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Removal of Iron Oxide Scale from Boiler Feed-water in Thermal Power Plant by Magnetic Separation -Aggregation States of Oxygenated Treatment Scale-

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Introduction

Scale generation decreases power generation efficiency in thermal power plants.

✓ **What is scale?**

- Iron oxide generated by corrosion of water supply system pipes
- Thermal conductivity is about 10% of pipe material
  → Adhesion on pipe wall decreases in power generation efficiency.

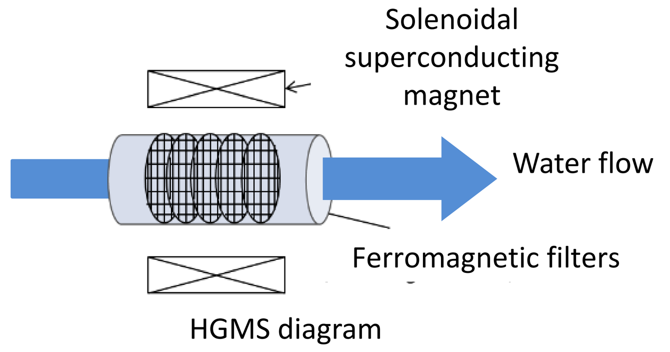
Removing the scale can prevent decrease in power generation efficiency and reduce CO_2 emission.

Water treatment in thermal power plant. (χ: Magnetic susceptibility [-])

Water treatment in thermal power plant	AVT (All Volatile Treatment)	OT (Oxygenated Treatment)
Main component of the scale	Magnetite (Ferromagnetic) Fe_3O_4	・Hematite (Paramagnetic) α-Fe_2O_3 (χ =1.3×10^{-3}) ・Magnetite Fe_3O_4 (-) ・Goethite (Paramagnetic) α-FeOOH (χ =1.1×10^{-3})

Removal with high-gradient magnetic separation (HGMS)

- Operable under high temperature and high pressure
- Low pressure drop due to coarse filters
- Filters can be reused by cleaning

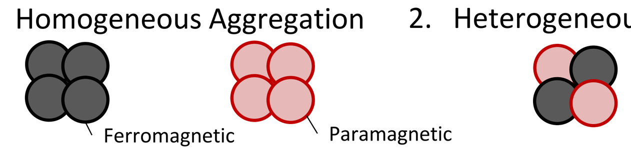


HGMS diagram

In this study, we targeted Oxygenated Treatment(OT) scale.

Aggregation states

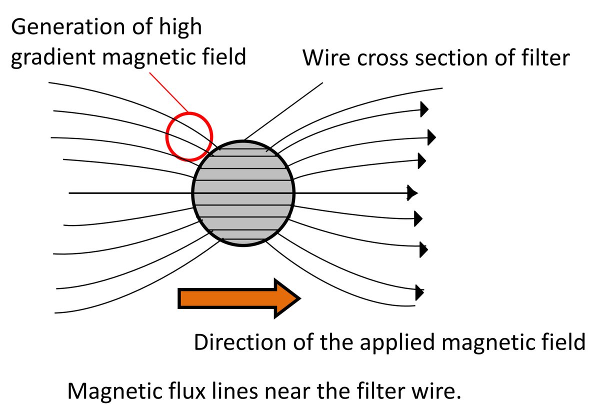
1. Homogeneous Aggregation
2. Heterogeneous Aggregation



HGMS System and practical place to install

High gradient magnetic separation method (HGMS)

When a ferromagnetic filter is installed in the magnetic field, magnetic field gradient is generated around the filter, and ferromagnetic and paramagnetic materials are trapped by the magnetic force.



Magnetic flux lines near the filter wire.

