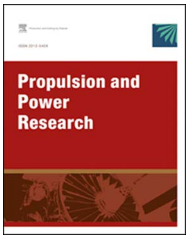
Propulsion and Power Research ▮▮▮▮;▮(▮):▮▮▮–▮▮▮

HOSTED BY
ELSEVIER

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com



ORIGINAL ARTICLE

Cu-water nanofluid flow induced by a vertical stretching sheet in presence of a magnetic field with convective heat transfer

Kalidas Das[a,*], **Amit Sarkar**[b], **Prabir Kumar Kundu**[b]

[a]*Dept. of Mathematics, A.B.N. Seal College, Cooch Behar 736101, West Bengal, India*
[b]*Dept. of Mathematics, Jadavpur University, Kolkata 700032, West Bengal, India*

Received 3 June 2015; accepted 25 August 2015

KEYWORDS
Nanofluid;
Slip velocity;
Magnetic field;
Convective boundary condition

Abstract The convective heat transfer performance of nanofluid over a permeable stretching sheet with thermal convective boundary condition in presence of magnetic field and slip velocity is studied in the present paper. Cu-water nanofluid is used to investigate the effect of nanoparticles on the flow and heat transfer characteristic. The numerical results are compared with published results and are found in an excellent agreement. The influences of various relevant parameters on the velocity and temperature as well as the rate of shear stress and the rate of heat transfer are elucidated through graphs and tables. It is observed that nanoparticles volume fraction and surface convection parameter both increase the thickness of thermal boundary layer.

1. Introduction

A nanofluid, coined by Choi [1] is a new type of heat transfer fluids containing base fluid and nanoparticles. It has been observed from the open literature that nanoparticles changed the fluid characteristics duo to high thermal conductivity of these particles. Nanofluids are produced by solid nanoparticles dispersion in a base fluid like water, ethylene glycol etc. The nanoparticles which are used to produce nanofluid are copper, aluminum etc. The enhanced thermal conductivity of nanofluid and turbulence induced by their motion contribute to a remarkable improvement in the convective heat transfer coefficient. These features of nanofluid make them attractive for use in application such as advanced nuclear system [2] and cylindrical heat pipes

---

[*] Corresponding author. Tel.: +91 9748603199.
E-mail address: kd_kgec@rediffmail.com (Kalidas Das).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

http://dx.doi.org/10.1016/j.jppr.2017.07.001

Please cite this article as: Kalidas Das, et al., Cu-water nanofluid flow induced by a vertical stretching sheet in presence of a magnetic field with convective heat transfer, Propulsion and Power Research (2017), http://dx.doi.org/10.1016/j.jppr.2017.07.001

[3]. There have been published several recent papers [4–12] on the mathematical modeling of convection heat transfer in nanofluids. In these studies the fluid velocity is assumed to be zero relative to the solid boundary. Navier [13] introduced a boundary condition which states that the tangential component of fluid velocity is proportional to tangential stress. Later, several researchers [14–16] extended the Navier boundary conditions. Numerous investigations [17–20] have been done analytically and numerically regarding the slip flow regimes over surfaces. These results demonstrated that the boundary layer equation can be used to study flow at the micro electro mechanical system (MEMS) scale. Recently, Das [21] analyzed the convective heat transfer characteristic of nanofluid over a permeable stretching surface with partial slip velocity.

The boundary conditions that are usually used for the boundary layer flow problem are either a specified surface temperature or a specified surface heat flux. But there are some problems in which heat transfer at the surface depends on the surface temperature. The situation with Newtonian heating arises are known as conjugate convective flow. The configuration of Newtonian heating occurs in many important engineering devices. Recently, boundary layer flow problems with convective boundary condition were investigated by Aziz [22], Ishak [23] and Makinde and Aziz [24]. Aziz and Khan [25] considered natural convective boundary layer flow of nanofluids over a convectively heated vertical plate. But so far, no attempt has been made to analyze the nanofluid flow past a convectively heated vertical permeable stretching surface in the presence of heat source/sink. Recently, Malvandi et al. [26] discussed the slip effects on unsteady stagnation point flow of a nanofluid over a stretching sheet.

