

Studies on the Failure of Economizer Tubes Involving Acid Dew-Point Corrosion in High Pressure Boilers

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Abstract

Boiler tube failure is a major cause of concern to plant engineers as it leads to many forced outages of the power plants. The cause of failure may be associated with waterside corrosion, fire side corrosion, overheating, stress rupture, erosion or fatigue. H₂SO₄ dew-point corrosion or cold end corrosion has been a quite common occurrence in boilers running on fossil fuels, S plays an important role in promoting the attack. The H₂SO₄ dew-point corrosion sometimes inflicts catastrophic failure resulting in colossal losses in terms of power production.

This paper gives an account of the phenomenon of acid dew-point corrosion in power plants. It provides information about the cause(s) of corrosion, mechanism(s) involved and the ways to combat the problem. Three case studies dealing with the failures of economizer tubes in different power/water cogeneration desalination plants are illustrated.

Keywords: Power/water cogeneration plant, economizer tube, high pressure boiler, flue gas, dew-point corrosion, sulfur, Vanadium

1 INTRODUCTION

Boilers are used to heat water to generate steam for power generation. The main components of boiler include water-wall tube, superheaters and economizer. The failure of boiler is a common phenomena and the causes of the failure might include pitting, erosion, fatigue, creep and stress corrosion cracking. Some specific types corrosion include caustic gouging, acid phosphate corrosion, acid dew-point corrosion and hot corrosion. The cause(s) of tube failure in different sections of the boiler have been reported: 40% in water wall tubes, 30% in superheater, 15% in reheater, 10% in economizer and 5% in cyclotron [1].

The literature is abound with numerous studies regarding corrosion of boiler tubes, some recent references worth-mentioning are those of Lopez-Lopez et.al. [2] who related carbonization of austenitic stainless steels with high corrosion rates, Srikanth et.al. [3] studied fire side corrosion in a heat recovery boiler, Dhua [4] carried out investigations of boiler of water wall tubes failure in a thermal power station and pointed out the cause of failure to localized exposure to

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high temperature (723-908°C). Some case studies related to boiler failure in power/water cogeneration (dual purpose) desalination plants include: multiple type corrosion failure of boiler tubes [5], premature water side corrosion of furnace wall tubes in a high pressure boiler [6] and caustic corrosion failure of back wall riser tube in a high pressure boiler [7].

In recent years, Saline Water Desalination Research Institute (SWDRI) received many cases of failure of economizer tubes from different power/water cogeneration (dual purpose) thermal desalination plants. In general, the investigations showed that the failure had been reported mainly from plants using high sulfur content fuel oil and the cause of the failure could be attributed to dew-point corrosion. The presence of sulfur oxides (predominantly SO₂ with small concentration of SO₃) in the flue gas is the major cause of corrosion. Depending on the sulfur content of the fuel, amount of excess air during combustion and flame temperature, approximately 1 to 2% of SO₂ is further oxidized SO₃. The sulfur oxides combining with moisture in the flue gas or superheated water vapors form sulfuric acid (H₂SO₄) vapors which condensed to sulfuric acid (liquid) at lower temperature. When SO₃ combines with superheater water vapors, the formation of H₂SO₄ begins to occur at the temperature which is commonly known as acid dew-point. Under normal boiler conditions, the acid dew-point is in the range of 115.5 to 138°C. For dew-point temperature, the metallic temperature is the most important parameter to be mentioned and not the flue gas temperature. It means that if the flue gas temperature is above the dew-point temperature and the tube metal temperature is lower than the dew-point temperature even then acid condensation can occur.

The economizer is a horizontal continuous type counter flow heat exchanger located beneath the horizontal section of primary superheater where a low gas temperature is maintained. The economizer is the final preheat of the boiler feed water before it passes into the steam drum. The boiler feed water before entering the steam drum passes through the economizer where heat is recovered from the flue gases leaving the boiler. Economizer tubes are either constructed with cast iron as in case of low pressure industrial boilers ($\leq 2.5\text{MPa}$) or steel tanks for high pressure boilers.

