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OPTIMIZING BOILER WATER CHEMISTRY AND CORROSION CONTROL SYSTEMS FOR ENHANCED EFFICIENCY AND RELIABILITY

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Abstract

Background: *Industrial boilers are vital in power generation, petrochemical processing, and large-scale heating applications. Maintaining proper water chemistry is essential to prevent scale formation, corrosion, and operational inefficiencies, as deviations can reduce heat transfer, increase fuel consumption, and shorten equipment lifespan.*

Objectives: *The study aimed to: (1) assess the impact of water chemistry on scale formation, corrosion, and overall boiler performance; (2) evaluate conventional and advanced chemical treatment methods; (3) investigate corrosion behavior under varying operating conditions; and (4) develop a comprehensive boiler water management and corrosion control framework to enhance system reliability and longevity.*

Methods: *A hybrid approach combined long-term field monitoring, laboratory analysis, and corrosion-coupon testing. Samples were collected from feedwater, deaerator outlets, boiler drums, and condensate return lines. Parameters measured included pH, alkalinity, hardness, TDS, conductivity, dissolved oxygen (DO), and silica. Scale deposition was assessed via suspended solids and microscopic examination, while corrosion rates were determined using weight-loss coupons and electrochemical techniques. Controlled laboratory tests were used to supplement field observations.*

Results: *Maintaining alkaline pH, moderate TDS, and low DO effectively minimized corrosion and scale deposition. Chemical treatments including oxygen scavengers, phosphate conditioning, dispersants, and controlled blowdown reduced corrosion rates in treated boiler water to 1.0–1.4 mpy, compared to 8–12 mpy in untreated water. Silica accumulation in the boiler drum and minor DO variations in condensate return lines indicated areas needing ongoing monitoring. Hardness and alkalinity levels confirmed effective softening and internal phosphate reactions.*

Conclusions: *Coordinated water-management strategies combining chemical treatment, mechanical pretreatment, and continuous monitoring improve boiler reliability, energy efficiency, and lifespan. Regular evaluation of water chemistry is essential to prevent scaling, corrosion, and operational disruptions.*

Introduction:

Boilers are important in a number of industrial processes such as power generation, petrochemical processing, chemical manufacture, and in large scale heating applications. The proper water chemistry, as well as corrosion prevention is essential to their performance and working integrity due to the high temperature and pressure of their work. Boilers can be affected by the scale formation, sludge formation and corrosive attack when the water quality is not under control; this fact reduces the efficiency, interrupts the operation and decreases the life of the equipment [1]. These challenges demonstrate the fact that effective boiler water control is a critical operation requirement, and not merely a service activity [2].

The feedwater supplied to boilers normally contains a number of dissolved and suspended contaminants, such as as silica, iron compounds, total dissolved solids (TDS), hardness minerals, such as calcium and magnesium, carbonates and organic matter [3]. These species can either be subjected to the changes of a chemical nature or can be deposited under boiler conditions in the solid state. The mere presence of a thin layer of scale drastically interferes with heat transfer and the boiler burns up more fuel to produce the same amount of steam. It is shown that very small changes in the thickness of deposits can lead to considerable losses in heat exchange and increased operating costs [4]. This is a demonstration of the good connection between the water chemistry regulation and the efficiency of the boilers.

Corrosion is another major threat to the reliability of the boilers. Under-deposit corrosion processes, carbon dioxide acidic attack, chloride pitting, caustic gouging and oxygen-induced corrosion are more likely to occur in high-pressure systems [5]. Any type of corrosion may lead to tube wastes, structural instabilities, or disastrous failures and is predetermined by specific chemical or electrochemical environments within the boiler. The engineers need to understand these mechanisms fully so that they can implement appropriate mitigation measures since corrosion needs different strategies depending on the water quality, temperatures, and pressure, as well as system design [6].

