CORROSION OF BOILER TUBES IN A PALM OIL MILL

HOCK-CHYE QUA*; KOK-CHEONG WONG**; JEE-HOU HO**; ENG-HWA YAP**
and CHING-SEONG TAN‡

ABSTRACT
This article investigates the leaking of tubes in a water tube boiler used in a palm oil mill. Leaks were discovered in the roof tubes and the rear wall tubes of the boiler. Samples of the punctured tubes were removed for examination. Micro- and macro-examinations were conducted to determine the causes of failure. EDX/SEM (energy dispersive X-ray spectroscopy/scanning electron microscope) was also conducted to examine the composition of the elements of the specimens and a high concentration of sodium was shown. Key outcomes from the investigation are outlined in this article. They indicate that caustic corrosion was the cause of the leakages of the tubes.

INTRODUCTION
A D-Type water tube boiler (Figure 1) was used in a palm oil mill. The boiler used biomass products from the oil palm estate as fuel. The work-flow of the boiler has been described by Heselton (2005). The dashed yellow arrows in Figure 1 show the hot gases flowing into the boiler where these gases impinged directly on the rear wall tubes, the roof tubes and the superheater tubes. The roof tubes were located at the top of the boiler where there was direct exposure to the hot gas flow path. The rear wall tubes connected the steam drum and the water drum, and were similarly exposed to the hot gas flow. Two roof tubes were initially found to be leaking, and many others were also found to be similarly affected when subjected to a hydrostatic test. Leaks were later discovered in the rear wall tubes as well. An investigation was conducted into the factors causing the leakages in the boiler tubes. Samples from both the punctured roof tubes and rear wall tubes were examined, and it could be observed that all the tubes had sharp-lipped punctures with deep gouges in the vicinity of the punctures. There were also localised groupings of deposit mounds located in the same axial line with the puncture. Raw water was obtained from a pond, while the chemicals that were added for boiler water treatment were sodium sulphite, phosphate and sludge conditioner.

METHODS OF INVESTIGATION
Samples of the tubes that had leakages were removed from the boiler, and were subjected to macro-examination, metallographic examination and EDX/SEM (energy dispersive X-ray spectroscopy/scanning electron microscope) examination. The macro-examination was conducted to inspect the physical attributes of the damage, and to examine the internal and external surfaces of all the tubes, especially around the vicinity of the punctured areas. Cut-out sections were taken from the samples to examine the extent of the defects (the initial and advanced stages of defect development) in the tubes. The metallographic examination was conducted to study the micro-structure of the deposits both on the punctured areas and on unaffected areas. Finally, the EDX/SEM examination was conducted into the factors causing the leakages in the boiler tubes. Samples from both the punctured roof tubes and rear wall tubes were examined, and it could be observed that all the tubes had sharp-lipped punctures with deep gouges in the vicinity of the punctures. There were also localised groupings of deposit mounds located in the same axial line with the puncture. Raw water was obtained from a pond, while the chemicals that were added for boiler water treatment were sodium sulphite, phosphate and sludge conditioner.
to analyse the chemical composition of the deposits in the vicinity of the punctured areas. The tubes were made of carbon steel which had been verified to contain about 0.1% carbon.

Macro-examination/Visual Inspection

Three tube samples shown in Figure 2 were removed for examination. Two of them were roof tubes with an outer diameter (OD) of 75 mm; these were designated as Tubes A1 and A2. The third tube was taken from the rear wall, and had an OD of 60 mm; this was designated as Tube B. All the tubes were straight except for Tube A2 which had a bend. All three tubes had sharp-lipped punctures originating from the inside of the tubes. Enlarged views of the punctures in Tubes A1, A2 and B are shown in Figures 3a and 3b, respectively. Figure 3a (Tube A1) shows that the puncture side contained irregular, separated mounds of deposits (L1) over half of the circumference of the tube. A deep gouge (L2) was present in the vicinity of the puncture. Figure 3b (Tube A2) shows that the puncture had occurred at the intrados of the bend where several deposit mounds were present on the internal surface. These deposits were in the same axial line with the intrados and occurred up to the flank or midway between the intrados and extrados (circled in yellow) as shown in Figure 3b. A deep gouge (P) was present in the vicinity of the puncture. Only traces of deposit mounds could be seen in the same axial line with the extrados, while more deposits were present in the same location between the intrados and extrados, as described above. Definitions of the terms intrados, extrados

Examination of the internal surfaces of the tubes was carried out. The side of the internal surfaces containing the punctures in Tubes A1 and A2 are shown in Figures 3a and 3b, respectively. Figure 3a (Tube A1) shows that the puncture side contained irregular, separated mounds of deposits (L1) over half of the circumference of the tube. A deep gouge (L2) was present in the vicinity of the puncture. Figure 3b (Tube A2) shows that the puncture had occurred at the intrados of the bend where several deposit mounds were present on the internal surface. These deposits were in the same axial line with the intrados and occurred up to the flank or midway between the intrados and extrados (circled in yellow) as shown in Figure 3b. A deep gouge (P) was present in the vicinity of the puncture. Only traces of deposit mounds could be seen in the same axial line with the extrados, while more deposits were present in the same location between the intrados and extrados, as described above. Definitions of the terms intrados, extrados
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The internal surface of rear wall tube (Tube B) is shown in Figure 4. The internal surface viewed from the B1 end (Figure 4a) near the puncture shows that deep gouges were present in the vicinity of the puncture. Traces of deposit mounds (circled in black) were also visible. At the other end, B2 (Figure 4b), a localised grouping of deposit mounds could be observed and the cross-section of this location is shown in Figure 5. This cross-section clearly showed that the internal deposits had a thickness of approximately 1 mm, covering almost the entire internal circumference of the tube. However, the deposit thickness in the localised area in the same axial line with the puncture was greater than 2 mm, and was composed of constituents with different colours (white and brownish).

