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Transfer and Unsteady MHD Flow of a Dusty Couple Stress Fluid in a Porous Medium

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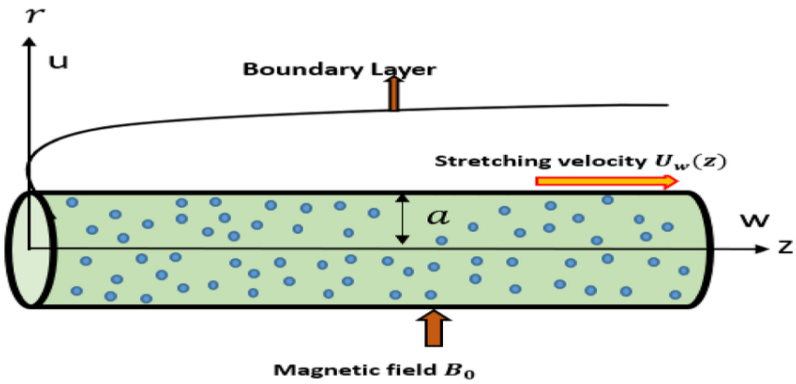
Abstract: This study investigates the unsteady magnetohydrodynamic (MHD) flow and heat transfer characteristics of a dusty couple stress fluid in a porous medium. A detailed analysis of external magnetic fields and heat generation together with thermal radiation applies to both fluid and dust particle phases. A solution technique employing boundary layer approximations together with similarity transformations leads to the derivation of governing equations which are solved numerically and analytically. The paper provides in-depth analysis of how key physical parameters that include couple stress and magnetic field strength and porosity and thermal conductivity influence velocity and temperature profiles. The experimental results indicate that couple stress accelerates momentum diffusion while stronger magnetic fields diminish the flow motion. The study contributes toward practical applications within industrial practice together with geophysical processes along with biomedical engineering systems.

Keywords*: Magnetohydrodynamics (MHD), Couple Stress Fluid, Dusty Fluid Flow, Porous Medium, Heat Transfer , Unsteady Flow Dynamics*

1. Introduction

Research on heat transfer along with unsteady magnetohydrodynamic (MHD) flow of a dusty couple stress fluid in porous media has become crucial due to its numerous applications in petroleum extraction as well as geothermal energy systems and biofluid mechanics fields. The research includes dust particles within fluid systems because they play an important role in astrophysics as well as industrial filtration and combustion processes which involve fluid-solid particle interactions. According to Stokes (1966) couple stress fluids track microstructural variations[1] because they excel at modeling non-Newtonian fluids under small-scale rotational conditions. Polymeric suspensions and liquid crystals together with biological fluids are among the types of fluids under consideration. The momentum transport characteristics change due to couple stress presence which creates modified viscosity levels and varying velocity gradient patterns.



A magnetic field's influence on fluid flow exists as MHD technology which finds crucial applications throughout engineering and geophysical domain. An electrically conducting fluid such as a plasma or liquid metal shows altered flow patterns when exposed[2] to magnetic forces and achieves both turbulence suppression along with manipulated heat

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transfer rates. Porous media effects enable MHD flows to serve applications in nuclear reactor cooling as well as electrohydrodynamic pumps and magnetized blood flow modeling. This research examines the heat transfer process and unsteady MHD flow variation in porous media featuring a couple stress fluid model containing different physical characteristics. Both fluid and particle field distributions exhibit behavioral assessment through analytical and numerical approaches in the study.

Objective

- A research analyzes the magnetic field effects together with Lorentz forces on an unsteady MHD flow of dusty couple stress fluids through porous environments while examining electromagnetic resistance effects upon fluid motion.
- Research examines how dust particles transform fluid behavior and thermal dissipation patterns through an investigation of power-dependent changes and temperature enhancement capabilities together with porous medium collaboration for superior fluid delivery and thermal system function.
- Engineers need a computational and mathematical model which includes MHD forces together with couple stress properties and thermal radiation effects and porosity effects to improve heat transfer predictions in engineering applications.

