Establishing Entropy Generation in Three-Dimensional Williamson Nanofluid Flow Utilizing Hybrid Carbon Nanotubes on a Stretching Sheet.

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Abstract

The current research employs a three-dimensional Williamson nanofluid flow model, investigating the behavior of a stretching sheet with the influence of the Cason parameter and hybrid carbon nanotubes. The governing equations are transformed into nonlinear coupled ordinary differential equations through appropriate similarity transformations and the consideration of physical phenomena. To solve these equations, a Python coding program, along with an open-source boundary value problem solver, is utilized. The obtained numerical results are validated against relevant literature results. These findings are then presented and analyzed using graphs and tables, focusing on thermos-physical parameters such as the thermal Peclet number.

Introduction

Recently, there has been a significant interest in using high thermal conductive fluids, specifically nanofluids, for heat and mass transfer systems. Nanofluids are created by suspending nanoparticles (typically 10nm or smaller) in a base fluid, such as water, similarly to how particles dissolve in water. Various fluids, including engine oil, kerosene, and ethanol, are commonly used to disperse nanoparticles. The application of nanofluids has shown promise in enhancing thermal conductivity for heat transport purposes in engineering, biomedical, and industrial fields. The development of nanofluids began with Choi's work in 1995, and since then, extensive research has been conducted to investigate their properties, particularly concerning heat and mass transfer capabilities. Numerical solutions have been explored to address flow problems in porous media, taking into account chemical reaction parameters and fluid properties [1]. Additionally, the impact of nanoparticle shapes on heat transfer rates has been numerically analyzed using the control-volume-based finite element method (CVFEM). Correlations between the thermophysical parameters of nanofluids were examined based on the research [2-3].

Krishna [4] conducted a study to calculate and analyze the thermal and mass transfer coefficients of nanofluids (Ag and TiO2) concerning suction and chemical reaction parameters. Additionally, they examined the temperature and concentration profiles of nanofluid flow, considering Brownian motion and thermophoresis, as reported in their work [5-7]. Furthermore, [8] investigated the skin friction coefficient of nanofluids undergoing magnetohydrodynamic (MHD) free convective rotating flow over a moving semi-infinite flat plate. Several research papers have investigated nanofluids with different geometries. The study aims to contribute valuable insights into the behavior of nanofluids containing hybrid carbon nanotubes under the influence of thermal Peclet number, offering potential applications in various fields, such as heat and mass transfer systems and nanofluid-based technologies [9-10].

Mathematical Formulation

The researchers are currently investigating the dynamics of a three-dimensional, incompressible nanofluid flow that incorporates hybrid carbon nanotubes (CNTs). This flow is initiated by stretching sheets located at z=0 (as shown in Figure 1). The plate is positioned and maintained within the XY plane at z=0, while the flow takes place in the region where z>0. Let p=pw, q=qw, T=Tw, and C=Cw be the velocities, temperature, and concentration of the nanofluid near the surface of the stretchingsheet. Moreover, investigators assume that the rheological state of an incompressible Williamson's nanofluid with Cason effect can be written as [11].

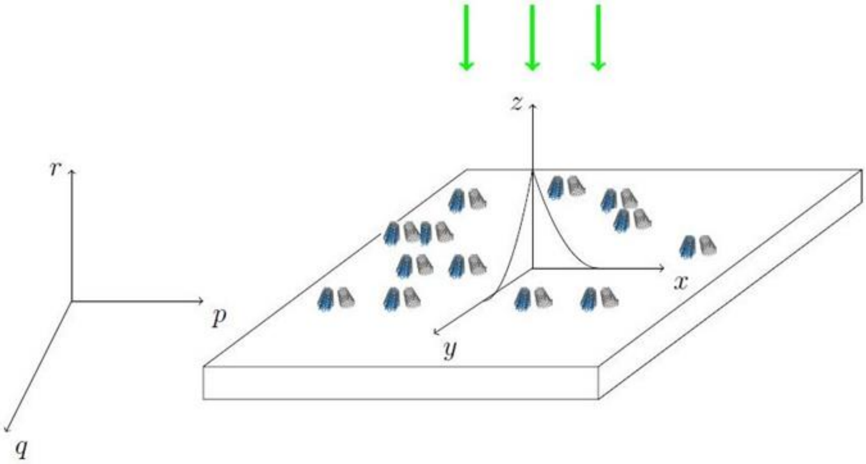

Figure 1 – Flow diagram

$$\frac{\partial p}{\partial x}+\frac{\partial q}{\partial y}+\frac{\partial r}{\partial z}=0, \tag{1}$$

