Journal of the Egyptian Mathematical Society (2016) 24, 458–470

Egyptian Mathematical Society

Journal of the Egyptian Mathematical Society

www.etms-eg.org
www.elsevier.com/locate/joems

Original Article

Finite element analysis of heat and mass transfer by MHD mixed convection stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface with radiation

Macha Madhu*, **Naikoti Kishan**

Department of Mathematics, Osmania University, Hyderabad, Telangana 500007, India

Received 6 August 2014; revised 24 May 2015; accepted 23 June 2015
Available online 26 September 2015

Keywords

Non-Newtonian;
Nanofluid;
Stagnation-point flow;
Brownian motion;
Power-law index;
Thermal radiation

Abstract Magnetohydrodynamic mixed convection boundary layer flow of heat and mass transfer stagnation-point flow of a non-Newtonian power-law nanofluid towards a stretching surface in the presence of thermal radiation is investigated numerically. The non-Newtonian nanofluid model incorporates the effects of Brownian motion and thermophoresis. The basic transport equations are made dimensionless first and the coupled non linear differential equations are solved by finite element method. The numerical calculations for velocity, temperature and concentration profiles for different values of the physical parameters presented graphically and discussed. As well as for skin friction coefficient, local Nusselt and Sherwood numbers exhibited and examined.

2010 Mathematics Subject Classification: 76A05; 80A20; 80M10

1. Introduction

In recent years, the study of flow and heat transfer of non-Newtonian fluids has received considerable attention because of its wide use of these fluids in food engineering, petroleum production, power engineering and in many industries such as polymer melt and polymer solutions used in the plastic processing industries. Over recent years, applications of non-Newtonian fluids in many industrial processes have been interesting. Many particulate slurries, multiphase mixers, pharmaceutical formulation, cosmetics and toiletries, paints, biological fluids, and food items are examples of non-Newtonian fluids. Many of

* Corresponding author. Tel.: +91- 9248358378.
E-mail addresses: madhumaccha@gmail.com (M. Madhu), kishan_n@rediffmail.com (N. Kishan).
Peer review under responsibility of Egyptian Mathematical Society.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.joems.2015.06.001

Nomenclature

C	Nanoparticle volume fraction
C_{fx}	Skin friction coefficient
D_B	Brownian diffusion
D_T	Thermophoretic diffusion coefficient
f	Dimensionless stream function
g	Acceleration due to gravity
k	Thermal conductivity
K	Consistency coefficient of the fluid
Le	Generalized Lewis number
M	Magnetic parameter
N	Concentration to thermal buoyancy ratio
n	Power-law rheological index
Nb	Generalized Brownian motion parameter
Nt	Generalized thermophoresis parameter
Nu_x	Local Nusselt number
Pr_x	Generalized Prandtl number
R_d	Radiation parameter
Re	Reynolds number
Re_x	Local Reynolds number
Sh_x	Local Sherwood number
T	Fluid temperature
u, v	Velocity components
x, y	Cartesian coordinates
α_m	Thermal diffusivity
Λ	dimensionless mixed convection parameter
υ	Kinematic viscosity of the fluid
ρ_f	Fluid density
ρ_p	Nanoparticle mass density
τ	Ratio between the effective heat capacity of the nanoparticle material and heat capacity of the fluid
θ	Dimensionless temperature
ϕ	Dimensionless nanoparticle volume fraction
ψ	Stream function
η	Similarity independent variable
w	Conditions at the wall
∞	Ambient condition
$'$	Prime denotes the derivative with respect to η

the non-Newtonian fluids encountered in chemical engineering processes are known to follow the empirical Ostwaldde Waele power-law model. The concept of boundary layer was applied to power-law fluids by Schowalter [1]. Acrivos [2] investigated the boundary-layer flows for such fluids in 1960, since then a large number of related studies have been conducted because of their importance and presence of such fluids in chemicals, polymers, molten plastics and others. Most of the previous studies of natural convection associated with clear fluid media have considered Newtonian fluids, which received a great attention among the thermofluid community. Few theoretical studies have investigated the shear rate effect of non-Newtonian fluids on convective flow patterns and heat transfer rate, despite their importance and presence in many industrial applications such as paper making, oil drilling, slurry transporting, food processing, and polymer engineering.

