pISSN 1229-3008 eISSN 2287-6251
Progress in Superconductivity and Cryogenics
Vol.26, No.3, (2024), pp.1~4 https://doi.org/10.9714/psac.2024.26.3.001

The review of IFMFC activities since 2011

Tsuneo Watanabe*

Tokyo Metropolitan University, Tokyo, Japan

(Received 23 May 2024; revised or reviewed 26 September 2024; accepted 27 September 2024)

Abstract

The usefulness of the magnetic force control technology has been recognized as MS (magnetic separation) technology in the fields of environment remediation and resource recovery. Especially the use of the superconducting magnet is expected to develop the application fields using MS technology. Since 2011, the researchers from China, Korea and Japan started and have been holding in every year the IFMFC (International Forum of Magnetic Force Control) to develop the application of the magnetic force control technology and exchange the experiences. Recently the United Nations is asking each country to contribute the global issues such as SDGs 2030 and carbon neutral 2050. This review reports the activities of IFMFC since 2011 as to the MS technology application.

Keywords: superconducting magnet, magnetic separation, environment remediation, material recycle, SDGs, carbon neutral

1. INTRODUCTION

Physical treatment techniques that utilize magnetic force have the characteristics of little change in substances before and after treatment, and few secondary products. It has been confirmed that this feature is useful for environmental remediation, and resource recovery. The MFC (magnetic force control) technology is good for realizing the sustainable society of Reduce, Reuse and Recycle.

In addition to permanent magnets and electromagnets, the use of superconducting magnets is expected to expand the application of magnetic force control technology. The Research Committee of the Institute of Electrical Engineers of Japan summarized the results of its research from 2006 to 2010 in the report "Current status and trends in precision magnetic force control application technology that utilizes the magnetic properties of materials [1]." This report has been used as a summer school textbook for magnetic separation with the aim of training the next generation of researchers and engineers who will utilize magnetic force. In addition, since 2011, the committee has been organizing the International Forum of Magnetic Force Control (IFMFC) for the purpose of international dissemination and information exchange of magnetic force utilization technology. The event has been held annually by executive committees from three countries (China, Korea and Japan). IFMFC activities up to 2016 were introduced in "The history of IFMFC: The accumulated knowledge and experience of the magnetic force control [2]." Over the next eight years, the United Nations resolutions of 2015 and 2018 ushered in an era in which the world was required to address global environmental quired to address global environmental issues such as SDGs 2030 and Carbon Neutral CN 2050. Furthermore, the improvements in various magnets and devised methods for utilizing magnetic force have developed the fields in which magnetic force can be used.

From these new situations, this paper reviews IFMFC's activities from 2011 to 2023.

2. THE ACTIVITY AND CONTRIBUTION TO SDGS 2030 OF IFMFC

Table Ⅰ shows the numbers of research and technology reports since 2011.

TABLE I
THE REVIEW OF IFMFC PRESENTATION.

Year	Place	Num.	CHN	JPN	KOR	BAN	FRA	JOR
2011	OSAKA	6	2	2	2	0	0	0
2012	BUSAN	9	1	5	3	0	0	0
2013	OSAKA	19	4	14	0	1	0	0
2014	BEIJING	10	5	5	0	0	0	0
2015	SEOUL	11	3	6	2	0	0	0
2016	KANAZAWA	9	3	4	2	0	0	0
2017	BEIJING	9	4	4	1	0	0	0
2018	BUSAN	14	3	8	3	0	0	0
2019	NARA	30	9	17	2	0	1	1
2020	ONLINE	17	1	15	1	0	0	0
2021	ONLINE	17	5	11	1	1	1	0
2022	ONLINE	17	2	12	2	1	0	0
2023	ONLINE	11	0	10	1	0	0	0
TOTAL		179	42	113	20	3	2	1

* Corresponding author: twtm@tmu.ac.jp

The executive committees take turns holding face-to-face meetings every year. The event has been held online as a precaution against the coronavirus since 2020. There were 179 presentations. The distribution of presentation fields is shown in Fig. 1. Many of the presentations were in the environmental remediation and resource recovery as shown Table II and Table III. There is also the development of devices and basic research related to MFC technology. These activities of IFMFC cover nine of the 17 goals of SDGs 2030 in Table IV [3]. The related presentations to carbon neutrality are also gradually increasing in recent five years [4]. As to the environment remediation, the almost target is wastewater and the few is the Cs contaminated soil. The wastewater treatment is wet-type processing and Cs soil treatment is dry-type processing. Table II shows the details. The material resource processing is shown in Table III. The almost is the wet-type processing due to the slurry and water contaminating the raw material. Considering these many application fields, the MFC technology is contributing to 8 goals of SDGs 2030.

