EPRI ChemExpert: Cycle Chemistry Advisor for Fossil Power Plants

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ABSTRACT

To help power plant operators and chemists to control cycle chemistry and corrosion, EPRI developed ChemExpert, an expert system based on EPRI Guidelines and experience. This software uses inputs from plant analytical and other instrumentation and grab sample analyses to determine current problems and recommend corrective actions. It also verifies the chemical analytical data, automatically produces reports, and provides cycle and water treatment descriptions.

The Training Module gives definitions, cycle chemistry tutorials, and allows training in water chemistry control and problem recognition for the specific power plant. ChemExpert currently covers drum and once-through boiler units with and without condensate polishers, using acid and alkali-forming cooling water, all-ferrous and mixed metallurgy, and phosphate, equilibrium phosphate, sodium hydroxide, AVT, and oxygenated treatments.

INTRODUCTION

Today's competitive environment and shortages of electric power require operation of the utility power plants at top efficiency with minimum forced outages. Corrosion, scale, and deposits have been the No. 1 contributor to the increased cost of steam and power generation (1). The highest component of this cost is the cost of replacement power which has been up to $300/MWh and during the summer of 2000, reached up to $10,000/MWh in the U.S. At the same time, many plants do not have a round-the-clock chemist, and the control room operators, often not trained in water chemistry control, are the first line of defense. Each year serious contaminant events happen and the operators do not know how to respond. The result can be serious damage to the unit and the need to chemically clean various parts of the plant.

EPRI ChemExpert (2) was developed to assist plant operators and chemists in water/steam chemistry and corrosion control and problem diagnosis in fossil power plants. It is an expert system which detects cycle chemistry related problems in the steam/water cycle as they occur (see Figure 1) and recommends corrective actions. Using ChemExpert improves plant control of water and steam chemistry, thereby reducing the likelihood of equipment damage and efficiency loss.

The water chemistry features of ChemExpert are based on the philosophy and action and target levels of EPRI's fossil plant cycle chemistry guidelines (3 to 7) and experience (8, 9).

The expert system, artificial intelligence approach is based on the principles developed in Refs. 10 and 11 and applied by Jonas, Inc. to control of water chemistry in nuclear units (12). These principles were modified to make the Advisor's decisions quantitatively proportional to the values of the monitored parameters.

Figure 1.
Cycle Diagram Showing the Detection of Air Inleakage below the Hotwell Water Line on TVA's Kingston 9.

CHEMEXPERT DESCRIPTION

As shown in Figure 2, ChemExpert uses data from on-line chemical analytical instruments, other on-line data, and manually entered grab sample analysis data to determine if any cycle chemistry related problems are occurring in real-time. It can access existing data acquisition systems (DAS) or distributed control systems (DCS) through a serial port connection, or through a network using DDE communications to acquire data.

Figure 2.
Block Diagram Showing the Basic Data Flow through EPRI ChemExpert

ChemExpert consists of four separate programs:

1. **ChemExpert Customization** - This program allows the user to completely customize ChemExpert for a specific unit and cycle chemistry, the number of Action Levels, the chemistry parameters which are monitored, and their Action Level limits. ChemExpert can be customized for drum or once-through boiler units using all-volatile treatment (AVT), or oxygenated treatment (OT), or for drum boiler units on phosphate treatment (PT), equilibrium phosphate treatment (EPT), or caustic treatment (CT) (Table 1). The program is also customizable for:
   - ferrous or copper alloys in the feedwater system
   - condensate polishers (individual and combined effluents) or not
   - deaerator or not
   - acid- or alkali-forming cooling water
   - number of Action Levels (2 or 3)

Table 1.
Available EPRI ChemExpert Unit/Chemistry Combinations

Boiler Type and Chemistry	Copper in Feedwater?	Condensate Polishers?	Deaerator?	Acid- or Alkali-Forming Cooling Water
Drum on AVT	Yes/No	Yes/No	Yes/No	Acid/Alkali
Drum on EPT	Yes/No	Yes/No	Yes/No	Acid/Alkali
Drum on PT	Yes/No	Yes/No	Yes/No	Acid/Alkali
Drum on OT	No	Yes	Yes/No	Acid/Alkali
Drum on CT	Yes/No	Yes/No	Yes/No	Acid/Alkali
Once-through on OT	No	Yes	Yes/No	Acid/Alkali
Once-through on AVT	No	Yes/No	Yes/No	Acid/Alkali

