SIDE WALL TUBE FAILURE IN LOW PRESSURE BOILER

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Introduction:

Several leaks observed in boiler water wall tubes after being in service for 22 years. Design capacity was 137 T/h of steam at max pressure of 15.7 barg and design temperature of 203 ́C. Steam operating temperature was about 198 ́C.

Carbon steel A-178 Grade A tubes were 50.8 mm in OD and wall thickness of 2.9 mm. Steam drum thickness was 32 mm and water drum 20 mm.

Boiler feed water treatment program based on trisodium phosphate, oxygen scavenger and anti-scalant. BFW inlet temperature was about 160 ́C.

Portions of failed tubes received for lab examinations and analyses.

VISUAL VIEWS OF INTERNAL SURFACES AS RECEIVED

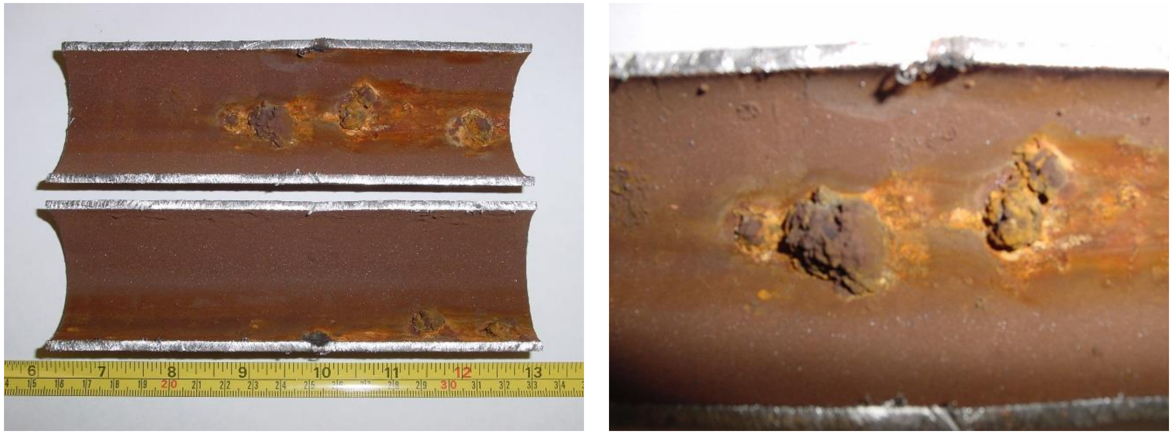


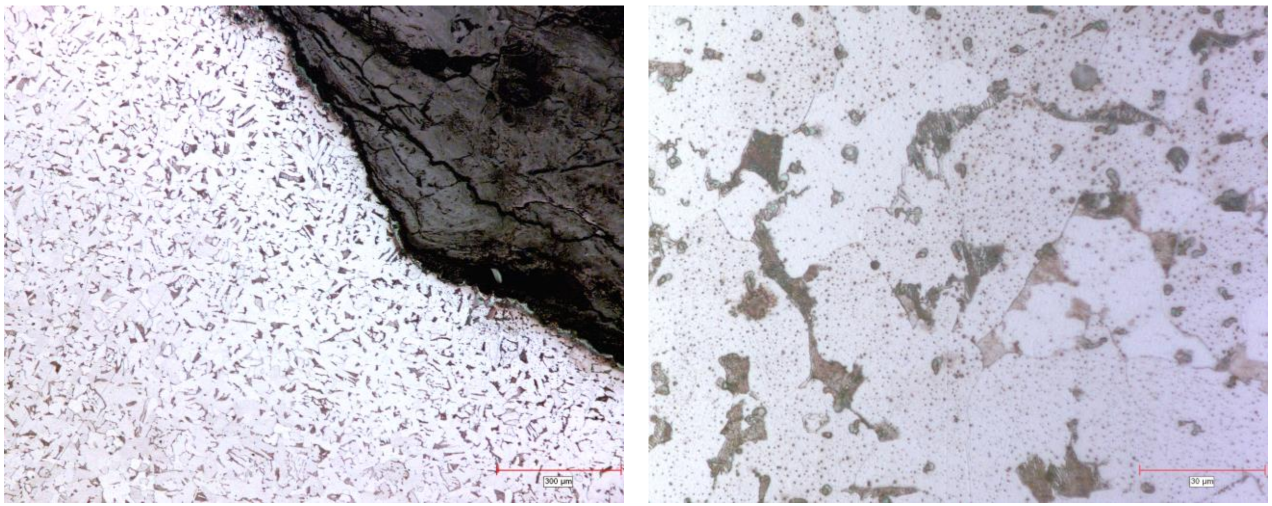
Figure 1: Close-up photos of split tube showing separate big (10 mm in height & diameters up to 12 mm) tubercles developed on ID surface exposed to hot gas.

