Modelling the impact of Temperature-Dependent Specific Heat capacity of $TiO_2 - CNTs - SiO_2$ Tri-Hybrid Casson Nanofluid for enhanced Solar Panels

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BEING A PAPER PRESENTED AT THE INTERNATIONAL CONFERENCE AND ADVANCED WORKSHOP ON MODELLING AND SIMULATION OF COMPLEX SYSTEMS

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Introduction

- Energy powers our movements, industries, and homes.

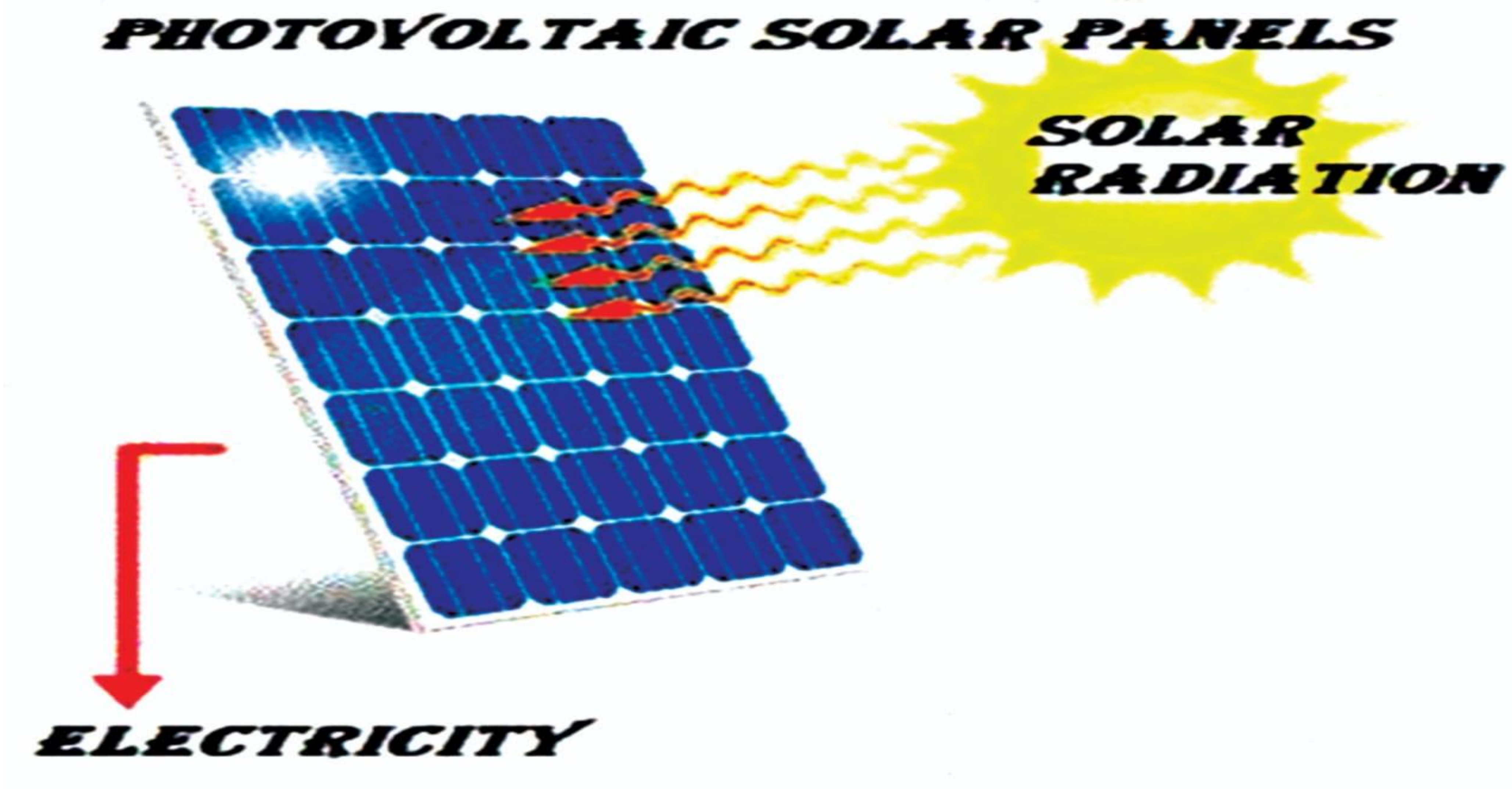
- Increasing energy demand due to population growth and economic development leads to reliance on fossil fuels, causing climate change.

- Global warming and rising fuel prices drive the shift towards renewable energy sources like solar, wind, and hydropower.

- Solar energy is crucial for generating electricity and powering various applications with zero greenhouse gases.

- **Challenges:** Weather variability, energy storage issues, and overheating reduce efficiency and battery lifespan.

Photovoltaic Solar Panels



Nanofluids as a solution to solar panel cooling

- Nanofluids enhance thermal conductivity and heat transfer performance.

- Hybrid nanofluids combine multiple nanoparticle types for superior thermal conductivity.

- Tri-hybrid nanofluid achieve remarkable heat transfer properties and are promising for cooling systems in various devices, including solar panels.

- **Challenges:** Nanoparticle stability, agglomeration, and optimizing thermophysical properties

Tri-Hybrid Casson Nanofluids for Solar Panel Heat Transfer

- 1. Combines Casson Fluid Properties: Shear-thinning behavior improves flow under high shear rates.

- 2. Enhanced Thermal Conductivity: Multiple nanoparticles (e.g., metal oxides, carbon nanotubes) significantly boost heat transfer.

- 3. Improved Efficiency: Better heat absorption and dissipation enhance solar panel performance.

- 4. Optimal Temperature Regulation: Maintains ideal operating temperatures for photovoltaic cells.

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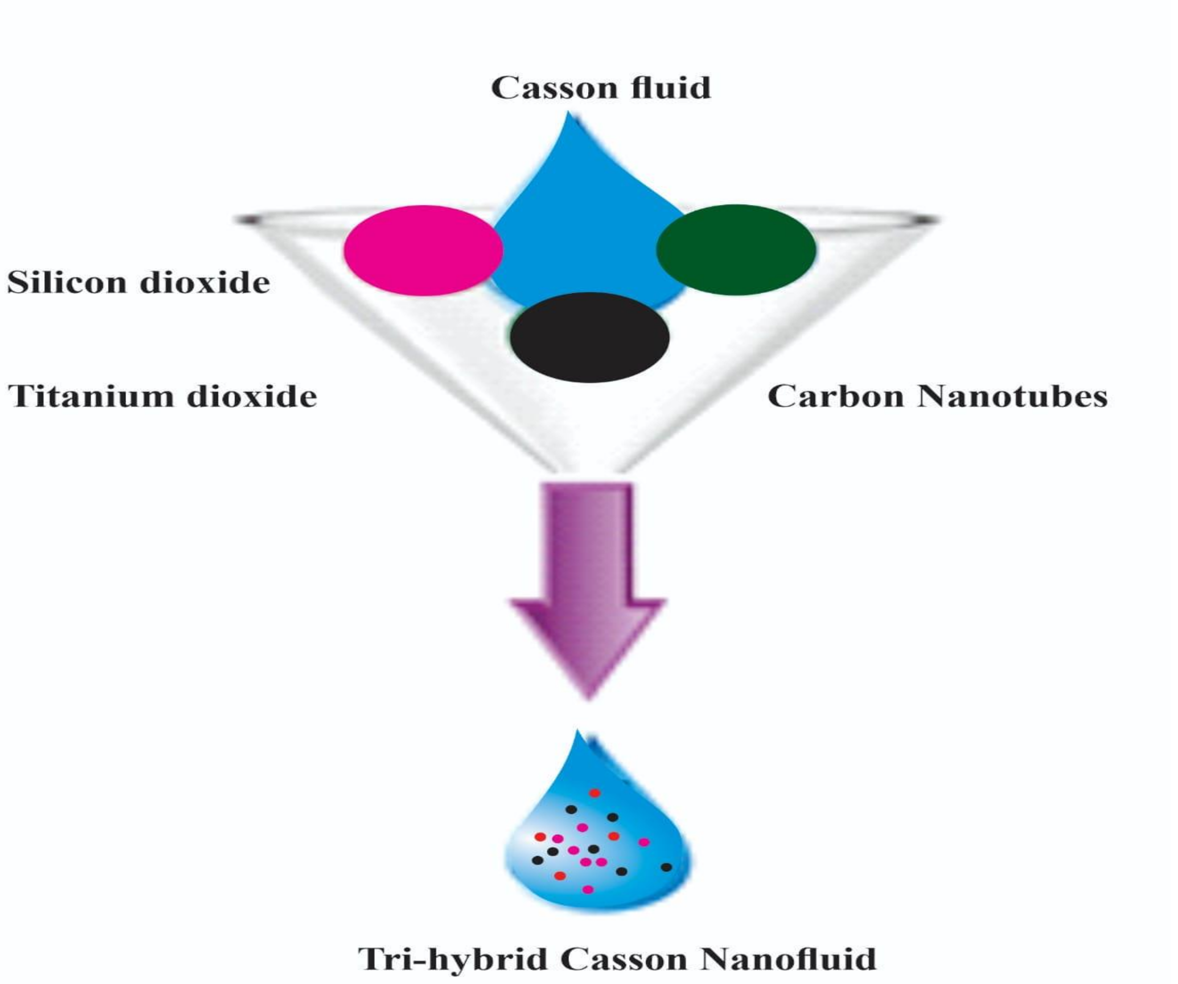
The choice of Nanoparticles

