Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

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Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

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02. Superconducting magnetic separation technology

03. Magnetic seeds

04. Sludge

05. Cooperation with industrial factories
Global climate has become warmer since the late 19th century and this is most likely to be caused by anthropogenic activity.
Most of the observed increase in global average temperature is likely to be caused by the increase in **greenhouse gas** concentrations found in the atmosphere.

- *carbon dioxide*
- *methane*
- *nitrous oxide*

The accumulation of emitted greenhouse gases now threatens not only human beings but also entire ecosystems on the earth.
The issue of **carbon emission reductions** has drawn worldwide attention.

At the “Earth Summit” in Rio de Janeiro in 1992, 189 countries including USA, China, India and all European countries signed on to the UNFCCC, and agreed to stabilize greenhouse gas emissions **at a low enough level** to prevent dangerous anthropogenic interference with the climate system.
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

In 1997
Kyoto, Japan, Kyoto Protocol

In 2009
Copenhagen, Denmark

In 2015
Paris, France
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

In China

With the development of economy, almost everything have a great improvement except the environment.
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Compare to any country in the world:

China is the country that most demanding New Tech to reduce CO$_2$ emission
China is reported to have one of the largest total potential emissions.

In 2007, the rapid economic and industrial development of China enabled the country to surpass the United States as the largest emitter of greenhouse gases in the world.

Faced with this situation, the Chinese government has committed to cut the carbon dioxide emission per unit of gross domestic product by 40%-45% by 2020 from the 2005 level of 7.467 billion tons of CO₂ equivalent.
A large source of greenhouse-gas emissions comes from *wastewater treatment industry*

The **concept** that *wastewater treatment* could result in direct emissions of greenhouse gas such as CO$_2$, CH$_4$ and NO, as well as indirect emissions resulting from

- **energy cost** (耗费电能)
- **sludge disposal** (污泥处置)
At present, commonly used wastewater treatment techniques are chemical and biological methods, such as:

- Depositing
- Filtering
- Neutralizing
- Biological contact oxidizing
- Active sludge process

The problems of those methods are high investment, high running cost, long time of processing, large area occupied, and low efficiency.
In traditional active sludge method

- Organic contaminants are degraded into CO₂ and water under aerobic conditions (有氧), or transformed to methane under anaerobic conditions (厌氧);

- The thickening and burning of sludge can also produce a large amount of CO₂.
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Direct discharge to the river

The picture was shot in Jan. 29, 2016, only 25km far from center of Beijing
Advances in wastewater treatment over the past two centuries have made great contributions to the mitigation of environmental pollutions.

Recently, particular attention has been paid to the broader environmental implications of these improvements.

Thus, new wastewater treatment which has higher efficiency, low cost and low greenhouse gases emission are urgently needed.
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05 Cooperation with industrial factories
Magnetic Separation?

First time I know SHGMS used in water treatment is in 2004 when I visit Prof. Nishijima’s Laboratory.

A physical and efficient method
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Dec. 2004, Osaka

02 Superconducting magnetic separation technology
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Nov. 2005, Beijing
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Dec. 2007, Osaka

02 Superconducting magnetic separation technology
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Oct. 2009, Beijing

02 Superconducting magnetic separation technology
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Feb. 2012, Beijing

Strategic Japanese-Chinese Research Cooperative Program on “Science and Technology for Environmental Conservation and Construction of a Society with Less Environmental Burden”

Japanese Research Leader

Name (Given) Shigehiro (Family) Nishijima
Organization Osaka University
Division/Department Division of Sustainable Energy and Environmental Engineering

Chinese Research Leader

Name (Given) Laifeng (Family) Li
Organization Technical Institute of Physics and Chemistry, Chinese Academy of Sciences
Division/Department Cryogenic Materials and Applied Superconductivity

02 Superconducting magnetic separation technology
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Nov. 2013, Osaka

02 Superconducting magnetic separation technology
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Oct. 2014, Beijing
According to different magnetic field, magnetic separation can be classified as:

- **Traditional magnetic separation**, whose magnetic field concludes:
  - *rare earth permanent magnet (ReCoMag) (<1T)*
  - *ordinary electromagnet, contains high-gradient magnetic separation (HGMS)*
Superconducting high-gradient magnetic separation (SHGMS), whose magnet is made of superconducting wire.

