RESEARCH ARTICLE OPEN ACCESS

Corrosion Mapping of Water Wall Tubes of Boiler using LFET

Gagan Kumar Gupta
(Manager, BPSCL, B. S. City, India
Email: gagan_k_gupta@rediffmail.com)

ABSTRACT
Corrosion of boiler tubes results in forced outage and it turns into huge loss of money. Maximum failure of water wall tubes is associated with the phenomenon of corrosion. The present paper discusses a technique for inspection of water walls before failure. Water wall tubes were inspected in situ condition by using Low Frequency Electromagnetic Technique (LEFT). Visual inspection of tubes was also carried out before scanning and it was observed that some of the tubes were bulged, eroded and having mechanical dent. During scanning signal wave forms were found not in uniform nature with respect to base line due to erosion, mechanical damage & bulging and those were recommended to be replaced.

Keywords – *Corrosion, Combustion, Electromagnetic waves, LEFT Scanner, Water wall tubes*

Date of Submission: 17-11-2017 Date of acceptance: 28-11-2017

I. INTRODUCTION

Boiler tube components operating at high temperature and pressure tend to degrade as a function of service life due to one or more types of damage mechanisms such as creep, fatigue, corrosion, erosion, etc. The root cause for these failures is associated with either the actual operating or environmental conditions. The corrosion of boiler tube components results in forced outage of components and in turn responsible for non – availability of plant for power generation. Various reasons may be attributed to the root cause of boiler tube corrosion such as quality of fuel, combustion phenomena, operating conditions and water and its chemistry. Fireside and waterside corrosions are due to quality of fuel as well as water. The corrosion resistance of boiler tubes depends on the pH level of water and the amount of contaminations. Inability to maintain pH greatly increases the probability of serious water-side corrosion. A significant factor in water wall-side corrosion is the amount of corrosion products deposition on the tube wall. Deposit build-ups occur when coolant flow is disrupted in bends, welds with backing rings, high heat flux regions and inclined tubes.

High temperature water and steam react with boiler steel to form oxide, hydroxide, hydrates and hydrogen, by formation of a protective layer, such as magnetite (Fe_30_4), on metal surface generally impedes further a reaction. Such protective oxide films are maintained and corrosion prevented by appropriate control of boiler water chemistry. With adequate control of water and steam chemistry, internal corrosion of boiler circuitry can be avoided. Good monitoring and documentation of system chemistry can facilitate identification of the root cause. Identification of root cause is an essential step towards avoidance of further corrosion. Common cause are flow accelerated corrosion, oxygen pitting, caustic corrosion, acid corrosion, organic corrosion, phosphate corrosion, hydrogen damage and corrosion–assisted cracking.

Nearly fifty percent of the mechanisms responsible for boiler tube failures arise from those related to corrosion occurring on both fire side and water side of the boiler tubes. However, boilers being the heart of any steam generating system failure of its components have led in forced plant outages, resulting in heavy economic losses in terms of non–availability of plant for several days and replacement/repair of damaged parts. Hence, an advanced stage of inspection is required for minimizing the water wall tube failures. The present work has applied the LFET (low frequency electromagnetic technique) for corrosion mapping of water wall tubes of boiler and identified the several defected tubes before their failures. Water Wall Tubes from all the section were scanned by Low Frequency Electromagnetic Technique. During scanning each tube with flaw indications if any is detected / identified as a change in phase angle from the base line and marked on the tube surface. This marked region is inspected using UT technique to measure remaining thickness of the tube. Many researchers have described the guidelines and methods for inspection of tubes of boiler. Doooley [1] has describes the various reason of tube failures. Sylvester [2] has defined the causes of tube failures consisting of corrosion. Various conditions which influence the working of boiler and corrosive products have described by the many researchers

[3,4,5,6 & 7]. Esmacher et. al. [8] have discussed the impact of stress-assisted corrosion in paper mill boilers. Chattoraj et. al. [9] have analyzed the corrosive degradation and failure of vertical furnace wall tubes of a boiler. Some researchers [10, 11, 12 & 13] have described the corrosion and its impact on tubes. The impact of corrosive products on the life of tubes has also been discussed by the researchers [14 & 15]. The present work discusses the various types of corrosion and the advanced inspection technique for investigation of corrosion in the water wall tubes at site.

