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An Exploration of the Influence of MHD, Porosity, and Wall Transpiration on Jeffrey, Fluid Flow

***Dr. P. Aparna[1], Dr. M.V.D.N.S. Madhavi[2], Dr. Ravitheja Badugu[3], Mr. Hari Kumar Andem[4], Dr. P. Satish[5], Mr. Umakanta Choudhury[6], Dr. Nellore Manoj Kumar[7]**

[1]Associate Professor, Department of Mathematics, VNR Vignana Jyothi Institute of Engineering and Technology, Hyderabad, Telangana, India, Pincode: 500090, Email-id: aparnapodila@gmail.com

[2]Assistant Professor, Department of Mathematics, VR Siddhartha Engineering College, Siddhartha Academy of Higher Education, Deemed to be University, Vijayawada, Andhra Pradesh, India, Pincode: 520 007. Email id: mvdnsmadhavi@vrsiddhartha.ac.in

[3]Assistant Professor, Department of Mathematics (H&S), CMR College of Engineering and Technology, Medchal, Telangana, India, Pincode: 501401. Email: baduguraviteja@gmail.com

[4]Assistant Professor, Department of Mechanical Engineering, Kakatiya Institute of Technology and Science, Warangal, Telangana, India, Pincode: 506015.Email id: ahk.me@kitsw.ac.in

[5]Associate Professor, Department of Mathematics,Aditya University, Surampalem, Andhra Pradesh, India, Pincode: 533437. Email Id- satishmaths.7@gmail.com

[6]Professor, Department of Electrical Engineering, NIET, Alwar, Affiliated to Bikaner Technical University, Bikaner, Rajasthan, Pincode: 301028, Email id : ukchoudhury22@gmail.com

[7]Department of Mathematics, Saveetha School of Engineering, Saveetha Institute of Medical and Technical Sciences (SIMATS),Thandalam, Chennai, Tamilnadu, India, Pincode: 602 105. Email id: nelloremk@gmail.com

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Abstract:

This work explores the complex dynamics of Jeffrey fluid flow, with a focus on the effects of wall transpiration, porosity, and magnetohydrodynamics (MHD). The goal of the study is to offer a thorough grasp of how these variables affect the flow properties of Jeffrey fluid. Additionally, the effects of porosity and MHD on fluid velocity are examined. Finding the analytical solution for the incompressible transient flow of MHD (magneto hydrodynamic) Jeffrey fluid above an accelerating porous plate is the main goal of this research work. The plate is infinite in the x-direction and produces an oscillating motion when the fluid flows over it at. Porous plates are utilized to allow both injection and suction phenomena to occur. Using the right choice of nondimensional variables makes the model's governing equation dimensionless. These nondimensional differential equations of the Jeffrey fluid are solved with the aid of perturbation techniques and Laplace transformation. Studies are conducted on how various characteristics affect velocity. Oscillating frequency (ω), ratio of relaxation to retardation time (λ1), Jeffrey fluid parameter (β), wall transpiration parameter (γ), time (t), porosity parameter (k), and magnetic parameter (Ha) are some of these characteristics. The results have ramifications for different technical and industrial situations where Jeffrey fluids are encountered and add to the corpus of knowledge on non-Newtonian fluid dynamics.

Keywords: MHD, Porosity, Transpiration, Jeffrey, Fluid Flow, Transpiration Parameter

1.INTRODUCTION

Environmental sciences, industrial operations, and many other scientific and engineering domains depend heavily on the study of fluid dynamics. Non-Newtonian fluids have attracted a lot of attention lately because of their extensive uses and intricate behavior. The Jeffrey fluid model is unique among these non-Newtonian fluids since it can represent viscoelastic and shear-thinning characteristics, which makes it applicable in a variety of real-world situations. An intriguing field of study is the behavior of Jeffrey fluids in various scenarios, including the presence of magnetic fields (MHD), porous media, and wall transpiration. The term magnetohydrodynamics (MHD) is the study of how electrically conducting fluids behave when magnetic fields are present. Applications in magnetic drug targeting, electromagnetic material processing, and magneto-rheological fluids require an understanding of how MHD affects the flow of Jeffrey fluids. Another important component that influences fluid flow is porosity, which is particularly important in biological tissues, industrial filtering systems, and geological formations. The existence of pores modifies the way fluids flow, resulting in phenomena including improved mass transfer, filtration, and interactions between fluids and solids. Examining the relationship between porosity and Jeffrey fluid flow sheds light on fluid transport in porous surfaces and has applications in biomedical engineering, increased oil recovery, and groundwater remediation.