- The three nanoparticles includes Titanium dioxide, TiO_2 , Carbon Nanotubes (CNTs), and Silicon di oxide, SiO_2.

- The base fluid is **Casson fluid**

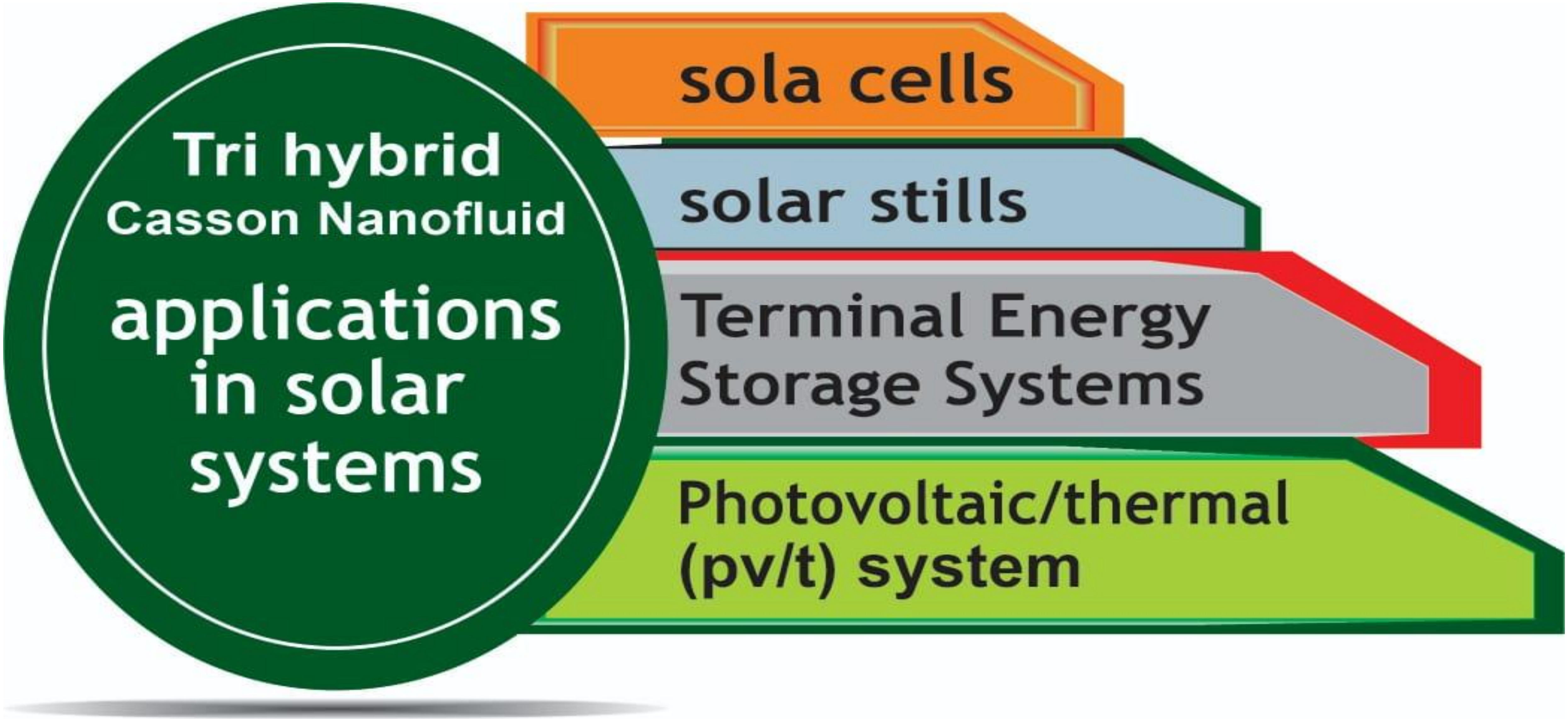
- **Why these three Nanoparticles?**
  - TiO_2 **:** enhances thermal conductivity,
  - CNTs : promote efficient photon absorption,
  - SiO_2 **:** aids in emission control.

What is Tri-Hybrid Casson Nanofluid?



Suspension of Three nanoparticles in Casson fluid

APPLICATION OF TRI-HYBRID CASSON NANOFLUID ON SOLAR PANELS



Motivation and Research gap of this study

- **MOTIVATION:**

Researchers aim to improve convective heat transfer rates in solar panels using Tri-Hybrid Casson nanofluids, which are crucial for enhancing photovoltaic efficiency.

- **RESEARCH GAP:**

While previous studies have explored the effects of various properties like thermal conductivity, viscosity, and density of Tri-Hybrid nanofluids on solar panel performance, limited research has been conducted on specific heat capacity, especially considering the variable temperature-dependent aspect.

AIM AND NOVELTY OF THE WORK

- **AIM:**

This research aims to bridge this gap by investigating the modeling impact of temperature-dependent specific heat capacity of Tri-Hybrid Casson Nanofluid on solar panel performance.

- **NOVELTY:**

The novelty of this work lies not only in incorporating the variable temperature-dependent specific heat capacity but also in its focus on a unique Tri-hybrid Casson nanofluid formulation with promising properties for solar panel applications.

