

Predicting Corrosion and Scaling Tendencies In Industrial Boilers Using Novel Software Program

ARIF E. JAFFER, Baker Petrolite Corporation, Sugar Land, TX
ABDULMOHSEN D ALMAJNOUNI, Saudi Aramco, Dhahran, Saudi Arabia

JOE BATES, iSagacity, Half Moon Bay, CA

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ABSTRACT: Corrosion and Scaling are the major waterside problems in industrial boilers. Calcium, magnesium, iron, copper and silica predominate in most boiler deposits. These deposits usually form a dense layer that impedes heat transfer and cause costly boiler tube failures. Most corrosion products that deposit in the boiler originate in the pre-boiler systems. The majority of corrosion products consist of colloidal and particulate metals and their oxides. The compounds are swept into the boiler and deposit on boiler tube surfaces. A major factor contributing to this problem is increased return of condensate containing corrosion products from various processes used throughout the steam plant. Internal corrosion must also be considered. Corrosion not only contributes to deposits, but also results in metal damage.

The new software program can predict scaling and corrosion tendencies based on relevant thermodynamic and transport processes in the steam cycle. Plant data is input on a routine basis and the software provides early warning of abnormal conditions and improves overall plant efficiency. The paper discusses the capability of this novel software program and demonstrates cost benefit in implementing this unique tool in steam plants.

INTRODUCTION

Boiler tube failures continue to be the single largest source of forced outages in industrial type steam generators. Worldwide there are millions of steam generators installed to produce steam for manufacturing, process, and heating purposes. These boilers are extremely important to the overall operation of the processing facilities; therefore, the need to maintain trouble free boilers is mandatory.

A concentrated effort is being made to minimize boiler tube failure occurrences. The aggressive operation environment of industrial boilers is largely the reason for these failures. The combined effects of corrosion, scaling, stress, temperature, erosion and vibration cause deterioration of boiler tube material properties and reduction in wall thickness. Eliminating boiler tube failures could be worth millions of dollars a year to the company. If the main

operating problems with the boilers (corrosion and scaling) could be predicted, a contingency plan could be arranged to overcome the shutdown problems.

Determination of the boiler tube failure mechanism is important for the prevention of future problems. The root cause for a failure can be established and proper corrective measures taken only when the failure mechanism is identified correctly. The correct identification/prediction of failure mechanism is a complex process that includes many individuals and institutions. Technical specialists in metallurgy, chemistry, combustion, and boiler design frequently cooperate with the station staff in a failure investigation. These individuals rely on personal experience and a tremendous amount of reports, theories, studies, private communications, and investigations concerning the different failure modes and mechanisms.

Largely a result of many years of steady effort by various companies and boiler manufacturers, software systems are being developed to mitigate the problem of boiler tube failures. Predictive software systems, also known as knowledge-based predictive systems, appear to be an effective tool for transferring this knowledge gained through research and field experience to individuals responsible for the design, construction, operation, and maintenance of industrial steam generators.

Software predictive systems are being modeled to make possible correct identification of all routine mechanisms of boiler tube failure, which occur in currently operating boilers. Since availability and reliability of steam plants are key components for increasing operational life expectancy, periodic software expert system analysis can be a useful tool for evaluating the water chemistry and the potential impact of the chemical treatment program. It is believed that proper dissemination of this knowledge and future findings will contribute to fewer incidents of boiler tube failures. Based on this, a scope was outlined to develop software to predict corrosion and scale tendencies in boilers.