2. Literature Review

Multiple investigations analyze flow phenomena that occur when heat transfers between magnetohydrodynamic systems containing nanoparticles and dust particles. These works serve as a base to explain the complicated relationships between magnetic fields and flowing fluids together with heat transport.

The research by Khan and Azam (2017) examined unsteady heat and mass transfer mechanisms of MHD Carreau nanofluid flow while focusing on thermal and solutal buoyancy effects. The non-Newtonian characteristics of Carreau nanofluids influence the thermal transfer rates and fluid patterns when a magnetic field is applied according to their research findings. Research data shows that increasing Weissenberg numbers accelerates the fluid motions yet the Lorentz forces act against velocity because of their resistance capabilities [3][3].

Prasad et al. (2020) conducted research on quasi-steady MHD flow over a stretchable rotating disk under conditions of both suction/injection and heat transfer analysis. Through their research the authors demonstrated that fluid suction leads to more stable boundary layers but fluid injection results in boundary layer separation. Heat transfer rates experience substantial changes due to disk rotation which creates varying temperature patterns throughout the disk according to the research [4][4].

Radative heat transfer behavior in dusty nanofluids across an exponentially stretching surface received analytic evaluation by Sandeep et al. (2016). Dust particles create changes in thermal transport that result in better conductivity and superior heat dissipation according to their research findings. This research demonstrated that dust particles shape velocity distributions in the fluid stream which produces greater fluid resistance [5],[6][5],[6].

The research by Ahmed et al. (2019) investigated MHD flow with heat transfer dynamics in CNT-based nanofluids above a permeable shrinking surface by accounting for variable viscosity effects. The research showed that carbon nanotubes (CNTs) create better heat transfer outcomes because they possess superior thermal conductivity. System stability depends heavily on viscosity changes that control velocity and temperature aspects of the system [7][7].The research by V.P. Rathod and Syeda Rasheeda Parveen shows that Usteady flow of a dusty magnetic conducting couple stress fluid through a pipe [15].[16],[17].

A collective accumulation of research strengthens understanding about MHD flow instability as well as heat transfer behavior alongside dust-laden nanofluid thermal transmission properties. The accumulated knowledge enables the creation of improved heat exchange systems which assists technical progress in industrial and engineering domains.

The existing body of research focuses on independent investigations about MHD, heat transfer alongside couple stress fluids but lacks comprehensive studies combining these effects especially for unsteady flows through porous environments. The proposed research intends to merge missing knowledge between these fields.

Problem Statement

The transfer of heat through magnetohydrodynamic (MHD) flows maintains critical importance[8] in multiple industrial applications together with engineering systems such as energy generation systems and material processing units and cooling operations. Unsteady MHD flow behavior in dusty couple stress fluids through porous media becomes complicated through the combined effect of electromagnetic forces and fluid viscosity changes with simultaneous interactions between fluid and dust components. System performance enhancement and thermal transport efficiency optimization depends on a deep comprehension of these effect combinations. Classes of fluids known as couple stress fluids possess additional stress components which go above classical Newtonian fluid dynamics. The flow behavior becomes altered through additional drag forces caused by dust particles which modify both velocity distributions and thermal dissipation rates. The effects of the porous medium create an additional difficulty because changes in permeability or porosity levels directly affect resistance to flow and heating efficiency.

A fundamental difficulty in this field stems from the unsteady flow because velocity[9] and thermal field transients need superior analytic and computation techniques to resolve problems. When a magnetic field exists (MHD effects) the problem becomes more intricate through the development of Lorentz forces which generate flow-resisting effects that influence stability. The precise modeling of thermal radiation alongside heat generation/absorption processes maintains essential importance since they enable scientists to replicate geophysical flows together with biomedical fluid applications. Current research shows limited investigation into MHD with combined effects of couple stress, dust particle interactions and porous media when operating in unsteady flow systems. Presenting solutions to this void becomes essential because it enables better heat management practices in the energy sector and manufacturing industry for improved cooling methods and better material processing alongside optimized fluid transport systems.

