C-1.3.1. Study on the Deposition Velocity of Gases and Fine Droplets

Contact Person Tsutomu Fukuyama
Section Chief
Atmospheric Measurement Section
Atmospheric Environment Division
The National Institute for Environmental Studies
16-2 Onogawa, Tsukuba 305 Japan
Tel. +81-298-50-2515 Fax +81-298-50-2579
e-mail fukuyamt@nies.go.jp

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Abstract Dry deposition velocities of O_3, NO_2 and SO_2 were measured for croplands where bean, wheat, or corn was grown. Deposition velocities of O_3 and SO_2 were measured also for a red-pine forest and for Chinese soils, respectively. Fine droplet deposition was studied by artificial fog experiments carried out in a vertical shaft.

Main results obtained in this study are as follows: 1) In croplands, O_3 was found largely to deposit to the plant bodies, and its velocity depended on the stomata opening, whereas SO_2 seemed to deposit onto soil. 2) Deposition velocity of O_3 measured for a red-pine forest was found unusually large in summer, suggesting a contribution of gas phase reactions to the removal process. 3) The surface resistance of a loess sample was measured separately from the other resistance components. 4) In a field observation undertaken at an urban site of Beijing, deposition velocity of SO_2 was found generally larger that reported for common soils. 5) It was confirmed that the fine droplet deposition was more like dry deposition than wet deposition by using model leaves made of water-absorbing polymer.

Key Words Dry Deposition, Occult Deposition, Deposition Velocity, Sulfur Dioxide, Ozone, Cropland, Red-pine Forest, Loess

1. Introduction

Dry deposition is the process whereby atmospheric gases and airborne particles are directly transported to and captured by the Earth's surfaces without mediation of precipitation. Even in areas having relatively high precipitation, such as Japan, the annual amount of dry deposition is estimated to be comparable to that of wet deposition. Accordingly, dry deposition is likely to be predominant in the dry regions of East Asia, and during the dry seasons in regions, such as Southeast Asia, where the climate is characterized by distinct cycles of dry and wet seasons. However current data on dry deposition are quite deficient because of difficulty in the measurement inevitably resulting from the complexity of the process. This study is an effort to fill such a gap.

2. Dry Deposition of Gases to Croplands and a Forest

2.1 Research Objective

Dry deposition velocity of gases is strongly dependent on the nature of the surfaces. Therefore, in order to evaluate the dry deposition to a certain area, it is, in principle, necessary to obtain the velocity for all the surfaces existing in the region. Such a task, however, is impractical. A feasible way is to construct a model by which the velocity for various surfaces can be calculated from several measurable parameters, and to validate the model on the basis of the field data. The research described in this section was carried out to get such data for croplands and a forest.

2.2 Results for Croplands

Deposition velocity of O_3 was measured by the Bowen-ratio technique at the experimental fields of Tokyo University of Agriculture and Technology. Figure 1 illustrates the diurnal variation of O_3 deposition velocities, and in Figure 2 is shown the deposition velocities of O_3 and SO_2 to bare soil. From these figures it seems that the deposition of O_3 mainly goes to the plant bodies and its velocity depends on the stomata opening. The measurement of the deposition velocity of SO_2 to corn plant was seriously obstructed by the low concentration level during the observation period, but it was estimated to be less than to bare soil anyway. This suggests that the SO_2 maily deposits onto soil.

2.2 Results for a Forest

The deposition velocity of O_3 to a red-pine forest was measured in Ohshiba Kogen, Nagano Prefecture; an observation tower of about 15 m in height was constructed in the forest and the Bowen ratio method was used again. Figure 3 shows the diurnal variation of the deposition velocities for Augsut(a) and for October and November (b). A conspicuous feature is that the velocity is very much larger in August than in November. The average velocity of 6 cm s^{-1} observed in August is larger than any reported values , while 1 cm s^{-1} obtained in November is close to the values for common plants. A plausible explanation for this phenomenon is that the reaction of O_3 with gases, such as terpens, contributes to the O_3 remaoval.