Figure 2: Photographs showing through thickness hole on ID (A) and OD (B) after mechanical removal of hard tubercle. Note conical crater of hole on ID.

Stereo Microscopy & Metallographic Examinations

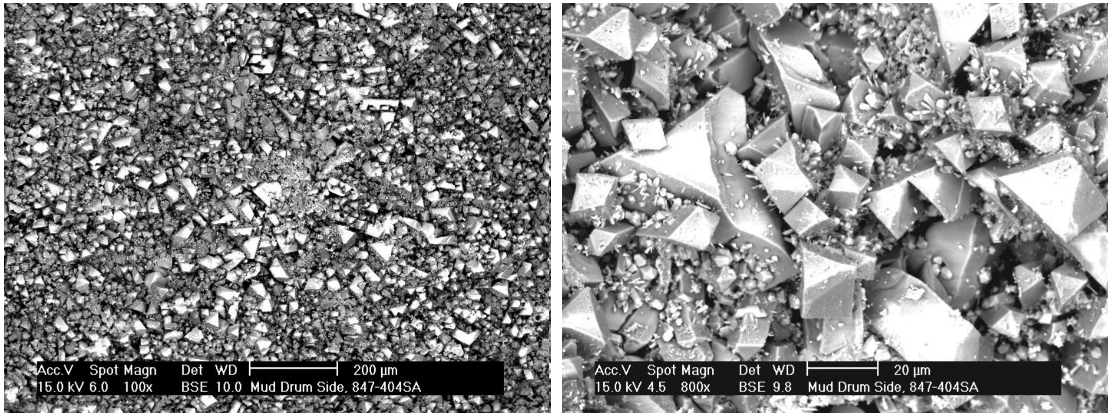
Figure 3: ID sound surface showing the presence of uniform brownish layer with incorporated numerous bright particles.

A



B

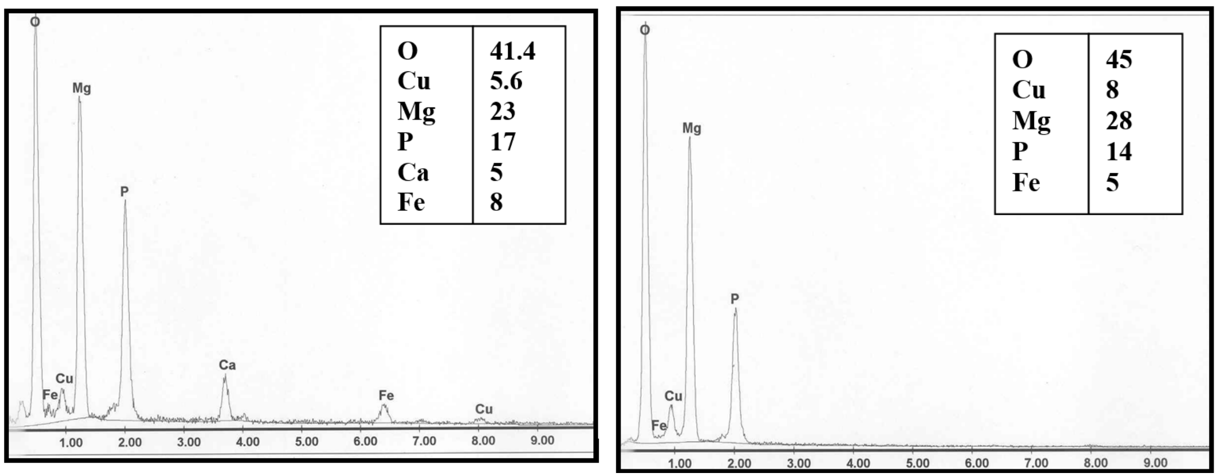
Figure 4: Normal pearlite-ferrite microstructure of area next to the hole at OD, A,100X; B, 1000X.