II. BOILER TUBE CORROSION

Basically, there are two types of corrosion as fire side and water side corrosion. Fire side corrosion includes low temperature corrosion, water wall corrosion, coal ash corrosion and oil ash corrosion whereas water side corrosion comprises of caustic corrosion, hydrogen damage pitting and stress corrosion. Fuel constituents and metal temperature promote fire side corrosion whereas variations in the water quality parameters have a direct bearing on the water side corrosion. Besides two corrosion processes viz. corrosion fatigue and chemical excursion damage are also known to occur. Corrosion fatigue arises due to cyclic stresses in the presence of corrosive environment. Chemical excursion damage results due to lack of quality in chemical cleaning procedures.

1. Fire Side Corrosion

Fire side corrosion arises because fossil fuels produces solid, liquid and gaseous compounds which when deposited can be corrosive to structural components and heat transfer surfaces. Low temperature corrosion (cold end/sulphuric acid corrosion) occurs in the economiser section of a boiler, air-preheater, induced draft fan, flue gas scrubbers and stack, and is associated with the combustion of fuels that contain sulphur or sulphur compounds. Sulphur in the fuel is oxidized to sulphur dioxide and a small fraction (1% to 3%) of sulphur dioxide gets converted to sulphur trioxide which can form sulphuric acid below certain temperatures. These temperature known as the dew point of sulphuric acid ordinarily range from 120^0C to 150^0C for SO_3 concentrations of 15 to 30 ppm which are common for coal fired boilers. The condensation of sulphuric acid occurs on metal surfaces and corrodes the metal.

1.1 Water Wall Fire-Side Corrosion

This arises on account of incomplete combustion of fuel due to insufficient oxygen in the furnace burner zone resulting in fuel rich reducing atmosphere with high levels of carbon monoxide and deposition of un-burnt coal particles on the tube surfaces. These release volatile sulphur compounds which form sodium and potassium pyrosulphates ($Na_2S_2O_7$ and $K_2S_2O_7$), of high chemical activity with melting temperatures around 387^0C and 396^0C respectively. These pyrosulphates form molten slag which fluxes the protective magnetite on tube surface causing accelerated metal deterioration along the crown of the tube. The chloride concentration, if any, in the fuel also affects tube wastages. Water wall fire side corrosion produces wall thinning at the water wall tube crown and failure occurs when the material no longer withstands the internal water pressure. Abnormally thick iron oxide and iron sulphide scales are formed when the metal is attacked by the corrosive products.

1.2 Coal Ash Corrosion

This occurs in superheater and reheater sections of boiler in the temperature range of 566 ^{0}C to 732^0C. Corrosion arises from the ash products such as complex alkali-iron-trisulphates ($K_3Fe(SO_4)_3$ and $Na_3Fe(SO_4)_3$) at the metal deposit surface. The molten trisulphate flux the protective oxide scale, exposing the base metal to oxygen, resulting in oxide formation causing the metal loss. Increased stresses on account of wall thinning, coupled with high metal temperatures, finally leads to failure by stress rupture. Coal ash corrosion is always associated with a sintered or slag type deposit. This deposit consists of three distinct layers. The outer layer is of bulky, porous fly ash, the intermediate layer which is responsible for corrosive attack, consists of whitish water soluble alkali sulphates and a thin inner layer is composed of glassy black iron oxides and sulphides at the metal surface.

