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A review on slip-flow and heat transfer performance of nanofluids from a permeable shrinking surface with thermal radiation: Dual solutions

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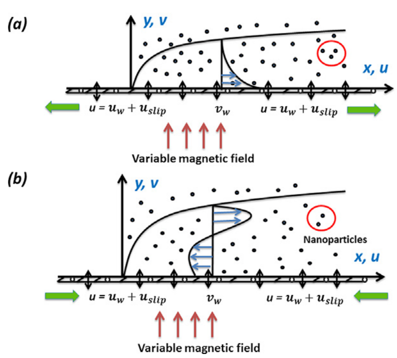
HIGHLIGHTS

- Heat transfer performance of nanofluid in the presence of non-linear radiation is investigated.
- Dual solutions of the flow fields are presented for certain range of shrinking and suction parameters.
- The effects of velocity slip and magnetic field on the nanofluid flow are further examined.
- Presence of velocity slip significantly widens the dual solution existence range.
- The rate of heat transfer was found to be a decreasing function of power-law parameter.

GRAPHICAL ABSTRACT



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ABSTRACT

A computational study on the stagnation-point flow of an electrically conducting nanofluid over a non-linear stretching/shrinking surface with first-order slip phenomenon is carried out. Because, nanofluids are considered as one of the closest kinds to the practical application of fluid flows owing to its comprehensive properties such as the Brownian motion and thermophoresis. The simulations were performed to understand the heat and mass transfer traits in the presence of non-linear radiation. Moreover, the Rosseland approximation model is incorporated to investigate the mechanisms of radiative heat transfer performance of nanofluids. For all cases, it has been seen that the governing conservation equations of current model possesses a similarity solution. The transformed system of nonlinear ordinary differential equations, is then integrated numerically with a boundary value problem solver, bvp4c in Matlab software. The captured numerical results have been displayed graphically and some interesting features like multiple (upper and lower) solutions are found. The critical values corresponding to the suction parameter f_w and the shrinking parameter λ are computed. The rising thermo-physical dimensionless parameters overseeing the flow are power-law parameter, Hartmann number, slip parameter, Eckert number, temperature ratio parameter, radiation parameter, Brownian motion and thermophoresis parameters and Lewis number. It is found that, the slip parameter has a reducing impact on the skin friction coefficient for both upper and lower branch solutions. The major outcome of the present study is that the temperature ratio parameter boosts the temperature profiles for both solutions. While the temperature profiles show a decreasing behavior for higher non-linear radiation parameter. Validation of numerical scheme is accomplished by means of benchmarking with some already reported studies, and a great correlation is illustrated.

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1. Introduction

In modern research era, the convectional heat transfer fluids like water, kerosene, engine oil and acetone assume a crucial part in numerous industrial segments including power generation, manufacturing and transportation, chemical production, air-conditioning and microelectronics. On the other hand, because of their low thermal conductivity they have restricted heat transfer capabilities. Recently, scientists are curious to develop different methods to increase their heat transfer performance. One of such methods to overcome this limitation is to improve thermal conductivity of conventional fluids via suspensions of nanoparticles in base fluids and led us to generate a new composite called "nanofluids". Moreover, this field is much efficient in terms of heat transfer performance. Technically, these suspensions contain the base fluids and the nanoparticles with a size of (1–100 nm)which are suspended in them. Current works on nanotechnology has proved that nanoparticles with (diameter less than 50 nm) can change properties of the fluid since thermal conductivity of nanoparticles particles was higher than convectional fluids which are widely used as heat transfer fluids in thermal processes. The common nanoparticles those are being used are aluminum, copper, iron and titanium or their oxides. Initially, this idea was given by Choi and Eastman (1995) who concluded that these nanofluids have better conductivity and convective heat transfer coefficient relative to the base fluid. Based on their shape, size, and thermal properties, the thermal conductivity can be enhanced by about 40% with low concentration (1–5% by volume) of solid nanoparticles in the mixture. A broad spectrum of their application includes the sterilization of medical suspensions, cooling of heat sinks, hybrid-powered engines and nuclear reactor coolant.