The study of magnetic field effect on fluid flow has important applications in physics and engineering. Recently, Mabood and Khan [27] discussed magnetohydrodynamic (MHD) stagnation point flow in porous medium. To the author's knowledge very few studies [28–31] have thus far been communicated with regard to convective heat transfer in a nanofluid over a permeable stretching sheet in presence of external magnetic field. Thus the objective of present work is to extend the work of Das [21] by taking the nanofluid flow over a permeable stretching sheet with surface slip and thermal convective boundary condition in the presence of magnetic field.

2. Mathematical formulation

Consider the steady incompressible two-dimensional boundary layer flow of a viscous nanofluid over a permeable stretching sheet coinciding with the plane $y=0$ and the flow being confined to $y>0$. Keeping the origin fixed, the sheet is then stretched with a velocity $u_w(x)=ax$, where a is a constant and x is the coordinate measured along the stretching surface from the slit (Figure 1). There is a constant suction/injection velocity normal to the stretching sheet. The stretching surface is maintained at constant temperature higher than the constant temperature of the ambient nanofluid. The fluid is water based nanofluid containing nano-solid particles, say copper (Cu). It is also assumed that the base fluid (i.e. water) and the nanoparticles are in thermal equilibrium and no slip occurs between them. The thermophysical properties of the nanofluids are given in Table 1 (Oztop and Abu-Nada [32]).

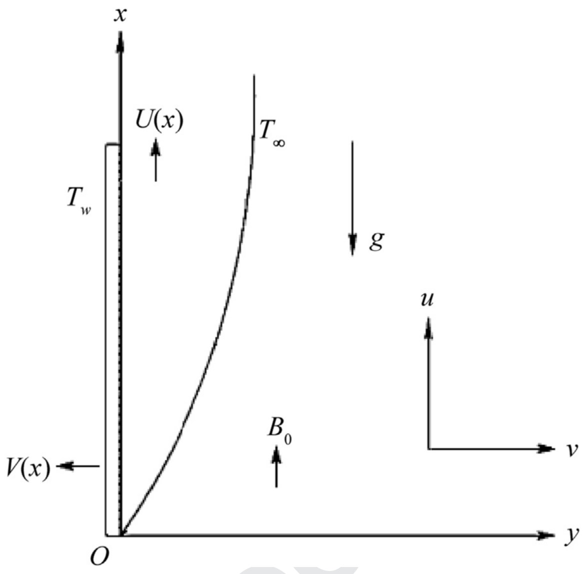


Figure 1 Physical model and physical coordinate system.

Table 1 Thermo physical properties of regular fluid and nanoparticles.

Physical properties	Regular fluid (water)	Cu
C_p/(J/(kg · K)	4179	385
ρ/(kg/m^3)	997.1	8933
κ/(W/(m · K))	0.613	400
$\alpha/10^7$(m^2/s)	1.47	1163.1
$\beta/10^{-5}$(1/K)	21	1.67

Under these assumptions, the governing boundary layer equations for a nanofluid flow in the presence of transverse magnetic field can be written as [21]

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial v}{\partial y}=\frac{1}{\rho_{nf}}\left[\mu_{nf}\frac{\partial^2 u}{\partial y^2}+g(\rho\beta)_{nf}(T-T_\infty)-\sigma B_0^2 u\right], \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2}+\frac{Q}{(\rho C_p)_{nf}}(T-T_\infty), \tag{3}$$

where u, v are the velocity components along x, y-axis respectively, ρ_{nf} is the effective density of the nanofluid, σ is the electrical conductivity of the fluid, B_0 is the uniform magnetic field strength, g is the acceleration due to gravity, T is the temperature of the nanofluid, T_∞ is the temperature

Please cite this article as: Kalidas Das, et al., Cu-water nanofluid flow induced by a vertical stretching sheet in presence of a magnetic field with convective heat transfer, Propulsion and Power Research (2017), http://dx.doi.org/10.1016/j.jppr.2017.07.001