In addition, the dynamics of boundary layers and heat transfer processes are greatly affected by wall transpiration, which is defined as the mass or momentum transfer via permeable walls. Our understanding of fluid-solid interactions and the performance of membrane filtration, heat exchangers, and microfluidic devices can both be improved by knowing how wall transpiration affects the flow of Jeffrey fluids. Although Jeffrey fluid flow and its applications are gaining popularity, little is known about the combined effects of wall transpiration, porosity, and MHD on flow behavior. Research on the intricate relationships between these variables and their practical ramifications can take advantage of this gap in knowledge. This study intends to provide light on the basic principles guiding non-Newtonian fluid dynamics in various contexts by examining the effects of MHD, porosity, and wall transpiration on Jeffrey fluid flow. This work aims to improve our understanding of Jeffrey fluid behavior and help create novel technologies and engineering solutions by combining numerical simulations, experimental validation, and mathematical modeling.

1.1 Significance of Fluid Dynamics

Fluid dynamics is extremely important in a wide range of scientific and technical fields, serving as the foundation for many different disciplines. It is applicable to a wide range of domains, including industrial operations, biomedical engineering, and environmental sciences. Fluid dynamics is used in environmental studies to study atmospheric and oceanic events, which helps with climate modeling and weather forecasting. Understanding fluid behavior in industrial processes is essential for improving energy generation, streamlining transportation systems, and streamlining manufacturing procedures. Moreover, fluid dynamics is essential to the development of medical devices, drug delivery systems, and simulations of arterial blood flow in biomedical engineering. Therefore, fluid dynamics is important because it may offer understanding and answers to a wide range of real-world problems in a variety of applications and sectors.

1.2 Non-Newtonian Fluids

The traditional linear relationship between stress and strain rate found in Newtonian fluids is fascinatingly absent from non-Newtonian fluids. Rather, they exhibit complex responses that change according upon the pace of applied stress or strain. The Jeffrey fluid model is one of the more notable non-Newtonian fluid models. Its viscoelastic nature, which includes both viscous and elastic reactions to deformation, and its shear-thinning qualities, where viscosity falls as shear rate increases, set it apart. The Jeffrey fluid model is an invaluable resource for comprehending and characterizing the behavior of intricate fluids seen in a wide range of real-world settings, from biological systems to industrial processes. The framework's capacity to accurately represent the complex rheological properties of non-Newtonian fluids makes it an essential tool for fluid dynamics study and engineering.

2. REVIEW OF LITREATURE

A. Khan, G. Zaman, S. Ahmad, and M. I. Chohan (2017) In this research, the N-transform technique is used to analyze exact solutions of generalized Jeffrey fluid. The authors provide a thorough examination of this specific fluid type's behavior, illuminating its dynamic characteristics under various circumstances. They add significant knowledge to the field of computational mathematics by using the N-transform approach to provide insights into the complex behavior of the fluid.

S. Han, L. Zheng, and X. Zhang (2016) The impact of slip effects on a generalized Burgers' fluid flow with fractional derivatives confined between two side walls is investigated by the authors in this work. By means of their inquiry, they ascertain the impact of slip phenomena on the dynamics of fluid flow, so furnishing a more profound comprehension of the intricate interplay between fluid motion and boundary conditions. Fractional derivatives add a level of intricacy to the analysis and enhance the corpus of fluid dynamics literature that already exists.

M. Jamil (2016) By analyzing how slip affects oscillating fractionalized Maxwell fluid, this work provides important new information about how this particular kind of fluid behaves in oscillatory situations. By examining how slip occurrences affect the flow properties, the author clarifies how boundary conditions affect fluid dynamics as a whole. They advance our knowledge of fluid behavior in complicated systems by adding to the expanding corpus of study on nonlinear engineering through their analysis.