This explanation is consistent with the fact that partculate sulfate measured simultaneously showed sometimes upward flux.

3. Deposition of SO_2 to Chinese Soil

3.1 Research Objective

Coal is heavily relied upon as a source of energy in Chinese Continent, and SO_2 emission from coal combustion causes rain acidification. However it is reported that the spatial distribution of SO_2 emission is not directly connected to that of rain acidification: in the northern part of China, rain is not significantly acidified in spite of large SO_2 emission from the industrial zone extending in that part. This is probably due to rapid deposition of SO_2 onto soil such as loess, which covers vast areas in North China. Since the transport of SO_2 is determined by a balance between emission and deposition, it is important to have data on the deposition to evaluate the amount transported to Japan. The objective of this study is to collect such data.

3.2 Surface Resistance of Loess

A flow reactor experiment was carried out to measure the surface resistance of a loess sample. In this experiment, a soil sample of known surface area is exposed to a flow of air containing known concentration of SO_2 in a known period. Then the deposition amount is determined by extracting sulfur in the form of sulfate or sulfite from the sample, and by quantifying the total sulfur by ion chromatography. Finally the deposition flux and velocity are evaluated through

$$F = \text{deposited amount} / (\text{exposure period})(\text{surface area})$$
$$V_d = F / (\text{concentration})$$

The velocity thus derived is related to the deposition resistance as

$$r = 1/V_d$$

and the resistance is divided into three components:

$$r = r_a + r_b + r_c$$

where r_a, r_b and r_c are aerodynamical, quasilaminar and surface resistance, respectively. Among these, r_a and r_b depend on meteorological conditions but r_c does not, and it represents a property of the surface. In this study, it is aimed at to determine r_c separately from the other resisitances by using the reference soil material treated with alkali. The surface resistance thus evaluated for a loess sample was 0.2 cm^{-1}. By adding typical values of r_a and r_b, the total resistance comes out to be 1 $cm^{-1}s$, which leads to a velocity value of 1 cm s^{-1}. This value is significantly larger than the values reported for common soils.

3.3 Dry Deposition of SO_2 onto an Urban Site in Beijing

Deposition velocity of SO_2 was measured in a open lot close to China-Japan Friendship Evironment Protection Centre, Beijing, by the wind-profile method. An observation pole of about 4 m in height was set up, and the vertical profiles of wind velocity and SO_2 concentration were measured at four elevations: 0.24, 1.16, 2.46 and 4.06 m. The eddy diffusion constant was calculated from the wind profile:

$$D = \kappa^2 (U_2 - U_1) z / \ln(z_2/z_1)$$

where κ is von Karman Constant, and U_1 and U_2 are wind velocities at two elevations z_2 and z_2; then deposition flux and velocity were derived by

$$F = D \ \Delta C / \Delta z$$
$$V = F/C$$

where $\Delta c/\Delta z$ is the concentration gradient.

Results obtained in November 14, 1998 is shown in Table 1. The deposition velocity was found to be generally close to or larger than the esitmate shown in the preceding section, supporting the view that the dry deposition to soils plays an important role in the SO_2 balance over North China.

Table 1. Deposition Flux and Velocity of SO_2 at an Urban Site in Beijing (Nov. 14, 1998; Reference Height = 0.24 m)

Time	Flux / $\mu gm^{-2}s^{-1}$	Velocity / $cm\ s^{-1}$
9:00	0.07	0.78
10	0.12	1.25
20	0.23	2.35
40	0.14	1.15
50	0.29	1.94

10:20	0.20	0.71
30	0.21	0.62
50	0.49	1.06
11:00	0.66	1.29
10	0.75	1.35
20	0.62	1.08
12:00	0.82	1.39
10	0.68	1.06
14:30	0.66	0.83
:40	0.71	0.93
15:20	0.52	0.60
:30	1.09	1.13
40	0.96	0.91
50	1.07	0.93

4. Deposition of Fine Droplets

4.1 Reseach Objective

Fine water droplets suspended in the atmosphere absorb air pollutants and then act as their transport media. One of such transport processes is, of course, the wet deposition, which is mainly controlled by the gravitational settling of rain droplets. Another process is the transport mediated by fog droplets, which are much smaller and accordingly less subject to the gravity. This process is called occult deposition. The study on the occult deposition is far behind that on the wet deposition because of the fact that the spatial and temporal extent of the fog event are much more limited than that of rainfall. In order to make a breakthrough in this situation, this study was undertaken by generating artificial fog in a vertical shaft and observing the fog droplet deposition onto model leaves made of water-absorbing polymer.

