G, Re, \) axial velocity \( f'(\eta) \) and tangential velocity \( g(\eta) \). For growing estimation \( G, \) axial velocity \( f'(\eta) \) and tangential velocity \( g(\eta) \) are upsurges, for amassed estimation of \( Re, \) tangential components of velocity \( g(\eta) \) is upsurges and declines both \( f'(\eta) \) and \( g(\eta) \) for amassed estimations of \( \lambda, M, \bar{k}, \) for amassed approximation of \( Re, \) axial \( f'(\eta) \) is diminishes. Table 2 designates the effect of \( Pr, N_0, R \) on \( \theta(\eta) \). By cumulative estimations of \( Pr, N_0, \) R temperature are upsurges for \( N_0, R \) and decreases for \( Pr. \)

### Table 2: Effect of different physical constraints over temperature profile θ(ξ) when

| Pr | R | N_0 | θ(ξ)       |
|----|---|-----|------------|
| 2.5| 0.5| 0.1  | 0.2413839  |
| 3.5| 0.5| 0.1  | 0.2363087  |
| 4.5| 0.5| 0.1  | 0.2320797  |
|    | 1.0| 0.3  | 0.1863008  |
|    | 1.3| 0.4  | 0.1876480  |
|    | 1.5| 0.7  | 0.1885374  |

### Table 3: Effect of various physical factors over concentration profile φ(ξ) when \( \lambda = 0.2, F_1 = 0.3, k_1 = 0.4, M = 1.5, Re = 3, e_3 = 0.5, Pr = 0.7, R = 0.6, G = 2, Nb = 1, N_1 = 0.1, \alpha = 1, \beta = 1, \gamma = 1; \)

| \( \sigma_1 \) | \( \delta \) | \( S_c \) | \( E_b \) | \( \phi(\xi) \) |
|------|------|------|------|----------|
| 0.3  | 1.0  | 0.7  | 1.0  | 0.1365641 |
| 0.4  |      |      |      | 0.1343125 |
| 0.5  |      |      |      | 0.1312486 |
|      | 2.0  |      |      | 0.1363540 |
|      | 3.0  |      |      | 0.1165641 |
|      | 3.5  |      |      | 0.1067743 |
|      | 4.0  |      |      | 0.1349019 |
|      | 4.5  |      |      | 0.1310831 |
|      | 5.0  |      |      | 0.1212651 |
| 0.3  |      |      |      | 0.1404120 |
| 0.4  |      |      |      | 0.1596392 |
| 0.5  |      |      |      | 0.1688679 |
Table 3 displays the effect of $\text{Sc}_E$, $\beta$, $E$ on $\phi(\eta)$. For amassed estimations of $E$ concentration is an upsurge and declines for $\text{Sc}_E$. Table 4, examine the influence of $C_f$ and $C_g$ in the impact of different factors. The possessions of $l_M\Re_e$, $\tau$ upsurges the $C_f$ while $C_g$ is decreases function of $G\Re_e$. It is supposed that the amassed values of $M$, $\lambda$, $k_1$ upsurges the $C_g$ while $C_f$ is decreases function of $G\Re_e$. We have analyzed the variety of Nusselt and Sherwood numbers with their outcomes as appeared in tables 5 and 6. We can understand from these tables our results tie with present values from a constraining perspective. The trivial difference is because of the decision of the numerical method utilized in both efforts. Their estimations are acquired by utilizing an algorithm (shooting method with R-K scheme) while we have utilized the homotopy analysis method in Mathematica subject to Casson nanofluid stream actuated by the solid turning disk.

7. Conclusions

This article’s expected major results include:

Table 4. Influence of various physical factors over Skin friction $Re^{1/2}C_f = f''(0)$ and $Re^{1/2}C_g = g''(0)$ when $F_0 = 0.3$, $\epsilon_1 = 0.5$, $Pr = 1$, $N_b = 0.2$, $R = 0.5$, $N_t = 0.1$, $Sc = 0.6$, $\alpha = 1$, $\beta = 1$, $\gamma = 1$, $\sigma_1 = 1$, $\delta = 0.5$, $E_1 = 0.4$.