SCOPE

This study developed a predictive software program that would utilize the operating conditions of an operating boiler as input parameters and then predict the severity scaling and corrosion tendencies. This software follows from the work described at the 2003 IWC by Millett, Bates and Hussey (see IWC 03-32 in references). The primary purpose of the predictive system is to provide support to the staff/plant engineers by:

- Diagnosing system conditions such as chemistry excursions or equipment performance issues
- Prediction of corrosion and scaling conditions in the boiler prior to equipment degradation
- Prediction of general corrosion concerns in the pre-boiler equipment prior to equipment degradation
- Detailing proper corrective actions
- Instructing the user on the consequences of neglecting the abnormal conditions

Input to the software program includes but is not limited to type of boiler, capacity, steam rate, design pressure and temperature, heat flux, operating pressure and temperature, firing medium, number of tubes, types and metallurgy, type of manufacture of

boilers, operating data, type of treatment programs, daily control log sheet, quality of feedwater, boiler water and steam analysis. Outputs from the program include diagnostics of the system chemistry, identification of suspect instruments, suggested remedial actions and long-term consequences of the current conditions on plant equipment.

APPLICATIONS AND BENEFITS

Producing quality steam on demand for industrial plants is very important. Reliability of these systems is the key to operate industrial plants. Achieving this goal depends on properly managed water treatment program to minimize scale and corrosion. The boiler must be free of scale forming solids to allow rapid and efficient heat transfer and it must not be corrosive to boiler internals. Scaling and corrosion can result in boiler tube failures and inability to produce steam. If these two main problems could be predicted, then a contingency plan could be developed. Hence, the Company can save million of dollars in downtime.

The software program assists in the optimization of the boiler water treatment program and in energy conservation.

Human experts can be distracted or rushed and led to incorrect or inconsistent deductions. The predictive software system consistently applies the same logic and gives reliable results; these results are more precise given accurate inputs. This will help to obtain better consistency and accuracy in engineering decisions related to operations, control, and treatment of boiler water systems.

All conclusions reached by the predictive system are produced for the inputs and the decision making schema incorporated in the software. This tool has value to both the expert and operations personnel alike. The human expert can use this tool to handle routine situations more quickly and is freed from the cumbersome aspects of detailed data review and archiving and consulting support materials and related files. This is a great time saver in areas where justification is repeatedly requested for slightly different inputs. In this case, the program is developed based on agreement among the experts to archive system data and diagnosis. This archive can be analyzed by corporate experts, as corporate has a vast experience on boiler performance, corrosion and scaling. This feature is particularly important as it creates a "learning function" that is not static, but improves over time.

With appropriate help facilities, a software system can become an excellent tutor for transferring knowledge

from an expert to his successor or for expanding an awareness of corrosion and scaling issues with operational personnel. This provides a company with some measure of protection against loss of expertise through attrition (preservation of knowledge) and is an education tool for staff involved in plant operations and maintenance.

Non-specialists have access to expert knowledge if the expert is not available; problems that are well understood can be solved by anyone who has access to the expert system, this frees the expert from repeatedly executing the same task so that he can concentrate his efforts on acquiring new knowledge (efficient use of manpower).

SYSTEM DIAGNOSTICS

iSagacity has developed the Remote Manager technology for diagnosing systems using the Internet. Any process that has measurable and obtainable parameters with characteristic relationships can be monitored and diagnosed with Remote Manager. The software described in this paper was built using Remote Manager technology.

Data are entered into Remote Manager via a web page interface for this application. However, it is also noted that data stored in SCADA, DCS, ODBC Compliant Databases, Data Historians, or PDAs can be retrieved by iSagacity's Data Transfer software and communicated to the Remote Manager via the Internet, or company intranet/LAN system.. All data undergoes a series of algorithms. First, the data are screened for their timeliness. Secondly, key pieces of data are reviewed to ensure that the system is in a condition to be analyzed. Remote Manager has the ability to suspend diagnosis if conditions exist where performing a diagnosis is inappropriate or not possible. For example, if the entire system is off line or out of service, diagnosis is suspended. Thirdly, there are seven layers of screening applied to each data channel to determine its integrity and individual impact on the overall system. This screening process is the precursor to identifying suspect measurements and abnormal conditions.

