ATMOSPHERIC ELECTRICITY AS A FACTOR OF DRY DEPOSITION OF PARTICULATE POLLUTION

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ABSTRACT: The electrical deposition is known in case of unattached radon daughter clusters which are unipolarily charged and of high mobility. The role of the electrical forces in deposition of aerosol particles is estimated comparing the fluxes of particles carried by different deposition mechanisms in a model situation. The ratio of electrical and diffusion deposition fluxes decreases about ten times only when the mobility decreases thousand times from the values characteristic for small ions to the values characteristic for large ions. The electrical flux of fine particles can dominate on the tips of leaves and needles even in a moderate atmospheric electric field of few hundreds V/m as measured over the plain ground surface. Unlike the diffusion deposition, the electrical deposition is essentially non-uniform: the plate out on the tips of leaves and especially on needles of top branches of conifer trees is more intensive than on the ground surface and electrically shielded surfaces of plants. The knowledge of deposition geometry could improve our understanding of air pollution damages of plants.

INTRODUCTION

The turbulent diffusion approaches zero on the surface of plant leaves and needles. *Porstendörfer* [1994] writes: “3.3.1. *Deposition processes*. In general, the dry deposition of aerosol particles is governed by the physical processes of sedimentation by gravity, impaction by inertial forces, interception and Brownian diffusion”. Two mechanisms, impaction and interception, are considered together below and called the aerodynamic deposition. All four non-electrical mechanisms together are called the mechanical deposition. The electrical mechanism of deposition is neglected by *Porstendörfer* [1994] as is common in the literature about aerosol deposition.

The electrical deposition has been considered when discussing deposition of radon daughters, considerable amount of which are carried by positive small ions [*Wilkening*, 1977; *Willett*, 1985; *Tammet and Kimmel*, 1998]. The electrical mobilities of aerosol particles are three orders of magnitude less than the mobilities of small ions, and they are not unipolarily charged. However, the diffusion coefficient of the aerosol particles is low as well, and the relative effect of electrical field could appear considerable. *Schneider et al.* [1994] showed how the particles are deposited on the faces and eyes of people exposed to a strong electric field e.g. near a computer display. New discussion was started by *Henshaw et al.* [1996], who published an impressive demonstration of the enhanced deposition of radon daughters in the vicinity of electric power cables indoors, and explained the effect by the electrical deposition of dust particles carrying the attached fraction of radon daughters. Additionally, *Henshaw et al*. [1996] pointed out the problem of the electrostatic deposition of radon daughters as a possible mechanism of the environmental effect of HV power lines.

The hypothesis by *Henshaw* was not accompanied by a theoretical model of the effect. A quantitative theoretical estimate is required to decide, under which conditions the electrical deposition should be considered or could be neglected.

ESTIMATES OF COMPONENTS OF DEPOSITION VELOCITY

The deposition velocity is defined as the ratio of the deposition flux to the surface area. Specific deposition velocities caused by gravity, aerodynamic effect (impaction and interception), Brownian diffusion and electric field are denoted below as u_G, u_A, u_D, and u_E.

The deposition velocities u_G and u_E of uniformly charged particles over a plain surface are easy to estimate:

$$u_G = mgB, \qquad u_E = EZ = EqB,$$

where g is the gravitational acceleration, E is the electric field, m, q, B, and Z are respectively the mass, charge, mechanical and electrical mobility of the particle.

The natural ground is mostly covered by plant canopy. The electric field is strongly enhanced on the tips of leaves and on needles of plants. Deposition to specific elements of plants depends on their geometry. The shapes and positions of leaves and needles are variable. Thus a model of a needle is considered as a cylinder or wire of radius R at distance H from the horizontal plain surface. The field on the surface of a long wire is

$$E = \frac{H}{R\ln(2H/R)} E_{\mathrm{o}},$$

where E_{o} is the undisturbed atmospheric electric field over the plain surface. The field on the surface of a short needle is a little enhanced when compared with the estimate above. Numeric examples will be given for a long wire with R = 0.5 mm and H = 7 cm. In this occasion, $E = 25\ E_{\mathrm{o}}$.

If the particles are not uniformly charged, the probability p_i of a particle to carry the charge $q = ie$ should be considered and the deposition velocity is to be calculated as a sum: $u_E = E\sum_{i=1}^{\infty} p_i Z_i$, where Z_i is the mobility of a particle with a charge ie.

The aerodynamic deposition on a cylinder is estimated according to a simplified model fitting the empirical data presented by *Fuchs* [1964] and numerical results by *Wessel and Righi* [1988]:

$$u_A = \left[\left(\frac{\mathrm{Stk}}{0.6 + \mathrm{Stk}}\right)^2 + \frac{r}{R}\right]\frac{v}{\pi},$$

where r is the particle radius, v is the air flow velocity, and Stk is the Stokes number:

$$\mathrm{Stk} = \frac{vmB}{R}.$$

The Brownian deposition on a cylinder is estimated according to the Churchill-Bernstein equation for heat transfer translated according to *Eckert and Drake* [1972] to the terms of diffusion as explained by *Tammet and Kimmel* [1998]:

$$u_D = \frac{kTB}{2R}\left(0.3 + \frac{0.62\,\mathrm{Re}^{1/2}\,\mathrm{Sc}^{1/3}}{\left(1+(0.4/\mathrm{Sc})^{2/3}\right)^{1/4}}\right)\left(1+\left(\frac{\mathrm{Re}}{282000}\right)^{5/8}\right)^{4/5},$$

where Re and Sc are the Reynolds number and Schmidt number:

$$\mathrm{Re} = \frac{2Rv}{\mu}, \qquad \mathrm{Sc} = \frac{\mu}{kTB},$$

k, T and μ being the Boltzmann constant, temperature, and kinematic viscosity of the air.

