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Comparing thermal enhancement of Ag-water and SiO_2-water nanofluids over an isothermal stretching sheet with suction or injection

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Abstract

In the present paper, the flow and heat transfer of two types of nanofluids, namely, silver-water and silicon dioxide-water, were theoretically analyzed over an isothermal continues stretching sheet. To this purpose, the governing partial differential equations were converted to a set of nonlinear differential equations using similarity transforms and were then analytically solved. It was found that the magnitude of velocity profiles in the case of SiO_2-water nanofluid was higher than that of Ag-water nanofluid. The results showed that the increase of nanoparticle volume fraction increased the non-dimensional temperature and thickness of thermal boundary layer. In both cases of silver and silicon dioxide, increase of nanoparticle volume fraction increased the reduced Nusselt number and shear stress. It was also demonstrated that the increase of the reduced Nusselt number was higher for silicon dioxide nanoparticles than silver nanoparticles. However, the thermal conductivity of silver was much higher than that of silicon dioxide.

Nomenclature

a	Parameter of Padé method
c	Coefficient of stretching sheet velocity
C_f	Skin friction coefficient
C_p	Specific heat at constant pressure
e_1, e_2	Parameters of symbolic power series method
f	Dimensionless flow
k	Thermal conductivity
K	A constant
L	Degree of denominator in Padé method
M	Degree of numerator in Padé method
Nur	Reduced Nusselt number
p	Parameter of Padé method
Pr	Prandtl number
q	Parameter of Padé method
Re_x	Local Reynolds number
s	Mass transfer parameter
Sh_x	Local Sherwood number
T	Temperature
T_∞	Ambient temperature
T_w	Temperature at the stretching sheet
U, U_w	Local velocity of the sheet
u,v	Velocity components along x- and y-axes

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v_w	Velocity in y direction on the sheet surface
x,y	Cartesian coordinates (x-axis is aligned along the stretching surface and y-axis is normal to it)
Greek	
α	Thermal diffusivity
ζ, γ, β	Function variables
η	Similarity variable
θ	Dimensionless temperature
λ	Avariable which shows the effect of nano particles in the momentum equation
μ	Dynamic viscosity
ρ	Density
τ	A variable defined by Eq. (25)
υ	Kinematics viscosity
φ	Nanoparticle volume fraction
Subscripts	
∞	Ambient value
f	Pure fluid property
l, k	Parameters of Padé method
n	Value at the previous step
nf	Nanofluid property
s	Solid nanoparticle property
w	The stretching sheet (wall)

1. Introduction

The flow and heat transfer of a viscous fluid over a continues stretching surface have promising applications in a number of technological processes such as metal and polymer extrusion, continuous casting, drawing of plastic sheets, paper production, etc. [1 and 2]. In these applications, the heat transfer rate in the boundary layer over stretching sheet is important because the quality of the final product depends on the heat transfer rate between the stretching surface and the fluid during the cooling or heating process [3]. Therefore, the choice of a proper cooling/heating liquid is essential as it has a direct impact on the rate of heat transfer.

Recently, convective heat transfer in nanofuids has become a topic of major contemporary interest because of the unique thermal properties of these fluids. Nanofuids can be described as a fluid in which the particles in the size of nanometer, 1–100 nm, are suspended. Nanofluids were first coined by Choi [4] in 1995. Dispersed uniformly and suspended stably in a pure base fluid, a very small amount of nanoparticles can provide impressive improvement in the thermal properties of the base fluid [5].

Based on the application of nanofluids, nanoparticles have been made of various materials such as oxide ceramics, nitride ceramics, carbide ceramics, metals, semiconductors, carbon nanotubes as well as composite materials such as alloyed nanoparticles $Al_{70}Cu_{30}$ or nanoparticle core–polymer shell composites, etc. [5].

The boundary layer flow and heat transfer past a stretching sheet have received a wide range of attention among researchers. Crane [6] was the first who obtained an analytical solution for laminar boundary layer flow past a stretching sheet. Gupta and Gupta [7] solved the boundary layer flow over a stretching sheet with suction and injection. After these pioneering works, a large number of studies have been developed to analyze various aspects of this phenomenon such as magnetic flows [8], micropolar fluids [9] and viscoelastic flows [10 and 11].

Khan and Pop [12] examined boundary layer and heat transfer of nanofluids over a linear stretching sheet. Makinde and Aziz [13] analyzed heat transfer of nanofluids over a stretching sheet subjected to convective heat transfer. Rana and Bhargava [14] studied the boundary layer and heat transfer of nanofluids over a nonlinear stretching sheet.

