Investigation into Steam Boiler Rupture: A Case Study of Egbin Electrical Power Business Unit (EEPBU), Lagos State

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Abstract:
The study was conducted to investigate the causes, effects and controls of Boiler rupture in Egbin Steam Thermal power plant, Lagos State. Three classes of boiler rupture were investigated for twenty-nine cases of boiler rupture. The cases were grouped into classes through stratified sampling technique. Analysis of Variance (ANOVA) at 95% level of significance was used to test the two research questions set for the study. The results of the study indicate that the various classes of boiler rupture are not equally significant, one class more prevalent and responsible for incessant forced power outages than the others. With respect to tube failure, the findings indicate that each of the various factors responsible is uniformly significant. Recommendations for proper maintenance planning, in order to prevent boiler rupture which could lead to forced power outage, were made. The effects of boiler rupture include reduction in load factor, plant utilization factor, profit, plant generation factor, plant efficiency and increase in down time, operation and maintenance costs.

Key words: Boiler-rupture, Effects, Tube failure, Thermal-plant, Maintenance, Forced power-outages.

1 Introduction
Steam generator, popularly called Boiler, is a complex integration of furnace, superheater, re heater, evaporator, economizer, and air-preheater along with various auxiliaries. Boilers come in different shapes, sizes and are used for different purposes; they can be used to produce hot water to heat building and/or produce hot water or steam for personal or industrial use. They are classed based on mode of circulation of the working [1] fluid, steam pressure, mode of firing, nature of the heat source, content of the tubes, application and manufacturer’s trade name [2].

Electrical energy holds a key role in the development of a country. It is the basis of existence of industrialization and modernization. A country is classed as developed country just because of her energy generation capability which is the bedrock for economic growth.

Energy is one of the four fundamental requirements- food, water, energy and environment- which comfort the humanity [3]. Energy demand positively correlates with the level of development, as the economy expands the need for energy rises. There are various sources of energy which many be renewable, non-renewable, commercial or not commercial. Whatever the sources, electricity is the only type of energy which is easy to generate, and transmit, distribute and control; among the various means of generating it, Thermal power plants generate more than 80 % of the source [4]. During the process of generating steam required in the turbine, Boiler components are being subjected to high temperature and pressure (e.g. 587 °C and 12000 kPa in the case of Egbin Steam Thermal Power Plant Egbin) which could give rise to overheating and high thermal stresses of tubes, malfunctioning of units, tripping and ultimately failure of the units. This failure is referred to as boiler rupture. Plant age, temperature sensitivity, variation in quality and quantity of steam and water chemistry, contribute to the failure of steam boilers.

Boiler rupture or explosions are catastrophic failures of boilers. Boiler ruptures are of two kinds. One kind is failure of tube. The second is due to explosion either in the furnace or in the boiler proper [5].

Ford Rouge Power Plant in Dearbon, Michigan, an Auto-power Plant, experienced an explosion, of furnace type, in the year, 2000 when the gas inside one of the boilers at the Power Plant ignited causing a massive explosion and fire ball that ripped through the facility killing six people and injuring dozens of workers. The blast was caused by a buildup of gas inside the boiler as the two safety devices were de-activated because they were not working correctly and caused production delays [6].

A narrative example of the disaster that struck at Chernobyl-power station is an example of rupture due to tube failure; Chernobyl-Power Station is a Nuclear Power Plant located in Pyrite, Ukraine which consisted of four reactors of type
“RBMK-100, each capable of producing 1.0 GW electric power (4 x 1.0 GW) witnessed an explosion [7]. The reasons for the failure were attributed to deficiency in reactor design, specifically the control rod [8]. Different researchers have worked on various causes of boiler rupture in thermal plants: Whilst reasons responsible for tubes damage in the superheated Platen section of 320 MW Bisotoun Power Plant, Iran, was studied [9], study of rupture of a boiler pipe by using chemical analysis, scanning electron microscope and energy dispersive spectroscopy [10]. Failure analysis of final superheater tube on ultra-supercritical (USC) coal power plant was investigated [11]. The main causes of rupture in a superheater tube and water-wall tube of a power plant boiler was examined and preventive measures were proffered [12, 13].

