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# Superconductivity Web21

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# What's New in the World of Superconductivity

초전도 뉴스 –세계의 동향–

超导新闻 –世界的动向-

chāo dǎo xīnwén - shìjiè de dòngxiàng-

Yutaka Yamada, Principal Research Fellow
Superconductivity Research Laboratory, ISTEC


★ News sources and related areas in this issue

## ▸Wire 선 재료 线材料 [xiàn cáiliào]

### Commercialization of CuNb-Reinforced $Nb_3Sn$Wire

**Furukawa Electric Co., Ltd. (12 June, 2014)**

Furukawa Electric Co., Ltd. has delivered newly developed cables for the superconducting magnets. As part of the High Magnetic Field Collaboratory Plan progressed in collaboration with Tohoku University (Sendai, Miyagi Prefecture), Furukawa Electric has successfully developed the world's first CuNb reinforced $Nb_3Sn$ superconducting cable that can be wound after heat treatment for $Nb_3Sn$ generation. Such cables offer high critical magnetic field characteristics and are currently being employed for superconducting magnets that generate a strong magnetic field.

The newly developed cable can be wound in a magnet after heat treatment thereby simplifying the magnet manufacturing process and reducing costs. This cable will be used as a main component in the

 

Non-Refrigerated 25 T Superconducting Magnet, which is under construction at Tohoku University. Collaborating with Tohoku University in the High Magnetic Field Collaboratory Plan, Furukawa Electric has delivered mass produced products with lengths of 7.8 km to Toshiba Corporation in March of this year. The cable is also to be employed for the 30T magnet and 50 T hybrid magnet, which aim at generating stronger magnetic fields, ultimately offering great potential to existing consumer NMR applications by replacing $Nb_3Sn$ cables using conventional methods.

Source: "Successful commercialization of superconducting cables that are distortion resistant and that can be wound after heat treatment"
Furukawa Electric Press Release (12 June, 2014)
URL: http://www.furukawa.co.jp/english/what/2014/kenkai_140612.htm
Contact: http://www.furukawa.co.jp/english/inquiry/index.htm

## ►Medical Application 의료응용 医疗应用 [yīliáo yìngyòng]

### World's Highest Field 21 Tesla Magnet

**Bruker Corporation (16 June, 2014)**

Bruker Corporation and the National High Magnetic Field Laboratory (NHMFL) at Florida State University (FSU) announced the successful installation of the world's first 21 T magnet for Fourier Transform Ion Cyclotron Resonance (FT-ICR). This is the world's highest field superconducting magnet suitable for FT-ICR mass spectrometry, designed and built by Bruker in collaboration with NHMFL, which will be employed in the NHMFL FT-ICR program funded by the National Science Foundation. The magnet is anticipated to offer greater improvements in mass resolution, mass accuracy and dynamic range, with three primary science drivers; (a) faster throughput without loss of mass resolution for top-down proteomics; (b) extension in the size and complexity of protein complexes, and (c) improved mass resolution and dynamic range for characterizing compositionally complex organic mixtures (petroleum, dissolved organic matter, metabolome).
The *21T* magnet design includes a 110 mm room temperature horizontal bore. The design features were pioneered by Bruker, which include operation at ~2 Kelvin using Bruker's *UltraStabilized*™ sub-cooling technology and *UltraShield*™ technology design to reduce stray fields, as well as active magnet refrigeration technology that almost eliminates cryogen refills and reduces user maintenance of the magnet.

Professor Alan Marshall, the Robert O. Lawton Professor of Chemistry and Biochemistry at Florida State University and Director of the High Field FT-ICR program at the NHMFL stated: "We are delighted to report that the *21T* Bruker magnet is at full field. The other subsystems of the *21T* FT-ICR mass spectrometer have been designed and are currently being assembled and aimed for availability towards the early fall of 2014." He also added, "The higher magnetic field should result in dramatic improvement (by factors of 40-100 %) in FT-ICR MS figures of merit, including mass resolution and resolving power, mass accuracy, dynamic range and data acquisition speed."

Source: "World's Highest Field 21 Tesla Magnet for FT-ICR Mass Spectrometry Installed at National High

Magnetic Field Laboratory (NHMFL)"
BRUKER Press Release (16 June, 2014)
URL:
http://ir.bruker.com/investors/press-releases/press-release-details/2014/Worlds-Highest-Field-21-Tesla-Magnet-for-FT-ICR-Mass-Spectrometry-Installed-at-National-High-Magnetic-Field-Laboratory-NHMFL/default.aspx
Contact: Tony Lewtas tony.lewtas@bruker.com

## ▸ Magnet 자석 磁石 [císhí]

### World Record of 17.6 T

**University of Cambridge (27 June, 2014)**

A decade-old world record has been broken by a team led by University of Cambridge engineers, who have trapped a magnetic field with strength of 17.6 Tesla in a high temperature gadolinium barium copper oxide (GdBCO) superconductor. The results are published in the journal *Superconductor Science and Technology*. The new record was realized using 25 mm diameter samples of single grain GdBCO high temperature superconductors fabricated using a melt processing method. The previous record of 17.24 Tesla was set in 2003 by a team led by Professor Masato Murakami based at the Shibaura Institute of Technology in Japan, who employed a similar superconductor, but with different, composition and structure.

The large magnetic field was successfully contained with the copper and oxygen cuprates. In order to trap the magnetic field, the researchers altered both the microstructure of GdBCO to enhance its current carrying and thermal performance characteristics, and reinforced with a stainless steel ring. By engineering the bulk microstructure, the field is retained in the sample by flux pinning centers distributed throughout the material. Dr Yun-Hua Shi, who has been developing the melt process fabrication was quoted as saying, "the development of effective pinning sites in GdBCO has been key to this success."

The research reveals the potential of high-temperature superconductors for an array of applications, including flywheels for energy storage, magnetic separators for mineral refinement and pollution control, and in high-speed levitating trains. The Cambridge team and its collaborators are currently developing a number of niche applications, anticipating widespread commercial applications for superconductors within the next five years. The research was funded by The Boeing Company and by the UK Engineering and Physical Sciences Research Council (EPSRC). The National High Magnetic Field Laboratory performed the measurements, which was funded by National Science Foundation and the State of Florida.