Jakati et al. (2018). Analyze the behavior of suspended nanoparticle nanofluids in a Jeffrey fluid medium. The paper focuses on the effects of thermophoresis and Brownian motion on nanofluid stretching, and utilizes the Jeffrey fluid model to describe the fluid dynamics. Through mathematical modeling and numerical simulations, the authors investigate the effects of various factors on the flow and temperature fields, providing insights into the underlying concepts governing the behavior of nanofluids. The findings deepen our understanding of nanofluid dynamics and have significant ramifications for engineering applications involving fluid flow and heat transfer.

T. Hayat, M. Waqas, S. A. Shehzad, and A. Alsaedi (2015) This work investigates the radially stretched surface magnetohydrodynamic (MHD) stagnation point flow of a Jeffrey fluid while taking viscous dissipation and Joule heating effects into account. The Jeffrey fluid model can be used in a variety of industrial and biological applications because it can be used to characterize materials that have both viscous and elastic properties. The incorporation of MHD effects, viscous dissipation, and Joule heating renders this study especially pertinent to comprehending the behavior of thermally-effectuated electrically conducting fluids. The writers offer a thorough examination that includes considerations of physical interpretations, numerical solution approaches, and mathematical modeling. The paper's accessibility and organization make it easier for researchers and industry practitioners to understand. The paper's impact may be increased, nevertheless, by going into more detail on the results' practical implications and possible directions for experimental validation.

3. GOVERNING EQUATIONS OF JEFFREY FLUID MODEL

For the present issue, we use the velocity field.

$$V = (u\,(y,t)\,, V_0, 0)\,,$$

where is the fluid's velocity in the y-direction and is the velocity distribution in the -direction.

The equations that make up a Jeffrey fluid are

$$\tau = -p\mathrm{I} + \mathrm{S},$$

$$\mathrm{S} = \frac{\mu}{1+\lambda_1}\left[\mathrm{R}_1 + \lambda_2\left(\frac{\partial \mathrm{R}_1}{\partial t} + V.\nabla\right)\mathrm{R}_1\right]$$

where denotes the Cauchy stress tensor, S stands for the extra stress tensor, is the fluid's dynamic viscosity, is the retardation time, is the ratio of relaxation and retardation durations, and is the Rivlin–Ericksen tensor, which has the following well-defined values

$$\mathrm{R}_1 = (\nabla V) + (\nabla V)^t$$

4. MATHEMATICAL MODELING

Assuming that the accelerating plate is porous, let's look at the incompressible transient flow of the MHD Jeffrey fluid model covering the area above it. It is suggested that the fluid's velocity field be thought of in the form (1).

A strong, homogeneous transverse magnetic field is applied parallel to the y-axis. The Jeffrey fluid flow's velocity profile will start at zero. The porous plate's velocity at that moment is. Figure 1 looks like this.

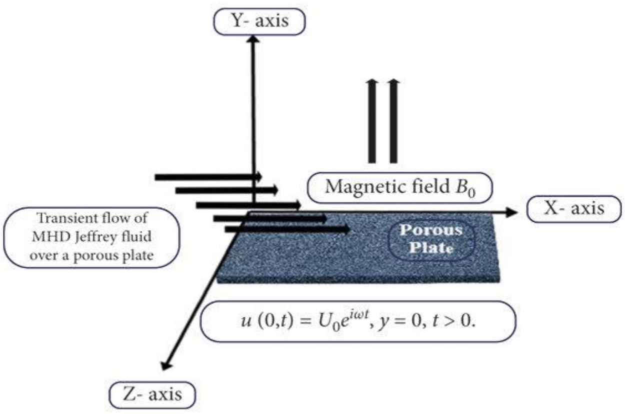

Figure 1: Fluid flow atop an accelerating porous plate in MHD Jeffrey.