Fourthly, a complete system diagnostic routine is applied to the data to determine any abnormal conditions. A library of abnormal conditions is maintained for the system. The diagnostic algorithm first identifies if an abnormal condition exists. Then the diagnosis determines if the abnormal condition is known or unknown. Finally, the diagnosis is revealed on a secure web page for the user. In addition, abnormal conditions can be alerted directly to the users e-mail, text pager, cell phone, or PDA for

an immediate response. The diagnostic routine also evaluates each data channel individually and as they interrelate. The routine lists all suspect measurements in a separate area for the user to investigate. A suspect measurement is either an invalid instrument result or a leading indicator of an event. Suspect measurements require customer interaction and attention.

Lastly, all data and results are reported on a secure web page for visualization, corrective action statements, and consequences to long-term operation in the diagnosed condition. Individual alerts are also established on data channels as specified by the customer. All information is stored remotely on a SQL back end database.

PREDICTION OF CORROSION AND SCALING TENDENCIES IN STEAM GENERATING SYSTEMS

In this paper, we will describe how the current capabilities of Remote Manager were leveraged with corrosion and deposition algorithms to provide the predictive capability desired by industrial boiler operators. We describe some specific examples to show how we apply this capability in the application for industrial boiler operators. Much of the basic corrosion and deposition science has been developed and compiled by organizations such as ABMA, EPRI, NACE, ASTM, ASME and others. Water chemistry specifications developed by industry groups are organized around the same scientific knowledge base that is used in our work. This software program could be used as a leading edge technology for all industrial boilers. With this program, one can predict corrosion and scaling tendencies, hence avoid costly, unexpected shutdowns of the boiler.

In addition to on-line process data from DCS, SCADA or Data Historians, Remote Manager can also take direct input of data through its Data Entry web interface and can be used in conjunction with a PDA interface for use in the process plant. Remote Manager includes a proprietary data analysis engine that is used to diagnose abnormal conditions in the process plant. Remote Manager uses a library of system "fingerprints" and a pattern recognition algorithm to detect any number of abnormal events or "scenarios" that can occur in the process being monitored. Remote Manager is the backbone technology on which other vertical applications are developed in order to monitor and diagnose other real time processes in industrial plants.

The vertical application being applied to industrial boilers and described here is the corrosion and scale tendency (CAST) module. CAST is fully integrated into Remote Manager and determines the corrosion and scaling

tendencies in the boilers and general corrosion tendencies in the pre-boiler equipment. The underlying technology in performing boiler corrosion and scale tendency calculations is with thermodynamic prediction software for high temperature aqueous solutions.

THERMODYNAMIC PREDICTIONS

The foundation for our calculation capability is EPRI's MULTEQ thermodynamic engine. MULTEQ is a computer program that calculates the composition and pH of an aqueous solution as a source solution is concentrated by evaporation. The program considers equilibrium relation including combination of species, precipitation reactions, and volatilization to calculate concentration variation in the liquid phase as boiling proceed along the saturation curve to temperatures of 335° C. It also calculates activity coefficients over the entire concentration and temperature range of interest.

The code includes an extensive database of the properties of additives and impurities typically found in steam cycles. The database can be applied over a range of temperature from 25°C to 350° C and pressures from atmospheric to well over 2000 psi. The code has been used extensively by many organizations to define water chemistry parameters in steam cycles. iSagacity has taken the thermodynamic engine inside MULTEQ and coupled it with algorithms to determine real time tendencies of corrosion and scaling in operating industrial boilers.

In this real-time approach, the local boiler tube chemistry is modeled using the plant parameters, current operating and chemistry data, and cumulative calculated deposits. The modeling aspects of the software allow for a site-specific application of the technology. By using rigorous models to calculate the key quantities of interest (e.g. high temperature pH, solubilities, etc.), our approach can be directly used with existing corrosion and scaling algorithms and correlations. Most importantly, the CAST module automatically accounts for plant design and operational changes.

CORROSION AND SCALING PREDICTIONS

The CAST module uses a series of algorithms in order to determine the corrosion and scaling conditions inside the boilers and the general corrosion conditions that exist in the pre-boiler equipment.

