Cycle chemistry monitoring system as means of improving the reliability of the equipment at the power plants

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Abstract. There are many problems in domestic energy at the present that require urgent solutions in the near future. One of these problems - the aging of the main and auxiliary equipment. Wear of equipment is the cause of decrease reliability and efficiency of power plants. Reliability of the equipment are associated with the introduction of cycle chemistry monitoring system. The most damageable equipment’s are boilers 52.2%, turbines (12.6%) and heating systems (12.3 %) according to the review of failure rate on the power plants. The most part of the damageability of the boiler is heated surfaces (73.2 %). According to the Russian technical requirements, the monitoring systems are responsible to reduce damageability the boiler heating surfaces and to increase the reliability of the equipment. All power units capacity of over 50 MW are equipped with cycle chemistry monitoring systems in order to maintain water chemistry within operating limits. The main idea of cycle chemistry monitoring systems is to improve water chemistry at power plants. According to the guidelines, cycle chemistry monitoring systems of a single unit depends on its type (drum or once-through boiler) and consists of: 20…50 parameters of on-line chemical analyzers; 20…30 «grab» sample analyses (daily) and about 15…20 on-line monitored operating parameters. The operator of modern power plant uses with many data at different points of steam/water cycle. Operators do not can estimate quality of the cycle chemistry due to the large volume of daily and every shift information and dispersion of data, lack of systematization. In this paper, an algorithm for calculating the quality index developed for improving control the water chemistry of the condensate, feed water and prevent scaling and corrosion in the steam/water cycle.

1. Introduction

Reliability of the equipment are associated with the introduction of cycle chemistry monitoring system. The most damageable equipments are boilers, turbines and heating systems according to the review of failure rate [1] on the Russian power plants for 2001-2007. The most part of the damageability of the boiler is heated surfaces (73.2%). According to the Russian technical requirements [2] the monitoring systems are responsible to reduce damageability the boiler heating surfaces and to increase the reliability of the equipment.

Chemistry monitoring system is a part of the automated control system, with up to 1.000 different input signals. Development CCMS as subsystems of automated control system integrate the operational staff for the timely removal and prevention of emergencies due to failures of water chemistry.

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At present there are different variants of development CCMS water chemistry. The typical structure of chemistry monitoring system is showed in Figure 1.

According to the Russian guidelines, monitoring system have developed on the basis of industrial and research experience, there should be at least three main sources of the incoming information in the system such as

- on-line measured water chemistry parameters
- "grab" sample analyses
- technological parameters mostly affecting water chemistry (main flow rates, unit capacity etc.).

Although data presentation on CCMS PCs' monitors gives color or sound warnings in the event of deteriorating or failed water chemistry, large volumes of the incoming information can overwhelm the operating personnel preventing the determination of current chemistry related “weakest links” and their priority actions. Application of automatic dosage reagents and technological algorithms as aid for the operating personnel to evaluate water chemistry and reduce quantity reagents.

![Figure 1. The schematic diagram of structure of the cycle chemistry monitoring system.](image)

The monitoring system consists of two main subsystems as shown in Figure 1:

- dosing system;
- technological algorithms for the analysis of water chemistry.

2. **Dosing system**

All Russian plants are equipped with chemical dosage, but small number of plants have automatic dosage. The automatic dosing systems have been using at the power plants as with drum as once-through boilers. The function of the dosing system is to control the water chemistry of the condensate, feed water to prevent corrosion in the water/steam circuit.

Reagent dosage can be obtained through two schemes as shown in Figure 2:

- the flow rate of treated water
- the flow rate of treated water and the on-line measured parameter of the coolant.

However, the dosage of the reagent proportional flow rate water is usually not enough at nominal regime. Reagent dosage is necessary realize as flow of water as water quality. In this case, automatic dosing system is used with a flow compensation. System with disturbance compensation provides raise dynamic accuracy by reducing the effect of the measured water flow disturbance on the controlled water quality.
Scheme of dosing system to water quality parameter with disturbance compensation is showed in Figure 3.

Figure 3. Diagram of combined dosing system with disturbance compensation.