- greater magnetic field (>3T)
- low energy required

advantages
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

<table>
<thead>
<tr>
<th></th>
<th>HGMS</th>
<th>ReCoMag</th>
<th>SHGMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Magnetic field intensity ((T))</td>
<td>(~1)</td>
<td>(~0.3)</td>
<td>(3\sim5)</td>
</tr>
<tr>
<td>Running capacity ((10000 m^3/d))</td>
<td>50kWh</td>
<td>40kWh</td>
<td>10kWh</td>
</tr>
<tr>
<td>Separation process</td>
<td>Uncontinuous</td>
<td>Continuous</td>
<td>Continuous</td>
</tr>
<tr>
<td>Capture rate of Magnetic seeds</td>
<td>(&gt;99%)</td>
<td>(&gt;99%)</td>
<td>100%</td>
</tr>
<tr>
<td>Requirements of magnetic seeds</td>
<td>High magnetization saturation and permeability, (Fe_3O_4)</td>
<td>High magnetization saturation and permeability, (Fe_3O_4)</td>
<td>Red clay, slag etc</td>
</tr>
<tr>
<td>Chemical agent addition</td>
<td>Saving 1/3</td>
<td>Saving 1/3</td>
<td>None or Saving 2/3</td>
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<tr>
<td>Reaction time</td>
<td>&lt; 3min</td>
<td>&lt; 3min</td>
<td>&lt; 3min</td>
</tr>
<tr>
<td>Area occupation</td>
<td>&lt; 100m(^2)</td>
<td>&lt; 100m(^2)</td>
<td>&lt; 50m(^2)</td>
</tr>
<tr>
<td>Running cost ((10000 m^3/d))</td>
<td>0.2 yuan/t</td>
<td>0.22 yuan/t</td>
<td>0.13 yuan/t</td>
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<tr>
<td>Removal rate</td>
<td>good</td>
<td>good</td>
<td>Very good</td>
</tr>
<tr>
<td>Investment (comparing to traditional method)</td>
<td>1/3</td>
<td>1/3</td>
<td>1/3</td>
</tr>
</tbody>
</table>
Superconducting magnet technology used in wastewater treatment is a new technology with representative and obvious advantage!
Superconducting high-gradient magnetic separation (SHGMS)

Under Courtesy of Prof. S. Nishijima

02 Superconducting magnetic separation technology
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

**SHGMS advantages:**

- Very efficient removal of magnetic particles
- Smaller space occupation than conventional technologies
  
  *potentially less expensive because less real estate*
- Fewer chemicals (safer) - *ferrite process vs. conventional precipitation technique*
- Environmentally friendly - *ferrite process produces non-hazardous, non-leachable waste*
- Cheaper to dispose of waste
- Easier sludge collection and treatment
- Since 1987, fundamental researches for superconducting magnetic separation were started in Osaka University.
- Prototype of wastewater separator for paper factory was developed and a demonstration in lab scale has been carried out.
Superconducting magnet technology has been widely used in medical and mineral separating field, **SHGMS is considered as another promising new technology.** Since the cryocooler cooled superconducting magnets are commercial available, it becomes **easier and cheaper** to establish a superconducting magnetic separation system.