OBJECTIVES

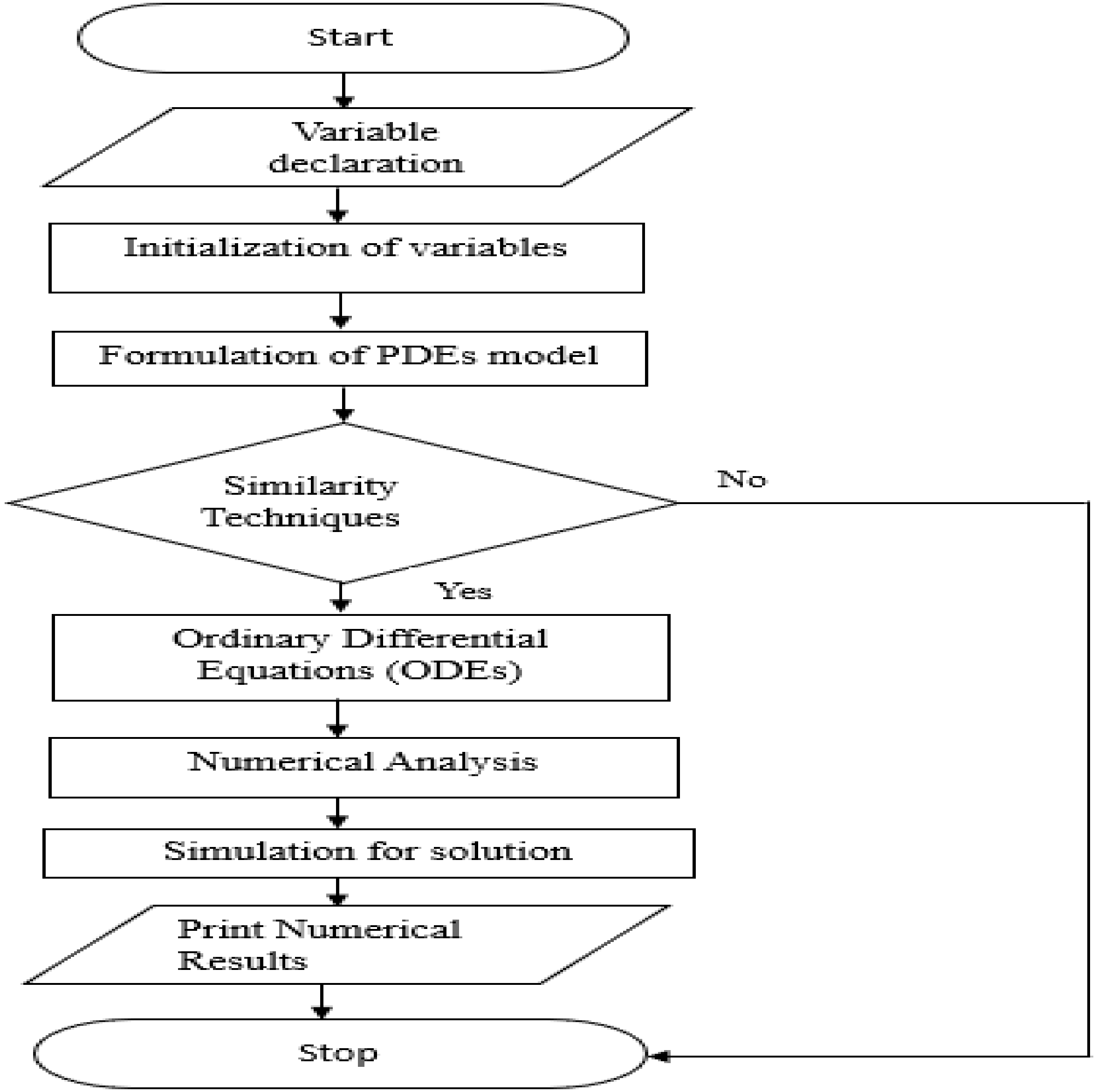
THE SPECIFIC OBJECTIVES OF THIS WORK ARE TO:

1. formulate a model of the governing Partial Differential Equations (PDEs) and transform them into a system of Ordinary Differential Equations (ODEs) using similarity techniques.

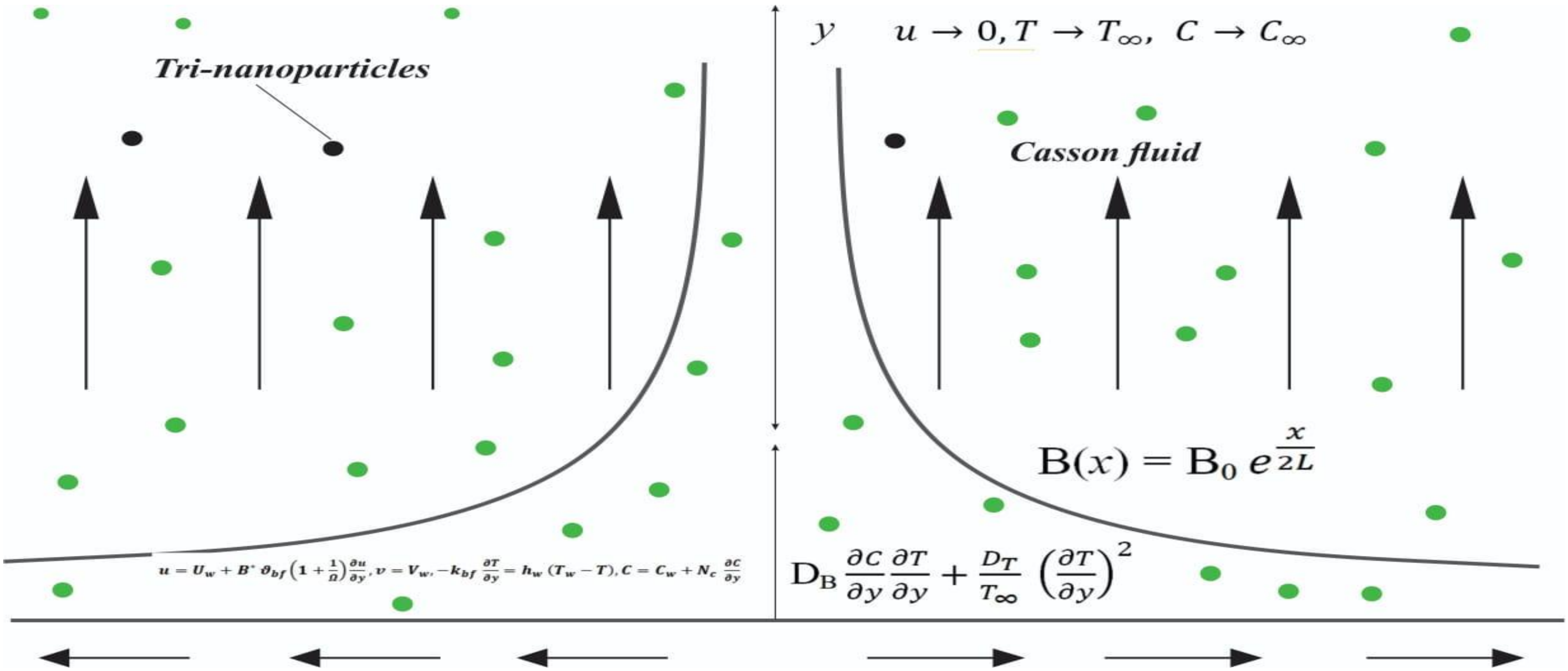
2. solve the ODEs numerically using the Runge-Kutta method of the 4th order alongside the shooting method with the aid of Maple 18.0 software.

3. investigate the effect of the thermophysical parameters of Tri-Hybrid nanofluid on the skin friction, Nusselt number, and Sherwood number, also, on the velocity, temperature and concentration profile.

FLOWCHART OF THE STUDY



Description of the problem



Assumptions

The flow of electrically conducting 2D Tri-Hybrid Casson Nanofluid on exponentially shrinking/stretching surface.

It is considered by incorporating:

- Variable temperature-dependent specific heat capacity,
- magnetic field, and
- thermal radiation.

Mathematical modelling of the problem

- $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad (1)$$
- $$u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = \frac{\mu_{TriNf}}{\rho_{TriNf}}\left(1 + \frac{1}{\Omega}\right)\frac{\partial^2 u}{\partial y^2} - \frac{\sigma^* {B_0}^2 u}{\rho_{TriNf}} \qquad (2)$$
- $$u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} = k_{TriNf}\,\frac{\partial}{\partial y}\left(\frac{1}{\left(\rho C_p\right)_{TriNf}(T)}\frac{\partial T}{\partial y}\right) - \frac{1}{\left(\rho C_P\right)_{TriNF}(T)}\frac{\partial \overline{q_r}}{\partial y} + \tau_w\left[D_B\frac{\partial C}{\partial y}\frac{\partial T}{\partial y} + \frac{D_T}{T_\infty}\left(\frac{\partial T}{\partial y}\right)^2\right] \qquad (3)$$
- $$u\frac{\partial C}{\partial x} + v\frac{\partial C}{\partial y} = D_B\frac{\partial^2 C}{\partial y^2} + \frac{D_T}{T_\infty}\frac{\partial^2 T}{\partial y^2} \qquad (4)$$

Boundary conditions

- $u = U_w + B^* \nu_{bf}\left(1+\frac{1}{\Omega}\right)\frac{\partial u}{\partial y}, v = V_w, -k_{bf}\frac{\partial T}{\partial y} = h_w\left(T_w - T\right), C = C_w + N_C \frac{\partial C}{\partial y}$ at y=0 (5)

- $u \to 0, T \to T_\infty, C \to C_\infty$ as $y \to \infty$ (6)

- $\overline{q_r} = -\frac{4\sigma^*}{3k^*}\frac{\partial T^4}{\partial y}$ (7)

- $T^4 \approx 4T_\infty^3 T - 3T_\infty^4$ (8)

- $\frac{\partial \overline{q_r}}{\partial y} = -\frac{16\sigma^* T_\infty^3}{3k^*}\frac{\partial^2 T}{\partial y^2}$ (9)

