# Water Quality Control Technology for Thermal Power Plants (Current Situation and Future Prospects)

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*Water treatment for thermal power plants is conducted to prevent problems such as carryover to the turbine components, as well as corrosion and scale formation/deposition in the boiler and turbine systems. Since 1959, water treatment methods have been improved to deal with equipment nonconformities. The required water quality for boilers and turbines of thermal power plants is stipulated by the Japanese Industrial Standard (JIS) B 8223. JIS B 8223 is regularly amended, in which Mitsubishi Heavy Industries, Ltd. (MHI) has also participated. The improvement of water treatment methods for aging plants, higher operational efficiency, and better environmental conservation has been high on the agenda in recent years. This paper introduces a package of new products and technologies that we are developing.*

## 1. Introduction

Water treatment for thermal power plants is conducted to prevent problems such as carryover to the turbine components, as well as corrosion and scale formation/deposition in the boiler and turbine systems.

The Japanese Industrial Standards Committee established a “specialists group for boiler feedwater and boiler water” in the Mechanical Engineering Division to assess and determine the water quality control criteria. In February 1961, these were stipulated by JIS B 8223 (titled “Water conditioning for boiler feed water and boiler water”). JIS B 8223, which stipulates the required water quality for boilers and turbines of thermal power plants, is regularly amended based on operational results, technological innovation, equipment nonconformities, etc., to which we have also contributed[1].

In recent years, with increased focus on water treatment methods for aging plants, higher operational efficiency and better environmental conservation, we are developing a package of new products and technologies that address the following problems: (1) powdered scale deposition for oxygenated treatment (combined water treatment; CWT)-applied plants, (2) flow-accelerated corrosion (FAC) and the use of hydrazine, and (3) turbine contamination due to the leakage of seawater.

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## 2. Water systems of thermal power plants

**Figure 1** gives an example of water-related systems used at thermal power plants[2]. In the main water system of power plants, water circulates starting as condensate, followed by boiler feedwater, boiler water (in the boiler) and steam (in the turbine), and finally returning to condensate. The water that is lost during the circulation is compensated for by supplying make-up water. The other water-related systems are: (1) the make-up water treatment system to supply highly-purified water obtained after the treatment of raw water such as industrial water, (2) the chemical dosing and water quality monitoring systems to monitor and adjust water quality for corrosion prevention, (3) the condensate treatment system to purify the circulating-water in a plant (mainly installed for once-through boilers), and (4) the wastewater treatment system to purify wastewater from the devices and components of thermal power plant facilities.

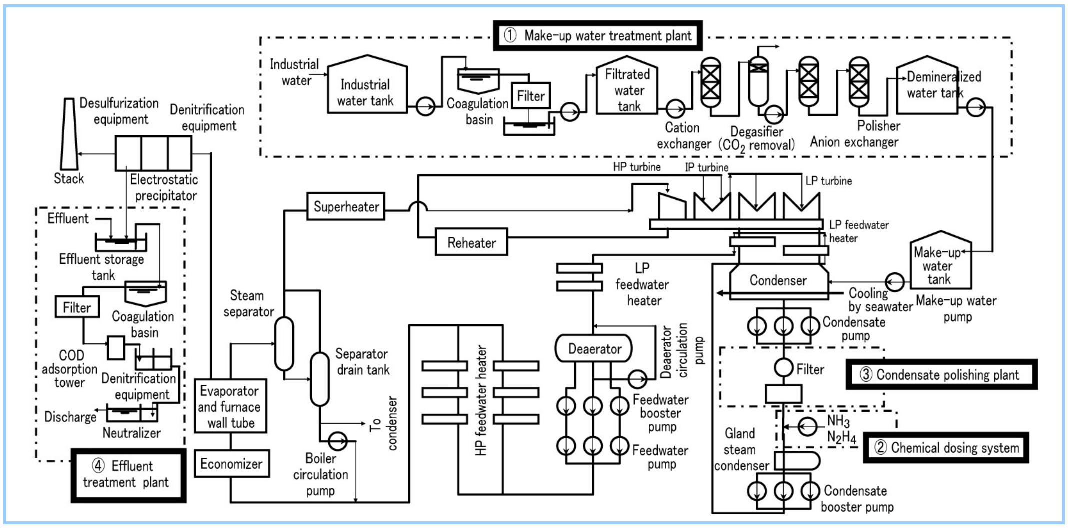



**Figure 1 Water systems at thermal power plants**

## 3. History of water treatment methods for thermal power plants

The history of water treatment methods for domestic thermal power plants is shown in **Figure 2**. **Table 1** gives identified problems and the relevant events for water treatment. **Table 2** is a list of the treatment methods for boiler feedwater and boiler water[3].