Source: "Cambridge Team Breaks Superconductor World Record"
University of Cambridge Press Release (27 June, 2014)
URL: http://www.cam.ac.uk/research/news/cambridge-team-breaks-superconductor-world-record
Contact: communications@admin.cam.ac.uk

 

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## ►Basics 기초 基础[jīchǔ]

### Unlock Mystery of HTS

**Binghamton University (30 June, 2014)**

Michael Lawler, assistant professor of physics at Binghamton University and his colleagues have unlocked a key mystery surrounding high-temperature superconductivity. Their research is published in the *Proceedings of the National Academy of Sciences* and relates to a remarkable phenomenon in BSCCO copper-oxide (cuprate) high-temperature superconductors. A scanning tunneling microscope (STM) has been used to visualize the electronic structure of the oxygen sites within a superconductor. The team discovered a density wave with a d-orbital structure, which is considered extraordinary because the electron density in high temperature superconductors is isotropic whilst most density waves have an s-orbital structure.

Lawler as part of an international team of physicists, has quoted as saying, "Evidence has been accumulating that this mysterious pseudogap phase in the cuprate phase diagram supports an exotic density wave state that may be key to its existence." A density wave forms in a metal when the fluid electrons themselves crystalize. The research team now believes these density waves exist in all cuprates.

Source: "Study helps unlock mystery of high-temp superconductors"
Binghamton University Press Release (30 June, 2014)
URL: http://www.binghamton.edu/mpr/contact-us.html
Contact: Ryan Yarosh ryarosh@binghamton.edu

## ►Management and Finance 경영정보 经营信息[jīngyíng xìnxī]

### AMSC: 2013 Financial Results and Business Outlook

**AMSC (5 June, 2014)**

AMSC reported financial results for its fourth quarter and full year 2013 ended March 31, 2014. Revenues for the fourth quarter of 2013 were $16.3 million, compared with $20.4 million for the same period of 2012. The decrease in revenues was a result of lower revenues in the company's grid segment. AMSC's net loss for the fourth quarter of 2013 increased to $22.7 million, from $19.8 million, for the same period of 2012, and was due to restructuring and impairment charges, as well as a non-cash charge for a loss on extinguishment of debt associated with the final conversion of the Company's outstanding convertible note. Revenues for 2013 were $84.1 million as compared to $87.4 million in 2012. Wind revenue grew by 26% in 2013 compared with 2012, but this growth was offset by lower grid revenue.

For the first quarter ending June 30, 2014, AMSC expects that its revenues will be around $11 to $13 million. Revenues are expected to be lower in the Company's Wind segment due to temporary manufacturing issues at one of their customers. The Company's net loss for the first quarter of 2014 is expected to be less than $16 million. For the full fiscal year 2014, company's revenue is expected to fall slightly compared to

2013.

Source: "AMSC Reports Fourth Quarter 2013 Financial Results and Provides Business Outlook"
AMSC Press Release (June 5, 2014)
URL: http://ir.amsc.com/releasedetail.cfm?ReleaseID=852658
Contact: Kerry Farrell kerry.farrell @ amsc.com

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# Feature Article: Applications of Superconducting Magnetic Separation - Publication of Feature Articles on Magnetic Separation

Shigehiro Nishijima, Professor
Department of Sustainable Energy and Environmental Engineering
Graduate School of Engineering, Osaka University

Magnetic separation is a process whereby particles are divided by exploiting differences in the magnetic force acting on them [1),2)], and is an established methodology conventionally applied for mineral separation (separation of large-sized ferromagnetic particles). In those days, the magnetic separation involved separating target materials by only using the gradient magnetic field derived of magnet itself, the so-called open gradient magnetic separation (OGMS) method. Later, a high gradient magnetic separation (HGMS) was developed [3)], able to generate higher gradient magnetic fields by using a ferromagnetic wire installed within a magnetic field thereby offering greater magnetic forces. This method led to the realization of finer particle separation, which had previously been impossible using conventional methodology. Practical applications that have been established include kaolin clay refining used by the paper industry, which require large volumes and high-speed processing and industrial wastewater purification vital for steel manufacturers. Advancements in superconductors as potential sources of magnetic field generation have led to the development of a superconducting high gradient magnetic separation method. Research activities in this field have focused on developing an array of applications that include the recovery of valuable paramagnetic materials [4)]. Whilst magnetic separation drives performance to capture and separate target materials, in recent years the discovery of the "magneto-Archimedes levitation" effect has led to magnetically levitate and separate materials in a working medium that surrounds the target [5)]. Feasibility studies involving this method are underway to separate the paramagnetic and diamagnetic materials, which exhibit feeble magnetic susceptibilities. Magnetic separation technologies exploiting magnetic force can be therefore divided into three methods, namely: OGMS, HGMS, and magneto-Archimedes. Figure 1 shows the array of application afforded by each methodology (SI units of susceptibility). Prior to magnetic separation the diamagnetic and paramagnetic materials undergo a magnetic seeding process, which physically and chemically attaches ferromagnetic particles. This allows the system to separate those weakly magnetic materials even in low fields, enabling high-speed/large volume processing once the parameters have been appropriately set. Moreover, magnetic separation makes it possible to separate ionic crystal materials. Combining the three magnetic separation methods and preprocessing technology, one can separate a variety of materials selectively owing to differences in their degrees of magnetic susceptibility. Table 1 summarizes the articles published in this feature article.