The governing equation for the flow of an unstable incompressible MHD Jeffrey fluid over a porous plate has the following form in light of the aforementioned observations for the specified Jeffrey fluid model.

$$\rho\left(\frac{\partial u}{\partial t}-V_0\frac{\partial u}{\partial y}\right)=\frac{\mu}{1+\lambda_1}\left[\frac{\partial^2 u}{\partial y^2}+\lambda_2\frac{\partial^3 u}{\partial y^2\partial t}+\lambda_2 V_0\frac{\partial^3 u}{\partial y^3}\right]$$
$$-\frac{\mu\phi}{\kappa(1+\lambda_1)}\left(1+\lambda_2\frac{\partial}{\partial t}\right)u-\sigma B_0^2 u,\ y>0,\ t$$

where are, respectively, the components of velocity in the x- and y-directions. shows the consistent transpiration (suction or blowing) velocity at the permeable wall's surface. is the retardation time, and is the ratio of relaxation to retardation times. It is noteworthy that the governing equation of a Newtonian fluid can be obtained by inserting into the equation mentioned above; if, the fluid is of second grade. indicates the fluid's electrical conductivity, the fluid's density, the permeability and porosity of the porous plate, the strength of the applied magnetic field, and the coefficient of fluid viscosity.

Initial and boundary conditions that are suitable include

$$u(y,0)=0,\quad y>0,$$
$$u(0,t)=u_0(t)=U_0e^{\iota\omega t}\quad \text{at}\, y=0, t>0,$$
$$u(\infty,t)=0,\quad \text{as}\, y\longrightarrow\infty, t>0,$$

Where is the frequency of oscillation?

We now utilize the following collection of dimensionless variables as the basis for the dimensionless form of the aforementioned equations.

$$u^*=\frac{u}{U_0},$$
$$y^*=\frac{U_0 y}{\nu},$$
$$t^*=\frac{U_0^2 t}{\nu},$$
$$\omega^*=\frac{\omega\nu}{U_0^2},$$
$$\beta=\frac{U_0^2}{\nu}\lambda_2,$$
$$2\gamma=\frac{V_0}{U_0},$$
$$\frac{1}{k}=\frac{\nu^2\phi}{\kappa U_0^2},$$
$$Ha=\frac{\sigma B_0^2\nu}{\rho U_0^2}.$$

The initial-boundary value problem's nondimensional form (dropping the () notation for convenience) as

$$\frac{1}{1+\lambda_1}\left(\frac{\partial^2 u}{\partial y^2}+\beta\frac{\partial^3 u}{\partial y^2\partial t}+2\beta\gamma\frac{\partial^3 u}{\partial y^3}\right)-\frac{1}{k\left(1+\lambda_1\right)}\left(1+\beta\frac{\partial}{\partial t}\right)u-Hau$$
$$+2\gamma\frac{\partial u}{\partial y}-\frac{\partial u}{\partial t}=0,$$
$$u\left(y,0\right)=0,\quad y>0,$$
$$u\left(0,t\right)=u_0\left(t\right)=e^{\iota\omega t}\quad \text{at } y=0, t>0,$$
$$u\left(\infty,t\right)=0,\quad \text{as y}\longrightarrow\infty, t>0,$$

where is the wall transpiration value (for injection and suction) and displays the Jaffrey fluid parameter. and Ha are the magnetic and porosity parameters.

5. EXAMINE THE VELOCITY FIELD'S SOLUTION

We obtain the solution of the nondimensional initial boundary value issue by using the Laplace transformation approach in conjunction with a regular perturbation. The following equations are obtained by using the Laplace transformation method with regard to t (time) on the original equations:

$$\frac{1}{1+\lambda_1}\left(1+\beta s\right)\frac{\partial^2\overline{u}}{\partial y^2}+\frac{2\beta\gamma}{1+\lambda_1}\frac{\partial^3\overline{u}}{\partial y^3}+2\gamma\frac{\partial\overline{u}}{\partial y}-s\overline{u}$$
$$-\frac{1}{k\left(1+\lambda_1\right)}\left(1+\beta s\right)\overline{u}-Ha\overline{u}=0,$$
$$\overline{u}\left(0,s\right)=\frac{1}{s-\iota\omega},\overline{u}\left(\infty,s\right)$$
$$=0 asy\longrightarrow\infty, t>0,$$

where is designated as the transform parameter and is called the preimage of.