**Table 1 Identified problems at thermal power plants and the relevant events for water treatment**

| Year | Newly identified corrosion-related problems | Events for water treatment |
|---|---|---|
| 1940 | ・Pitting and brittleness of steam generating tubes<br>・Cracks in turbine components | |
| 1950 | ・Alkali corrosion in steam generating tubes<br>・Ammonia corrosion in aluminum or brass condenser tubes | ・Technological introduction from USA<br>・PT/AVT application<br>・Boiler chemical cleaning application |
| 1960 | ・Increase of pressure loss and overheating due to steam-generating tube scale deposition<br>・Feedwater heater inlet attack | ・JIS criteria (1 Feb. 1961)<br>・Oxygenated treatment application (Germany and Russia) |
| 1970 | ・Detachment of deposited scale from the superheater or reheater<br>・Corrosion fatigue | ・Use of titanium condensers<br>・Use of total condensate treatment equipment |
| 1980 | ・Feedwater heater drain attack | ・Start of commercial combined-cycle plant operations<br>・JIS oxygenated treatment criteria (1989) |
| 1990 | ・Valve corrosion caused by oxygenated treatment | ・Realization of commercial application of oxygenated treatment |
| 2000 | ・FAC (flow-accelerated corrosion)<br>・Powdered scale deposition in oxygenated treatment | ・Viability assessment of High-AVT for nuclear power plants (as a measure against FAC) |

As shown in Figure 2, a subcritical pressure drum-type boiler of 17 MPa class was built in 1959 and started operations using alkali treatment. However, problems due to alkali corrosion of water-wall tubes frequently occurred about 6 months after the commencement of operations. The subsequent demand for urgent improvement of feedwater and boiler water treatment technologies led to the introduction of all-volatile treatment (AVT) using ammonia and hydrazine, which had been under development in Europe. AVT was adopted by subcritical pressure drum-type boilers in 1960 and by once-through boilers in 1961, both producing good results. Thereafter, with the rapid popularity of its application, AVT was used for most of the new large-scale thermal power plants.

In the middle of 1965, the inspection results of scale deposition on the inner surface of steam generating tubes over the years necessitated the re-assessment of phosphate treatment (PT) application. As a result, drum-type high pressure boilers adopted low-phosphate treatment (Low-pHT), in which the phosphate ion level was maintained low (3 mg/L or less) and the Na/PO4 molar ratio in sodium phosphate was adjusted to be between 2.5 and 2.8 in terms of the prevention of alkali corrosion. Favorable effects, such as a reduced build-up rate of scale deposition in steam generating tubes, more stable scale properties, and less frequent chemical cleaning of boilers, were demonstrated.

