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Original Research Paper

Numerical simulation of water based magnetite nanoparticles between two parallel disks

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A B S T R A C T

Present study examines the fully developed squeezing flow of water functionalized magnetite nanoparticles between two parallel disks. For strongly magnetite fluid (water) three different types of nanoparticles having better thermal conductivity: Magnetite (Fe_3O_4), Cobalt ferrite ($CoFe_2O_4$) and Mn–Zn ferrite ($Mn{-}ZnFe_2O_4$) are incorporated within the base fluid (water). Systems of equations containing the nanoparticle volume fraction are rehabilitating in the form of partial differential equations using cylindrical coordinate system. Resulting mathematical model is rehabilitated in the form of ordinary differential equations with the help of compatible similarity transformation. Results are analyzed for velocity, temperature, reduced skin friction and reduced Nusselt number with variation of different emerging parameters and determine the superb thermal conductivity among mentioned nanoparticles. Comparison among each mixture of ferrofluid has been plotted as response to differences in reduced skin friction and reduced Nusselt number distributions. Dominating effects are analyzed for squeezing parameter and it is found that water based-magnetite (Fe_3O_4) gives the highest reduced skin friction and reduced Nusselt number as compared to the rest of the mixtures. Isotherms are also plotted against various values of nanoparticle volume fraction to analyze the temperature distribution within the whole domain of squeezing channel.

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1. Introduction

Squeezing flow is a term frequently addressed in practical environments to define a fluid movement along a contracting domain of a prescribed length. Such flow can be set up by positioning an initial stagnant fluid between two parallel rectangular plates and disks or even in a channel to represent the corresponding mathematical models on specific coordinate planes. Hence the squeezing flow is generalized when the fluid is suppressed to pass through the commonly horizontally narrow enclosure due to one of the surface contracting vertically in relation to the other stationary surface. Adversely there are generous studies incriminating a contracting rotating disk as well as two rotating disks or two moving walls toward or away from each other. Research interests in squeezing flows are rapidly developed due to existing and growing applications in the transport of biological fluids and in the manufacturing processes of polymer, lubrication, hydrodynamic compression, purification, filtration, injection molding and many others. Squeezing motion at varying distance between two moving disks is inspected by Ishizawa [1] using a perturbative solution. Moreover, Usha and Sridharan [2] derive an exact solution for similar pertinent factor but between two elliptic plates in the form of infinite time-dependent multifold series. The squeezing flow of couple stress fluid through an elongated rectangular channel is solved numerically by Srinivasacharya et al. [3] via a generalized Newton's method. They observed increment in radial velocity near the central plane when the wall expansion ratio increases. Recently, many authors contribute in the development of squeezing flow for different fluid models [4–7].

Recently Khan et al. [8] did a method convergence study for a unidirectional axisymmetric squeezing flow by employing variation of parameters method (VPM) as compared to the fourth-order Runge–Kutta (RK) method and homotopy analysis method (HAM). They asserted that VPM converges at fifth-order solution while HAM converges at seventh order for the two-dimensional problem between two parallel plates. Later they extended the analysis to investigate the influence of magnetohydrodynamics (MHD) using VPM [9]. Numerical solution based on a three-stage finite difference formula for a viscous fluid between contracting rotating disks is

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provided by Nazir and Mahmood [10]. Taking into account the viscous dissipation effects in the energy equation and rotating porous heated disks, Si et al. [11] solved the fluid flow with the help of HAM. It is drawn that sufficiently large rotation can dominate the squeezing flow radial velocity field over the permeability Reynolds number. Moreover Si et al. [12] discovered that the stream-wise velocity and the temperature of a micropolar fluid flow in a porous channel are of increasing functions of micropolar parameter in the presence of suction at two expanding/contracting walls. The effects of Dufour (diffusion-thermo) and Soret (thermal diffusion) commenced as the energy flux is inducted by composition gradient and mass flux is devised by temperature gradient respectively between two contracting rotating porous disks have been considered by Srinivas et al. [13] while Fang et al. [14] examined the unsteady flow outside a contracting cylinder where a unique non-trivial solution has been found.

Choi [15] is the first researcher who introduced the brief terminology of nanofluids to refer regular fluids suspended with solid nano-sized particles possibly via two specific preparation methods. The thermal and transport properties of these base fluids are highly influenced by the stable suspended nanoparticles. Timeless demands in acquiring, producing and utilizing regular fluids for prominent enhancement in heat transfer and conductivity have boosted up research and technical publications related to nanofluids and still. Complete transport model for nanofluid flow under slip condition is primarily proposed by Buongiorno [16] based on seven assumptions while treating nanofluid as a two-component mixture. Natural convection of micropolar nanofluids in a square cavity is modeled by Bourantas and Loukopoulos [17]. At the outset, they emphasized the agreement of the proposed theoretical model of single-phase nanofluid flow with numerical solutions obtained from finite volume method and secondly with available experimental data. Extensive review on the heat transfer characteristics of nanofluids is written by Wang and Mujumdar [18]. Rashidi et al. [19] studied buoyancy and thermal radiation correspond to magnetohydrodynamic (MHD) flow over a stretching surface using water as the base fluid suspended with Cu metal and Cu-oxide nanoparticles. Both the skin friction coefficient and the Nusselt number are greater for Cu metal nanofluid compared to Cu-oxide nanofluid. Next, mixed convective flow of Al_2O_3–water nanofluid inside a vertical microtube is analyzed by Malvandi and Ganji [20]. They concluded that Hartmann number, slip and mixed convection parameters enhance heat transfer rate in the nanofluid flow where the impacts are more pronounced as the size of the nanoparticles is reduced. Some current research of nanofluids can be reviewed from [21–31].