Economizer tubes are subjected to both external (fireside) and internal (water side) corrosion. The external corrosion is a function of sulfur and moisture in the economizer, tube metal temperature and method of firing and is generally caused due to the condensation of water vapors in the flue gases. Such type of corrosion can be avoided by keeping the tube metal temperature above the dew-point and tube surface free from corrosive deposits. The internal corrosion is caused due to the presence of oxygen in the feed water and improper pH. The internal corrosion can be prevented by maintaining the feed water heaters or deaerators and injection of proper chemicals into the feed water for oxygen scavenging and pH control.

Failure of economizer tube of a high pressure boiler of a dual purpose power/water cogeneration plant was reported [8]. The failure was observed in the form of rupturing of one tube and a manhole (pin hole) in another tube. The cause of the failure of the economizer tube was attributed to be H₂SO₄ – dew-point corrosion. Relatively low temperature of feed water lowered the tube metal temperature and promoted the condensation of H₂SO₄. The bunker oil firing further helps in lowering down the metal temperature which resulted in enhancing the corrosion of the tube wall. Failure investigation was carried out on 3 tube sample from an

economizer using visual/metallographic examination and analysis of operational testing [9]. Three tube samples were found to suffer from abnormally high wastage at both the external and internal surfaces and deep pitting. The wastage at the external surface has been attributed to acid condensation attack on the cold surfaces during stoppages. Wastage and pitting at the internal surfaces has been due to oxygen attack. The source of oxygen in the feed water had been due to mal-functioning of the deaerator over long periods. Internal wastage/pitting led to excessive tube thinning and in consequence leakage of the tube.

2 CASE STUDIES

In the following section, four case studies related to failure of economizer tubes in Saline Water Conversion Corporation (SWCC) power/water cogeneration desalination plants are described and the mechanism and cause (s) of failure are discussed. Recommendations are given to prevent the reoccurrence of failures.

2.1 Case – 1

Leakages were reported in the economizer tubes in boiler #7 of SWCC dual purpose power/water plant. The plant had been in service for about 4 years after commissioning at the time of failure. Figure 1 shows a sketch of the boiler leaked economizer coils. Table 1 provides operating parameters of the economizer tubes.

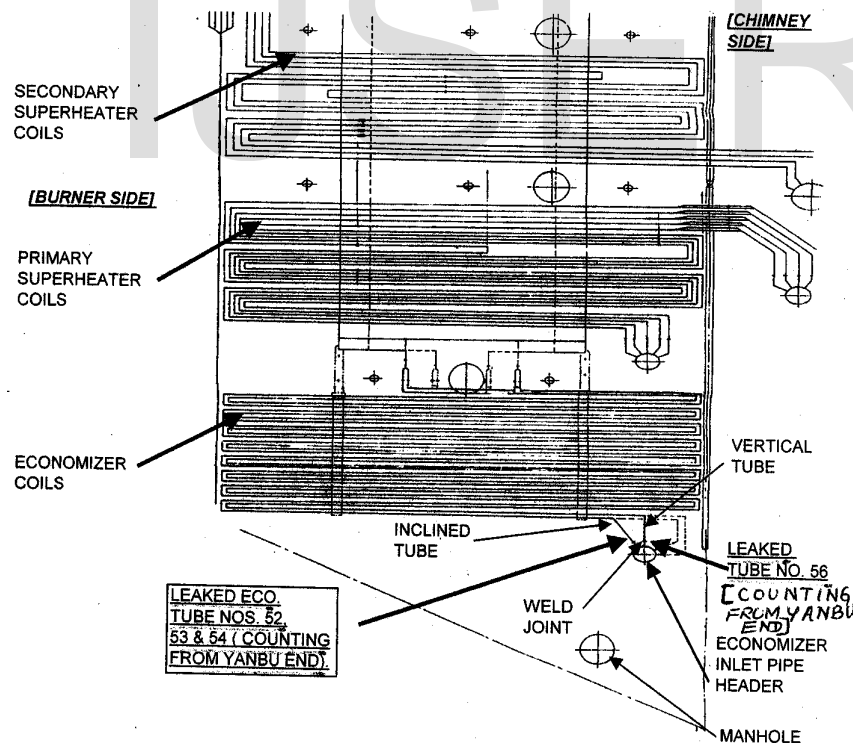


Figure 1. Sketch of Boiler # 7 leaked economizer coils

Table 1. Technical information, Boiler # 7

Make : Ansaldo Energia, Italy

Boiler design pressure	:	76 bars
Feed water temp. at economizer inlet	:	196°C
Steam flow at SH-2 outlet	:	602 Ton/Hour
Steam pressure at SH-2 outlet	:	64 bar G
Temp. at SH-2 outlet	:	530 °C
Drum operating pressure	:	64 bar G
Feed water temp. at economizer outlet	:	227°C
Flue gas inlet temperature	:	435°C
Flue gas outlet temperature	:	341°C

