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Particle deposition with thermal and electrical effects in turbulent flows

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ABSTRACT

Development of relationships for the particle concentration and convection velocity profile has been obtained by the adaptation of the surface renewal model to the particle continuity and momentum equations of the turbulence boundary-layer flow in the presence of thermal field [1]. The predictions obtained on the basis of this model for nonisothermal deposition velocity of particles have been found to be in good agreement with the experimental measurements for fully-developed turbulence tube flow conditions. The aim of this work is to extend the previous model for an applied electric field, with the inclusion of the effect of Coulombic force in addition to the Brownian and turbulent diffusion, the eddy impaction, the turbophoresis, and the thermophoresis. The calculations show an interaction between thermophoresis and turbophoresis in the presence of an applied electric field. The effect of electric force in nonisothermal flows can have a dramatic effect on thermophoretic deposition for $\tau_p^+ < 0.02$, where turbophoretic effect has ceased. The effect of axial pressure gradient is also included.

1. Introduction

The free-flight model was one of the most used calculation methods for the observed large increase in deposition velocities [2–5]. The fundamental difference between different calculation methods of this model lies in prescribing the initial velocity that the particles possess at the distance where they effectively breaks away from the containing eddies and embarks on a free flight toward the wall. This model yielded reasonable agreement with deposition rate measurements for intermediate relaxation times, but poor agreement at high values. The measured deposition velocities, which are generally accepted as one of most dependable data set, have been found to be changed fairly to a slowly falling value with increasing the particle relaxation time τ_p^+ [6]. The previous paper [7] gave an alternative approach to formulate the thermophoretic velocity and the particle concentration profiles in a nonisothermal turbulence flow with fully-developed boundary layer. The characteristic features of this approach model were based on the consideration that a net particle flux J arises mainly from the Brownian diffusion D_b and thermophoretic force suspended in a flowing fluid,

$$J = -D_b\frac{\partial C}{\partial y} + \upsilon_{\mathrm{th}}C, \tag{1}$$

where y is the wall-normal distance and $\partial C/\partial y$ is the wall-normal gradient of mean particle concentration C. The mean thermophoresis velocity υ_{th} depends on the wall-normal gradient in mean fluid temperature. Incorporating the Cunningham correction as shown by Hinds [8]

$$C_c = 1 + \frac{1}{Pd_p}\left[15.6 + 7.0\exp(-0.059Pd_p)\right], \tag{2}$$

the Brownian diffusion D_b for a rarefied gas effect can be calculated by

$$D_b = C_c\frac{K_bT}{3\pi\mu d_p}, \tag{3}$$

where P is the absolute pressure in kPa, d_p the particle diameter in μm, μ the dynamical viscosity, T the absolute temperature, and Boltzmann's constant $K_b = 1.38\times10^{-23}$ J/K.

The proposed relationships for the particle concentration distribution and transport coefficient within the average sublayer growth period $\overline{\tau}$ was obtained by adaptation of the surface rejuvenation model [9,10] to the particle continuity equation,

$$\frac{\partial C}{\partial \tau} = \frac{\partial}{\partial y}\left[D_b\frac{\partial C}{\partial y} - C\upsilon_{\mathrm{th}}\right], \tag{4}$$

where τ is the residence time between two successive eddies. The calculations of particle transport coefficient $\overline{\upsilon}_d\overline{H}/D_b$ within the average sublayer growth period $\overline{\tau}$ were presented for various values

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