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EXAMINATION OF WATER-FORMED DEPOSITS IN STEAM BOILERS BY SCANNING ELECTRON MICROSCOPY

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Industrial boiler from a broad range of industrial, commercial, and institutional operations commonly fail due to overheating caused by the deposition of water-borne mineral scales inside the boiler tubes. It is estimated that the major cause of steam generator downtime is due to failure of tubular components [1]. The growth of water-borne deposits results from the combination of precipitated mineral matter and tube-metal oxidation products. If allowed to grow unchecked, eventually these deposits can lead to an insulating deposit layer with reduced heat transfer, causing tube bulging and eventual failure due to stress rupture [2]. In addition, underdeposit concentration of acidic or caustic species can rapidly pit or gouge tube metallurgy.

Characterization of boiler deposit composition can be performed using various laboratory techniques [3,4,5,6] such as scanning electron microscopy-energy dispersive X-ray analysis (SEM-EDS), energy dispersive fluorescence (XRF), Fourier transformed infrared analysis (FTIR), and X-ray diffraction (XRD). SEM-EDS is particularly useful in identifying the non-uniform nature of deposits and chemical layering. Proper analysis of boiler deposits requires that the degree of material heterogeneity be taken into account during the SEM-EDS analysis [7,8].

A boiler tube was analyzed that had failed in a bulged area via a longitudinal rupture, indicative of long term overheating. Figure 1 shows the severity of the internal deposit build-up on the waterside surface. Metallographic analysis confirmed overheating, as evidenced by decomposition of the carbide phase in the steel microstructure, and the presence of intergranular creep voids. Examination of the waterside deposit showed that it was composed of iron oxide, metallic copper, silica, and hardness scale, see Figure 2. These constituents indicate poor control of plant water chemistry. A subsequent review of on-line chemistry showed there were many upsets in feedwater chemistry and steam condensate quality being returned to the boiler as make-up.

Acid phosphate corrosion was determined to be the failure mechanism in boiler tubing removed from a heat recovery steam generator (HRSG). This plant was subject to significant cycling, which made it difficult to maintain consistent boiler feedwater quality. Figure 3 shows the black deposit on the internal surface of the tube. A whitish deposit layer which was revealed after the top layer was removed, see Figure 4. The extracted layers of the white deposit were analyzed by ìXRD techniques. Maricite ($NaFePO_4$) and magnetite (Fe_3O_4) were confirmed as the two principal compounds. SEM-EDS analysis of the top layers of the deposit showed they were composed of magnetite/hematite and elemental copper. This fouling created a localized deposit accumulation increasing the potential for under-deposit acid phosphate corrosion, which perforated the tube, see Figure 5.

In summary, SEM-EDS is a valuable technique for examination of water-borne deposits in industrial boiler tubes. However caution should be exercised to fully appreciate the limitations of microscopic deposit analysis whenever regional differences in elemental concentration exist.

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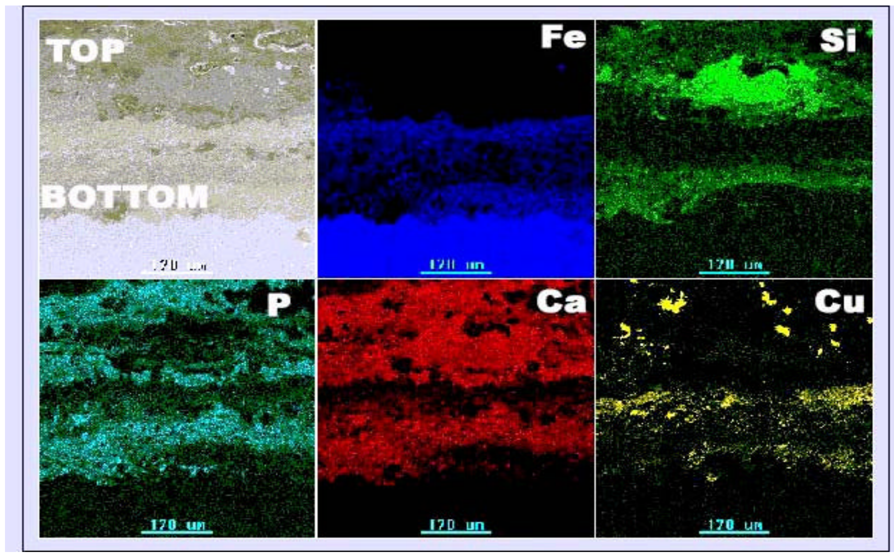

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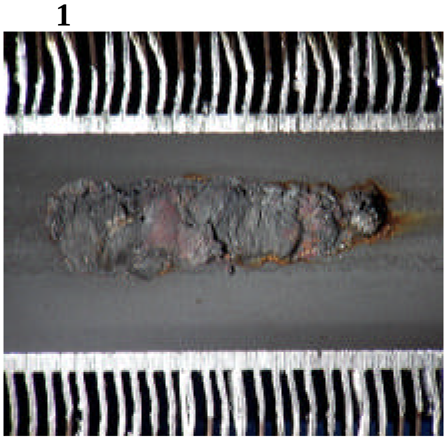

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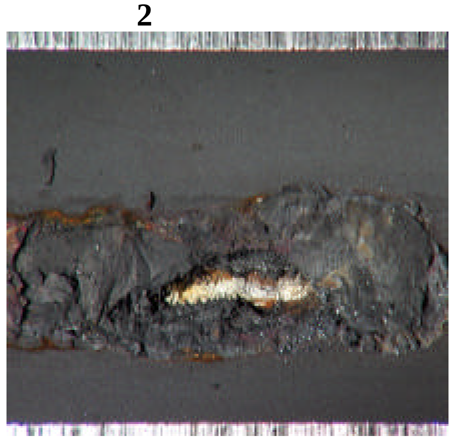

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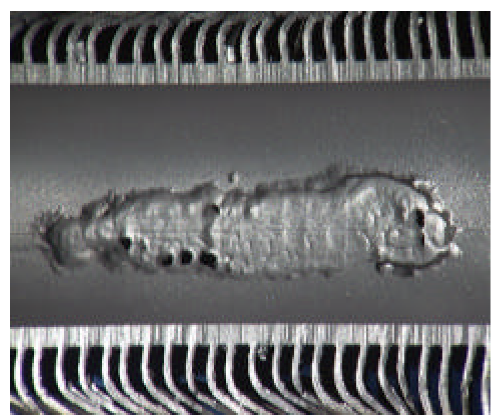

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FIG 1. Build-up of internal copper, silica, and hardness scale on the boiler tube waterside surface.

FIG 2. SEM-EDS Mapping of elemental constituent concentration at 150x, cross-sectional view.

FIG 3. Build-up of iron and copper deposits at corrosion gouge in a HRSG boiler tube interior.

FIG 4. Discovery of white maricite ($NaFePO_4$) underneath magnetite (Fe_3O_4) at corrosion site.

FIG 5. Topography of corrosion gouge, revealed after glass bead cleaning, note perforations.

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