A B

Figure 5: BSE images of ID sound surface showing numerous big pyramidal crystals along with finer particles and EDX spectra detecting high O, Mg, P, Ca and Cu peaks , (A, 100X; B, 800X).

A



B

Figure 6: EDX spectra of the sound surfaces showed in Figure 5 (A – Area analysis ; (B) pyramidal crystals

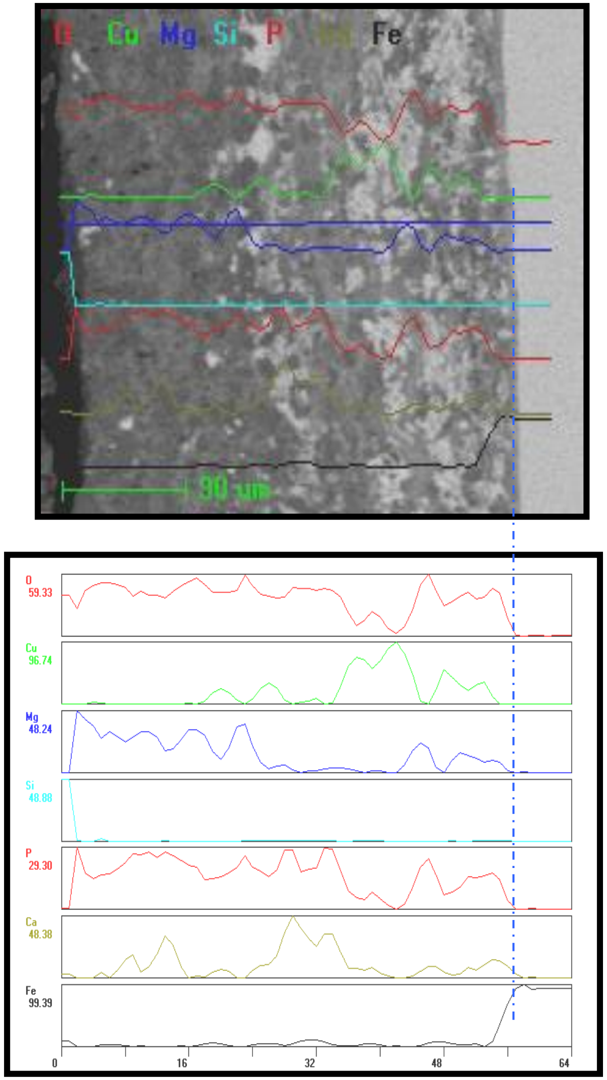
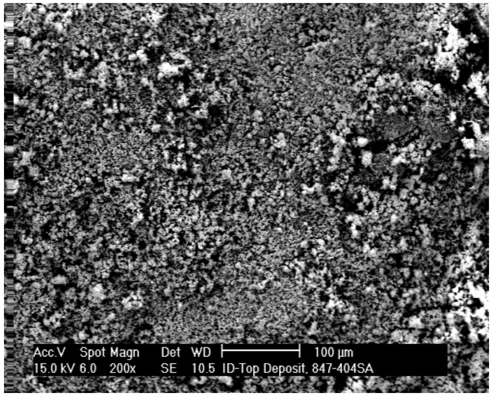
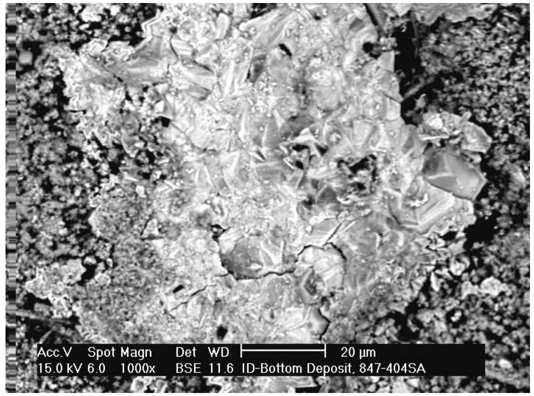


Figure 9: Distribution of the detected elements in the thin parallel plate-like crystals showing in Fig. 8.



