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Magnetic Force Control Technique for Recycling and Environmental Preservation

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Abstract-- **The applicability of the two types of magnetic separation system, high gradient magnetic separation (HGMS) and Magneto Archimedes method were studied considering the magnetic susceptibility of targeted substances. It was noted that the combination of the two methods can control the almost all the substances, paramagnetic and diamagnetic in addition to ferromagnetic substances. The principle of the methods was given and the conceput of the magnet force control technology is discussed. The practical applications of the technique were introduced together with the new application of HGMS.**

Abstract: **Magnstic force, Magneto-Archimedes, HGMS, Recycling, Purification.**

1. INTRODUCTION

The strong magnetic field has been actively applied in various areas. In particular, the technology, that uses the strong magnetic field for the highly controlled magnetic force generation, has been developed especially in the field of recycling materials and environmental preservation.

The high gradient magnetic separation (HGMS) has been applied in the field of water purification. The Magneto Archimedes method has also attracted attention for recovering the valuable substances. The two techniques are combined and re-established as "magnetic force control technique" and now are opening the way for wide spread of application.

The HGMS has been used in practical application such as the wastewater treatment system of paper factory [1], the wash water drum treatment system [2], the recycle system of waste slurry from the solar cell manufacturing [3], the system for river purification [4] and so on. The removing arsenic from geothermal water [5] and purifying the landfill leachate water [6] have been studied and achieved the notable results. The removal and recovery of phosphorous form disposed swage [7], and wastewater treatment in the university [8] were also reported. Furthermore, in the medical application as the magnetic drug delivery (MDDS) should be in this category [9]. In addition, the separation system with superconducting magnet have recently employed for purifying the contaminated soils and groundwater [10].

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It should be noted that the new application of superconducting HGMS was developed. The device separates detonator from the coals and was placed at export ports [11].

On the other hand, magneto-Archimedes method has been considered to be applied for the fractionation of waste glass, but has not put into practical use [12]. Therefore, the development has been accomplished mainly on a magnetic separation.

In this work both method are studied considering the properties of the targeted substances and will be reported some examples.

2. MAGNETIC FORCE CONTROL

2.1. High Gradient Magnetic Separation

Magnetic separation is a method to separate the particles with the magnetic force acting on the particles. When the particles are dispersed in the fluid in the magnetic field, the force to the particles is the magnetic force and the drag force. The particle properties such as magnetic susceptibility, saturated magnetization, and particle size decide the magnetic force. The gravity of the particles and the magnetic property of the medium are usually neglected.

The magnetic force exceeds the drag force to the particles, can control the particle magnetically. The magnetic force generated is shown by equation (1),

$$\mathbf{F} = V(\mathbf{M}\cdot\nabla)\mathbf{B} \qquad (1)$$

Here, V is the volume, M is the magnetization of the particle and B is the magnetic flux density at the position of the particle. In Fig.1 the magnetization of three kinds of materials that is ferromagnetic, paramagnetic and diamagnetic materials are presented with external magnetic field. In paramagnetic and diamagnetic materials the magnetization is proportional to the external field. Whereas that of ferromagnetic materials saturates at lower magnetic field. When we use the one dimensional expression, the equation (2) is derived,

$$F = VM\frac{dB}{dx} = V\frac{\chi_P}{\mu_0}\frac{dB}{dx} \qquad (2)$$

Where χ_P is susceptibility of the paramagnetic or diamagnetic particles and μ_0 is the permeability of

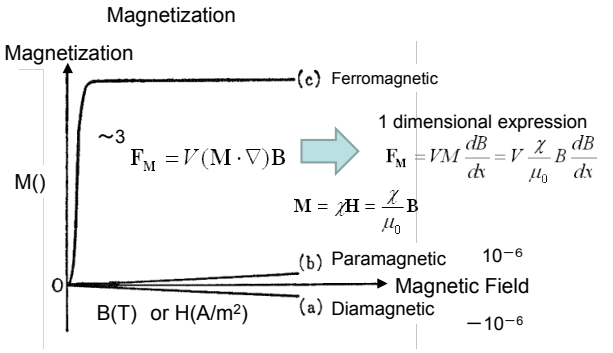

Fig. 1. Magnetization of ferromagnetic, paramagnetic and diamagnetic materials. Both the three or one dimensional expression of magnetic force are also shown.

