PROMOTION EFFECTS OF FALLING DROPLETS ON CARBON DIOXIDE ABSORPTION ACROSS THE AIR-WATER INTERFACE

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ABSTRACT

The effect of rainfall on mass transfer across the air-water interface was investigated through the CO_2 absorption experiments in a turbulent open-channel flow with the free surface. The results show that the rainfall enhances both the turbulent mixing near the free surface on the liquid side and the CO_2 transfer across the interface. The mass transfer coefficient on the liquid side is well correlated by both the mean vertical momentum flux of rainfall, *M*, and the mean kinetic energy of rain droplets impinging on the unit area of the air-water interface, *KEF*. However, it was not concluded which of *M* and *KEF* is a better parameter for expressing the rainfall effects on the mass transfer. The comparison between the mass transfer coefficient obtained in this study and that obtained in wind-driven turbulence suggests that it is of great importance to consider the rainfall effect on the CO_2 exchange rate between the atmosphere and ocean in precisely estimating the global carbon cycle in a climate model.

INTRODUCTION

To precisely estimate CO_2 transfer between atmosphere and ocean, it is important to investigate some fluid-mechanical factors that control the mass transfer across the air-water interface. One of the significant factors may be the effect of the rainfall on the CO_2 transfer. Generally, the rainfall effect is expected to promote the mass transfer, since the air-water interface is broken and mixed by falling rain droplets. However, it has not been estimated how the promotion effect of rainfall is significant, compared to wind shear that also promotes the air-water mass transfer. The purpose of this study is, therefore, to investigate the effect of falling droplets on the air-water mass transfer through laboratory experiments. The CO_2 absorption experiments were conducted by using a rain generator in a fully developed turbulent open-channel flow.

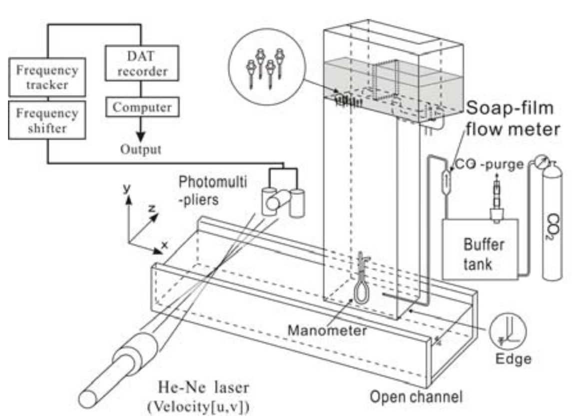

Fig. 1 Schematic diagram of experimental apparatus.

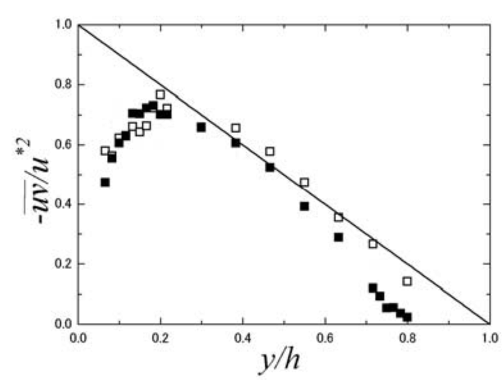

Fig. 2 Vertical distribution of the Reynolds stress.

EXPERIMENTS

Figure 1 shows the experimental apparatus. The rain droplets were generated in a closed rain chamber by using about 500 needles with the same diameter. The needles were installed at the bottom of a head tank which was located at the top roof of the rain chamber. Droplets falling from the needles impinged on the free surface in a developed turbulent open-channel flow. The height of the chamber, h_t, ranged from 0.57 to 1.17 m. The droplet diameter, d_r, 2 ~ 5.6 mm. The falling velocity of the droplets, v_p, was 3.15 ~ 4.69 m s^{-1}, and the rain rate, R, was 5.9 ~ 430.1 mm h^{-1}. Pure CO_2 was filled at the atmospheric pressure in a rain chamber. The mass transfer coefficient on the liquid side, k_L, was estimated from the absorption rate measured by a soap-film meter. The motions of the droplets and breaking interface were visualized using a high speed video system. Turbulence quantities in an open-channel flow were measured using LDV.

RESULTS AND DISCUSSION

Figure 2 shows the vertical distribution of the Reynolds stress in an open-channel flow. In the free surface region of $y/h > 0.6$, the Reynolds stress for the rain case (closed squares) decreases, compared to no rain case(open squares). This shows that turbulence is promoted by the rain droplets impinging on the free surface. Figure 3 shows the mass transfer coefficient k_L against (a) M and (b) KEF. Open symbols show the case of the chamber height of h_t = 0.57 m and other closed symbols show the case of h_t = 1.17 m. The M and KEF are the vertical momentum and the kinetic energy of droplets impinging on the unit area of the air-water interface per second, respectively. k_L is well correlated with both M and KEF. It is found that the mass transfer is promoted by rain droplets. This suggests that the interface is intensively broken by the impinging rain droplets and the mass transfer is promoted owing to the intense mixing in the free surface region. However, it is difficult to conclude which of M and KEF is a better parameter for describing the rainfall effect on the mass transfer. In order to compare with the correlation between k_L and wind speed in wind-driven turbulence [*Komori and Misumi*, 2002] the maximum values of k_L estimated by using the values of M and KEF observed in nature together with the relations in Fig. 3(a) and (b) are indicated by two horizontal bars ($U_\infty$and ⋯) in Fig. 4, respectively. The maximum value of the mass transfer coefficient due to rainfall corresponds to that obtained in wind-driven turbulence with wind speed of 13 ~ 15 m s^{-1}. This suggests that it is of great importance to consider the rainfall effect in estimating the air-sea CO_2 exchange rate.

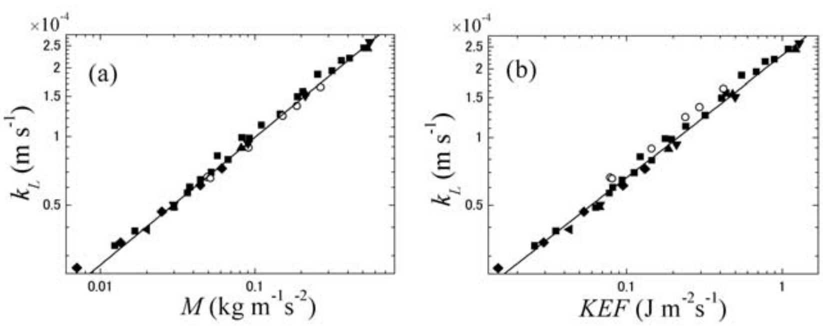

Fig. 3 Relationships between k_L and (a) M or (b) KEF.

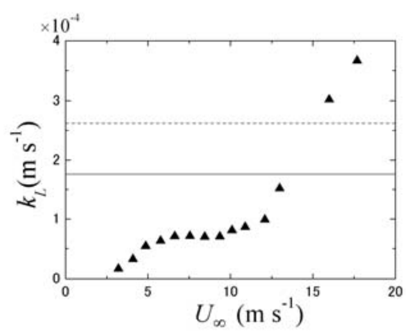

Fig. 4 Comparison of k_L by rainfall with that by wind shear.

REFERENCES

Komori, S. and R. Misumi (2002), The effects of bubbles on mass transfer across the breaking air-water interface, In: *Gas Transfer at Water Surfaces* Geophysical Monograph 127, AGU, pp. 285-290.