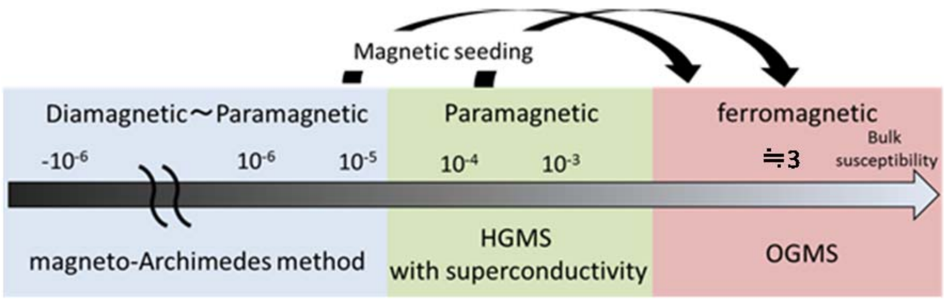


Fig. 1 Array of applications employing magnetic separation methodologies

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Table 1 Technologies highlighted in this feature article

| Applications | Persistent substances | Sewage treatment | Nickel recovery | Protein crystallization | MDDS |
|---|---|---|---|---|---|
| Magnetic seeding | Magnetic activated carbon | $Fe_3O_4$ | Crystallization | | $Fe_3O_4$ |
| | Magnetic zeolite | | | Simulation | |
| Magnetic field generation source | Superconducting magnet | Permanent magnet | Bulk superconducting magnet | Superconducting magnet | Bulk superconducting magnet |
| Author | Miura | Sakai | Oka*Fukui | Okada | Mishima |

This feature article introduces examples of magnetic seeding applied to water treatment technology; one utilizing magnetic adsorbent and the other utilizing a magnetic activated sludge process. Whilst the former is a recovering system operating by adsorbing pollutants in wastewater, the latter is a biofiltration process involving the addition of ferromagnetic seeding to activated sludge (microorganism), producing enhanced sludge recycling due to the employment of a magnetic force. Both case examples employ the same magnetic seeding technology, however the separation mechanisms differ. Since both systems exploit ferromagnetic particles as part of the magnetic seeding process system architectures utilizing either low-field permanent magnets or electromagnets can be employed. A superconducting magnet is however required in order to realize greater processing speeds and larger volumes. Recovery of nickel from plating waste fluid can also be conducted by magnetic separation after the nickel ions are crystalized in preprocessing. Here, a bulk superconductor magnet is employed as a source of magnetic field generation because of the small magnetic susceptibilities involved.

The magnetic separation system has been designed using prior calculations, taking into account the magnetic force required for separation and was based upon options of the type and the scale of the magnetic field generation source as well as the separation methodology to be applied. An example of the calculations performed is highlighted in an article entitled “Magnetic separation simulation technology and its progress”.

Although it may not be strictly categorized as ‘magnetic separation’, magnetic drug delivery systems (MDDS) are also introduced in this feature article as one of the so-called “magnetic force control technologies”. With fundamental principles similar to magnetic separation, a magnetic force is exploited to steer the motion (location) of the separating target in the small regions of a body. The technology brought about by this field offers further potential applications for magnetic separation. As an example process, the author deems that it will be possible to realize precise separation corresponding to their magnetic susceptibilities.

For further details, please refer to the following articles.

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# Feature Article: Applications of Superconducting Magnetic Separation - Magnetic Drug Delivery System

Fumihito Mishima
Division of Sustainable Energy and Environmental Engineering,
Graduate School of Engineering, Osaka University

Research and development aimed at overcoming the potential side effects and deteriorating efficacy of drug treatments have been undertaken by employing a drug delivery system (DDS), which can navigate and accumulate the drugs at a local diseased part inside the body. The majority of conventional DDSs methodologies have utilized the chemical or biological functional characteristics of the drugs, but this has been problematic in effective local drug accumulation undertakings. Here, the focus is drawn to a magnetic drug delivery system (Magnetic DDS, hitherto MDDS), which employs magnetic forces of the magnetic field that are generated outside of the body. For the research undertaken until now, the author and his research group have demonstrated that it is possible to boost drug concentrations at a locally diseased area [1)-2)]. The methodology involved applying a magnetic seeded drug into the network of blood vessels and then navigating this drug to the intended direction using a magnetic force at a branching point. This specific magnetic separation methodology is typically employed when capturing ferromagnetic and paramagnetic materials and selectively separating them at the targeted site by controlling the magnetic field strength. The demonstration conducted here proved as an example application of this method for a small region like blood vessels in the human body. With further enhancements in the precision afforded by magnetic force control technology aimed in the present study of MDDS, the author plans to navigate and accumulate magnetic seeded drugs locally at a diseased area deep in the human body. The prospective developmental progress afforded by these magnetic force control technologies has the potential to bring about new and novel industrial-scale magnetic separation applications. This article introduces the magnetic force controlling method.

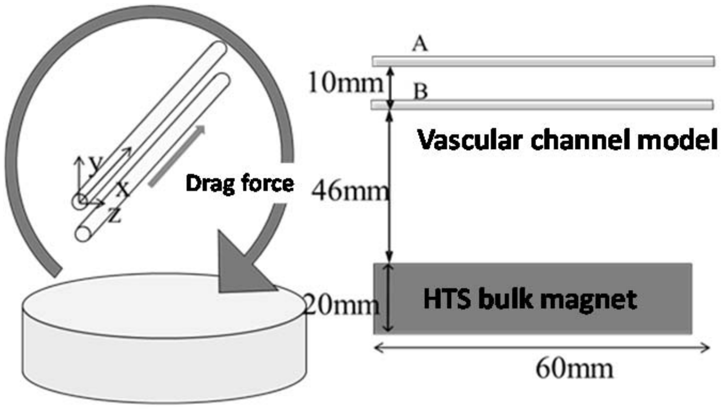

Fig. 1 Conceptual diagram of MDDS with a rotating magnetic field

The exploitation of high magnetic fields and steep field gradients enables ferromagnetic materials to be attracted from a distance. Applying a magnetic field from only one direction outside the body however accumulates ferromagnetic seeded drugs towards the body surface, making it ineffective when the deceased parts are located deep within the human body. To overcome this issue, the author and his group have proposed a MDDS method equipped with a rotating magnetic field [3)]. As shown in Figure 1, a rotating magnetic field centered on the targeted site allows for the magnetic seeded drug to accumulate only where it is required, thereby preventing the drug invading other parts of the body. With the targeted site being set within a 10mm-diameter deep in the body, an analytical study of magnetic particle

 

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accumulations was undertaken using particle trajectory simulations. Based upon the experimental simulation data the strength of magnetic fields and rotational frequencies were determined. Actual accumulation experiments conducted using rotating magnetic fields and a model system of blood vessel have been performed. The experiment data verified the potential application of magnetic field control to navigate and accumulate drugs locally from a distance to the targeted site.