Physical Examination

Physical examination of the economizer tube in as received condition shows that most of the corrosion activity was confined to weld or surrounding area. The front side (A) and back side (B) of the economizer tube have different morphologies. Side A (Fig. 2): corrosion products are concentrated at the weldment and the metal is eaten away at the weld. Side B (Fig. 3): it has macropits, pinholes and holes at and in the vicinity of weld. There is marked reduction in thickness of the tube wall in the vicinity of the weld. Figure 4 shows wall thickness at different locations of the tube at side B. Figure 5 shows thinning of the tube wall of economizer tube.

Metallographic Studies

The microstructure of the cross-section of economizer tube show tempered martensitic structure at the weld (Fig. 6).



Figure 2. Photograph of economizer tube showing frontal view (Side A)



Figure3. Photograph of economizer tube showing backside view (Side B)

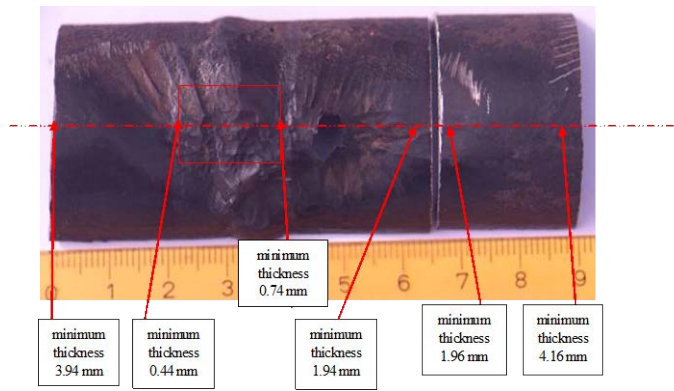


Figure 4. Photograph showing wall thickness at different locations of the tube (Side B)



Figure 5. Photograph showing thinning of the tube wall of the economizer tube (side B)



Figure 6. Photomicrograph of a cross-section of economizer tube at the weld 200 X

EDX Studies

The EDX studies provide useful information about the elemental composition of corrosion products at different locations of leaked economizer tube (Figs. 7 and 8).

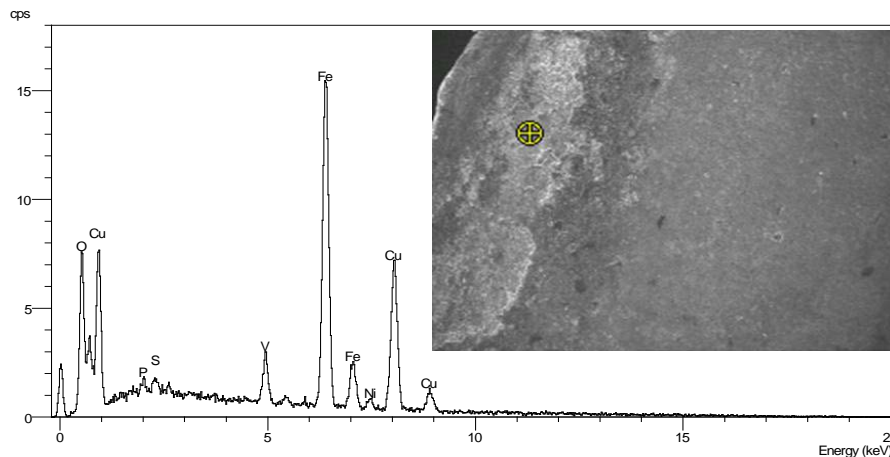


Figure 7. EDX profile of the corrosion products deposited on the pitting area (side B) of economizer tube