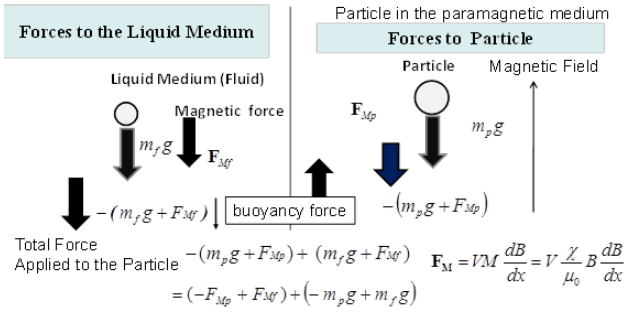

Fig. 2. Principle of Magneto-Archimedes method . Due to the magnetic force to the medium, the buoyancy force exceeds the sum of gravity and magnetic force to the substance.

vacuum, respectively. As shown in Fig 1, the magnetization of paramagnetic and diamagnetic material is proportional to the magnetic field. Equation (2) cannot be applied to the ferromagnetic materials. Instead of M, Ms saturated magnetization will be used at higher magnetic field and hence the third term in equation (2) should not be used. It is easy to understand that the magnetic force is proportional not only to magnetization but also gradient of magnetic field. This is the reason why we can attract even paramagnetic and diamagnetic materials under high and high gradient magnetic fields.

When you want to produce the high gradient magnetic fields, the magnetic filter would be used. When thin ferromagnetic material is located in the magnetic fields, the gradient of magnetic field is produced. The ferromagnetic materials are called “magnetic filter”.

2.2. Magneto-Archimedes Method

In this method, the magnetic susceptibility and gravity of liquid medium have important roles in contrast with HGMS. The particle is immersed in the paramagnetic medium and is located in the magnetic field. The magnetic force and the gravity to the liquid state medium are taken into account in calculating the buoyancy force.

The buoyancy force to the particle is usually calculated as the gravity to the medium of which volume is just same as the particle. In the magnetic field, however, the buoyancy force comes to be the sum of gravity and the magnetic force to the medium as shown in Fig 2. When the sum of the magnetic force and the gravity to the medium is large enough to exceed that of the gravity and magnetic force to the particle, the particle should be levitated. This method is a kind of heavy-media separation.

The condition where both the buoyancy and the gravity becomes equal is shown by the following equation [12],

$$-\rho_1 g + \frac{\chi_1}{\mu_0} B\frac{\partial B}{\partial z} - \left(-\rho_2 g + \frac{\chi_2}{\mu_0} B\frac{\partial B}{\partial z}\right) = 0 \qquad (3)$$

Here, χ_1 and χ_2 are the mass magnetic susceptibilities, ρ_1 and ρ_2 are the specific gravities of the particle and medium respectively, μ_0 is the permeability in vacuum and B is magnetic flux density. If you use the bulk susceptibility the same equation as (3) is obtaine. The delivation of the equation is also shown in Fig.2. In the equation, the terms shown in parentheses indicates the buoyant force. The particle levitates when the left-hand side of equation (3) becomes positive. In this way, the diamagnetic substance levitates depending on the combination with paramagnetic medium. Whether the object substance levitates or not is determined by the sign of the left-hand side of equation (3). It has been reported that even the paramagnetic particle can be levitated. Levitation of the objective substances can be controlled by changing the magnetic susceptibility of liquid medium, magnetic field and the gradient of magnetic field. It can be noted that the volume or weight of the particle are eliminated form the equation.

2.3. Magnetic Force Control Techniques

The magnetic force control technique is to separate and/or guide the objective substances freely by taking advantage of HGMS and magneto-Archimedes method. As shown in equations (1) and (3), “magnetic product” defined as the product of magnetic field and gradient of magnetic filed (or magnetic field density) is important parameter in the magnetic force control techniques.