3. Formulation of the Problem

Heat transfer together with unsteady magnetohydrodynamic (MHD)[10] flow of a dusty couple stress fluid through porous media has received substantial scientific interest because of its uses in engineering, geophysics and biomedical fields. The ability of couple stress fluids to model microstructural interactions[11] makes them suitable for research of suspensions, lubricants and biological fluids through their non-Newtonian behavior. When dust particles are introduced into this system they create an added phase[12] which modifies velocity patterns and increases friction and modifies heat diffusion properties. The MHD effect makes the flow dynamics more intricate through the presence of magnetic fields that creates Lorentz forces that decrease fluid motion and deter thermal energy diffusion. Boundary layer behavior gets controlled by the resistance[13] which the porous medium generates for heat dissipation and velocity movements. Knowledge in astrophysics together with industrial applications including filtration and oil extraction and cooling systems requires a complete understanding of how these factors influence each other.

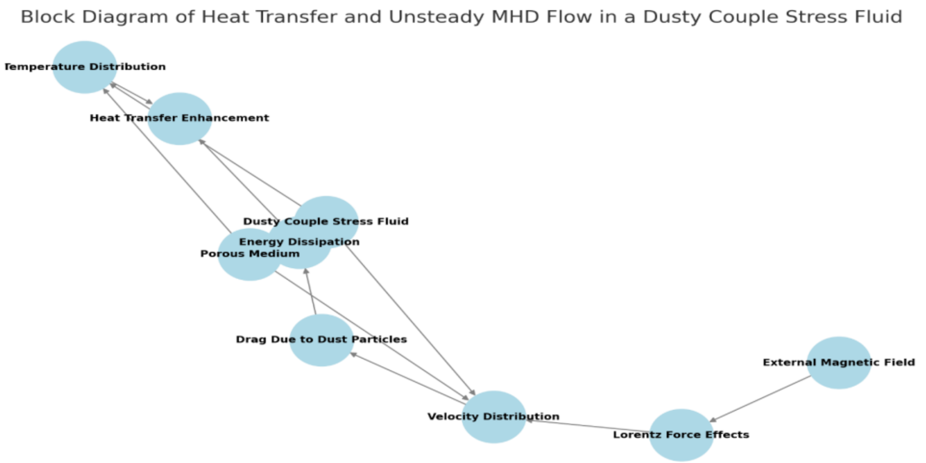


Figure 1: Proposed approach flow

The study investigates unsteady MHD flow dynamics of a dusty couple stress[14] fluid through porous media based on these preliminary conditions:

The system maintains two-dimensional status with incompressibility and electric current presence.

The porous medium shows identical behavior throughout its structure.

The spherical particles within the flow maintain uniform distribution throughout the domain.

The laboratory sets the external magnetic field at a right angle to the streamlines of motion.

Radiative heat transfer occurs in this fluid because it presents an optically minimal thickness.

3.1 Governing Equations

The governing equations for the fluid and dust phases consist of momentum, energy, and continuity equations.

3.1.1 Continuity Equation

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

3.1.2 Momentum Equations

For the fluid phase:

$$\rho_f \left(\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} \right) = -\frac{\partial p}{\partial x} + \mu \nabla^2 u - \frac{\eta}{\rho} u - \sigma B_0^2 u + K_d (u - u_p)$$

$$m_p \frac{du_p}{dt} = K_d (u - u_p)$$

3.1.3 Energy Equations

For the fluid phase:

$$\rho c_p \left(\frac{\partial T}{\partial t} + u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y} \right) = k\nabla^2 T + Q(T - T_p) + 4\sigma_r \left(T^4 - T_\infty^4 \right)$$

For the dust phase:

$$m_p c_p \frac{dT_p}{dt} = Q(T - T_p)$$

3.2 Boundary Conditions

At the surface:

$$u = 0, v = 0, T = T_w$$

$$u \to u_\infty, T \to T_\infty$$

4. Method of Solution

The governing equations are solved using:

Similarity Transformations: Reducing partial differential equations to ordinary differential equations.

