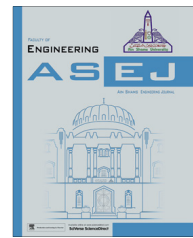




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Transient thermophoretic particle deposition on forced convective heat and mass transfer flow due to a rotating disk



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Abstract This paper investigates thermophoretic deposition of micron sized particles on unsteady forced convective heat and mass transfer flow due to a rotating disk. Using similarity transformations the governing nonlinear partial differential equations are transformed into a system of ordinary differential equations that are then solved numerically by applying Nachtsheim–Swigert shooting iteration technique along with sixth-order Runge–Kutta integration scheme. The effects of the pertinent parameters on the radial, tangential and axial velocities, temperature and concentration distributions, and axial thermophoretic velocity together with the local skin-friction coefficient, and local Nusselt number are displayed graphically. The inward axial thermophoretic deposition velocity (local Stanton number) is also tabulated. The obtained results show that axial thermophoretic velocity is increased with the increasing values of the thermophoretic coefficient, thermophoresis parameter, rotational parameter as well as unsteadiness parameter. The results also show that inward axial thermophoretic particle deposition velocity decreases with the increase of the Lewis number.

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1. Introduction

Flow due to a rotating disk is encountered in many industrial, geothermal, geophysical, technological and engineering applications. A few of them are rotating heat exchangers, rotating disk reactors for bio-fuels production, computer disk drives and gas or marine turbines. The pioneering study of fluid flow due to an infinite rotating disk was carried out by von Karman [1]. He formulated the problem and introduced a famous transformation which reduced the governing partial

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List of symbols

C_f	skin-friction coefficient	u, v, w	velocities along radial, tangential and axial direction respectively
c_p	specific heat at constant pressure	U_T	thermophoretic velocity along the radial direction
C	concentration within the boundary layer	V_d^*	nondimensional thermophoretic particle deposition velocity
C_w	concentration at the surface of the disk	W_T	thermophoretic velocity along the axial direction
C_∞	concentration of the ambient fluid	W_T^*	nondimensional thermophoretic velocity along the axial direction
D_B	Brownian diffusivity	z	axial coordinate
F	dimensionless radial velocity	ρ	density of the fluid
G	dimensionless tangential velocity	μ	coefficient of dynamic viscosity
H	dimensionless axial velocity	ν	kinematic viscosity
k	thermal conductivity of the fluid	κ	thermophoretic coefficient
Kn	Knudsen number	α	thermal diffusivity
N_t	thermophoresis parameter	η	similarity variable
Nu	Nusselt number	δ	time dependent length scale
Pr	variable Prandtl number	λ	unsteadiness parameter
q	velocity vector	λ_g	thermal conductivity of the fluid
q_w	surface heat flux	λ_p	thermal conductivity of the diffused particles
R	rotational parameter	ϕ	azimuthal coordinate
Re	rotational Reynolds number	ϕ	dimensionless concentration
r	cylindrical radial coordinate	τ_r	radial shear stress
Sc	Schmidt number	τ_t	tangential shear stress
St	Stanton number	θ	dimensionless temperature
t	time	Ω	angular velocity
T	temperature within the boundary layer		
T_w	temperature at the surface of the disk		
T_∞	temperature of the ambient fluid		

differential equations into ordinary differential equations. Cochran [2] obtained asymptotic solutions for the steady hydrodynamic problem formulated by von Karman. Benton [3] improved Cochran's solutions and solved the unsteady problem. The problem of heat transfer from a rotating disk maintained at a constant temperature was first considered by Millsaps and Pohlhausen [4] for a variety of Prandtl numbers in the steady state. Sparrow and Gregg [5] studied the steady state heat transfer from a rotating disk maintained at a constant temperature to fluids at any Prandtl number. Attia [6] studied the problem of unsteady MHD flow near a rotating porous disk with uniform suction or injection. Maleque and Sattar [7] investigated the influence of variable properties on the physical quantities of the rotating disk problem by obtaining a self-similar solution of the Navier–Stokes equations along with the energy equation. Attia [8] investigated the steady flow over a rotating disk in porous medium with heat transfer. Rahman [9] studied convective hydromagnetic slip flow with variable properties due to a porous rotating disk. Zueco and Rubio [10] analyzed the network method to study magnetohydrodynamic flow and heat transfer about rotating disk. Recently, Rahman [11] studied thermophoretic deposition of nanoparticles due to a permeable rotating disk considering the effects of partial slip, magnetic field, thermal radiation, thermal-diffusion, and diffusion-thermo. It is observed that slip mechanism, thermal-diffusion, diffusion-thermo, magnetic field and radiation significantly control the thermophoretic particles deposition rate.

Thermophoresis, the motion of suspended particles in a fluid induced by a temperature gradient, is of practical importance in a variety of industrial and engineering

applications such as design of thermal precipitators, study on the behavior of soot or seeding particles in combustion systems, nuclear reactor safety, gas cleaning, chemical or physical vapor deposition and microcontamination control, etc. Due to the practical importance of thermophoresis phenomenon many researchers (Goren [12], Talbot et al. [13], Mills et al. [14], Jia et al. [15], Chiou and Cleaver [16], Tsai [17], Postelnicu [18] and the references therein) have studied and reported results on this topic considering various flow conditions in different geometries. Alam et al. [19–21] studied thermophoretic particle deposition on two dimensional hydromagnetic heat and mass transfer flow over an inclined flat plate with various flow conditions. Rahman and Postelnicu [22] studied the effects of thermophoresis on steady forced convective laminar flow of a viscous incompressible fluid over a rotating disk. Rahman et al. [23] studied the thermophoresis particle deposition on unsteady two-dimensional forced convective heat and mass transfer flow along a wedge with variable viscosity and variable Prandtl number whereas Postelnicu [24] studied the thermophoresis particle deposition in natural convection over inclined surface in a porous media.

The objective of the present paper was to extend the work of Rahman and Postelnicu [22] for unsteady case and to investigate the deposition mechanism of micron-sized particles due to thermophoresis on transient forced convective heat and mass transfer flow over an impermeable rotating disk whose surface temperature is lower than the temperature of its surrounding fluid. Using similarity transformations the governing equations for flow, heat and mass transfer have been transformed into a system of ordinary differential equations that

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