Wastewater from paper factory was treated by SHGMS
### The application of SHGMS in Japan

<table>
<thead>
<tr>
<th>適用対象</th>
<th>担磁方法</th>
<th>状況</th>
<th>研究開発機関</th>
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<tr>
<td>地熱水</td>
<td>コロイド化学</td>
<td>実証</td>
<td>岩手県地域結集-</td>
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<tr>
<td>湖沼水</td>
<td>コロイド化学</td>
<td>実用化</td>
<td>物質材料研究機構</td>
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<td>浸出水</td>
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<td>実証</td>
<td>日立製作所</td>
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<td>実用化</td>
<td>都立大・神奈川工大</td>
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<tr>
<td>半導体加工廃液</td>
<td>メカノケミカル</td>
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<td>都立大・神奈川工大</td>
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<tr>
<td>製紙廃水</td>
<td>コロイド化学</td>
<td>実証</td>
<td>阪大・岡山大・京都工織大</td>
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<tr>
<td>都市下水</td>
<td>磁化活性汚泥</td>
<td>実証</td>
<td>阪大・京都工織大</td>
</tr>
<tr>
<td>養豚廃水</td>
<td>磁化活性汚泥</td>
<td>実証</td>
<td>宇都宮大</td>
</tr>
</tbody>
</table>
In China, we are the first group to introduce such technology.

After 10 years’ effort, our superconducting separator has been established, which has drawn a hot interest from both the industrial factories and government.
AEGREEMENT

At NYC 4 September 2010 Tokyo

We agree with the following cooperative relation with sincere respect and friendship for the development of MFUTEMR (Magnetic Force Utilizing Technology for Environment and Material Recycling) to contribute the world wide problems as to Environment and Material Recycling.

This agreement will be continued from September 2010 to December 2014. This agreement will be discussed at the end of 2014 as to the results and the future program. This agreement will be proofed in need with agreement of the steering committee members before the end of 2014.

1. Object
To develop the MFUTEMR (Magnetic Force Utilizing Technology for Environment and Material Recycling) to contribute the world wide problems as to Environment and Material Recycling.

2. Activity
1) To operate the MFUTEMR Forum
2) To exchange the information as to MFUTEMR
3) To exchange the students, researchers and related peoples
4) To do the cooperative activities

3. Organization
The steering committee is composed from each country's representative persons.

1) Japan Dr. Shigehiro Nashijima (Osaka University)
Dr. Tsuno Watanbabe (Tokyo Metropolitan University)
2) Korea Dr. Dong-Woo Ha (KRI Korea Electrotechnology Research Institute)
Dr. Young-Hun Kim (Andong National University)
3) China Dr. Zian Zhu (HEP Institute of High Energy Physics, CAS)
Dr. Laifeng Li (TIPC Technical Institute of Physics and Chemistry, CAS)

4. Steering committee
Chairman
Dr. Tsuno Watanabe
Vice chairpersons
Dr. Shigehiro Nashijima (Japan)
Dr. Dong-Woo Ha (Korea)
Dr. Zian Zhu (China)
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**From the government**

- In 2012, our group led the study of *Academician Advisory Report*, which is named as "**Suggestion of the comprehensive application of new material and new technology in the wastewater and sludge treatment**".

- The report was submitted by the Chinese Academy of Science to the State Council of China.

- Further, **premier Jiabao Wen** wrote **an official instructions** on the report.

> 温家宝总理：要重视城市污水污泥处理和地下管网建设，就要加强建设前期工作，进行合理设计与规划，选择新技术、新材料、新方法，提高污水污泥处理和管网建设的质量和效益，中科院的这份报告给人以启示，请发改委、环保部、住建部、科技部研究。

> 刘延东：请万钢、志刚、小涟同志阅研。
Superconducting magnetic separation can deal with different kinds of wastewater.

**Industrial Wastewater:**
- Oil injection water,
- Pharmaceutical and chemical wastewater,
- Paper wastewater,
- Dyeing wastewater,
- Food processing wastewater,
- Steel factory wastewater,
- Coal mine's acidic wastewater,
- Textile wastewater,
- etc.

**Municipal Wastewater:**
- Domestic sewage,
- Waterscape wastewater,
- etc.
There are **two key technologies** in the application of SHGMS.