1.3. Oil Ash Corrosion

Oil ash corrosion is a high temperature liquid phase corrosion process occurring in super-heater and re-heater section of the boiler in the metal temperature range of 593^0C to 816^0C. Oil-ash corrosion occurs when high levels of vanadium, sodium and sulphur are present in the fuel oil used. The mechanism of corrosion follows the following sequence .Conversion of vanadium compounds and sodium compounds present in the oil to V_2O_5 and Na_2O during combustion. The binding action of Na_2O makes the ash particles to stick to the metal surfaces. V_2O_5 and Na_2O react on the metal surface to form a liquid which fluxes the magnetite, exposing the base metal to accelerated oxidation.

The rapid oxidation of metal with catalytic influence of V_2O_5 or complex vanadates results in wall thinning, which in turn, reduces load carrying area. This reduction in load carrying area creates more stresses through the thinned region which eventually leads to failure by creep rupture at high temperatures.

2. Water Side Corrosion

Water chemistry plays an important role in the promotion of water side or internal surface corrosion of boiler tubes. pH of water and the amount of contaminants affect the corrosion resistance of tube steels. At high temperatures, the reaction of water with steel is spontaneous and a protective layer of magnetic iron oxide (Fe_3O_4) is formed on the steel surface. This protective magnetite is unstable at pH values below 5 and above 12. Serious water side corrosion occurs, if moderately alkaline environment is not maintained in order to keep the oxide film intact.

2.1 Caustic Corrosion

This type of failure in boiler tubes occurs due to the attack of steel by sodium hydroxide. Caustic corrosion is also referred to as “caustic attack” “caustic gouging” or “ductile gouging”. Sodium hydroxide can concentrate by a hideout mechanism called “wick boiling” and having a high solubility it can give hydroxide solution dissolves the protective magnetite oxide layer as follows:

$4NaOH + Fe_3O_4 \rightarrow 2NaFeO_2 + Na_2FeO_2 + 2H_2O$ (1)

Further, the sodium hydroxide can react with the iron according to the following equation:

$Fe + 2NaOH \rightarrow Na_2FeO_2 + H_2$ (2)

The critical factors that contribute to caustic corrosion are the availability of sodium hydroxide or alkaline producing salts in boiler water, poorly controlled or malfunctioning chemical feed equipment and the mechanism of concentration of sodium hydroxide. According to a concentrating film theory, the amount of caustic concentration can vary from only 100 ppm NaOH in the bulk of water to 2,20,000 ppm in the water film adjacent to the tube surface. The effect of caustic corrosion will be irregular wall thinning or gouging of the tubes water side surface and metal loss which results in failures. Boiler tube failures also occurred by a form of caustic corrosion called steam blanketing. This corrosion results in stratification of the steam/water mixture which leads to concentration of caustic hydroxide. The corrosion occurs at steam/water interface where deposits are formed. These deposit formations are also called as “bath tub rings” or ghost lines. The steam/water stratification occurs especially at low loads and full pressure. The steam blanketing corrosion can be eliminated by control of water chemistry and using ribbed or smaller bore tubing to prevent stratification phenomena.

2.2. Hydrogen Damage

In this case corrosion reactions occur resulting in the liberation of atomic hydrogen. Concentrated sodium hydroxides present in water dissolves the magnetic iron oxide as per the reactions given below to produce atomic hydrogen.

$3Fe + 4H_2O \rightarrow Fe_3O_4 + 8H$ (3)

$Fe + 2NaOH \rightarrow Na_2FeO_2 + 2H$ (4)

The hydrogen can also originate from the reaction of concentrated free chelant with steel. Sometimes acid remaining from acid cleaning can attack the boiler tubes to give hydrogen. The atomic hydrogen diffuses into the tube steel and reacts with iron carbide to produce methane

$Fe_3C + 4H \rightarrow CH_4 + 3Fe$ (5)

The larger methane gas molecules becomes trapped between the grain boundaries and produces discontinuous inter-granular micro cracks which can grow further and diminish the strength of tube steel. This finally results in blow out of rectangular section of boiler tube in a manner termed as “window opening”.

