Superconductivity and Cryogenics
Vol.13, No.2, (2011), pp.21~24

Application of Superconducting Magnetic Separation for Condenser Water Treatment in Thermal Power Plant

You-Jin Lee[1], Jun-Mo Kwon[1], Seung-Kyu Baik[1], Kwang-Soo Han[2], Rock-Kil Ko[1], Myung-Hwan Sohn[1], and Dong-Woo Ha[1] *

[1] Korea Electrotechnology Research Institute, Changwon 642-120, Korea
[2] Korea South-East Power Co., Goseong, 638-932, Korea

Received 20 April 2011; accepted 6 May 2011

Abstract-- **Superconducting high gradient magnetic separation (HGMS) has advantages to treat wastewater because it can generate high magnetic field and achieve rapid purification. In this study superconducting HGMS was applied to remove impurities from the condenser water in thermal power plant. The condenser water contained mainly hematite and maghemite and it was highly magnetized than hematite. In the HGMS tests using a 6-T cryo-cooled Nb-Ti superconducting magnet, the turbidity of the condenser water was effectively reduced up to 99.6% and the result showed better performance than that of the 0.5-T permanent magnet test. The higher magnetic field was applied in the range of 1-6 T, the more iron oxides were removed. The effect of magnetic filter configuration on the condenser water treatment was also investigated. Consequently superconducting HGMS system can be applicable to remove iron oxide impurities from condenser water in thermal power plant.**

1. INTRODUCTION

Conventional chemical and biological wastewater treatment techniques are depositing, filtering, neutralizing, biological contact oxidizing, and active sludge process. However, these methods have several problems such as high investment, high running cost, long time of processing, large area occupied, and low efficiency. Comparing to traditional treatment methods, superconducting magnetic separation has some advantages, such as the lower investment, smaller area occupied, and shorter period of processing. Since the cryo-cooler cooled superconducting magnets are commercially available, it becomes easier and cheaper to establish a superconducting magnetic separation system [1].

Superconducting magnetic separation aimed to use in wastewater treatment has been received great attention. The superconducting high gradient magnetic separator (HGMS) offers many advantages over conventional models because it consumes only a fraction of the power required by conventional HGMS and is capable of generating induced magnetic field higher than 2 T [2].

Many studies have demonstrated that the HGMS is very successful in purifying wastewater from paper factory [3, 4] and geothermal power plant [5].

In thermal power plant, condenser water contains very small amount of impurities and it is important to control condenser water quality because scale on pipes reduces the efficiency of the condenser. Oxygenated treatment (OT) is one of the typical water treatment methods to prevent pipe corrosion and to reduce scale generation on the pipe surface in boiler and condenser. In this method, a proper amount of oxygen is injected in order to oxidize magnetite (Fe_3O_4), a major cause of scale formation, into hematite (Fe_2O_3) and goethite (FeOOH) because hematite shield coating is hard and insoluble [6]. However, it is not easy to remove suspension material by a conventional method using electromagnet because hematite is relatively less magnetized and the suspension size is extremely small. Therefore, to eliminate fine-size suspension of iron oxides from the condenser water, the superconducting HGMS system can be applied.

In the present work, the feasibility of superconducting HGMS system was investigated for the application to condenser water treatment in thermal power plant. For the study, the effect of magnetic field strength and double filter configurations on the reduction of the water turbidity were tested in the HGMS system.

2. MATERIALS AND METHODS

2.1. Condenser Water

The condenser water used in this study was collected from a thermal power station located in Goseong, Korea. Since the turbidity of the original condenser water was over the measuring range of a turbidity meter, it was adjusted by mixing with distilled water around 450 NTU and thus the diluted condenser water was used in this study.

2.2. Preliminary Test

Prior to superconducting HGMS tests, a preliminary test was conducted using permanent magnet for a comparative purpose. For the test, the permanent magnet was arranged like rails and the strength of the magnetic field on the rail surface was 0.5 T. After the condenser water was passed on

* Corresponding author: dwha@keri.re.kr

the rail at the flow rate of 450 mL/min, the turbidity change of the treated solution was measured by a turbidity meter to investigate the removal of iron oxides by permanent magnet.