This work studied boiler rupture in the six units of steam generators (popularly tagged as ST-01, ST-02, ST-03, ST-04, ST-05 and ST-06) at Egbin Steam Thermal power Plant, Egbin, Lagos State, Nigeria. Lagos Thermal Power Station, Egbin is one of the biggest additions to the electricity industry in Nigeria. It is located in Ijede, about 40 km North-East of the City of Lagos in Ikorodu Local Government Area of Lagos state, Nigeria.

2 Methodology
The method adopted for the analysis of causes, effects and controls of boiler rupture was based on observations and on the pieces of information/data collected in the field during inspection and repair of the boilers in Egbin Steam Thermal Power Plant. Analysis of Variance (ANOVA) was used to test the hypothesis set for the study at 95% level of confidence. For clarity, classifications of data were done for the purpose of carrying out in-depth study of the subject with little ambiguity. They were made into three classes through stratified sampling technique as data were considered in cluster.

2.1 Case Studies
This study investigates causes, effects and controls of boiler rupture in Lagos Steam Thermal Power Station Egbin, Lagos state. Twenty nine cases of boiler rupture that occurred in this Power Plant for a period of 3 years were considered and classified into: tube failure and explosion (boiler explosion and furnace explosion) using stratified sampling technique.

2.1.1 Case Study 1 (Tube Failure)
Unit-4 of the boiler failed as a result of tube leakage. Hydrostatic and Dye penetrating tests were carried out to determine points of leakages and causes of the failure. Hot and cold Reheater water walls of the secondary and primary super-heaters and Economizers tubes were covered as subject of inspection Points of leakage in hot and cold re-heater tubes were found through hydrostatic test which was carried out before commencement of the site non-destructive inspection. The procedure and result of these investigations are as presented below:

**Hydrostatic test (Procedure)**
All parts of the boiler casing, including the insulation and brickwork were accessed. The drum internals were left-off to allow access, in case of a fault, in the area being inspected. Safety valves were detached and all connections left blank to avoid any collection of dirt entering the valve and to prevent gagging the valves against a high pressure.
Feed-water was supplied at a temperature between 38.9 and 50 °C; and at a pressure not more than one and one-half times boiler working pressure in the drum. Finally, points of leakages were located

**Dye-Penetrating (DP) Test**
The surface of the affected tubes were moistened with a good solvent (e.g.kerosine) and a developer was applied to the clean surface. Finally, a penetrant was applied to the surface.

**Causes of tube failure**
The factors causing the failure were pitting, corrosion, low pH value in the feed-water, short-term overheating, long-term overheating and dissimilar metal weld. Oxygen pitting occurs as a result of presence of Oxygen in the boiler feed-water. Air ingress into the boiler tubes arose due to in-leakage of air at Pump (BFP) due to partial de-aeration of feed-water by Deaerator. The air ingress caused water hammering on the tube walls. Acid corrosion occurs due to drop in the pH level of boiler feed-water. As a result of this occurrence, thinning, etching and ultimately cracking of the tubes. The combined corrosion and repeated water hammering from the air ingress resulted in high fatigue and the occurrence of cracking. Figures 1 – 7 show the affected parts of unit 4 of the boiler due to tube failure.
Figure 1: Crack on secondary Superheater tube due to Long-term Overheating

Figure 2: Swiss-mouth Crack due to Oxygen Pitting on secondary cold reheater line

Figure 3: Crack on hot reheater tube due to Dissimilar metal weld at Joints confirmed by Dye penetrating (DP) test

Figure 4: Etching due to hydrogen damage on cold reheater line near bent tube
2.1.2 Case Study II (Boiler Explosion)