When magnetic force > drag force, the scale magnetic separation is possible. ($F_M > F_D$)

・Magnetic force (force received from the filter)

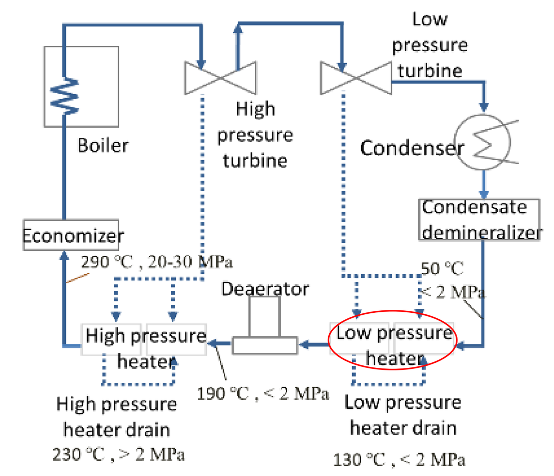
$$\mathbf{F_M} = \frac{4}{3}\pi r_p^3 \frac{\chi}{\mu_0}(\mathbf{B}\cdot\nabla)\mathbf{B}$$

・Drag force (force received from fluid)

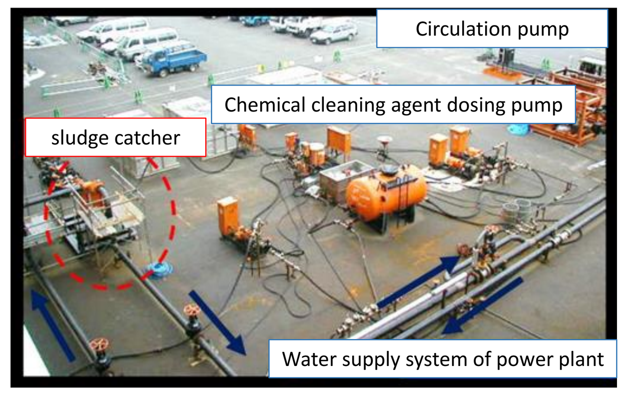
$$\mathbf{F_D} = 6\pi\eta r_p(\mathbf{v_f} - \mathbf{v_p})$$

- r_p : Particle radius [m]
- χ : Magnetic susceptibility[-]
- μ_0 : Permeability of vacuum [H/m]
- $\mathbf{B}$: Magnetic flux density [T]
- η : Viscosity coefficient[kg/m·s]
- $\mathbf{v_f}$: Fluid velocity [m/s]
- $\mathbf{v_p}$: Particle velocity [m/s]

	Introduction to the boiler water system	Introduction to chemical cleaning line
Advantages	Scale removal is possible even during power plant operation.	A relatively high removal rate can be achieved when combined with chemical cleaning.
Installation place	Low-pressure feed-water (high scale concentration and ferromagnetic materials)	Introduced as an alternative to sludge catchers
Environment	130℃、2MPa、Basic pH	80～85℃、organic mixed acid (Acidic pH)



Installation place of OT-applied thermal power plant.



Chemical cleaning line

Firstly, we assumed the introduction of a chemical cleaning line.

Particle trajectory calculation of hematite using finite element method

◆ **Purpose of analysis**

To investigate change in the hematite capture performance of the filters used in the HGMS system by the temperature.

◆ **Analysis method**

Magnetic field and fluid flow around the filter wire using the finite element method.

The particle trajectories of hematite was calculated by solving the equation of motion of a particle with time evolution.

◆ **Analysis conditions**

Filter conditions

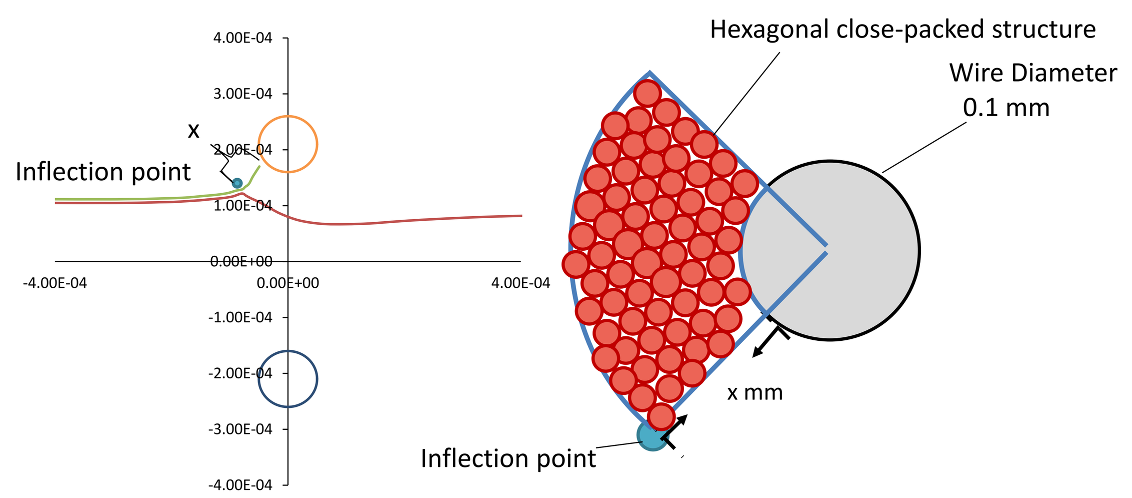
Filter material	Magnestain®
Mesh number	60
Mesh opening	0.32 μm
Wire diameter	0.1 mm

