Specialized aerosol solver for calculation of photophoretic motion characteristics of soot aggregates in stratosphere

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Specialized aerosol solver for a wide range of calculations related to the photophoretic motion of soot particles is developed. It is useful to keep the mathematical formalism used in model of homogeneous spheres (the general solution of fractal-like particle problem is extremely difficult). The calculation of force and velocity of longitudinal radiometric photophoresis is based on the molecular-kinetic theory of this phenomenon (Beresnev et al, 1993). This theory is based on the solution of gas-kinetic model equation with the corresponding boundary conditions for the velocity distribution function on the particle surface, and covers the entire range of the Knudsen number at arbitrary ratio between the thermal conductivities of the particulate matter and gas, taking into account the optical and accommodation properties of the particle-gas system.

For calculations of optical characteristics for fractal-like particles it is possible to use methods of effective medium approximations (e.g., Chylek et al, 1988) and theoretical predictions for fractal-like soot particles by Mackowski (2006). It was revealed that the choice m =1.764+0.570i for λ=0.68 μm (the wavelength of the He-Ne laser) is optimum. The optimal choice of the complex refractive index m allows to estimate with sufficient reliability the J_1 value which determines not only direction, but also magnitude of photophoretic velocity.

Effective thermal conductivity of fractal-like soot particles can be calculated using the method offered for estimation of thermal properties of nanofluids with significantly enhanced thermal conductivity by the aggregation of nanoparticles into clusters (Evans et al, 2008). The determined above characteristics are used in gas-kinetic calculations for photophoretic force and velocity. Reliability and accuracy of suggested model is necessary to estimate by comparison with adequate experimental and theoretical data. The experimental results of Karasev et al (2004) on photophoretic velocities of soot particles in nitrogen provide a unique opportunity to compare results. In experiment two groups of aggregates sizes distinctly differ: small particles at $R_m \leq 0.5$ μm and large particles $R_m > 0.5$ μm for which the mobility radius R_m was defined by various techniques at invariable fractal dimension D_f =1.80.

Thus, we can offer now the new model for photophoretic motion of fractal-like soot aggregates treated as equivalent to various characteristics spherical particles with effective values of microphysical and optical parameters.

On Fig. 1 the comparison of the new theory for fractal-like particles with experiment is presented. This comparison finds out the very good qualitative and quantitative agreement of theory and experiment.

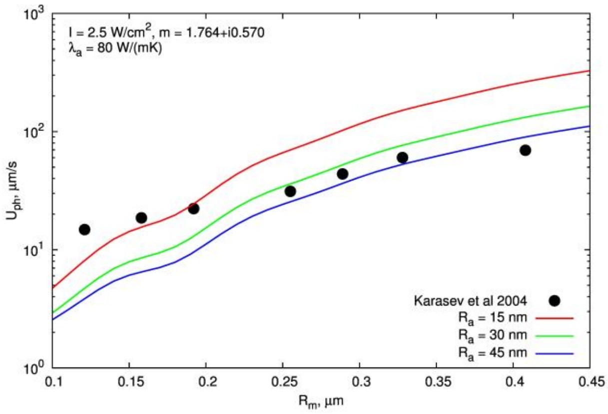

Figure 1. Dependence of the photophoretic velocity U_{ph} of soot aggregates on the mobility radius R_m. Black circles – the group of aggregates with $R_m \leq 0.5$ μm from experiment (Karasev et al, 2004), lines relate to various radius of primary particles R_a and heat conductivity of primary particles λ_a = 80 W/(mK) with effective heat-conductivity by Evans et al (2008).

It is also possible to calculate atmospheric applications of photophoretic motions using advanced atmospheric radiation block of the model. Thus it is possible to consider the cases of negative "solar" (motion of particles in the field of short-wave solar radiation against gravity) and positive "thermal" (motion in the field of thermal outgoing radiation) photophoresis of soot particles.

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