| $k_1$ | $\lambda$ | $Re_e$ | $M$ | $Gr$ | $f''(0)$ | $g''(0)$ |
|-------|-----------|--------|-----|------|----------|----------|
| 0.1   | 0.2       | 1.0    | 0.1 | 2.0  | 0.303666 | 0.614491 |
| 1.0   |           |        | 0.1 |      | 0.306890 | 0.615497 |
| 1.2   | 0.4       | 1.0    |     |      | 0.314098 | 0.617505 |
|       | 0.5       |        |     |      | 1.273120 | 0.633996 |
|       | 0.6       |        |     |      | 1.627693 | 0.623272 |
|       | 2.0       |        |     |      | 1.380366 | 0.614491 |
|       | 3.0       |        |     |      | 0.648585 | 0.639068 |
|       | 4.0       |        |     |      | 0.742143 | 0.630887 |
|       | 0.5       |        |     |      | 0.352308 | 0.620512 |
|       | 1.1       |        |     |      | 0.445780 | 0.649502 |
|       | 1.6       |        |     |      | 0.399236 | 0.668494 |
|       |           |        |     |      | 0.270072 | 0.399032 |
|       |           |        |     |      | 0.240445 | 0.401969 |
|       |           |        |     |      | 0.220845 | 0.400889 |

Table 5. Validation of result by comparisons of result for Nusselt number with past results.

| $\beta$ | $\gamma$ | $Pr$ | $M$ | $Nt$ | $Nu$ | $Re_e^{1/2}Nu = -\theta'(0)$ | $Re_e^{1/2}Nu = -\theta'(0)$ |
|---------|----------|------|-----|------|------|----------------------------|----------------------------|
|         |          |      |     |      |      | Present Result              | Past Result [30]            |
| 0.2     |          |      | 0.2 | 0.34662 | 0.32660 |
| 0.5     |          |      | 0.1 | 0.30365 | 0.30363 |
| 0.8     |          |      | 0.0 | 0.28727 | 0.28724 |
| 0.5     |          | 1.0  | 0.2 | 0.25000 | 0.24999 |
| 1.0     |          | 1.5  | 0.2 | 0.32929 | 0.32924 |
| 0.5     | 0.1      | 0.5  | 0.2 | 0.46189 | —             |
| 0.5     | 0.5      | 0.5  | 0.2 | 0.46258 | —             |
| 0.5     | 0.7      | 0.5  | 0.2 | 0.46327 | —             |
| 0.5     | 1.0      | 0.5  | 0.2 | 0.25918 | 0.25916 |
| 1.0     | 0.7      | 0.5  | 0.2 | 0.23880 | 0.23879 |
| 0.5     | 1.0      | 0.7  | 0.2 | 0.21026 | 0.21025 |
| 0.5     | 0.7      | 1.0  | 0.2 | 0.23680 | 0.23680 |
| 0.7     | 0.7      | 1.0  | 0.2 | 0.20069 | 0.20068 |

Table 3 displays the effect of $\text{Sc}_E$, $\sigma_1$, $\beta$, $E$ on $\phi(\eta)$. For amassed estimations of $E$ concentration is an upsurge and declines for $\text{Sc}_E$. Table 4, examine the influence of $C_f$ and $C_g$ in the impact of different factors. The possessions of $M$, $k_1$, $\lambda$, $G\Re_e$, $Re_e$ on skin friction for the dissimilar approximations are presented in table 4. It is observed that the growing values of $k_1$, $\lambda$, $M$, $Re_e$ upsurges the $C_f$, while $C_g$ is decreases function of $G\Re_e$. It is supposed that the amassed values of $M$, $\lambda$, $k_1$ upsurges the $C_g$, while $C_f$ is decreases function of $G\Re_e$. We have analyzed the variety of Nusselt and Sherwood numbers with their outcomes as appeared in tables 5 and 6. We can understand from these tables our results tie with present values from a constraining perspective. The trivial difference is because of the decision of the numerical method utilized in both efforts. Their estimations are acquired by utilizing an algorithm (shooting method with R-K scheme) while we have utilized the homotopy analysis method in Mathematica subject to Casson nanofluid stream actuated by the solid turning disk.
Higher Magnetic field show diminishing pattern for $f' (\xi)$ and $g (\xi)$.

Increases in values of $F_t$ represent a decreasing in $f' (\xi)$ and $g (\xi)$.

Higher values of $Gr$ express an increasing in $f' (\xi)$ and $g (\xi)$.

Increments in $Re$, represent a decreasing in $f' (\xi)$ and inverse impact for $g (\xi)$.

Advanced $Pr$ relates to more fragile temperature.

Concentration $\phi (\xi)$ is a diminishing component of higher $Sc$.

Greater $E$ displays more concentration $\phi (\xi)$.

Higher $R$ shows an increasing pattern for the $\phi (\xi)$.

Concentration $\phi (\xi)$ portrays diminishing conduct for bigger $\delta$ and $\sigma_1$.

Stronger temperature dissemination is perceived for $N_b$ and $N_t$.

Concentration $\phi (\xi)$ shows inverse behavior for $N_b$ and $N_t$.

Concentration $\phi (\xi)$ is a diminishing component of higher $Sc$.

Data availability statement

The data that support the findings of this study are available upon reasonable request from the authors.

Funding statement

The author(s) received no specific funding for this study.

Conflict of interest

The authors have no conflict of interest.

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