The two primary elements of the usual boiler water treatment are chemical conditioning and mechanical pretreatment. In order to manage the level of contaminants, mechanical processes encompass filtration, softening as well as periodical blowdown [7]. Any type of amines, oxygen scavengers, alkalinity regulators, phosphate treatments, dispersants and various forms of alkalinity regulators are used to maintain the proper pH, reduce oxygen levels and prevent the formation of scales. Nevertheless, the presence of irregular dosage control, poor monitoring, and fluctuating quality of feedwater are the reasons why many industrial boilers still have an issue in operational problems despite using these proven techniques [8].

With automation, it is now feasible to develop continuous online monitoring systems which can fluctuate the conductivity, the hardness, the pH and the dissolved oxygen in real time. To enhance the stability and reduce the risk of human error, automated dosing machines adjust the levels of the chemicals according to the real-time feedback [9]. At the same time, there has been a surge in the attention to environmentally friendly corrosion inhibitors and hybrid treatment technologies, which offer safer and potentially more effective alternatives to standard chemicals.

Another trend is predictive maintenance systems which use data analytics to identify indicators of scaling or corrosion at an early stage. Such technologies help reduce the number of unexpected shutdowns and the service life of boiler parts by predicting the tendencies of failures and chemical imbalances and preventing their further deterioration. This new approach stresses the importance of integrating advanced diagnostic systems with live surveillance to enhance the reliability in the long-term [10].

However, the large number of old and poorly maintained plants continue to operate without appropriate surveillance, appropriate treatment regimes, and modern corrosion-control solutions. These environments are the best locations where enhanced boiler water management methods can be implemented because these places are mostly prone to scaling, fouling, and corrosion. The need and demand in most of the various industrial sectors are that treatment solutions should be strong, flexible and affordable.

This paper will explore the reactions governing boiler water chemistry, the reasons behind corrosion, and the effectiveness of the traditional and the newest treatment methods to resolve these problems. The objective is to establish an effective water management system that enhances the heat transfer efficiency, reduces the corrosion rate, reduces operation cost and increases the service life of industrial boiler systems.

Objectives:

1. Examine the effects of water chemistry issues on scale, corrosion, and boiler performance as a whole.
2. Create and assess novel corrosion inhibitors and chemical treatment techniques appropriate for industrial boiler applications.
3. Examine how corrosion behaves when temperature, pressure, and feedwater composition are changed.
4. Create and implement an updated boiler water management and corrosion control scheme for an antiquated facility.
5. Evaluate the gains in equipment life, operational dependability, and efficiency brought about by improved water chemistry and corrosion management.

Methodology:

The method was employed in this research in order to provide a practical and reproducible model to understand the corrosion behavior, water chemistry of the boiler, and the efficacy of the chemical treatment program in an industrial high-pressure boiler. To develop the dynamic behavior of the water quality under the real working conditions, the method incorporated the long-term corrosion observation, the controlled lab testing, and the field testing. The work provided a strict basis of analyzing corrosion inhibitors, determination of scaling risks, and the overall effectiveness of water-treatment procedures by integrating field observations with laboratory accuracy.

To eliminate uncertainty in the reporting of analytics, the study computed Total Dissolved Solids (TDS) based on conductivity where it was estimated using a constant and documented conversion factor. TDS (ppm) = Conductivity (uS/cm) × 0.64 which is appropriate to mixed salt industrial boiler water was used to estimate TDS. The alkalinity was determined as total alkalinity and the hardness and alkalinity were reported as ppm as $CaCO_3$ using standard titrimetric methods. The corrosion rate was determined using weight-loss coupons that had a construction known surface area of 12.5 cm^2 and a standard density of carbon-steel of 7.86 g/cm^3. The rate of the corrosion was calculated with the help of the following formula:

The rate of corrosion (mpy) is (534 x W)/(D x A x T) wherein W is the loss in weight (mg), D is the density (g/cm^3), A is the exposed area and T is the exposure time (hours). To offer a better operational background, deposition tendency was also explained in terms of normal deposition rates (mg/cm 2/month) of high-pressure boilers, although the blowdown suspended particles were reported in g/L as a concentration value.