$$p\frac{\partial p}{\partial x}+q\frac{\partial p}{\partial y}+r\frac{\partial p}{\partial z} = \nu_{hnf}\left(1+\frac{1}{\beta}\right)\frac{\partial^2 p}{\partial z^2}+\sqrt{2}\tau\nu_{hnf}\frac{\partial p}{\partial z}\frac{\partial^2 p}{\partial z^2}-\sigma_{hnf}\frac{B^2}{\rho_{hnf}}p, \tag{2}$$

$$p\frac{\partial q}{\partial x}+q\frac{\partial q}{\partial y}+r\frac{\partial q}{\partial z} = \nu_{hnf}\left(1+\frac{1}{\beta}\right)\frac{\partial^2 q}{\partial z^2}+\sqrt{2}\tau\nu_{hnf}\frac{\partial q}{\partial z}\frac{\partial^2 q}{\partial z^2}-\sigma_{hnf}\frac{B^2}{\rho_{hnf}}q, \tag{3}$$

$$p\frac{\partial T}{\partial x}+q\frac{\partial T}{\partial y}+r\frac{\partial T}{\partial z} = \frac{k_{hnf}}{(\rho c_p)_{hnf}}\frac{\partial^2 T}{\partial z^2}+\frac{D_T}{T_\infty}(\frac{\partial T}{\partial z})^2+\frac{16\sigma^*}{3k^*}\frac{\partial}{\partial z}(T^3\frac{\partial T}{\partial z}). \tag{4}$$

Boundary conditions [12]

$$\begin{gathered}p = p_w = p_0 e^{\frac{x+y}{l}}, q = q_w = q_0 e^{\frac{x+y}{l}}, r = 0,\\ -k_{hnf}\frac{\partial T}{\partial z} = (\rho c_p)_{hnf} p_w (T_w - T), as\ z \to 0\\ p \to 0, q \to 0, r \to 0, T \to T_\infty, as\ z \to \infty.\end{gathered} \tag{5}$$

In the preceding equations and derivation, the variables p, q, and r denote the velocity components in the x, y, and z directions, respectively. Additionally, the kinematic viscosity of the hybrid nanofluid and the kinematic viscosity of the nanofluid are denoted by the terms mentioned above.

Similarity transformations [12]

$$\begin{gathered}p = p_0 e^{\frac{x+y}{l}} f^1(\eta),\ q = p_0 e^{\frac{x+y}{l}} g^1(\eta),\\ r = -(\frac{p_0 v}{2l})^{0.5} e^{\frac{x+y}{l}}[(f(\eta) + g(\eta)) + \eta(f^1(\eta) + (g^1(\eta)],\ \eta = (\frac{p_0}{2vl})^{0.5}\ z e^{\frac{x+y}{l}},\\ \theta(\eta) = \frac{T - T_\infty}{T_w - T_\infty}.\end{gathered} \tag{6}$$

The following set of ordinary equations is obtained through the application of similarity transformations derived from Equation (6).