Noghrehabadi et al. [15] investigated the thermal enhancement of nanofluids over an isothermal stretching sheet. They considered a slip boundary condition for the flow over the stretching sheet in the presence of nanoparticles. All of these studies [12–15] analyzed the effect of parametric variation of non-dimensional parameters on the thermal enhancement of nanofluids. They did not perform any case study to show the enhancement of using nanofluids in comparison with pure base fluid. In contrast, some researchers have performed case studies to indicate the enhancement of using nanofluids in comparison with the pure base fluid. Yacob et al. [16] used a numerical analysis to compare the thermal enhancement of two types of nanofluids, namely, Ag-water and Cu-water nanofluids, over an impermeable stretching sheet. Hamad [17] studied boundary layer and heat transfer of nanofluids over an impermeable isothermal stretching sheet for the metallic and metallic oxide nanoparticles.

The purpose of the present study is to analyze the effect of two types of nanoparticles, namely, silicon dioxide and silver, on the thermal enhancement of water base nanofluids over an isothermal stretching sheet with suction or blowing. A similarity solution, depending on the volume fraction of nanoparticles, is obtained and analytically solved.

2. Problem Formulation

Consider an incompressible laminar steady two-dimensional boundary layer flow past an isothermal stretching sheet in a water-based nanofluid. The nanofluid can contain different volume fractions of SiO_2 or Ag nanoparticles. The scheme of the physical model and geometrical coordinates are shown in Fig. 1. It is assumed that the base fluid (i.e. water) and the nanoparticles are in thermal equilibrium, and also no slip occurs between them. The thermophysical properties of the water and nanoparticles are given in Table 1.

Table 1. Thermophysical properties of water and nanoparticles.

Physical Properties	Fluid Phase (water) [15]	Ag [18]	SiO_2 [19]
C_p (J/kg.K)	4179	235	765
ρ (kg/m^3)	997.1	10500	3970
k (W/m.K)	0.613	429	36
$\alpha \times 10^7$ (m^2/s)	1.47	1738.6	118.536

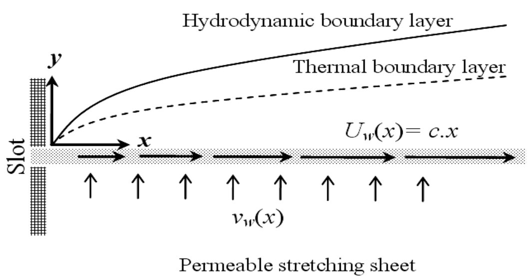

Fig. 1. Scheme of stretching sheet.

The sheet surface has the constant temperature of T_w, and the temperature of ambient fluid is T_∞. The fluid outside the boundary layer is quiescent and the stretching sheet velocity is linear. Therefore, the velocity of the sheet is $U(x)=c.x$, where c is a constant. By applying boundary layer assumptions, the steady two-dimensional boundary layer equations of the momentum, flow and heat for the nanofluid in the Cartesian coordinate system are written as:

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

$$u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}=\frac{\mu_{nf}}{\rho_{nf}}\left(\frac{\partial^2 u}{\partial y^2}\right) \tag{2}$$

$$u\frac{\partial T}{\partial x}+v\frac{\partial T}{\partial y}=\alpha_{nf}\frac{\partial^2 T}{\partial y^2} \tag{3}$$

subject to the following boundary conditions at the sheet surface:

$$v=v_w(x),\ \ u=U_W(x),\ T=T_W,\ at\ y=0 \tag{4}$$

and the boundary conditions in the far field (i.e. $y\to\infty$):

$$v=u=0,\quad T=T_\infty,\quad as\ y\to\infty \tag{5}$$

where the subscript of nf denotes nanofluid. The thermophysical properties of nanofluid can be evaluated as follows:

$$\alpha_{nf}=k_{nf}\big/\left(\rho C_P\right)_{nf}, \tag{6}$$

$$\rho_{nf}=\left(1-\phi\right)\rho_f+\phi\rho_s, \tag{7}$$

The effective dynamic viscosity of nanofluids can be obtained using Brinkman model [20 and 21] as:

$$\mu_{nf}=\frac{\mu_f}{\left(1-\phi\right)^{\frac{5}{2}}}, \tag{8}$$