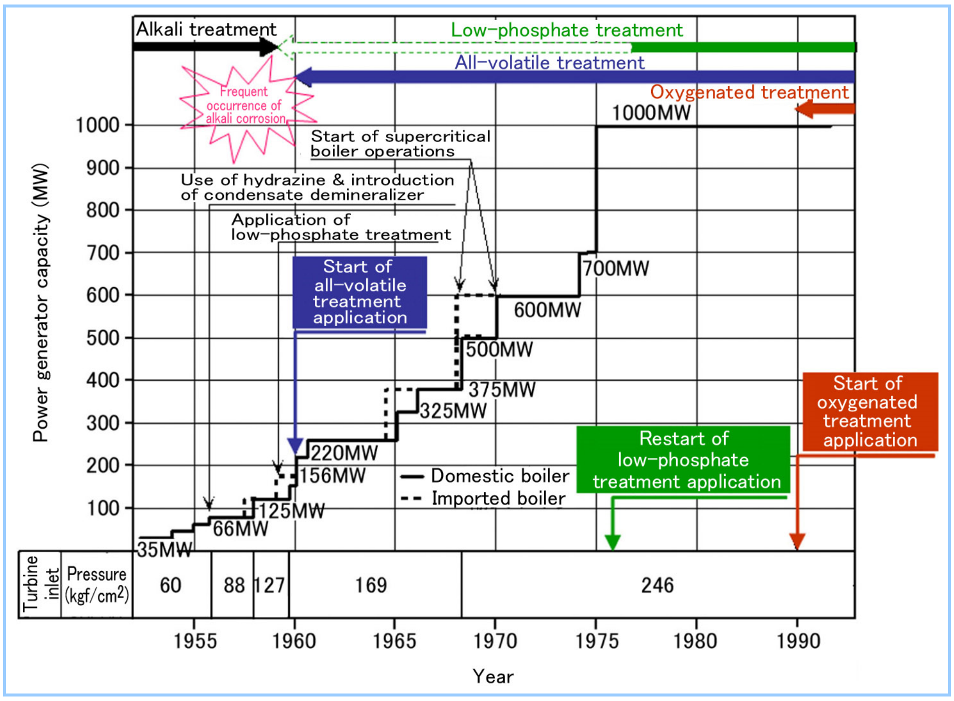



**Figure 2 History of water treatment methods for domestic thermal power plants**

**Table 2 Treatment methods for boiler feedwater and boiler water**

| Treatment | | Water quality control: Feedwater | Water quality control: Boiler water | Application | JIS B8223 |
|---|---|---|---|---|---|
| CT | | Ammonia<br>Hydrazine | Caustic soda (NaOH)<br>Trisodium phosphate | LP or IP drum-type boilers | Published in 1961 |
| PT | Phosphate treatment | Ammonia<br>Hydrazine | Trisodium phosphate | IP drum-type boilers | |
| | Low-pH phosphate treatment | Ammonia<br>Hydrazine | Disodium phosphate<br>Trisodium phosphate | IP or HP drum-type boilers | |
| AVT | | Ammonia, hydrazine<br>[AVT(O): only for ammonia] | | HP drum-type boilers<br>Once-through boilers | |
| OT | NWT | Oxygen | | HP drum-type boilers (with condensate demineralizer) | Published in 1989 |
| | CWT*1 | Ammonia<br>Oxygen | | Once-through boilers | |

CT : Caustic Treatment
PT : Phosphate Treatment
AVT : All Volatile Treatment
OT : Oxygen Treatment
NWT : Neutral Water Treatment
CWT : Combined Water Treatment
*1 : In Japan, OT generally indicates CWT.

In both AVT and Low-pHT, scale deposition and corrosion of materials used for the system components are suppressed by maintaining the dissolved oxygen level as low as possible, thereby preventing the occurrence of water-related problems.

In CWT, on the other hand, a high anti-corrosion effect can be achieved through the use of highly-purified water containing an appropriate level of dissolved oxygen. Following the success in other countries such as Germany and Russia, Japan also conducted verification tests for CWT and in 1989 published its first water quality control criteria in JIS B 8223. The first domestic CWT application was to a large once-through utility boiler in 1990. As of the end of March 2013, CWT is operational at 53 plants.

## 4. Package of new products and technologies regarding water treatment for thermal power plants

### 4.1 Measures against powdered scale deposition in CWT

**Figure 3** shows the difference of scale on the inner surface of steam generating tubes between AVT and CWT. The advantages resulting from CWT application include (1) reduced frequency of chemical cleaning owing to lowered build-up rate of scale, (2) the prevention of rippled scale formation leading to the alleviated increase of boiler pressure loss, and (3) decreased scale deposition on equipment surfaces.