2.3. Pitting or Localized Corrosion

This arises in boiler tubes due to the attack of oxygen. The localized corrosion produces perforations of the tube walls from galvanic activity when the small area on the tube becomes anodic to the rest of the tube surface. The creation of differential aeration cell about a deposit leads to severe local corrosion. However the pitting or localized corrosion is relatively unknown in operating boilers, but frequently found in idle boilers. The corrosion can occur anywhere in the boiler, but the most common attack site is in super-heater tubes. The dissolved oxygen in water attacks the boiler tube steels. If the steel is not covered by the protective from of iron oxide, the corrosion reaction occurs according to the following equation

$2Fe + H_2O + O_2 \rightarrow Fe_2O_3 + 2H$ (6)

In addition to tube wall perforation, oxygen corrosion can promote stress related failures such as corrosion fatigue cracks, caustic cracks.

2.4 Stress Corrosion Cracking (SCC)

SCC in boiler tubes occurs as a result of the combined effects from tensile stress and corrosive environment. Austenitic stainless steel materials used for super-heater and re-heater tubing are usually susceptible to stress corrosion cracking. However, SCC failures have also occurred in some ferritic re-heater tubing when high levels of caustic were introduced from the de-superheating or attemperators spraying section. Both fire side and steam side corrosive products are known to promote SCC in austenitic steels. The fire side corrosive products are nitrates, sulphates and polythionic acids (H_2SnO_6, n = 3, 4 or 5). On steam side sodium hydroxide and chlorides take part in the corrosion phenomena. The contributing factors for tensile stresses in the tube steels are severe service conditions and production of residual stresses during fabrication assembly. Stress corrosion produces tight, hairline type cracks which cannot be identified by normal visual observation. The locations that mostly experience cracks are bends and straight tubing located low points in a tube circuit, because these areas are exposed to the highest concentration of contaminants.

3. Fatigue Corrosion

Fatigue corrosion is a process in which metal fractures permanently under condition of simultaneous corrosion and repeated cyclic loading. Corrosion fatigue failures most frequently occur in boilers that are in ‘peaking’ service, used discontinuously or otherwise operated cyclically. Corrosion fatigue failures can occur in wall tubes, re-heater tubes, super-heater tubes, economizer tubes, de-aerators, and the end of the membrane on water wall tubing. Corrosion fatigue cracks are typically straight and un-branched and difficult to see since they are often filled with dense iron oxides. They are needle or wedge shaped and propagates perpendicularly to the metal surface.

Reducing or eliminating cyclic operations of the boiler as well as extending start up and shut down times can help in reducing corrosion fatigue cracking. Controlling pH and excessive dissolved oxygen levels helps to eliminate pitting corrosion, which in turn eliminates the nucleating points for corrosion fatigue. Measures such as containing of welds and redesign of tube attachments are necessary to eliminate constraints to thermal expansion and contraction in order to avoid fatigue cracking.

III. CORROSION MAPPING

The present work has adopted this technique for performing inspection of water wall tubes of boiler. This is an advanced Non-Destructive method, wherein the waterside corrosion of boiler tubes can be detected by way of mapping. This is followed by the interpretation of the results obtained for prediction of corrosion damage of the tubes. The method adopted is Low frequency electromagnetic Techniques (LFET), wherein frequency in the range of 10 to 25Hz is produced using a horseshoe type of electromagnet with a suitable oscillator circuit. The electromagnetic sensor is able to scan the area of the tube covering 170° and this procedure is continued for the entire length of the tube. The output of the sensor is connected to a wave form monitor. The tube which does not have any internal corrosion will give an indication on the monitor in the form of a baseline. In case of pitting corrosion damage due to caustic, acid attack etc., there is a change in the wave pattern in the form of a peak at the damaged location. In this way, the corrosion damage locations of the tubes can be identified. The effective application of LFET inspection technique embodies skillful interpretation of the corrosion damage analysis of the wave form pattern.

IV. EXPERIMENTAL SETUP

A view of the TS 2000 equipment and OD scanner used for corrosion mapping of water wall tubes are shown in Fig.1 & 2 respectively.