It is important to understand the appropriate range of the application of the magnetic force control method when we want to apply the technique. It was mentioned above that the efficiency of HGMS depended on the volume of the targeted substances, an external magnetic field and the gradient of the magnetic field. In the practical application, it also depends on the flow rate of the suspending medium. In the Archimedes method, the separation efficiency depends on the magnetic susceptibility and specific gravity of the object material. Taking into account of these conditions, the appropriate range of each method was shown in Fig 3 according to the magnetic susceptibility of the object substances. The HGMS can apply to the materials with larger susceptibility of absolute value. The magneto Archimedes method is applicable for the diamagnetic materials and the weakly paramagnetic substances. Though the ferromagnetic material is not shown in this figure, it can be separated by permanent

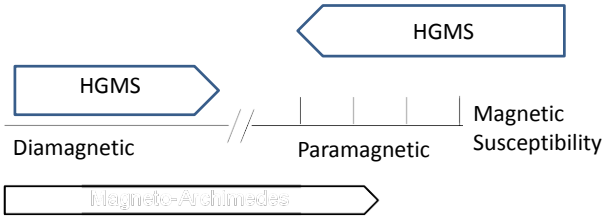

Fig. 3. Effective range of HGMS and Magnteto-Archimedes method based on the susceptibility of the substance.

magnet or electromagnet easily. The magnetic force control techniques have been developed focusing on the magnetic separation so far. However it became evident that almost all substances can be controlled by the combination of magneto-Archimedes method and HGMS. The combination of the two methods is considered as the "Magnetic Force Control Technique" and is beginning to be applied in various fields energetically.

3. RECYCLING MATERIALAS

HGMS and magneto-Archimedes method using superconducting magnet have large possibility in the classification and recycling materials. The environmental preservation is also the possible area especially water purification.

3.1. Recycling of Cerium Oxide

The polishing agent mainly composed with cerium oxide has been used for the precise polishing of a photo mask, optical lens and glass substrate in the liquid crystal panel. Recently the shortage of the cerium oxide polishing agent affects the production process results in the difficulty of the manufacturing of optical products.

Magnetic force control technology has been used for the recycling of the cerium oxide. In the sludge from the purifying process of the polishing waste water, such impurities as iron oxide, alumina, silica and glass are mixed in the purifying process. To recycle the polishing agent, the impurities have to be removed. To remove these impurities from sludge the magnetic force control technique has been employed.

Fig.4 shows the HGMS and Magneto-Archimedes system which are installed in the factory. Most of the debris are produced through the calcination process of the sludge. In the system first the pH of the sludge suspension is controlled to disperse the particles and then is introduced to the magnet system.

In the HGMS the permanent magnets are employed. HGMS removes the iron oxide. The reason why we employed HGMS is the size of the iron oxide particle. The size of the iron oxide is too small to remove with open gradient magnet.

In the Magneto-Archimedes method, the diamagnetic impurities such as glass debris, silica and alumina particles are removed. Even if the weakly magnetic impurities exist in the sludge this process can levitate and separate them. To produce the magnetic field, the superconducting magnet was used in the process as shown in Fig. 4.

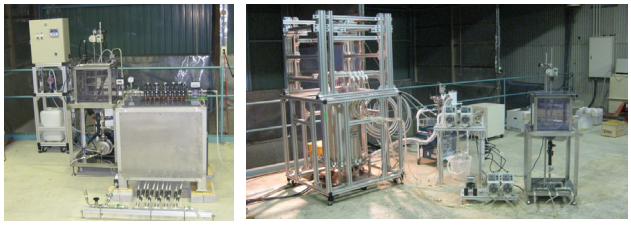

Fig. 4. Photos of HGMS and Magneto-Archimedes system. In the HGMS permanent magnet is used and in magneto-Archimedes system, a superconducting magnet is employed.

By means of the magnetic force control technique, that is the combination of HGMS and magneto-Archimedes methods, the cerium oxide with higher purity was obtained. It was confirmed that the recycled cerium oxide polishing agent is possible to reuse.

3.2. Recycling of Phosphor

The recycling of the waste phosphor has been studied for practical use of magnetic force control technique. The waste phosphor is usually a mixture of different colour emitting phosphor including rare earth elements. The separation and the reuse of the phosphor have been studied and, in recent years, the demand of the phosphor has been rapidly increasing, and then the development of techniques that can reuse the phosphor is required especially separate calcium halophosphate phosphor (HP) form the waste.