$$\frac{V_1}{V_2}(1 + \frac{1}{\beta})f^{111} + \frac{V_1}{V_2}\lambda 1 f^{11} f^{111} - \frac{V_3 V_4}{V_2} M1 f^1 + f f^{11} + g f^{11} - 2(f^1)^2 - 2 f^1 g^1 = 0, \tag{7}$$

$$\frac{V_1}{V_2}(1 + \frac{1}{\beta})g^{111} + \frac{V_1}{V_2}\lambda 1 g^{11} g^{111} - \frac{V_3 V_4}{V_2} M1 f^1 + g g^{11} + f g^{11} - 2(g^1)^2 - 2 f^1 g^1 = 0, \tag{8}$$

$$\begin{aligned}Pr[f^1\theta + g^1\theta - \theta^1 f - \theta^1 g] = {} & \frac{V_9}{V_{10}}\theta^{11} + \frac{Ra}{V_{10}}[3(1 + (\theta_w - 1)\theta)^2(\theta_w - 1)(\theta^1)^2]\\ & + \frac{Ra}{V_{10}}[((1 + (\theta_w - 1)\theta)^3\theta^{11}] + Pr[Nt(\theta^1)^2].\end{aligned} \tag{9}$$

Results

The methodology of this theme is to examine the properties of hybrid carbon nanotubes on Williamson nanofluid over a stretching sheet.

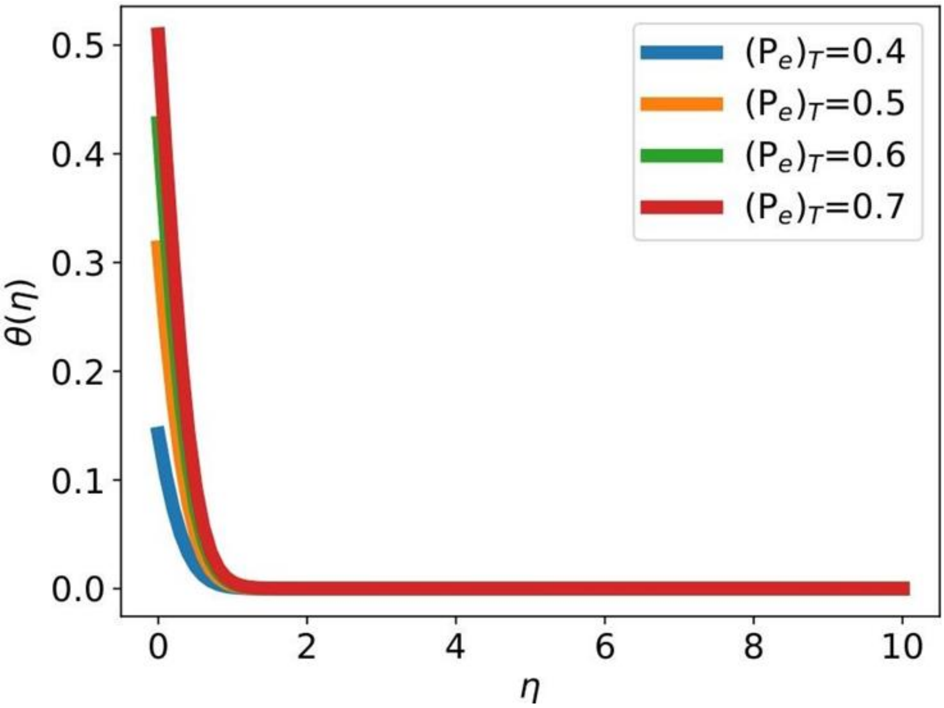

Fig. 2. Influence of thermal Peclet number (PeT) on temperature profile

The following graphs depicts the momentum, temperature, and entropy generation of base fluids with SWCNT, MWCNT and hybrid CNTs at boundary layer of stretching sheet.