1. **The device of the SHGMS system**

2. **Magnetic seeds**
The continuously working prototype of the SHGMS system

The design of the system

Inlet tank → Mixing → Sedimentation → Superconducting magnet → Outlet

wastewater → clean water

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Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

The continuously working prototype of the SHGMS system

The design of the system

Parameters:

It is a cryocooler cooled SHGMS wastewater treatment system:

- Magnetic field: 3.5T;
- Diameter: 200 mm;
- Treatment capacity: 500-2000 t/d;
- Occupied area: ~ 6 m²
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The continuously working prototype of the SHGMS system.

- We prepare *methyl violet* solution, and use *magnetic active carbon* to purify it;
- When it comes out from the SHGMS system, the solution is very clear.
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**What** are magnetic seeds and **why** the SHGMS need them?

- Most pollutants in wastewater from paper, chemical, pharmaceutical or food factories are organic substances which are **not ferromagnetic**;
- They **cannot be removed** by magnetic separation;
- Therefore, **magnetic seeds are required** to be added into the wastewater previously;
- When the paramagnetic and diamagnetic **pollutants combined with magnetic seeds**, the wastewater can be treated by superconducting magnetic separation.
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**Magnetic Seeds** 机能铁

- **Magnetic property**: which allow for effective magnetic separation by the SMS.

- **Functional groups**: which can capture, adsorb or degrade the pollutions in the wastewater.
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1. Industrial traditional composites

- Fe₃O₄ particles
- Magnetite or Slay
- Poly acrylamide (PAM)
- Poly Aluminum Chloride (PAC)

03 Magnetic seeds
2. Magnetic active carbon

1). $\text{Fe}_3\text{O}_4$ deposited on the active carbon

The active carbon part: ensure the removal of a wide range of contaminants from industrial and municipal wastewaters, landfill leachate and contaminated groundwater.

2). $\text{Fe}_3\text{O}_4$ immersed in the hollow active carbon ball
3. Plasma polymerized Fe₃O₄

- Plasma functionalized method can modify the surfaces of particles;
- The polymer can capture the pollutions. The functional group can be chosen as –COOH, -NH₂, -OH etc.;
- The thickness of the polymer increases as the reaction time increases.

![Image of plasma polymerized Fe₃O₄](image-url)
4. Hydroxyapatite (HAp) magnetic seeds

- Due to strong affinity for cationic species, HAp is one of the most promising mineral phases for *heavy metal ion removal*, as Hg$^{2+}$, Pb$^{2+}$, Sb$^{3+}$, Cd$^{2+}$ etc.;
- The HAp is an environmentally friendly material.

1). 10nm Fe$_3$O$_4$ deposited on the surface of HAp.
4. Hydroxyapatite (HAp) magnetic seeds

2). HAp coated on the surface of Fe₃O₄ spheres.
### Wastewater treatment examples

#### 1. Dyeing wastewater treatment

<table>
<thead>
<tr>
<th></th>
<th>COD mg/ml</th>
<th>COD Removal %</th>
<th>Turbidity mg/l</th>
<th>Turbidity Removal %</th>
<th>chroma</th>
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</thead>
<tbody>
<tr>
<td>1</td>
<td>844</td>
<td>5.69</td>
<td>205</td>
<td>40.23</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>788</td>
<td>11.95</td>
<td>180</td>
<td>47.52</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>888</td>
<td>0.78</td>
<td>296</td>
<td>13.70</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>778</td>
<td>13.07</td>
<td>22</td>
<td>93.59</td>
<td>40</td>
</tr>
<tr>
<td>5</td>
<td>~560</td>
<td>37.43</td>
<td>10</td>
<td>97.08</td>
<td>&lt;2</td>
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<tr>
<td>6</td>
<td>639</td>
<td>28.60</td>
<td>1</td>
<td>99.71</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>679</td>
<td>24.13</td>
<td>15</td>
<td>95.63</td>
<td>13</td>
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<tr>
<td>8</td>
<td>590</td>
<td>34.08</td>
<td>14</td>
<td>95.91</td>
<td>20</td>
</tr>
<tr>
<td>9</td>
<td>592</td>
<td>33.85</td>
<td>2</td>
<td>99.42</td>
<td>&lt;2</td>
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<tr>
<td>10</td>
<td>608</td>
<td>32.07</td>
<td>3</td>
<td>99.12</td>
<td>&lt;2</td>
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<tr>
<td>11</td>
<td>503</td>
<td>43.80</td>
<td>7</td>
<td>97.96</td>
<td>&lt;2</td>
</tr>
</tbody>
</table>
2. Oil field wastewater treatment