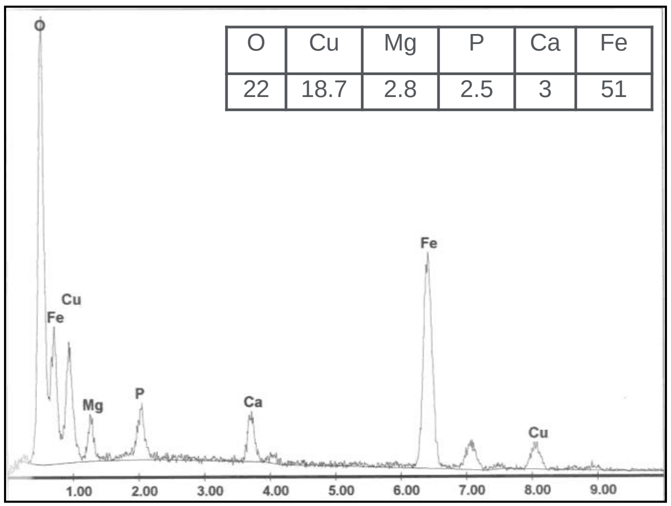
A



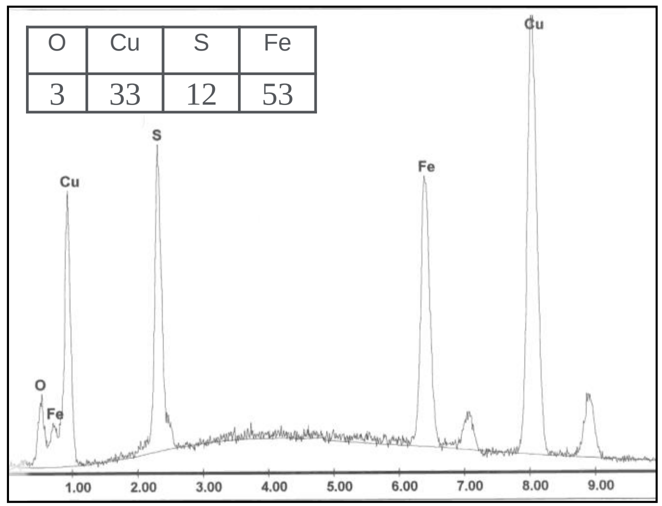
B

Figure 7: Micrograph (SEM) of the tubercle top surface beneath of loose outer layer (A, 200X) and BSE image of its bottom surface (B, 1000X). Note large whitish area rich in Cu and S (form EDX spectrum).

