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Review

Flow and heat transfer of nanofluid with injection through an expanding or contracting porous channel under magnetic force field

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A B S T R A C T

This present study considers flow and heat transfer of nanofluid, conveyed through expanding or contracting porous channel under uniform magnetic field. Influence of magnetic field on flow and heat transfer with injection is investigated. The nanofluid is described by high order coupled nonlinear equations of the fourth order, analyzed utilizing the homotopy perturbation method (HPM). Analytical solutions obtained are adopted in describing the effect of various thermal-fluidic parameters such as Reynolds number, Hartmann parameter and temperature power index. Results reveal increasing Hartmann parameter causes increase in skin fluid friction effect while increasing temperature power index leads to increasing Nusselt number effect. Also comparison of obtained analytical solution against previous literatures shows satisfactory agreement. This study provides good insight to practical applications such as nanofluidics, energy conservation, friction reduction and power generation.

Contents

1. Introduction

Flow and heat transfer of fluids plays significant role in determining best ways to convey different categories of fluids with the aim of achieving high efficient transport system at economical cost. Due to their vast importance in industrial fields such as reservoir engineering, flow through porous industrial materials, heat exchange between fluid beds, ceramic processing, polymer solution, food technology, environmental protection, power plant operations, manufacturing, transportation and oil recovery amongst others.

In past efforts to study flow and heat transfer, numerical methods was adopted by Pourmehran et al. [1] in optimizing nanofluid flow in saturated porous medium while Tang and Jing [2] investigated sinusoidal wavy cavity effect of heat transfer under natural convection with phase deviation. High accuracy spherical motion particle was presented by Hatami et al. [3] in coquette fluid film flow. Hatami et al. [4] optimized circular wavy cavity nanofluid flow under natural convection. Ghasemi et al. [5] utilized least square methods of weighted residuals to analyze electrohydrodynamic effect of fluid flowing through a circular conduit, shortly after Ghasemi et al. [6] studied blood flow through porous arteries under the influence of magnetic force field with nanoparticles. Multi step differential transform method was applied by Hatami and Ganji [7] to analyze spherical particle motion of a rotating parabola while Hatami and Jing [8] optimized lid driven T-shaped porous cavity in the bid to improve mixed convective heat transfer. Non-Newtonian fluid flow under natural convection through vertical

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Nomenclature

A	Wall permeability
A_{1-4}	Constant parameters in nanofluid
a	Distance between parallel plates
a(t)	Expand or contract function
C_p	Specific heat in constant pressure
C_{1-4}	Constants in trial function
F(η)	Stream function variable
K	Thermal conductivity
M	Temperature index
Nu	Nusselt number
P	Pressure
q	Heat transfer
R	Reynolds number
R(x)	Residual function
t	Time
T	Temperature
u	Velocity in x direction
v	Velocity in y direction
W(x)	Weighted function
x	Horizontal axes coordinate
Y	Vertical axes coordinate

Greek symbols

α	Expansion ratio
μ	Viscosity
ϕ	Nanoparticle volume fraction
ρ	Density
ψ	Stream function
η	Non-dimensional y direction $[y/a]$

Subscript

f	Fluid
nf	Nanofluid
s	Solid
w	Wall

parallel plates was investigated by Karger and Akbarzade [9]. Fakour et al. [10] presented micropolar flow and heat transfer flowing in a channel with permeable walls. Nanoparticle migration around heated cylinder was studied by Hatami [11] considering wavy enclosure wavy.

In the bid to improve the thermal conductivity of viscous fluids such as water, oils, grease, ethylene. Choi [12] presented a novel approach to improving thermal conductivity of incompressible fluid through the addition of nanometer sized particle into the base fluid, it was observed that upon the addition of metallic nanosized particle into base fluid thermal conductivity of fluid improves to about three times it present state . Therefore improving the overall transport capability of fluids making them potentially useful in fields such as biomedicine, manufacturing, fuel cells, and hybrid power generators amongst other practical application. These have created renaissance amongst researchers in science and engineering to explore the useful potential of nanofluid [13–19].

Since higher order nonlinear equations which describes the flow and heat transfer of the nanofluid requires the use of approximate analytical or numerical methods of solution to analyze the system of coupled equations. Approximate analytical methods of solutions applied by researchers in study of the heat transfer include the pertubation method (PM), adomian decomposition method (ADM), homotopy pertubation method (HPM), variational iteration method (VIM), differential transformation method (DTM) and methods of weighted residuals [20–40]. Methods such as PM are limited owing to the problems of weak nonlinearities and artificial pertubation parameter which are non existence in real life. The need to find initial condition to satisfy the boundary condition makes methods such as VIM, DTM, HAM requires computational tools in handling a solution of large parameters resulting to large computational cost and time . Also the problem of finding the adomian polynomials makes the ADM not attractive to researchers. Whereas the methods of weighted residuals which includes the collocation method (CM), Garlerkin method (GM) and least square method (LSM) involves the need to determine weighing residuals to satisfy weighing functions which may be arbitrary. However the homotopy pertubation method been a relatively simplistic method of solving nonlinear, coupled equations due to its highly successive and accurate approximation makes it a favourable analytical technique to researchers.

Motivated by past research works, the homtopy pertubation method (HPM) is used to analyze the unsteady flow and heat transfer of nanofluid with injection through an expanding or contracting porous channel under the influence of uniform magnetic flux. Table 1.

2. Model development and analytical solution

Here nanofluid flows through parallel plates held horizontally against each other unsteadily under magnetic force field influence. The upper plate expands and contracts with time while the lower plate is stationary and is externally heated which is described in the physical model diagram Fig. 1. The heated wall is cooled by injecting cool fluid with uniform velocity v_w from the upper plate which expands and contract at time rate a (t). The both plates are perpendicular to y axis. u and v are the velocity component of x and y direction. According to this view, fluid flow may be assumed to be stagnation flow. The models are developed assuming a two component nanofluid mix, incompressible fluid flow since fluid is liquid, negligible radiation effect owing to flow geometry, nanoparticle and base fluid are in thermal equilibrium since Nano mixture is thermodynamically compartible. With respect to these condition Navier – Stokes equation can be presented as:

$$\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}=0 \tag{1}$$

$$\rho_{nf}\left(\frac{\partial u}{\partial t}+u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}\right)=-\frac{\partial p^*}{\partial x}+\mu_{nf}\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}\right)-\sigma B^2(t)u \tag{2}$$

$$\rho_{nf}\left(\frac{\partial v}{\partial t}+u\frac{\partial v}{\partial x}+v\frac{\partial T}{\partial y}\right)=-\frac{\partial p^*}{\partial y}+\mu_{nf}\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}\right) \tag{3}$$

$$\frac{\partial T}{\partial t}+u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\frac{k_{nf}}{(\rho C_p)_{nf}}\left(\frac{\partial^2 T}{\partial x^2}-\frac{\partial^2 T}{\partial y^2}\right) \tag{4}$$

Table 1
Thermo physical properties of nanofluid.

	Density (kg/m^3)	Specific heat capacity (J/kgK)	Thermal conductivity (W/mk)
Water	997.1	4179	0.613
Copper	8933	385	401

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