MEASUREMENTS OF PHORETIC VELOCITIES IN MICROGRAVITY CONDITIONS OF PARABOLIC FLIGHTS

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INTRODUCTION

Small particles suspended in non-isothermal gas experience a force in the direction opposite to the temperature gradient as a result of differences in momentum and energy transferred to the particles by molecules colliding with them from their hot and cold side. This phenomenon, known as thermophoresis , is of considerable importance in a variety of engineering fields (coating of surfaces, gas cleaning, optical fiber production). It is also of central interest in the scavenging of aerosol particles in cloud, when droplets and/or ice crystals grow or evaporate, and below cloud, during the fall of hydrometeors. Although thermophoresis has been studied extensively, both experimentally and theoretically, the data and theory remain controversial, particularly with reference to the transition region (Derjaguin and Yalamov, 1965; Brock, 1967; Talbot et al., 1980; Prodi et al, 1979). Thermophoresis is thought to be more effective when the temperature gradient becomes steeper. In normal gravity the gas flow of natural convection which is also induced by the temperature gradient has an influence on the behaviour of particles. When the temperature gradient becomes steep, the effect of natural convection becomes dominant, making it difficult to determine the thermophoretic effect. As regards diffusiophoresis, i.e. the movement of aerosol particles in a concentration gradient, the microgravity environment simplifies the problem, as it eliminates the continuous renewal of the vapour concentration field. This difficulty will be avoided if experiments are performed in microgravity, where the effect of natural convection becomes negligible. Previous experiments on thermophoretic velocity measurements in microgravity conditions were carried out in a drop tower. This facility provides a microgravity level of about 10^{-5} g and a duration ranging from 5 to 10 s (Toda et al., 1996; Oostra et al., 1997).

EXPERIMENTAL ARRANGEMENT AND RESULTS

The microgravity environment was obtained through parabolic flights on an Airbus Zero-G. In addition to drop towers, sounding rockets, satellites and space stations, this facility is a useful tool for performing short duration scientific experiments. A reduced gravity environment is achieved by flying through a series of parabolic manoeuvres, which result in approximately twenty-two second periods of 0-g acceleration (actually around 10^{-2} g). A normal mission lasts two to three hours and consists of thirty parabolic manoeuvres.
For the first experiments we used a cell with two plane plates (surface of about 100 cm^2) at a fixed distance (0.8cm) and different temperatures. As aerosol, we used carnauba wax and sodium chloride. The carnauba wax aerosol was produced with the MAGE, a condensation aerosol generator for solid particles designed by V.Prodi (1972), while the sodium chloride came from vaporisation of a thin film of sodium chloride deposited on a heated ceramic tube. The aerosol is injected in the cell after the desired temperature gradient is created. The maximum temperature gradient was in the order of 190 K cm^{-1}.
For the second experiment, we used a pendant drop with surrounding aerosol. In this case thermophoretic and diffusiophoretic forces are coupled and the previous results are contradictory.

The velocity of aerosol was deduced by using a new type of digital holography microscope (Dubois et al., 1999) that allows investigation of three-dimensional objects. After storing a reference image at the beginning of the experiment, only one image is sufficient to reconstruct the current three dimentional coordinates of all the aerosol particles. It decrease considerably the amount of information to store during the experiment that is very important for the equipment used in microgravity conditions. The microscope provides the sampling rate of 30 s^{-1} and accuracy better than 2 μm for the coordinate determination. It allows to get accurate data even for the particles moving as slow as several micrometers per second. The latter makes it possible to measure phoretic velocities at much lower gradients that are ususlly applied in such kind of experiments.
Based on digital image processing the experimental volume is reconstructed slice by slice in order to achieve a full focused volume. Particular 3D areas of the reconstructed images may be analysed digitally, easily changing magnification and area of interest. For the aerosol applications, three-dimensional co-ordinates of the particles are retrieved by these procedures and particle trajectories are reconstructed by the analysis of the sequence of particle positions.
The use of digital holographic microscope and microgravity conditions open a way to investigate quantitatively the individual motion of small aerosol particles in the vicinity of larger particles, the system, which is very important in the atmospheric processes, particularly in scavenging.

The reported experiments are our first steps in this direction and they were devoted mostly to work out instrumentation and procedures, find appropriate experimental systems. Preliminary results gave reduced thermophoretic velocity values comparable with those calculated from Brock’s equation for carnauba wax and from Talbot for sodium chloride.

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