WASHOUT AND DRY DEPOSITION OF ATMOSPHERIC AEROSOLS

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INTRODUCTION

Essentially all air pollution is eventually cleansed from the atmosphere by the natural processes generally referred to as precipitation, scavenging and dry deposition. The purpose of this report is to present below-cloud rain scavenging rates or washout coefficients and the deposition velocities to rough surfaces on the earth for submicron aerosols.

The washout coefficient Λ (d) for a monodisperse aerosol with a diameter d is the integrated product of the flux densities of the rain drops, their cross sections, and their collection efficiencies E (d, d_{Tr}):

$$\Lambda(d) = \frac{\pi}{4} \int_0^\infty \frac{\partial N_{Tr}}{\partial d_{Tr}} v_{Tr} E(d, d_{Tr}) d_{Tr}^2 \partial d_{Tr} \qquad (1)$$

The flux densities of the drops are obtained from the number distribution for raindrops $\partial N_{Tr}/\partial d_{Tr}$ and their terminal velocities v_{Tr}. The collection efficiencies of the raindrops were measured in dependence on particle (d) and droplet size (d_{Tr}) (1).

The major mechanisms of the dry particle transport from an air flow to a rough surface are eddy diffusion, sedimentation by gravity, Brownian diffusion and inertial forces. The deposition velocity v_g, is defined as the flux to a surface F devided by the aerosol concentration c: $v_g = F/c$. The influence of particle size, roughness of the surface and wind velocity on the deposition velocity were studied in a wind channel (2).

EXPERIMENTAL TECHNIQUES

The collection efficiencies of the raindrops were studied in a wind channel using spheres as simulated drops. The particles were labelled with radioactive Pb-212 and sucked into the wind channel, where the wind velocities agreed with the terminal fall velocities of the rain drops simulated by spheres. The wind velocity, the precipitated activity on the sphere and the activity concentration in air were measured. With this technique collection efficiencies were measured for spheres in the size range of 0.35 - 7 mm and for the monodisperse aerosol particles with diameters between 0.04 and 4µm (standard deviation 3 - 7 %).

For the deposition studies the monodisperse radioactive particles were led into a second wind channel with a cross section of 20 cm x 20 cm, where the floor of the working section (2 m long) was completely covered with the test surface. The used test surfaces consisted of plants (barley), filter paper and simulated grass, constructed by metal cylinders (2 mm diameter) planted in a plasticine layer. The fractions of particles filtered by the roughness elements and deposited on the substrate were measured separately. The height (H) and the density (n) of the roughness element were varied. From the measured wind profile the roughness length (z_o) and the friction velocity (u_*) were calculated.

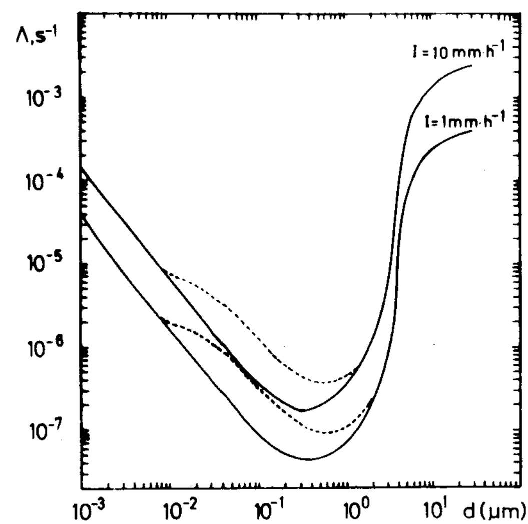

Fig. 1 Washout coefficients for neutral (——) and charged (- - -) raindrops as a function of the particle diameter for rainfall rates of 1 and 10 mm/h

RESULTS OF THE WASHOUT EXPERIMENTS

In a number of investigations the following parameters were studied:

1. The influence of drop shape, compared to the shape of the volume equivalent sphere on the collection efficiency was checked and found to be negligible (1).
2. The sticking probability of the aerosol (DES-droplets) up to 4 µm diameter on spheres (stainless steel) 0.37 - 7 µm diameter was measured to be unity (1).
3. The influence of the electric charge of the droplets for a normal rainfall and aerosols with Boltzmann charge equilibrium on the collection efficiency (electrostatic forces) and the washout coefficient, respectively, is negligible (Fig. 1, solid line). Only for typical charges of raindrops in the case of thunderstrom (3) there is a threefold increase of collection efficiency in relation

to collection without electric forces (Fig. 1, dotted line).
4. The collection efficiencies as a function of droplet and particle size were measured and washout coefficients (Fig. 1) for rainfall rates of 1 and 10 mm/h were calculated (equation (1)).

