Bull. Chem. Soc. Jpn., **75**, 1299–1300 (2002) 1299

Size Distribution of Dew Droplets and Dew Formation Effect on Deposition Fluxes

Masaki Takeuchi, Tetuo Hasegawa, Hiroshi Okochi, and Manabu Igawa*

Department of Applied Chemistry, Faculty of Engineering, Kanagawa University, 3-27-1 Rokkakubashi, Kanagawa-ku, Yokohama 221-8686

(Received November 26, 2001)

Dew droplets have a distribution of sizes up to 1.5 mm diameter. Large-sized droplets controlled the dewwater amount and the number of small-sized droplets decreased during the evaporation process. The wetting by dew formation enhances the dry deposition of air pollutants.

Dew droplets enhance the deposition of air pollutants onto the ground because of the wetting of the surface.[1] Dew chemistry was dominated by the deposition of air pollutants, but many factors, e.g. meteorological conditions and the characteristics of the surface on which dew is formed, affect the dew chemistry. There are some reports on the growth of droplets artificially formed on the surface to investigate the controlling factors of dew chemistry.[2,3] The droplet size is an important factor determining the concentration of the chemical components in fog- and cloudwater.[4] The acidity and the concentration of dew components would vary with the droplet size, but the effect of the droplet size on the chemical composition of dewwater has never been studied until now. This paper will clarify the size distribution of dew droplets and the dew formation effect on the deposition flux of air pollutants.

Dewwater was collected from January 2000 to May 2001 on the roofs of the six-story buildings in Kanagawa University in Yokohama, Japan. In order to measure the accumulation and evaporation rate of dew, the variation of the dewwater amount was monitored with a balance (Sartorius LC-34000P) placed under the dew collector. The dew droplets formed at the center of the collector was photographed with a digital camera (Nikon COOLPIX 990) and the size of each droplet in 1 cm^2 was measured. The weight of the dewwater was recorded every minute using a personal computer (Epson PC-486 NOTE AS). Dewwater as a bulk sample was collected with a Teflon scraper. Dry deposition was also collected simultaneously with the collection of dewwater using a 0.05-mm-thick Teflon sheet (90 cm × 90 cm) mounted on a frame (90 cm × 90 cm × 10 cm) built up with angle irons with 4 cm width, and was dissolved into pure water to be analyzed. The pH and soluble components of these samples were measured using a pH meter and an ion chromatograph, respectively, after the filtration with a 0.45-μm pore-size membrane filter. Details of the sampling site and methods and the analytical methods were described in the previous papers.[5–8]

Sixty dewwater samples were collected during the sampling periods, and the dewwater amounts were in the range of 2.6 – 416 g m^{-2}. The average amount was 106 g m^{-2} (CV, 0.94). Figure 1 shows the size distribution of the dew droplet number and the ratio of dewwater amount for each droplet diameter to total dewwater amount and a photograph of the dew droplets on the collector in a dew event (Nov. 6, 2000). The diameter of dew droplets ranged from the resolving power, 0.1 mm, to 1.5 mm. The dew-droplet amount was calculated from each measured droplet size on the assumption that each dew droplet is hemispherical. The calculated value of the dewwater amount agreed well with the measured value, which was 105% of the value calculated in the accumulation process of dew (0500 at local time). The number concentration of droplets decreased with time; 316 cm^{-2} at 0500, 203 cm^{-2} at 0700, and 105 cm^{-2} at 0900. The ratio of dew-covered area to the collector surface was approximately constant in the accumulation process (0.67 at 0500, 0.71 at 0700) and decreased in the evaporation process (0.41 at 0900). In the first two dew samples (0500 and 0700), the size distribution of droplet ranged from the resolving power, 0.1 mm, to 1.5 mm was characterized by two modes and the large droplets controlled the dewwater amount. Small droplets were united to become larger ones by condensation in the accumulation process.[9] In the evaporation process, the size of

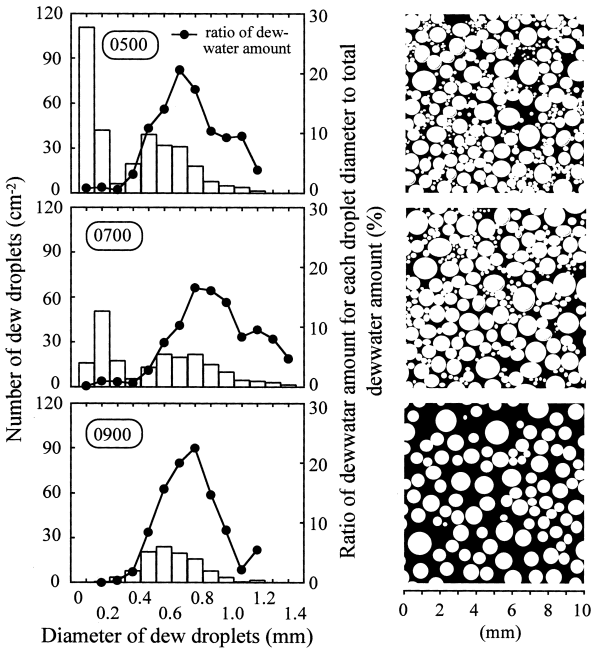

Fig. 1. Diameter of dew droplets and number and dewwater amount distribution (left panel) and droplets pattern formed onto Teflon film (right panel, dew droplets are shown as white circles) at 0500, 0700, and 0900 on November 6, 2000. The dewwater was formed from about 1730 on November 5, became a maximum amount (198 g m^{-2}) at about 0630 in the following day, after 30 min. from sunrise, and disappeared completely at about 1100.