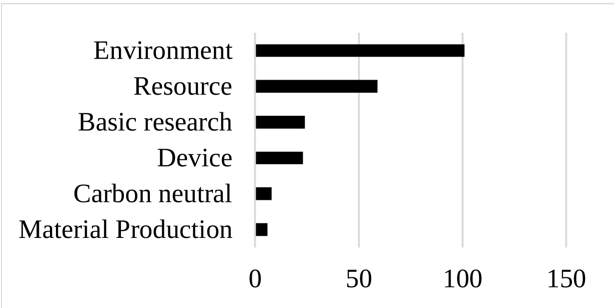

Fig. 1. The distribution of fields of the presentations.

TABLE II
WATER AND SOIL REMEDIATION WITH MS CONTRIBUTING SDGs (REMOVED SUBSTANTS)

Case 1 Recycle of Industrial wastewater: SDGs9 (Ion oxide matter, Heavy metal, Mercury, Dye)
Case 2 Urban swage treatment before disposal:SDGs6,14 (Organic compound, Nonbiodegradable substance, Nitrogen, Phosphorus)
Case 3 Hazmat removal of Livestock wasts:SDGs13,15 (Lopid, Phosphorus, Nitrogen, Medicine)
Case 4 Hazmat removal of Landfill water:SDGS11, 15 (Organic compound, Nonbiodegradable substance, Phosphorus, Nitrogen, Arsenic and others)
Case 5 Hazmat removal of Lake and pond water:SDGs7 (Organic compound, Nonbiodegradable substance, Phosphorus, Nitrogen, Microstics, Chlorella)
Case 6 Separation of Ce contaminated soil :SDGs9,15 (Vermiculite clay containing Ce clay)

TABLE III
RESOURCA RECOVERY WITH MS CONTRIBUTED SDGs AND CN (COLLECTED MATERIAL)

Plating waste	→Ni compound	:SDGS9,11
Silicon slurry	→silicon powder	:SDGS9,11
Aluminum slurry	→Aluminum	:SDGS9,11
Glass slurry	→high quality glass	:SDGS9,11
Kaolin Clay	→pure Kaolin clay	:SDGS9,11
Geothermal water	→hot spring	:SDGS12
Dam lake water	→hydro power generation water	SDGS7
Boiler circulating	→heat transfer water of thermal power generator	: SDGS13, CN

TABLE IV
THE SDGs GOALS CONTRIBUTED WITH MFC TECNOLOGY

1.NO POVERTY
2.ZERO HUNGER
3.GOOD HEALTH AND WELL BEING
4.QUALITY EDUCATION
5.GENDER EQUALITY
6.CLEAN WATER AND SANITATION
7.AFFORDABLE AND CLEAN ENERGY
8.DECENT WORK AND ECONOMIC GROWTH
9.INDUSTRY INNOVATION AND INFRASTRUCTER
10.REDUCED INEQUALITY
11.SUSTANABLE CITIES AND COMMUNITIES
12.RESPONSIBLE CONSUMPTION CONSTRUCTION
13. CLIMATE ACTION
14.LIFE BELOW WATER
15.LIFE ON LAND
16.PEACE JASTUS AND STRONG INSTITUTION
17.PARTNERSHIPS FOR THE GOALS

(shaded) The contributed areas with MFC technology

3. THE CORE MS TECNOLOGY AND TYPICAL MS SYSTEM

The core of the magnetic force control technology described so far is the MS (magnetic separation) technology. The magnetic force F_m is shown by (1) (2)

$$\mathbf{F_m} = \mathbf{V_p} \cdot \mathbf{M^*} \cdot \mu_o \nabla \mathbf{H} \quad [\mathbf{N}] \quad (1)$$

$$\mathbf{M^*} = M_p - M_f = \chi_{eff}\ \mathbf{H} \quad [A/m] \quad (2)$$

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

$\mathbf{F_m}$ the magnetic force
$\mathbf{V_p}$ the particle volume $\mathbf{M^*}$ the relative magnetization
μ_o the relative magnetization
χ_{eff} the effective susceptibility

Fig. 2 shows the parameters designing an MS system, and the relating useful technical processes and facility.