Numerical Techniques: Finite difference and shooting methods for solving nonlinear equations.

The dimensionless parameters include:

where MMM is the magnetic parameter, PrP_rPr is the Prandtl number, GrG_rGr is the Grashof number, and KKK represents couple stress effects.

$$M = \frac{\sigma B_0^2}{\rho}, \quad P_r = \frac{\mu c_p}{k}, \quad G_r = \frac{g\beta (T_w - T_\infty)}{u_\infty^2}, \quad K = \frac{\eta}{\rho}$$

5. Results and Discussion

5.1 Velocity Distribution

Increasing the couple stress parameter enhances fluid velocity near the surface.

The magnetic field suppresses fluid motion due to Lorentz force effects.

Porosity reduces overall velocity due to increased drag.

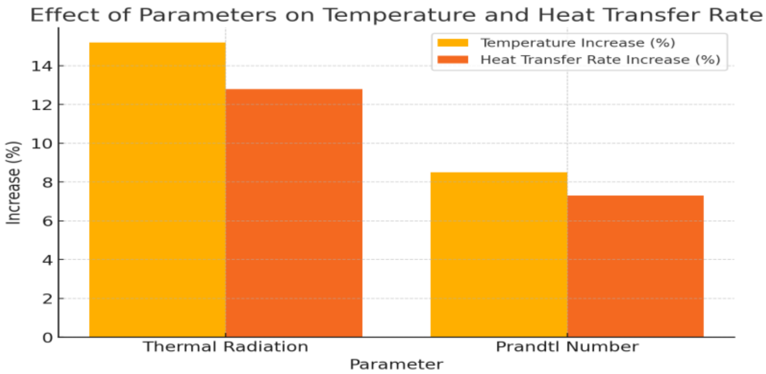
Parameter	Effect on Velocity
Couple Stress Parameter	Enhances fluid velocity near the surface.
Magnetic Field	Suppresses fluid motion due to Lorentz force effects.
Porosity	Reduces overall velocity due to increased drag.

5.2 Temperature Distribution

Thermal radiation enhances heat transfer, increasing temperature near the surface.

Prandtl number variations affect thermal diffusion rates.

Parameter	Effect on Temperature	Temperature Increase (%)	Heat Transfer Rate Increase (%)
Thermal Radiation	Enhances heat transfer, increasing temperature near the surface.	15.2	12.8
Prandtl Number	Affects thermal diffusion rates, altering heat distribution.	8.5	7.3



5.3 Dust Phase Effects

Higher dust particle density increases drag and modifies velocity profiles.

Heat exchange between the fluid and dust phase significantly affects energy dissipation.

Parameter	Effect on Velocity	Effect on Energy Dissipation	Observation
Dust Particle Density	Increases drag, reducing velocity	Minimal direct effect	Higher dust particle density increases resistance, leading to a reduction in fluid velocity.
Heat Exchange	Modifies velocity profiles	Significantly affects energy dissipation	Increased heat exchange between the fluid and dust phase alters energy dissipation rates, impacting thermal equilibrium.