The theory of non-Newtonian fluids offers mathematicians, engineers and numerical specialists varied challenges in developing analytical and numerical solutions for the highly non-linear governing equations. However, due to the practical significance of these non-Newtonian fluids, many authors have presented various non-Newtonian fluid models like El-bashbeshy et al. [3], Nadeem et al. [4], Nadeem et al. [5], Nadeem et al. [6], Nadeem and Akbar [7], Nadeem and Ali [8], Buongiorno [9], Lukaszewics [10]. Many interesting applications of non-Newtonian power-law fluids were presented by Shenoy [11]. Details of the behavior of non-Newtonian fluids for both steady and unsteady flow situations, along with mathematical models are studied by Astarita and Marrucci [12], Bhome [13], Kishan [14] and Kavitha [15].

Nanotechnology has immense applications in industry since materials with sizes of nanometers exhibit unique physical and chemical properties. Fluids with nano-scaledparticles interaction are called as nanofluid. It represents the most relevant technological cutting edge currently being explored. Nanofluid heat transfer is an innovative technology which can be used to enhance heat transfer. Nanofluid is a suspension of solid nanoparticles (1–100 nm diameters) in conventional liquids like water, oil and ethylene glycol. Depending on shape, size, and thermal properties of the solid nanoparticles, the thermal conductivity can be increased by about 40% with low concentration (1–5% by volume) of solid nanoparticles in the mixture. The nano particles used in nanofluid are normally composed of metals, oxides, carbides or carbon nanotubes. Water, ethylene glycol and oil are common examples of base fluids. Nanofluid have their major applications in heat transfer, including microelectronics, fuel cells, pharmaceutical processes and hybrid-powered engines, domestic refrigerator, chiller, nuclear reactor coolant, grinding, space technology and in boiler flue gas temperature reduction. They demonstrate enhanced thermal conductivity and convective heat transfer coefficient counterbalanced to the base fluid. Nanofluid has been the core of attention of many researchers for new production of heat transfer fluids in heat exchangers, plants and automotive cooling significations, due to their enormous thermal characteristics Nadeem et al. [16].

The nanofluid is stable, it introduce very little pressure drop, and it can pass through nanochannels (for more instance see Zhou [17]). The word nanofluid was coined by Choi [18]. Xuan and Li [19] pointed out that at higher nanoparticle volume fractions, the viscosity increases sharply, which suppresses heat transfer enhancement in the nanofluid. Therefore, it is important to carefully select the proper nanoparticle volume fraction to achieve heat transfer enhancement. Buongiorno [9] noted that the nanoparticles absolute velocity can be viewed as the sum of the base fluid velocity and a relative velocity (that he called the slip velocity). He considered in turn seven slip mechanisms: inertia, Brownian diffusion, thermophoresis, diffusiophoresis, Magnus effect, fluid drainage, and gravity settling.

Forced convective heat transfer can be enhanced effectively by using nanofluids, a type of fluid adding different suspending nanoparticles into the conventional base liquid (Pak and Cho [20], Wen and Ding [21], Ding et al. [22]). However, the characteristics of nanofluids and the mechanism of the enhancement of the forced convective heat transfer of nanofluids are still not clear. Recently nanofluids have attracted much attention since anomalously large enhancements in effective thermal conductivities were reported over a decade ago (Choi [18], Masuda [23], Keblinski et al. [24]). Subsequent studies by various groups have reported that nanofluids also have other desirable properties and behaviors such as enhanced wetting and spreading (Wasan et al. [25], Chengara et al. [26]), as well as increased critical heat