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THE BEHAVIOR OF DISSOLVED OXYGEN IN GAS OIL USING HIGH GRADIENT MAGNETIC FIELD

HARUNOBU ARIMA[a], HAJIME MUTO[b], BARACHANDRAN JEYADEVAN[a], KUNIHIKO YMAMAGUCHI[a], ISAO TAKAHASHI[c] and TOYOHISA FUJITA[a,*]

[a]*Faculty of Engineering and Resource Science, Akita University, 1-1 Tegata Gakuen-cho Akita city, Akita 010-8502, Japan;* [b]*Environmental Research Center, Akita University, 1-1-1 Hondo, Akita city, Akita 010, Japan;* [c]*Toho Metal Industries Co. Ltd., 4-37-6 Matsusima, Edokawa-ku, Tokyo 132, Japan*

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In recent years, considerable attention is being focused on environmental problems. In the case of gas pollution, exhaust gases from automobiles is an area that needs a solution to keep the environment clean. In order to solve this problem, we have proposed an improvement of combustion efficiency through the control of the dissolved oxygen concentration of gas oil by treatment in a high gradient magnetic field. In this paper, we report the results of a basic study on the control of the dissolved oxygen concentration in a gas oil. Here, the gas oil maintained at different conditions is passed through a low volume percentage of iron particle chains exposed to the magnetic field of 1 T. Determination of the dissolved oxygen concentration of the gas oil exposed to the magnetic field indicated a reduction in the dissolved oxygen concentration.

Keywords: Dissolved oxygen; Gas oil; High gradient; Magnetic field; Iron particle

INTRODUCTION

Exhaust gases from automobiles pollute the atmosphere by releasing toxic gases such as CO, NO_x, etc. into the environment. The production

* Corresponding author. E-mail: fujita@ipc.akita-u.ac.jp.

of such gases is due to incomplete combustion. Various researches are progressed to minimize the concentration of toxic gases released to the environment. Favorable solution is warranted for the continuous usage of gas oil in automobiles.

We propose that improvement of the combustion efficiency can be attained by the treatment of the gas oil in a high gradient magnetic field (HGMF). At first, we suggest to manipulate the concentration of dissolved oxygen. The influence of the magnetic field on dissolved oxygen in water has been demonstrated by Ueno *et al.* [1]. They report that the change in dissolved oxygen concentration in water can only be sensed when the applied magnetic field is as high as 8 T [2]. But, there is no literature available on the use of HGMF to control the dissolved oxygen or nitrogen concentration in fuel oil. It was applied to mineral processing [3], waste water treatment [4–6], etc.

When ferromagnetic wool or expanded metal as matrices are introduced into the high magnetic field, the magnetic trapping force for fine and weakly magnetic particles is greatly increased [7]. In this case the configuration of matrices is important and the volume fraction of matrices should be low to keep the external magnetic field intensity. Very strong magnetic forces are created on the edges of fine ferromagnetic materials in the presence of a strong background magnetic field.

On the other hand, it has been shown in many experimental studies that the capture efficiency of the ball matrix is comparable to that of the steel wool matrix. The magnetic force of ball matrix at high magnetic fields is relatively poor [8]. However, we use the low volume percentage of fine iron powders as matrix to keep the external magnetic field strength. We have attempted to create a greater force on the paramagnetic oxygen molecules by increasing the magnetic field gradient with iron powders.

In order to predict the effect of HGMF treatment, it is important to understand molecular movement of oxygen and nitrogen in fuel oil. Here, we report the results of a basic study on the control of dissolved oxygen concentration in gas oil. The gas oil maintained at different conditions is passed through iron particle chains exposed to a magnetic field and the dissolved oxygen concentration of the HGMF treated gas oil is measured. We report the results of the change in dissolved oxygen concentration at different magnetic field strengths.

EXPERIMENTAL

Samples

The gas oil used in these experiments was obtained from the commercial outlets of Cosmo Oil Co. Ltd. The average particle size of iron particles used in preparation of the 20 vol% packed bed was 5 μm.