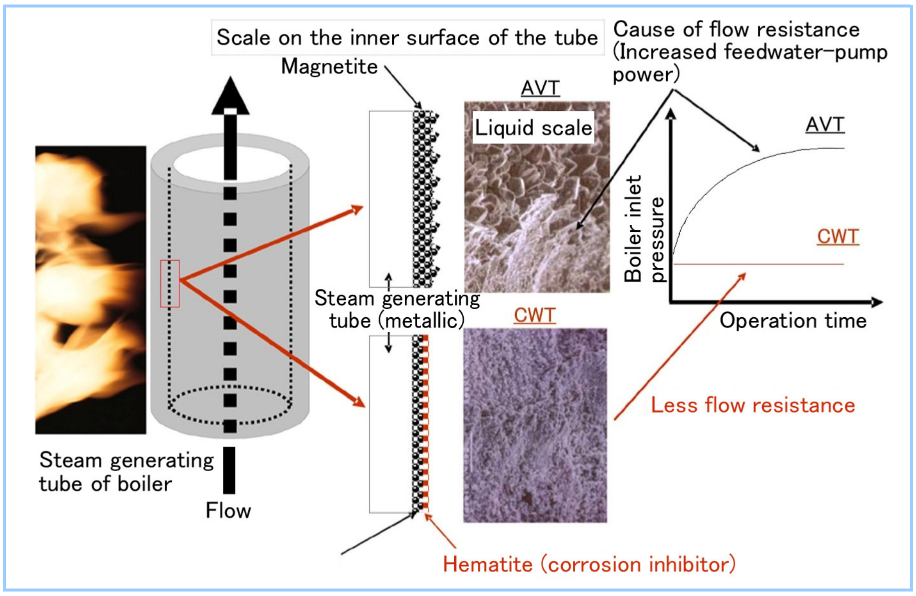



**Figure 3 Difference of scale on the inner surface of furnace steam-generating tubes between AVT and CWT**

In recent years, some of the CWT-applied plants experienced increased amounts of iron transferred into the boiler, and the deposition of hematite scale on the inside surface of boiler furnace wall tubes, causing an increase in the temperature of metal furnace wall tubes. The deposited hematite scale, known as "powdered scale," has low thermal conductivity and a porous structure consisting of small particles.

For the prevention of powdered scale deposition, the iron levels transferred into the boiler need to be lowered. As stipulated by the water quality control (recommended) criteria (**Table 3**), the iron level at the inlet of boiler (economizer inlet) should be 2 μg/L or less (targeting 1 μg/L or less). According to the material balance of iron in the plant system, the examination results indicate the low-pressure feedwater heater drain system as the primary source of iron, thus making it essential to reduce iron levels in the drain system. Suspended iron removal equipment with a high-temperature filter has been developed and installed at the actual plants. The results were satisfactory[4].

**Table 3 Once-through boilers: water quality control criteria during CWT operation (our recommended values)**

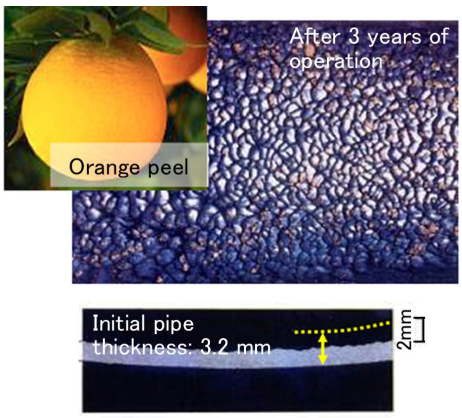
| | [Recommended value] Economizer inlet |
|---|---|
| pH | 8.5-9.3 (9.0) |
| Dissolved oxygen (μg/l) | 20-200 (50 ± 30) |
| Iron (μg/l) | 2 or less (1 or less) |
| Electrical conductivity (mS/m) | 0.02 or less |

( ): Target value

### 4.2 Measures against FAC and use of hydrazine

**Figure 4** is an example of FAC-caused thinning of pipe walls in a heat recovery steam generator (HRSG) of an overseas combined-cycle plant. In this case, after three years of operation, 1.2-mm thinning of the walls was identified at the ventilation part of the low-pressure evaporator. As a countermeasure, we recommend the adoption of High-AVT, which is an all-volatile treatment using feedwater with a pH level higher than the feedwater quality control criteria (upper limit: pH 9.7) stipulated by JIS B 8223:2006. It has been used mainly in nuclear power plants. As shown in **Figure 5**, higher pH levels decrease the rate of FAC, and the thinning of pipe walls caused by FAC is expected to be suppressed.

High-AVT water treatment was introduced to the Tuxpan No. 2 combined-cycle power plant in Mexico5. Since the start of commercial operations in 2001, no abnormalities have been found during equipment inspections over more than 10 years, thus producing good operational results. It has also been demonstrated that higher pH levels cause no rust, even after long operational interruptions. Switching to hydrazine-free water treatment becomes possible.




FAC often causes an orange peel-like pattern on the thinned part of pipes, and is thus called orange peel corrosion.

**Figure 4 FAC example**

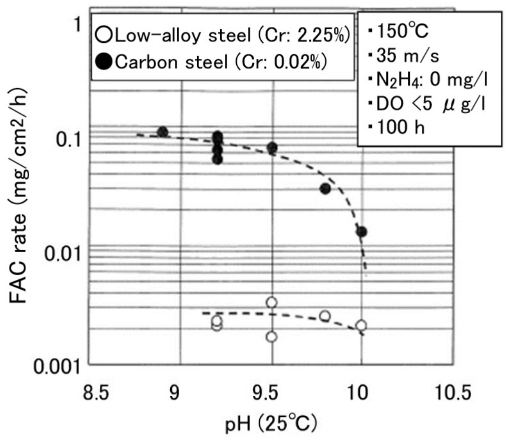



**Figure 5 Relationship between pH levels and FAC rates[6]**

### 4.3 Measures against turbine contamination due to the leakage of seawater

**Figure 6** shows the detrimental effects caused by the leakage of seawater (in the boiler). The seawater leaking into the plant system is concentrated in the boiler and produces hydrochloric acid, leading to equipment damage from acid corrosion. The seawater was considered to leak because of deterioration over time such as corrosion of copper-alloy condenser tubes and therefore to be preventable through the adoption of titanium condenser tubes. However, as indicated in **Figure 7** and based on our experience over the past 30 years, more than half of the seawater leakage incidents occurred as a result of mechanical damage to the titanium condenser tubes.

