Detection of the negative thermophoresis phenomenon in microgravity experiments

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Thermophoresis (motion of particles due to temperature gradient in a gas) is a subject of many-year experimental and theoretical investigations of great significance for fundamental and applied aerosol physics.

Substantial improvement of accuracy and sensitivity due to diminishing convective effects is possible to get in microgravity conditions performing experiments in drop towers, in parabolic airplane flights, or onboard the orbital space station. Microgravity conditions are the most advantageous, if not the only suitable for decisive experiments in tackling the problem of "negative thermophoresis", i.e. predicted for high-conductivity aerosol particles at small Knudsen numbers motion in the direction of temperature gradient and not against as for the traditional thermophoresis. Among recent researches in this area we will note the attempt to detect this phenomenon in the experiments with model macroparticles (Ventura *et al*, 2012) and new theoretical results for negative thermophoretic force for high-conducting particles (Takata and Hattori, 2012).

According to theoretical analysis the thermophoretic force and velocity are very sensitive to the variation of energy accommodation coefficient α_E. The value of α_E governs the magnitude of the heat flux normal to the surface, which, in its turn, controls the competition of oppositely directed thermal creep and thermal stress gas flow near the particle surface so that the thermophoretic velocity can be positive even for high-conductivity particles at very small Kn numbers. Experimental analysis of negative thermophoresis thus splits into two tasks: 1) testing which theories are adequate – those taking into account the thermal stress slip or without it and 2) which model most accurately takes into account peculiarities of these phenomena.

Experiments were performed at Bremen Drop Tower (Germany) with 4.7 s duration of high quality microgravity (better than 10^{-5}g). We used two types of particles *a*) high heat conductivity ($\Lambda = \lambda_p / \lambda_g$ =20500) polydisperse copper spherical particles with mean diameter of 74 µm and *b*) low conductivity ($\Lambda = 1.8$) hollow glass spheres with about the same particle size distribution. Particles were injected separately into the cubic cell filled with nitrogen at normal pressure with four windows for stereoscopic observation in back illumination. The gradient was created by a heated wire in the cell center. Velocities were analyzed for the particles, for which three-dimensional trajectories were identified. Radial components of particle velocities were related to the thermophoretic motion. Previous results (Vedernikov *et al* (2008) and Beresnev *et al* (2008)) are here completed with the analysis of motion of low conductivity particles and detailed three-dimensional simulation of residual convective motion.

Typical velocities of low conductivity particles were around 0.3-0.5 mm/s depending on their distance from the wire and showed excellent agreement with the theory of Brock (1962). Velocities of copper particles appeared to be 30-50 times lower under the same conditions. Reduced thermophoretic velocities of copper particles are presented on Fig. 1 after refinement on residual convective motion.

These results meet predictions of gas-kinetic theories that take into account the thermal stress slip flow. As for the second task mentioned at the beginning, the experiments were still not sensitive enough to define the sign of the motion and relate it to a particular set of accommodation coefficients.

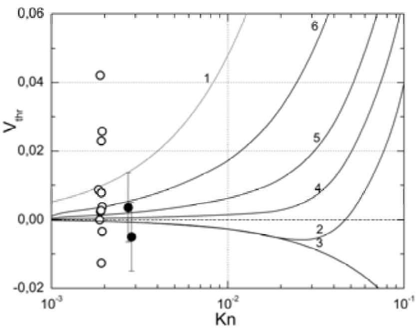

Figure 1. The dimensionless thermophoretic velocity V_{thr} for copper particles. Microgravity experiments: black circles stand for particles close to the wire where negative thermophoresis is dominant; open circles stand for particles far from the wire where dominates residual convection. Theory: 1 – Brock (1962); 2-6 – Beresnev et al (1995): 2 – calculations and 3 – asymptotic solution at $\alpha_\tau = \alpha_E = 1.0$; 4 – calculations at $\alpha_\tau = 1.0;\ \alpha_E = 0.95$; 5 – at $\alpha_\tau = 1.0;\ \alpha_E = 0.90$; 6 – at $\alpha_\tau = 1.0;\ \alpha_E = 0.80$.

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