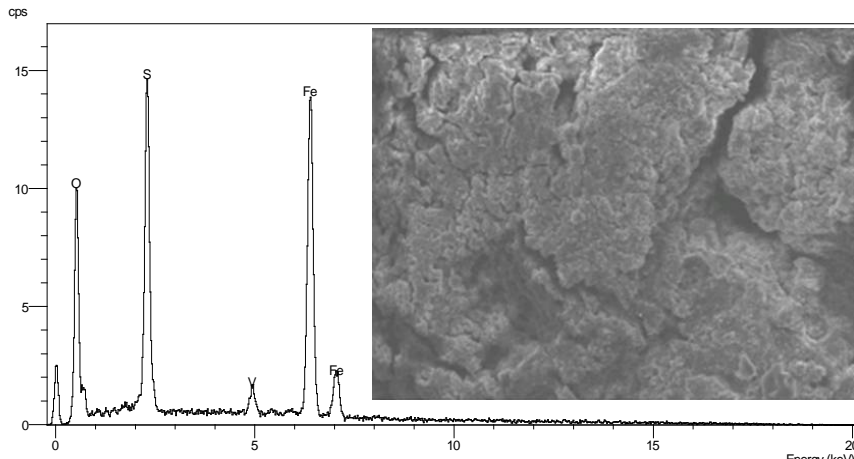


Figure 8. EDX profile of the corrosion products collected from the weld (side A) – outside surface

The sources of V and S are from condensed flue gas. Cu and P are from water leaked through hole.

Discussion

The failure of economizer has two interesting features.

1. At the front side (A) of the economizer tube corrosion products rich in S are accumulated in the encaved (depressed area) as a result of intense corrosion brought about by corrosive liquid (H_2SO_4). The latter which was presumably formed by the condensation of SO_2 and water vapor at the temperature below the dew-point of the acid. Dew-point of H_2SO_4 ranges from 120 to 150°C for SO_3 concentrate of 15 to 30 ppm. The presence of V_2O_5 in the gas might have promoted the conversion of SO_2 into SO_3 .
2. The backside (B) appeared to be more corroded and has pits and holes with thinning of tube wall. Here again, the flue gas temperature dropped down and approached to dew-point resulting in condensation of H_2SO_4 on the metal surface. The design and location of the economizer tube and V and S content of the flue gas, appear to play an important role in more severe attack at the back side. The attack at this location is presumably more severe due to the fluxing reaction between vanadium oxide and iron sulfate. This resulted in pitting, hole formation and wall thinning at reaction sites.

As the corrosion activities are predominantly centered at the weld it is imperative to conclude that dew-point corrosion was localized at and around weld region where leaking of water through the holes could have dropped the temperatures below dew-point of sulfuric acid.

Conclusions

1. The leakages in the economizer tubes (where final preheating of the feed water occurred before it passes into the steam drum) appear to be caused by dew-point corrosion.

2. The dew-point corrosion occurred as a result of the dropping down of the flue gas temperature to dew-point of the acid and condensation of acid on metal followed by initiation of corrosion attack.
3. The weldments appear to be the preferential site for attack. The dew-point corrosion was localized mostly to weld region.
4. The intensity of corrosion attack is further aggravated by the fluxing reaction between iron sulfate and vanadium compounds present in the flue gas.

Recommendations

1. The main cause of leakage in economizer tubes appears to be dew-point corrosion which occurred as a result of operation of the economizer at temperatures near or below the dew-point of the sulfuric acid. Therefore, maintaining the temperature of the economizer much above the dew-point is the most plausible solution to prevent condensation of acid.
2. Temperature monitoring of the economizer can be helpful in operating the economizer above the dew-point.

2.2 Case – 2

Tripping of boiler in a SWCC power plant occurred as a result of economizer tubes failures. A huge rupture was noticed as revealed by nearly fish-mouthed full opening (Fig. 9). Figure 10 shows back view of the ruptured area of the economizer tube. Figure 11 shows thinning of the cross-section of the tube. The total length of the tube was 145 cm and the length of ruptured portion was 0.28 cm. Due to rupture, the tube reduced its original thickness by 0.25 to 2.00 mm.



Figure 9. Photograph showing economizer tube in as received condition



Figure 10. Photograph showing back view of the ruptured area of economizer tube and greenish deposits

SEM and EDX Studies

Figure 12 shows EDX profile of the external (fire side) deposits. The profile shows the presence of S, V and Mg in substantial concentration. The source of S and V appears to be the heavy oil (fuel) which is usually rich in these elements. Na, Ni, Fe and C are present in very small concentrations.

