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The review of IFMFC (International Forum on Magnetic Force Control) –The accumulated knowledge and experience of the magnetic force control with IFMFC

Tsuneo Watanabe[*,a]

[a] *Tokyo Metropolitan University, Tokyo, Japan*

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Abstract

The practical use of superconducting magnets is limited to medical equipment, energy equipment and the like. Therefore, it does not fully utilize the superior features of superconducting magnet or magnetic force. In order to overcome this blockage condition, The international Forum on Magnetic Force Control (IFMFC) was launched in Tokyo in 2010 by the magnetic separation researchers in Japan, Korea and China. The policy is to hold around the country every year, to apply the application to the engineering field of magnetic force utilization and information exchange about the development of applied science to mutual visit of researchers and to develop the application field of superconducting magnets in particular. The main object is to review the field of application of magnetic force with respect to published papers at 8 IFMFCs, and to introduce the trend of research forum utilizing strong magnetic force which is rare in the world. The United Nations is asking each country to achieve Corporate Social Responsibility (CSR) targets for 2030. This IFMFC review will be utilized in this field.

Keywords : superconducting magnet, magnetic separation, CSR, environment remediation, material recycle

1. INTRODUCTION

The application of superconducting technology is a very attractive one. The R & D have been actively conducted. In spite of them, the developed industrial applications are limited to the medical equipment of NMR, MRI and single crystal pulling equipment. For other field, the application to accelerator, nuclear fusion reactor, superconducting cable, maglev train and SMES (Superconducting Magnetic Energy Storage) could not get the wide market.

The IFMFC (International Forum on Magnetic Force Control) started on 2010 at Tokyo aming to exchange the experience and information as to the magnetic force control technology and the related magnetic science. The IFMFC is organized by three countries researchers in China, Japan and Korea.

The management policy is as follows;

1) to hold around the country every year
2) to exchange the information as to the engineering field of magnetic force utilization
3) to exchange the information about the applied science by magnetic force control
4) to mutual visit of researchers
5) to develop the application field of superconducting magnets in the practical use.

Now, there are some suitable items for magnetic force application within the 17 items of the on Sustainable Development Goals (SDGs) for the year 2030 decided by the United Nations [1].

* Corresponding author: twtm@tmu.ac.jp

The following four items are powerful candidates for the application of superconducting technology:

6th : Securing the availability and sustainable management of water and sanitation
9th : Strong infrastructure construction, promotion of comprehensive sustainable industrialization and innovation
12th : Securing sustainable production consumption form
14th : Sustainability Marine resources and others

Practically the magnetic separation (MS) technology is good for using in the fields of environment remediation and material resource.

The MS technology is the unique separation one with many features due to the physical treatment:

1) A simple equipment system
2) Few secondary waste
3) The stable treatment
4) The fast treatment
5) The small and flexible space equipment

The MS material processing with superconducting magnet is useful as shown in Table. 1.

The materials underlined corresponds to the substance in Fig. 2. The current practically used MS technology with superconducting magnet have been introduced in the above mentioned fields. The various types of MS equipments have been proposed for the practical use. These MS equipments are introduced by the medium-sized companies. Their equipment size is not so large that shows the development possibility.

TABLE 1
THE MATERIAL PROCESSING BY MS TECHNOLOGY

(1) Downstream material processing (environment Remediation) : The MS technology will be used to produce the harmless waste.
(2) Downstream material processing(material resource): The MS technology will be used to produce raw material from waste.
(3) Upstream material processing(material resource): The MS technology will be used to produce the new material from low material.

TABLE 2
MAGNETIC SEEDING METHODS

1. Coupling method:
/ Flocculant binding method
/ Surface adsorption method
/ Chemical modification / adsorption method
2. Amorphization method
3. Comprehensive method:
/ Polymer inclusion method
/ Porus material comprehensive method
/ Microcapsule method
4. Electrochemical method

This thesis will review the presented papers from 2011 to 2017 IFMFC and show the usefulness to apply the superconducting technology for nominated tasks in SDGs.