They are the volume V_p of the target substance to be separated, the magnetic susceptibility M*,the magnetic field gradient ∇H, and the magnetic field strength H. For the use of magnetic force F_m, various measures are taken

(parameter)		(relating technical process and facility)
$\mathbf{V_p}$	=>	(Magnetic) aggregation
M*	=>	Magnetic seeding, Magneto-Archimedes effect
∇H	=>	High gradient Magnetic field
H	=>	Magnet; Superconducting, High Tc, Permanent

Fig. 2. The key parameters and technical processes and facilities of MS technology

in actual device design. When the target material to be separated is fine, the magnetic aggregation is introduced for the purpose of increasing the volume V_P. Regarding the magnetic susceptibility M*, when the substance to be separated is increased by a magnetic seeding method, In the case of diamagnetic substances, separation is performed using the Magneto-Archimedes effect [5]. Also, in order to lower the magnetic field strength of the magnet, a magnetic filter is used to increase ∇H and obtain a high gradient magnetic field. In some cases, high H can be utilized by using superconducting magnets that generate magnetic fields with even higher magnetic field strengths. Superconducting magnets include coil magnets and high-temperature T_c bulk magnets. In the case of a coil-type magnet, a magnetic filter is used to increase the magnetic field gradient inside the coil, making it possible to achieve a high separation effect. In the case of high-temperature T_c bulk magnets, the magnetic force can be utilized in an open space, so there is a high degree of freedom in designing surrounding equipment.

Fig. 3 shows a guideline for the use of magnets for magnetic separation according to the magnetism of the object. For the paramagnetic material and diamagnetic material, the strong magnetic field is needed. For the ferromagnetic material, strong permanent magnet and electromagnet is useful. Table V shows the magnetic seeding methods for increasing the magnetic susceptibility of paramagnetic materials. The magnetic seeding device is installed before MS processing. The magnetite is the temporal seeding substances and designed in the recycle system. In almost cases, the target material is contaminated in slurry state. The pretreatment of the contaminant is very important for the effective magnetic seeding.

3.1. MS system for Environment remediation

Fig.4 shows the MS system for environmental remediation. The temporal MS system for environment remediation is superconducting magnet is used. And the permanent magnet is used to treatment of a small amount of wastewater or preliminary treatment for testing wastewater. The selection of magnetic seeding method is important for the efficiency of MS system.

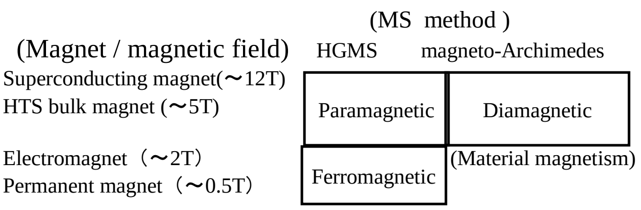

Fig. 3. The magnet selection map for magnetic separation due to the material magnetism

TABLE V
MAGNETIC SEEDING METHODS

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

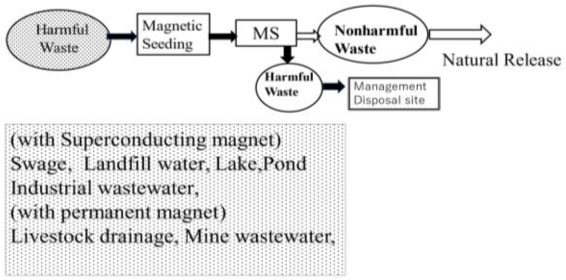

Fig.4 MS system for Environment remediation [6-11]

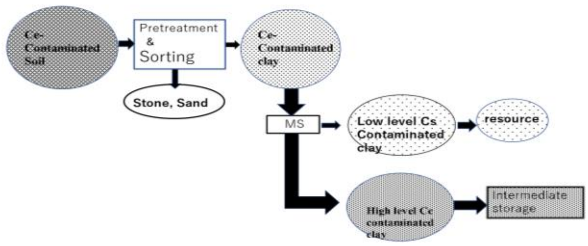

Fig. 5. MS system with superconducting magnet for decreasing contaminated high level contaminated Cs-soil volume [12-14].