Squeezing nanofluid flow is an emerging spectrum of studies from abundant industrial applications of squeezing problems especially when the outcome of products highly affected by the heat transfer rate is of desirable priority. Domairry and Hatami [32] demonstrated that a reduced local Nusselt number can be improved when Eckert number, squeeze parameter and nanoparticle volume fraction are increased in the case of squeezing Cu–water nanofluid flow between parallel disks using DTM-Pade method. The unsteady squeezing nanofluid flow is solved analytically by Sheikholeslami et al. [33] using the Adomian decomposition method (ADM) while Dib et al. [34] compared the approximate analytical solution via Duan–Rach Approach (DRA) with Runge Kutta method for the same model. Least square method is employed by Hatami et al. [35] on an asymmetric flow incorporating Cu, Ag and Al_2O_3 nanoparticles where the flow temperature circulation is spread up with an increment in the squeeze number. The study is further extended as they imposed an externally heated plate while the other plate is injected with a coolant fluid through it [36]. They highlighted that the squeezing flow of copper nanofluid gives the maximum Nusselt number in this model as compared to silver and alumina nanofluids. Recently the squeezing nanofluid flow between two parallel disks in the highlight of variable magnetic field applied perpendicularly on the lower stationary disk with the contracting upper disk is emphasized by Hatami and Ganji [37]. It is observed that higher values of Brownian and thermophoresis parameters contribute to significant hike in both Nusselt and Sherwood numbers. Some recent studies that reflect the better analysis on nanofluid with various geometries are [38–42].

In view of potential applications of squeezing nanofluid flow in scientific and engineering sectors including food, hydraulic and chemical processing equipment as well as for cooling and freezing industries, more updated studies are needed to unclench more characteristics behaviors of such models. Secondly, the available literatures of squeezing nanofluid flows are limited in the extent of breakthrough on more prominent physical parameters, types of fluid and nanoparticles considered, variations of both analytical or numerical methods and also due to the fact that current research of squeezing nanofluid boundary layer flows are mostly dominated by a minority of journals and researchers. Looking at this scenario as motivation and opportunity, the present study is dedicated to consolidate three different types of nanoparticles namely magnetite (Fe_3O_4), cobalt ferrite ($CoFe_2O_4$) and Mn–Zn ferrite ($Mn–ZnFe_2O_4$) saturated within water as the base fluid. The similarity transformation is adopted together with shooting technique and Runge–Kutta–Fehlberg to solve the resulting system of nonlinear ordinary differential equations. Various profiles of velocity, temperature, reduced skin friction and reduced Nusselt number are plotted and discussed including rundown of isotherms of the flow. Finally it is our hope that through the present study, research in this field can be expanded and benefited eminently in the future of broad disciplines.

2. Mathematical model

Consider MHD incompressible water based nanoparticles flowing between two infinitely parallel disks in such a way that the distance between disks remains finite. We have considered three different kinds of Ferro particles: magnetite (Fe_3O_4), cobalt ferrite ($CoFe_2O_4$) and Mn–Zn ferrite ($Mn–ZnFe_2O_4$) within the base fluid (water). It is further assumed that magnetic field $B_o(1-at)^{-1/2}$ is applied normal to the disks and based on the flow assumption due to low Reynolds number, the induced magnetic field is neglected. Constant temperatures T_w and T_h are defined at lower surface $z=0$ and upper surface $z=h(t)$ of the disks respectively. Moreover, it is assumed that upper disk is moving with the velocity $aH(1-at)^{-1/2}/2$ in both directions (toward and away) from the stationary lower plate at $z=0$. Physical description of the model is presented in Fig. 1. The cylindrical coordinate system (r,α,z) is considered and due to the rotational symmetry of the flow $(\partial/\partial\alpha=0)$, the azimuthal component v of the velocity $V=(u,v,w)$ vanishes identically. Thus the governing and energy equations for the unsteady two-dimensional flow of a viscous fluid take the following form [7]

$$\frac{\partial u}{\partial r}+\frac{u}{r}+\frac{\partial w}{\partial z}=0, \tag{1}$$

$$\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial r}+w\frac{\partial u}{\partial z}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial r}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial r^2}+\frac{1}{r}\frac{\partial u}{\partial r}-\frac{u}{r^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{\sigma}{\rho_{nf}}B^2(t)u, \tag{2}$$

$$\frac{\partial w}{\partial t}+u\frac{\partial w}{\partial r}+w\frac{\partial w}{\partial z}=-\frac{1}{\rho_{nf}}\frac{\partial p}{\partial z}+\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 w}{\partial r^2}+\frac{1}{r}\frac{\partial w}{\partial r}+\frac{\partial^2 w}{\partial z^2}\right), \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial r}+w\frac{\partial T}{\partial z}=\alpha_{nf}\left(\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{\partial^2 T}{\partial z^2}\right). \tag{4}$$

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