The measured g/L values were interpreted with reference to deposition rate 0.5-3 mg/cm2/month, high pressure boilers, to relate the values of concentration to the operational risk, thus enabling classification of the deposition tendency although a time based deposition test was not conducted.

All tests were converted to weight-loss measurements and it was recorded that the coupon density (7.86 g/cm^3) and the exposed surface area (12.5 cm^2) were measured. All these parameters were held constant to all coupons to eliminate variation in interpretation.

The research design was a hybrid one that involved field research and experimental analysis. Collected water samples were measured in the laboratory to identify important chemical properties such as pH, alkalinity, hardness, conductivity, dissolved oxygen, silica and chloride content. The most significant variables that stimulate corrosion and scale formation can be properly evaluated due to these experiments. Meanwhile, the field component involved strategic positioning of corrosion-monitoring devices, regular monitoring of boiler systems and inspection of chemical dosing processes. This two-fold approach facilitated the comparison of the controlled laboratory outcomes against the real variations that are realized in an industrial plant whereby, water chemistry is usually affected by boiler load, feed water fluctuations, and malfunctions of the system.

The location of the study was an industrial plant with a high-pressure water-tube boiler because of its comprehensive water-treatment systems, including a deaeration system, a condensate-recovery system and a chemical-dose system. These attributes enabled the study to trace boiler water in its entry state, feedwater, to the condensate outlet ensuring that the system understands all the chemistry of the process. It was planned to visit it regularly over a few weeks to record the work process, monitor the changes in the behavior of the system, and obtain new samples in different operating conditions. This was due to the fact that variations that would have otherwise not been realized in one sampling event were captured thanks to this uniform sampling method.

The treatment programme utilized certain chemical additives such as catalyzed sodium sulfite as the main oxygen scavenging agent, trisodium phosphate to condition the internal phosphate, low temperature polymeric dispersant, and a combination of neutralizing amines (mainly morpholine and DEA) to control the condensate-line pH. All the chemicals were metered in using automated metering pumps.

The four primary locations where samples had been taken were the boiler drum, condensate return line, deaerator outlet, and the feedwater entry. All the sampling stations were soon flushed to eliminate any standing water to ensure representative data. In situations where the samples were very hot, cooling coils were used to cool the sample before collection. The same water that was collected was used to pre-rinse sterile glass bottles to avoid cross-contamination. They were then completely filled to eliminate air exposure, particularly of such parameters as dissolved oxygen and carbonate equilibrium. All the samples were labeled with sampling and assessed within a day to ensure chemical correctness.

All the samples were analyzed in the laboratory through conventional methods. A calibrated digital meter was used in the determination of pH in order to ensure accuracy in the determination of the corrosion and scaling hazards. Alkalinity was determined through titration to determine the buffer capacity that is required to maintain steady operation of the boiler. Electrical conductivity was used as a measure of total dissolved solids, which is an important parameter to indicate the ionic concentration and probable carryover. In order to analyze the potential of scale formation, hardness EDTA titration was used to measure the hardness mainly that of calcium and magnesium. In order to determine the effectiveness of the treatment, the dissolved oxygen was measured in the presence of oxygen scavengers before and after. In sum, these two methods of analysis could provide an extensive insight into the quality of boiler-water under different working conditions.

Table 1 displays an example of typical laboratory measurements made during testing. These measurements assisted in determining if the water stayed within permissible operating limits and whether blowdown or chemical treatment modifications were required.

Table 1. Example Chemical Analysis Results

Sample Point	pH (Measured)	Conductivity (µS/cm)	TDS Estimate (ppm)	Status
Feedwater	7.8	640	˜410	Acceptable
Deaerator	8.2	720	˜460	Within range
Boiler Drum	9.6	1850	˜1200	Optimal
Condensate	9.1	1580	˜1020	Controlled