A



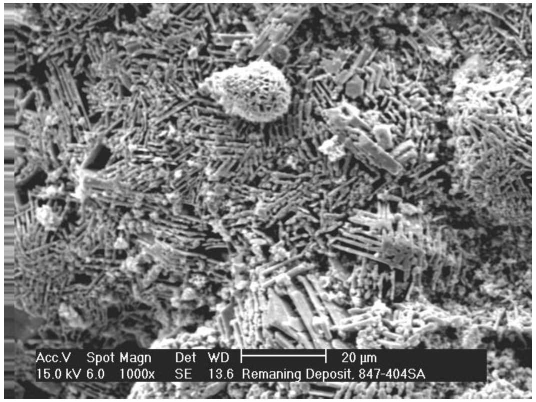
O	Cu	Mg	P	Ca	Fe
22	18.7	2.8	2.5	3	51



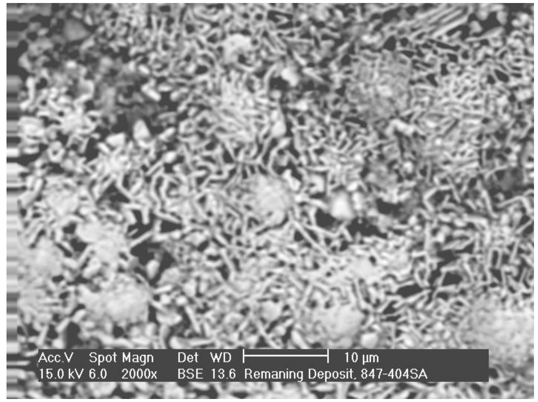
O	Cu	S	Fe
3	33	12	53

B

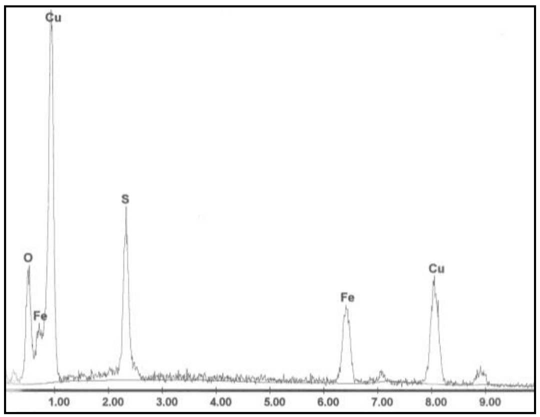
Figure 8: Micrograph (SEM) of the tubercle top surface beneath of loose outer layer (A, 200X) and BSE image of its bottom surface (B, 1000X). Note large whitish area rich in Cu and S (form EDX spectrum).



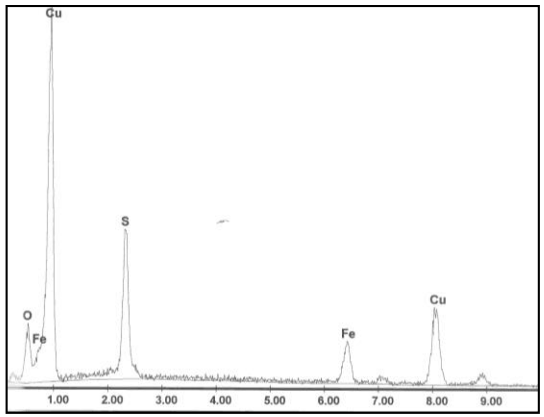
A



B

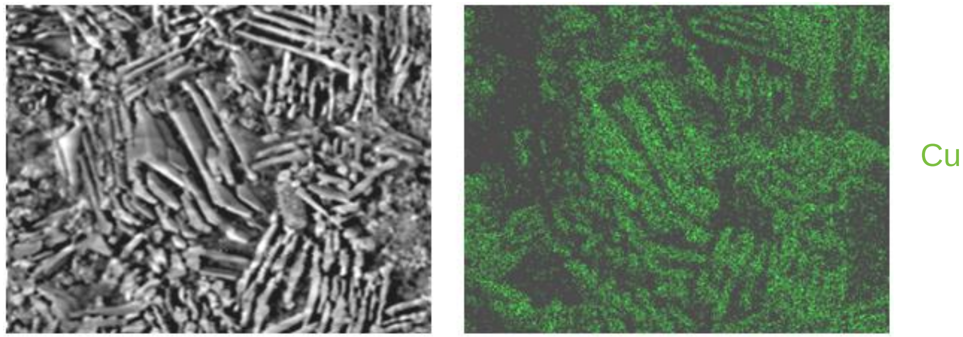


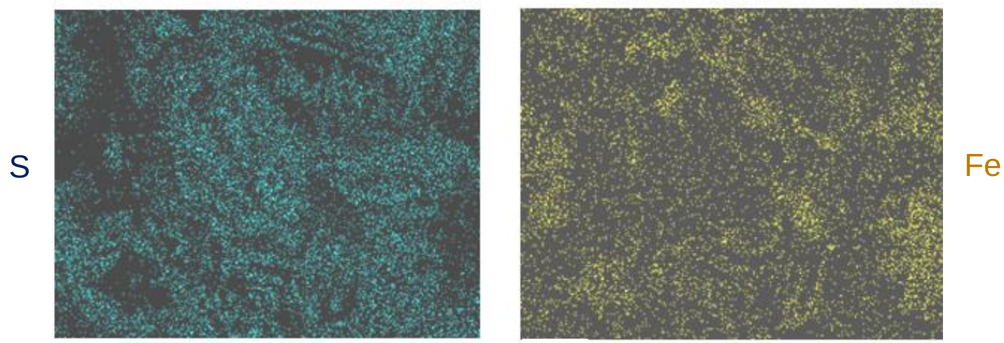
A



B

Figure 9: BSE image and EDX spectra of the tubercle remaining middle portion (black in color) removed by hammering. Note the presence of crystals as thin parallel plates and rounded particles rich in Cu and S.





