Numerical Solutions of Mixed Convection Hybrid Nanofluid Flow past an Inclined Stretching Sheet with Gravity Modulation Effect

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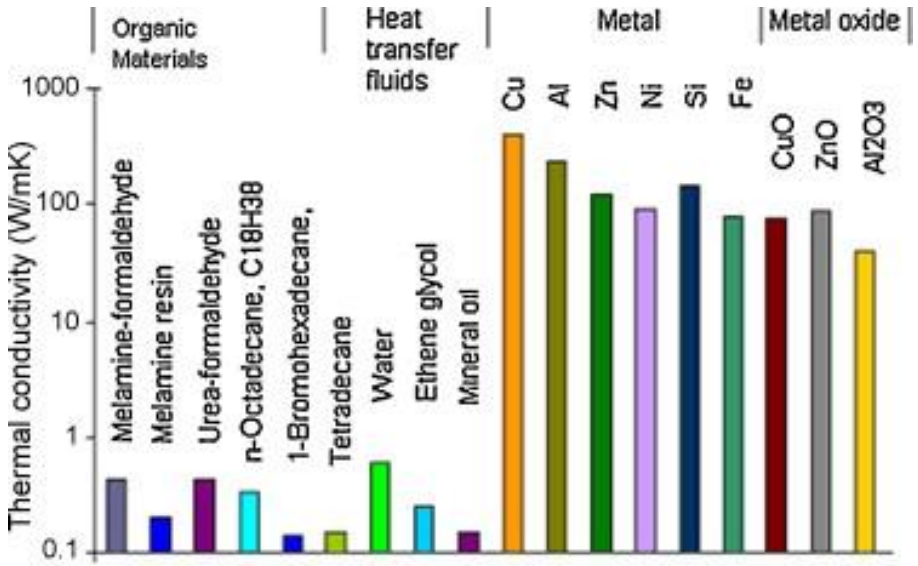
Introduction

Nanofluid



Conventional heat transfer fluids have inherently poor thermal conductivity compared to solids

WHY nanoparticles?
-stay suspended much longer
-possess higher surface area
- Extreme stability
- Ultrahigh thermal conductivity

Maxwell (1873) presented theoretical basic for predicting the effective conductivity of suspension

the idea of dispersing milimeter /micrometer sized particle to break fundamental limit (in order to improve the heat transfer characteristic)

Major problems:
Rapid settling of particles in fluid, sedimentation, erosion, high pressure drop, etc.

Choi (1995) proposed the novel concept of nanofluid by exploiting the unique properties of nanoparticles

Introduction

What is **hybrid nanofluid**?

The fluid contains a **mixed** or **composed** of **two different nanoparticles,** which **disperse** in the **base fluid**.

Why consider hybrid nanofluid?

Proper hybridization may make the hybrid nanofluids very promising for **heat transfer enhancement**

Introduction

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Gravity modulation (g-JITTER)

Characterizes as a small fluctuating gravitational field in microgravity environment

Caused by oscillatory or transient accelerations arising from crew motions and machinery vibrations

Model considered: $$g^{*}(t) = g_0\left[1+\varepsilon\cos\left(\pi\omega t\right)\right]\mathbf{k}$$

Literature Review

01 **GRAVITY MODULATION (G-JITTER)**

Sharidan, S., Amin, N. and Pop, I. (2006). g-Jitter mixed convection adjacent to a vertical stretching sheet. Microgravity-Science and Technology. 18(1): 5–14.

02 **MIXED CONVECTION FLOW OF NANOFLUID & G-JITTER**

Uddin, M. J., Khan, W. A. and Amin, N. S. (2014). g-jitter mixed convective slip flow of nanofluid past a permeable stretching sheet embedded in a darcian porous media with variable viscosity. PLoS ONE. 9(6): 1–12.

03 **NANOFLUID MODEL (TIWARI AND DAS)**

Tiwari, R. K. and Das, M. K. 2007. Heat transfer augmentation in a two-sided lid-driven differentially heated square cavity utilizing nanofluids. International Journal of Heat and Mass Transfer. 50(9): 2002–2018.