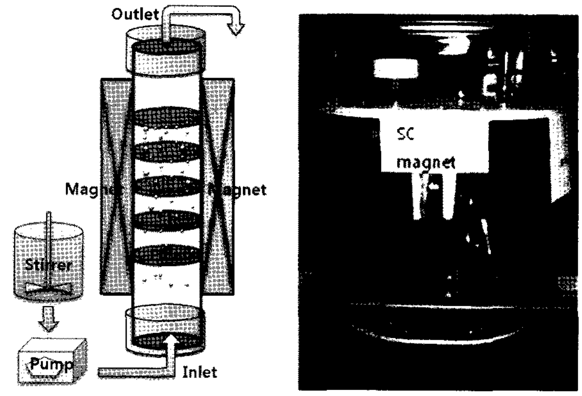
2.3. Superconducting HGMS System

Fig. 1 shows the superconducting HGMS system with a vertical type superconducting magnet and wire mesh disk filters used in this study. The system was equipped with a 6-Tesla cryo-cooled Nb-Ti superconducting magnet and the magnetic filters were made of stainless steel 430, which is suitable for wet magnetic separation due to its good corrosion resistance. The bore size of the magnet was 100 mm in diameter. The magnetic filters (Φ0.8 × 5 mesh) with 65 mm in diameter were located at the center of the magnet bore by fixing with brackets and the location was revised as the center of magnetic field was shifted. The magnetic field was controlled from 1 T to 6 T, and the flow rate of test samples was 450 mL/min or 2,900 mL/min. Before the magnetic separation tests the sample was diluted in a 6-L vessel by stirring at a speed of 500 rpm and then it was supplied to the system with stirring at 288 rpm.

The magnetic separation tests were conducted under various magnetic field strength (1-6 T) and the effect of magnetic filter configuration on the removal of impurities was also investigated using a double filter which consisted of an additional filter between filters.

2.4. Measurement and Analysis

The characteristics of the condenser water used in this study were investigated by performing several analyses. X-ray fluorescence (XRF) analysis was conducted to analyze the elements of impurities in the condenser water and the size distribution of particles that existed in the condenser water was also investigated in the range of 0.04 ~ 2,000 μm. The phase analysis and magnetic properties of the sample were performed by X-ray diffraction (XRD) analysis and vibrating sample magnetometer (VSM) measurement, respectively. The turbidity of solution samples was measured with a turbidity meter to observe the removal of iron oxides from the condenser water.



(a) (b)

Fig. 1. Schematic diagram of superconducting HGMS system (a) and Nb-Ti superconducting magnet (b).

TABLE I

COMPONENTS OF IMPURITIES IN CONDENSER WATER.

Components	Content, %
Fe_2O_3	98.7758
SiO_2	0.3007
Cr_2O_3	0.1813
MnO	0.1793
Al_2O_3	0.1062
TiO_2	0.0882
ZnO	0.0842

3. RESULTS AND DISCUSSION

3.1. Characteristics of Condenser Water

The result of X-ray fluorescence (XRF) analysis of the condenser water was listed in Table 1. It was observed that the condenser water impurities mainly consisted of Fe_2O_3 (98.8%). SiO_2, Cr_2O_3, MnO, and Al_2O_3 existed at a small quantity.

Fig. 2 shows the size distribution of particles that existed in the condenser water. The particle size distribution curve had two peaks about at 10 μm and at 30 μm. The particle size ranged from 1.5 μm to 200 μm and the mean was 26.53 μm. It seemed that superconducting magnetic separation could remove these particles because their size was large enough to attach magnetic filter wires.

The result of XRD analysis shows many α-Fe_2O_3 (hematite) peaks and some γ-Fe_2O_3 (maghemite) peaks (Fig. 3). Therefore, the particles in the condenser water were found to consist of mainly hematite and maghemite. Cr and Si peaks were also detected.

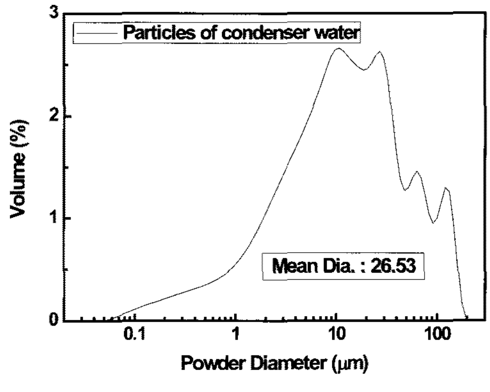


Fig. 2. Size distribution of particles in condenser water.