Analysis conditions

Applied magnetic field	6 T
Magnetic field direction	Right
Inflow rate	20 cm/sec
Fluid direction	Right
Fluid temperature ①	25 ℃
Fluid temperature ②	80 ℃

◆ **Calculation method**

The saturated trapping capacity of hematite per filter was estimated from the inflection point of the particle trajectory calculation.

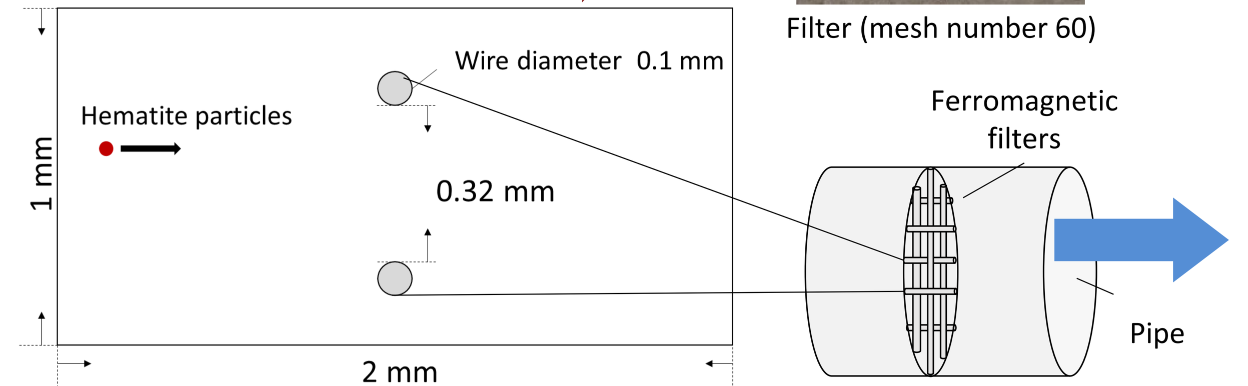


Assume that the distance x from the inflection point to the wire is the range where the filter can capture particles.

The amount of separation was estimated assuming that the particles adhere to the fan-shaped area connecting the inflection point and the center of the wire in a close-packed structure.

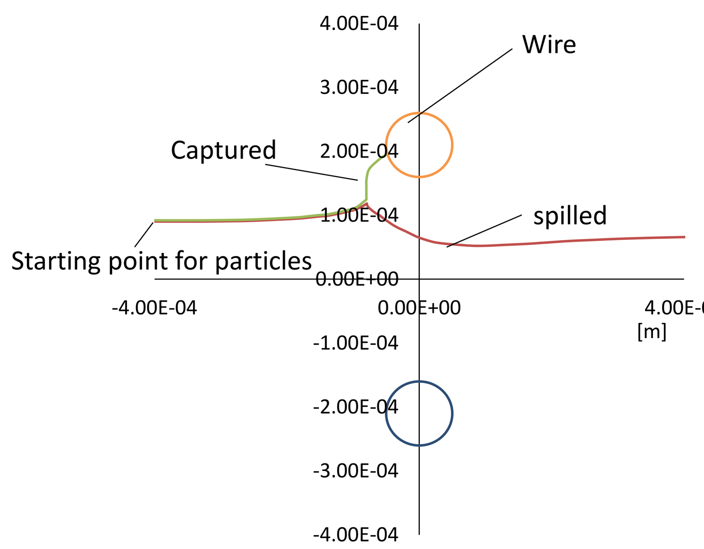
◆ **Analysis summary**


Filter (mesh number 60)