Fig.1- TS 2000 equipment

Fig. 2 - OD Scanner

TS 2000 DSP based Water Wall Inspection System with suitable OD scanners has been developed and manufactured by M/s TesTex Inc., U.S.A. The Low Frequency Electromagnetic Field, which is generated by the system, penetrates through the tube thickness and the sensors detect any abnormal variation in the tube thickness whenever the scanner approaches the flaw.

The system runs on DSP / PC based imaging software. The menu driven program provides for real time data acquisition. All the signals are collected at a given sample rate and are displayed as Phase signals which helps to locate and verify the flaws real time. Selected printouts of various scanning locations are prepared giving 3D views / Top views / Side views of the selected areas after signal processing. Fig. 3 shows the region of water walls of boiler where corrosion mapping is carried out.

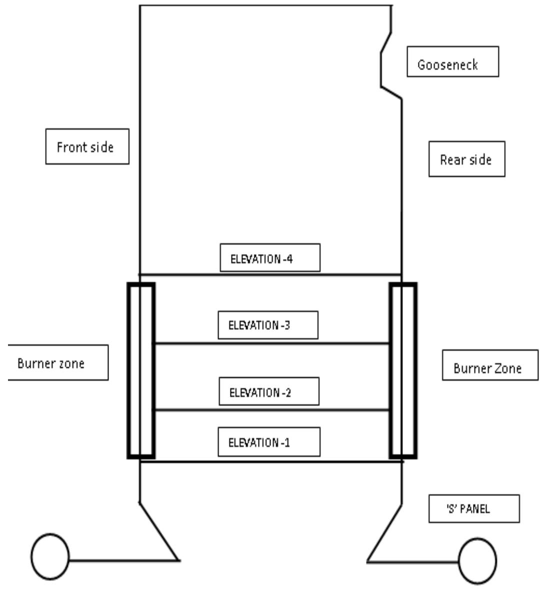

***Fig. 3 - Inspected Region* of water walls of boiler**

V. RESULTS AND DISCUSSIONS

The LFET system was calibrated using new tube having size of 57X5 mm that has been collected at site and prepared three steps of metal loss having 1, 2.5 and 5 mm thickness on fire side by drilling holes of 15 mm diameter to select the proper frequency and gain for scanning the water wall tubes. Each tube of water wall was scanned by using 2.5" OD scanner with necessary overlaps for full coverage. Exact locations where defect like signals are observed were marked for further verification with Ultrasonic Technique. Furnace Wall Tubes from all the section were scanned by Low Frequency Electromagnetic Technique. During scanning each tube with flaw indications if any is detected / identified as a change in Phase angle from the base line and marked on the tube surface Fig. 4 & 5 show scanning of water wall tubes and capturing of the wave forms respectively.

Fig. 4 - Scanning of water wall tubes

Fig. 5 - Calibration with exposed tube

Inspection of water wall tubes of boiler is carried out consisting of the scanned area corrosion mapping in burner zone, below & above burner zone and goose neck consisting of Front, Rear, LHS and RHS water wall panels.

Fig. 6 shows the LEFT output of a water wall tube which provides the information of no defect. Fig. 7 shows the LEFT output of another water wall tubes which consists of a defect of metal loss from inside.