Table 1. Comparison of Deposition Fluxes of Air Pollutants to Dewwater and Dry Surface (Teflon Film) from 2100 April 11 to 0600 April 12, 2001

	H^+	NH_4^+	Na^+	K^+	Mg^{2+}	Ca^{2+}	Cl^-	NO_3^-	SO_4^{2-}	HCO_3^-	NO_2^-	S(IV)	For.	Ace.	Total
Dewwater	0.053	3.97	0.91	0.15	0.20	1.86	1.29	0.46	3.66	0.11	0.25	0.66	0.35	0.62	14.54
Dry surface	0.001	0.79	0.51	0.07	0.09	0.92	0.66	0.24	0.38	0.59	0	0.22	0	0	4.49

All units are μeqiv m^{-2} h^{-1}. For. and Ace. are $HCOO^-$ and CH_3COO^-, respectively. The dewwater was formed about 2230 on April 11, became a maximum amount (98 g m^{-2}) at about 0600 in the following day, and disappeared completely at about 0930.

Table 2. Deposition Fluxes of Air Pollutants into Dew on April 12, 2001

Time	Water	H^+	NH_4^+	Metals	Cl^-	NO_3^-	SO_4^{2-}	NO_2^-	S(IV)	Car.	Total
0000 to 0300	15.8	0.03	3.09	3.96	1.67	0.61	4.77	0.34	1.01	1.04	16.34
0300 to 0600	21.0	0.12	4.71	3.86	1.32	0.61	4.72	0.41	0.68	1.16	17.54
0600 to 0900	−31.8	−0.15	0.22	2.13	0.23	0.76	0.45	−0.39	0.46	−0.32	6.48

All units are μeqiv m^{-2} h^{-1} except time and water (g m^{-2} h^{-1}). Metals are Na^+, K^+, Mg^{2+}, and Ca^{2+} and Car. are $HCOO^-$ and CH_3COO^-. The dew samples were collected at the same time as the samples in Table 1.

each droplet decreased, the small size droplets disappeared, and the size distribution became to be characterized by one mode. The evaporation rate of dew droplets in the edge of the dew collector was faster than that at the center and the measured dewwater amount collected on the 45 cm × 45 cm collector was 52% of the amount calculated from the observed dewwater size and number at 0900.

Table 1 shows the deposition fluxes to dewwater and dry surface (Teflon film) from 2100 April 11 to 0600 April 12, 2001. The deposition fluxes of chemical components originating from aerosol to the dewwater were several times higher than those to the dry surface, except for hydrogencarbonate. This is because the presence of dewwater prevented the aerosol particles from scattering. The ratios of deposition flux to dewwater to that to dry surface for sodium, potassium, magnesium, and calcium ions, which were originated from coarse aerosol, were about 2, and were nearly equal to each other (Na 1.8, K 2.2, Mg 2.2, Ca 2.0). Weak acid anions such as nitrite, formate, and acetate were not detected on the dry surface because these components originated from gases.[8] The deposition flux ratio for ammonium and sulfate ions that originated partly from gases[6] were relatively high (NH_4^+ 5.0, SO_4^{2-} 9.6). The deposition flux ratios for chloride, nitrate, and S(IV) were low (Cl^- 1.9, NO_3^- 1.9, S(IV) 2.9), which may be caused by the low concentration of hydrogen chloride and nitric acid gases at the sampling period and the aqueous phase oxidation of S(IV) to S(IV). The deposition flux of total components to the dewwater was 3.2 times higher than that to the dry surface, as seen in Table 1. The frequency of dew occurrence was about 20% of each year at the sampling site and the increase of the deposition velocity of air pollutants in the dew events may cause a very important effect on the environment.

The time dependence of deposition fluxes of air pollutants was also measured on the dew event on April 12, 2001 and shown in Table 2. In the accumulation process, the total deposition flux was approximately constant, although the deposition fluxes of some components fluctuated. In the evaporation process, the components which originated from gaseous species are readily vaporized with water and the deposition flux values became minus. The deposition flux values of ammonium and sulfate ions that originated partly from gases also decreased greatly. The flux of metal ions that originated from aerosol decreased to be only 55%, which was caused by the decrease of the area of the collector covered with dew. The results of the flux variation with time shown in Table 2 correspond well with the results of the comparison shown in Table 1.

This investigation was partly supported by the Japan Science & Technology Corporation, the CREST program 1996–2001 for funding.

References

1 P. A. Mulawa, S. H. Cadle, F. Lipari, C. C. Ang, and R. T. Vandervennet, *Atmos. Environ.*, **20**, 1389 (1986).

2 F. Family and P. Meakin, *Phys. Rev. Lett.*, **61**, 428 (1988).

3 D. Beysens, A. Steyer, and P. Guenoun, *Phase Transitions*, **31**, 219 (1991).

4 A. Bator and J. L. Collett Jr., *J. Geophys. Res. D.*, **102**, 28071 (1997).

5 H. Okochi, T. Kajimoto, Y. Arai, and M. Igawa, *Bull. Chem. Soc. Jpn.*, **69**, 3355 (1996).

6 M. Takeuchi, H. Okochi, and M. Igawa, *Taiki Kankyo Gakkaishi* (*J. Jpn. Soc. Atmos. Environ.*), **35**, 158 (2000).

7 M. Takeuchi, H. Okochi, and M. Igawa, *Water Air Soil Pollut.*, **130**, 613 (2001).

8 M. Takeuchi, H. Okochi, and M. Igawa, *Bull. Chem. Soc. Jpn.*, submitted.

9 D. Beysens, *Atmos. Res.*, **39**, 215 (1995).