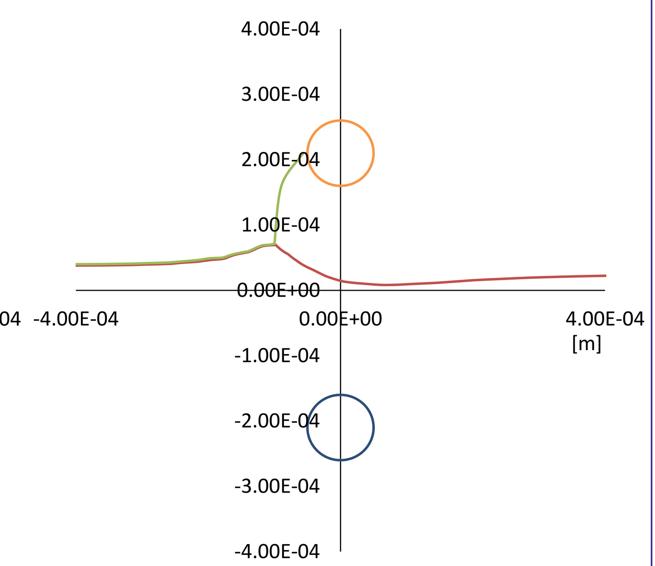


Analysis diagram

◆ **Results and Discussion**



Particle trajectory analysis at 25 ℃


Particle trajectory analysis at 80 ℃

Amount captured by one filter 0.29 g	Amount captured by one filter 0.78 g

- At high temperature, the drag force becomes smaller due to the decrease in viscosity, and the saturated trapping capacity is expected to increase.
- The capture amount was larger than that of the experimental value, which may be due to that the deposition of hematite particles is not in a close-packed structure.

Lab-scale magnetic separation of hematite

◆ **Purpose of experiment**

To investigate magnetic separation properties of hematite and compare with analytical results.

◆ **Experiment contents**

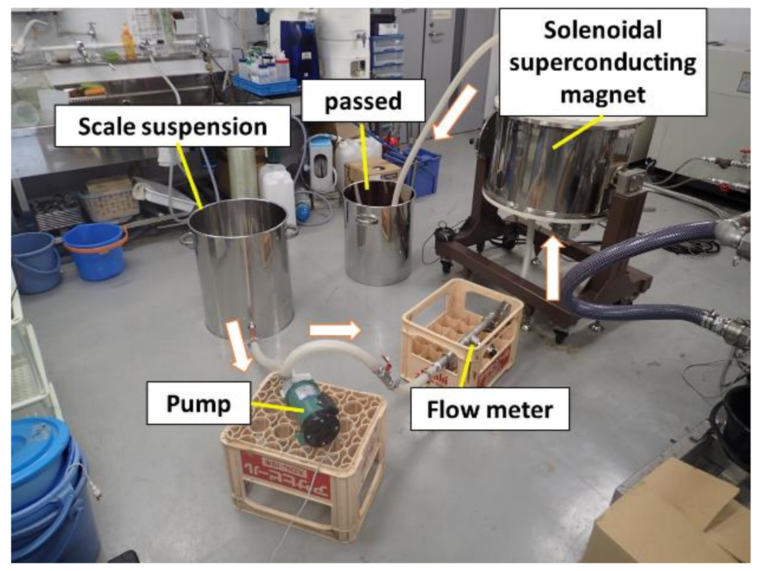
➢ This experiment was conducted under two conditions.

- 200 ppm simulating the suspension of chemical cleaning line.
- 500 ppm to investigate the saturation capture rate.