**Figure 8** is based on a case in which the plant had to be shut down immediately after the occurrence of seawater leakage. Even in the process of shutting-down, the condensate supplied to the spray attemperator of the turbine gland was contaminated by seawater, precipitating salt in amounts sufficient to cause the formation of rust in the gland. Application to actual plants is being examined and carried out by commercializing the anti-contamination method for this cause (purification system).

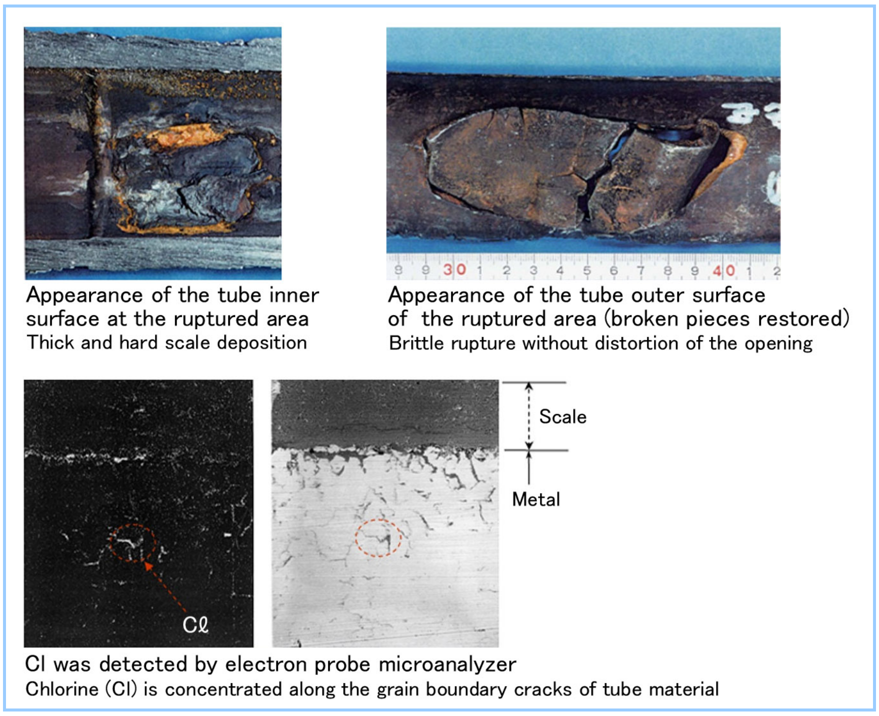



**Figure 6 Detrimental effects caused by the leakage of seawater (in the boiler)**

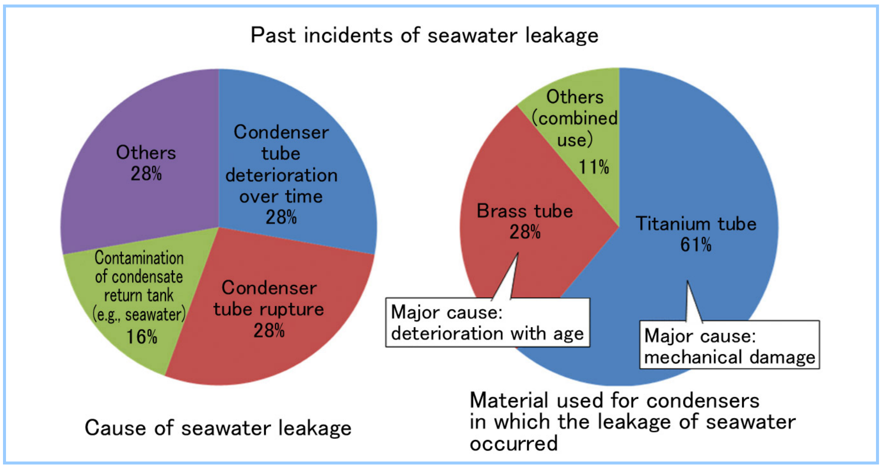



**Figure 7 Incidents of the leakage of seawater (1981-2010; based on our reported cases)**

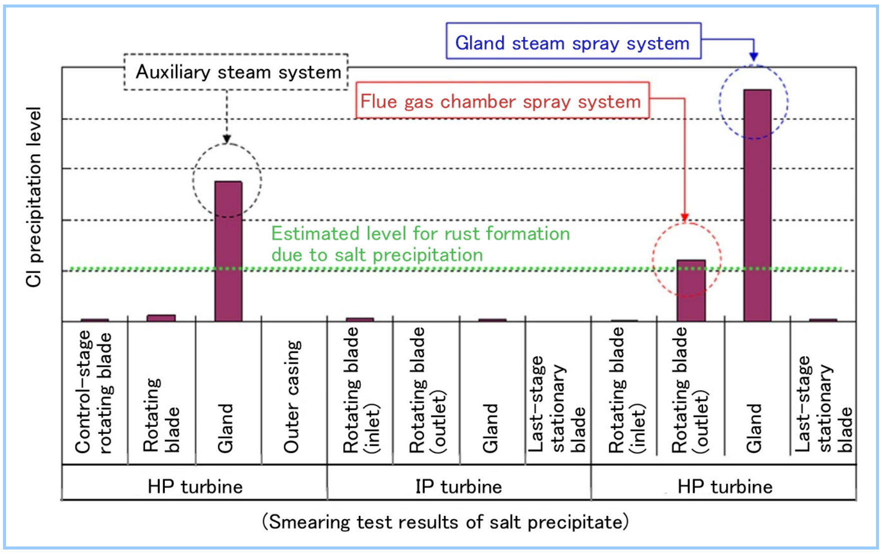