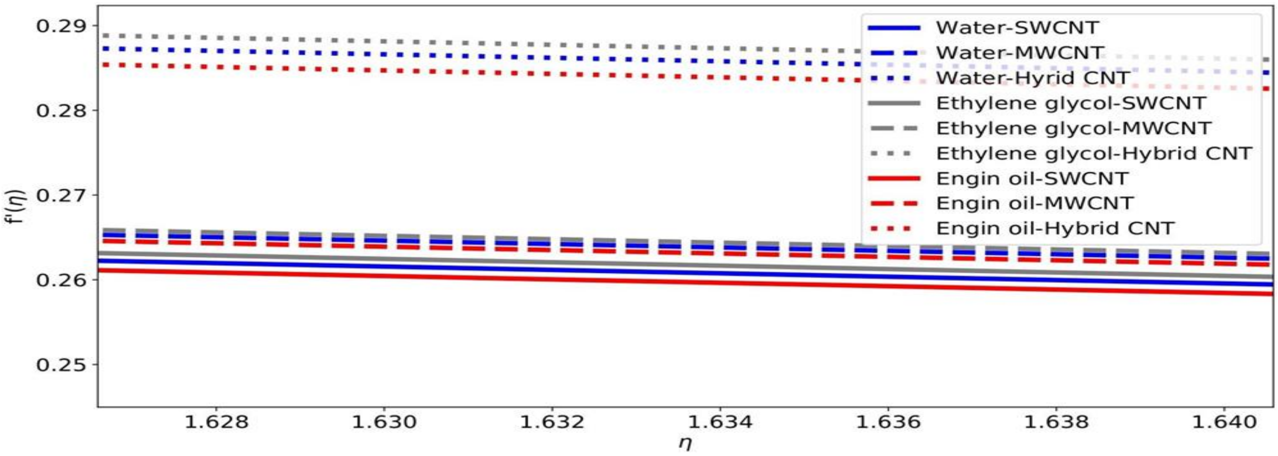

Fig. 3. Influence of different base fluids explored with CNT on horizontal velocity profile

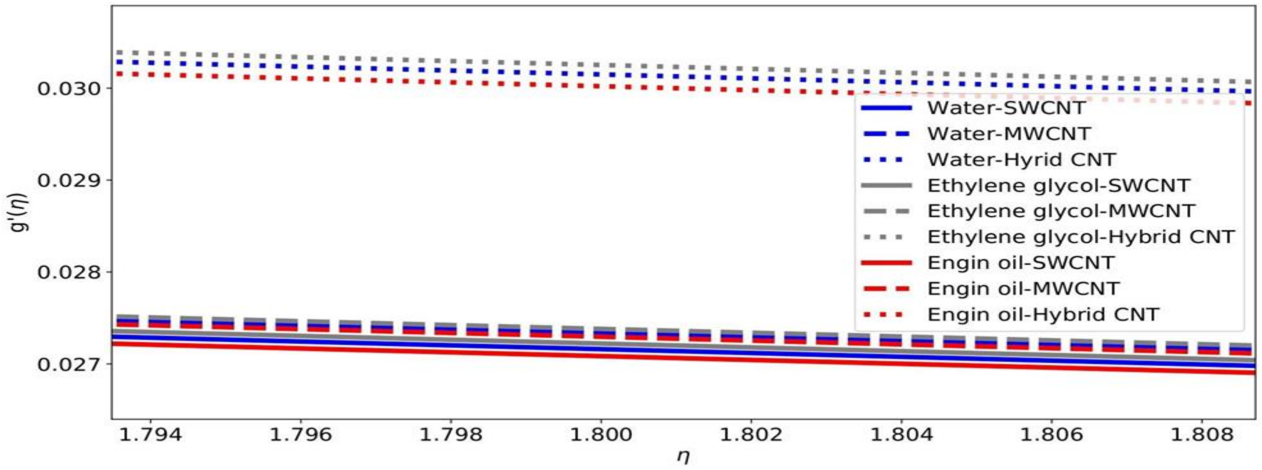

Fig. 4. Influence of different base fluids explored with CNT on vertical velocity profile