The control action $\mu(t)$ is a change flow rate of reagent. Water flow is changed by moving the regulating mechanism of the dosing pump, changing the stroke length of the plunger. Controlled variable is a chemical parameter. Movement of the plunger pump occurs with a water quality deviation from the set point. Flow rate of treated water is a measurable parameter, i.e. it can be seen as a controlled disturbance. Consequently, it is advisable to use the dosing system with disturbance compensation.

3. Evaluation of water chemistry quality by means technological algorithm

Experience has shown that a failure of the water chemistry is one of the reasons that lead to the intensification of corrosion processes and the processes of formation of deposits on the heating surfaces of the boiler. Thus, it is important to evaluate the nature of the failures of the water chemistry.

The water chemistry index (WCI) is implemented as the monitoring system algorithm to evaluate water chemistry and to determine the priority actions for the operating personnel. The principle of WCI is to compare monitored parameters with their limiting and average values.
Recent researches and available industrial experiences [3] show that the ranges of limiting values of the water chemistry parameters are too broad. These values need to be revised so that a narrower range should be used. The average values of the parameters also should be defined under the condition of minimum corrosion rate and deposit build-up on heat transfer surfaces.

The WCI formulation varies for three different groups of parameters:
• only upper limiting values
• only lower limiting values
• both upper and lower limiting values.

The WCI for the first group of parameters with only upper limiting values [4] (conductivity, sodium and dissolved oxygen etc.) can be calculated in accordance with the formulation 1:
\[
WCI_i = \frac{|z_i - z_{av}^i|}{limit_{upper}^i - z_{av}^i},
\]
where:
- \(WCI_i\) - WCI of the \(i\)-parameter;
- \(z_i\) - measured value of the \(i\)-parameter;
- \(z_{av}^i\) - average value of the \(i\)-parameter;
- \(limit_{upper}^i\) - upper limiting value of the \(i\)-parameter.

The WCI for the second group of parameters with only lower limiting values (steam pH), can be calculated in accordance with the formulation 2:
\[
WCI_i = \frac{|z_i - z_{opt}^i|}{z_{opt}^i - limit_{lower}^i},
\]
where:
- \(z_{opt}^i\) - optimal value of the \(i\)-parameter;
- \(limit_{lower}^i\) - lower limiting value of the \(i\)-parameter.

The WCI for the third group of parameters with both upper and lower limiting values (feed water and boiling water pH) can be calculated in accordance with the formulation 1 if \(z_i \geq z_{av}^i\) and formulation 2 if \(z_i < z_{av}^i\).

Some boundary conditions have been formulated for the WCI calculations:
- in the case of ideal situation, when \(z_i = z_{av}^i\), the WCI of the parameter is equal to zero;
- in the case, when monitored parameter reaches its limiting value \(z_i = limit_{upper}^i\) or \(z_i = limit_{lower}^i\) the WCI of the parameter is equal to one;
- higher the WCI value of the parameter, the more severe water chemistry failure.

4. Example
As example of realization full-scale CCMS at the power plants is introduction sample monitoring system at the Iriklinskaya GRES for units # 1-8 300 MW of each. The Iriklinskaya power plant has an capacity of 2400 MW (eight units of 300 MW each), located in the Eastern part of the Orenburg region. As of today - this is one of the largest power plants in the South Urals. The power plant was started up in the mid-70s and in accordance with the principle of power production. The maximum power capacity of power plant is approx. 2430 MW. The maximum temperature is 545 °C at a steam pressure of 24 MPa.

Main water is purified by passing it through 3-stage water softening plant with pretreatment and ion exchange filters. The resulting fully demineralized water has a mean total conductivity of approx. 0.3 \(\mu\)S·cm\(^{-1}\) and it is stored in a special water storage tank; it is added to condenser as makeup water. Main condensate is purified by passing it through a polishing system. The degassed feed water is
preheated using three HP heaters. The generated steam is led through superheater stages and heated to approx. 545 °C at 24 MPa.

300 MW units are operated at an oxygen-ammonia water chemistry for surface passivation of steel pipes feed circuit. The passivation is performed by the excess oxygen in the range of 100-400 µkg·L⁻¹ and provided low conductivity feed water <0.3 µS·cm⁻¹. pH feed water 8.0±0.5 provides decrease corrosion in the steam/water cycle.