The simulation involved simulated blood flows into two vascular channel models (model A, B), and a HTS bulk magnet (surface flux density 4 T, 60 mm-diameter, 20 mm-thickness) as the external magnetic field. The distance between the center rotation axis and the magnet was set at 50mm, whilst the distance between the internal tubes was set at 22 mm. The magnetic flux density was around 0.34 T at the center rotation axis where model A tube was located. The magnetite suspension was adjusted in order to allow for 0.2 g/L of magnetite in 50nm-particle diameter. A metering liquid feeding pump was utilized for simulated blood into vascular channel models at a flow rate of 3mm-sec. During the simulation studies vascular channel models were rotated at 4 rpm. The accumulation data is shown in Figure 2.

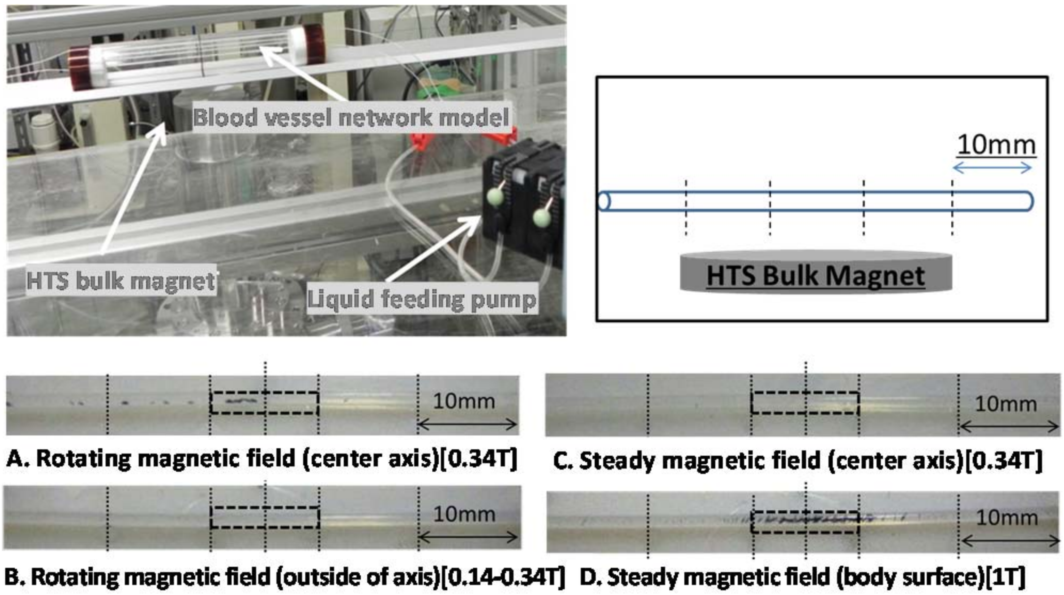


Fig. 2 Experiment of MDDS with a rotating magnetic field along with the accumulated drug data obtained from simulated blood vessels

The results were mostly comparable to the accumulation data undertaken at the body surface area (1 T) by MDDS without rotation. However, when magnetic field rotation was utilized the results demonstrated that magnetic seeded drug was accumulated in the region ±5 mm from central axis of the tube located on the rotation axis. Furthermore, magnetic field rotation confirmed that effective drug accumulation occurred even in low magnetic field gradients regions (on the center axis) and typically where it was previously problematic to attain drug accumulation using a steady magnetic field.

The magnetic control method alluded to here is not limited to only MDDS applications, but can also be applicable to conventional magnetic separation technology, promising greater separation selectivity and

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separation efficiency. Magnetic separation (magnetic force control method) is anticipated to deliver further new developments in the future.

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1) Investigations on the magnet location for magnetically targeted drug delivery systems - Magnet location close to the branching point and its efficiency -Fumihito Mishima, Suketaka Fujimoto, Shin-ichi Takeda, Yoshinobu Izumi, Shigehiro Nishijima, Cyogenics and Superconductivity Society of Japan
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# Feature Article: Applications of Superconducting Magnetic Separation - Magnetic Separation Simulation Technology and its Progress

Hidehiko Okada
Fine Particles Engineering Group
National Institute for Materials Science

The development of simulation technology applicable to high gradient magnetic separation, which is widely employed as a separation process utilizing a high magnetic force is introduced herewith. Magnetic separation is applicable in waste treatment processes and differs from other filtration methods. The characteristics of the magnetic separation process include its applicability in extreme environments such as high temperatures, high pressures, strong acidic and alkali conditions as well as being operable in radioactive environments. As shown in Figure 1, a ferromagnetic wire (the majority of systems employ SUS430 wire netting) situated in the same extreme environment as the target materials is responsible for capturing the materials, whilst the main system comprising of the magnet can be located external to the environment. Despite their versatilities, development of magnetic separation systems and replicating the experiments in the hostile environments prove challenging. Thus, a combination of simulations and experiments facilitates an effective route of system development allowing separation capabilities, parameters and designs to be optimized.

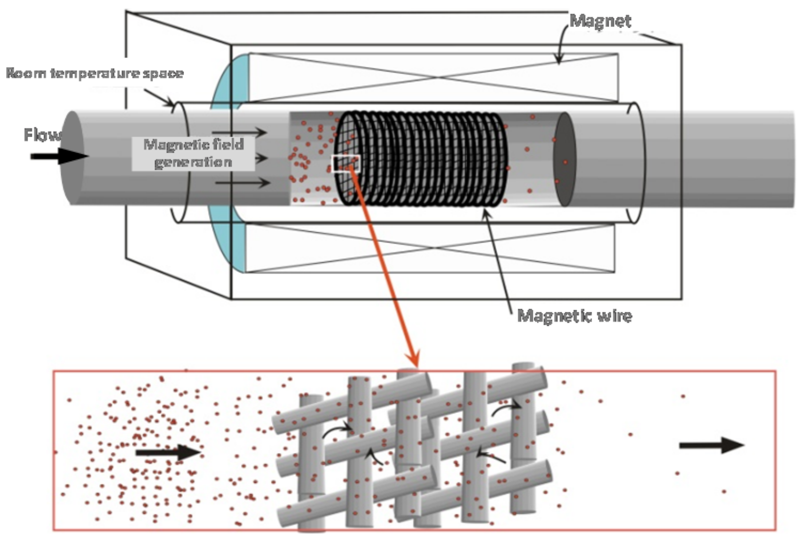


Fig. 1 Conceptual diagram of high-gradient magnetic separation

A method to simulate the motion of fine particles in a fluid experiencing an external magnetic force involves invoking the Navier-Stokes and diffusion equations as part of the simulations and is presented here. Figure 2 is an example calculation of the particle density distribution around a ferromagnetic wire. This method calculates the magnetic force of the wire surroundings, flow distributions and motions along with the distribution of particles. Since actual experiments cannot observe such fine details, simulation studies

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therefore realizes an optimized system design, including individual wire locations as well as operational parameters.