2. THE KEY METHODS OF MS TECHNOLOGY

The development of MS technology depends on the following key factors; high gradient magnetic field method, magnetic seeding and high magnetic field superconducting magnet.

The magnetic force $\mathbf{F_m(N)}$ influenced on the magnetized material is shown as eq. (1). Vp(m^3) is the particle volume. M*(A/m) is the relative magnetization between the particle Mp and the fluid M_f as eq. (2). μ_0 (A/m) is the vacuum magnetic permeability. χ_{eff} is the effective susceptibility. H(A/m) is the magnetic field strength.

$$\boldsymbol{F_m} = Vp \cdot M^* \cdot \mu_0 \nabla \boldsymbol{H} \quad [\mathrm{N}] \quad \textbf{(1)}$$

$$M^* = Mp - M_f = \chi_{eff} \boldsymbol{H} \quad [\mathrm{A/m}] \quad \textbf{(2)}$$

$$\chi_{eff} = (\chi_p - \chi_f) / \{(1+\chi_p)(1+\chi_f)\}$$

Several element methods are used so that magnetic force (F_m) can be efficiently applied to target substances. The first one is the magnetic seeding methods which have been developed for the purpose of increasing the magnetic moment(M *) of the target substance. The second is the high gradient magnetic separation(HGMS) method order to increase ∇H. The third is to use a superconducting magnet using in order to increase H.

2.1. Magnetic seeding method, magneto-Archimedes Effect

Owing to the magnetic properties of substance, there are two type separation methods are used. One is HGM method with the magnetic seeding, the other is the separation method with magneto-Archimedes effect. The magnetic seeding method for nonmagnetic or weak magnetized substances to increase the magnetic moment M*. The other is mgneto-Archimedes effect for diamagnetic substance. The Magneto-Archimedes effect is used to levitate the diamagnetic substance by superconducting magnet with the aid of the magnetically induced buoyancy force that comes from its surroundings with superconducting magnet from its surroundings [2].

Table. 2 shows the temporal magnetic seeding methods. With HGMS method, the magnetic seeding method is practically important to separate the target material from the compound for environment remediation and material resource [3].

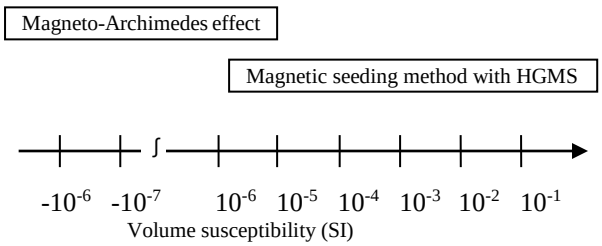

Fig. 1. Separable range by the magnetic seeding method and magneto-Archimedes effect due to the target substance's volume susceptibility.

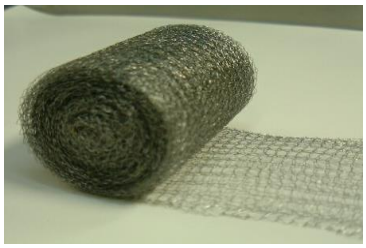

Fig. 2. The ferromagnetic thin wire mesh filter. The wire diameter is 0.1 mm SUS430.

By using the high gradient magnetic separation method and the magneto-Archimedes effect, it becomes possible to separate a wide range of target substances due to the volume magnetic susceptibility as shown in Fig. 1. Fig. 1 shows the separable range by the magnetic seeding method using HGMS and the magneto-Archimedes effect on the volume susceptibility of the target substance with superconducting magnet. From Fig.1, it is considered that most substances can be separated by magnetic force by choosing both methods [4].

2.2 Magnetic filter for HGMS

In order to effectively apply the HGMS technique, a ferromagnetic thin wire is effective as the magnetic filter as shown Fig. 2. The ferromagnetic thin wire is not best one considering the cost of magnetic thin wires, cleaning and recycling of magnetic flocks, long-term use. The other type ferromagnetic filters were presented; small sphere, net plate and other constructions.

