Numerical study of dynamics of growing droplets in Kelvin spectrometer

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Instruments capable of measuring droplet concentrations at given supersaturations are called Kelvin spectrometers. They are important for reliably characterizing atmospheric particles (Holländer et al., 2002). The rapid pressure drop in measuring chamber of cylindrical cross section is accompanied by an adiabatic temperature decrease, which may lead to sufficient supersaturation followed by droplet formation due to heterogeneous nucleation. The growing droplets move in the chamber, and part of them will deposit on the walls or evaporate with time. Heat conduction and natural convection flow due to the difference between the wall and volume gas temperatures will increase the interior temperature and reduce the supersaturation that in turn affects droplets growth and deposition.

We developed a mathematical model describing the transient thermal convection flow and deposition of growing droplets in the expansion-type Kelvin spectrometer. The model includes the Navier-Stokes equations to describe the gasdynamic processes and droplet growth model with account for vapor depletion due to condensation and release of latent heat. Numerical calculations of gas flow by means of Fluent CFD software show that the evolution of processes inside the spectrometer chamber can be divided into two main stages. The first stage is the adiabatic gas expansion. During it the pressure in the chamber establishes very quickly. The gas temperature falls down practically uniformly in the entire volume of the chamber. The next stage is characterized by a slow temperature increase beginning from regions near the walls. The temperature gradient causes the development of a gas flow upwards near the wall in the course of time transforms into a global vortex flow inside the chamber. The values of the thermal convection flow velocity magnitude can achieve ~0.05 m/s. To study the droplet dynamics we neglect the expansion stage in view of its small duration and calculate the temperature and convection flow development starting with the uniform temperature distribution inside the chamber and a constant wall temperature larger than the interior gas temperature. Using the gas flow velocity and temperature distribution from CFD calculation in the spectrometer chamber we calculate the droplets paths taking into account their growth resulting from the local super-saturation. The time dependencies of the droplet deposition rate were found from numerical calculations. The deposition rates with and without convection flow influence are compared.

The relative droplet concentrations obtained taking into account the main processes in the measuring chamber (droplet growth by condensation, sedimentation, heat conduction, thermal convection, droplet evaporation) and without gravity influence (g=0) are shown in fig.1. Curves obtained without gravity allow estimating the concentration dynamics due to the evaporation only. For the smaller initial saturation the losses of droplets generated by nucleation is determined mainly by evaporation. But for larger initial saturation sedimentation becomes main mechanism of droplet losses in the measuring chamber. In last case the vortex flow formed by thermal convection will reduce the deposition rate.

Figure 1. The relative droplet concentration for N=1000 cm⁻³ and various initial saturations S₀

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