04 **HYBRID NANOFLUID**

Anuar, N. S., Bachok, N., & Pop, I. (2021). Influence of buoyancy force on Ag-MgO/water hybrid nanofluid flow in an inclined permeable stretching/shrinking sheet. International Communications in Heat and Mass Transfer, 123, 105236.

PROBLEM FORMULATION

continuity equation

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

momentum equation

$$\rho_{hnf}\left[\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right]=\mu_{hnf}\frac{\partial^2 u}{\partial y^2}+g^*(t)(\rho\beta)_{hnf}(T-T_\infty)\cos\gamma$$

energy equation

$$(\rho C_p)_{hnf}\left[\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right]=k_{hnf}\frac{\partial^2 T}{\partial y^2}$$

Initial & boundary conditions

$$t=0: u=v=0, T=T_\infty \text{ for any } x,y,$$
$$t>0: u_w(x)=cx, v=0 \text{ , T}=T_w=T_\infty+ax \text{ at } y=0,$$
$$u\to 0 \text{ , } T\to T_\infty \text{ as } y\to\infty,$$

Similarity transformation

$$\tau=\omega t,\ \eta=\left(\frac{c}{\upsilon_f}\right)^{1/2}y,\ \psi=(c\upsilon_f)^{1/2}xf(\tau,\eta),\ \theta(\tau,\eta)=\frac{(T-T_\infty)}{(T_w-T_\infty)}$$

PROBLEM FORMULATION

Transformed equations

$$\frac{1}{(1-\phi_1)^{2.5}(1-\phi_2)^{2.5}}\frac{\partial^3 f}{\partial\eta^3}+\frac{\rho_{hnf}}{\rho_f}\left(f\frac{\partial^2 f}{\partial\eta^2}-\left(\frac{\partial f}{\partial\eta}\right)^2\right)=\frac{\rho_{hnf}}{\rho_f}\Omega\frac{\partial^2 f}{\partial\tau\partial\eta}$$

$$+\frac{(\rho\beta)_{hnf}}{(\rho\beta)_f}\lambda[1+\varepsilon\cos(\pi\tau)]\theta\cos\gamma$$

$$\frac{k_{hnf}}{k_f}\frac{\partial^2\theta}{\partial\eta^2}+\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}\Pr\left(f\frac{\partial\theta}{\partial\eta}-\frac{\partial f}{\partial\eta}\theta\right)=\frac{(\rho c_p)_{hnf}}{(\rho c_p)_f}\Pr\Omega\frac{\partial\theta}{\partial\tau},$$

$$f=0,\quad \frac{\partial f}{\partial\eta}=1,\quad \theta=1 \text{ at } \eta=0,$$

$$\frac{\partial f}{\partial\eta}\to 0,\quad \theta\to 0 \text{ as } \eta\to\infty,$$

PROBLEM FORMULATION

Table 1. Nanofluid and hybrid nanofluid thermophysical properties

Properties	Nanofluid	Hybrid nanofluid
Heat capacity	$(\rho C_p)_{nf} = (1-\varphi_1)\,(\rho C_p)_f + \varphi_1\,(\rho C_p)_{n1}$	$(\rho C_p)_{hnf} = (1-\varphi_2)\left[(1-\varphi_1)(\rho C_p)_f + \varphi_1(\rho C_p)_{n1}\right] + \varphi_2(\rho C_p)_{n2}$
Density	$\rho_{nf} = (1-\varphi_1)\rho_f + \varphi_1\rho_{n1}$	$\rho_{hnf} = (1-\varphi_2)[(1-\varphi_1)\rho_f + \phi_1\rho_{n1}] + \varphi_2\rho_{n2}$
Dynamic viscosity	$\mu_{nf} = \dfrac{\mu_f}{(1-\varphi_1)^{2.5}}$	$\mu_{hnf} = \dfrac{\mu_f}{(1-\varphi_1)^{2.5}\,(1-\varphi_2)^{2.5}}$
Thermal conductivity	$k_{nf} = \dfrac{k_{n1}+2k_f-2\varphi_1(k_f-k_{n1})}{k_{n1}+2k_f+\varphi_1(k_f-k_{n1})} \times (k_f)$	$k_{hnf} = \dfrac{k_{n2}+2k_{nf}-2\varphi_2(k_{nf}-k_{n2})}{k_{n2}+2k_{nf}+\varphi_2(k_{nf}-k_{n2})} \times (k_{nf})$ where $k_{nf} = \dfrac{k_{n1}+2k_f-2\varphi_1(k_f-k_{n1})}{k_{n1}+2k_f+\varphi_1(k_f-k_{n1})} \times (k_f)$

