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Research on Factors Affecting Boiler Feedwater Quality and Its Improvement

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Abstract

Nowadays, with the rapid progress and development of the Chinese society, people's material level has been continuously improved, and the demand for electricity has also been increasing year by year. For thermal power plants, it is of great importance to strictly control the feedwater quality and to conduct real-time tracking and supervision, as well as to ensure the safety of the production process. In this paper, we take the boiler feedwater quality in the production process as the research object. First of all, the cause-and-effect diagram is used to find out the reasons for the deviation of feedwater quality; Secondly, each index of feedwater is analyzed by multiple linear regression method to find out the key variables affecting the change of its pH value, so as to develop and implement improvement measures; Finally, the pH value is compared and verified by control chart and process capability analysis, and relevant improvement suggestions and countermeasures are proposed.

Keywords

Water Quality, Multiple Linear Regression, Control Chart, Process Capability Analysis

1. Introduction

According to data released by the National Energy Administration on January 15, 2016, in 2015, overall social electricity consumption was 5550 billion kWh, an increase of 0.5% year-on-year. In terms of industries, the primary industry consumed 102 billion kWh, up 2.5% year-on-year; the secondary industry consumed 404.6 billion kWh, down 1.4% year-on-year; the tertiary industry consumed 715.8 billion kWh, up 7.5% year-on-year; and urban and rural residents consumed 727.6 billion kWh, up 5.0% year-on-year. It is thus clear the importance of electricity in people's daily life and production.

Nowadays, more and more high-capacity and high-parameter units are put into thermal power plants. Therefore, production safety is especially important, especially some measures to prevent corrosion and scaling should be well implemented. Otherwise, causes such as varied water quality and corrosion may cause unit failures, and lead to unnecessary safety hazards and economic losses. Hence, all parameters in the chemical water of thermal power plants need to be thoroughly tested in order to have a better understanding of the real production situation. In particular, detailed statistics are needed for temperature, oxygen, pressure, and many other indicators.

Several scholars have studied the water vapor quality monitoring system, water treatment methods, corrosion resistance, and pH fluctuations in thermal power plants in terms of safety and stability.

Zhang *et al.* [1] [2] analyzed the current situation of 2 × 300 MW subcritical steam package feedwater operation in a power plant in Tianjin as research background, and presented in detail the improvement of boiler feedwater treatment and the current status of application after replacing the oxidizing full volatile treatment with oxygenated treatment in the power plant. It provides some reference value for other boiler feedwater treatment of the same type. Liu *et al.* [3] took Taiyuan No.1 thermal power plant as the research background, and analyzed the pH value for its sixth phase 13# and 14# units, and found out the reasons affecting the fluctuation of feedwater pH value, among which the main reason was the adjustment problem of operator supervision, thus the problems found were solved by the method of modifying the ammonia addition automation equipment, and finally achieved the improvement of water quality, making the pH value stabilized and the ultimate goal of reducing the corrosion process of thermal equipment was achieved. Nie *et al.* [4] [5] [6] analyzed the current situation of chemical supervision in thermal power plants in China and mentioned that chemical supervision is related to the production safety and efficiency of the whole thermal power plant and needs to be paid strict attention. On this basis, a series of recommendations for sustainable development were put forward. Cao *et al.* [7] [8] [9] [10] [11] mentioned that the implementation of automatic control of dosing can more effectively control the water quality of feedwater in power plants, and also better ensure the efficiency and accuracy of water quality regulation. In this paper, the author proposed a more accurate and improved PID algorithm to promote the application of automatic dosing system in power plants. After verification, the final achieved field control effect is satisfactory. Zhang *et al.* [12] [13] [14] introduced that the basis for laying the safety, stability and efficiency of thermal power plants is the water vapor quality monitoring system of power plants. The authors introduced its composition, principle and function in detail, and mentioned that the application and improvement of the system will largely improve the automation of chemical supervision. Hao *et al.* [15] [16] describe in detail the latest developments and applications of water treatment technologies in terms of monitoring and processes of water treatment, taking into account the main trends and characteristics of chemical water treatment in power plants at home and abroad in recent years. Gajić Anto *et al.* [17] [18] [19] described the processes and types of corrosion in boilers and proposed relevant recommendations and measures to eliminate corrosion for different causes.

