The First Evidence for the Acceleration of Dissolution Process of Oxygen into Water by a Homogeneous Magnetic Field

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Homogeneous magnetic field effect on dissolved oxygen from atmosphere was investigated by electrochemical measurement. Under a homogeneous magnetic field, amounts of dissolved oxygen during initial 10 min increased linearly with a magnetic flux density up to 1.0 T and over 1.0 T it showed almost constant value.

The effect of a magnetic field on dissolved oxygen is considered one of the interesting problems of the influences of the magnetic field on water. Ueno et al. reported redistribution of dissolved oxygen was observed during both desorption and absorption processes of oxygen in the magnetic field of 1.0 T with the gradient of 10 T m^{-1} when the surface of the water was contacted with atmosphere.[1] They also studied the behavior of dissolved oxygen under strong magnetic fields up to 8 T with the gradient of 50 T m^{-1} and showed redistribution of oxygen occurred clearly.[2] On the other hand, there were many papers that magnetic field affected the concentration of dissolved oxygen in water. From the calculation of thermodynamics, however, the deviation of the concentration of oxygen molecule under a magnetic field predicted by it's paramagnetic susceptibility should be very small, about 0.07% even under 10 T condition.[3] This variation would be too small to observe it. Recently, Kitazawa et al. reported that the rate of dissolution of oxygen into water is accelerated more than twice under controlled conditions by a magnetic field gradient.[4] These phenomena are considered to result from a magnetic convection caused by a magnetic force acting on oxygen molecules, described as $F_m = (\chi/\mu_o) \cdot B \cdot dB/dx$ where χ is the magnetic susceptibility, B is the magnetic flux density, and μ_o is the magnetic permeability of the vacuum. We used electrochemical method to reveal the effect of magnetic field gradient on the acceleration of the dissolution of the atmospheric oxygen molecule into an electrolytic solution.[5] Even in the case of a magnetic levitation, which is noted recent years,[6] an only value of a product of the magnetic field and the field gradient, $B \cdot dB/dx$ is thought as a dominant factor of the effect of magnetic field on mass transport processes. No attention has been denoted to the effect of homogeneous magnetic field on mass transport processes.

In this communication, we will report the results of electrochemical measurement of the amount of dissolved oxygen in order to clarify the effect of homogeneous magnetic field on the dissolution of oxygen into water in the initial state.

High-Tc superconducting (HTSC) magnet (7 Tesla type, Sumitomo Electric Industries) was used. The measurement of the distribution of the magnetic field in the bore of HTSC magnet was carried out with a Gauss meter (A. D. S. Co., MODEL HGM 8300-1) which had a special probe of 2 mm diameter and of 800 mm length. Electrolytic solution was prepared with 10 mL of water purified by a Milli-Q purification train and tetraethylammonium perchlorate (Wako Pure Chemical) as a supporting electrolyte. A platinum disk microelectrode (BAS Co.) with 15 μ m in diameter and platinum wires were used as the working, the auxiliary and the quasi-reference electrodes, respectively. Electrochemical measurements for concentrations of dissolved oxygen were performed outside the magnet using a conventional three-electrode potentiostat (NIKKO KEISOKU Co., NPGS-2501-10nA), a function generator (TOHO TECHNICAL RESEARCH Co., FG-02) and an X-Y recorder (RIKEN DENSHI Co., Model F-45). The solution was deaerated with Ar gas before the measurements. After the solution was exposed to homogeneous magnetic fields up to 7 T at the magnetic center for 10 min and then stirred enough with a cover to prevent extra oxygen from dissolving, steady state voltammograms were measured with a microdisk electrode outside the HTSC magnet. An experimental setup is shown in Figure 1.

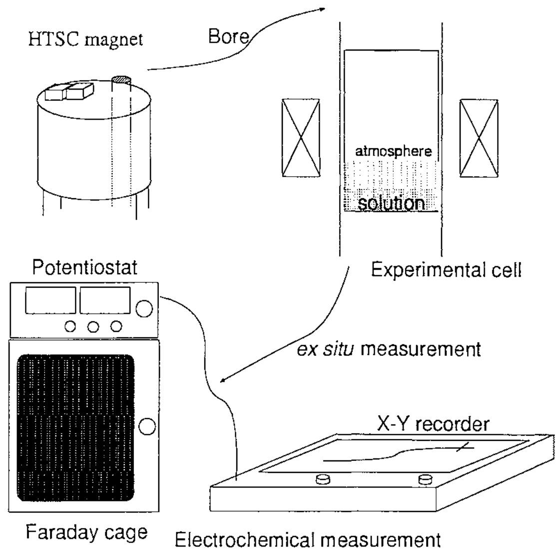

Figure 1. Schematic representation of an experimental setup.

The magnetic flux density in the bore had three-dimensional distribution; for the highest value of 7 T at the bore center, the distribution was changed in z-direction (vertical direction) as shown in Figure 2(a). Though the distribution of magnetic flux density in x-direction (horizontal distribution) displayed downward curvature at the point 70 mm lower from magnetic center(Figure 2(b)), it was reversed at the point 105 mm lower in z-direction of the bore(Figure 2(c)). Careful measurements of the magnetic flux density revealed that there were two regions (z=±77 mm) where a fairly homogeneous magnetic field existed, one of them was shown in Figure 2(c). The experimental cell without a cover was settled in the bore of HTSC magnet, and the gas-solution interface was vertically adjusted to the region mentioned above, i.e., the lower one.