The upgraded work of CCMS of 8 units was proceeding during 7 years since 2003 till 2010 an experience of operation from another plants had been considered. The main target was to realize many functional CCMS that can unite measurement and control of technological equipment of each blocks and the whole plant.

Water parameters such as conductivity, sodium, pH, dissolved oxygen, hydrogen are continuously monitored on line by analyzers. In addition, other parameters such as iron, silica are determined at regular intervals. The average values for one month in comparison to Russian guidelines are showed in table 1 [4]. The limiting values required by the guidelines for all parameters could be observed.

Table 1. Average values for the analysis of condensate, feed water, steam for one month.

|                        | Condensate after condensate pump | Feed water | Steam |
|------------------------|----------------------------------|------------|-------|
|                        | Measured value | Requirement as per [4] | Measured value | Requirement as per [4] | Measured value | Requirement as per [4] |
| **Total conductivity** | 0.07               | 0.5        | -     | -     | -   | -   |
| **Conductivity after H-cation** | -   | -   | 0.13 | 0.3   | 0.13 | 0.3 |
| **Sodium**, µkg·L⁻¹   | 2.3                | -          | 1.6   | 5     | 0.9  | 5   |
| **pH**                 | -                  | -          | 7.95  | 8±0.5 | 7.83 | >7.5 |
| **O₂**, µkg·L⁻¹        | -                  | 20         | 500   | 100÷400 | 250 | -   |
| **H₂**, µkg·L⁻¹        | -                  | -          | -     | -     | 0.22 | -   |
| **Iron**, µkg·L⁻¹      | 32                 | -          | 9     | 10    | 9   | -   |
| **Silica**, µkg·L⁻¹    | -                  | -          | 12    | 15    | -   | 15  |

* data from online analyzers
b data from "grab" sample

The subsystem of automatic dosage of ammonia is realized at each unit of the Iriklinskaya GRES. This subsystem is used to control the dosing pumps ammonia. Dosage of ammonia depends on pH feed water 8.0±0.5 and ammonia content of the feed water should be 500 mg·L⁻¹ at concentration of 0.7 - 1%. Automatic dosage of reagent into feed circuit has been realized according to the ratio of treated water flow and reagent flow, pH of feed water. Measurement reagent flow occurs by volume dosing pumps. The amount of reagent is dependent on the plunger strokes number of dosing pump. Measurement flow rate is made by flowmeter.

Industrial tests were performed in the nominal operating mode at the unit of power plant. The purpose of the test is to evaluate the correlation thermal parameters to chemistry in stationary, start up modes, choice and justification of controlled variable and controlled disturbance. On the basis of determining the dynamic characteristics were obtained transients ammonia dosing system.
Figure 4. Change of ammonia in relation to the flow of feed water.

The results of the test unit with an once-through boiler in stationary operating mode are shown in Fig. 4.

Figure 5 shows compensation decrease the dynamic error approx. 1.3 times. Thus, it is advisable to use compensation flow of treated water.

Technological algorithms have been implemented in all units power plant. Algorithms have been developed for monitoring of failures and/or deviations of water chemistry. Such decision allows identify the most dangerous trends in the current time. Thus technological algorithms allow to define the priorities for the personnel of chemical plant.

For the calculation used the following information:
- online measuring data
- standardized value of the parameter
- average value of the individual parameter
- time interval.

Assessment of water chemistry using quality index during the reporting period at the end of a work shift, the quality indexes are defined: main condensate, feed water and steam at each unit. Figure 6 shows an example of water chemistry index of feed water for all units.
5. Conclusions
Complex of on-line, "grab" chemical and technological parameters together with technological algorithms and control of water chemistry can quickly respond on changes water quality and give recommendations for personnel actions chemical plant.

Cycle chemistry monitoring system have been developed and introduced for different unit at the thermal power plant. Ammonia dosing system to increase the efficiency of cycle chemistry monitoring. The use of compensation to water flow is appropriate. Technological algorithms for the evaluation of water chemistry are designed to identify dangerous trends in the steam/water circuit.

The results of the work are used in the design of the cycle chemistry monitoring system at Iriklinskaya thermal power plant capacity 2430 MW.

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