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Ferric Substance Formed in Water Circulating in Boilers and Steam Piping, and an Apparatus for Magnetic Treating it

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Abstract. Substances in side the boilers and pipes become attached as scale or precipitate, and these badly effect the thermal efficiency of the steam. We made a detailed investigation, particularly on the ferric substances which are present in boilers for heating buildings, generating steam at 100°C and boilers which supply 180°C steam to multistory buildings. In the case of heating buildings, 20% of these substances are made up of Fe_3O_4 . The average particle size of Fe_3O_4 is 17~27 nm, and the saturation magnetization σ_s is 65~85 emu/g, by correcting the content of calcite and non-magnetic surface layer. The substances in boilers which supply multistory buildings contain ~98% of Fe_3O_4 and $\alpha\text{-Fe}_2\text{O}_3$, whose average particle size is 105 and 160 nm, respectively. The σ_s of Fe_3O_4 was 79~92 emu/g, if we correct the content of the non-magnetic layer, and this value is almost the same as for the bulk material. In our present research we tried to attach a bypass in the pipe and set a magnet from outside, and the substances can be removed from the system while the boiler is still in operation.

1. Introduction

Boilers are widely used to generate steam in various field, such as buildings and thermal power plants. Substances adhere to boilers and their piping facility as scale or precipitate as sludge. These substances disturb the flow of steam and badly effect the thermal efficiency of the steam. Researches on the composition of these substances have been reported [1], however, the detailed data on ferric substance in composition of such scale and sludge are not well known yet. We made an investigation, particularly on the ferric substances which are present in boiler for heating buildings, generating steam at 100°C and boilers which supply 180°C steam to multistory buildings [2]. In our present research, we made a detailed study on the ferric substance formed in these boilers, and tried to attach a bypass in the pipe and set a magnet from outside in order to remove ferromagnetic ferric substance, Fe_3O_4 , in the boiler.

2. Experimental procedure and results

Arrangement of the boiler, heat exchanger and pipings is shown in Fig. 1. The substances formed in the boiler are yellowish, and are magnetically separated by agitating them in ethanol. The substances taken out from the boiler is called [A], the magnetically-attracted substances is called [B], and non-magnetically-attracted one is called [C]. These substances were determined by Fluorescent X-ray spectrographic analysis (XFA). These materials were determined by X-ray diffraction (XRD) and the average crystalline size D_{311} was evaluated from the width a half maximum of X-ray diffraction line (311) of [B], using Scherrer's formula. The particle morphology was observed by transmission electron microscopy (TEM). The element analysis was made by Energy Dispersive X-ray Spectroscopy (EDX). Magnetization measurements in a magnetic field of up to 15 kOe at 300K were performed by using a vibrating sample magnetometer (VSM). A trial experiment was conducted with a magnetic collective unit by constructing a magnetically-controlling apparatus.

In case of the boiler for heating, water supply is made with city water with a pH of 7.4, which increased to a pH of 10.5 after 6 months during the operation. The XFA data of [A], [B], and [C] reveals that CaCO_3 is contained most, which might supposedly be caused by the use of the city water. Then, Fe_3O_4 , SiO_2 , and MgCO_3 are the order. Fe_3O_4 is contained more than ~20%. On the other hand, the boiler for supplying high-temperature steam is in operation under a pH of 11.5 and the deionized water is used for water supply. Thus, almost none of substances such as CaCO_3 , MgCO_3 , are contained, whereas ferric oxides are contained 98%. Fig. 2 shows XRD patterns of [A], [B], and [C] formed in the boilers. The heat-generation temperature is 100°C in case of heating and CaCO_3 (calcite), spinel structure substance, and SiO_2 can be seen with [A], but the intensity of CaCO_3 is the greatest. The intensity of XRD by the spinel structure is the greatest with [B], and almost all of EDX data shows the peaks by Fe. With [C],

almost all consist of CaCO_3 . This coincides with the XFA data described above. The steam-generation temperature is 180°C in case of high-temperature steam supply, and Fe_3O_4 and $\alpha\text{-Fe}_2\text{O}_3$ are seen with [A] by XRD. The intensity of Fe_3O_4 is the greatest with [B], and almost all consist of $\alpha\text{-Fe}_2\text{O}_3$ with [C]. The lattice constants of Fe_3O_4 and $\alpha\text{-Fe}_2\text{O}_3$ coincide with that of the bulk materials. The average particle size of Fe_3O_4 is 17–27 nm with respect to the boiler for heating, and is 105 nm with respect to the one for high-temperature steam supply. In accordance with TEM observation, either the particle is granular. On the other hand, $\alpha\text{-Fe}_2\text{O}_3$ is 160 nm and is the hexagonal particle. The σ_s with [B] of the boilers for heating and high-temperature steam supply, remains 35–51 and 79 emu/g, respectively. The contents of the ferromagnetic fine particles are great enough to be 67–77 and 92 emu/g, respectively, in consideration of the existence of non-magnetic substances, CaCO_3 , and non-magnetic surface layer [3]. Thus it is revealed that the magnetization of the ferromagnetic fine particles is considerably close to 92 emu/g of the bulk Fe_3O_4 .

An example of the apparatus is shown in Fig. 3. With the plant, collective is made by allowing the substances to be attracted to fall with a bypass attached on part of the pipings and with a magnet equipped on the outer side of the bypass. Furthermore, an example was given by changing the configuration of the magnet to allow the magnetic field to be biased, to be inversely-biased, and to be in parallel. In this investigation, the flow rate and concentration of the aqueous solution were compelled to follow the condition as close as possible to the duration of the operation of the boiler. Higher raise of the collective ratio was noted for the biased and inversely-biased magnetic fields compared with the parallel magnetic field. Additionally, from the TEM observation of the collective and non-collective substances, the result of the composition analysis of the small area with a diameter of ~ 20 nm by EDX is shown in Fig. 4. Judging concurrently from the above-mentioned result and both the results of the fluorescent X-ray spectrographic analysis and XRD in Fig. 2, it can be said that (1) in Fig. 4 are the particles corresponding to CaCO_3 , whereas (2) are the particles corresponding to Fe_3O_4 .

Figure 1: Arrangement of the boiler and piping facility.

Figure 3: Apparatus and bypass in a collective experiment.

a): Boiler for heating buildings.

b): Boiler for supplying high-temperature steam.

Figure 2: X-ray diffraction patterns of substances formed in boiler.

Figure 4: Element analysis using EDX.

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