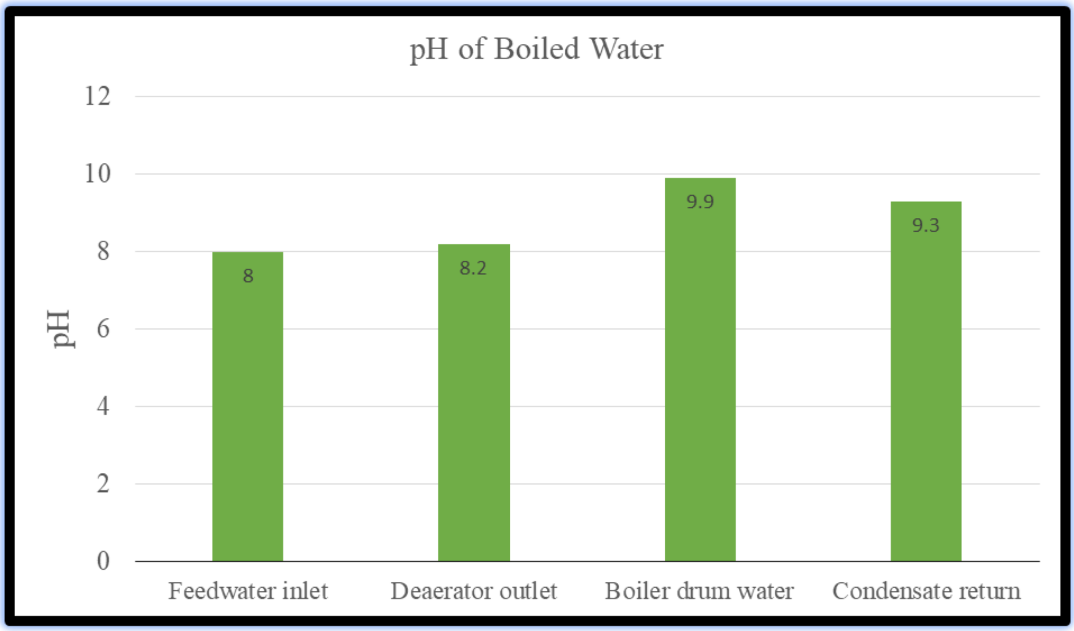

Figure 1: pH measurements

Blowdown water suspended solids as well as solid deposits collected on heat-transfer surfaces were analyzed to identify the potential of forming the scale. Filtering and drying blowdown samples were used to measure the amount of particle debris that can add to future scale layers. Mineral content and surface texture were determined through the microscopic analysis of deposits which had been removed in boiler tubes. This analysis was necessary in establishing the success or failure in preventing the formation of hard, adherent deposits by the use of phosphate treatments and dispersants.

The boiler was run on a Coordinated Phosphate Treatment (CPT) program and the target limits were residual phosphate 2040mg/L and Na/PO 4 ratio in agreement with sodium-to-phosphate congruent control. These control windows were kept during the study and were utilized as the point of interpreting the phosphate-alkalinity reactions.

Coupons of weights were employed to monitor the behavior of corrosion in the most important places in the water-steam cycle including the condensate return, boiler drum, and feedwater line. The coupons were washed and weighted to evaluate the loss of materials according to pre-determined exposure periods. Complementary electrochemical investigations were conducted to provide real-time information about the corrosion status through the Linear Polarization Resistance (LPR). All these combined techniques provided an evaluation of the protective efficiency of the existing treatment program and ensured a complete understanding of the rates of corrosion in the actual conditions of the boiler functioning. Table 2 is the summary of corrosion-rate measurements of weight-loss coupons. These findings allowed the identification of the aspects of the system that were put under the greatest stress of corrosion and the extent to which the treatment chemicals were effective.