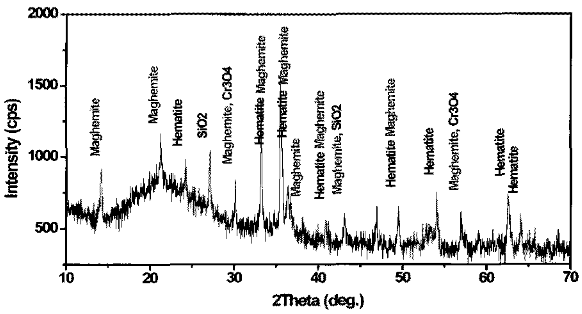


Fig. 3. XRD analysis of particles in condenser water.

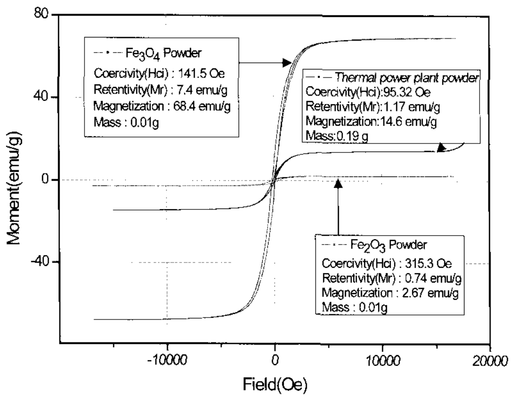


Fig. 4. Magnetization behavior of particles in condenser water.

Fig. 4 shows the magnetization behavior of particles in the condenser water as well as magnetite and hematite powders (reagent grade). From the VSM measurement, the magnetization value of the condenser water particles was 14.6 emu/g, which indicates that the condenser water had higher magnetization value than that of the hematite powder (2.67 emu/g). This may have been because maghemite contained in the sample shows similar characteristics to magnetite although it has same structure with hematite.

However, the magnetization value of the sample was lower than that of a ferromagnetic material, magnetite (68.4 emu/g). Since magnetic force on a particle is proportional to magnetization value, the particles in the condenser water could have been removed easier than the hematite powder with a same size but it may require a higher strength of magnetic field than that needed for magnetite removal.

3.2. Effect of Magnetic Field Strength

To investigate the effect of magnetic field strength on the turbidity decrease of the test sample, magnetic separation tests were conducted using permanent magnet which has 0.5 T of magnetic field on the surface and superconducting magnetic system where the magnetic field strength varied from 1 T to 6 T.

As shown in Fig. 5, when the condenser water passed through the permanent magnet rail of 0.5 T, the turbidity of the sample water decreased from 450 NTU to 172 NTU. Besides, when the condenser water was treated using the superconducting HGMS system at the same flow rate (450 mL/min), its turbidity was dramatically reduced. As the strength of magnetic field increased to 1 T, 2 T and 6 T, the turbidity was changed to 16.8, 4.44 and 1.8 NTU, respectively. This result indicates that the superconducting HGMS system is much more effective to treat the condenser water of thermal power plant than a magnetic separation using permanent magnet.

3.3. Effect of Magnetic Filter Configuration

The effect of magnetic filter configuration on superconducting magnetic separation was investigated by setting an additional filter between filters (double filter). Three types of double filter configurations were tested: no double filter was installed (none), or it was added only in the middle part (middle) or all parts (all). The test results are shown in Fig. 6.

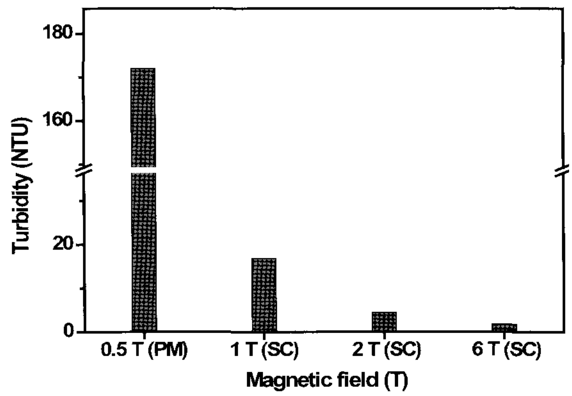


Fig. 5. Effect of magnetic field strength on condenser water treatment.