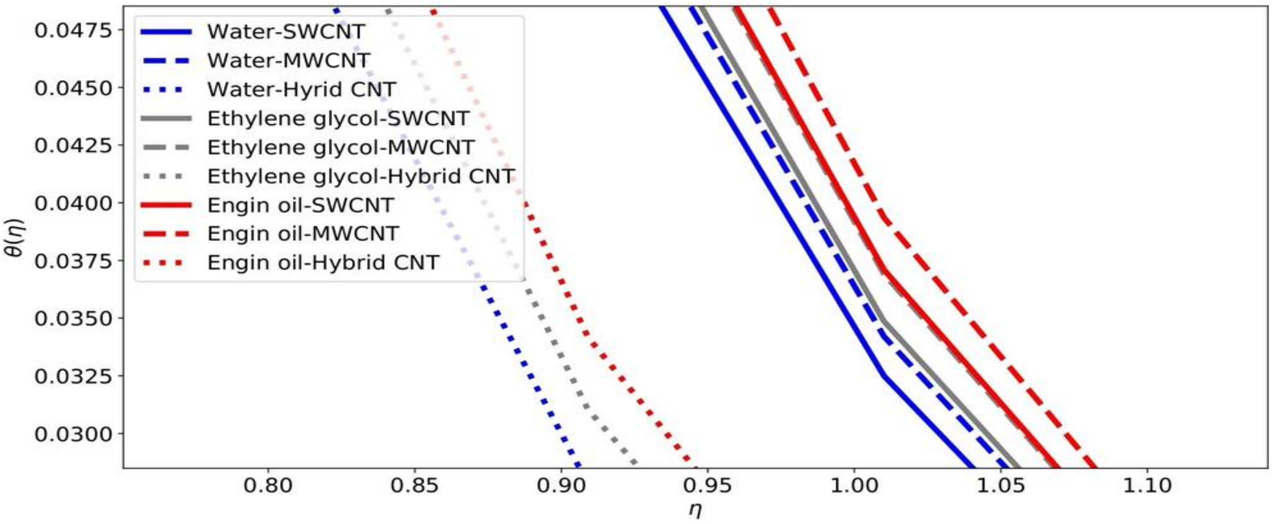

Fig. 5. Influence of different base fluids explored with CNT on temperature profile

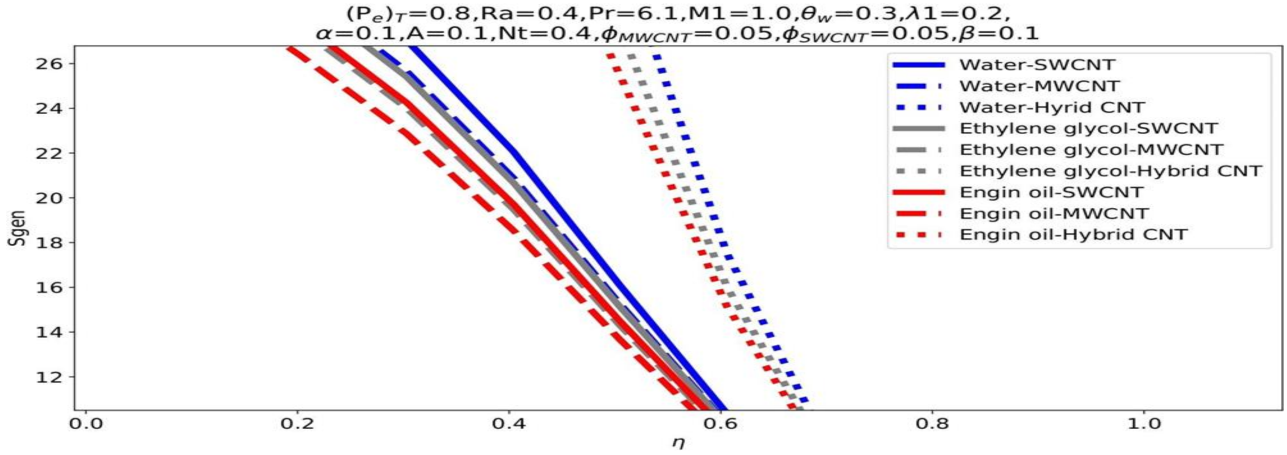

Fig. 6. Influence of different base fluids explored with CNT on the rate of entropy

Conclusion

The study concluded that the behavior of Williamson nanofluid was investigated using various carbon nanotubes (CNTs), taking into account their thermo-physical properties. The entropy rate of water is amplified when exploring it with hybrid carbon nanotubes (CNTs). However, as the Williamson parameter increases, the entropy rate decreases. For fluids with single-walled carbon nanotubes (SWCNT) and multi-walled carbon nanotubes (MWCNT), the entropy rate decreases as the Williamson parameter increases.

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