3.2. High level Ce soil volume reduction

Fig.5 shows the MS system for high level contaminated Ce soil.The temporal MS system for environment remediation is superconducting magnet is used. And the permanent magnet is used. The Fukushima nuclear power plant accident developed. The wide area of Cs contaminated soil. The challenging MS technology was developed to reduce the high level Cs contaminating soil volume. The paramagnetic vermiculite soil combining with high level Cs ions is separated with superconducting MS system. After that, the high concentrated Cs contaminating soil is stored in the intermediate storage and the low level Cs contaminated soil are used as the resource.

3.3. MS system for separating resource

Fig.6 shows the MS system for material resource.The superconducting MS system is also developed to produce material resource. Recently the reuse and recycle of the materials in urban mine is very important for sustainable society. The MS system is developed in the wet and dry

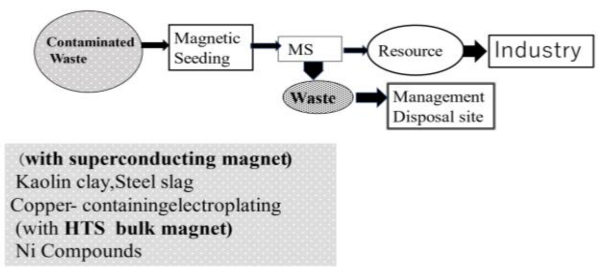

Fig. 6. MS system for material resource [15-18].

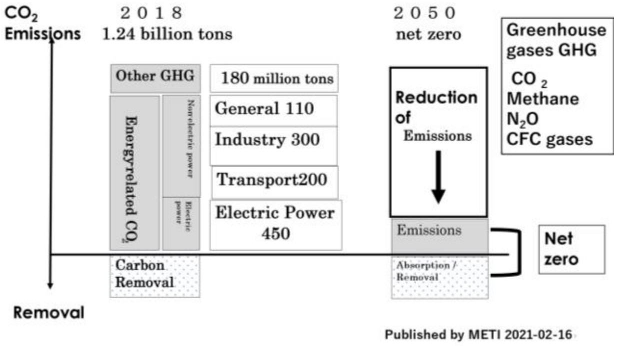

Fig. 7. The road map of Carbon neutral 2050 [20].

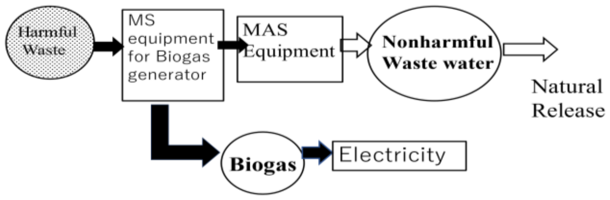

Fig. 8. The MS system for producing biomass energy and Wastewater treatment with MAS process [22].

types. In case of magnetic seeding with magnetite, the magnetite recycle system is the key parameter.

4. THE POSSIBILITY OF CONTRIBUTION TO CARBON NETRAL WITH MFC TECHNOLOGY

The MFC technology is the promising to realize Carbon neutral 2050. The METI (Ministry of Economy, Trade and Industry) presented the road map to the CO_2 net zero in Fig. 7. This road map requests the contribution to decrease the CO_2 emission in the field of energy production and use. This map also requests the change of Greenhouse gases to biomass fuels. This map shows the possibility of MFC technology usefulness. There are some reports as to CO_2 deduction in the fields of industry with IFMFC technology [21-22]. Fig.8 shows the promising MS system for producing biomass energy.

5. SUMMARY

As a review of the IFMFC activities since 2011, the development and application of magnetic force control technology are increasingly expected to solve the global SDGs and Carbon neutral problems. IFMFC plays an increasingly important role as its driving force. Finally I deeply thank for the cooperation of IFMFC members.