- Before treatment: COD 482mg/ml, Turbidity 108 mg/l
- After treatment:
  - COD 147 mg/ml
  - Turbidity 5 mg/l
2. Oil field wastewater treatment

- Plenty sediments inside

- Before treatment: COD 13000 mg/ml, Turbidity 2171 mg/l

- After treatment: A
  - COD 45 mg/ml
  - Turbidity 2 mg/l
3. Coal washing wastewater treatment

<table>
<thead>
<tr>
<th></th>
<th>COD mg/ml</th>
<th>COD Removal %</th>
<th>Turbidity mg/l</th>
<th>Turbidity Removal %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Φ45-Before</td>
<td>45360</td>
<td></td>
<td>3570</td>
<td></td>
</tr>
<tr>
<td>Φ45-After</td>
<td>0</td>
<td>100%</td>
<td>205</td>
<td>82.9%</td>
</tr>
<tr>
<td>Φ24-Before</td>
<td>12000</td>
<td></td>
<td>880</td>
<td></td>
</tr>
<tr>
<td>Φ24-After</td>
<td>28</td>
<td>99.2%</td>
<td>5400</td>
<td>88.1%</td>
</tr>
</tbody>
</table>

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Sewage Sludge

- Over the last decade the increase in municipal wastewater treatment activities has been confronted with a dramatic increase of sewage sludge amount.

The annual discharge of sludge (with high content of organic substance and 80% water ratio) is estimated to be more than 20 million tons.
Processes adopted in China for sludge treatment include

- **Drying**
- **Thickening**
- **Dewatering**
- **Burning**
- **Composting** (堆肥)

and the potential final destinations are agricultural application and landfill.
Organic matter in the sludge is partly mineralized by microorganisms through both aerobic and anaerobic processes:

- **Aerobic processes** (好氧) are more efficient and mainly form carbon dioxide \((\text{CO}_2)\) as a by-product,
- whereas **anaerobic decomposition** (厌氧) is much slower and also produces **methane** \((\text{CH}_4)\).

Among those methods, **firing** is the most attractive disposal route with the advantages of **volume reduction, stabilization and harmlessness**; however, it will lead to **significant CO\textsubscript{2} emissions**!
Reducing carbon emissions and energy consumption in industrial sectors is necessary to reduce greenhouse effects.

At present, the principal approaches to decrease industrial carbon emissions include:

- **adjusting energy and industrial structures**
- **improving technology and energy efficiency**
- **implementing a strict management system**
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**Sewage Sludge from SHGMS**

- Remove remanence
- Separate sludge and magnetic seeds
- Recycle magnetic seeds

Compared to traditional method, SHGMS need none or less chemical agent addition, thus the resulting sludge as the by-product is less.
the sludge solar drying technology

--- a new system of greenhouse sludge dry treatment

Thermal drying of the sludge is an important treatment and process, is an important prerequisite for the stabilization of sludge, the reduction of sludge volumes and the utilization of sludge, but a quite large amount of energy is required for drying sludge.