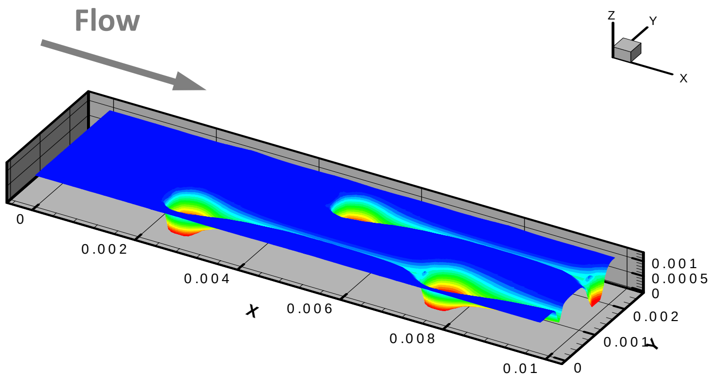


Fig. 2 Simulation of particle density distribution surrounding the ferromagnetic wire

Recent years has seen a growing trend towards developing technology to suppress convection utilizing a magnetic force. Drug R&D requires high quality crystals to analyze protein integrity. Crystallization trials have been performed in a microgravity environment in order to suppress fluid convection. A reduced-gravity environment on the ground was proposed, where the magnetic forces compensate for gravity and suppress the convection of fluids. Although crystallization trials have been also undertaken, it remains difficult to observe convection during the actual crystallization process and therefore no investigations have yet been performed. Figure 3 shows a magnetic separation simulation used to visualize the motion of a protein solution in a vessel positioned where the gravity was suppressed using a superconducting magnet. The simulation results confirmed that convection was suppressed by around 1/10 compared to that without the application of a magnetic force. The utilization of this simulation has enabled the convection mechanism to be visualized, including the conditions that suppress convection, thereby proving the simulation effectiveness for experimental set-up conditions.

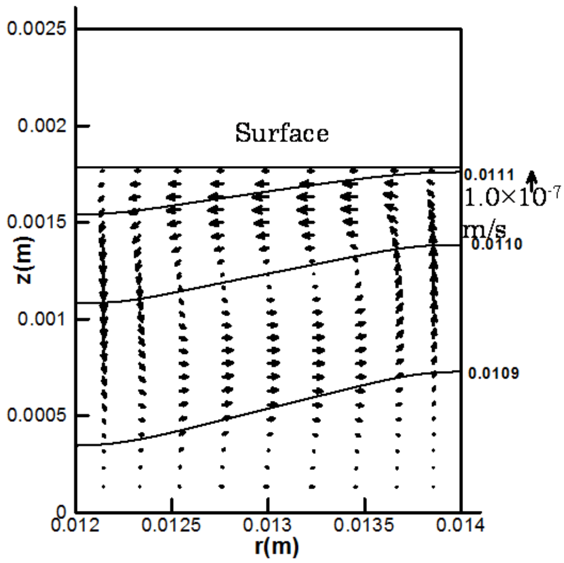


Fig. 3 Simulation of convection under magnetic force. The contour shows the concentration.

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The magnetic force is considered as force acting at a distance. It shows the effectiveness in fully isolated environment from external factors, which would otherwise make it difficult to observe the phenomenon. Further progress in R&D utilizing the simulation in this field is highly anticipated.

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# Feature Article: Applications of Superconducting Magnetic Separation - Magnetic Activated Sludge Process – Biological Wastewater Purification Process using Magnetic Separation, without the Need for Sedimentation and Membranes

Yasuzo Sakai
Department of Materials and Environmental Chemistry
Graduate School of Engineering, Utsunomiya University

**<About Magnetic Activated Sludge Process>**

The conventional activated sludge process is a superior wastewater treatment, however, that has two fundamental issues; (1) the difficulty in maintenance of a good settleability of activated sludge for sedimentation and (2) excess sludge production by bacteria growth as secondary environmental loading. The author and his research group have aimed their study towards enhancing the conventional activated sludge process by introduction of magnetic separation. Since the activated sludge is microorganism floc mainly consisting of flocculant bacteria, magnetic separation is not effective. However, the addition of magnetite to the microorganism floc enable magnetic separation because the floc strongly adsorbs magnetite. Furthermore, even though the bacteria generation are changing continuously, magnetite are used repeatedly because magnetite are adsorbed to new generation of microbe by physical interaction.

Issue (1) can be resolved by magnetic separation, which can separate target materials regardless of the settleability of bacteria. Regarding issue (2), under certain nutrient (organic pollutants) loading conditions, the growth and decay rate of bacteria can be balanced by keeping high concentration of activated sludge in the reactor. Apparently, the balanced biomasses were preserved without cell growth, thereby resolving issue (2). This new wastewater treatment called, “magnetic activated sludge process” has drawn attention in not only Japan but has amassed interest overseas being featured in Nature News [1) ] and Chemical Engineering News [2)]. The magnetic activated sludge process is still in the middle of development, but has the potential to be an essential technology for wastewater treatment in the future once the process is realized for practical use. Magnetic separation utilizing a permanent magnet offers superior performance attributes for small and mid-scale treatment plants. However, it is anticipated that superconducting magnets will be superior for large-scale plants exceeding several-thousand $m^3$ capacity per day, since permanent magnets employed for magnetic separation require large amounts of rare earths. The development of a superconducting magnetic separation system that can realize a continuous treatment of sewage is now highly anticipated.