Boiler predictions are driven by two factors, the characteristics of the boiler deposit and the modeled chemistry of the solution under the deposit that is in contact with the boiler tubes. The boiler deposit calculation takes into account two different mechanisms that are occurring simultaneously on the boiling surface; deposition of particulate such as iron and copper oxides that are transported to the boilers, and precipitation of salts such as calcium carbonate and calcium phosphate within the boiler at the boiling surface. The CAST module uses the boiler specific heat flux information along with site-specific chemistry data to determine a deposit thickness and concentration factor across the deposit for each boiler. This information is critical to the subsequent algorithms. From here, the thermodynamic model is used to calculate the amount and specific types of salts that precipitate in the deposit as well as the resulting chemistry under the deposit including specie specific concentrations and pH(t).

In addition, the amount and type of precipitates along with the deposition of transported metal oxides (typically iron and copper) are accumulated for deposits in each boiler. This information is used to determine the deposit weight, deposit thickness, deposit composition, and overall scaling tendency of the boiler.

Further algorithms then determine the insulating value of the deposit on the tube. The cumulative tube deposit information is maintained for each boiler in the CAST database. The tube wall temperature is calculated based on the heat flux on the tube and the deposit composition. A tube bulging tendency form of corrosion is predicted from this.

Each time new boiler data are entered, the deposit and tube surface conditions are updated and the corrosion and scaling tendencies are analyzed. The CAST module algorithms can be performed for multiple locations in each boiler. Often the algorithms are focused on the highly susceptible areas for each boiler as an initial warning system.

When boiler inspections are performed and tube deposit information, such as deposit weight, are collected, and the CAST module allows the user to manually update the cumulative calculated parameters with the measured data. At this time, updates to the deposit calculation parameters in the CAST are made as well.

The CAST module also monitors pre-boiler corrosion. Algorithms for general corrosion tendencies are performed using the following plant information at specific plant locations as designated by the user.

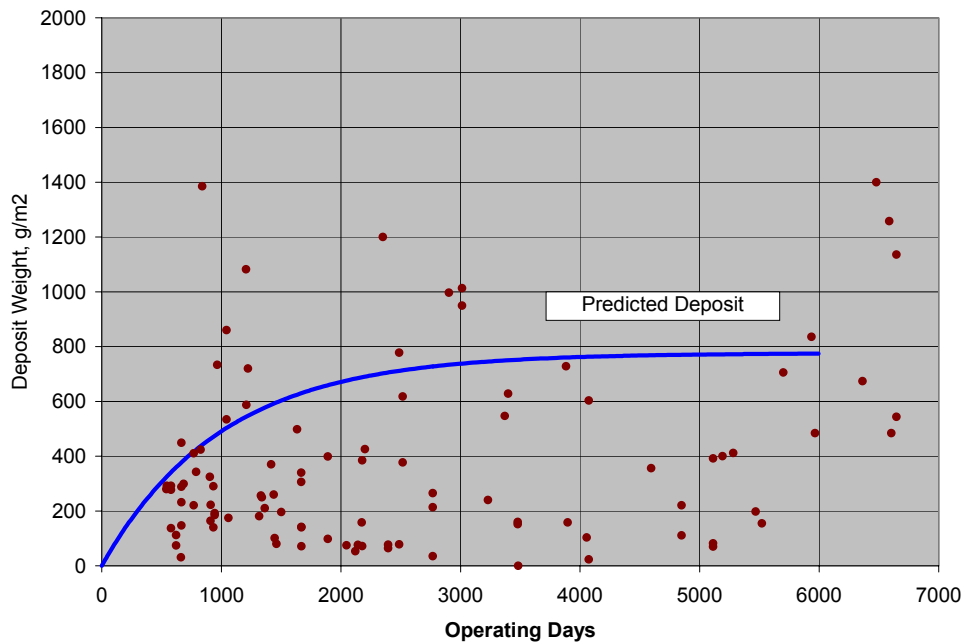
pH Oxygen Temperature

Velocity Phase (1/v)
Corrosion tendencies are predicted at user determined locations in the plant.