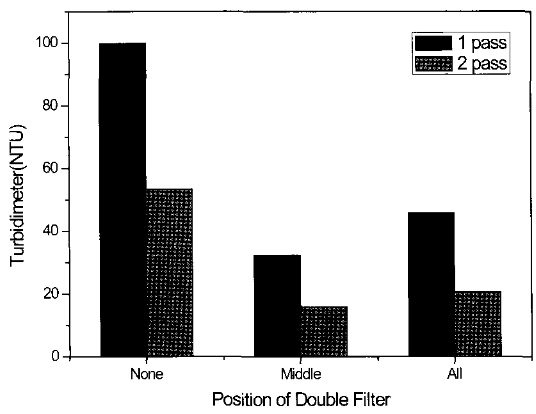


Fig. 6. Effect of magnetic filter configuration on condenser water treatment.

When the magnetic separation was performed with a magnetic filter of Φ0.8 × 5 mesh at the flow rate of 2,900 mL/min under the magnetic field of 6 T, it was observed that the installation of double filter enhanced the turbidity decrease. Moreover, when the double filter was used only in the middle section, the most turbidity was removed among three filter configurations. Among three configurations, "all" double filter configuration might have more points where the magnetic line is concentrated. However, it seems that its slope is changed more sharply in the "middle" case. This may have resulted in the higher reduction of the turbidity than the case of "all" double filter. In addition, when the condenser water was passed through the HGMS system twice, its turbidity decreased more in the tests of all three configurations.

4. CONCLUSIONS

In this study, the superconducting magnetic separation was applied for the treatment of the condenser water in thermal power plant. The condenser water impurities mainly consisted of hematite and maghemite and thereby it was highly magnetized than hematite but less than magnetite.

While the permanent magnet of 0.5 T obtained only 62% decrease of the condenser water turbidity, the superconducting HGMS tests achieved the effective reduction of the turbidity up to 99.6%. As the strength of magnetic field increased in the range of 1-6 T, the more turbidity was removed. Besides, the addition of double filter in the middle part of the magnet and the repeated treatment enhanced the turbidity decrease.

In conclusion, superconducting HGMS system is suitable to remove iron oxide impurities from condenser water in thermal power plant. A high magnetic field, a proper double filter configuration and re-treatment of the treated solution may improve the removal efficiency.

ACKNOWLEDGMENT

This work was supported by a grant from Basic Science Research Program of Korea Electrotechnology Research Institute funded by the Korea Councile for Industrial Science and Technology (KOCI).

EXAMPLE REFERENCES

[1] H. Zhang, Z. Zhao, X. Xu, and L. Li, "Study on industrial wastewater treatment using superconducting magnetic separation," *Cryogenics*, in press.

[2] N. P. H. Padmanabhan and T. Sreenivas, "Process parametric study for the recovery of very-fine size uranium values on super-conducting high gradient magnetic separator," *Advanced Powder Technol.*, vol. 22, pp. 131-137, Jan. 2011.

[3] S. Nishijima and S. Takeda, "Research and development of superconducting high gradient magnetic separation for purification of wastewater from paper factory," *IEEE Trans. on Appl. Supercond.*, vol. 17, pp. 2311-2314, 2007.

[4] Y. Kakihara, T. Fukunishi, S. Takeda, S. Nishijima, and A. Nakahira, "Superconducting high gradient magnetic separation for purification of wastewater from paper factory," *IEEE Trans. on Appl. Supercond.*, vol. 14, pp. 1565-1567, 2004.

[5] H. Okada, Y. Kudo, H. Nakazawa, A. Chiba, K. Mitsuhashi, T. Ohara, and H. Wada, "Removal system of arsenic from geothermal water by high gradient magnetic separation-HGMS reciprocal filter," *IEEE Trans. on Appl. Supercond.*, vol. 14, pp. 1576-1579, 2004.

[6] KEPCO (Korea Electric Power Corporation), *Thermal power generation – turbine*, KEPCO, Seoul, 2008, pp. 143-179.