**Figure 8 Detrimental effects caused by the leakage of seawater (degree of turbine system contamination)**

## 5. Conclusion

Water treatment technologies for thermal power plants have been examined and improved as a countermeasure against equipment damage due to factors such as corrosion and scale deposition. As shown in **Figure 9**, abnormalities in water quality can be a precursor of problems and therefore serious problems can be prevented by analyzing the data and taking necessary measures.

The use of a package of new products and technologies we are developing can be expected to produce a beneficial effect on aging plants, operational efficiency and environmental conservation.

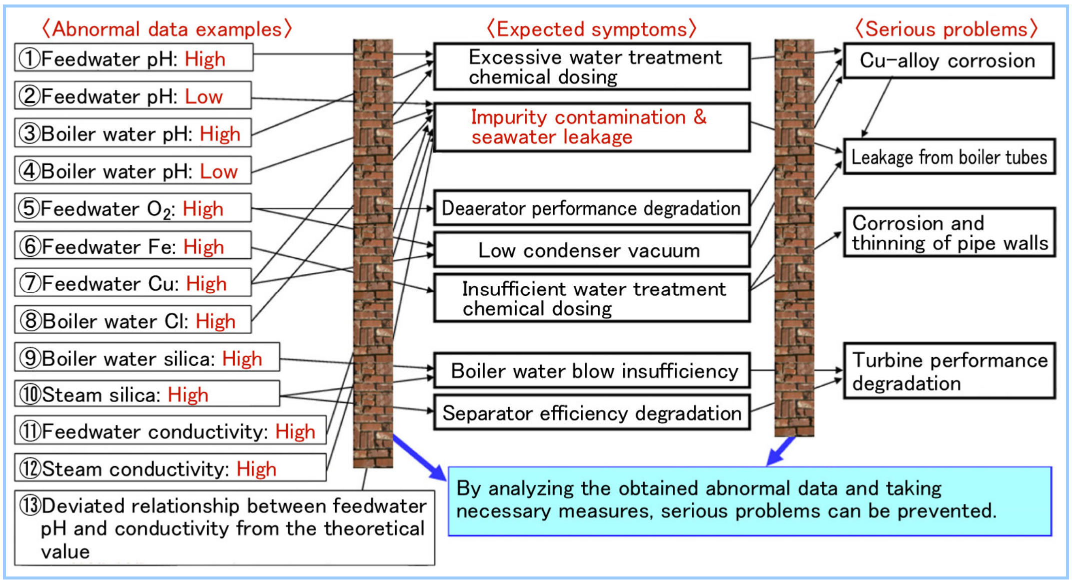



**Figure 9 Expected problems from abnormal water quality data**

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