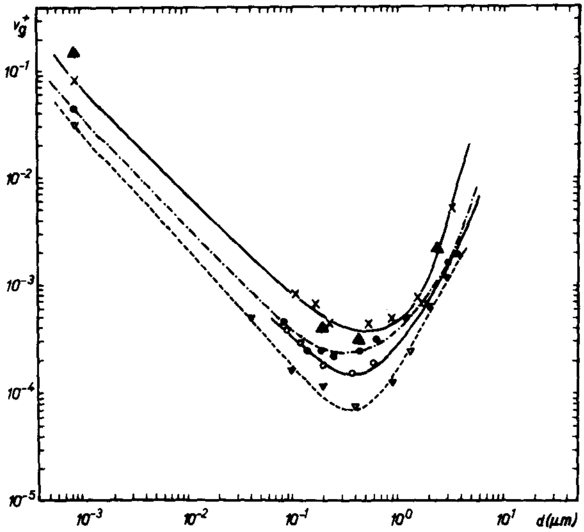

Fig. 2 Deposition velocities $v_g^+ = v_g/u_*$ of aerosols as a function of the aerosol diameter:

-x——x-	Simulated grass $n = 1.00\ cm^{-2}$	H = 7 cm
-o——o-	Simulated grass $n = 0.25\ cm^{-2}$	H = 7 cm
-•-.-•-	Filter paper	
-▽- -▽-	Smooth metal surface	
▲ ▲	Barely $n = 1.00\ cm^{-2}$	H = 7 cm

RESULTS OF THE DRY DEPOSITION EXPERIMENTS

The experimental results of these investigation can be summarized (2):
1. The height (H) and the density (n) of the roughness elements have a great influence on the deposition velocities.
2. The particle fluxes to the roughness elements is much greater than to the substrate.
3. The measured v_g^+ values ($v_g^+ = v_g/u_*$) in dependence of particle size for relatively smooth surfaces (filter paper) are nearly the same as for grass or simulated grass surfaces between the surface structures and friction velocities (Fig. 2).

Table: The fractions of washout, rainout and dry deposition for different atmospheric aerosols

AEROSOL / REMOVAL PROCESS	Activity size* distribution of Pb-210 $v_g = 3.9 \cdot 10^{-4}$ m/s $\Lambda = 5.4 \cdot 10^{-4}$ h^{-1}	Atmospheric** Aerosol (mass distribution (4)) $v_g = 7.6 \cdot 10^{-3}$ m/s $\Lambda = 7.6 \cdot 10^{-2}$ h^{-1}	Aerosol of*** a power plant plume; wind-velocity: 6 m/s $v_g = 3.9 \cdot 10^{-4}$ m/s $\Lambda = 5.4 \cdot 10^{-4}$ h^{-1} source height: 100 m distance from source: 2500 m
Dry FALLOUT $u_* = 40$ cm/s	5.3 %	87.4 %	99.3 %
WASHOUT rainfall rate: 1 mm/h rain: 600 mm/a	0.2 %	9 %	0.7 %
RAINOUT rainfall rate: 1 mm/h rain: 600 mm/a cloud depth: 2 km cloud height: 2 km rainout coeff.: 1.1 h^{-1}	94.5 %	3.6 %	-

* Activity size distribution of the short lived radon daughters is assumed (4); The vertical Pb-210 concentration distribution is after MOORE et al. (5)

** The vertical concentration distribution is after WIGAND (6)

*** The activity size distribution of the short lived radon daughters is assumed (4)

A COMPARISON OF THE REMOVAL PROCESSES

The particle fluxes of different atmospheric aerosols to the earth surface under consideration our experimental results were calculated. The fractions of washout, rainout and dry deposition for the mass distribution of the natural aerosol, the Pb-210 aerosol and for a radioactive aerosol of a power plant plume are listed in the table.

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