Methodology

Keller-box method

Mathematical Modelling

- ➢ Dimensional partial differential equations (Boundary layer and Boussinesq approximations)

Mathematical Analysis

- ➢ Transformation of governing equation using similarity transformation

Numerical Computation

- ➢ Finite difference method,
- ➢ Newton's method,
- ➢ block-triadiagonal elimination method

Results Verification

- compared with the related publication in order to show the accuracy of the applied method

Results & Discussion

Comparison Table

Comparison values of $-\theta'(0)$ when $\Pr = 1$, $\varepsilon = \Omega = 0$ (no g-jitter effect), $\gamma = 0$ (vertical stretching sheet), $\phi_1 = \phi_2 = 0$

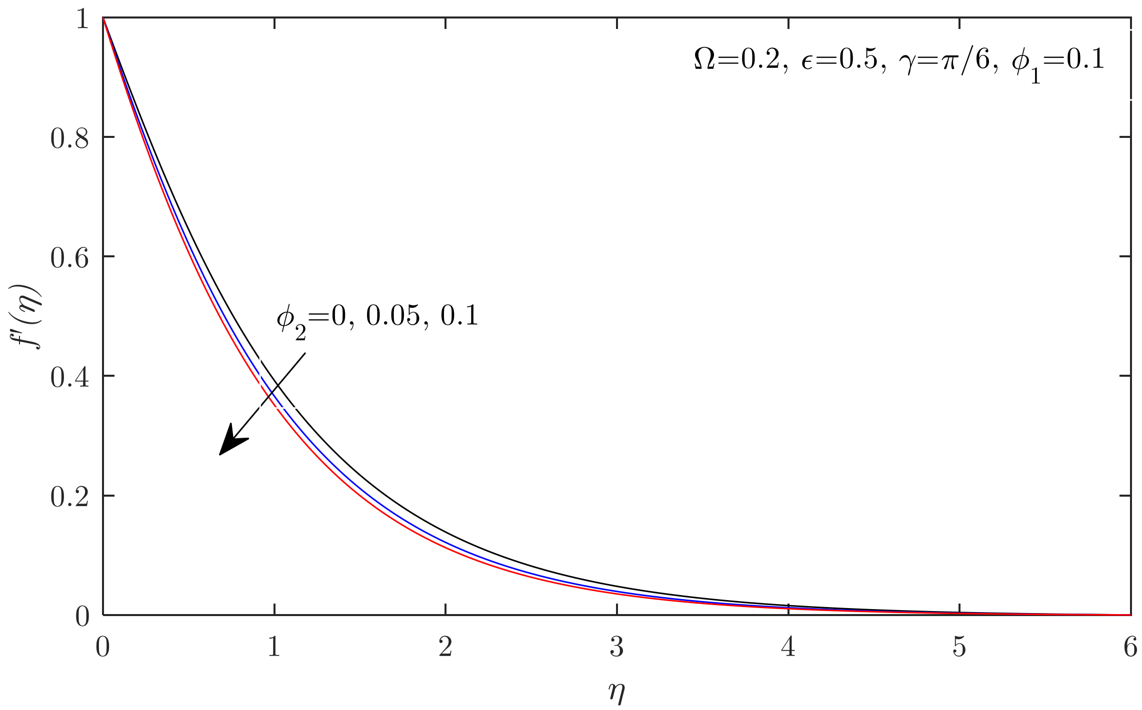
λ	Rosca and Pop (2003)	Anuar et al. (2021)	Present result
0	1.0000	1.000008	1.000483
1	1.0872	1.087275	1.087086
10	1.3715	1.371564	1.371581