Solar drying, using renewable energy, is becoming a popular option to replace mechanical thermal dryers.
The system is mainly composed of:

- **greenhouse**
- **sludge turner**
- **auxiliary heating source**
- **ventilation system**
- **insulation system** etc.
Advantages of the sludge solar drying technology

✓ Less energy needed
✓ Sustainable development (Using solar energy)
✓ Lower running cost
   (drying 1 t water, it needs only 25-30kWh; the traditional method needs 800-1060kWh)
✓ Better efficiency

After treatment, the volume of the sludge can be reduce by 3-5 times
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Example--- SHGMS system applied for oil-field wastewater treatment

- Currently in China, there are more than 200000 oil-water wells;
- Each oil-water well can produce about 10 t oil, then it will produce about 100 t wastewater;
- the designed daily wastewater treatment capacity is 500-2000 t;
- Thus, it need 10000 SHGMS system for the oil-field wastewater treatment.

\[
\frac{200000}{20} = 10000 \text{ (套)}
\]
Thus, **Superconducting magnetic separation** used for wastewater is an effective way.

Due to its advantages such as the

- lower investment
- smaller area occupied
- shorter period of processing
- lower running cost
- none or less chemical agent addition (saving 2/3)

*Superconducting magnetic separation can be considered as*

**a low carbon economy!**
Rare earth permanent magnet application for wastewater treatment example

1. Sichuan HuanNeng Technology and Science Company

- Sichuan SCIMEE Tech.&Sci.Co.,Ltd. has been focusing on R & D and application of magnetic separation water purification technology since its establishment, and it is one of the several domestic enterprises that master the magnetic separation water body purification core technology, and the company is the pioneer of China's magnetic separation water purification technology.

- The company provides customers with sewage treatment package equipments, operation services, engineering package services and integrated solutions based on its basis of magnetic separation water purification.
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04 Cooperation with industrial factories

(1) Add the MagCarrier
(2) Co-precipitate sols and MagCarrier into flocs by adding coagulant and flocculant in a 0-min process
(3) Removes floating flocs with ReMagDisc
(4) MagCarrier is collected from sludge and recycling to main process
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Water Treatment System: ReMagDiscHiSC system

- Processing Capacity: 30,000 m$^3$/d
- Effluent Quality: SS < 20 mg/L, COD removal > 50%
- Products sale: > 100 sets per year
- Sales: 30 million US dollars / year

04 Cooperation with industrial factories
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2. Suzhou Biyuan Landscape Company

◆ Company Business:
✓ Engaged in the urban landscape, landscape design and construction of professional nursery.
✓ Now aim in **expanding in the field of sewage treatment**

◆ Core Technology:
✓ **ReCoMag Technology**

- Residential building
- Park
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Superconducting magnet application for mineral separation example

3. JiangSu Jack-Zhongke Superconducting technologies Co.Ltd

The company has been focusing on **the equipment and technology of superconducting magnet and its application in resources and environment** since its establishment in 2009.

Their main product is the superconducting equipment for **mineral separation**.

One of their products is the superconducting magnetic separation for wastewater, which contain only **phosphorus pollution**.
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Parameters:

◆ Diameter of the magnet:
  \[ \Phi \ 102\text{mm} \]

◆ Maximum magnetic field intensity:
  \[ 6\text{T} \]

◆ Application:
  - iron removal in wastewater
  - low-intensity separation,
  - dry separation for the ferrous ore

04 Cooperation with industrial factories
Companies collaborated with us
1、Weifang Xinli Superconducting Company

◆ Company Business:
- superconducting MRI magnets, superconducting magnetic separator, superconducting iron separator
- Now aim in expanding in the field of sewage treatment

◆ Main Products:
(cooperate with Chinese Academy of Sciences (CAS) Institute of High Energy).

Rolling off of low temperature superconducting magnetic separator

The first set superconducting MRI (1.5T/4.2K)
We have designed a **5T-200mm cryocooler cooled superconducting magnet** for this company;

This magnet is supposed to use for waste water treatment.
2、Beijing Zhongke Superconducting magnetic environmental technology Co., Ltd

Established in the end of 2015

Our aim is to realize the application of SHGMS in wastewater treatment this year.
Superconducting magnet technology, a promising way to reduce industrial emissions and pollutions in China

Laifeng Li
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