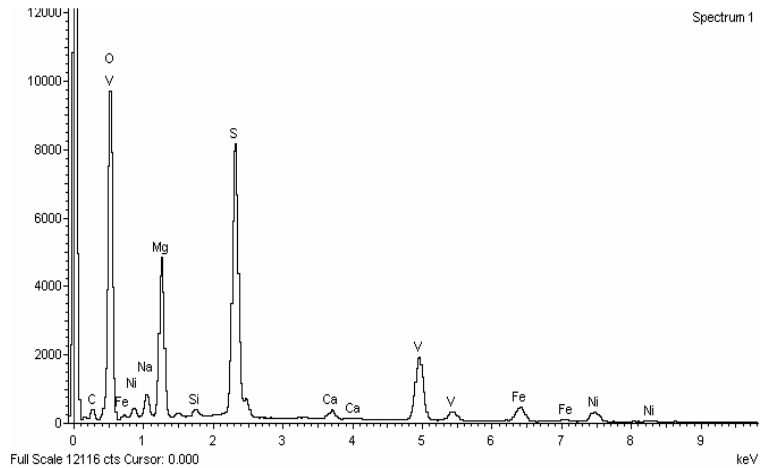


Figure 11. Photograph of the cross-section of the showing thinning of the tube

Figure 12. EDX profile of the deposits showing presence of S and V

Discussion

In the present scenario, the visual examination and the metallographic studies show that there is nominal corrosion attack at the inner (steam) side of the economizer tube. This is further confirmed by low value of scale thickness and scale density ($20.0 \mu\text{m}$ near rupture) obtained from experiments. The corrosion activity in the economizer tube appears to be concentrated at the fire side where huge deposits of corrosion products rich in sulfur and significantly rich in vanadium were found. The inner surface around the ruptured areas is free from scales or corrosion products therefore, the possibility of overheating is ruled out. It appears that the failure of economizer tube is a case of H_2SO_4 dew-point in which there is condensation of acid on the outer surface of the tube causing severe corrosion. In consequence, this resulted in the thinning of the metal to a state where it could not bear the inside pressure of feed water and eventually got ruptured. A reduction in wall thickness of the tubes, located inside the furnace support the initiation of corrosion from fire side as a result of acid condensation. Furthermore, the external deposits on the tube helped in lowering down the tube metal temperature and thus favoring acid condensation over the deposits.

Conclusions

1. No significant corrosion activity or abnormal scaling was observed at the inner side of the boiler tube.
2. The corrosion activity in the economizer tube appears to be mainly concentrated at the fire side where massive corrosion deposits rich in S and V were found.
3. The relatively low temperature of feed water caused the lowering of the tube metal temperature and promoted the condensation of H_2SO_4 .
4. The thinning and rupture of the economizer tubes are the results of H_2SO_4 dew-point corrosion.

Recommendations

1. An increase in the economizer feed inlet temperature will help in reducing the severity of cold end corrosion.
2. Sulfur content should be reduced to minimum which can be helpful in combating the acid dew-point corrosion.
3. A powerful and efficient soot blowing system can reduce the possibility of acid dew-point corrosion effectively.

2.3 Case – 3

Two economizer tubes (A and B) from boiler SWCC power/water cogeneration desalination plant were found leaking. The boiler was operated usually in conjunction with turbine generator. The locations of the leakage were as follows:

- Tube A: Approx 10 mm hole below the weld point
- Tube B: Approx 10 mm holes above and below the weld joint.

Visual Inspection

Figures 13 and 14 show closer view of the economizer tube samples A and B, respectively, in as received condition. The tubes show holes due to corrosion particularly close to weld joints. There is a marked thinning of the wall tube at and near the corrosion sites (holes). The corrosion appears to be from out side (fire side) to inside (water side) surface. This is further evident by the measurement of internal and external diameters.

EDX Studies

EDX studies provide very important information about the composition of deposits and corrosion products on metal scales, hole, welding area. The information is summarized in the following table.