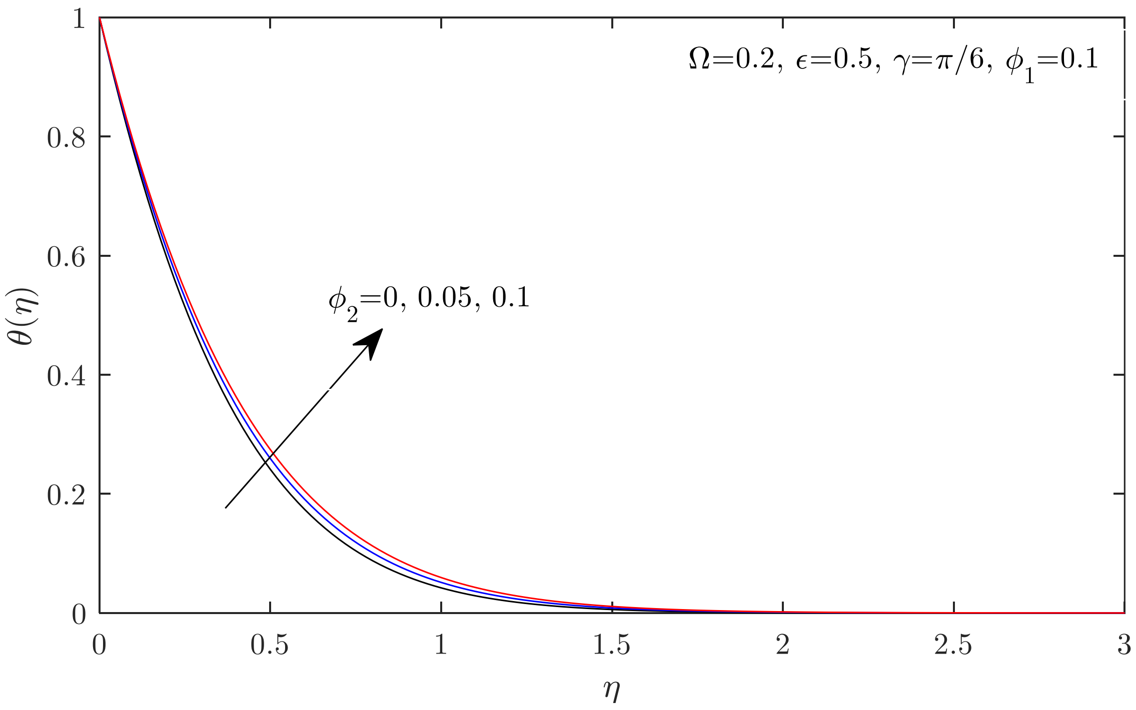
References:

1. A.V. Rosca, I. Pop, Flow and heat transfer over a vertical permeable stretching/ shrinking sheet with a second order slip, Int. J. Heat Mass Transf. 60 (2013) 355–364.
2. Anuar, N. S., Bachok, N., & Pop, I. (2021). Influence of buoyancy force on Ag-MgO/water hybrid nanofluid flow in an inclined permeable stretching/shrinking sheet. International Communications in Heat and Mass Transfer, 123, 105236.

