Investigation of Soret and Dufour in Ternary Nanofluids with Boron Nitride Nanotubes, Ag and Cu with Thermal Radiation in a Tapered Asymmetric Channel: Crank-Nicolson Scheme

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Abstract: Ternary nanofluids are promising for revolutionizing heat transfer applications and offer numerous advantages over traditional heat transfer fluids. Their enhanced thermal properties, tunability, stability, and potential energy savings make them an attractive choice for various engineering and industrial processes, paving the way for more efficient and sustainable technologies in the future. The study investigates the thermal behavior and heat transfer characteristics of a ternary nanofluid in a porous medium under the influence of a magnetic field and Soret-Dufour effects through a tapered asymmetric channel. The study aims to determine the thermal and physical properties of the ternary nanofluid composed of three different types of nanoparticles, namely Boron Nitride Nanotubes (BNNT), silver (Ag) and copper (Cu). The governing equations are transformed into a system of coupled non-linear partial differential equations through suitable dimensionless transformations, and subsequently, solved using the Crank-Nicolson scheme. In this regard, velocity, temperature, and concentration graphs are generated. The numerical results are obtained by ode solver Bvp4c.

1. INTRODUCTION & OBJECTIVE

The Soret and Dufour effects are crucial in the magnetohydrodynamic oscillatory nanofluid flow through a tapered asymmetric channel. The soret effect influences heat and mass transfer due to thermal gradients, while the Dufour effect relates to the impact of concentration gradients on heat transfer. Understanding these phenomena is essential for optimizing nanofluid applications in tapered channels under magnetic fields. Ahammad [1] examines the influence of Soret and Dufour effects in an unsteady two-dimensional boundary layer flow in a vertical channel/duct with viscous dissipation and constant suction. The investigation highlights the importance of Soret effects in the overhanging mixture and fluid. The impact of thermal conductivity and magnetic field intensity on heat and mass transfer flow in a vertical channel through numerical and analytical methods is investigated by Uwanta [2]. The study emphasizes the significance of understanding the effects of various parameters on heat and mass transfer in a vertical channel with a magnetic field. The influence of the Atangana-Baleanu time-fractional integral on a second-grade fluid containing a ternary nanoparticle suspension flowing over an infinite vertical plate is analysed by Shah [3]. The results show that increasing the values of volume frictions leads to a decrease in the Prandtl number and an increase in temperature, heat flux, and velocity. Sudarsana [4] presents a numerical solution for the problem of MHD flow, heat, and mass transfer of a viscous incompressible nanofluid over a uniformly stretching sheet through porous media. Jakeer [5] considers factors such as heat generation/absorption, thermal radiation, chemical reaction, thermo-diffusion, and diffusion-thermo effects. It is analysed that the increase in the nanoparticle volume fraction enhanced heat and mass transfer rates in Al_2O_3–water and TiO_2–water nanofluids. The study observed that ternary hybrid nanofluids exhibited a more pronounced effect on the temperature profile than regular and hybrid nanofluids.

The aim of the study is to investigate the thermal behavior and heat transfer characteristics of a ternary nanofluid in a porous medium under the influence of a magnetic field and Soret-Dufour effects through tapered asymmetric channel. The research focuses on:-

• How does the presence of Boron Nitride Nanotubes (BBNT), silver (Ag), and copper (Cu) nanoparticles affect the thermal behavior of the ternary nanofluid in a porous medium?

• What are the heat transfer characteristics of the ternary nanofluid in the presence of a magnetic field, Soret and Dufour effects within an asymmetric wavy channel?

2. PROBLEM FORMULATION

An unsteady, oscillatory flow of an incompressible fluid containing ternary-Boron Nitride Nanotubes (BNNT) with Ag and Cu nanoparticles with water as base fluid is considered. The flow occurs in a tapered asymmetric channel, where the fluid moves towards the x-axis. It is assumed that the transversely applied magnetic field and magnetic Reynolds number are very small and hence the induced magnetic field can be negligible. Viscous and Darcy resistance terms are taken into account with the constant permeability of the porous medium. The walls of the tapered asymmetric channel are maintained at different temperatures, T_1 and T_2.

The Governing Equations are:-

$$\rho_{nf}\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p}{\partial x}+\mu_{nf}\frac{\partial^2 u}{\partial y^2}-\left(\sigma B_0^2+\frac{\mu_{nf}}{k_1}\right)u+(\rho\beta_T)_{nf}g(T-T_0)+(\rho\beta_c)_{nf}g(C-C_0), \quad (1)$$

$$\left(\rho c_p\right)_{nf}\left(\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}\right)=k_{nf}\frac{\partial^2 T}{\partial y^2}-\frac{\partial q_r}{\partial y}+Q_H(T-T_0)+D_M\frac{\partial^2 C}{\partial y^2}, \quad (2)$$

$$\frac{\partial C}{\partial t}+u\frac{\partial C}{\partial x}+v\frac{\partial C}{\partial y}=D_{nf}\frac{\partial^2 C}{\partial y^2}-K_r^*(C-C_0)+D_T\frac{\partial^2 T}{\partial y^2} \quad (3)$$

Boundary Conditions

$$y=H_1,\qquad u=0,\qquad T=T_0,\qquad C=C_0;$$
$$y=H_2,\qquad u=0,\qquad T=T_0+(T_1-T_0)e^{i\omega t},\qquad C=C_0+(C_1-C_0)e^{i\omega t}. \quad (4)$$

3. METHODOLOGY

The numerical approach utilizing the Crank-Nicolson method is employed to investigate the thermal behavior and heat transfer characteristics of the ternary nanofluid in a porous medium through a tapered asymmetric channel. The Crank-Nicolson method is based on a central difference scheme, which combines information from past and future time steps to approximate the solution at the current time. For a given time-dependent PDE, the method discretizes the spatial and temporal domains, resulting in a system of linear equations.

4. CONCLUSIONS

- As the magnetic field parameter increases, the velocity of the ternary nanofluid decreases. The presence of a magnetic field in a ternary nanofluid causes the magnetic nanoparticles to align and form structures that increase the fluid's effective viscosity and introduce a damping effect. As a result, the fluid's velocity decreases under the influence of the magnetic field.
- When the thermal radiation parameter increases, the temperature of the nanofluid also increases. This implies that thermal radiation is a significant factor influencing the heat energy transfer to the nanoparticles, causing them to absorb more energy and consequently raise their temperature.

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