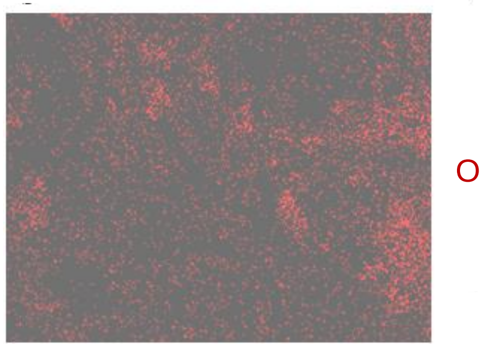


Figure 10: Distribution of the detected elements in the thin parallel plate-like crystals showing in Fig. 9.

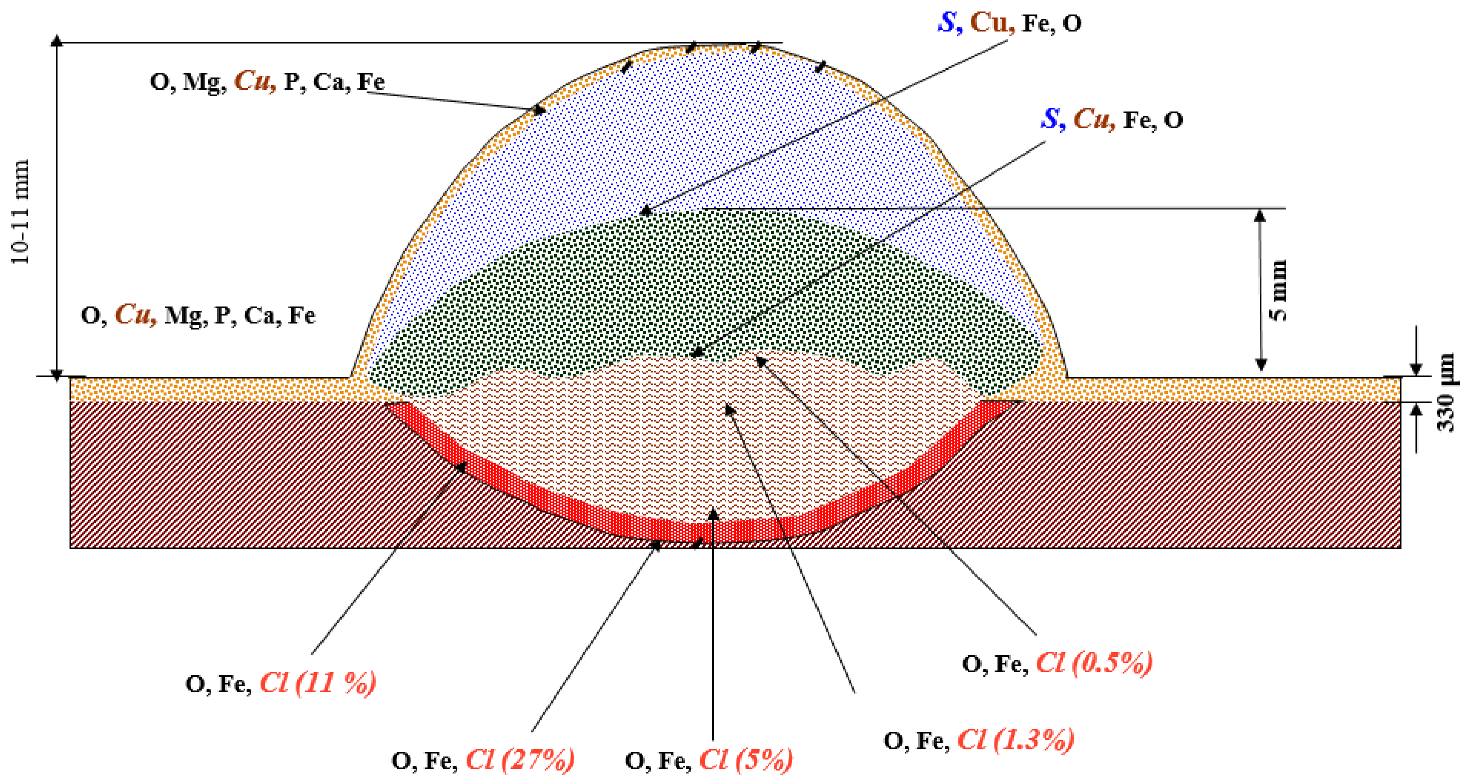


Figure 11: Schematic structure of the well-developed tubercle on the failed tube ID and distribution of the detected elements across thickness. Note high chlorine content in the bottom layers.

GENERAL FINDINGS AND COMMENTS

- No microstructural abnormalities.
- Highly structured tubercles with extremely high chlorides content in thin layer adjacent to the pit floor.
- Chlorides concentration gradually decreased from floor of the pit towards tubercle middle and was not found in areas above.
- Sea water mixed with BFW due to Cu-Ni tubes perforation in evaporation system resulting in increase of Cl and Cu contents and conductivity.
- Copper found mainly as elemental/metallic form with small quantity as copper sulfide.
- Maximum concentration of Cu was within thin (17 µ) layer about 70 µ away from tube metal surface in sound area.
- Copper was detected only on tubercle top portion, not in portion locate inside the hole.
- Generally, copper induced failures of boiler components are very rear in practice, excluding specific cases such as LME at welding.

PROPOSED FAILURE MAIN STEPS AND MECHANISM

- Sea water mixed with BFW due to Cu-Ni tubes leak in evaporation system and increased Cl and Cu concentration along with conductivity.
- Chlorides penetrate protective magnetite layer and activated tube surface at hot side and copper dispersed and precipitated in surface layer with max content slightly away from tube metal.
- Anodic dissolution (metal loss) started according to the reaction with formation of ferrous ions:

$$Fe \rightarrow Fe^{++} + 2e^{-}$$

- Chloride ions easily reacted with ferrous ions at the floor-boundary and near the floor forming hydrochloric acid and ferrous chloride:

