# Comparative Study of Corrosion Products Formed in Feedwater Heaters of Pressurized Water Reactor

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## 1. Introduction

Effective management and detailed research of corrosion products in the secondary system are essential for the optimal operation and maintenance of nuclear power plants (NPPs). In pressurized water reactors (PWRs), preventing impurities such as chloride, sulfate, and lead and corrosion product from entering the steam generator (SG) is crucial to maintaining plant efficiency and safety [1-3]. Corrosion products formed on the surfaces of secondary system components are transported to the secondary side of the SG, where their accumulation can reduce heat transfer efficiency and block critical flow paths [4-6].

This study focuses on the corrosion phenomena of low-pressure feedwater heater (LP FWH) and highpressure feedwater heater (HP FWH) which are integral to the thermal efficiency of the SG in PWR. By analyzing and comparing corrosion products formed after operation, this study provides valuable insights into how different temperature and pressure conditions affect the formation and behavior of corrosion products. These results are expected to inform maintenance strategies, thereby enhancing the long-term safety and efficiency of NPPs.

#### 2. Experimental methods

To characterize the corrosion products in the secondary system of a PWR (Westinghouse model-F type), samples were collected from the water boxes of the third LP FWH and sixth HP FWH. These water boxes are constructed using SA516 Gr.70 carbon steel. The positions were selected due to their distinct operating conditions with lower temperature and pressure for the LP FWH and higher temperature and pressure in deaerated water for the HP FWH. The corrosion products were scraped form the surfaces using a metal scraper, approximately 250 days after shutdown. Environmental conditions during sampling were a relative humidity of over 95 % and a temperature of approximately 12 °C. The samples were dried at 60 °C for 2 h to remove moisture and stored in a vacuum desiccator.

The collected corrosion products were characterized through various techniques. Optical microscopy (OM) was used to evaluate their macroscopic appearance including color and morphology. Chemical composition was measured using inductively coupled plasma mass spectrometry (ICP-MS). The phases of the corrosion products were identified by X-ray diffraction (XRD), and their microstructures were observed using scanning electron microscopy (SEM) coupled with energydispersive X-ray spectroscopy (EDS).

#### 3. Results and Discussion

Fig. 1 shows the OM images of corrosion products collected from the LP FWH and HP FWH. The samples from the LP FWH were generally red, while those from the HP FWH were dark-red. These color differences suggest the presence of different iron oxides and oxyhydroxides.



Fig. 1. OM images of the samples collected from LP FWH and HP FWH.

Table 1. Chemical composition of the samples collected from LP FWH and HP FWH using ICP-MS (wt.%).

Element	LP FWH	HP FWH
Al	0.04	0.06
Cr	0.06	0.03
Cu	0.01	0.11
Mn	1.77	0.47
Ni	0.02	0.26
Ti	0.02	0.15
Zn	0.02	0.04
Si	0.50	0.35
Na	0.03	-
Pb	-	0.02
Fe	Bal.	Bal.

The chemical composition of the corrosion products was analyzed using ICP-MS. As listed in Table 1, both samples consisted of over 97 wt.% Fe with trace amounts of elements such as Al, Cr, Cu, Mn, Ni, Ti, Zn, Si, Na, and Pb. Na was detected exclusively in the LP FWH sample, while Pb was detected only in the HP FWH sample. Although these impurities were present in small amounts, they could potentially impact material integrity.

Figs. 2 and 3 show the XRD results of the samples from LP FWH and HP FWH, revealing distinct differences between them. The LP FWH sample identified peaks for hematite, goethite, and magnetite. The HP FWH sample identified peaks for goethite, lepidocrocite, and magnetite, but no peaks for hematite. These results indicate that there is a difference in the crystal structure of the corrosion products depending on the operational conditions at the two positions.



Fig. 2. XRD result of the corrosion product collected from LP FWH.



Fig. 3. XRD result of the corrosion product collected from HP FWH.

Fig. 4 shows the SEM images of the LP FWH sample with various particle morphologies including polyhedral, spherical, and rod-like forms. The chemical composition of the polyhedral forms consists of approximately 54.3 at.% and 45.7 at.% Fe, the spherical forms consist of approximately 60.8 at.% O and 39.8 at.% Fe, and the rod-like forms consist of approximately 59.0 at.% O and 41.0 at.% Fe.

Fig. 5 shows the SEM images of the HP FWH samples with different particle morphologies such as thin and flat sheet, bar, and thorny forms. The chemical composition of the thin and flat sheet forms consists of approximately 69.9 at.% O and 30.1 at.% Fe, the bar forms consist of approximately 60.9 at.% O and 39.1 at.% Fe, and the thorny forms consist of approximately 69.4 at.% O and 30.6 at.% Fe. Notably, the polyhedral morphology that is characteristic of magnetite was not observed. As magnetite was detected by the XRD analysis, it is suggested that magnetite may be present inside the sample.



Fig. 4. SEM images of the corrosion products collected from LP FWH.



Fig. 5. SEM images of the corrosion products collected from HP FWH.

#### 4. Conclusions

Corrosion products collected from LP and HP FWHs were characterized using OM, ICP-MS, XRD, and SEM. The results revealed that hematite is the dominant corrosion product in LP FWH, while magnetite was predominantly formed in the HP FWH. However, SEM results indicated that the characteristic polyhedral morphology of magnetite was not observed, and only the distinct morphology of iron oxyhydroxides was present. These results deviated from the expected corrosion behavior in the HP FWH and were considered to be influenced by exposure to the atmosphere after shutdown.

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