Figure 13. Photograph of the economizer tube A in as received condition showing (closer view)



Figure 14. Photograph of the economizer tube B in as received condition showing (closer view)

<i>Location</i>	<i>Figure</i>	<i>Elemental Distribution</i>	<i>Source</i>
Scale deposits formed on the outer side (fire side) of the economizer tubes A and B	15	Relatively rich in S (12.4%); Fe (predominant)	Flue gas
Hole (in the weld on the steam and fire sides)	16	Al, Si, Ni, Si, P and S in very low concentration. Iron and iron-oxide in high concentration	Economizer tube

The feed water temperature of boiler was 195 °C while the turbine had been in service. This temperature was above the sulfuric acid dew-point. When the boiler was operated with out turbine in service then the feed water temperature dropped to 125 °C. According to plant authorities, the boiler was operated 8 times while turbine was out of service.

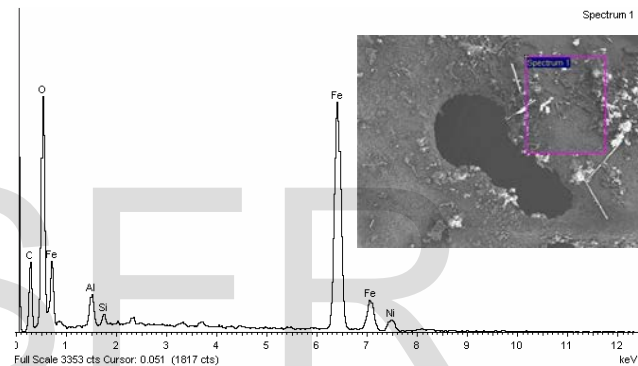
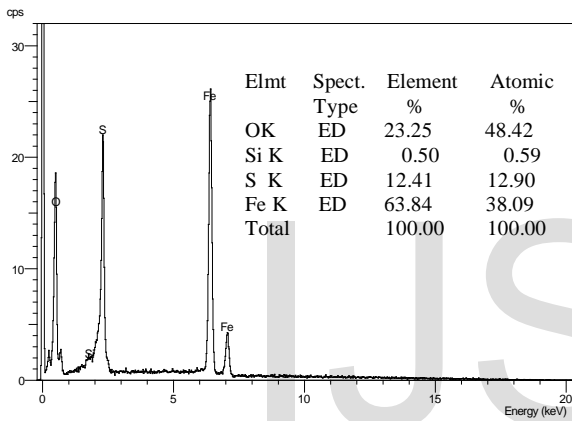


Figure 15. EDX profile of the deposits on external surface of economizer tube A, elemental analysis data are also shown

Figure 16. EDX profile of a location (+Spectrum 1) away from the hole in the weld on the steam side of the economizer tube B

When the feed water temperature dropped to the dew-point or below, the sulfuric acid condenses which is an indication of the on set of corrosion activities. For this process, the feed water temperature is the most important factor. Therefore, the most affected area in the economizer tube which is prone to the dew-point corrosion is the inlet side, because feed water will be at the lowest temperature. The weld joints in the boiler tube are the most accessible sites for corrosion attack if the conditions are favorable as has been observed in the economizer tube. The EDX analysis of the corrosion products on the external (fire side) of the tubes A and B show the presence of high concentration of sulfur (10-12%) presumably in the form of iron sulfide (Figs. 15 & 16). These products were formed as a result of acid (H₂SO₄) attack on metal which is manifested by the wall thinning and subsequent hole formation at attack site. Except corrosion product deposits at or near the attack sites, no sulfur was detected on the metal or the weld indicating that leakage in the tube was the outcome of solely acid attack.

Conclusions

1. The boiler economizer tubes failure could be attributed to the sulfuric acid dew-point corrosion.

2. The operation of the boiler, while turbine was out of service, had resulted in dropping of feed water temperature from 195 °C to 125 °C.
3. The increasing accumulation of deposits, over the economizer tubes, with time would have lowered the pH and increased the corrosion process timing.

Recommendations

1. It is advised to avoid the operation of boiler while the connected turbine is out of service.
2. In case, if the boiler is required to be operated while the turbine is down, the feed water temperature should be raised to above the dew-point.
3. It is recommended to decrease the sulfur content in the fuel gases in order to decrease the sulfuric acid dew-point temperature.

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