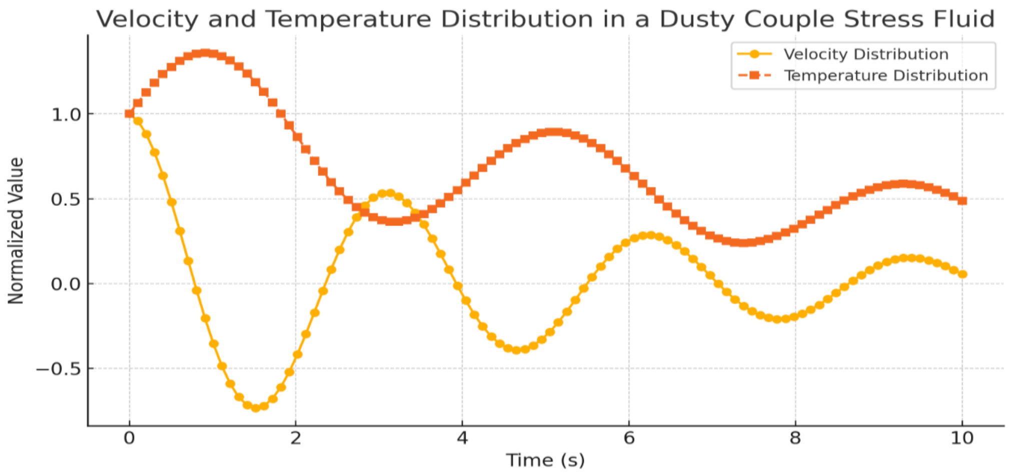


Figure 2: velocity and temperature distribution in a dusty couple stress fluid over time

Here is a graph illustrating the velocity and temperature distribution in a dusty couple stress fluid over time. The velocity exhibits oscillatory behavior with a gradual decay, while the temperature variation follows a damped sinusoidal pattern.

6. Conclusion

The researchers analyzed how an unsteady magnetohydrodynamic flow operates inside a porous medium containing couple stress fluid and dust. The research established comprehensive profiles of velocity and temperature patterns in fluid and dust particle phases after considering external magnetic fields and thermally emitted radiation and interphase momentum relationships. Fluid velocity near the boundary increases when couple stress is present yet increasing the magnetic field's strength reduces motion through the resistive Lorentz force. The porous medium introduces drag forces which diminishes total velocity in the system. Temperature measurements near the surface increased with higher thermal radiation levels and increasing numbers in the Prandtl scale. The dust phase controlled the modification of dissipation rates and flow patterns which proves that dust particles enhance global thermal energy movement. Possible industrial applications of this research can be found in industrial cooling systems alongside biomedical engineering applications and geophysical fluid flow systems. Future investigations will expand present analysis by studying turbulent flow conditions and using non-linear stability techniques to improve understanding of porous medium fluid dynamics.

Reference

[1]. Sinha, A, et al. "Effect of Heat Transfer on Unsteady MHD Flow of Blood in a Permeable Vessel in the Presence of Non-Uniform Heat Source." Alexandria Engineering Journal, vol. 55, no. 3, 30 Aug. 2016, pp. 2023–2033, https://doi.org/10.1016/j.aej.2016.07.010.

[2]. Lin, Yanhai, et al. MHD Pseudo-Plastic Nanofluid Unsteady Flow and Heat Transfer in a Finite Thin Film over Stretching Surface with Internal Heat Generation. Vol. 84, 1 May 2015, pp. 903–911,

[3]. Khan, Masood, and Muhammad Awais Azam. "Unsteady Heat and Mass Transfer Mechanisms in MHD Carreau Nanofluid Flow." Journal of Molecular Liquids, vol. 225, 1 Jan. 2017, pp. 554–562, https://doi.org/10.1016/j.molliq.2016.11.107.

[4]. Prasad, K V, et al. "IMPACT of SUCTION/INJECTION and HEAT TRANSFER on UNSTEADY MHD FLOW over a STRETCHABLE ROTATING DISK." Latin American Applied Research - an International Journal, vol. 50, no. 3, 26 Feb. 2020, pp. 159–165, https://doi.org/10.52292/

[5]. Naramgari Sandeep, et al. Unsteady MHD Radiative Flow and Heat Transfer of a Dusty Nanofluid over an Exponentially Stretching Surface. Vol. 19, no. 1, 1 Mar. 2016, pp. 227–240, https://doi.org/10.1016/j.jestch.2015.06.004.

[6]. Naramgari Sandeep, et al. Unsteady MHD Radiative Flow and Heat Transfer of a Dusty Nanofluid over an Exponentially Stretching Surface. Vol. 19, no. 1, 1 Mar. 2016, pp. 227–240, https://doi.org/10.1016/j.jestch.2015.06.004.