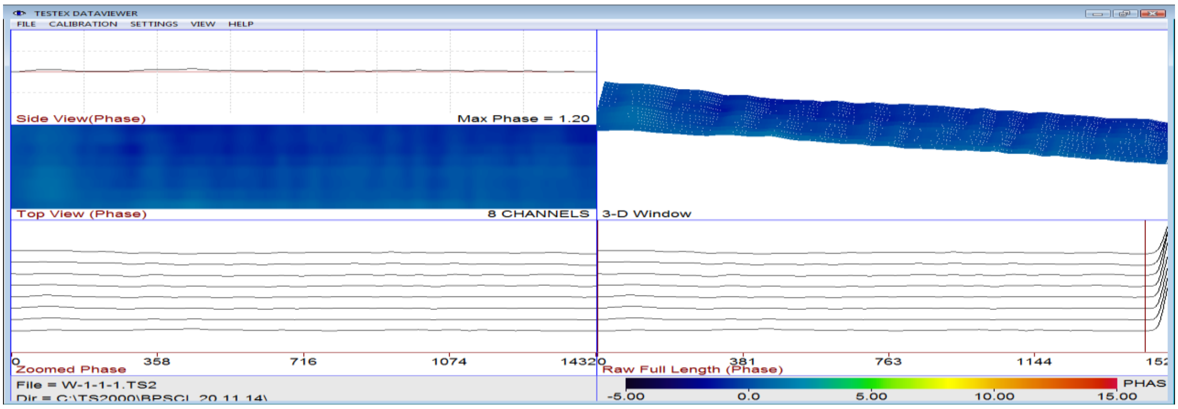

Fig. 6 LFET Waveform signal output indications for no defects

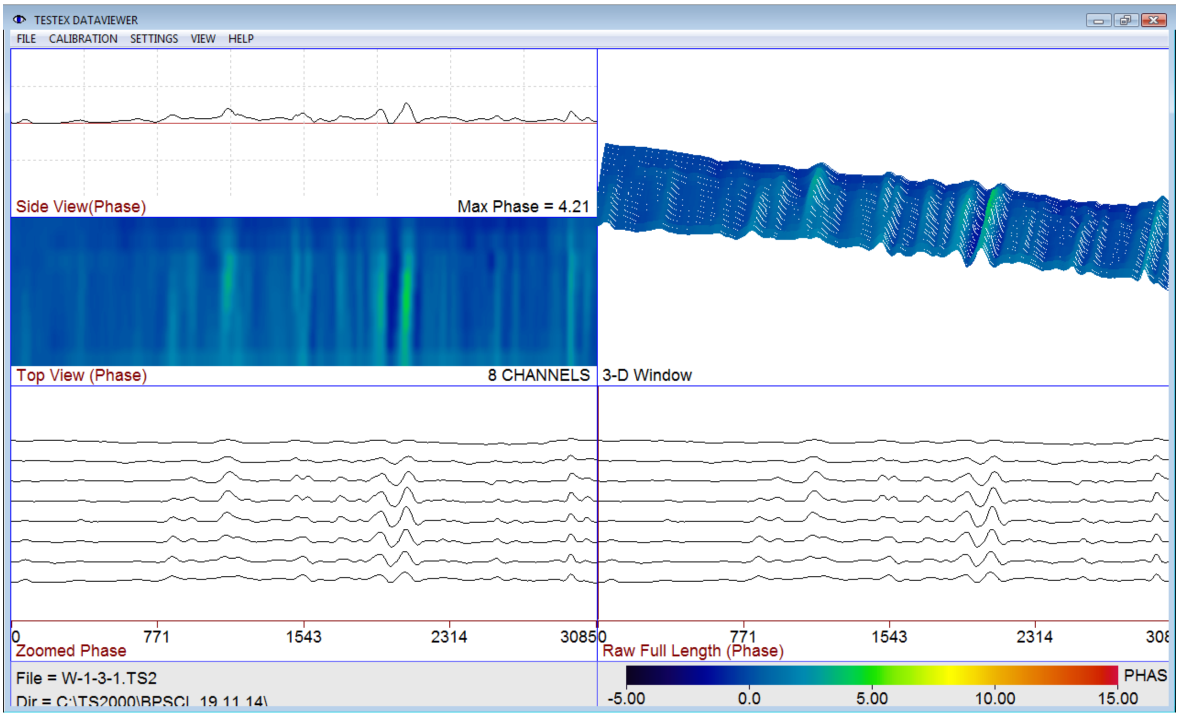

Fig. 7 - LFET Waveform signal indications for Tube No.48 with ID metal loss

VI. CONCLUSIONS

Corrosion mapping of water wall tubes were carried out to verify the severity of the corrosion and internal metal loss of tubes. During scanning with the Low frequency electromagnetic, waves signals observed in some of the tubes were not uniform in nature with respect to base line. These water wall tubes which were found with ID metal loss due to corrosion were required to be replaced.

