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ORIGINAL ARTICLE

MHD flow of a nanofluid in an expanding or contracting porous pipe with chemical reaction and heat source/sink

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Lewis number

Abstract In the present investigation, an analytical analysis has been carried out to study the influence of chemical reaction on MHD flow of a nanofluid in an expanding or contracting porous pipe in the presence of heat source/sink. The pipe wall expands or contracts uniformly at a time dependent rate. Similarity transformations have been invoked to reduce the governing flow equations into coupled nonlinear ordinary differential equations. An analytical approach, namely the homotopy analysis method (HAM) is employed to obtain the analytical solutions of the ordinary differential equations. The convergence of the obtained series solutions is analyzed. The effects of various physical parameters such as wall expansion ratio, Brownian motion parameter, thermophoresis parameter, Lewis number, chemical reaction parameter and heat source/sink parameter on flow variables have been discussed. Further, for the case of hydrodynamic viscous fluid, we find a good agreement between the HAM solutions and solutions already reported in the literature.

1. Introduction

In recent years, study of laminar flow in a porous pipe or channel with expanding or contracting walls received much attention of several researchers due to their wide

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Nomenclature

$a(t)$	radius of the pipe
$\dot{a}(t)$	time dependent rate
A	the injection/suction coefficient
B_0	applied magnetic field
C	dimensional nanoparticle concentration
C_0	reference nanoparticle concentration at the center
C_p	specific heat at constant pressure (unit: J/(kg·K))
C_w	nanoparticle concentration at the wall
k_1	first order chemical reaction rate
K_1	dimensionless constant
Le	Lewis number
M	Hartmann number
Nt	thermophoresis parameter
Nb	Brownian motion parameter
$\hat{p}$	dimensional pressure (unit: Pa)
Pr	Prandtl number
Q	heat source/sink parameter
R	permeation Reynolds number
$\hat{r}, \hat{z}$	dimensional cylindrical coordinates (unit: m)
T	dimensional temperature (unit: K)
T_0	reference temperature at the center
T_m	mean temperature
T_w	temperature at the wall
$\hat{u}, \hat{v}$	velocity components along $\hat{r}$ and $\hat{z}$ directions respectively (unit: m/s)
v_w	injection/suction velocity
Q_0	dimensional heat source/sink

Greek symbols

ρ_f	density of the base fluid (unit: kg/m^3)
σ	electrical conductivity (unit: S/m)
β	thermal diffusivity (unit: m^2/s)
η	dimensionless radial position
α	dimensionless wall expansion ratio
μ	dynamic viscosity of the fluid (unit: N·s/m^2)
ν	kinematic viscosity of the fluid (unit: m^2/s)
γ	dimensionless chemical reaction parameter
$(\rho C_p)_p$	heat capacity of the nanoparticle (unit: kg/(m^3·K))
$(\rho C_p)_f$	heat capacity of the fluid (unit: kg/(m^3·K))
θ	dimensionless temperature
$\hat{\psi}$	stream function (unit: m^2/s)
ψ	dimensionless stream function
τ	ratio between the heat capacity of the nanoparticle and heat capacity of the fluid
ϕ	dimensionless nanoparticles concentration

Subscripts

f	base fluid
p	nanoparticle
w	pipe wall

applications in technological as well as biological flows. For example, in the transport of biological fluids through expanding or contracting vessels, the synchronous pulsation of porous diaphragms, the air circulation in the respiratory system and the regression of the burning surface in solid rocket motors [1–8]. Boutros et al. [9] have applied Lie-group method for unsteady flows in a semi-infinite expanding or contracting pipe with injection or suction through a porous wall. Si et al. [10] have analyzed the problem of laminar flow in a porous pipe with suction at slowly expanding or contracting wall. Asghar et al. [11] analyzed the flow in a slowly deforming channel with weak permeability. Srinivas et al. [12] studied the thermal diffusion and diffusion thermo effects in a two-dimensional viscous flow between slowly expanding or contracting walls with weak permeability. Recently, Srinivas et al. [13] have investigated the influence of heat transfer on MHD flow in a pipe with expanding or contracting permeable wall by employing homotopy analysis method (HAM).

Nanofluid is a liquid containing nanometer-sized particles having diameter less than 100 nm, called nanoparticle [14]. Nanoparticle is currently an area of intense scientific interest due to a wide range of applications in biomedical, optical and electronic field. These can be found in metals such as (Al, Cu), oxides (Al_2O_3), carbides (SiC), nitrides (AlN, SiN) or nanometals (Graphite, carbon-nanotubes) [15–20]. Buongiorno [21] examined the convective heat transport in nanofluids. In this study the author developed a two-component four equation nonhomogeneous equilibrium models for mass momentum and heat transport in nanofluids. Further, Buongiorno [21] concluded that in the absence of turbulent effects, the Brownian diffusion and thermophoresis will be important and also he has considered the conservation equations based on these two effects. Rosca and Pop [22] have examined unsteady boundary layer flow of a nanofluid past a moving surface in an external uniform free stream using Buongiorno's model. The natural convective boundary layer flow of nanofluid over a flat vertical plate was investigated by Kuznetsov and Nield [23]. Nadeem et al. [24] have studied non-orthogonal stagnation point flow of a non-Newtonian fluid towards a stretching surface with heat transfer. Xu and Pop [25] examined the fully developed mixed convection flow in vertical channel filled with nanofluids. Mustafa et al. [26] investigated MHD boundary layer flow of second grade nanofluid over a stretching sheet with convective boundary conditions by employing HAM. Alsaedi et al. [27] applied HAM to study the effect of heat generation/absorption on stagnation point flow of nanofluid over a surface with convective boundary conditions. Chamkha et al. [28] analyzed the free convective boundary layer flow of a nanofluid over a vertical cylinder. Malvandi et al. [29] used modified Buongiorno's model for fully developed mixed convection flow of nanofluid in a vertical annular pipe. Fully developed mixed convection in horizontal and inclined tubes with uniform heat flux using nanofluid was