INTERNATIONAL JOURNAL OF HYDROGEN ENERGY XXX (2018) 1–8

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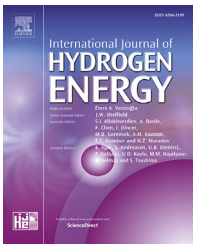

Crosswise stream of hydrogen-oxide (H_2O) through a porous media containing copper nanoparticles

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ARTICLE INFO

Article history:
Received 18 January 2018
Received in revised form
22 February 2018
Accepted 26 February 2018
Available online xxx

Keywords:
H_2O–Cu
Transverse flow
Porous media
Nanofluid
Numerical solution

ABSTRACT

Transport theories in porous media are quite operative to analyse heat transferral phenomenon in biological tissues, reducing bio convective flow instabilities by means of porous media and many more. Inspired by these remarkable features, the present study is conducted to analyse heat transfer phenomenon for obliquely striking nanofluid through a porous media. Copper (Cu) nanoparticles are suspended in traditional Hydrogen Oxide based fluid. Scaling group of transformations is conveniently employed to reduce governing transport equations and is tackled numerically afterwards. Influence of nanoparticles volume fraction, stretching ratio and porosity parameter on physical measures of concern such as normal and tangential skin friction and corresponding heat flux at wall is portrayed. Streamline patterns are traced out to discover the influence of porosity factor on actual flow behavior. It was observed that solid volume fraction of copper nanoparticles enhanced the skin friction coefficients and heat flux. Increasing the porosity parameter leads to greater heat flux and tangential skin friction co-efficient.

Introduction

Heat transfer enhancement through convection is an extremely essential feature in thermal devices such as electric tools and heat exchangers. Another useful technique for augmenting heat transferral characteristics is by means of porous medium and nanofluid. Ellahi et al. [1] inspected variable viscosity, porous medium in flow of nanofluid by incorporating slip condition. Maghrebi et al. [2] discussed transfer of heat in nanofluids through convection inside a porous channel. They discovered that Lewis number causes decline in Nusselt number inside porous channel. Bachok et al. [3] investigated stagnated fluid flow past penetrable stretching surface using copper nanoparticles. In another exploration Ellahi et al. [4] investigated similar kind of problem by using coaxial cylinder. Rashad et al. [5] explored the flow of fluid containing nanoparticles using porous medium considering mixed convection effects. Shanker et al. [6] examined mass and heat transfer of MHD chemically reacting nanofluid flow over a Porous media with influence of thermal radiation. Sheikholeslami et al. [7] examined nanofluid heat transfer through porous medium passing through spongy stretching sheet. Later on, Yirga et al. [8] inspected similar kind of problem where flow was induced by using stretched sheet. They found out that porous medium phenomenon and solid nanoparticles volume fraction has decreasing effect on boundary layer thickness significantly. The approach of augmenting heat transferral characteristics by means of porous medium and nanofluid is very much realistic because of the

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https://doi.org/10.1016/j.ijhydene.2018.02.166

Please cite this article in press as: Mehmood R, et al., Crosswise stream of hydrogen-oxide (H_2O) through a porous media containing copper nanoparticles, International Journal of Hydrogen Energy (2018), https://doi.org/10.1016/j.ijhydene.2018.02.166

fact that such flows are inevitable in numerous engineering applications such as thermal insulation, filtration process, heat exchangers, ground water transport and in oil flows [9].

