THE EFFECT OF SEA-ICE GROWTH ON CO_2 EXCHANGE BETWEEN THE SEA AND THE OVERLYING AIR ON THE BASIS OF EXPERIMENT IN THE LOW-TEMPERTURE ROOM

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ABSTRACT

We have carried out the tank experiment in the low-temperature room to clarify the CO_2 gas exchange mechanism between the sea and the overlying air during the sea-ice formation process. The air CO_2 concentration in the headspace of the tank began to increase simultaneously with the sea-ice formation and growth. The CO_2 flux was with in the range from 2.1×10^{-4} to 4.5×10^{-4} g-C m^{-2} hour^{-1} at ice thickness of 5cm. The CO_2 flux was mainly dependent on the brine salinity in the upper layer of sea-ice, which suggests that CO_2 was released from the brine in the sea-ice, and transported to the atmosphere.

INTRODUCTION

Because the sea-ice acts as a thermal insulator between the ocean and the atmosphere, it has been recognized that the sea-ice has an effect on mitigating the global warming. From the viewpoint of the geochemical cycles, the sea-ice was considered to impede the gas exchange (e.g. CO_2) with the atmosphere. However, there have been a few works that reports the possibility of gas exchange through the brine channel network in the sea-ice which was highly permeable to CO_2 [*Gosink et al.,* 1976; *Tison et al.,* 2002; *Semiletov et al.,* 2004]. In order to clear up the CO_2 exchange mechanism during the sea-ice formation, we have carried out the tank experiment by using natural seawater taken in the western North Pacific.

MATERIALS AND METHODS

An acrylic tank (30cm x 30cm x 65cm, seawater: 50L, headspace: 9L) has been installed in the low-temperature room. Before the sea-ice formation, the air temperature in the low-temperature room (R_T) was thermostated to be –1.3˚C over 2 days, which was the time enough to establish chemical equilibrium between the seawater and the headspace air. After the confirmation of constant CO_2 concentration in the air, the experiments has been started by decreasing R_T from -1.3˚C to -15, -20, -25, and -30˚C, respectively. During the sea-ice formation process, we measured the air CO_2 concentration in the headspace of the tank quasi-continuously by using a NDIR (LI-6262, LI-COR), temperature (headspace, seawater, sea-ice and R_T) by using thermocouples, and salinity of seawater and formed sea-ice. Sea-ice thickness has been measured visually at every 3 hour intervals, and we have finished the experiments when the thickness become 5cm. To calculate the brine volume fraction (F_b) and brine salinity (S_b) in sea-ice, a piece of sea-ice (15cm x 15cm x 5cm) has been collected, and it was divided into 3 layers (thickness; upper layer: 1cm, middle layer: 2cm, and bottom layer: 1cm) [*Cox and Weeks,* 1983].

RESULTS AND DISCUSSION

The temperature in the headspace was about -7 for R_T of -15˚C, -9 for R_T of -20˚C, -10 for R_T of -25˚C, and -11˚C for R_T of -30˚C during the experiment. Sea-ice thickness increased almost rectilinearly, and the sea-ice growth rate calculated by the linear fitting was 0.92 for R_T of -15˚C, 1.39 for R_T of -20˚C, 1.63 for R_T of -25˚C, and 1.68×10^{-1}cm hour^{-1} for R_T of -30˚C. Seawater salinity also increased rectilinearly with time, and it increased by 2.8 to 3.6 when the sea-ice thickness reached to the level of 5 cm. Increases in the CO_2 concentration in the air before and after the sea-ice formation (ΔCO_2) were plotted against the

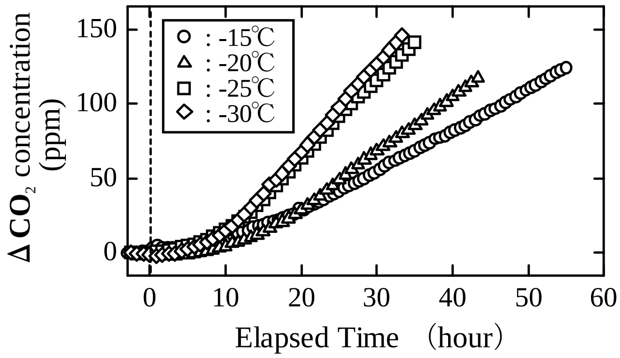

Fig. 1 The time series of air CO_2 concentration for R_T of -15˚C (circle), -20˚C (triangle), -25˚C (square), and -30˚C (diamond). ΔCO_2 indicates the change in CO_2 concentration from that before the sea-ice formation. The vertical dashed lines indicate the time when air temperature began to decrease (elasped time=0 hour) for respective experiments.

elapsed time (Fig. 1). The time when the CO_2 concentration began to increase agreed well with the time of the sea-ice formation, and at the end of the experiment the ΔCO_2 was larger than 100 ppm. The CO_2 flux, calculated by using changes in the CO_2 concentration at every 10 minutes, increased with the time (sea-ice thickness). When the sea-ice thickness reached to the level of 5 cm, the CO_2 flux was 2.1 ± 0.3 for R_T of -15˚C, 2.8 ± 0.4 for R_T of -20˚C, 4.0 ± 0.5 for R_T of -25˚C, and $4.5 \pm 0.5 \text{x} 10^{-4}$ g-C m^{-2} $hour^{-1}$ for R_T of -30˚C. From the sea-ice sample analysis, the S_b and F_b were estimated to be within the range from 43.1 to 79.0, and from 9.2 to 20.8%, respectively. We found that the CO_2 flux was mainly dependent on the brine salinity in the upper layer of the sea-ice. The enhancement of the CO_2 concentration in the brine occurred with the decrease of the temperature in the sea-ice. The increase of the brine salinity during the sea-ice growth led to the changes in the dissociation constants of carbonic acid, solubility of CO_2 and possibly the occurrence of $CaCO_3$ precipitation [*Papadimitriou et al.*, 2003]. Based on the experimental results conducted at various room temperature conditions, we concluded that the CO_2 was released from the brine in sea-ice through the brine-channel. The result of the present work suggests that the sea-ice growth acts as a CO_2 source for the overlying air (atmosphere), and sea-ice is not a simple insulator for the CO_2 exchange between the sea and the air.

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