**<Recent R&D trends >**

Recent R&D efforts have been focused towards realizing small and mid-scale treatment plant applications as well as by expanding research footprints by their standardization and the spread of systems specifically designed for research activities.

(a) Pilot-scale research demonstration at the municipal sewage treatment plant in Utsunomiya City.

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A pilot plant has been developed at the municipal sewage treatment plant in Utsunomiya City (Tank depth 4m, capacity 8 $m^3$). A magnetic separation system specifically designed for small and mid-scale wastewater treatment applications is now in development. Based upon a commercial system (max flux density 0.5 T), optimization is now underway (Figure 1). The development of superconducting magnetic separation system for large-scale plant is anticipated.

(b) Application to farm wastewater by magnetic activated sludge process
The feasibility of utilizing actual wastewater has been undertaken in farms belonging to the university and other farms located in Tochigi Prefecture. Demonstration trials proved in reducing the processing time to less than half. Additionally, it was possible to recover nitrogen and phosphorus. Collaboration with a company is now ongoing towards the realization for practical use.

(c) Application to industrial wastewater by magnetic activated sludge process.
A pilot plant has been constructed in a developing country in Asia, and the feasibility of industrial wastewater treatment is now being investigated [3)]. Also, a feasibility study of the practical magnetic activated sludge process targeted for wastewater from food industry is now underway in collaboration with a water treatment company.

(d) Standardization and spread of an experimental magnetic activated sludge process
In order to easily adopt a new treatment process utilizing magnetic activated sludge process and magnetic separation, a standard magnetic activated sludge process experimental system (Figure 2) has been developed. Rental of this system has begun to cultivate the footprints of magnetic separation research.

Fig. 1 Drum-type magnetic separation system installed at pilot plant

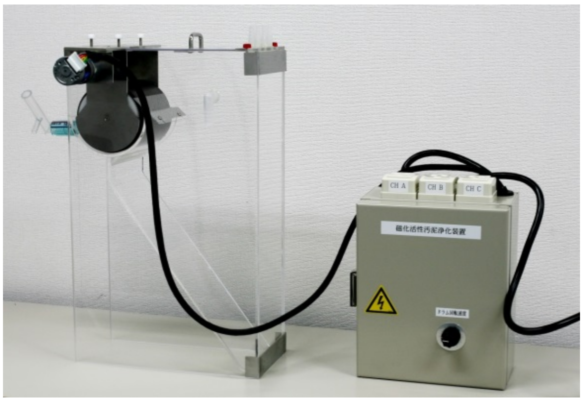

Fig. 2 5L-class standard magnetic activated sludge process system

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# Feature Article: Applications of Superconducting Magnetic Separation - Investigations of Advanced Water Purification System combining Magnetic Adsorbents and High-gradient Superconducting Magnetic Separation

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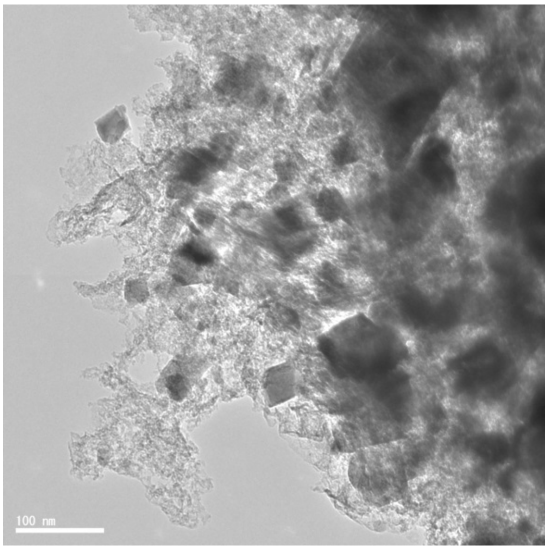


TEM image of the magnetic activated carbon

Recent years has seen increased concerns regarding the effects of persistent organic matter (mainly humic acid) affecting water quality in rivers, lakes, and bays. This organic matter is a precursor of trihalomethane, a carcinogenic, which significantly impacts supplies of drinking water. The government bureau of waterworks currently undertakes the removal of persistent organic matter and ammonia nitrogen from raw water by utilizing advanced water purification processes involving the combination of ozone treatment and biologically activated carbon. However, the removal rates of trihalomethane precursors still remains at around 60 % [1)]. Additionally other issues need to be taken into account such as the high-energy consumption for ozone generation and the sludge treatment necessary for the secondary waste from used activated carbon. In order to address these overall concerns, the author and his research group have proposed a new advanced water purification system that combines magnetic adsorbents and high gradient superconducting magnetic separation. The utilization of this new system promises the realization of water purification at high speeds and at large volumes, undertaken within a small footprint and moreover offers zero-emission water treatment without secondary wastes.

Three magnetic adsorbents developed include magnetic mesoporous activated carbon (MMPC), oxidized magnetic activated carbon (Ox-MAC), and magnetic zeolite (MZL) synthesized from coal fly ash. These magnetic adsorbents offer variable magnetic and absorptivity characteristics according to the removal targets. MMPC is made from activated carbon, which exhibits effective humic acid adsorption characteristics. The fabrication method involves a coconut shell activated carbon being immersed into an iron nitrate solution and impregnated. Then, gas heat treatment follows. Via these processes, the iron nitrate impregnated into the activated carbon forms the mesopores and magnetite on the surface that are effective in adsorbing humic acid. The magnetization of the magnetite increases with an increase in the iron nitrate concentration, exhibiting 30.7 emu/g max. Ox-MAC is also made from activated carbon and is effective in adsorbing ammonia nitrogen. Activated carbon is prepared by immersing into high-density/high-temperature nitric acid for a long period of hours to attach acid functionalities on the surface to enable ammonia nitrogen adsorption. For magnetic seeding, nanosize magnetites prepared by the coprecipitation method were physically adsorbed into the mesopores of the activated carbon. It was determined that the magnetization increases with an increase in the precipitation time of the magnetite, exhibiting 0.99 emu/g at max. MZL is another magnetic adsorbent with effective ammonia nitrogen adsorption properties, with magnetically seeded zeolite. The functional composites were prepared by combining ferric chloride and coal fly ash (raw materials of zeolite), adding sodium hydroxide for the reaction, resulting in the formation of MZL, a form of magnetite particle wrapped up by zeolite. Via these processes, magnetic zeolite has magnetic characteristics exhibiting a max of 35.2 emu/g.