A control volume finite element approach was employed by Nimafar et al. [10] for hydrothermal analysis of water based copper oxide nanoliquid with a complex geometry. It was observed that number of adulation improved temperature gradient. Shirvan et al. [11] considered a cosine corrugated square cavity occupied with nanofluid and investigated the impact of wavy surface characteristics on naturally convective heat transferal properties of fluid. Wavy amplitudes caused decline in Nusselt number. Tariq et al. [12] proposed a model for investigating the behavior of ferro-nanofluid upon a stretchable rotating disc under the influence of low oscillations. Analytic results were attained by homotopic analysis method. Mamourian et al. [13] considered two phase mixture model and Response Surface Methodology for sensitivity analysis of heat exchanger containing nanofluid with aluminum-oxide nanoparticles. They found that Reynold number caused enhancement in Nusselt number. Esfahani et al. [14] performed an entropy generation analysis for the flow of nanoliquid in a wavy channel upon a heat exchanger plate. Entropy generation was assumed as a function of temperature and velocity. It was concluded that viscous entropy generation improved with dimensionless amplitude. Rashidi et al. [15] developed a discrete phase model in order to track the discrete nature of Al_2O_3 particles in an obstructed duct with two side-by-side obstacles. Results indicated that particles with smaller diameter diffused with streamlines. A theoretical examination of nanoparticles shapes influence on heat and mass flow of ferrofluid over a disk with rotation in presence of low magnetic field was done by Hassan et al. [16]. A homotopic based approach Bvph2 was employed for solving the governing differential equations. In another investigation Shirvan et al. [17] considered a square cavity occupied with nanofluid and studied the mixed convective optimal conditions over it with aid of Taguchi method. Shirvan et al. [18] also used surface methodology to numerically investigate the impact of surface radiation and mixed convection in an inclined permeable solar cavity. Zeeshan et al. [19] studied various shapes effects of nano-sized particles on time independent mixed convective nanoliquid flow over rotating disk. It was shown that heat transfer and velocity of the flow can be controlled by proper choice of nanoparticles shapes. Shiekholeslami et al. [20] utilized a mesoscopic approach to examine the magnetic field influence on nanofluid within a permeable cavity along with heat source. Results revealed that Hartmann number reduced the temperature gradient. Mehmood et al. [21] investigated the aluminum oxide nanoparticles transport in ethylene glycol based nanoliquid upon a linearly stretching cylinder by considering convective condition at boundary. Shamlooei et al. [22] examined the isothermal behavior of ferrofluid with impact of thermal radiation and magnetic field. Outcomes showed that thickness of thermal boundary layer enhanced with radiation parameter and velocity of fluid reduced with Hartmann number. Ganji et al. [23] considered marangoni convection to study the magnetic field impact on nanoliquid flow. A reverse relation of Nusselt number and magnetic parameter was found. Sheikholeslami did an analysis of coulomb forces influence on thermal improvement of nanofluid in a cavity with moving boundaries. An enhancement in Nusselt number was noted with supplied voltage. Ellahi et al. [24] observed the impact of mixed convection over the flow of nanofluid with nimonic nanoparticles with spherical and non-spherical shapes upon a porous sheet stretched vertically. Influence of buoyancy forces is also considered. A model of fluid volume was proposed by Rashidi et al. [25] to investigate the water based aluminum oxide nanoliquid solar still productivity along with entropy generation analysis. It was noted that volume fraction caused enhancement in solar still productivity. The flow behavior with non-Newtonian based power law model was examined by Ijaz et al. [26] through a wavy channel with finite symmetric properties. Zeeshan et al. [27] studied the impact of convective condition, chemical reaction over the flow of MHD radiative Couette-Poiseuille nanofluid in a horizontal channel by taking Buongiorno model. Nanoparticles concentration was found directly proportional with chemical reaction. Sheikoleslami et al. [28] did an investigation on flow of nanoliquid in a porous medium by taking non-Darcy MHD model with viscosity depending upon external magnetic field. An increase in Nusselt number is found with buoyancy forces while opposite trend is noted with Lorentz forces.

The prime focus of current study is investigation of porous media effects on transverse nanofluid flow of over a stretching wall. Such flows find tremendous applications in processes like continuous strips cooling, fibre spinning and metal casting. Addition of nanoparticles can greatly improve the efficiency of cooling process which ultimately results in finest quality product. The governing physical problem is numerically solved by means of R–K Fehlberg merged with shooting routine. Physical flow parameters are varied to examine skin friction and heat transfer rate through graphs.

Model description and formulation

Consider steady, laminar, transverse Darcy nanofluid flow which meets a stretched surface at $y = 0$. Surface is kept stretched by means of two oppositely applied forces sideways the $x-$ axis in order to retain the origin fixed (see Fig. 1). Fluid under consideration occupies the plane $y > 0$. T_w and T_∞ are assumed to be temperature of surface and ambient temperature respectively. The nanofluid consists of water as base fluid

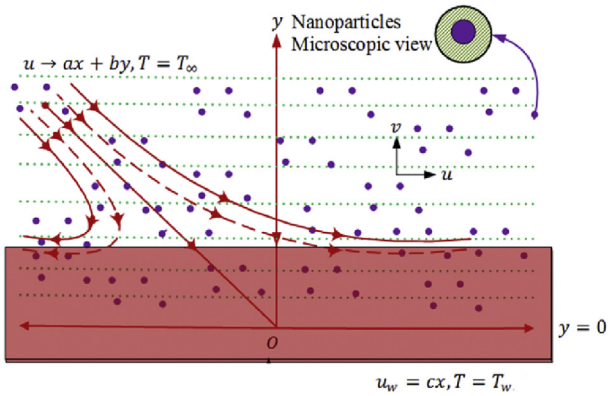

Fig. 1 – Geometrical illustration of physical problem.

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