Table 2. Example Corrosion-Rate Measurements from Weight-Loss Coupons

Location	Exposure Period (days)	Corrosion Rate (mpy)	Interpretation
Feedwater Line	60	0.82	Low corrosion
Boiler Drum	90	1.18	Acceptable
Condensate Line	60	0.93	Controlled

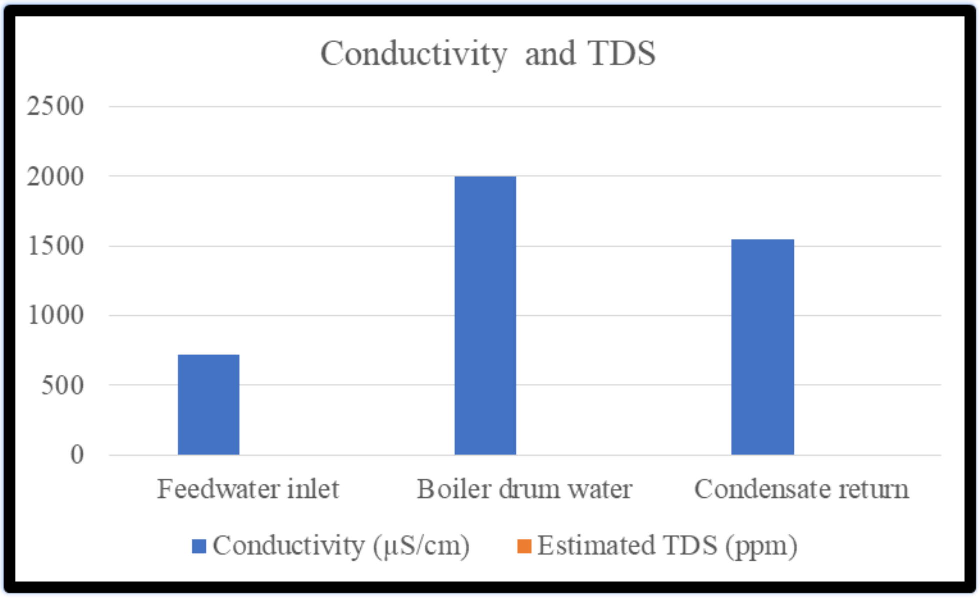

Figure 2: Conductivity & TDS Results

All things considered, the blended methodological approach which combined standard field sampling, laboratory analytical techniques, and corrosion monitoring offered a reliable and thorough way to assess the behavior of water chemistry and treatment effectiveness. This comprehensive approach provided a practical and theoretically valid basis for raising the overall efficiency of industrial boiler systems, reducing corrosion and scaling, and increasing boiler reliability.

Results:

The boiler that was studied was a high-pressure water-tube boiler with a pressure of 42 to 45 bar and all interpretation of TDS, silica, alkalinity and phosphate control limits was made based on the established water-quality guidelines of that pressure level. The operating pressure should be specified due to the fact that permissible values of silica, boiler-drum TDS, and carryover risk vary greatly across pressure ranges, and so all values reported in this study were interpreted based on the requirements of boilers operating at high pressure.

The comprehensive examination of the quality of the water in the boiler system, the formation of deposits, and corrosion activity allowed getting a comprehensive insight into the chemical and operating properties of the unit. Stable datasets to measure the efficiency of the treatment program and the stability of the system in high-pressure conditions were obtained in samples taken on the feedwater line, deaerator discharge, boiler drum, and condensate return.

The pH values were determined to indicate that the system was mainly within an alkaline environment that was suitable in regulating scale precipitation and corrosion. The success of upstream conditioning was due to the fact that the feedwater into the deaerator typically recorded a value of between 7.8 to 8.2. The pH increased even more after chemical dosing and deaeration to 8.1 -8.3. There was always a higher pH of boiler drum samples between 9.6 and 10.1 and this is in line with the expectations of phosphate-alkalinity therapy. Condensate return lines were in the 9.0 9.5 pH range, which is sufficient to avoid the weakening of low-carbon steel piping, caused by acid.

A summary of these results is provided in Table 3.