The phosphor waste consists of Europium activated Barium Magnesium Aluminate (BAM), Cerium-and Terbium-Activated Lanthanum Phosphate (LAP) and Europium-activated Yttrium oxide (YOX). They are used in the three-wavelength fluorescent lamp. The Calcium Halophosphate Phosphor (HP) also exists in the waste. The required technique is to separate HP form the four types of phosphor because the HP does not include the rear earth elements. To meet the requests the magnetic force control technique has been studied. HP together with the impurities is removed in terms of Magneto-Archimedes method though the magnetic susceptibility of HP is not smallest among them. The reason why the HP can be separated by the Magneto- Archimedes method is the density. The density of HP is smallest among them and hence HP can be separated in terms of Magneto-Archimedes method as shown equation (3).

3.3. Other Applications

The fractionation of waste glass and recycling of waste plastics were found to be possible in laboratory scale and the applicability in the field is under the investigation.

4. ENVIRONMENTAL PRESERVATION

The magnetic force control technique can be applied to

environmental preservation especially water purification. The conventional water purifying equipment has the complicated system constructed by such process as biological de-nitrification, coagulating sedimentation, sand filtration and activated carbon adsorption. The equipment has the problems of a large processing space, a long time, a large quantity of secondary sludge and a great maintenance expense. The magnetic force technique could solve the problems and hence the several systems have been developed aiming at to purify the waste water form paper factory [1], the wash water drum [2], the geothermal water [5], the landfill leachate water [6] and groundwater [10].

Recently the decontamination of radioactive cesium form soil has been paid particular attention after the nuclear plant accident. Fig 5 shows a flow diagram for the decontamination of cesium from the soil by using magnetic separation method. The system roughly consists of the following four process.

1. Soil classification
2. Clay washing
3. Adsorption of radioisotopes (RI) in wash fluid
4. Storage of high level RI

Soil is divided into sand gravel (0.02 to 2 mm), silt (0.02 to 0.002 mm) and clay (not over 0.002mm) depending on the particle size. Cesium is strongly adsorbed on clays among them, thus RI was concentrated in the clays which should be classified from the soil. The sand gravel and silt after soil classification can be backfilled to the original site, if it is confirmed that radioactive level is less than the acceptable level. Next, the residual clay is washed in order to reduce the volume of the clay. It is reported that cesium adsorbed on the clay is hardly eluted by the simple water washing. Thus cesium is removed from the clay using acid. The cesium ions which eluted from the clay into water phase are adsorbed on the adsorbents with ferromagnetism, and the ferromagnetic adsorbents are collected efficiently by magnetic separation using superconducting magnet. This is a series of flow of the system we are planning in this study.

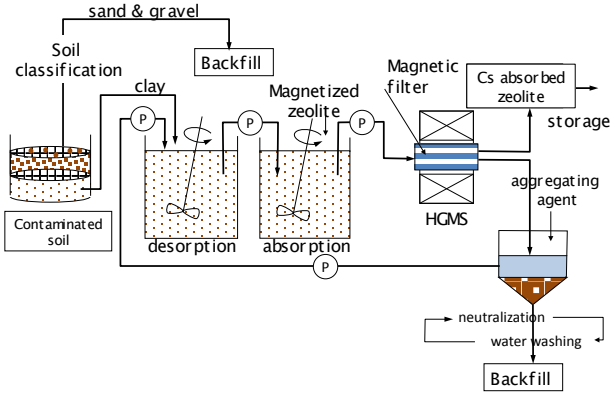

Fig. 5. Flow diagram of decontamination of radioactive soil.

It is important to reduce both the external and internal radiation exposure of the operator, the scattering of RI and the contaminated wastes. The HGMS is the one of the best systems to answer the requests.

5. CONCLUSION

As the applications of high magnetic field, the high gradient magnetic separation had been paid particular attention so far. Nowadays the high gradient magnetic separation technique is combined with the magneto-Archimedes method and was re-established as the magnetic force control technique and now is opening the way for wide spread of application. It is worth noting that almost all the substances can be controlled by the re-established magnetic force control technique. In the future, we will expand the application area toward the resolution of environment issues, including the decontamination of radioactive materials.

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