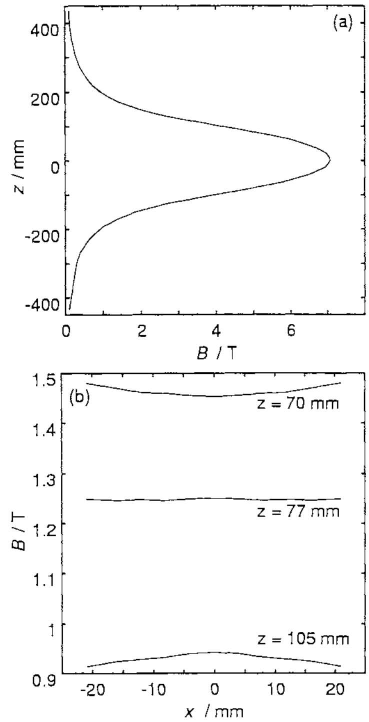

Figure 2. Magnetic field distributions along (a) perpendicular and (b,c,d) horizontal axes of the High-Tc superconducting magnet. z=70(b), 77(c) and 105(d) mm. Magnetic flux density at z=0 was 2 T.

The amounts of dissolved oxygen were obtained from the limiting current of the voltammetry with micro disk electrode described before.[5] The dependence of the total amount of oxygen dissolved during initial 10 min on the intensity of the magnetic field is indicated in Figure 3(a). Because the horizontal axis in Figure 3 indicates the magnetic flux density at the magnetic center, the magnitudes at z=77 mm decrease to about 65% of the highest value. Amounts of dissolved oxygen increased linearly with the magnetic flux density up to 1.0 T and beyond 1.0 T, however, the values were almost close to constant. The plots in Figure 3(a) indicates that amounts of dissolved oxygen under homogeneous magnetic fields increase more than those under magnetic field gradients shown in Figure 3(c).[5] Since the electrolytic solution containing large amount of supporting electrolyte had an ionic conductivity, this phenomenon might include some effect in magnetohydrodynamics which retards a convection by eddy currents. Plot in the absence of supporting electrolyte in Figure 3(b) exhibits similar behavior in (a), exhibiting that there is no effect of the supporting electrolyte ion. We speculate this experimental acceleration of dissolved oxygen as follow. As oxygen dissolves, a very thin layer containing oxygen is formed at the interface which is heterogeneous with regard to the magnetic susceptibility of oxygen. Since the thickness

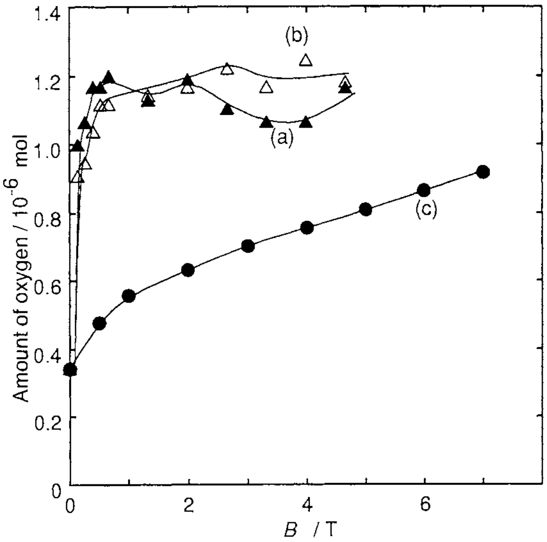

Figure 3. The relationship between the total amount of dissolved oxygen and the intensity of the homogeneous (a,b) and heterogeneous (c) magnetic field.

of this layer is supposed to be extremely thin (~1 μm), the vertical heterogeneity in the magnetic field is neglected. This nonuniformity of the magnetic susceptibility could be thus affected by a homogeneous magnetic field and would generate the magnetic convection. Because of paramagnetism of oxygen molecule, it is reasonable to consider that oxygen would be attracted to the magnetic center by a magnetic field gradient shown in Figure 2(a). Even though the experimental cell was placed in the region mentioned above, the enhancement of the amount of dissolved oxygen was observed indicating that this phenomenon would be due to homogeneous magnetic field which affected the heterogeneity in the concentration distribution of dissolved oxygen. As shown in the previous paper, the air on the water surface also moves to increase the amount of oxygen in the progress of the dissolution.[5] In order to remove such disturbance, a piece of absorbent cotton was therefore stuffed over the surface. After comparing two cases with and without a cotton piece, it was concluded that in the present work, the air on the surface is almost stationary without any disturbance. The effect of a homogeneous magnetic field on the mass transport process is in any event very interesting and its applications are considered as an important subject. We are progressing the detailed analysis which is based on quite a new mathematical model.

References and Notes

1 S. Ueno, and K. Harada, *IEEE Trans. Magn.*, MAG **18**, 1704 (1982).
2 S. Ueno, M. Iwasaka, and G. Furukawa, *IEEE Trans. Magn.*, MAG **31**, 4259 (1995).
3 K. Kitazawa, *Kagaku kogyo*, **48**, 769 (1997).
4 Y. Ikezoe, N. Hitora, T. Sakihama, K. Kunio, H. Uematsu, T. Honma, J. Nakagawa, H. Sugawara, and K. Kitazawa, *J. Magn. Soc. Jpn.*, **22**, 821 (1998).
5 S. Kishioka and R. Aogaki, *Chem. Lett.*, **1999**, 91.
6 Y. Ikezoe, N. Hirota, J. Nakagawa, and K. Kitazawa, *Nature*, **1998**, 6678.