Yang *et al.* [20] used multiple linear regression, statistical process control, process capability analysis, neural networks and other methods to analyze the data related to water quality.

All of these findings are conclusions obtained by scholars from their own research perspectives, which have good implications for the Guangxi Yuan Laibin Power Plant, but still need to be analyzed specifically according to the actual situation of this power plant to find ways to improve boiler water quality.

2. Contents of Boiler Feedwater Quality Control

Strict control of boiler feedwater quality is of great importance to effectively prevent scaling, corrosion and salt accumulation in the thermal system of the power plant so as to ensure the economical operation of the power plant boilers while improving the safety of the production process.

Strict chemical supervision of boiler feedwater quality, specifically, has the following three purposes.

1) To prevent scaling

If the water quality entering the boiler does not meet the relevant standards and is not properly treated in a timely manner, then after a period of operation, in contact with the water on the heating surface, a layer of solid adhesion will be generated, which is scale. Because of the poor thermal conductivity of scale, compared to ordinary metal to dozens or even hundreds of times, which will cause the scaling parts of the temperature is too high. At the same time, it will also cause a significant decline in the strength of the metal, will produce local deformation and produce bulging, serious and even cause bursting. On the other hand, scaling will also greatly reduce the economics of boiler operation. For example, if there is a 1 mm thick scale in the economizer, the fuel consumption will be 1.5% - 2.0% more. Since scale will make the vacuum inside the turbine condenser lower, the thermal efficiency and output of the turbine will be greatly reduced, and in serious cases, it will even be forced to shut down for maintenance.

2) To prevent corrosion

The water-cooled wall of the coal generator, the feed pipe, each heater, the superheater and the condenser of the turbine will corrode under the influence of bad water quality. This corrosion will make the service life of the equipment become shorter, resulting in irreparable economic losses. Meanwhile, part of the impurities generated by corrosion will be put back into the water in the system to continuously pollute the water, intensifying the corrosion on the heated surface and forming the structure, while the structure further promotes the corrosion. The final result is a vicious circle of corrosion and scaling that complements each other.

3) To prevent the accumulation of salt

The accumulation of salt means that in the boiler with the steam is brought out part of the impurities and salts mixed in the feed water, after deposition it will appear in the superheater and turbine. The overheating of the metal tube wall is caused by the accumulation of salt in the superheater, and in serious cases, it can even produce bursting, greatly increasing the safety risks.

In this case, the indicators to be monitored are water hardness, oil content, dissolved oxygen, hydrazine, pH, total carbon dioxide, silicon content, conductivity, iron content and copper content. According to the table of power plant boiler feed water supervision index standard (see Table 1), it can be concluded that for boiler water quality, pH is the most important index, while the three indexes of dissolved oxygen, conductivity and silicon content have significant influence on the pH value of boiler feed water.

3. Measures of Water Quality Improvement in the Power Plant

3.1. Analysis of the Causes of Deviations in Feedwater Quality

Exactly what causes the boiler feed water dissolved oxygen, conductivity and silicon content index changes? It is necessary to find the reason from the perspective of people, machines, materials, method, environment, measurement, that is, 5M1E, to find out the cause of the deviation of the boiler feed water quality. In this case, the cause-and-effect diagram is a most clear and concise method. As shown in Figure 1.

According to the nine possible factors confirmed, the initial review was conducted (see Table 2), and the causes were examined successively to determine whether they were the main causes.

1) Failure of monitoring of water quality by the operator

After conducting on-site observation, it was confirmed that the staff carried out chemical water monitoring in strict accordance with the requirements, with corresponding records every two hours. Based on the historical data provided by the laboratory team of the power plant concerning the quality of furnace water and steam vapor of unit 3, there was no missing data. Thus, this end factor is not a main factor.