The flow and heat transfer phenomena for nanofluids has been a topic of much research over the past two decades. In recent years, numerous analysts have assessed the properties and impact of nanofluids on the heat transfer change in thermal systems. After the work of Choi and Eastman (1995), numerous endeavors in this field have been accomplished to formulate the heat and transfer characteristics of nanofluid flows. In 2006, Buongiorno (2006) presented a comprehensive study concerning the heat transport in nanofluids and in his work he found an extraordinary rise in the thermal conductivity of nanofluids. After that, Khan and Pop (2010) have broken down the boundary layer flow of a nanofluid over a stretching surface. This was probably the first attempt to ponder the flow of nanofluids over stretching sheet by utilizing a model in which the Brownian motion and thermophoresis impacts were considered. A theoretical analysis has been done by Makinde and Aziz (2011) to investigate the impact of convective heat transfer on the flow of nanoparticle past a stretching sheet. Sheikholeslami (2014) scrutinized the hydrothermal characteristics of nanofluid flow and heat transfer between two parallel plates. The MHD thin film flow and heat transfer of pseudo-plastic nanofluids over a unsteady stretching surface is analyzed by Lin et al. (2015). Furthermore, Hashim and Khan (2016) numerically investigated the heat and mass transfer analysis in the flow of Carreau nanofluids. In this article, they utilized the revised model for nanofluids and solutions are obtained with the help of Runge-Kutta numerical technique. The influence of particle shape on Marangoni convection boundary layer flow of nanofluid is deliberated by Ellahi et al. (2016). They implemented the convective boundary and nanoparticles mass flux conditions in this analysis. Sheikholeslami (2016) reported the impact of variable magnetic field on the flow of $Fe_3O_4 - H_2O$ nanofluid in a cavity with circular hot cylinder. Innovative numerical method, namely CVFEM is selected to perform the numerical computations. Further, Akbarzadeh et al. (2016) presented a study that concentrate on the sensitivity analysis of the thermal and hydraulic managements simultaneously for nanofluid flow inside a wavy channel. Recently, a number of investigations have been carried out to highlights the nanofluids transport by various authors, for instance, Bhatti et al. (2017), Esfahani et al. (2017), Ellahi et al. (2017), Shirvan et al. (2017), Sheikholeslami (2017b,c) and Sheikholeslami and Bhatti (2017).

In recent times, heat transfer problem with the impact of non-linear thermal radiation is one of the thrust fields of contemporary research by reason of their tremendous applications in the field of Engineering and Physics. For example, in space technology such as comical flight aerodynamics rocket, in high-temperature processes such as plasma physics and space craft reentry aerodynamics. Furthermore it assumes a key part to enhance the heat transfer properties in polymer processing industry. Further, the MHD flow problems have attracted the interest of many researchers due to their wide appearances in technological process, such as, in MHD accelerator, nuclear fusion device, astrophysics, aeronautics and aerospace. In some conditions, the thermal radiation assumes prominent part on MHD flow and heat transfer with specific parameters, which has been verified in lots of research works. There are right now some delightful works on the fluid flows with non-linear radiation. Impact of thermal radiation on mixed convection flow over a vertical surface in a porous medium was studied by Bakier (2001). He employs the fourth-order Runge–Kutta method to obtain the numerical solutions of the governing equations. Cortell (2008) presented an endeavors to study the flow of viscous fluid over a nonlinear stretched surface by encountering the effects of thermal radiation in the energy equation. Later on, Lin et al. (2014) performed a numerical computation to discuss the radiation effects on Marangoni convection flow driven by a power-law temperature gradient for pseudo-plastic nanofluids. Again, the radiative heat transfer analysis of nanofluids against a flat plate in the presence of first order chemical reaction is investigated by Zhang et al. (2015). In this study, they employed the DTM-BF method to obtain approximate analytic solutions of their problem. Recently, Hashim et al. (2017) obtained the dual solutions in heat transfer analysis of a non-Newtonian Carreau fluid flow by encountering the non-linear thermal radiation. In their study, they utilized the non-linear Rosseland approximation for thermal radiation and noticed that the dual solutions exist for different values of shrinking parameter. Further, Sheikholeslami (2017a) investigated the influence of Lorentz forces on Fe_3O_4-water nanofluid by taking into account the radiation source term in energy equation.

With the deepening of the studies, researchers started to find that boundary slip condition portraying the relative motion between the solid surface and the fluid adjacent to the solid surface is an imperative interfacial property to affect the fluid flow characteristics. There is a finite velocity of the fluid-solid interface and such type of boundary condition for velocity is the so-called boundary slip, and it can be characterized by slip length. Possibly, Navier (1827) was the first who proposed the velocity slip boundary condition in which the tangential slip velocity u_w is linearly related to the wall shear stress τ_w, in the form $u_w = L\tau_w$, where L is the slip coefficient varies with temperature, pressure, normal stress, molecular parameter, and the characteristic of the fluid solid interface. It may be pointed out that there are several physical situations for which slip on a solid surface occurs. For instance, it happens in flow of rarefied gas (Sharipov and Seleznev, 1998), in flow over lubricated or coated surfaces (Teflon), rough or striated surfaces (Wang, 2003) and most recently, superhydrophobic nano-surfaces (Choi and Kim, 2006). Further, no-slip phenomenon