4.2 Results

The artificial fog experiment was carried out in a 430-m deep vertical shaft in Kamaishi Mine, Iwate Prefecture. At the bottom of the shaft, the relative humidity of the air is kept close to 100 % because of abundant flow of underground water, and fog is formed in the shaft when an updraft of about 1 m/s is generated by operating an electric fan placed at the top. A model tree was placed in a driftway connected to the shaft; onto the tree were mounted artificial leaves made of water-absorbing polymer (material used for disposable diaper), and the amount of droplet deposition to those leaves was evaluated by the gravimetric method. Special attention was paid to the relation between the deposition amount and the orientation of the leaves relative to the wind direction. The results of the measurement are summarized in Table 2.

Table 2. Fog Droplet Deposition Flux onto Model Leaves

Orientaion of Leaves	Deposition Flux $/\mathrm{g\ m^{-2}\ h^{-1}}$
0[a]	77
90	62
180	63
270	60
Horizontal,	
face up	62
face down	64

a) Angle between the wind direction and the normal of the leaf surface;

Besides the deposition measurement, the liquid water content (LWC) was measured by a Forward Scattering Spectrometer Probe to be about 0.3 g m^{-3}. Then by putting an average flux F = 62 g m^{-2} h^{-1} from Table 2 into an equation

$$V_d = F/LWC$$

the depostion velocity is evaluated to be V_d = 5.7 cm s^{-1}. On the other hand, the diameter of the fog droplets measured by a hot-film device was 7 μm on the average, and the gravitational settling velocity for this size is 0.15 cm s^{-1}, which is much smaller than the the deposition velocity. Hence the gravitational settling is not the controlling process of the fog droplet deposition. Table 2 also shows that the depositon flux is almost independent of the orientation of the leaves although a slightly larger flux was observed for leaves facing the wind direction. Thus it is deemed that fog droplets are mainly carried on the turbulent flow of air and deposited onto leaves probably through inertial impaction. This picture forms a reason for distinguishing the occult deposition from the wet deposition.

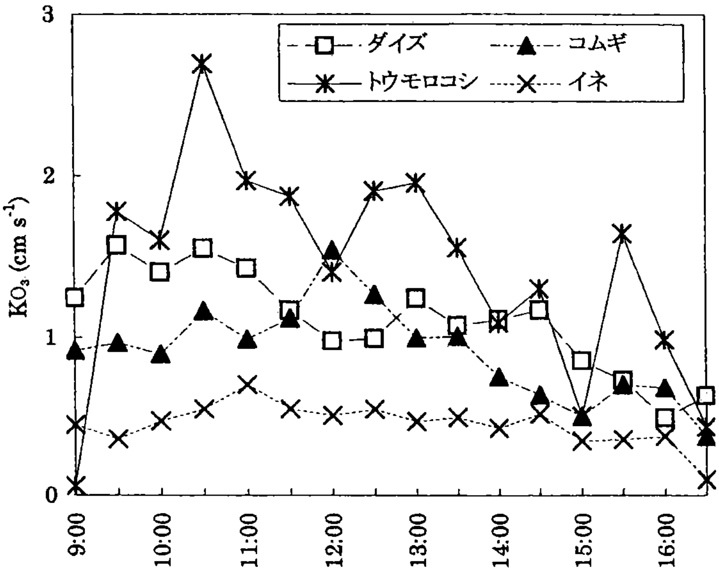
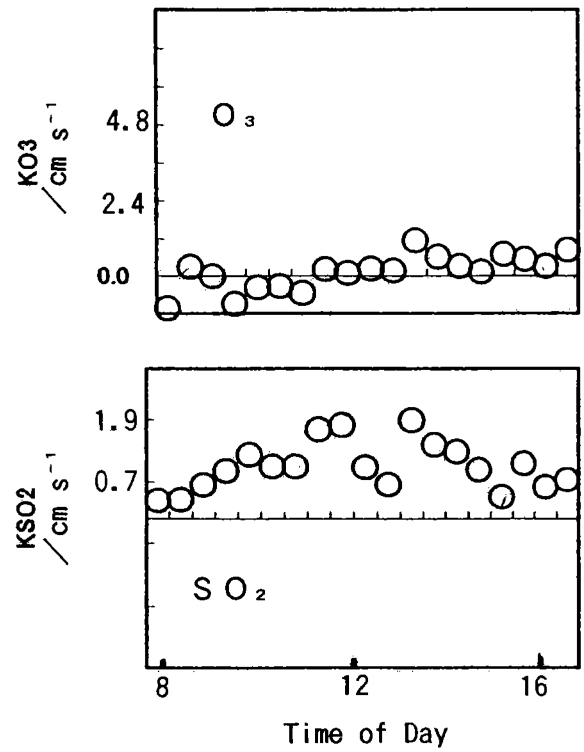