REFERENCES

[1] Investigating R&D Committee of the precise magnetic force control technology using magnetic characteristics of materials, "State and trends of the precise magnetic force control technology using magnetic characteristics of materials," *IEEJ Technical report*, 1198 July 2010

[2] T. Watanabe," The history of IFMFC: The accumulated knowledge and experience of the magnetic force control," *PSAC*, vol.18, No.1. 2016, pp6-9

[3] United Nations "Draft resolution referred to the United Nations summit for the adoption of the post-2015 development agenda by the General Assembly at its sixty-ninth session" Transforming our world: the 2030 Agenda for Sustainable Development, 18 Sept. 2015

[4] COP26 Glasgow Climate Pact 2021

[5] N. Hirota, Y. Ikezoe, H. Uetake, T. Kaihatsu, T. Takayama and K. Kitazawa "Magneto-Archimedes levitation and its application" *Riken Review*, vol.44, pp.159-161, Feb.2002

[6] T. Watanabe and I. Ihara, "The ecological and novel system of landfill water treatment" IFMFC SEOUL 2015 Abstract (unpublished)

[7] "Recent magnetic separation technology ~Environment remediation, material resource application~," *IEEJ Technical report*, 982 July2003, pp58-60

[8] H.-P. Hong, H.-W. Kwon, T.-C. Shin, D.-W. Ha and Y.-H. Kim, "Evaluation of Contamination for the Andong-dam Sediment and a Magnetic Separation for Reduction the Contamination Level," IFMFC BUSAN 2018 Abstract (unpublished)

[9] C. Mukuta and Y. Akiyama "Fundamental Study on Sustainable Treatment System of Mine Water," IFMFC BUSAN 2018 (unpublished)

[10] X.Shan. R. Huang, H. Liu, H. Zhang, F. Shen and Laifeng Li, "The Wastewater Treatment Apparatus Employing the Superconducting High-Gradient Magnetic Separation System," IFMFC ONLINE 2020 Abstract (unpublished)

[11] I. Ihara and T. Watanabe, "Human Wastewater Treatment by Superconducting Magnetic Separation Using a Bench Scale System," *J. Cryo. Super. Soc. Jpn*. Vol.55, No.3, 2020, pp195-199

[12] Sanitaria, "Application of Superconducting Magnetic Separation for Decontamination Soil in Fukushima," IFMFC BEIJING 2014 Abstract(unpublished)

[13] Y. Akiyama, S. Nishijima and Y. Ito, "Superconducting Magnetic Separation System for Volume Reduction and Recycle of Removed Soil," IFMFC BEIJING 2017 Abstract (unpublished)

[14] Y. Akiyama, N. Nomura, F. Mishima and S. Nishijima, "Possibility of Applying Superconducting High-gradient magnetic Separation to Volume Reduction of Cesium-contaminated Soil," *TEION KOGAKU*, vol. 55, No. 3, pp. 172-178, 2020

[15] Z. Zian, W. Meifen, N. Feipeng, Y. Huan, Z.Gouqing and L.Zhongxiu, " Progress of superconducting magnetic separation for kaolin," IFMFC SOUEL 2015 Abstract (unpublished)

[16] T.Oka, "Sepration for Recycling Ni Compounds from Processed Plating Waste with Use of HTS Bulk Magnet," 123 IFMFC KANAZAWA 2016 ABSTRACT (unpublished)

[17] T.Oka, "Resoure Recovery from Nickel-plating Waste Fluid Using Intense Magnetic Field of Superconducting Bulk Magnet," *J.Cryo. Super.Soc.Jpn*. vol.55, No.3, 2020, pp164-171

[18] T.-C. Shin, H.-W. Kwon, D.-W.Ha, Y.-H. Kim, "Recovery of Resources from Steel Slag by a Superconducting Magnetic Separation System," IFMFC KANAZAWA 2016, Abstract (unpublished)

[19] S. Li et al, "Study on Copper-Containing Electroplating Wastewater Treatment by Superconducting HGMS with Iron Containing Substrate," IFMFC BUSAN 2018, Abstract (unpublished)

[20] "Growth Strategy for Carbon Neutrality by 2050," METI, Feb. 2021

[21] I. Ihara "Energy Saving Potential for Cleaning-in-Place in Milk Processing: An Application of Highly Smooth Surface by Magnetic Abrasive Finishing" IFMFC ONLINE 2023 Abstract (unpublished)

[22] Y. NOMURA, Y. Sakai, T. Nikata, M. Roppongi and S.M.Lai, "Proposal of Combined Process Magnetic Methan Fermentation and MAS Process and Evaluation" IFMFC NARA 2019 Abstract (unpublished)