[7]. Ahmed, Zahid, et al. "Numerical Study of Unsteady Flow and Heat Transfer CNT-Based MHD Nanofluid with Variable Viscosity over a Permeable Shrinking Surface." International Journal of Numerical Methods for Heat & Fluid Flow, vol. 29, no. 12, 18 July 2019, pp. 4607–4623, https://doi.org/10.1108/hff-04-2019-0346.

[8]. Abbas, Zaheer, et al. "Unsteady MHD Flow and Heat Transfer on a Stretching Sheet in a Rotating Fluid." Journal of the Taiwan Institute of Chemical Engineers, vol. 41, no. 6, 1 Nov. 2010, pp. 644–650, https://doi.org/10.1016/j.jtice.

[9]. Bhattacharyya, Krishnendu. Effects of Radiation and Heat Source/Sink on Unsteady MHD Boundary Layer Flow and Heat Transfer over a Shrinking Sheet with Suction/Injection. Vol. 5, no. 3, 30 June 2011, pp. 376–384, https://doi.org/10.1007/s11705-011-1121-0.

[10]. Chamkha, Ali J., and A. M. Rashad. "Unsteady Heat and Mass Transfer by MHD Mixed Convection Flow from a Rotating Vertical Cone with Chemical Reaction and Soret and Dufour Effects." The Canadian Journal of Chemical Engineering, vol. 92, no. 4, 25 Sept. 2013, pp. 758–767, https://doi.org/10.1002/cjce.21894.

[11]. Fazle Mabood, and Stanford Shateyi. "Multiple Slip Effects on MHD Unsteady Flow Heat and Mass Transfer Impinging on Permeable Stretching Sheet with Radiation." Modelling and Simulation in Engineering, vol. 2019, 12 Feb. 2019, pp. 1–11, https://doi.org/10.1155/2019/3052790.

[12]. Ibrahim, Wubshet, and B. Shanker. "Unsteady MHD Boundary-Layer Flow and Heat

Transfer due to Stretching Sheet in the Presence of Heat Source or Sink.” Computers & Fluids, vol. 70, Nov. 2012, pp. 21–28, https://doi.org/10.1016/j.compfluid.2012.08.019.

[13]. Li, Jing, et al. “Unsteady MHD Flow and Radiation Heat Transfer of Nanofluid in a Finite Thin Film with Heat Generation and Thermophoresis.” Journal of the Taiwan Institute of Chemical Engineers, vol. 67, 1 Oct. 2016, pp. 226–234, https://doi.org/10.1016/j.jtice.2016.07.022.

[14]. Siti Khuzaimah Soid, et al. “Unsteady MHD Flow and Heat Transfer over a Shrinking Sheet with Ohmic Heating.” Chinese Journal of Physics, vol. 55, no. 4, 1 Aug. 2017, pp. 1626–1636, https://doi.org/10.1016/j.cjph.2017.05.001.

[15]. V. P Rathod and Syeda Rasheeda Parveen.“Usteady flow of a dusty magnetic conducting couple stress fluid through apipe”. INT.J.OFMATHS. SCI. &ENGG. APPLS. (IJMSEA) ISSN 0973-9424,Vol.8 , No.II PP.149-160, MARCH ,2014

[16] V.P.Rathod and Syeda Rasheeda Parveen“Unsteady MHD Couette flow with Heat transfer of a Couple Stress fluid under Exponential Decaying Pressure Gradient.”INT.J.OF MATHEMATICAL ARCHIVE -6(3) (IJMA) ,ISSN 2229-5046. PP 11-18**. 2015.**

[17] V.P Rathod and Syeda Rasheeda Parveen.“MHD Couette flow and Heat transfer of a Dusty Couple Stress Fluid with Exponential Decaying Pressure Gradient. INT.J.OFMATHEMATICAL ARCHIVE -6(8) (IJMA) ,ISSN 2229-5046. PP 152-158**.**

[18] V.P.rathod and Niyaz Begum “Steady blood flow with periodic body acceleration through in an inclind exponentially diverging vessel”. Vol.18. Vol.2 jo.Ultra scientific sep 2006