To analyse the corrosion occurring in the internal surface in the puncture area, two specimens were...
extracted from the punctured areas of Tubes A1 and B as shown in Figures 6a and 6b, respectively. The arrows in Figure 6a show the extent of the gouging (approximately 36 x 30 mm diameter) and two small punctures (as enclosed by the circle). Figure 6b shows the various layers of deposits with different hues, including white, that were present in certain areas. Thick and even brownish deposits were present in other areas.

**Metallographic Examination**

Metallographic examinations were conducted in the vicinity of the punctures of Tubes A1 and B. Various metallographic specimens were extracted from Tubes A1 and B as follows:

- Specimen SP-B2: a longitudinal section removed from the B2 end of Tube B, containing thick scale/deposits but no puncture. This specimen would show the initial stages of the development of leakages in the rear wall tube.
- Specimen SP-B1: a transverse section removed from the B1 end of Tube B, in the vicinity of the puncture. This would show an advanced stage of failure in the rear wall tube.
- Specimen SP-A1: a transverse section across the puncture in Tube A1. This would show an advanced stage of failure in the roof tube.
In Specimen SP-B2, a thick, multi-layer deposit with a mottled appearance was observed with some of the sub-layers containing needle-shaped crystals as shown in Figure 7.

In Specimen SP-B1, a thick, multi-layer deposit was also present, as shown in Figure 8a. The layer had a mottled appearance and was composed of sub-layers with different colours. Needle-shaped crystals were also present in certain sub-layers. The deposit layer was similar in structure to that observed in SP-B2, with the only difference being the colour. The etched microstructure comprised medium-grained pearlite (darkish) in a matrix of ferrite (whitish) with a carbon content of approximately 0.1% as shown in Figure 8b. No abnormalities were observed, and there was no visible thermal degradation of the pearlite.

For Specimen SP-A1, the microstructure of the tube wall is presented in Figure 9b. A sharp-lipped puncture can be observed near the location of the arrow. The microstructure had transformed from the original, equilibrium pearlite and ferrite to more non-equilibrium forms (Figure 10). When the region Q in Figure 9b was magnified, the microstructure appeared to be coarse Widmanstatten ferrite with some pearlite as shown in Figure 10.

The circled area in Figure 9b was enlarged in Figure 9a, showing only a thin layer of mottled deposits. When the regions shown by arrows in Figure 9a were magnified, needle-shaped crystals were observed. The deposit layer was similar to that observed in SP-B2.

**Elemental Analysis Using EDX**

A small section of the specimen containing the multi-hued deposit (Figure 6b) and a small section of Specimen SP-B2 (Figure 7) were analysed using EDX in a scanning electron microscope. Both samples gave the same pattern of results. A typical result is presented in Figure 11, which shows abnormally high sodium (Na) content, in excess of 16% by weight. The high detected content of aluminum (Al) came from the residues of aluminum used in treating the raw water, and this is not
normally tested for by the palm oil mill. The high detected content of silicon (Si) came from the silica dissolved in the water, which was not removed by treatment. Both Al and Si were in dissolved form and though initially in low concentrations, would have been concentrated by wick-boiling. They only contributed to the formation of the deposits and did not contribute to the corrosion process.

DISCUSSIONS

The three tube samples supplied for examination all had sharp-lipped punctures which were initiated from the inside of the tubes. It may be inferred that the problem had been caused by some interaction between the water/steam and the metal of the tube wall. The internal surfaces of all the tubes had the following common characteristics:

- separated mounds of deposits were present;
- the vicinity of the punctures contained deep gouges on the internal surface of tubes;
- deposits of varying thicknesses and hues were present, in particular, whitish deposits visible to the naked eye. Sections examined under the microscope had a mottled appearance and some sub-layers contained needle-shaped crystals; and
- EDX analysis showed the presence of abnormally high concentrations of Na.

The above characteristics are typical of a form of under-deposit corrosion known as ‘caustic gouging’ (EPRI, 1993; Howell, 2006; Khajavi et al., 2007; Wood et al., 2007). This corrosion is due to the presence of NaOH, possibly from a direct source or from an indirect source of sodium salt (Khajavi et al., 2007). The reactions of the caustic corrosion with iron (base material) and iron oxide (oxide on...
Caustic gouging corrosion in industrial boilers is a common phenomenon (Khajavi et al., 2007; Wood et al., 2007). However, there are very limited references or case studies related to caustic gouging corrosion in the boilers of palm oil mills which is different from industrial boilers with regards to water source and treatment.

**CONCLUSION**

The three tube samples investigated comprised two roof tubes and one rear wall tube. All contained visible punctures that would have caused leaks. All tubes had characteristic multi-hued, multi-layered deposits and gougings in the vicinity of the punctures. Some of the layers contained needle-shaped crystals within the deposits, and in general, contained very high concentrations of Na. These features are typical characteristics of a form of under-deposit corrosion known as caustic gouging. The proximate causes are the formation of a porous deposit layer, the presence of NaOH in the water (from added chemicals) and a heat flux high enough to cause wick-boiling and concentration of NaOH, which then becomes a corroding agent. It is suspected that the sodium content found in the deposits may have originated from the chemicals used in the internal treatment of the boiler, one of which is sodium sulphite. The high content of dissolved solids detected in the raw water was very likely the root cause of the formation of the porous deposits, which in turn had resulted in local overheating and subsequently the production of a corrosive environment capable of inducing caustic gouging corrosion. Unlike other industrial boilers, the feedwater for the palm oil mill boiler is mainly derived from raw water because not much condensate return can be recovered; thus, the water treatment for a palm oil mill boiler needs to be enhanced.

**REFERENCES**