Experimental Setup

Figure 1 shows the schematic diagram of the experimental setup used for measurement of the dissolved oxygen in gas oil. The system consists

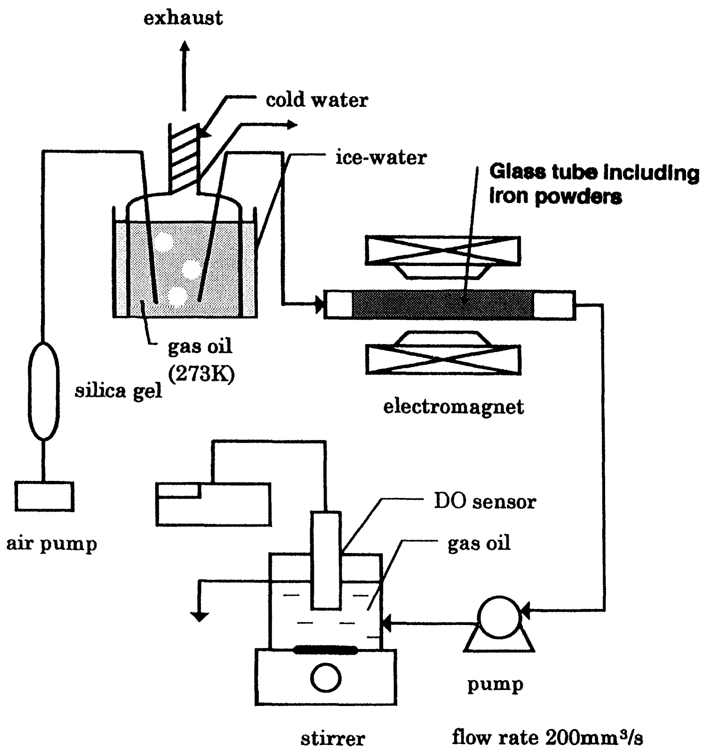

FIGURE 1 Experimental apparatus to investigate the changes in concentrations of dissolved oxygen in gas oil (273 K) by the application of magnetic field.

of a feed tank containing gas oil, electromagnet, pump, accumulation tank, and dissolved oxygen (DO) sensor. The gas oil is pumped through a magnetic field area. The magnetic field and the magnetic field times the magnetic gradient distribution of the electromagnet in the absence of iron powder matrices is given in Fig. 2.

In the magnetic field area, the gas oil is passed through a 20 vol% of iron powder bed of 20 mm diameter and 250 mm length that is placed in the center of the electromagnet. This was designed to increase the force exerted on the paramagnetic oxygen molecules by increasing the magnetic field gradient. The gas oil passing the magnetic field area is accumulated in a tank where the DO sensor is placed to measure the

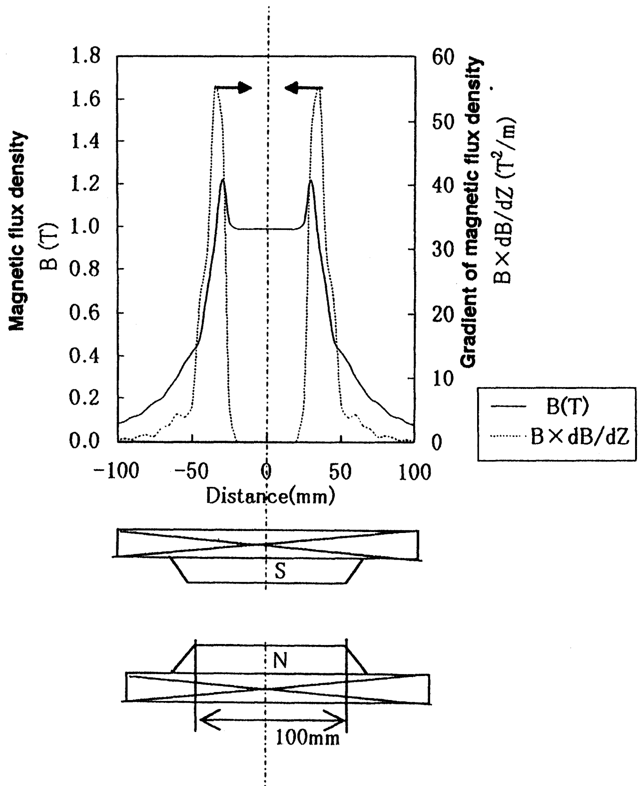

FIGURE 2 External magnetic flux density and its gradient in the absence of iron powder between magnetic poles.

dissolved oxygen concentration. In Fig. 1 the experimental system is semi-closed to prevent the volatilization of gas oil when the DO sensor box is closed and only the gas oil outlet is open, or open when DO sensor box is open to the air.

