Chapter 2

Numerical Study of Stratification and Radiation in MHD Fe3O4–Cu–Kerosene/Engine Oil Flow on Cylinder

Digbash Sahu
https://orcid.org/0009-0005-8925-2048
Gauhati University, India

Hiya Saharia
https://orcid.org/0009-0002-3562-5361
Gauhati University, India

ABSTRACT

This study investigates the effects of stratification, radiation, and MHD flow on the behavior of a ternary hybrid nanofluid (Fe_3O_4-Cu-kerosene/engine oil) along a stretching-shrinking cylinder within a porous medium. Using conservation laws and similarity transformations, the governing PDEs are transformed into ODEs and solved with MATLAB's bvp4c function, revealing key thermal and dynamic characteristics. Findings show that ternary hybrid nanofluids, with enhanced thermal conductivity, outperform conventional nanofluids. Both temperature and velocity decrease under heat stratification, while heat transfer rates significantly improve in hybrid nanofluids. These insights support applications in environmental monitoring technologies, such as pollution control, thermal sensors, chemical detection, and water treatment. Understanding the flow of ternary hybrid nanofluids under these factors aids in enhancing global health technologies through improved performance and efficiency.

INTRODUCTION

The `bvp4c` function in MATLAB is a numerical solver designed for boundary value problems (BVPs) involving ordinary differential equations (ODEs). It employs the Lobatto IIIa method, a collocation technique that provides highly accurate solutions by solving nonlinear boundary value problems using a finite difference method. The solver can handle systems of equations, accommodating both linear and

DOI: 10.4018/979-8-3693-8532-6.ch002

nonlinear cases, and allows for the specification of boundary conditions at different points. Key features include adaptive mesh selection, which adjusts the number of mesh points to meet user-specified error tolerances, and the ability to handle singularities. It is particularly useful in physical and engineering applications, such as fluid dynamics, heat transfer, and structural mechanics, where differential equations are common. `bvp4c` requires users to define the ODEs, boundary conditions, and an initial guess for the solution. It iterates to minimize the error and converge to an accurate solution. Due to its flexibility and efficiency, `bvp4c` is widely used in research and industrial applications that involve complex boundary conditions.

Magnetohydrodynamics (MHD) studies the behavior of electrically conducting fluids, such as plasmas, liquid metals, and saltwater, in the presence of a magnetic field. It combines principles from both fluid dynamics and electromagnetism, examining how magnetic fields influence the motion of these fluids and how fluid movement affects the magnetic field. MHD has applications in various fields, including astrophysics, nuclear fusion, and engineering systems like cooling processes in reactors and magnetic propulsion. Its mathematical framework involves coupling the Navier-Stokes equations with Maxwell's equations, resulting in complex interactions between fluid flow and magnetic fields.

Thermal radiation is the emission of electromagnetic waves from a body due to its temperature. All objects with a temperature above absolute zero emit radiation, with intensity and wavelength distribution depending on the object's temperature. This form of heat transfer occurs without the need for a medium, unlike conduction or convection. Thermal radiation plays a crucial role in various applications, such as energy transfer in engineering systems, climate science, and astrophysics, and is governed by laws like Planck's and Stefan-Boltzmann's laws.

Thermal stratification refers to the formation of temperature layers within a fluid, where warmer, lighter fluid sits above cooler, denser fluid. This phenomenon occurs in natural and engineered systems, such as oceans, lakes, and storage tanks. It results from the differences in temperature, which create density gradients, preventing mixing between the layers. Thermal stratification significantly impacts heat transfer, fluid dynamics, and energy efficiency in various systems. In natural environments, it influences weather patterns and aquatic ecosystems, while in industrial applications, such as solar energy storage and HVAC systems, it affects thermal management and performance. The study of thermal stratification is essential for optimizing energy use and understanding environmental processes.

A ternary hybrid nanofluid consists of three distinct nanoparticles, such as metals, metal oxides, or hydrocarbons, dispersed in a base fluid like water, ethylene glycol, or oils, offering enhanced thermal properties compared to conventional or binary hybrid nanofluids. The combination of multiple nanoparticles creates synergistic effects that significantly improve thermal conductivity, viscosity, and heat transfer performance, making them ideal for applications in heat exchangers, cooling systems, energy storage, and advanced thermal management. For instance, a ternary hybrid nanofluid combining Fe_3O_4 (magnetite), Cu (copper), and $C_{12}H_{26}C_{15}H_{32}$ (paraffin-based hydrocarbon) exhibits unique properties, including high thermal conductivity, magnetic responsiveness, and thermal energy storage. Fe_3O_4's magnetic properties enable applications in magnetic fluid hyperthermia, drug delivery, and magnetically driven heat transfer systems, while copper nanoparticles, known for their excellent thermal conductivity, enhance the fluid's heat transfer efficiency in cooling systems and heat exchangers. The inclusion of $C_{12}H_{26}C_{15}H_{32}$ improves the stability and dispersibility of nanoparticles while providing phase change capabilities for storing and releasing thermal energy. These properties make ternary hybrid nanofluids highly versatile for industrial and environmental applications, including renewable energy systems, biomedical devices, and thermal management in electronics, where precise heat transfer control is essential. Their tunable properties,