Results & Discussion

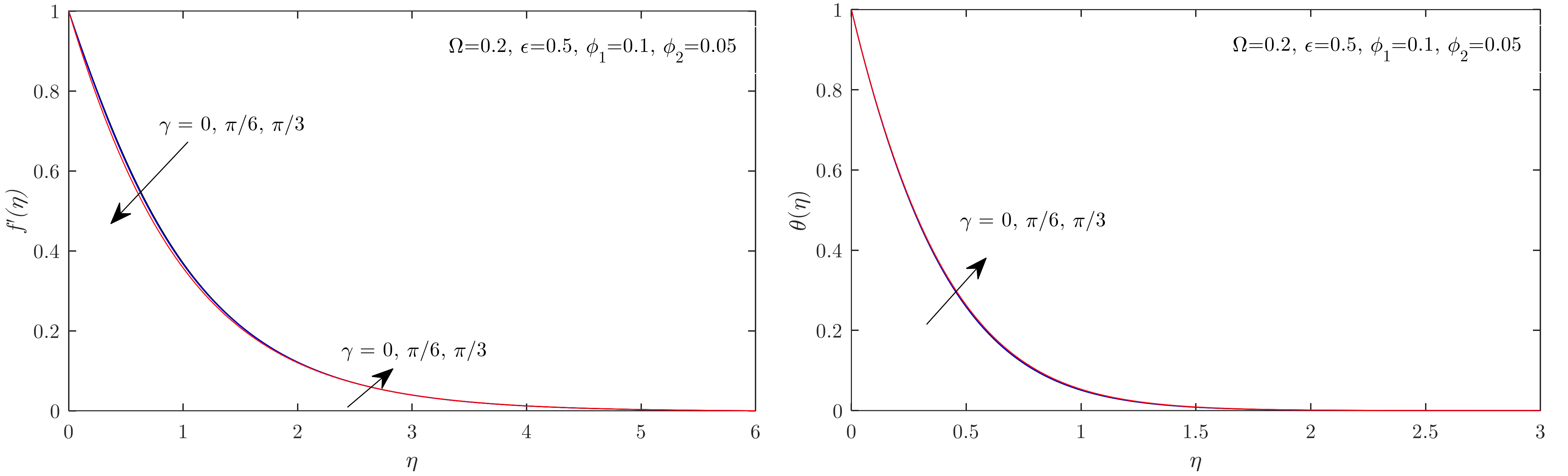
Effect of nanoparticle volume fraction (Copper)