Experimental Procedure

Gas oil is cooled to 273 K using ice and bubbled with air for 1 h prior to the beginning of the experiment. This is done to standardize the initial condition and to maximize the dissolved oxygen concentration in the gas oil. Gas oil is pumped at a flow rate of 200 mm^3/s through the high gradient magnetic field. The gas oil passing the magnetic field area is collected in a tank of volume 0.5 dm^3, stirred, and the dissolved oxygen concentration is measured by the DO sensor. The magnetic field is switched on only after the temperature of the gas oil collected at the tank becomes constant.

In addition to the standard experimental procedure stated above, experiments are also carried out under the following conditions.

(a) To determine the influence of the oxygen partial pressure between a gas phase and liquid phase. The tank where gas oil is accumulated for the determination of the dissolved oxygen concentration is kept exposed to the atmosphere.
(b) The gas oil is bubbled with air at room temperature.
(c) The gas oil is bubbled at room temperature, and the dissolved oxygen at the accumulation tank is measured at 278 K.

Experiment (c) was continued measuring dissolved oxygen after switching off the electromagnet for the determination of the oxygen trapping on the iron particle surface.

The particle size and morphology of the iron powder used in the experiment was observed using scanning electron microscopy and is shown in Fig. 3(a) and (b).

The magnetic flux density was measured using the Hall sensor by changing the volume fraction of iron powders between magnetic poles. The result is shown in Fig. 4. When the iron powder is put into magnetic flux space, the iron powder forms long thick chain structures connecting magnetic poles. The magnetic flux decreases by more than 20% by

(a)

(b)

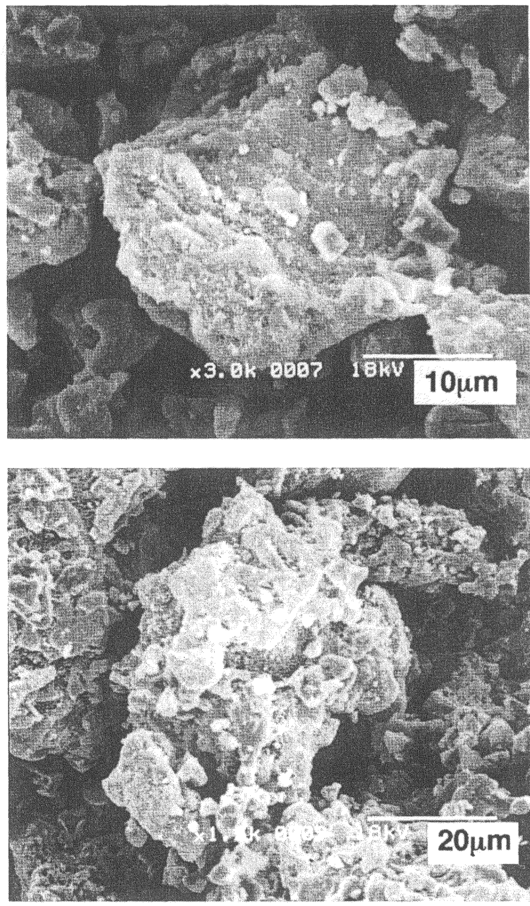

FIGURE 3 SEM photographs of iron particles used for HGMF.

shield effect of iron powders surrounding Hall sensor, when about 20% volume of iron powders is used. We set 20% volume of iron powders between magnetic poles in our experiment.

On the other hand, iron powder is used to prepare magnetorheological fluids [11,12]. The iron volume percentage of magnetorheological fluid is generally much higher than 30 vol%, therefore, flux concentration decreases by introducing magnetic powders in magnetic field.

