Ain Shams Engineering Journal (2016) 7, 441–452

Ain Shams University

Ain Shams Engineering Journal

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www.sciencedirect.com

ENGINEERING PHYSICS AND MATHEMATICS

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

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Received 6 June 2014; revised 17 March 2015; accepted 15 April 2015
Available online 6 June 2015

KEYWORDS

Forced convection;
Heat transfer;
Mass transfer;
Unsteady flow;
Rotating disk;
Thermophoresis

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.

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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Peer review under responsibility of Ain Shams University.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.asej.2015.04.005

List of symbols

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

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