Properties of Tri-hybrid nanofluids

- The properties of Tri-hybrid nanofluids are defined by [22,23] as:
-
$$\left.\begin{aligned}
\mu_{TriNf} &= \frac{\mu_{bf}}{(1-\phi_{Np1})^{2.5}(1-\phi_{Np2})^{2.5}(1-\phi_{Np3})^{2.5}} \\
\rho_{TriNf} &= \rho_{bf}\left(\left(1-\varphi_3\right)\left\{\left(1-\varphi_2\right)\left[(1-\varphi_1)+\varphi_1\frac{\rho_{Np1}}{\rho_{bf}}\right]+\varphi_2\frac{\rho_{Np2}}{\rho_{bf}}\right\}+\varphi_3\frac{\rho_{Np3}}{\rho_{bf}}\right) \\
(\rho C_p)_{TriNf} &= (\rho C_p)_{bf}\left(\left(1-\varphi_3\right)\left\{\left(1-\varphi_2\right)\left[(1-\varphi_1)+\varphi_1\frac{(\rho C_p)_{Np1}}{(\rho C_p)_{bf}}\right]+\varphi_2\frac{(\rho C_p)_{Np2}}{(\rho C_p)_{bf}}\right\}+\varphi_3\frac{(\rho C_p)_{Np3}}{(\rho C_p)_{bf}}\right) \\
\frac{K_{TriNF}}{K_{hNF}} &= \frac{(k_{Np3}+2k_{hNFF})-2\phi_{Np3}(k_{hNF}-k_{Np3})}{(k_{Np3}+2k_{hNF})+\phi_{Np3}(k_{hNF}-k_{Np3})}
\end{aligned}\right\} \quad (10)$$

- The temperature dependent specific heat capacity of Tri-hybrid nanofluid is given as:
-
$$(\rho C_p)_{TriNf}(T) = (\rho C_p)_{bf}(T)\left(\left(1-\varphi_3\right)\left\{\left(1-\varphi_2\right)[(1-\varphi_1)+\varphi_1\frac{(\rho C_p)_{Np1}}{(\rho C_p)_{bf}}]+\varphi_2\frac{(\rho C_p)_{Np2}}{(\rho C_p)_{bf}}\right\}+\varphi_3\frac{(\rho C_p)_{Np3}}{(\rho C_p)_{bf}}\right) \quad (11)$$

Temperature-dependent Specific heat capacity

- where the variable temperature dependent specific heat capacity of base fluid can be given as:
- $$\left(\rho C_p\right)_{bf}(T)=\left(\rho C_p\right)_{bf}\left[1+c\left(T-T_\infty\right)\right] \qquad (12)$$
- $$\left(\rho C_p\right)_{bf}(T)=\left(\rho C_p\right)_{bf}\left[1+c(T_w-T_\infty)\theta(\eta)\right] \qquad (13)$$
- $$\left(\rho C_p\right)_{bf}(T)=\left(\rho C_p\right)_{bf}\left[1+\delta\theta(\eta)\right] \qquad (14)$$
- where;

$$\delta=c(T_w-T_\infty)$$

- is the variable temperature-dependent specific heat capacity parameter

Similarity Techniques

The similarity solution of equations (1) –(6) is achieved by defining the independent variable η, a stream function ψ, in terms of dependent variables $f(\eta)$, $\theta(\eta)$, and $g(\eta)$ as:

$$\left.\begin{aligned} &\psi = \sqrt{2\nu_{bf} Lb}e^{\frac{x}{2l}} f(\eta), \eta = y\sqrt{\frac{b}{2\nu_{bf} L}}e^{\frac{x}{2l}}, \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}, g(\eta) = \frac{C - C_\infty}{C_w - C_\infty} \\ &u = \frac{\partial \psi}{\partial y} = be^{\frac{x}{L}} f'(\eta), v = -\frac{\partial \psi}{\partial x} = -\sqrt{\frac{\nu_{bf} b}{2L}}e^{\frac{x}{2L}} f(\eta) - \frac{by}{2L}e^{\frac{x}{L}} f'(\eta) \end{aligned}\right\} \quad (15)$$

Equation (1) is satisfied automatically

Coupled Nonlinear Ordinary Differential Equations

$$\frac{\Delta_1}{\Delta_2}\left(1+\frac{1}{\Omega}\right)f''' + ff''(\eta) - 2\left(f'\right)^2 - \frac{Ha}{\Delta_2} f'(\eta) = 0 \qquad (16)$$

$$\frac{\Delta_4}{\Delta_3 \Pr}\left(\frac{\theta''}{(1+\delta\theta)} - \frac{\delta(\theta')^2}{(1+\delta\theta)^2}\right) + \frac{\theta''}{\Pr(1+\delta\theta)\Delta_3} Ra + f\theta' + N_B\phi'\theta' + N_T\left(\theta'\right)^2 = 0 \qquad (17)$$

$$\phi'' + Scf\phi' + \frac{N_T}{N_B}\theta'' = 0 \qquad (18)$$

The initial/boundary conditions

$$f(0) = S_u,\; f'(0) = \alpha + \lambda\left(1 + \frac{1}{\Omega}\right) f''(0), \theta'(0) = -Bi\left[1 - \theta(0)\right],$$

at $\eta = 0$ (19)

$$\phi(0) = 1 + \Psi g'(0)$$

$$f'(\eta) \to 0, \theta(\eta) \to 0, \phi(\eta) \to 0 \qquad (20)$$

The values of the unknowns

The resulted thermophysical parameters

$$\Delta_1 = \frac{1}{(1-\varphi_1)^{2.5}(1-\varphi_2)^{2.5}(1-\varphi_3)^{2.5}}, \Delta_2 = (1-\varphi_3)\left\{(1-\varphi_2)\left[(1-\varphi_1)+\varphi_1\frac{\rho_{Np1}}{\rho_{bf}}\right]+\varphi_2\frac{\rho_{Np2}}{\rho_{bf}}\right\}+\varphi_3\frac{\rho_{Np3}}{\rho_{bf}}$$

$$\Delta_3 = (1-\varphi_3)\left\{(1-\varphi_2)\left[(1-\varphi_1)+\varphi_1\frac{(\rho C_p)_{Np1}}{(\rho C_p)_{bf}}\right]+\varphi_2\frac{(\rho C_p)_{Np2}}{(\rho C_p)_{bf}}\right\}+\varphi_3\frac{(\rho C_p)_{Np3}}{(\rho C_p)_{bf}}$$

$$\Delta_4 = \left(\frac{(k_{Np1}+2k_{bf})-2\varphi_1(k_{bf}-k_{Np1})}{(k_{Np1}+2k_{bf})+\varphi_1(k_{bf}-k_{Np1})}\right)\left(\frac{(k_{Np2}+2k_{NF})-2\varphi_2(k_{hNF}-k_{Np2})}{(k_{Np2}+2k_{NF})+\varphi_2(k_{NF}-k_{Np2})}\right)\left(\frac{(k_{Np3}+2k_{hNFF})-2\varphi_3(k_{hNF}-k_{Np3})}{(k_{Np3}+2k_{hNF})+\varphi_3(k_{hNF}-k_{Np3})}\right)$$

The skin friction, Nusselt number, and Sherwood number

The skin friction, Nusselt number, and Sherwood number are the physical quantities of interest and are given as:

$$C_{fx} = \frac{\mu_{TriNf}\left(1+\frac{1}{\Omega}\right)}{\rho_{bf} b^2 e^{\frac{3x}{2L}}} \left.\frac{\partial u}{\partial y}\right|_{y=0}$$

- $$Nu = \frac{-k_{TriNf} L}{k_{bf}(T_w - T_\infty) e^{\frac{x}{2L}}} \left.\frac{\partial T}{\partial y}\right|_{y=0} \quad (21)$$
- $$S_h = \frac{-L}{(C_w - C_\infty) e^{\frac{x}{2L}}} \left.\frac{\partial C}{\partial y}\right|_{y=0}$$

- After differentiation equation (21) becomes:

$$C_{fx}\sqrt{2\,\mathrm{Re}_x} = \frac{1}{\left(1-\varphi_1\right)^{2.5}\left(1-\varphi_2\right)^{2.5}\left(1-\varphi_3\right)^{2.5}}\left(1+\frac{1}{\Omega}\right)f''(0)$$