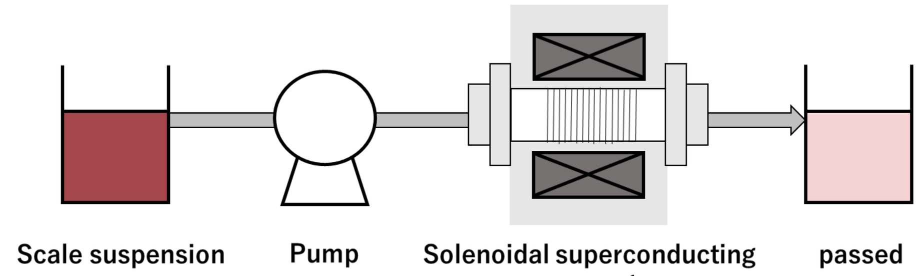
➢ The separation ratio was calculated as follows.

$$\text{Separated ratio}[\%] = \frac{\text{Captured scale[g]}}{\text{Captured scale[g]} + \text{passed scale[g]}} \times 100$$

◆ **Experimental setup**



Experimental equipment of HGMS.



Outline of experimental system

◆ **Experiment conditions**

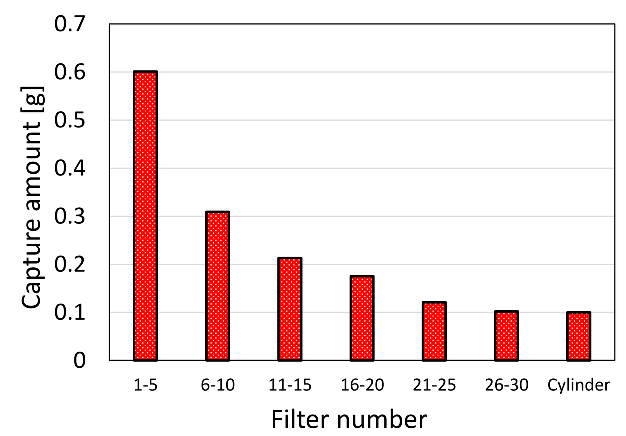
Experimental conditions.

Flow velocity	20 cm/s
Fluid temperature	25 ℃
Applied magnetic field at the center	6.0 T
Hematite amount ① Input concentration ①	8.0 g 200 ppm
Hematite amount ② Input concentration ②	20.0 g 500 ppm
Input concentration	200 ppm
Number of filters	30 sheets
Solution pH	pH=4

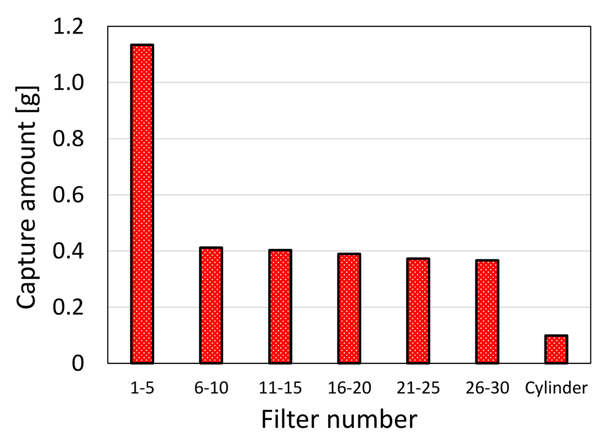
Filter conditions.

Filter material	Magnestain®
Mesh number	60
Opening	0.32 μm
Wire diameter	0.1 mm

◆ **Results and discussion**



Hematite separation (200 ppm)



Hematite separation(500 ppm)

- The overall separation rate of hematite was 20.9% at 200 ppm and 16.0% at 500 ppm.
- The average capture amount per filter for the 1st to 5th filters from the inlet side was 0.12 g at 200 ppm and 0.23 g at 500 ppm.

- From the experiment at 500 ppm, the calculation of capture particles is reasonable.
- From the empirical formula, it was estimated that the capture rate of hematite is 40% at 25 ℃ and 98% at 80 ℃, using 150 filters.

Summary

- **From the particle trajectory calculation and the experiment, the calculation of capture particles is reasonable.**
- **It was estimated that about 98% of scale can be captured by 150 filters at 80 ℃.**

Acknowledgement

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