Using the boundary conditions, we apply the regular perturbation technique to find the solution of and expand in terms of the parameter:

$$\overline{u}\left(y,s\right)=\overline{u}_0\left(y,s\right)+\beta\overline{u}_1\left(y,s\right)+o\left(\beta^2\right).$$

Now, equal the powers of and substituting (13) for (11) and (12), we have

$$\overline{u}_0''+2\gamma\left(1+\lambda_1\right)\overline{u}_0'-\left[\left(1+\lambda_1\right)s+\frac{1}{k}+Ha\left(1+\lambda_1\right)\right]\overline{u}_0=0$$
$$\overline{u}_0\left(0,s\right)=\frac{1}{s-\iota\omega},$$
$$\overline{u}_0\left(\infty,s\right)=0$$
$$\overline{u}_1''+2\gamma\left(1+\lambda_1\right)\overline{u}_1'-\left[\left(1+\lambda_1\right)s+\frac{1}{k}+Ha\left(1+\lambda_1\right)\right]\overline{u}_1$$
$$=-2\gamma\overline{u}_0'''-s\overline{u}_0''+\frac{s}{k}\overline{u}_0,$$
$$\overline{u}_1\left(0,s\right)=0,$$
$$\overline{u}_1\left(\infty,s\right)=0.$$

The following are the answers to the aforementioned equations:

$$\bar{u}_0(y,s) = \frac{1}{s-\iota\omega} e^{-y\left(\delta_0+\delta_1\sqrt{s+\delta_2}\right)},$$

$$\bar{u}_1(y,s) = -\frac{D_1(s)\,y}{2\delta_1\sqrt{s+\delta_2}} e^{-y\left(\delta_0+\delta_1\sqrt{s+\delta_2}\right)},$$

were

$$\delta_0 = \gamma\left(1+\lambda_1\right),$$

$$\delta_1 = \sqrt{1+\lambda_1},$$

$$\delta_2 = \frac{\gamma^2\left(1+\lambda_1\right)^2 + 1/k + Ha\left(1+\lambda_1\right)}{\left(1+\lambda_1\right)},$$

$$D_1(s) = \frac{2\gamma\left(\delta_0+\delta_1\sqrt{s+\delta_2}\right)^3}{s-\iota\omega} - \frac{s\left(\delta_0+\delta_1\sqrt{s+\delta_2}\right)^2}{s-\iota\omega} + \frac{s}{k\left(s-\iota\omega\right)}.$$

5.1 Limiting Case

A comparison of the current work with and without MHD and porosity effects is shown in the accompanying figure. This picture makes it evident that, in contrast to the current solutions in the absence of MHD and porosity effects, the velocity decays earlier in the presence of MHD and porosity effects (Figure2).

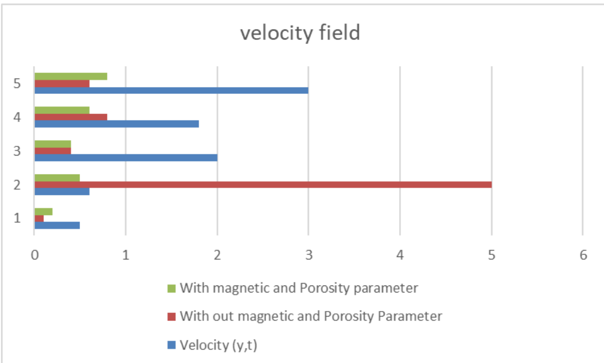

Figure 2: Velocity field comparison with and without porosity and magnetic characteristics.

The given data shows velocity values (shown as y) at two different time intervals (represented as t) under two separate sets of conditions: without and with magnetic and porosity factors. The velocity values under the first set of conditions vary in time intervals from 0.5 to 3. Interestingly, there is change in the velocities, indicating dynamic fluid behavior across time. These variations may be explained by intrinsic properties of the fluid system in question, such as variations in viscosity or outside factors influencing the dynamics of the flow.