The deposition velocities are not exactly additive. A rough approximation is used below to estimate the combined mechanical deposition velocity u_M:

$$u_M = \sqrt{u_G^2 + u_A^2 + u_D^2}$$

DISCUSSION AND CONCLUSIONS

The critical field strength is defined as that which makes the velocity of electrical deposition equal to the velocity of some other specific deposition. Different critical field strengths can be related to the gravitational, Brownian, aerodynamic, and joint mechanical deposition. The velocity of electrical deposition is proportional to the field strength. Thus the relative effect of the electric field is easy to estimate when the critical field strength is known. Some examples illustrating the quantitative role of the electrical deposition are given in Figures 1 and 2 below.

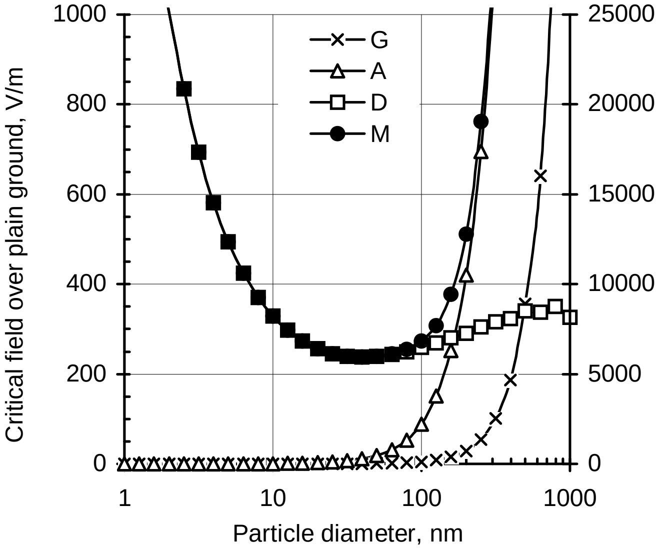

Figure 1. Critical electric field against different mechanisms of deposition:
G – gravitational,
A – aerodynamic,
D – diffusional,
M – joint mechanical.
Assumptions:
Standard atmospheric conditions.
Cylinder diameter 1 mm,
height 7 cm,
particle density 2 g/cm^3,
$\lambda_+/\lambda_- = 2$.
Wind velocity 1 m/s.

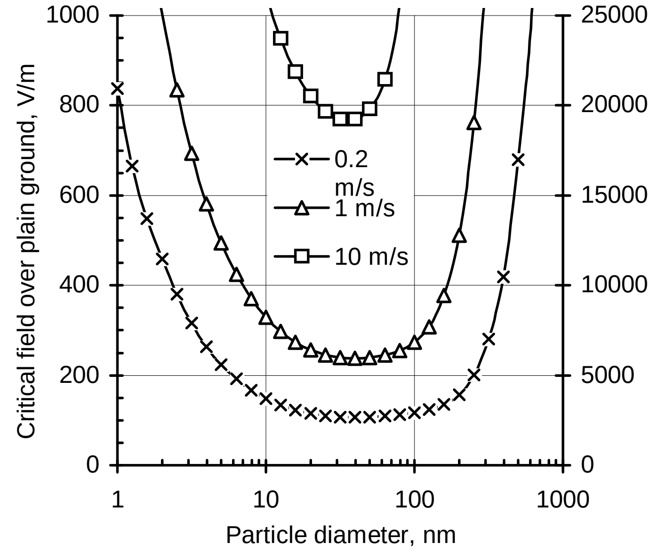

Figure 2. Critical electric field against joint mechanical deposition depending on the wind velocity.
Assumptions:
Standard atmospheric conditions.
Cylinder diameter 1 mm,
height 7 cm,
particle density 2 g/cm^3,
$\lambda_+/\lambda_- = 2$.

According to Figure 1, the gravitational mechanism has a secondary role in aerosol particle deposition and can play some part only at extremely weak wind. Aerodynamic sedimentation and Brownian diffusion are essential mechanisms of mechanical deposition of particles. The aerodynamic deposition is essential in case of particles of diameter above 100 nm. In the size range of large air ions the aerodynamic deposition is negligible and the Brownian diffusion dominates as the mechanism of mechanical deposition. In case of uniformly charged particles, the electrical mobility and diffusion coefficient are proportional to each other. Thus the dependence of the critical electric field on the particle size is weak in the size range of Langevin ions.

Figure 2 illustrates the role of electric deposition compared with joint mechanical deposition depending on the wind velocity. The critical field strength is lowest in the particle diameter range of 10–200 nm which consists of most of the atmospheric aerosol particles. The role of the electrical deposition essentially depends on the wind velocity. In case of a low wind of about 1 m/s or less, the critical field is comparable to the normal atmospheric electrical field, and electrical deposition of aerosol particles has considerable role as a factor of redistribution of deposit on different elements of the plants. In a strong wind about 10 m/s or more, the electrical deposition can be considerable only in a thunderstorm situation or on the top branches of trees.

The electrical deposition of aerosol particles should be considered when discussing enhanced pollution damages of the top branches of conifer trees.

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