- $$Nu\sqrt{\frac{2}{\mathrm{Re}_x}} = -\frac{k_{TriNf}}{k_{bf}}\theta'(0) \qquad (22)$$

$$S_h\sqrt{\frac{2}{\mathrm{Re}_x}} = -g'(0)$$

Numerical analysis

- **Importance of Numerical Methods:**

  Essential for scientific and engineering disciplines

  Analytical solutions often elusive for complex Boundary Values Problems

- **Challenges with Boundary Values Problems:**

  Traditional analytical techniques often inadequate

- **Common Numerical Methods:**

  - Fourth-order Runge-Kutta method
  - Runge-Kutta Fehlberg 45 (RK45) method
  - Adams-Bashforth method
  - Finite difference method
  - Finite element method

Shooting Method

- **Shooting Method:**

  - Robust approach for coupled nonlinear BVPs

  - Converts BVPs to initial value problems (IVPs)

  - Iteratively refines guessed initial conditions

  - Ensures solution meets boundary constraints

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Numerical method cont’d

The above coupled nonlinear third-order ordinary differential equations are reduced into a system of first order ordinary differential equations (ODEs) by letting:

$$f = n_1,\ f' = n_1{}' = n_2,\ f'' = n_2{}' = n_3,\ f''' = n_3{}' = n_4, \theta = n_5, \theta' = n_5{}' = n_6, \theta'' = n_6{}' = n_7, g = n_8$$
$$g' = n_8{}' = n_9, g'' = n_9{}' = n_{10} \tag{23}$$

Substituting the equation (23) into equations (16)-(20) give the required system of first order ODEs as:

- $$f''' = {n_3}' = n_4 = \frac{2\Delta_2}{\Delta_1\left(1+\frac{1}{\Omega}\right)}(n_2)^2 + \frac{Ha}{\Delta_1\left(1+\frac{1}{\Omega}\right)}n_2 - \frac{\Delta_2}{\Delta_1\left(1+\frac{1}{\Omega}\right)}n_1 n_3 \qquad (24)$$

- $$\theta'' = {n_6}' = n_7 = \frac{\Delta_4\delta}{(\Delta_4+Ra)(1+\delta n_5)}(n_6)^2 - \frac{\Delta_3(1+\delta n_5)}{(\Delta_4+Ra)}\Pr n_1 n_6 - \frac{\Delta_3(1+\delta n_5)}{(\Delta_4+Ra)}\Pr N_B n_9 n_6 - \frac{\Delta_3(1+\delta n_5)}{(\Delta_4+Ra)}\Pr N_T (n_6)^2 \qquad (25)$$

$$\phi'' = {n_9}' = n_{10} = -Sc n_1 n_9 - \frac{N_T}{N_B}n_7 \qquad (26)$$

Numerical method cont'd

$$n_1(0)=S_u, n_2(0)=\alpha+\lambda\left(1+\frac{1}{\Omega}\right)a, n_3(0)=a, n_5(0)=b, n_6(0)=-Bi[1-b],$$

$$n_8(0)=1+\Psi c, n_9(0)=c$$

The shooting method is used to guess the unknowns $a, b,$ and c until the boundary conditions $n_2(\infty), n_5(\infty),$ and $n_8(\infty)$ are satisfied. The resulting differential equations are solved numerically using the 4th order Runge-Kutta method.

Results and Discussions

Table 1: The Thermophysical properties of Casson fluid, and nanoparticles, (TiO_2, SiO_2 and CNTs) [37].				
Thermophysical Properties	Casson fluid $C_6H_9NaO_7$	TiO_2	SiO_2	CNTs
Thermal conductivity, (W/mk)	0.6376	8.9568	36	6600
Specific Heat Capacity, ($J.kg^{-1}k^{-1}$)	4175	686.2	765	425
Density, (Kg/ m^3)	989	4250	3970	2600

Results of Numerical method

In order to validate the correctness of this study the values of $f''(0)$, $-\theta'(0)$, and $-g'(0)$ were compared with the work of [1] and excellent agreement was established.

Table 2: Comparison with [1] for Pr = 6.2, $Ra = \delta = Sc = S_u = 0, \Omega = \infty$, $N_B = 0.1$

N_T	Work of [1] $f''(0)$	Present work $f''(0)$	Work of [1] $-\theta'(0)$	Present work $-\theta'(0)$	Work of [1] $-g'(0)$	Present work $-g'(0)$
0.1	-1.28180857	-1.28124179	0.25373483	0.25317044	0.37525393	0.37535393
0.2	-1.28180857	-1.28124179	0.25191726	0.25194002	0.20422841	0.29314672
0.3	-1.28180857	-1.28124179	0.25007701	0.25000529	0.03660735	0.03761834
0.4	-1.28180857	-1.28124179	0.24821431	0.24822423	-0.1275704	-0.12762371
0.5	-1.28180857	-1.28124179	0.24632921	0.24632848	-0.2882678	-0.28923355

Result and discussion

Table 3: Impact of Variable Specific heat capacity, δ , on $f''(0)$, $-\theta'(0)$, and $-g'(0)$

δ	$f''(0)$	$-\theta'(0)$	$-g'(0)$
0.05	- 0.146139249388517	1.52528741156937	- 0.580452428264102
0.1	- 0.146139249388215	1.56372271766941	- 0.614171468055997
0.5	- 0.146139249387869	1.83449564070648	- 0.852057072534243
1.0	- 0.146139249387676	2.10666386278441	- 1.09166714124498
Slope	**7.84369E-13**	**0.612852162**	**-0.538890398**

Result and discussion

Table 4: Effect of Thermal Radiation, Ra on $f''(0)$, $-\theta'(0)$, and $-g'(0)$			
Ra	$f''(0)$	$-\theta'(0)$	$-g'(0)$
0.5	- 0.146139249392372	1.25782516007649	- 0.348803216534943
1.0	- 0.146139249399646	1.06827684439477	- 0.185589731477336
3.0	- 0.146139249462864	0.703477537747997	0.128807741903066
5.0	- 0.146139249456675	0.547066217410380	0.268165579581688
Slope	**-1.59883E-11**	**-0.153819157**	**0.133488189**

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Result and discussion

Table 5: Effect of Casson parameter, Ω, on $f''(0)$, $-\theta'(0)$ and $-g'(0)$			
Ω	$f''(0)$	$-\theta'(0)$	$-g'(0)$
0.5	- 0.146139249388517	1.52528741156937	- 0.580452428264102
1.0	-0.199721438431961	1.53685311826791	- 0.597481889444215
3.0	- 0.273925515780488	1.54822224925624	-0.623153963390784
5.0	- 0.297521408058996	1.55105959357199	-0.631090133375942
Slope	**-0.0318084**	**0.005208544**	**-0.010734733**

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Effect of variation of thermophysical parameters on temperature profile