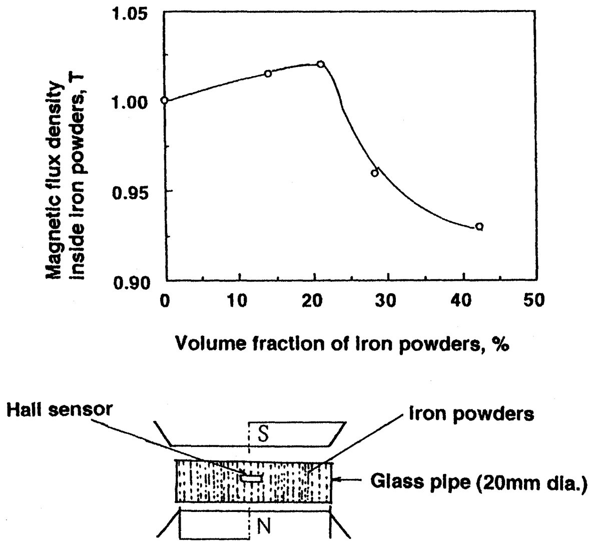

FIGURE 4 Magnetic flux density inside iron powder as a function of volume fraction of iron powder measured by the Hall sensor.

RESULTS AND DISCUSSION

The oxygen molecule is paramagnetic since the electron spin direction of the two electrons in the outer orbital are in the same direction. Therefore, the movement of oxygen molecules can be controlled by magnetic field, and also gas oil is diamagnetic. When a magnetic particle is exposed to the magnetic field, the magnetic force on the particle can be given by Eq. (1):

$$F = \frac{\chi_p - \chi_l}{\mu_0} VB \frac{dB}{dZ}, \tag{1}$$

where F is the magnetic force acting on particle along direction Z (N), χ_p the magnetic susceptibility of particle, χ_l the magnetic susceptibility of liquid, μ_0 the magnetic permeability of vacuum (H/m), V the volume of a small body (particle or bubble) (m^3), B the magnetic flux density (Wb/m^2), and dB/dZ the gradient of the magnetic flux density (Wb/m^3). Thus, the magnitude of the force exerted on an oxygen molecule can be increased either by increasing the magnetic field or the magnetic field gradient [11,12].

Ueno *et al.* working on manipulation of dissolved oxygen in water suggested that the control of dissolved oxygen concentration is possible only at magnetic fields higher than 5 T. However, such high magnetic field strengths are obtained only with expensive superconducting magnets. Therefore, in this paper we have resorted to increase the magnetic field gradient to obtain a high magnetic force. This is done by packing the pathway of the gas oil in the magnetic field area with low volumetric percentage of iron powder chains.

The oxygen bubble movement was observed under the magnetic field of 1 T. Photos (a) and (b) in Fig. 5 shows the oxygen bubble position in absence and presence of a magnetic field respectively. The oxygen bubble was attracted to the magnetic field. This fact indicates that the oxygen molecule is paramagnetic and the force in Eq. (1) is positive. Also, the same phenomenon was observed that nitrogen bubble could

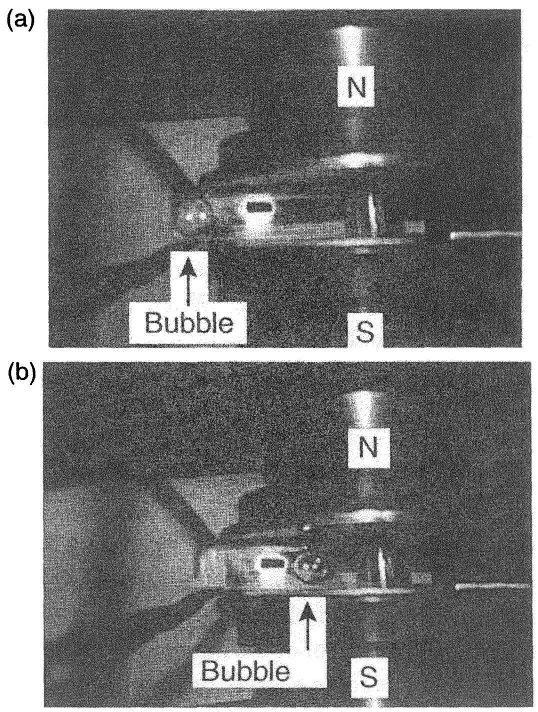

FIGURE 5 Behavior of the oxygen bubble in the glass cell filled with gas oil in the absence (a) and presence (b) of a magnetic field.

be attracted to the magnetic field even if it is diamagnetic. Since the nitrogen bubble susceptibility is much smaller than that of gas oil, this force in Eq. (1) is positive.