Table 3. pH and Conductivity Measurements

Location	pH Range	Conductivity (µS/cm)	Estimated TDS (ppm)	Status
Feedwater	7.9–8.1	650–720	~420–470	Within limits
Deaerator outlet	8.1–8.3	730–780	~450–500	Acceptable

Location	pH Range	Conductivity (µS/cm)	Estimated TDS (ppm)	Status
Boiler drum	9.7–10.0	1850–2050	~1200–1350	Meets boiler-water criteria
Condensate return	9.2–9.4	1500–1600	~1000–1050	Requires monitoring for carryover

Conductivity and TDS patterns depicted expected cycles of concentration. As the boiler drum water had inherently accumulated salts due to evaporation and due to addition of chemicals, the feedwater exhibited very low ionic loading. The increase in return samples was to some extent, indicating that non-volatile salts or small carryover events were in part traversed, despite the fact that condensate ought to be highly low in conductivity.

Hardness measures were consistent with these patterns. The softening was effective as shown by low hardness of the feedwater (typically 5570 ppm as $CaCO^3$). The presence of moderate raise in boiler drum hardness (90120 ppm) was also in line with controlled reactions of phosphates and the formation of sludge as opposed to crystalline scale. The infiltration of the hardness into the steam cycle was also limited as it was shown by lower levels of hardness in the condensate samples.

Corrosion rate (mpy) is determined as (534 × W)/D × A × T, W is the weight loss (mg), D is density (g/cm 3), A is exposed area (in 2), and T is period of exposure (hours). Even though the blowdown suspended particles were measured in g/L as a concentration measure, the deposition propensity was also put into perspective with regard to normal deposition rates (mg/cm 2/month) to give a clearer understanding of the operation of a boiler in high pressure.

The minor difference between the general feed water hardness range indicated in the text (55 to 70 ppm as $CaCO^3$) and the narrower range indicated in table 4 (60 to 65 ppm) indicates normal operational variation during the time span of the sampling due to the fact that the performance of the softener unit was constant and within reasonable control limits.

These findings are summarized in Table 4.

Table 4. Hardness and Alkalinity Results

Sample Point	Hardness (ppm as $CaCO_3$)	Alkalinity (ppm as $CaCO_3$)	Interpretation
Feedwater	60–65	85–95	Softened water; good conditioning
Boiler drum	105–120	730–800	Adequate buffering & phosphate reaction
Condensate	80–90	680–720	Acceptable return quality

The effect of deaeration and oxygen-scavenger dosage was significant in dissolved oxygen concentrations. DO in raw feedwater was between 0.28 and 0.35mg/L. DO in boiler drum water was maintained below 0.02mg/L after thermal deaeration and chemical treatment. This indicated effective oxygen de-oxygenation. Sometimes, the DO of the condensate was recorded to be 0.05-0.08 mg/L implying that there was some form of air entry or difference in amine protection.

The silica concentration in the boiler drum was found to exhibit expected trend of enrichment. Whereas the accumulation rate of the drum samples was 812 mg /L/silica, the feedwater was usually in the range of 1.01.2 mg. These values were near the level which leaves the deposition of silicate more likely, especially with magnesium, although no direct deposition of silica by the steam. Condensate silica was relatively low in the process of steam condensation and separation, and this indicates that some silica had been removed.

According to the analyses of scale formation, blowdown water contained suspended solids that were equal to approximately 0.8-1.4 g/L of depositable material. Depositable material is defined as the amount of suspended solids that was not removed by the filtration and drying process at 105 o C i.e. those solids that can form long term scales on the heat-transfer surfaces. The composition of materials removed out of boiler tubes contained a mixture of silicate, iron-oxide and carbonate phases. Such findings indicate that the internal corrosion as well as hardness leakage influence the deposit formation. Sample mass of the deposits in tube samples in the boiler drum region was slight higher compared to the downstream areas of the heat-exchanger sections.

The corrosion measurements of carbon-steel coupons revealed that there was a great difference between untreated and treated environment. Water-exposed coupons which were not chemically shielded exposed some pitting and corrosion rates of 8 to 12 mpy. Conversely, coupons in treated boiler-drum water exhibited minimal uniform corrosion and thinning of between 1.0 to 1.4 mpy.

In-between coupons showed moderate rates of corrosion (around 23 mpy), which are in line with the moderately high DO and conductivity obtained in the same section of the system.