2. **ChemExpert** - This program detects cycle chemistry problems in real time and recommends corrective actions. It contains the following features:
    - Verification of analytical results including a check of the ion balance
    - Warnings for parameters outside user customizable limits
    - Identification of current water and steam cycle chemistry problems and their possible consequences
    - Recommendation of corrective actions and action times
    - Pressure dependent impurity limits for drum boiler water
    - Data storage for the life of the unit (with periodic transfer of data to permanent storage media)
    - Plotting of current data vs. time and customized plots
    - Generation of daily, monthly, and yearly reports

3. **ChemExpert Cycle Description and Maintenance** - This program can be used as a concise database of basic plant information and as a record of water chemistry and corrosion related maintenance tasks. It contains the following:
    - Cycle description and characteristics of the equipment around the steam/water cycle
    - Scheduling of operation, maintenance, and calibration based on the information in the cycle description section

4. **ChemExpert Operator and Chemist Training** - This program contains information compiled from many published sources on cycle chemistry and is meant to increase the chemistry knowledge of the user. It also contains:
    - Tutorial using a drum boiler unit on AVT with condensate polishers and copper in the feedwater system
    - Simulation of the user customized unit for use in training and troubleshooting

In addition to chemical control parameters, several chemical feed and operational parameters can be entered into ChemExpert. The initial values for the Action Level limits for each chemistry parameter are the default EPRI Guideline values (3 to 5) for the type of unit and chemistry selected during customization.

ChemExpert can calculate percent (%) carry-over, and the sodium to phosphate molar ratio (13) for units on EPT or PT in real time. The carry-over is calculated using the current values for saturated steam sodium and blowdown/downcomer sodium. The verification of analytical data is done using an ionic balance program developed at Oak Ridge National Laboratory (14).

Using the current on-line instrument and grab sample values which are displayed on the ChemExpert Data Display screens, along with the Action Level limits, ChemExpert calculates the probability of the occurrence of each problem. The computation is based on influence diagrams (10) prepared by experts in which the relationship between each monitored parameter (mostly chemical, but also operational parameters) and the individual water chemistry problems is determined. The values from the influence diagram ('A' Constants) have been selected and tested to fit most installations. In some cases, the 'A' Constants may have to be customized for a particular unit by a water chemistry expert.

Figure 3 is an example of an influence diagram for Air Inleakage Below the Hotwell Water Line for a drum boiler unit using equilibrium phosphate boiler water treatment (EPT) and acid-forming cooling water, without condensate polishers, with copper in the pre-boiler feedwater system, and a deaerator. The 'A' Constants can range from –15 to 15. A positive 'A' Constant means an out of spec value for the parameter indicates the problem may exist, while a negative 'A' Constant means an out of spec value for the parameter indicates the problem does not exist. The more positive an 'A' constant is, the more influence that parameter has in determining the existence of that problem. If a parameter does not have an 'A' Constant associated with it, it receives a value of zero indicating that the parameter is not used in determining the existence of a particular problem.

Figure 3.
Influence Diagram Showing the 'A' Constants (in rectangles) Relating Relevant Parameters with Air Inleakage Below the Hotwell Water Line. Not all of these Parameters were Monitored at TVA's Kingston 9.

APPLICATION EXAMPLES

As a part of the development of ChemExpert, the program was installed and tested in Carolina Power and Light's Roxboro Unit 2 and TVA's Kingston Unit 9. The installation, connection to on-line data, and customization took only one day. During the Kingston 9 test, ChemExpert detected Air Inleakage Below the Hotwell Water Line. The existence of the air inleakage was later confirmed by TVA personnel. Figures 1 and 4 to 6 are ChemExpert displays showing typical data from Kingston 9.

In ChemExpert, the main display is a Cycle Diagram showing monitoring locations with color indicators of the status of monitored parameters and a display showing current problems. The list of the cycle chemistry problems detectable by ChemExpert for a drum boiler unit on phosphate treatment (PT) is shown in Table 2. Figure 1 shows the Cycle Diagram screen during the test in Kingston 9.

From the Cycle Diagram screen, the user can access two screens showing the current values of the monitored chemistry and operational parameters. The core parameter data display shows only the core parameters which are monitored in Kingston 9 (Figure 4). The other data display shows all of the parameters which are monitored (Figure 5), including grab sample analysis. Both figures show the current data at the time that the Air Inleakage Below the Hotwell Water Line problem was detected in Kingston 9.

Figure 4.
Display of Core Parameters during the Test in TVA's Kingston 9.

Figure 5.
Display of All Monitored Parameters during the Test in TVA's Kingston 9.