$$Fe^{++} + 2Cl^{-} + 2H_2O \rightarrow Fe(OH)2\downarrow + 2H^{+} + Cl$$

$$Fe^{++} + 2Cl^{-} \rightarrow Fe^{++} + 2Cl^{-}$$

- Ferrous chloride hydrolyzed in the presence of water forming hydrochloric acid:

$$FeCl_2 + 2H_2O \rightarrow Fe(OH)_2 + 2HCl.$$

- The presence of chlorides increased acidity inside the pit significantly intensifying corrosion process.
- Accumulation a lot of insoluble and little soluble corrosion products inside the formed pit.
- Usually tubercles form as mounds of corrosion products and deposit that cap localized pit.
- Often forms in oxygenated waters and waters with high bicarbonate alkalinity as well as in waters with high chlorides, sulfates, and other aggressive ions.

MAIN CONCLUSIONS

- The results of failure investigation make it possible to conclude that the boiler tube failed according to chloride induced localized corrosion mechanism.
- Primary reason for such failure was mixing of sea water with BFW due to perforation of cupro-nickel tubes in the evaporating system.
- Presence of copper aggravated intensity of localized corrosion.
- Frequent shutdowns and start-ups with relatively long intervals promoted possible oxygen and MIC type of damages in some extend.
- Schematic structure of well-developed tubercle was proposed.

MAIN RECOMMENDATIONS

- Avoid any mixing of sea water with BFW
- Chemical cleaning was recommended followed with hydro test and plugging of leaked tubes.
- Actual remaining thickness should be determined.
- Both steam and mud drums should be inspected for any corrosion intensity
- Asses complete re-tubing, if practical.
- Elbow portions with weld joints of economizer inspected by radiography to asses integrity.
- Care should be given to more precise and frequent monitoring of chlorides, copper and oxygen contents in BFW.
- More steady operation of the boiler was also recommended.