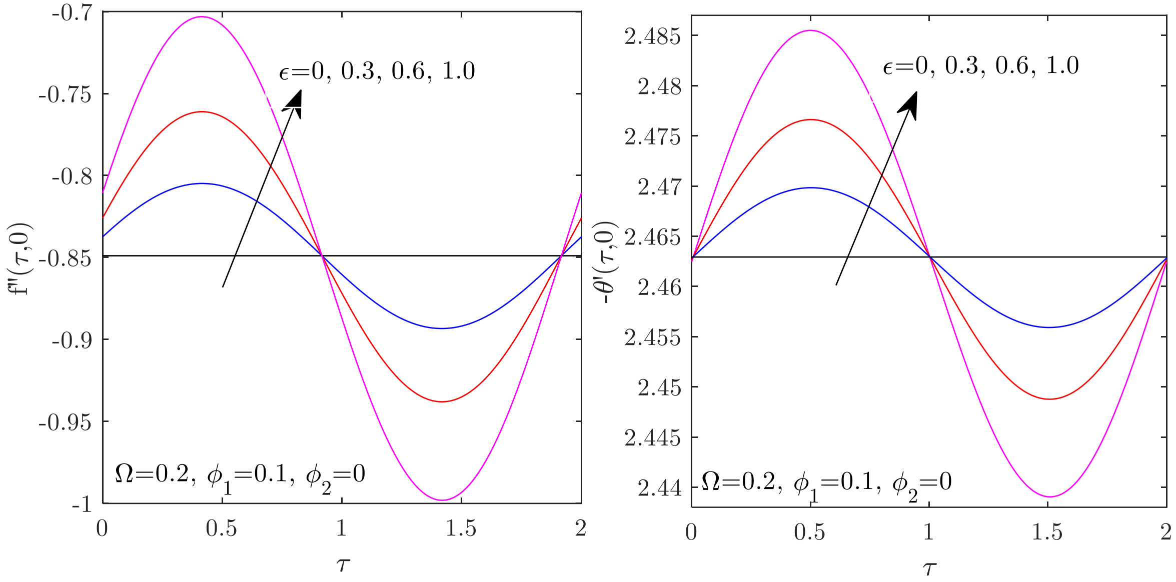
Results & Discussion

Effect of inclination angle

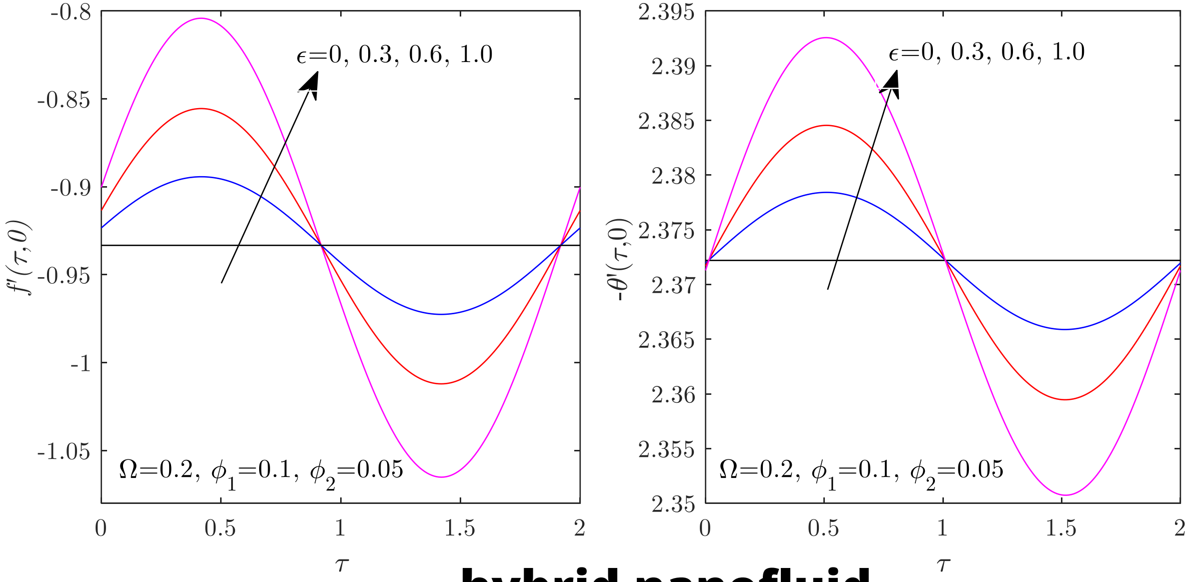


Results & Discussion

Effect of amplitude of modulation & nanoparticle volume fraction



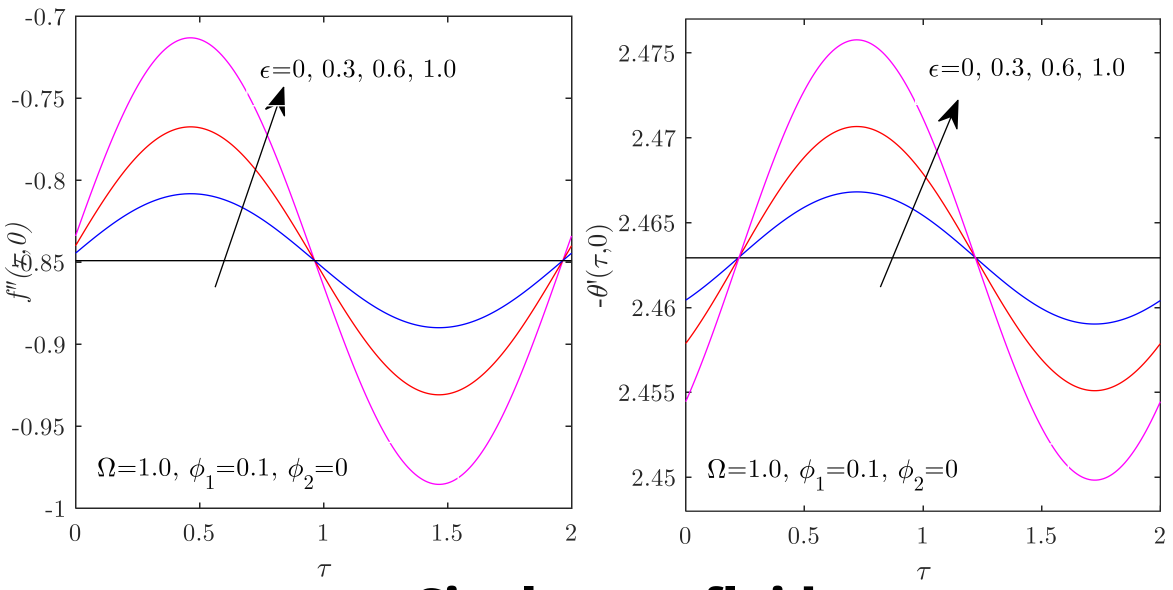
Single nanofluid



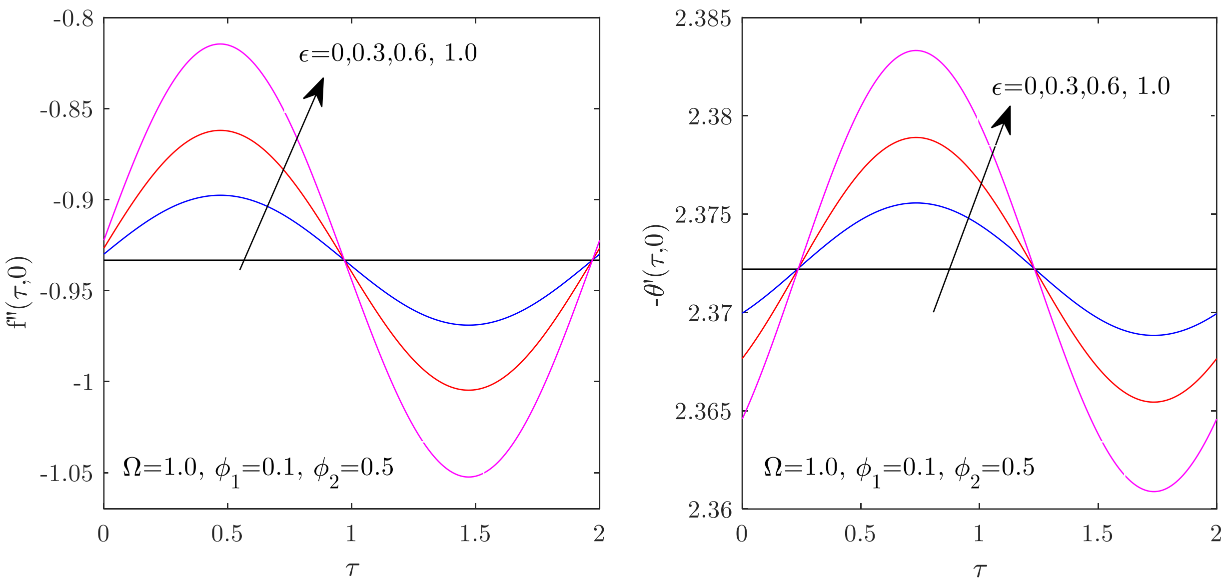
hybrid nanofluid

Results & Discussion

Effect of frequency of oscillation& nanoparticle volume fraction



Single nanofluid



hybrid nanofluid

Conclusions

- The effect of amplitude of modulation give an almost proportional increase and decrease in both skin friction and heat transfer rate
- Skin friction decrease significantly with the increase of frequency of oscillation and nanoparticles volume fraction
- The presence of both nanoparticles give a significant enhancement on temperature profiles, however, contradict behaviour is observed for heat transfer coefficient

THANK YOU

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