APPLICATIONS OF CAST

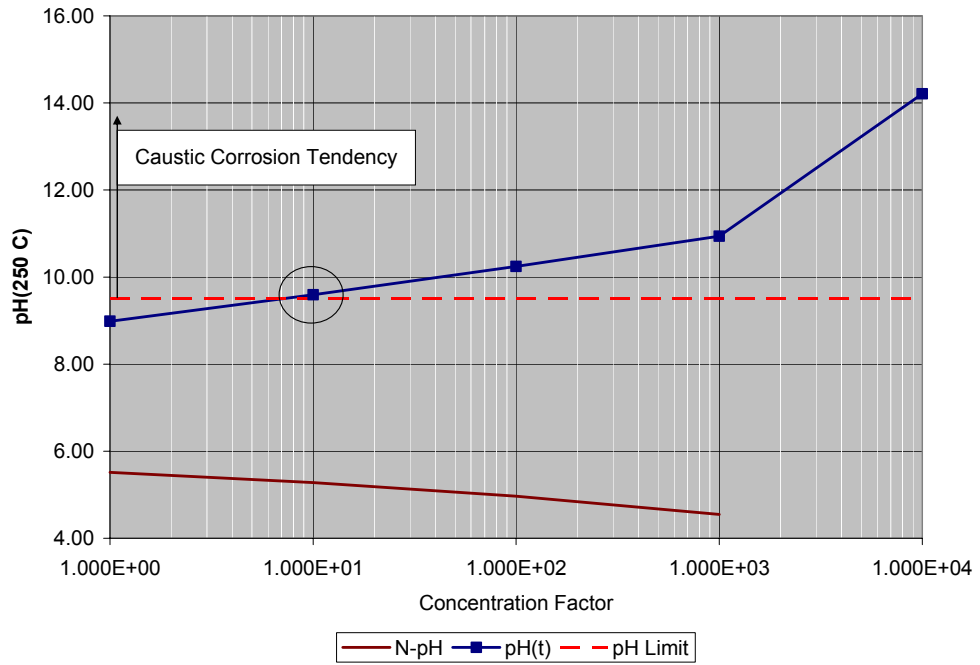
Benchmarks have been designed and used to test and evaluate the software in one refinery and one gas treating facility. Both of the benchmarks were designed to reflect the different manufacturing facilities and the different boilers used. Brief descriptions of two benchmarks follow. As soon as additional data becomes available regarding the use of CAST, it will be shared at future meetings and conferences.

Preliminary evaluation of the data shows a reasonable correlation of the modeling to the actual measured data. The following figure shows the calculated amount of deposit for one of the industrial boilers plotted against the historical measured deposit weights from multiple tube locations in a bank of nine similar industrial boilers. As expected, there is a reasonable amount of scattered to the measured data. However, the module would effectively predict deposit weights for planning purposes. In actual application, the CAST would be adjusted as measured data were obtained and the fit would be greatly improved. The ability of CAST to project deposit weights can be used to plan for chemical cleanings and other maintenance activities.



Further work at another facility showed the tendency for caustic corrosion based on reported chemistry and boiler design. Again, preliminary work to show the value of the software was performed. The boiler chemistry and design were used to determine the point at which caustic corrosion would be a concern. The results showed that by concentrating the boiler water by a factor of 10 (which is typical of a clean

tube), the solution chemistry in contact with the boiler tube had developed a caustic corrosion tendency. The pH(t) did not become appreciably elevated until the concentration factor exceeded 1000. Since one of the algorithms in CAST calculates the concentration factor in real time, this can be used to predict when the formation of caustic conditions is imminent in the boiler.



CONCLUSIONS

The use of a predictive software program that utilizes the operating conditions of an operating boiler as input parameters and then predicts the severity scaling and corrosion tendencies is of a high value to the industry. The aspects that deliver the highest value are:

- Diagnosing system conditions such as chemistry excursions or equipment performance issues
- Prediction of corrosion and scaling conditions in the boiler prior to equipment degradation
- Prediction of general corrosion concerns in the pre-boiler equipment prior to equipment degradation
- Detailing proper corrective actions
- Instructing the user on the consequences of neglecting the abnormal conditions

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