A combined summary of deposit and corrosion results is shown in Table 5.

Table 5. Scale Deposition & Corrosion Measurements

Parameter / Location	Measured Value	Interpretation
Blowdown suspended solids	0.85–1.30 g/L	Moderate deposition tendency
Boiler tube deposit mass	~1.20 g/L equivalent	Mixed carbonate–silicate scale
Feedwater corrosion rate	10–12 mpy (untreated)	Severe; dominated by pitting
Boiler drum corrosion rate	1.0–1.3 mpy (treated)	Within acceptable limits
Condensate line corrosion	2–3 mpy	Mild–moderate; linked to DO ingress

Overall, the measurement campaign verifies that stable chemistry was maintained across the majority of the system by the water-treatment operation. In a high-pressure boiler setting, pH, alkalinity, boiler water concentration cycles, oxygen control, and hardness removal all responded as predicted. Condensate conductivity, boiler-drum silica concentration, and air leakage into certain return-line sections are areas that need ongoing monitoring. These findings offer a comprehensive foundation for assessing the effectiveness of chemical treatment and operational dependability.

Discussion

The outcomes of the corrosion monitoring, deposit analysis, and water-chemistry evaluation suggest that a rather stable system has been observed, which however has a variety of underlying problems that can be observed in the operation of high-pressure boilers. The program under consideration has been typically effective in metal protection and in regulating scaling reaction as indicated by the consistent maintenance of alkalinity in the feedwater, boiler drum, and condensate back sections. The alkalinity boosters and phosphate preparations are performing effectively to enhance the buffering performance and to promote the development of non-adherent sludge instead of the hard crystalline deposits as observed by the pH gradually increasing with the feedwater section to the boiler drum [11].Similarly, the pH of the condensate return corresponds to neutralization of carbon acid production thus avoiding acid corrosion in the low-pressure return lines [12]. This stability is significant because slight changes in pH may accelerate dissolution of the tube metal, and in high-pressure systems, the changes often cause rapid pitting and localized failures [13].

The conductivity and TDS measurements evidence the assumption that the concentration cycles in the boiler are under effective management. The amounts of the boiler drum were increased according to the forecasted evaporation and the accumulation of treatment residues, with the values of the feedwater remaining low, which means that there was enough pretreatment. Such values demonstrate that the operations of blowdown are in effect controlling dissolved solids since they did not exceed permissible levels of concentration [14]. Conversely episodes of carry over, or entry of dissolved salts into the steam circuit are suggested by the rather high conductivity of the condensate return. Such enrichment over a period of time may promote foaming, priming and unwanted deposition on internal boiler surfaces despite that it will not result in immediate problems. The latter observation is consistent with the literature on international best practices indicating that the quality of condensates often forms the determining factor regarding the integrity of boilers in the long term [15].

The hardness and the alkalinity data indicate the effectiveness of internal boiler treatment and water-softening systems in the cooperation. Although average levels of hardness in the intermediary hardness levels in the boiler drum signify the normal phosphate reactions in high-temperature conditions, low feedwater levels of hardness confirm the successful softening process [16]. To hold on the metal passivation, to enhance phosphate chemistry and to avert interior reactions which can otherwise promote hard scaling, the boiler-drum alkalinity was kept sufficiently elevated. These buffered conditions correspond to the recommended control limits of high-pressure boilers that were reported in the recent studies [17].

The tests of the dissolved-oxygen (DO) show one of the major benefits of the treatment regime. After deaeration and scavenger dosing, the feedwater DO was reduced drastically, to levels that are far below the level commonly associated with oxygen-pitting corrosion. The levels of boiler drums that are below 0.02 mg/L are set according to accepted corrosion-management standards to indicate that mechanical deaeration and the use of scavengers are controlled and nearly at maximum efficiency [18]. The other issue is that a typical problem in old or improperly vented return systems is low air penetrations that are evidenced by the slightly higher DO concentrations in condensate return lines. The identified concentrations are not yet an immediate risk, but rather they are signs of a predisposition which when neglected might transform into local pitting [19].