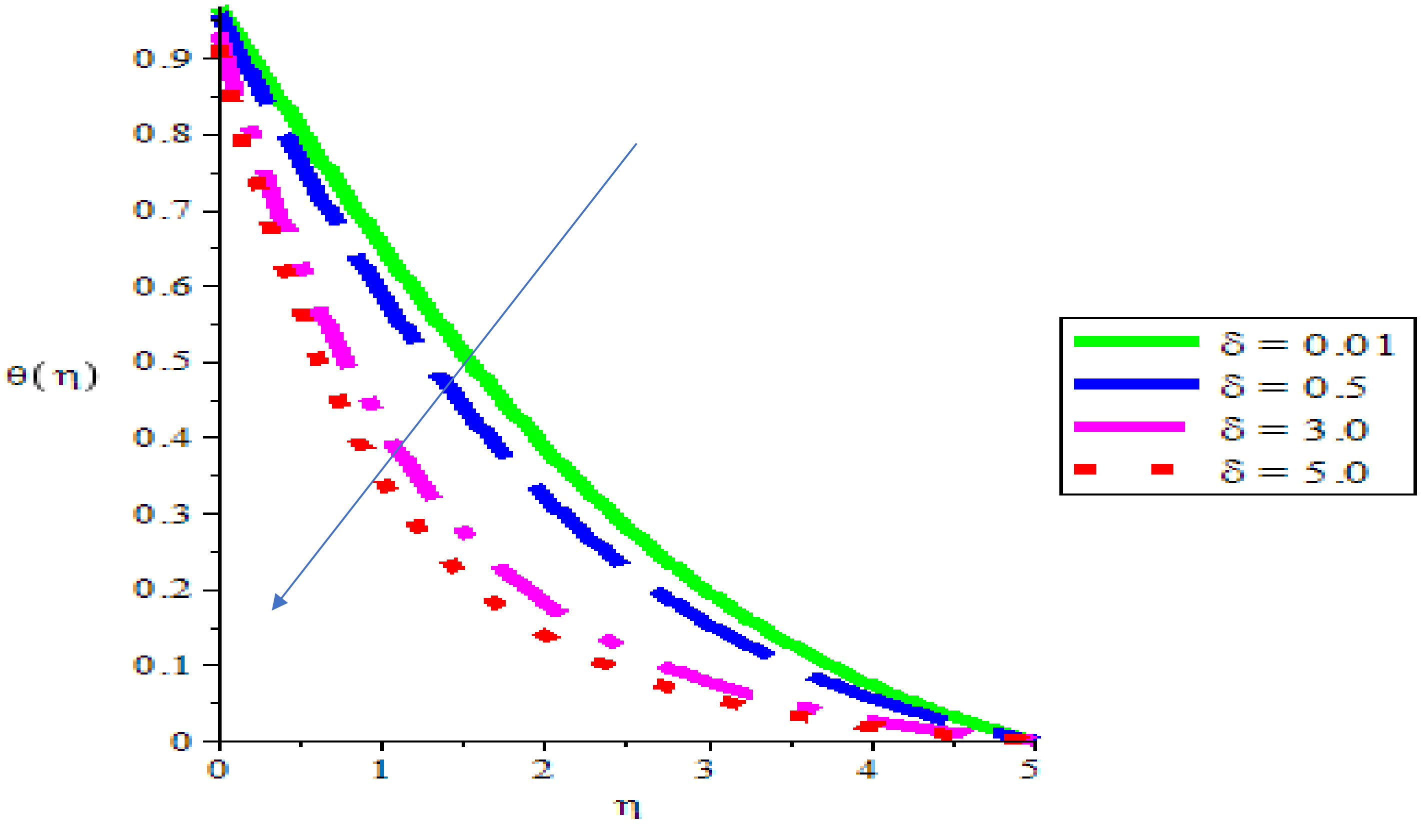

Figure 2: Temperature profile varying δ

Effect of variation of thermophysical parameters on temperature profile

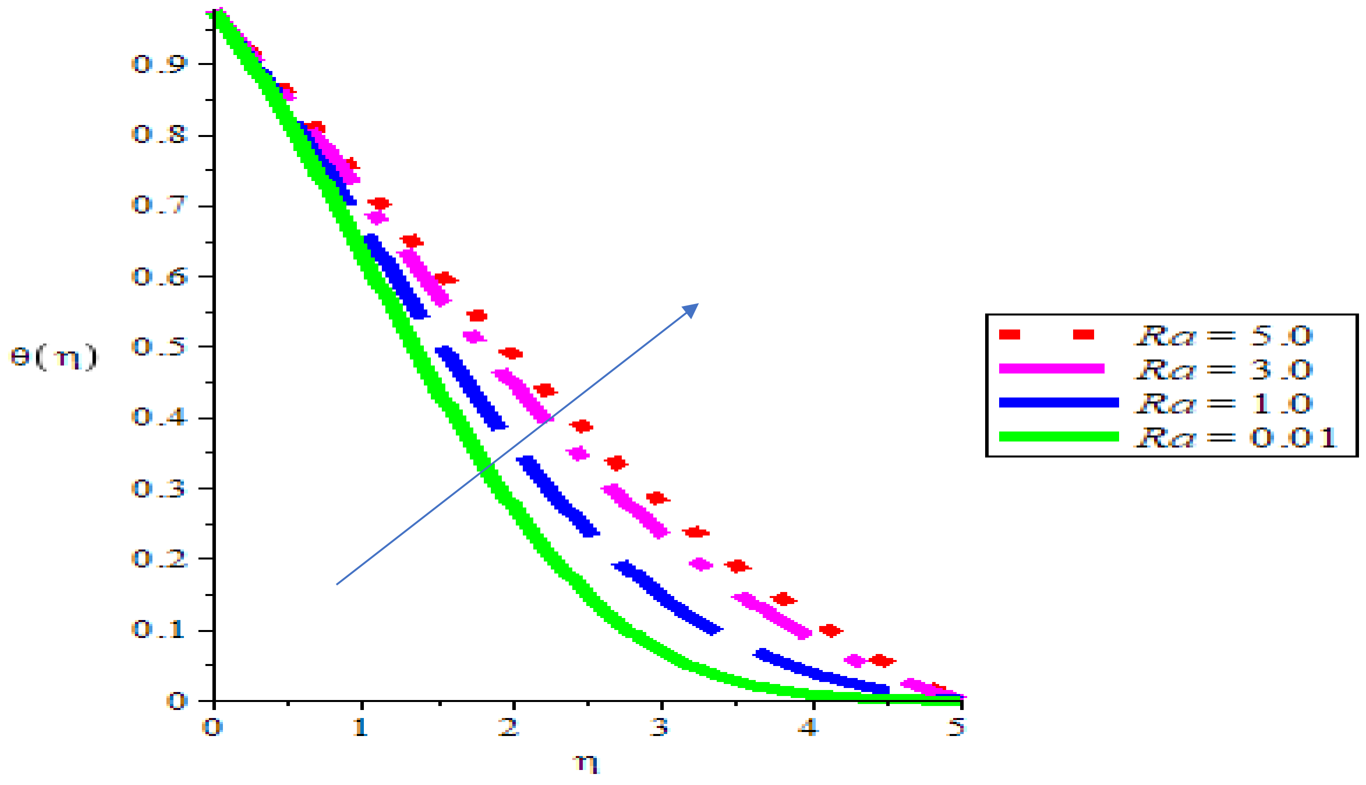

Figure 3: Temperature profile varying *Ra*

Effect of variation of thermophysical parameters on temperature profile

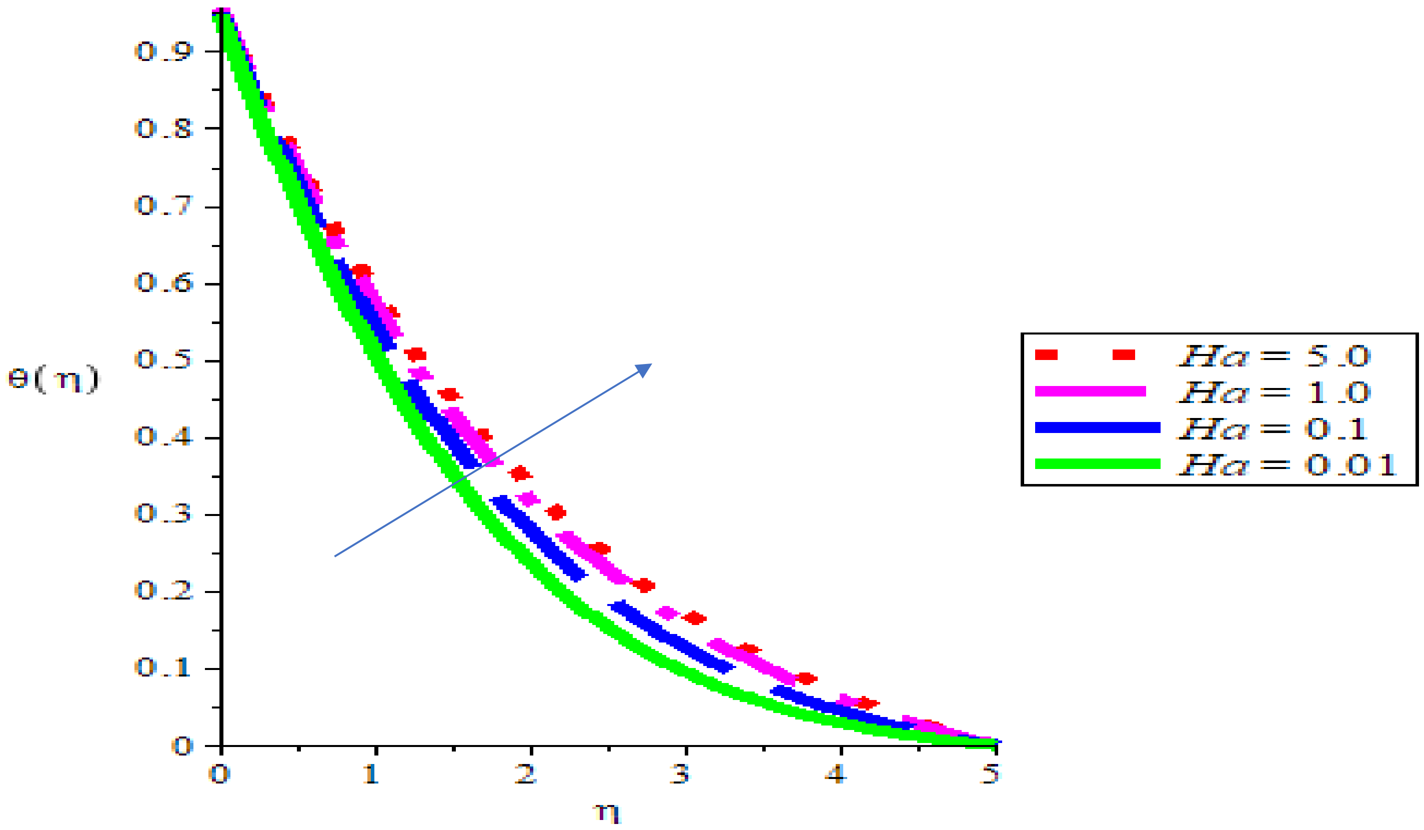

Figure 4: Temperature profile varying *Ha*

Effect of variation of thermophysical parameters on velocity profile

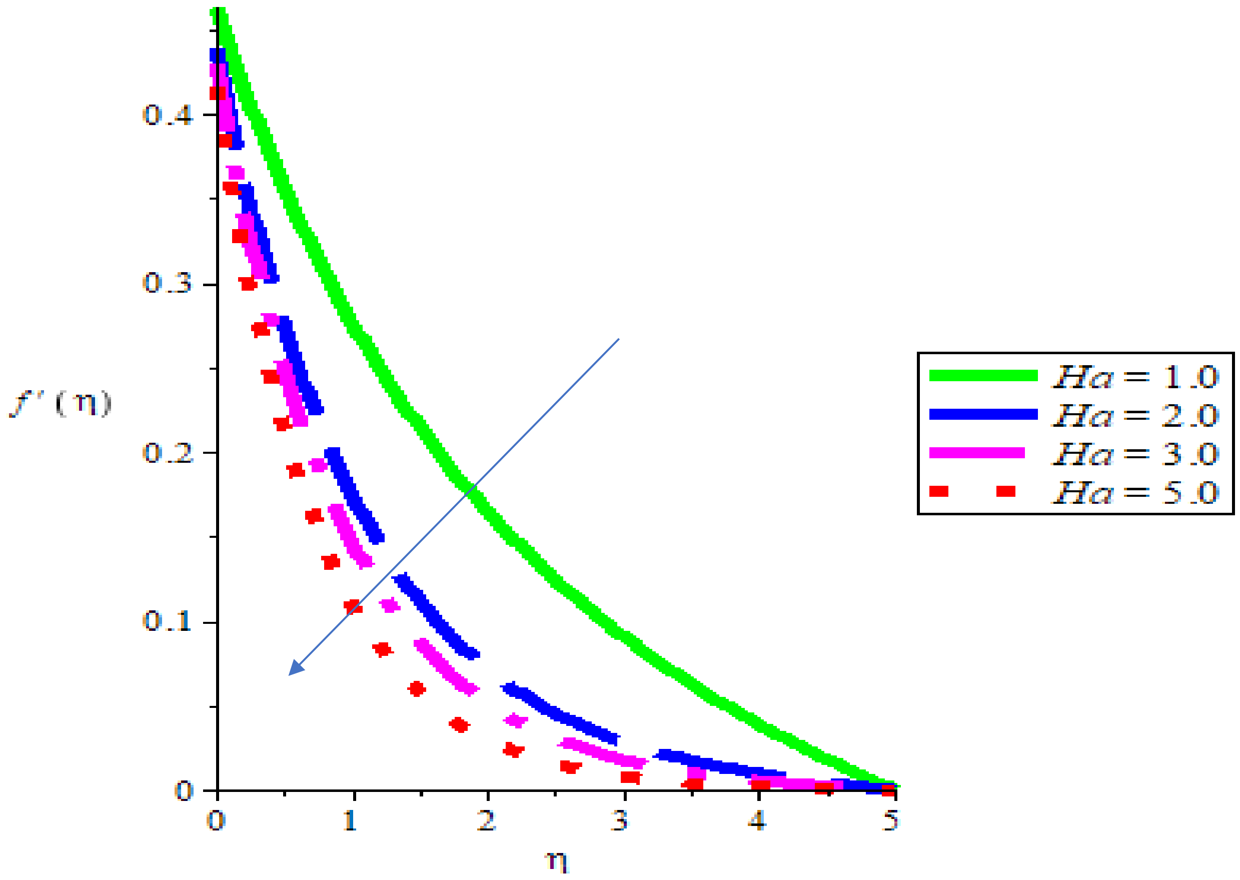

Figure 5: Velocity profile varying *Ha*