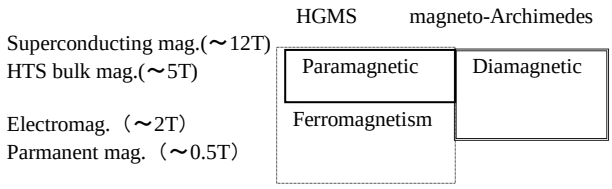

Fig. 3. The magnet mapping for magnetic separation.

2.3 Magnet for the target substance

Fig. 3 shows the selective mapping of magnets used for magnetic force control according to the magnetism of the target substance. The superconducting magnet makes it possible to separate any types of magnetism [5].

3. THE APPLICATION FIELDS WITH SUPERCONDUCTING MAGNET IN IFMFC

The 68 papers have been presented from 2011 to 2017. These papers present the material processing by MS technology with superconducting magnet. Fig.4 shows the distribution of three type material processing in Fig. 1.

3.1 Harmless waste production

MS treatment equipment was used to produce the harmless waste in the process of removing harmful substances contained in the domestic wastewater, industrial wastewater and natural environment. Table 3 shows the harmless waste production by MS equipment. The almost applications are to produce the harmless discharge water. The industrial wastewater treatment has been applied in Japan, China and Korea. The treatment of high level Cs soil has been started from 2012 in Japan as to decrease the volume of Cs contaminated soil in intermediate and final repository. The lowered Cs contaminated soil will be expected to reuse for building or Tetra pot material.

3.2 Raw material and New material production

In the factory, the reuse or recycling system is very important because the used materials are collected in urban mine. With MS treatment using superconducting magnet,

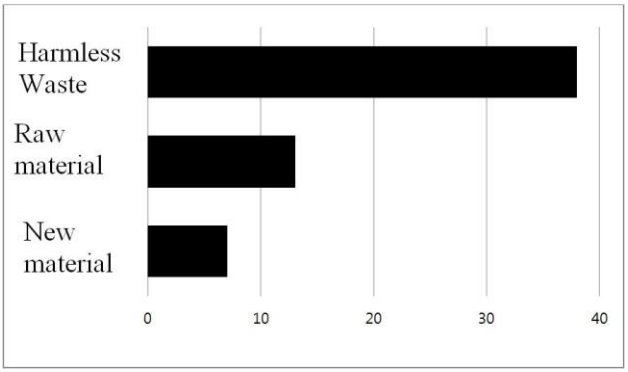

Fig. 4. The material processing of MS technology reported in 2011-2017 IFMFC.

TABLE 3
HARMLESS WASTE PRODUCTION

1. target water and eliminated substance
Industrial wastewater → Discharge water
(Iron oxide, Suspended matter, Heavy metal, Mercury,Dye)
Urban swage → Discharge water
(Organic compound, Non-biodegradable substance, Phosphorus, Nitrogen)
Livestock wastewater → Discharge water
(Lipid, Phosphorus, Nitrogen, Medicine)
Landfill water → Discharge water
(Organic compound, Non-biodegradable substance, Phosphorus, Nitrogen, Arsenic and others)
Lake and pond water → Lake and pond water
(Organic compound, Non-biodegradable substance, Phosphorus, Nitrogen, Microcystis, Chlorella)

2. target soil and eliminated substance
High level Cs soil → Low level Cs soil
(Cesium)

TABLE 4
RAW MATERIAL AND NEW MATERIAL PRODUCTION.

Plating waste	→ Ni compound
Silicon slurry	→ silicon powder
Alminum slurry	→ Alminum
Glass slurry	→ high quality glass
Kaolin Clay	→ pure Kaolin clay
Geothermal water	→ hot spring
Dam lake water	→ hydro power generation water
Boiler circulating Water	→ heat transfer water of thermal power generation

many materials have been produced as the raw and new materials. Table4 shows the cases of five solid materials and three liquid materials for new and raw materials. The solid material productions are aimed to reuse the valuable high quality ones in industries. The liquid material productions are useful for recuperation, energy souce and industrial water.

4. SUMMARY

As a result of the activities of IFMFC for 8 years, the development and application of magnetic force applied technology are increasingly required in East Asia to solve SDGs problems. IFMFC plays an increasingly important role as its driving force.

Finally I deeply thank for the cooperation of IFMFC Members.

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