Alexandria Engineering Journal (2016) 55, 857–865

HOSTED BY

ELSEVIER

Alexandria University

Alexandria Engineering Journal

www.elsevier.com/locate/aej
www.sciencedirect.com

Stagnation point flow of Maxwell fluid towards a permeable surface in the presence of nanoparticles

G.K. Ramesh [a,b,*], B.J. Gireesha [b], T. Hayat [c,d], A. Alsaedi [d]

[a] Department of Mathematics, SEA College of Engineering and Technology, K.R. Puram, Bengaluru 560049, Karnataka, India
[b] Department of Studies and Research in Mathematics, Kuvempu University, Shankaraghatta 577 451, Shimoga, Karnataka, India
[c] Department of Mathematics, Quaid-T-Azam University, Islamabad 44000, Pakistan
[d] Nonlinear Analysis and Applied Mathematics Research Group, Faculty of Science, King Abdulaziz University, Jeddah 21589, Saudi Arabia

Received 10 June 2014; revised 23 January 2016; accepted 20 February 2016
Available online 2 March 2016

KEYWORDS

Stagnation point flow;
Maxwell fluid;
Permeable surface;
Nanoparticles;
Numerical solution

Abstract Analysis has been carried out to study the stagnation point flow of Maxwell fluid towards a permeable stretching sheet in the presence of nanoparticles. Using suitable transformations, the governing partial differential equations are first converted to ordinary one and then solved numerically by fourth–fifth order Runge–Kutta–Fehlberg method with MAPLE. The flow and heat transfer characteristics are analyzed and discussed for different values of the parameters. Present work reveals that the velocity increases whereas the temperature and concentration decrease with the increase of Maxwell parameter. The thermal and concentration boundary layer thickness decreases with velocity ratio, Lewis number, Prandtl number suction, Brownian motion and thermophoresis parameters. Comparison with known results for Newtonian fluid flow is found an excellent agreement.

1. Introduction

There is no doubt that human society development greatly depends upon energy. However the rapid development of human society during the past few years leads to the shortage of global energy and the serious environmental protection. Sustainable energy generation in recent time is thus a challenging issue globally. Solar energy in which circumstances has been regarded one of the best sources of renewable energy via least environmental impact. Solar power in fact is a natural way of obtaining water, heat and electricity. Power tower solar collectors could benefit from the potential efficiency improvements that arise from using a nanofluid as a working fluid. Particle size of nanomaterial is similar or smaller than the wavelength of de Broglie and coherent waves. It is now recognized that solar thermal system with nanofluids becomes the new study hotspot.

On the other hand several industrial fluids are non-Newtonian in their flow characteristics. In a Newtonian fluid, the shear stress is directly proportional to the rate of shear strain, whereas in a non-Newtonian fluid, the relationship

* Corresponding author at: Department of Studies and Research in Mathematics, Kuvempu University, Shankaraghatta 577 451, Shimoga, Karnataka, India. Tel.: +91 9900981204.
E-mail address: gkrmaths@gmail.com (G.K. Ramesh).

Peer review under responsibility of Faculty of Engineering, Alexandria University.

http://dx.doi.org/10.1016/j.aej.2016.02.007
1110-0168

Nomenclature

A	velocity ratio
c	stretching rate
C_f	skin friction
c_p	specific heat
C	nanoparticle volume fraction
D_B	Brownian diffusion coefficient
D_T	thermophoresis diffusion coefficient
Nb	Brownian motion parameter
Nt	thermophoresis parameter
Nu_x	local Nusselt number
Le	Lewis number
Pr	Prandtl number
Sh_x	local Sherwood number
T	temperature of the fluid
T_w	temperature at the wall
T_∞	ambient fluid temperature
u, v	velocity components along x and y directions
U_w	stretching sheet velocity
U	free stream velocity
x	coordinate along the stretching sheet
y	distance normal to the stretching sheet