Effect of variation of thermophysical parameters on velocity profile

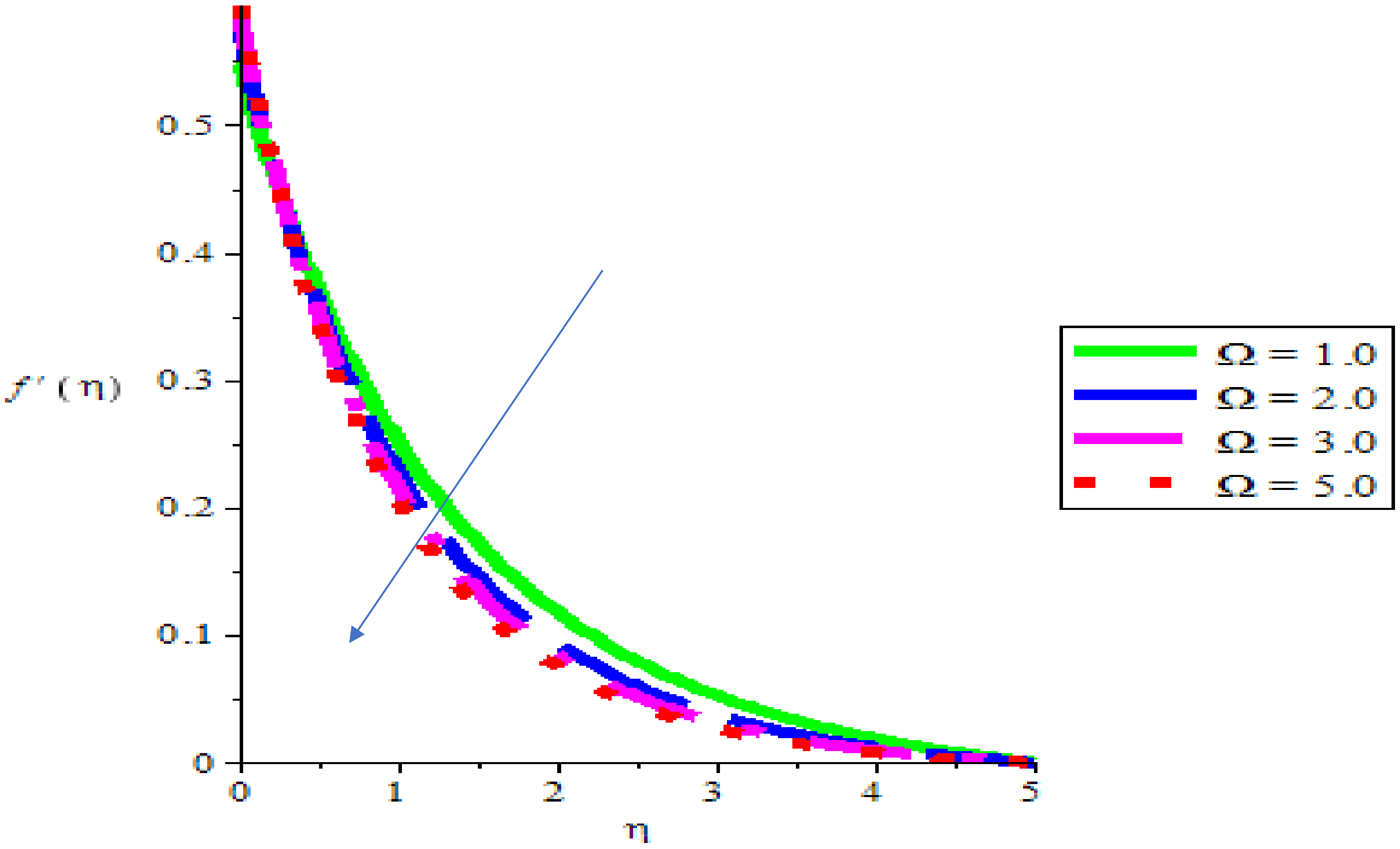

Figure 6: Velocity profile varying Ω

Effect of variation of thermophysical parameters on Concentration profile

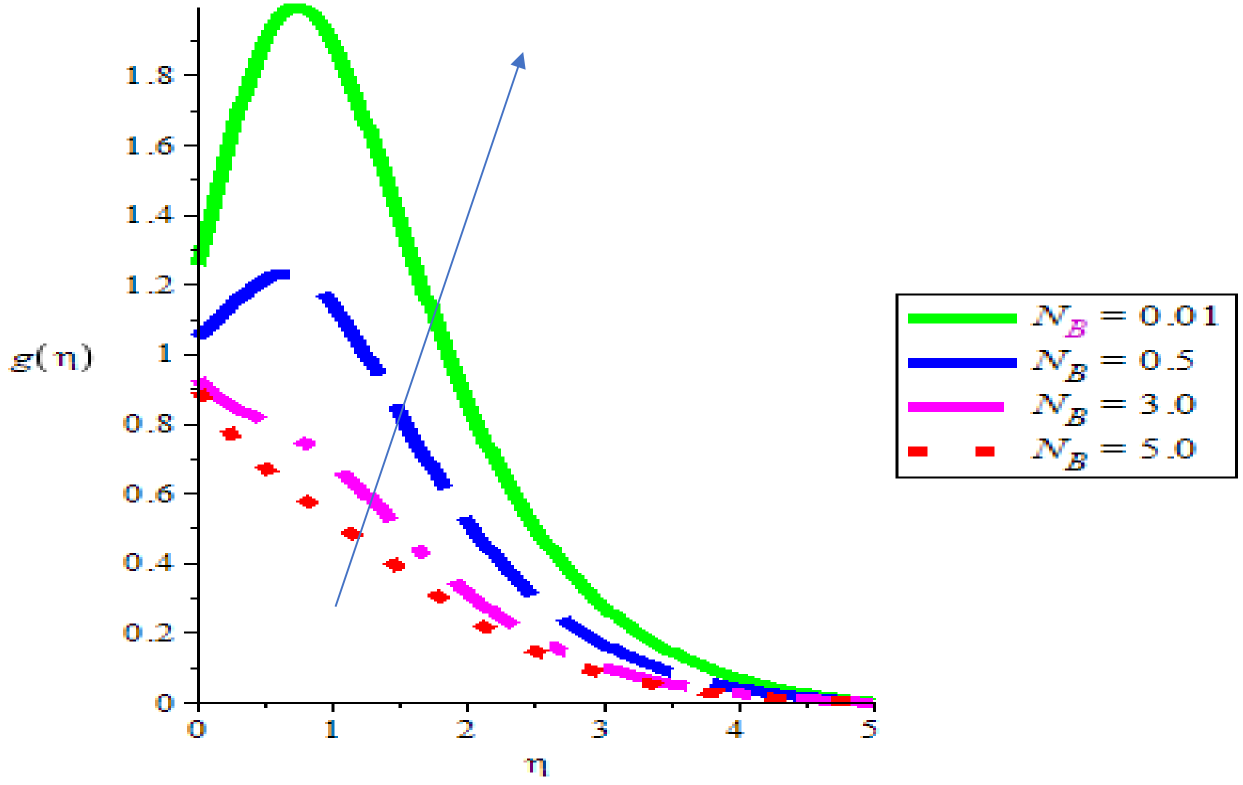

Figure 7: Concentration profile varying N_B

Effect of variation of thermophysical parameters on Concentration profile

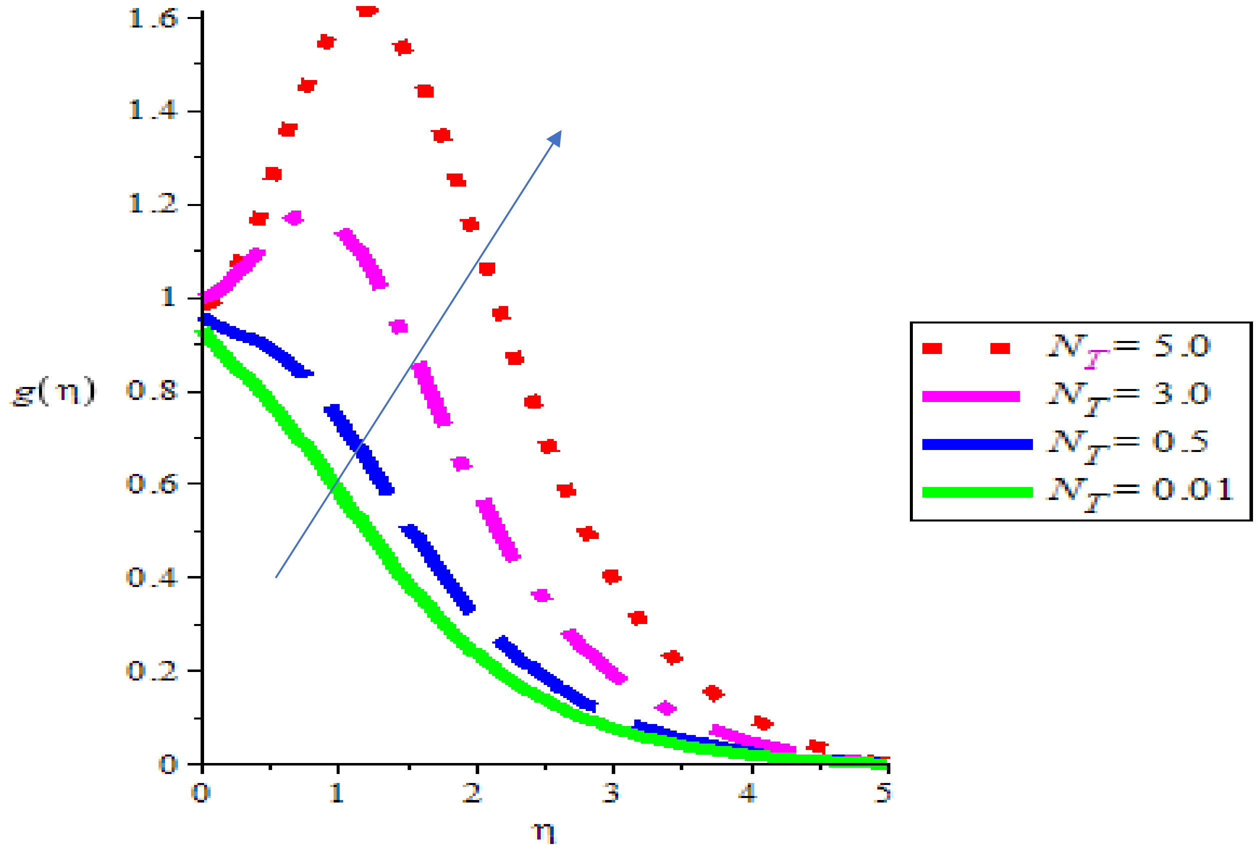

Figure 8: Concentration profile varying N_T

Conclusion

- Explored Tri-hybrid Casson nanofluids for improved solar panel cooling.
- Integrated temperature-dependent specific heat capacity into thermal modeling.
- Found significant potential for optimizing heat transfer and enhancing efficiency.
- Insights support the development of more effective and sustainable solar panels.

Future work

- Experimental validation and diverse nanoparticle analysis recommended.

- This research paves the way for advanced solar energy systems with extended lifespan and reliability.

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Thanks for your attention!!!