Evaluating the adsorption properties of the fabricated magnetic adsorbents involved a simple magnetic separation process employing a 0.5 T permanent magnet, after adding the magnetic absorbents into the solution where the removal target materials were contained. The residual concentration of target materials in the solution was then measured by a spectrophotometer (humic acid measured as it is, ammonia nitrogen measured by the indophenol method) to verify the removal performance characteristics. The research undertaken here verified how the target material removal ratio varied with the amount of adsorbents and the mixing (reactivation) time, by modifying these as experimental parameters.

Figures 1 and 2 shows the removal performance results of magnetic separation utilizing MMPC that was stirred into a humic acid solution with a concentration of 74 mg/L. The findings concluded that by utilizing 5000 mg/L MMPC the quantity of humic acid absorbed became saturated within 20 minutes, realizing a maximum humic acid removal of 92.3 %. Heating the used adsorbent at 335 °C for 15 hours successfully recovered 81.8 % of adsorbing performance attributes. Figures 3 and 4 shows the removal performance results of Ox-MAC and MZL to an ammonia nitrogen solution with a concentration of 0.8mg/L. The adsorption time was short, a typical time specified in chemical absorption characteristics, achieving removal rates of 74.9 % and 88.7 % for Ox-MAC with an input volume of 2000 mg/L and MZL with an input volume of 1000 mg/L, respectively. Whilst a 12-hour heating of Ox/MAC at 120 °C recovered 91 % of adsorption performance characteristics, MZL mixed into a sodium chloride solution for 12 hours recovered 88 % of adsorption performance owing to Na ion exchanges.

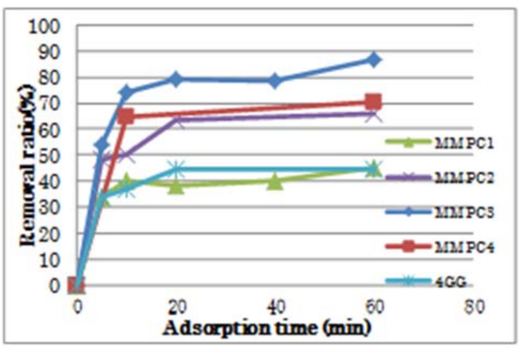


Fig. 1 Humic acid removal ratio as a function of adsorption time of MMPC

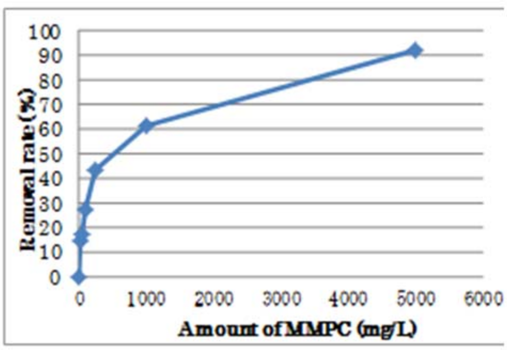


Fig. 2 Humic acid removal ratio as a function of the amount of MMPC

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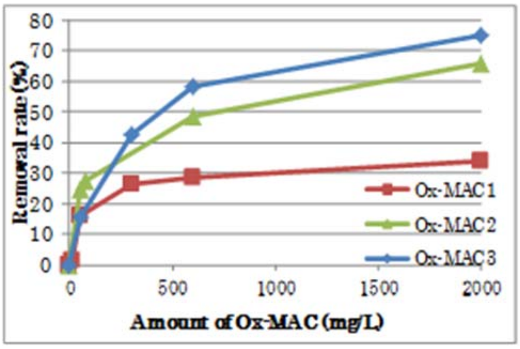


Fig. 3 Ammonia nitrogen removal ratio as a function of the amount of Ox-MAC

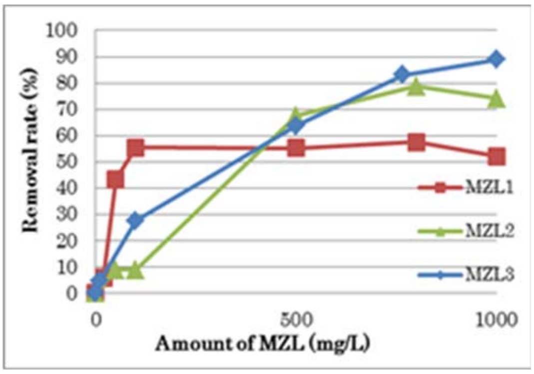


Fig. 4 Ammonia nitrogen removal ratio as a function of the amount of MZL

Lastly, in order to investigate the magnetic separation capabilities, magnetic adsorbent was magnetically separated from the solution utilizing a superconducting magnet. The experiment involved feeding a 10 L solution with MMPC with a concentration of 50 mg/L at a flow speed of 1 m/s into a 2 T superconducting magnet loaded with a filter made up of fine magnetic wires. The amount of MMPC leakage in the sample solution was collected by magnetic separation utilizing a superconducting magnet and measured by a high-resolution electronic balance. The results shown in Figure 5 confirmed the magnetic separation of MMPC, which exhibited a magnetization of 16.7 emu/g, successfully undertaken without any leakage. The experimental results were mostly in agreement with the simulation results.

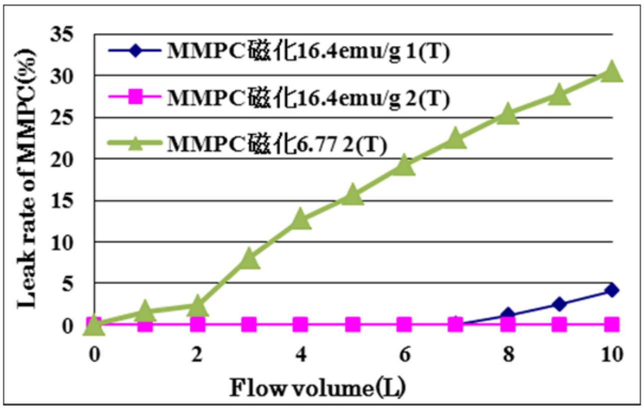


Fig. 5 Magnetic separation experiment results of MMPC

The author believes that the combination of a high gradient magnetic separating system and magnetic absorbents therefore have high potential to advanced water treatment plant in the near future.