REFERENCES

[1] Dooley, R.B., A vision for reducing boiler tube failures. *Power Eng. 96*, 1992, 33–37.

[2] Sylvester, W.R., Waterside Corrosion Fatigue Cracking—Is There a Single Cause and Solution? *ABB C-E Services TIS 8318, Combustion Engineering, Inc, Windsor, CT*, 1987.

[3] Gabrielli, F., An overview of water-related tube failures in industrial boilers. *Mater. Perform. **27**(1),* 1988, 51–56.

[4] Wu, X., Katada, Y., Corrosion fatigue behavior of low-alloy pressure vessel steels in high temperature water under multi-factor conditions, *J. Press. Vess. Technol. **126**(4),* 2004, 466–472.

[5] Dong, Y., Singh, P. M., Neu, R. W., Initiation and Propagation of Stress Assisted Corrosion (SAC) in Carbon Steel Boiler Tubes, *06241, Corrosion, CA*, 2006.

[6] Dong, Y., Singh, P. M., Neu, R. W., Effect of boiler water chemistry on corrosion and corrosion fatigue of carbon steels, *The 16th International Corrosion Congress, BJ, China*, 2005.

[7] Sarma, G. B., Pawel, S. J., Singh, P. M., Modeling of Recovery Boiler Tube Wall Panels to Investigate the Effect of Attachment Welds on Stress-Assisted Corrosion, *CORROSION-2006, Paper No. 06240, San Diego, CA, USA*, March 2006.

[8] Esmacher, M.J., Johnston, N.N., Sargent, M. A., Minimizing the impact of stress-assisted corrosion in paper mill boilers. *In: TAPPI Engineering, Pulping and Environmental Conference. Philadelphia, PA, United States*, Aug. 28–31, 2005.

[9] Chattoraj, S.K. Das, B. Ravikumar, D.K. Bhattacharya, Corrosive degradation and failure of vertical furnace wall tubes of a boiler, *Eng. Fail. Anal.* ***4****(4)*, 1997, 279–286.

[10] M. Imran, Effect of corrosion on heat transfer through boiler tube and estimating overheating. *Int. J. Adv. Mech. Eng.* ***4****(6)*, 2014, 629–638.

[11] A.U. Malik, I. Andijani, M. Mobin, F. Al-Muaili, M. Al-Hajri, Corrosion of boiler tubes-some case studies, *in* Proceeding of 4th SWCC Acquired Experience Symposium, *Jeddah*, 2005, 739–763.

[12] S.R. Bamrotwar, V.S. Deshpande, Failures in 210 MW thermal power plant, *IOSR J. Mech. Civil Eng.* ***2***, 2014, 6–10.

[13] A.U. Malik, S.A. Al-Fozan, M. Mobinand, M. Al-Hajri, Studies on the failure of

economizer tubes involving acid dew-point corrosion in high pressure boilers, *Int. J. Sci. Eng. Res.* ***4****(9)*, 2013, 21–30.

[14] Song S, Coit DW, Feng Q, Peng H., Reliability analysis for multi-component systems subject to multiple dependent competing failure processes, *IEEE Trans Reliab, 63(1), 2014*, 331–45.

[15] Seruga Domen, Fajdiga Matija, Nagode Marko, Creep damage calculation for thermo mechanical fatigue, *Journal of Mechanical Engineering*, Vol. 57, no. 5, 2011, 371-378.

International Journal of Engineering Research and Applications (IJERA) is **UGC approved** Journal with Sl. No. 4525, Journal no. 47088. Indexed in Cross Ref, Index Copernicus (ICV 80.82), NASA, Ads, Researcher Id Thomson Reuters, DOAJ.

Gagan Kumar Gupta Corrosion Mapping of Water Wall Tubes of Boiler using LFET." International Journal of Engineering Research and Applications (IJERA) , vol. 7, no. 11, 2017, pp. 23-29.