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Effect of thermophoresis on particle deposition rate from a natural convection flow onto a vertical wavy plate☆

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Abstract

This research discusses the impacts of the surface area that the wavy surface gets more than the flat plate upon the aerosol particle deposition. Starting from the full Navier–Stokes equation, the mathematical analysis takes the thermophoretic motion formed by the temperature gradient and the fluid thermal expansion into consideration, and converts the governing equations into the boundary layer equation by the simple coordinate transformation and non-similarity method, and then works out these equations by the Spline Alternating-Direction Implicit method (SADI). The numerical value result reveals that the average deposition effect of the wavy plate is greater than the flat plate and that the increasing rate is nearly equal to the value obtained by dividing the surface area that the wavy plate gets more than the flat plate by 2.2.

Keywords: Aerosol particles; Wavy surface; Thermophoresis; Coordinate transformation; Cubic spline

1. Introduction

In this Nano time, human beings not only pursue the small size manufacturing technology but also find it very important to research into the aerosol particles floating in the air. From the dusts produced by the daily cleaning and the waste gas discharged from cars and motorbikes, which deposit on the alveolus

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and do harm to human health, to the semiconductor quality control, the dust-collecting in the clean room, the air-pollution control and the human respiratory system protection, its importance can be seen everywhere in the latter-day high-tech life. Generally, the known transferring mechanism of the aerosol particle deposition includes Brown Diffusion, convection, thermophoresis, sinking and other external force effects, such as static electricity effect and electromagnetic effect (Reist [1]). Regarding the analysis on the natural convection of the thermal expansion, in early days, Nazaroff and Cass [2] discussed the deposition effect of the vertical flat plate as well as Epstein et al. [3] discussed the low temperature surface deposition in the laminar and turbulent flow fields; and recently, many researches found that the temperature gradient of the flow field made the thermophoresis that the particles floated from the place at high temperature to the place at lower temperature more obvious when the particle diameter was ranging between 0.1 and 10 um. Consequently, the relevant researches were taken seriously. For instance, Tsai and Lin [4] and Jayaraj [5] made use of the approximate solution and the finite difference method respectively to research into the impacts of the thermophoresis upon the vertical flat plate deposition effect. And later, Jayaraj et al. [6] and Chamkha and Pop [7] further researched into the impacts of the thermophoresis effect upon the vertical flat plate deposition effect under the changeable physical parameters and the porous materials.

Regarding the convectional heat transfer of the flat plate, some small and irregular surfaces are produced inevitably in the process of making flat plates, so these irregular surfaces change the flow fields and the thermophoresis and make the analysis more complex than the traditional one. On the other hand, for the aerosol particle deposition, we always hope to find a way to increase the deposition efficiency, namely, to get the required deposition effect within the shortest time, the smallest space and the lowest difference in temperature. Of many methods, to change the shape of the deposition surface is a simpler way to change the flow fields and the heat transfer distribution with concave and convex surfaces and to increase the surface contact area. However, looking back into the past researches on aerosol particles, we found that these researches all focused on the smooth surface and some simpler 2D geometric objects, such as circular cylinders (Chiou [8]) and circular discs (Tsai et al. [9]); and regarding some researches on more complex surfaces, because it is more difficult to deal with the mathematics and the boundary, no essay on the aerosol particle has been published and only a few traditional heat transfer analyses have been made, such as Yao [10] and Rees and Pop [11].

This research will use the Prandtl's Transposition Theorem to extend the original coordinates system to a certain direction and to convert the irregular surface into a plane coordinates system. As the analyzing process must take the impacts of the geometric relations of the slight displacement on the deposition surface upon the system into consideration, the mathematical analysis should start from the full Navier–Stokes equation and use the Spline Alternating-Direction Implicit Method (SADI) to work out the boundary layer equations obtained by the non-similarity conversion so as to discuss the natural convection of the aerosol particle fluid onto the vertical wavy plate.

2. Structure of theoretical model

A vertical semi-infinite wavy plate is placed into the static Newtonian fluid containing aerosol particles with the constant temperature T_∞ and the concentration C_∞. On the assumption that the temperature of the wavy surface (x axis) stayed constant T_w, the geometry of the wavy surface could be described as $\bar{S}(\bar{x})=\bar{a}\ \sin(2\pi\bar{x}/L)$. Its physical model and coordinate system are shown in Fig. 1. The