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# Feature Article: Applications of Superconducting Magnetic Separation - Magnetic Separation of Nickel from Electroless Plating Waste Fluid

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Surface coating technologies widely used by the automobile and electronics industries include electro-less nickel plating. The process utilizes hypophosphorous acid, which reacts with nickel ions in a plating solution to deposit the metal. This produces a homogeneous coating with superior wear and corrosion resistance characteristics, and can be used to coat complex shapes by only immersing them into the plating solution. The increase in phosphite ions during the plating reaction can be a cause of defects, introducing deposition anomalies onto products. Therefore, the plating solution has to be frequently renewed and disposed together with all the remaining nickel ions left in the solution. This practice places an environmental burden and leads to additional processing costs for their disposal. The current disposal process of nickel as rare metal in particular requires further enhancement from an environmental viewpoint.

Figure 1 shows an example of nickel recycling from waste fluid emerging from a plating process. Crystalized nickel phosphate is yielded during the plating reaction by controlling heating and pH, and the phosphorus is separated from the waste liquid. Nickel sulfate crystals form following the reaction with sulfuric acid and are the main raw materials required for refilling in the plating bath. If this material is generated continuously it becomes extremely viable for the effective utilization of the raw materials and increasing longevity of the plating solution. Nickel sulfate crystals are yielded from the nickel dissolving at supersaturation, at a temperature ranging from 40-60 °C [1]. However, this recycling process has not been conventionally utilized since yielding the nickel sulfate is unstable and takes many hours. Here, employing magnetic separation combined with this recycling process makes possible separating nickel sulfate and nickel phosphate crystals via disparities in their magnetic susceptibilities. To generate high magnetic field characteristics necessary, a high-temperature superconducting bulk magnet is employed with having a compact 3 T-class flux density architecture. The bulk magnet is cooled to 30 K by using a compact refrigerator and is excited by a pulsed or steady magnetic field, allowing it to be used as a quasi-permanent magnet.

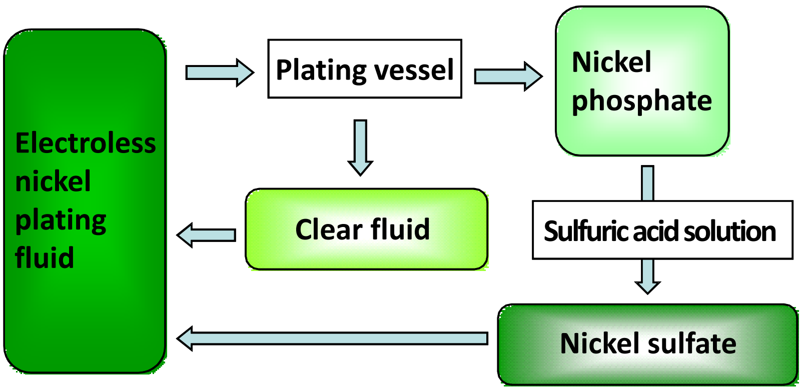


Fig. 1 The nickel recycling process showing the generation of the nickel phosphate and nickel sulfate compounds

 

Figure 2 shows the adsorption of nickel sulfate crystals being navigated from the processing solution to a magnetic pole during the crystallization. The susceptibility of nickel sulfate crystal is small at $3.33x10^{-4}$. Although this is almost equivalent to paramagnetic aluminum, the magnetic force generated in nickel sulfate can be twice as higher as nickel phosphate [2], leading to the anticipation of effective separation utilizing a high magnetic field. As shown in Figure 3, the crystals separated from the processing solution utilizing a 2T-class magnetic pole has a significantly reduced phosphorus concentration ratio compared with the numbers of sulfate ions in the crystal. This therefore proves the preferential magnetic separation for nickel sulfate crystals [3]. The author considers that further enhancement of crystal purity as well as optimization over the space of magnetic fields will lead to a verification of above-mentioned industrial benefit.

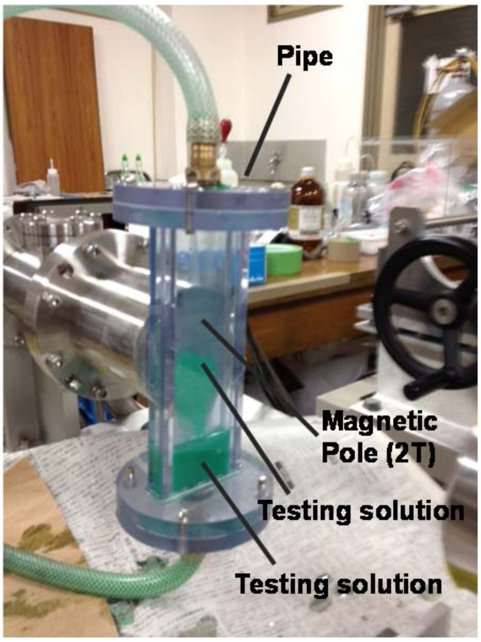


Fig. 2 Magnetic Separation Testing

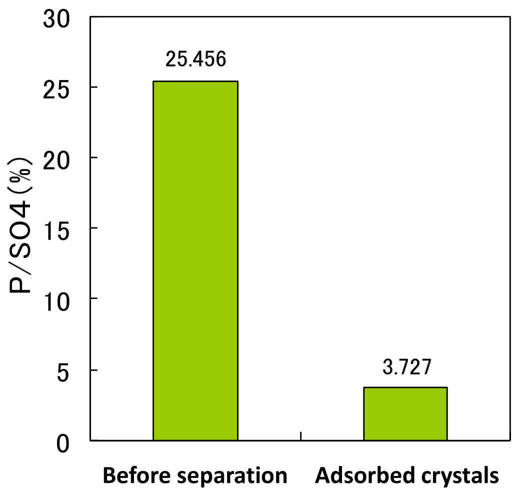


Fig. 3 Concentration ratios of separated crystals

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