Causes of the explosion

The valve position of lower level flow control valve was greater than the pre-determined light-off position when C-1 burner was lit after the fourth FCB operation due to improper combustion condition resulting from large amount of fuel consumption; an amount estimated as a double volume of the usual fuel consumption as inferred from the operation data. The excessive fuel gas having mixed up by middle burner level combustion air, consequently caught fire at the upper burner where the A-1 burner was lit-off during the FCB operation. Figures 8 to 11 show the defective parts of Unit-6 of the boiler.
Figure 8: Detached seal plaster (refractory lining) in all cell burners covered with SUPERBOND 50WA

Figure 9: Lower level Gas flow indicating 0 t/h and Main fuel Gas flow indicating 5 t/h at half always

Figure 10: Dislodged Economizer outlet header guide at the West side
2.1.3 Case Study III (Furnace Explosion)

Observation: The following damages were observed after a thorough inspection
(i) The roof tube casing of the penthouse expanded 250 mm approximately, the rear casing sheared at east end and the sealing plaster destroyed.
(ii) Both the three corner links and the four corner links of the Buck-stay and corner link were completely sheared and deformed and the Buck-stays were severally bowed.
(iii) Level burners dislodged (between 20mm to 25mm), all the sealing plasters at the three levels were destroyed and dropped, fragment of them scattered in the areas.
(iv) Roof casing plate, insulation material and outer cladding of the wind Box got completely destroyed. Both the A-level and B-level wind box vertical steel were seriously damaged.
(v) Refractory castable of the baffle water and side walls exfoliated at the East and West ends of tubes.
(vi) At the furnace internal, water tubes got sheared of Elevation + 19200 an elevation + 1400 buck stays in wind box
(vii) Three corner link covers of the furnace external deformed and dropped.
(viii) Secondary air duct casing plate sheared and cracked.

Causes of furnace explosion

The factors responsible for this rupture are as uncontrolled combustion at the furnace, admission of condensate into the furnace, failure of safety measuring equipment and failure of scrubbers / dryers. Figures 12 – 15 show the damaged area of the furnace.
Figure 14: Deformed and sheared water tubes with fragment of sealing plasters scattered round the area (an example of long term overheating)

Plate 15: Deformed Air Register Vanes

3 Data Analysis, Results and Discussions

The twenty-nine cases of boiler rupture that occurred in EEPBU Lagos State classed into three groups (tube failure, Boiler explosion and Furnace explosion) through stratified sampling technique were analyzed using Analysis of Variance (ANOVA). The statistical analyses were computed at 95 % confidence level

The two research hypotheses tested in the analysis are:
(i) Are the three classes of boiler rupture equally responsible for the causes of boiler rupture?
(ii) Are the various factors responsible for tube failure equally significant?

Table 1 gives a number of the causes of failures encountered in the course of this research

| Month | Furnace explosion | Boiler explosion | Tube failure |
|-------|-------------------|------------------|-------------|
| 1     | -                 | -                | 2           |
| 2     | -                 | -                | 1           |
| 3     | -                 | -                | -           |
| 4     | -                 | -                | 1           |
| 5     | -                 | -                | -           |
| 6     | -                 | -                | -           |
| 7     | -                 | -                | -           |
| 8     | -                 | -                | -           |
| 9     | -                 | 1                | -           |
| 10    | -                 | -                | 2           |
| 11    | -                 | -                | -           |
| 12    | -                 | -                | 3           |
| 13    | -                 | -                | -           |
| 14    | -                 | -                | 2           |
| 15    | -                 | -                | -           |
| 16    | -                 | -                | -           |
| 17    | -                 | -                | -           |
3.1.1 Result and Discussions of Hypothesis Test 1

Test-1: level of significance among Classes of Rupture
Test 1 was evaluated based on hypotheses, null and alternate, as detailed below:
Null hypothesis, $H_0$: The three classes of boiler rupture equally responsible for the causes of boiler rupture.
Alternative Hypothesis, $H_1$: the three classes of boiler rupture not equally responsible for the causes of boiler rupture

