Spreading of an aerosol cloud heated by illumination

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Many experimental studies in aerosol physics deal with clouds intensively illuminated to visualize particle motion. This is especially true for the research in microgravity condition on such topics as particle transport, complex/dusty plasma (Morfill and Ivlev, 2009), simulation of protoplanetary dust evolution (Blum *et al.*, 2008), etc. Use of high-resolution optics at high frame rates requires quite intensive illumination.

If the particles are not perfectly transparent, a part of the incident energy is absorbed by the particles, which in turn heat the ambient gas. Due to these effects 1) photophoresis, 2) thermophoresis, 3) thermal gas expansion, or 4) natural convection may arise. In microgravity, the latter is excluded as well as particle sedimentation.

It was shown (Steinbach *et al.*, 2004) that at high particle concentration, low gas pressure and relatively uniform illumination, a thermophoretic motion can dominate. Upon illumination, the temperature profile acquires the maximum in the cloud core and a minimum on the chamber walls, giving rise to thermophoretic particle motion towards the wall. As a result, the cloud expands with temporally decreasing velocity. The latter is because of cloud rarefaction and decrease of energy release per unit volume.

Our model deals with a cylindrical aerosol cloud consisting of identical spherical particles of diameter d_0, distributed uniformly with concentration n_0. The cloud of initial radius R_0 floats in a coaxial vacuum chamber of internal radius R_C. Initial temperature $T(r) = T_0$, with r being the radial coordinate inside the chamber. The cloud is abruptly illuminated with an intensity W_0.

Under the assumptions of quasi-steady temperature profile and of free-molecular thermophoresis regime, the mathematical model consists of the Poisson equation for the gas temperature and the continuity equation for particles. The exact solution of these equations gives the position of the cloud boundary depending on time:

$$R = R_0\sqrt{1 + k_{TP}\pi d_0^2 W_0 n_0 t/4\lambda}$$

where k_{TP} is a coefficient depending on the gas properties.

The gas temperature profile is defined by

$$T = T_0 + \frac{\pi d_0^2 W_0 n_0 R_0^2}{16\lambda}\begin{cases} 1 + 2\ln\left(\frac{R_C}{R}\right) - \left(\frac{r}{R}\right)^2, & r < R \\ 2\ln\left(\frac{R_C}{r}\right), & r \geq R \end{cases}$$

where λ is the heat conductivity of the gas.

Knowing the temperature gradient, we obtain the particle velocity field within the cloud:

$$v = \frac{k_{TP} s_0 W_0 n_0 R_0^2}{8\lambda}\frac{r}{R^2}$$

which linearly grows from zero in the centre to its maximum value at the cloud boundary. Finally, the particle concentration evolves as

$$n = n_0 / \left(1 + k_{TP} s_0 W_0 n_0 t/\lambda\right)$$

The solution describes decelerating expansion of the cloud with abrupt boundary, which remains uniform but becomes more and more rarefied (see Figure 1).

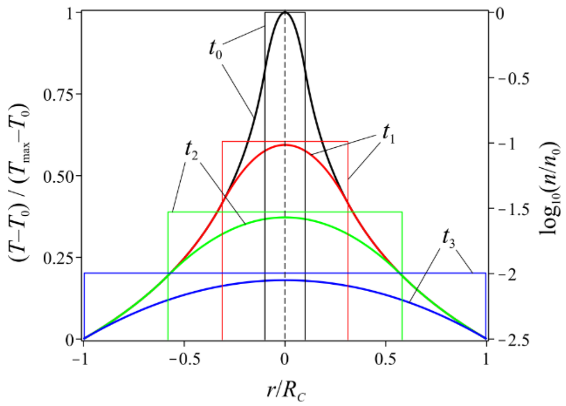

Figure 1. Temperature (thick curves) and particle concentration (thin curves) profiles at four time instants.

The analytical solution is compared to experimental results (Steinbach *et al.*, 2004) obtained under the following conditions: pressure $p = 100$ Pa; $T_0 = 300$ K; $d_0 = 1$ μm; $n_0 = 10^6$ cm^{-3}; $R_0 = 5$ mm; $W_0 = 1$ W/cm^2. The observed particle velocity is about 10 mm/s which corresponds well to the one predicted by the above model.

Dealing with illuminated clouds, one should take care – thermal cloud spreading may attain high velocity, at least locally as in the case of focused beams.

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