On the other hand, the velocity measurements show distinct trends when porosity and magnetic factors are added. The speeds still differ in magnitude, but they follow a different pattern than under the preceding conditions. Specifically, in contrast to the initial set of conditions, the velocities vary with time, falling between 0.1 and 0.8. These observed differences in velocity are probably the result of changing the underlying fluid dynamics by adding magnetic and porosity factors. Overall, the two sets of conditions are compared to show how much fluid velocity is affected by magnetic and porosity characteristics. These characteristics cause the system to become more complex, which leads to different velocity profiles over time. For a thorough analysis of fluid flow behaviors and process optimization in a variety of engineering and scientific applications, it is essential to comprehend and understand these variances.

6. DISCUSSION OF NUMERICAL RESULTS AND GRAPHS

Graphs for the fluid's velocity profile have been created in order to argue specific physical properties of the computed solution.

It is crucial to clarify the impact of time in this context. Figure 3 shows how the fluid's velocity field behaves when the values of are changed. It is clear from this picture that the velocity field increases when the values of time increase.

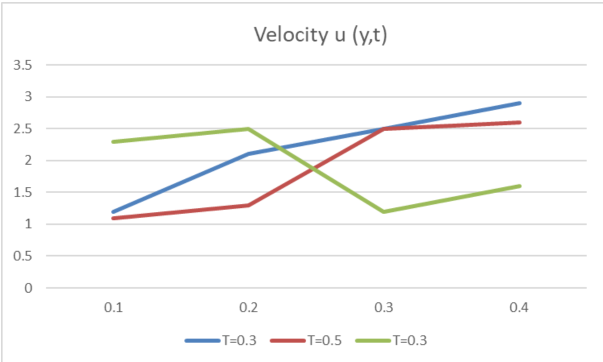

Figure 3: Speed profile for various time intervals

The velocity values (shown as Y) at various time intervals (represented as T) are shown in the given data, notably at T = 0.3 and T = 0.5. Every velocity value, denoted by Y Y, correlates to a particular location inside a fluid system. The velocity values at $T = 0.3$ T=0.3 range from 0.1 to 0.4, reflecting the dynamic behavior of the fluid at this specific time point. The velocities, which range in value from 1.2 to 2.9, show variations at various places within the fluid. This variety points to the possibility of spatial heterogeneity in the fluid flow, wherein some areas may see faster fluid velocities than others.

Likewise, with V = 0.5 T = 0.5, the velocity values exhibit additional variations at various fluid locations. The range of velocities is 1.1 to 2.6, and the corresponding positions show different flow properties. Interestingly, relative to $T = 0.3$ T=0.3, certain spots have a velocity increase, while others may show a reduction or stay mostly unchanged. This dynamic behavior emphasizes the significance of temporal considerations in the analysis of velocity distributions within a fluid system and illustrates the complexity of fluid flow phenomena. Overall, the findings highlight the temporal and spatial heterogeneity in fluid velocity, highlighting the necessity of thorough analysis to properly comprehend the underlying dynamics. Researchers may learn a great deal about fluid behavior and enhance operations in a variety of technical and scientific applications by looking at velocity profiles at different times and locations.

7. CONCLUSION

Understanding the governing equations and mathematical modeling of Jeffrey fluid models is important for understanding the dynamics of complex fluid systems. This is especially true when studying magnetohydrodynamic (MHD) flows over porous plates. Through investigating the effects of variables like porosity and magnetic fields on fluid velocity profiles, scientists can better comprehend the fundamental principles controlling fluid flow behaviors. The comparison of velocity numbers under various settings shows how important porosity and magnetic characteristics are to fluid dynamics and emphasizes how important it is to take these elements into account in scientific and engineering applications. Additionally, the discussion of the numerical results and graphical representations highlights the variety in fluid velocity both spatially and temporally, highlighting the need for rigorous investigations to fully understand fluid flow phenomena. All things considered, this review advances our grasp of non-Newtonian fluid mechanics and motivates more research projects targeted at process optimization and knowledge expansion in a variety of scientific and engineering fields.

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