Table 2.
Cycle Chemistry Problems Detectable by EPRI ChemExpert: Drum Boiler Unit on Phosphate Treatment (PT)

01. No Problems
02. Unit is not Running
03. Air Inleakage Above the Hotwell Water Line
04. Air Inleakage Below the Hotwell Water Line
05. Condenser Tube Leak
06. Contaminated Condensate Storage Tank
07. Makeup System Malfunction
08. Colloidal Silica through the Makeup System
09. Colloidal Iron through the Makeup System
10. Organic Impurities through the Makeup System
11. Makeup Regenerant - Sodium Hydroxide Leaking into the Cycle
12. Makeup Regenerant - Sulfuric Acid Leaking into the Cycle
13. Organic Impurities from Makeup Demineralizer Resin Degradation
14. Condensate Polisher Malfunction/Exhaustion
15. Condensate Polisher Resin Degradation
16. Condensate Polisher Resin Leakage
17. Condensate Polisher - Leakage of Caustic Regenerant
18. Condensate Polisher - Leakage of Sulfuric Acid Regenerant
19. Corrosion and/or Flow-Accelerated Corrosion of Carbon Steel in the Preboiler Cycle
20. Corrosion and/or Flow-Accelerated Corrosion of Copper Alloy Tubing in the Preboiler Cycle
21. Deaerator Malfunction - High Oxygen at Deaerator Outlet
22. Excessive Concentration of Oxygen Scavenger - High Iron in Feedwater
23. Insufficient Concentration of Oxygen Scavenger - High Copper in Feedwater
24. Feedwater Contamination from Boiler Feed Pump Gland Seal Water and/or Heater Drain Pumps
25. Phosphate Hideout – Severe
26. Phosphate Hideout Return – Severe
27. High Na/PO4 Ratio in Boiler Water
28. Low Na/PO4 Ratio in Boiler Water

29. High Phosphate Concentration in Boiler Water
30. High Boiler Carry-over
31. Sodium Hydroxide Carry-over
32. Impurity Introduction into Turbine by Attemperating Sprays
33. Boiler Layup - Lost Nitrogen Blanket
34. Boiler Layup - Low pH of Boiler Water
35. Boiler Layup - High Oxygen in Boiler Water

Also accessible from the Cycle Diagram screen are the **Current Problem Descriptions** (Figure 6). These screens describe the steps necessary to **confirm** the existence of, and **take action** towards correcting current cycle chemistry related problems, in this case, Air Inleakage Below the Hotwell Water Line. When a problem is detected, confirmation should take place within the specified time so that the necessary corrective action can be taken to prevent damage to equipment. The value for the action time is calculated based on the severity of the problem, so a severe problem has a shorter allowable time than a less severe problem. At the bottom of the screen are the **consequences**, which indicate what could occur if the recommended action is not taken.

Figure 6.
Current Problem Description Showing the Confirmation Steps, the Action to be Taken if the Problem is Confirmed, and the Consequences if No Action is Taken for Air Inleakage Below the Hotwell Water Line.

FURTHER DEVELOPMENT

As ChemExpert is installed in more plants, recommendations for additional capabilities have been received. With the ability to expand ChemExpert and to acquire and send additional digital and analog signals, ChemExpert could be programmed to analyze and/or control any number of systems. Work has been initiated to develop a combined cycle/HRSG version (CC ChemExpert). Some of the modifications which could be performed are to have ChemExpert control boiler blowdown and the feed of water treatment chemicals based on the current water chemistry around the cycle. ChemExpert also could be programmed to control the makeup and cooling water systems. Another possible modification is to have one master version of ChemExpert which can display the cycle diagrams and data displays for multiple units.

CONCLUSIONS

1. In most U.S. power plants, the round-the-clock control of water chemistry is performed by control room operators, and the station chemists (if any) are not always available. This often results in delayed problem detection, wrong corrective actions, and, in the worst cases, failures and severe contamination. ChemExpert is a useful tool for on-line diagnosis of water and steam chemistry problems and in training chemists and operators to recognize these problems. Use of this program could greatly reduce corrosion and scale/deposit buildup around the cycle.

2. ChemExpert has been successfully installed and demonstrated at Carolina Power and Light's Roxboro 2 high pressure drum boiler unit with mixed metallurgy on AVT and in TVA's Kingston 9 2000 psi drum boiler unit using phosphate boiler water treatment.

3. ChemExpert's functionality could be expanded to include combined cycles, automatic control of the unit's cycle chemistry and control of the makeup system and cooling water.

4. Approximately 100 copies of ChemExpert have been distributed to utilities around the world. It is being used in a wide range of applications from training to expert alarm and advice.

ACKNOWLEDGEMENTS

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