Figure 6 shows the changes in relative dissolved oxygen concentrations and temperatures of gas oil, with time after passing through in the absence and presence of magnetic field in a semi-closed system. The dissolved oxygen concentrations remained constant in the absence of magnetic field, but, when the field is switched on, the dissolved oxygen concentrations decreased by about 2–3%, and then increased gradually with time. However, the oxygen concentration did not reach the concentration at zero magnetic field within the time duration of the experiment.

The decrease in the oxygen concentration with the application of the magnetic field is believed due to the interaction between the edges of iron particles and oxygen molecules. The oxygen molecules are believed to be attracted toward the magnetic pole surface of the iron particles where the magnetic field gradient is high. Consequently, the dissolved oxygen concentration in the gas oil decreases. However, when the gas oil is pumped continuously through the iron powder chains, the magnetic pole surface of the iron particle becomes saturated with oxygen molecules that do not get trapped in the iron powder chains any more. Therefore, the dissolved oxygen concentration begins to increase with

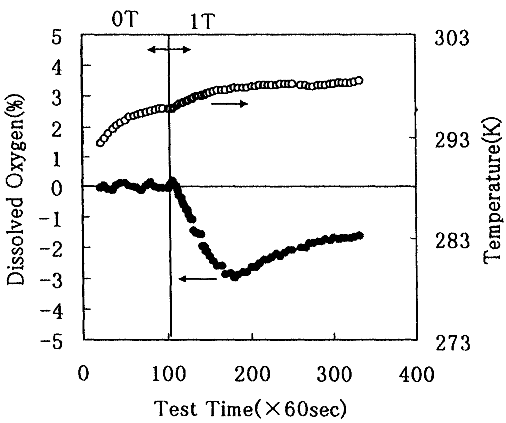

FIGURE 6 Changes in relative concentration of dissolved oxygen and temperature in gas oil, after passing through HGMF. (273 K: DO-saturated condition, semi-closed system.)

time. After approximately 2 h, the small oxygen bubble appeared at outlet of glass tube as shown in Fig. 7. This phenomenon is believed the result of saturation of the trapped oxygen.

Figure 8 shows the results in the open system. Compared to Fig. 6, the decreasing rate of dissolved oxygen concentration was higher. The difference in dissolved oxygen concentration between the presence and

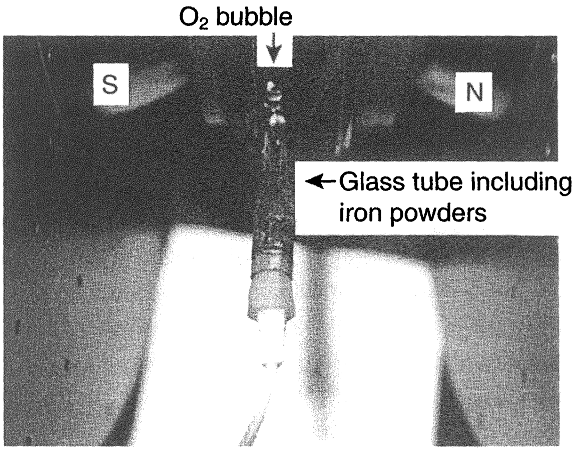

FIGURE 7 Appearance of O_2 bubble by passing gas oil into iron powder tube under 1 T of the external magnetic flux density for 1 h.

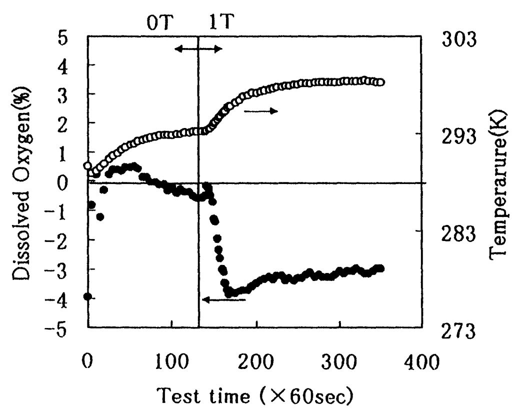

FIGURE 8 Changes in relative concentration of dissolved oxygen and temperature in gas oil, after passing through HGMF. (273 K: DO-saturated condition, open system.)

absence of the magnetic field was little higher than in the case given in Fig. 6 and showed little change in concentration with time. In general the solubility of dissolved oxygen decreases as temperature increases.