Silica trends show a more alarming trend. The rate of accumulation of silica in the boiler drum occurred gradually even though the regulated levels of feedwater were sufficient to reach amounts comparable to the amounts associated with silicate deposition at high pressure. Silica-based deposits are said to be extremely difficult to eliminate and may either move into steam systems and form turbine foulings or reduce heat-transfer effectiveness [20]. These elevated boiler-drum silica values are indicative of the fact that perhaps additional attention to the blowdown rate, feedwater treatment or condensate purity is required to maintain long-term stability.

The scale deposit was characterized and examined to have iron-oxide particles and mixed carbonate-silicate phases. This depicts the synergistic effect of low-level corrosion products into the boiler and leaks of hardness [21]. Even small coatings of scale can decrease the heat transfer coefficient and elevate the temperature of the tube metal, which can contribute to overheating or failure of tubes despite the measured deposition rates being in a rather modest range. Although the largely successful treatment is carried out by chemicals, the existence of iron oxides also proves that internal corrosion is the cause of the loading of particles in the boiler.

The rate of corrosion measurements give a clear evidence of the benefits of chemical treatment. Contrary to the coupons that were exposed to treated boiler water that exhibited a lower rate of corrosion of less than 1.5 mpy, which is within the safe operating limits, coupons that were exposed to untreated water exhibited significantly better higher rates of corrosion, including severe pitting [22]. Condensate-line coupons had a little higher corrosion rates in that portion of the system because of the higher DO and conductivity in that region. All the findings not only confirm the effectiveness of the treatment program but also indicate the areas in which it is necessary to pay a particular attention and control, in particular, the condensate return network.

The results in general prove that the treatment plan is fairly effective and that the boiler system is functioning below the acceptable chemical levels. The high silica, fluctuation of the conductivity of the condensate, and minute DO spikes in the return lines however are indicators of potential defects that may aggravate when not addressed. Strengthening the integrity of the system, increasing the condensate protection and improving the methods of boiler-drum blowdown would further enhance system dependability and long-term system performance. To ensure the optimum protection against the scaling, corrosion, and inefficiency in the operations, the findings emphasize the importance of continuous water-chemistry observations and periodical reassessment of the treatment program.

Conclusion

The conclusions made in the study show the importance of a balanced water chemistry to ensure the integrity of the boilers and the production of steam in the most efficient way possible. It was established that corrosion and mineral deposition reduction was necessary by maintaining a constant alkalinity, regulating dissolved solids, and efficient elimination of oxygen. Any variation of these parameters was soon augmenting the loss of metals and the formation of insulating scale. Poor conditioning accelerates wear and tear, reduces the heat-transfer coefficient, and consumes more energy, as analysed based on deposits and corrosion coupons. The results, conversely, demonstrate that the coordinated application of oxygen scavengers, phosphate treatment, dispersants, and controlled blowdown created a much more favorable operating environment that reduced the rate of corrosion as well as minimized the formation of deposits, which can serve as a valuable source of information on companies that want to increase the life of their system and its performance.

Recommendations

To ensure that the boiler is most likely to be at its best performance and last, it is recommended to use the appropriate scale-control chemicals and keep the pH alkaline to prevent corrosion. Dissolved oxygen must be maintained to the lowest possible level through an effective deaeration process and steady dosage of oxygen scavenger. Although the routine dosage of phosphate and dispersant will help in controlling the hardness and ensure that the sludge remains non-adherent, the dosage of the blowdown water TDS must be taken care of so as not to carry over and accumulate salt in the drum. To ensure the early detection of any issues it is essential to regularly monitor significant water-quality parameters, i.e. pH, DO, conductivity, hardness, alkalinity and silica. Corrosion-coupon testing must be conducted on a regular basis in order to determine metal loss and identify vulnerabilities in the system.To facilitate water quality in general, pre-treatment devices such as softeners and deaerators should be maintained. The employees are to be trained in responding rapidly to any change in the chemistry of the water and all monitoring activities should be thoroughly recorded.

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