Table 2 shows the result of the analysis for evaluating Hypothesis 1. From the decision Table 2 with the degree of freedom determined. The calculated value is 29.38 whilst the tabled value is 5.76. Therefore the null hypothesis is rejected; that is, certain class of rupture. (Tube Failure as it had the highest frequency) is more significantly responsible for the causes of boiler rupture in thermal power. This study, therefore, indicates that tube failure accounts for the major cause of boiler rupture and is the major technical cause responsible for incessant forced outages when electrical power is generated through thermal source

Table 2: ANOVA Decision

| Hypothesis | MSS_B | MSS_W | F_CAL | A | F_{5.6}=F_{tab} | Decision |
|------------|-------|-------|-------|---|----------------|----------|
| Ho         | 75.11 | 2.56  | 29.38 | 0.05 | 5.79          | Ho rejected |

3.1.2 Result and Discussions of Hypothesis Test 2

Test 2: Level of Significance among Factors responsible for Tube Failure
Test 2 was evaluated based on hypotheses, null and alternate, detailed as
Null hypothesis, $H_0$: All the factors responsible for tube failure are uniformly significant
Alternative hypothesis, $H_1$: All the factors responsible to failure are not uniformly significant.

Table 3 shows the ANOVA result for analyzing the second Hypothesis. From this ANOVA Decision Table 3, the calculated value, $F_{CAL}$, is less than the tabled value, $F_{5.12}$. Therefore, the null hypothesis is accepted. In other words, all the various factors: Caustic attack, Oxygen pitting, hydrogen damage, Short-term overheating, Long term overheating and dissimilar metal weld are equally responsible for the causes of tube failure.

Table 3: ANOVA Decision

| Hypothesis | MSS_B | MSS_W | F_CAL | A | F_{5.12}=F_{tab} | Decision |
|------------|-------|-------|-------|---|----------------|----------|
| Ho         | 3.164 | 1.89  | 1.674 | 0.05 | 3.26          | Ho accepted |
It was also found that apart from this afore-mentioned factors another contributing factor is the age of the Unit, Steam Generator; EEPBU was about 21 years old with no major overhaul on station Units ST ST-01, ST-02, ST-03 and ST-05, this has put immense stress on the units and their reliability is going down, frequent trips and equipment failure, therefore, imminent overhaul of these units is urgently required [14].

Boiler rupture affects the economics of power generation, such as load factor, reliability, capacity utilization factor, rating, running factor and thermal efficiency, load factor refers to the ratio of number of units (MWh of energy) actually generated in a given period to the number which could have been generated had the load or demand remained at the maximum, value throughout the period. The findings of the study corroborated the views of the earlier scholar that: boiler rupture can be classified as tube failure and explosion (boiler explosion and furnace explosion) [5]. The results of the study also showed that tremendous boiler rupture is part of the factors responsible for incessant forced outages and low pace of development of any nation

4. Conclusion
The causes and effects of boiler rupture in Egbin Steam Thermal Power Plant were investigated. Boiler rupture was classed as boiler explosion, furnace explosion and tube failure. Twenty-nine cases of failure that occurred over a period of three years were considered in the course of the investigation. Findings showed that tube failure accounts for 93.1 % of the main cause of boiler rupture and power outages; other factors are ancillary equipment failure, scarcity of consumables or administrative factors

The effects of boiler rupture include reduction in Generation utilization factor, Capacity utilization factor, thermal efficiency, load factor, energy generated, energy sent-out reliability index and increase in down-time, operating costs and tripping of Plant

Forced power outages due to boiler rupture could be reduced if proper maintenance planning is initiated and followed to the letter as observed from the results of the two hypotheses, and development of peak stations as standby stations for turkey ones so as to relieve them of prolong thermal stresses that could lead either to component or entire system failure and at the same time reduce the frequent incessant forced power outages.

it is hereby recommended that:
(i) procurement of spare parts for the repair of faulty equipment should be intensified so as to improve on the reliability of the plant and reduce downtime of equipment.
(ii) efforts must be made by the Government for the development of the other Power Plants that are not susceptible to Boiler rupture (e.g. hydro- and tidal Plants) to nip in the bud the incessant power outage and its after-effects.

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