Since the temperature of gas oil is higher when it reaches the accumulation tank after passing the magnetic field area and the oil surface is open to the atmosphere, the oxygen molecules disappear into the atmosphere in addition to the loss of dissolved oxygen in the iron powder chains. This is believed to be the cause for the rapid decrease in the dissolved oxygen concentration.

Furthermore, the dissolved oxygen concentration does not rise with time during the application of the magnetic field. This is because the oxygen molecules that pass the magnetic field area without being attracted by the iron particles are released into the atmosphere as soon as they reach the accumulation tank.

Figure 9 shows the results of the experiment carried out using gas oil saturated with oxygen at room temperature. Compared to Fig. 6 the change in dissolved oxygen concentration due to the application of magnetic field was small. The decrease in the amount of change under the application of the magnetic field is due to high temperature of the gas oil feed compared to the case in Fig. 6 where the initial dissolved oxygen concentration was high.

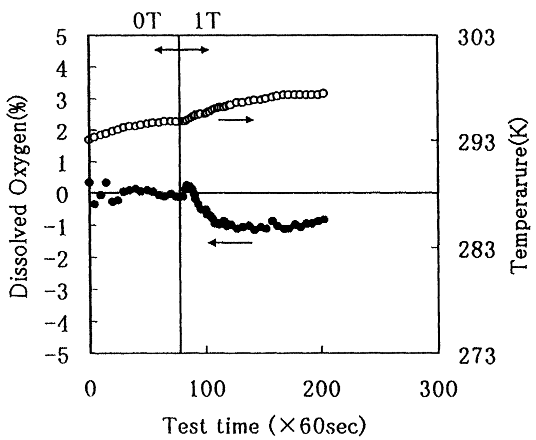

FIGURE 9 Changes in relative concentration of dissolved oxygen and temperature in gas oil, after passing through HGMF. (Room temperature: DO-saturated condition, semi-closed system.)

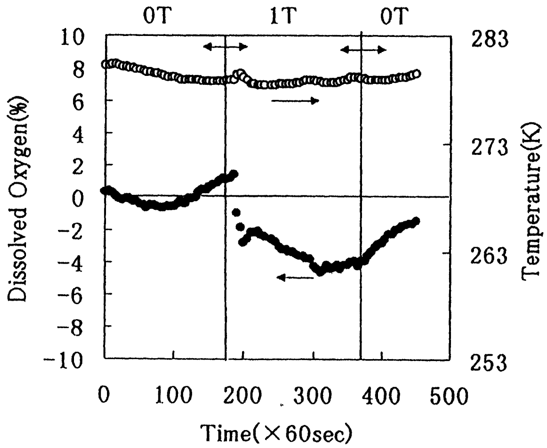

FIGURE 10 Changes in relative concentration of dissolved oxygen and temperature in gas oil, after passing through HGMF. (Room temperature: DO-saturated condition, measured tank temperature: 283K, semi-closed system.)

Figure 10 shows the results of the experiment where the gas oil was bubbled at room temperature, and the dissolved oxygen measured at the accumulation tank at 278 K. The behavior of dissolved oxygen is same as in Fig. 6 till the electromagnet was switched off. When the electromagnet is switched off, dissolved oxygen increased gradually.

CONCLUSION

Oxygen in gas oil is trapped on chains of micron size of iron particles in 20 vol% of iron powder bed by applying the magnetic field of 1 T. The amount of dissolved oxygen in an organic solvent, gas oil can be controlled by using the high gradient magnetic field. The trapped amount of oxygen depends on the temperature and surrounding atmosphere of gas oil. The influence of HGMF on the combustion efficiency is expected.

Acknowledgments

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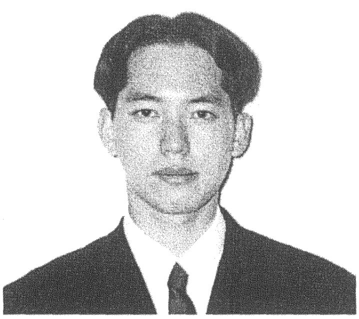
BIOGRAPHY



Harunobu Arima is Graduate school student of Mining & Engineering, Akita University. Toyohisa Fujita is Professor, Department of Materials-process Engineering & Applied Chemistry for Environments, Faculty of Engineering and Resource Science, Akita University, Fields of interest: Mineral processing and recycling, Applied surface chemistry, Intelligent fluids (magnetic fluid, ER fluid, MR fluid) environmental engineering.