Figure 1. Diurnal Variation in O_3 Deposition Velocity onto Croplands
□: Bean, ▲: wheat, *: corn, ×: rice plant



Fiure 2. Diurnal Variation in O_3 and SO_2 Deposition Velocities onto Bare Soil

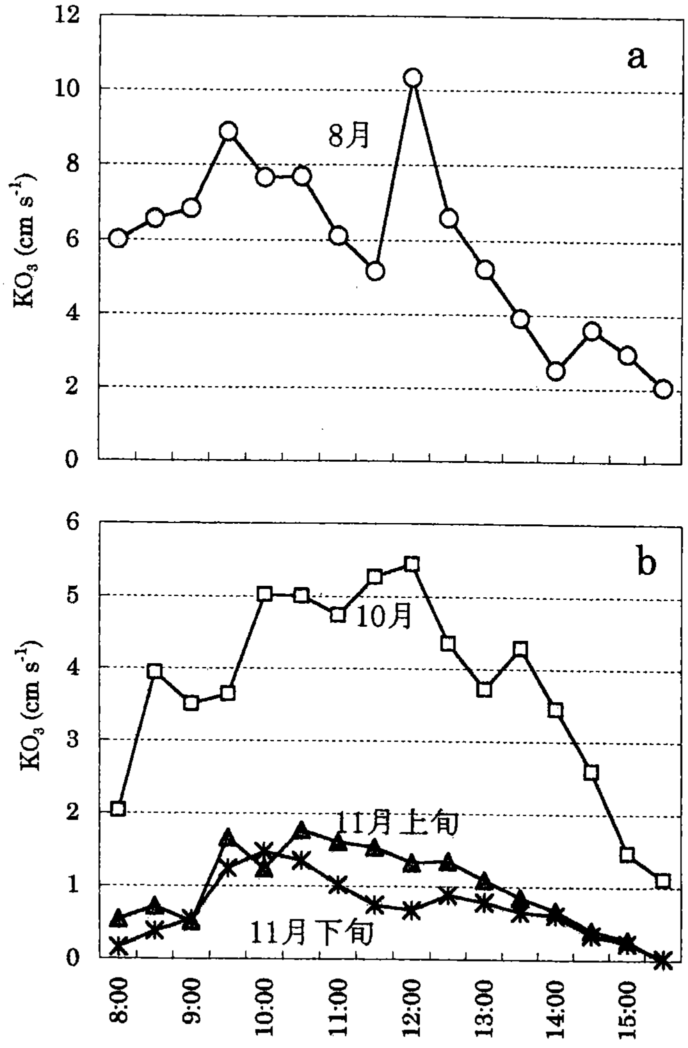


Figure 3. Diurnal Variation in O_3 Deposition Velocity onto a Red-pine Forest
a : August, b : October and November