Greek symbols

ν	kinematic viscosity
ϕ	rescaled nanoparticle volume fraction
ρ_f	density of the base fluid
ρ_p	density of the particles
λ	suction parameter
β	Maxwell parameter
θ	dimensionless temperature
η	similarity variable
α	thermal diffusivity
τ_w	wall shearing stress

between the shear stress and the rate of shear strain is nonlinear. Most of the particulate slurries such as china clay and coal in water, multiphase mixtures such as oil–water emulsions, paints, synthetic lubricants, and biological fluids including blood at low shear rate, synovial fluid, and saliva and foodstuffs such as jams, jellies, soups, and marmalades are examples of non-Newtonian fluids. Because of the large variety of the non-Newtonian fluids, many models of non-Newtonian fluids exist. Maxwell model is one subclass of rate type fluids. This fluid model predicts the relaxation time effects. Such effects cannot be predicted by differential-type fluids. This fluid model is especially useful for polymers of low molecular weight. A review of non-Newtonian fluid flow problems may be found in [1–3].

Initially, Sakiadis [4] introduced the concept of boundary layer flow over a moving surface. Crane [5] modified the idea introduced by Sakiadis and extended this concept linear stretching sheet. Flow in the neighborhood of stagnation point in a plane was first studied by Hiemenz [6]. Mahapatra and Gupta [7–9] investigated the magnetohydrodynamic stagnation point flow towards a stretching sheet. They shown that the velocity at a point decreases/increases with increase in the magnetic field when the free stream velocity is less/greater than the stretching velocity. Also they have studied the temperature distribution when the surface has constant temperature and constant heat flux. Further they have extended their work on power law fluid and discussed the uniqueness of solutions of stagnation-point flow towards a stretching surface. Accordingly, researchers in the [10–13] studied the stagnation point flow over a surface.

Aforementioned studies were primarily concerned with the laminar flow of a clear fluid. Nanotechnology is an emerging research topic having extensive use in industry due to the unique chemical and physical properties which the nano-sized materials possess. These fluids are colloidal suspensions, typically metals, oxides, carbides or carbon nanotubes in a base fluid. The term nanofluid was coined by Choi [14] in his seminal paper presented in 1995 at the ASME Winter Annual Meeting. It refers to fluids containing a dispersion of submicronic solid particles (nanoparticles) with typical length of the order of 1–50 nm. Kuznetsov and Nield [15] analytically studied the natural convective boundary layer flow of nanofluid past a vertical plate. Khan and Pop [16] first time studied the problem of laminar fluid flow resulting from the stretching of a flat surface in a nanofluid. Mustafa et al. [17] investigated the stagnation point flow of viscous nanofluid towards a stretching surface using homotopy analysis method. Alsaedi et al. [18] examined the influence of heat generation/absorption on the stagnation point flow of nanofluid towards a linear stretching surface. Rahman et al. [19] examined the dynamics of natural convection boundary layer flow of water based nanofluids over a wedge. They discussed the analysis in the presence of a transverse magnetic field with internal heat generation or absorption. Nandy and Mahapatra [20] analyzed the effects of velocity slip and heat generation/absorption on magnetohydrodynamic stagnation-point flow and heat transfer over a stretching/shrinking surface and then obtained the solution numerically using fourth order Runga–Kutta method with the help of shooting technique. Different from a stretching sheet, it was found that the solutions for a shrinking sheet are non-unique. Makinde et al. [21] studied the combined effects of buoyancy force, convective heating, Brownian motion and thermophoresis on the stagnation point flow and heat transfer of an electrically conducting nanofluid towards a stretching sheet. Effect of magnetic field on stagnation point flow and heat transfer due to nanofluid towards a stretching sheet has been investigated by Ibrahim et al. [22]. Nadeem et al. [23,24] reported the numerical solutions of non-Newtonian nanofluid flow over a stretching sheet using the Maxwell fluid model. Further they obtained the analytic solution for non-orthogonal stagnation point flow of a nanosecond grade fluid toward a stretching surface with heat transfer. Hady et al. [25] studied the natural convection boundary-layer flow over a downward-pointing vertical cone in a porous medium saturated with a power-law nanofluid in the presence of heat generation or absorption. Unsteady boundary layer