2) Insufficient staff training

Table 1. Water supply supervision index standards.

	Hydrogen conductivity	Dissolved oxygen	Na	Cu	Fe	SiO_2	Hydrazine added	Hardness	pH
	uS/cm	ug/L						umol/L	After adding ammonia
Standard value	≤0.15	≤7	--	≤3	≤5	≤20	10 - 50	--	9.0 - 9.7
Expected value	≤0.10	≤7	--	≤2	≤3	≤10		--	

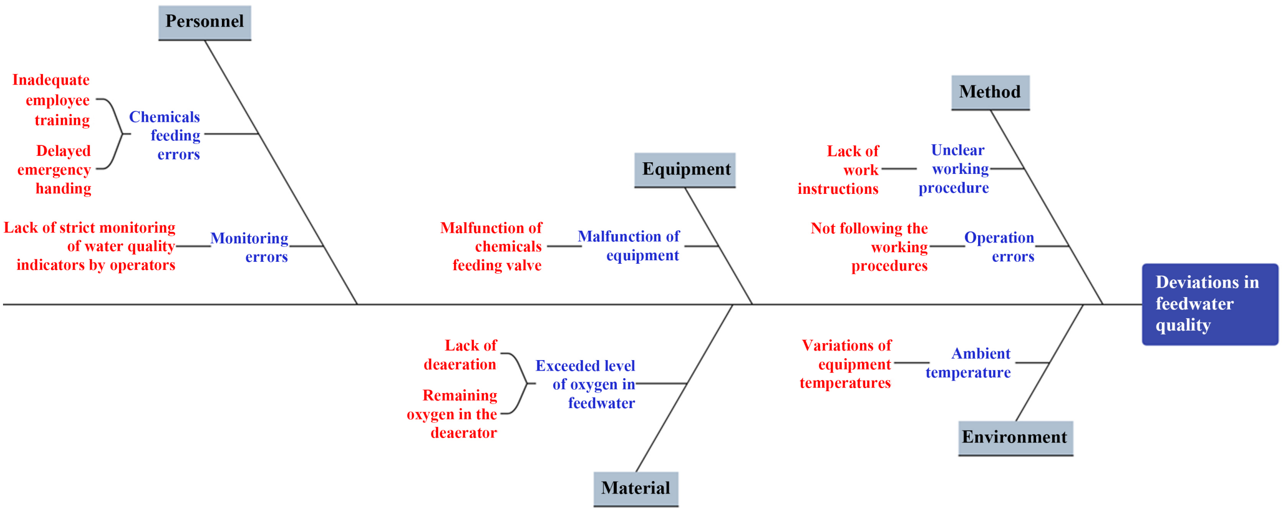

Figure 1. Cause-and-effect diagram of water quality deviation.

Table 2. Main factors confirmation form.

No.	End factor	Methods of confirmation	Method of argumentation
1	Failure of monitoring of water quality by the operator	Inspection of work records and on-site observation	Investigation and analysis
2	Insufficient staff training	Inspection of employee training records and induction certificates	Investigation and analysis
3	Delay in emergent chemical feeding	Inspection of work records and on-site observation	Investigation and analysis
4	Malfunction of chemical feeding valve	On-site confirmation of the chemical feeding valve	On-site verification
5	Failure to strictly follow the procedures	On-site confirmation of operational procedures	On-site verification
6	Lack of work instructions	On-site confirmation of the availability of operating instructions	On-site verification
7	Ambient temperature change	On-site temperature measurement	On-site verification
8	Lack of deaeration in feed water	On-site collection of relevant data for analysis	Investigation and analysis
9	Remaining oxygen in the deaerator	On-site collection of relevant data for analysis	Investigation and analysis

Through the investigation, the employees responsible for chemical water supervision on site all hold professional qualification certificates, and have the necessary professional skills and knowledge after relevant training and guidance. Therefore, the end factor is not a major factor.

3) Delay in emergent chemical feeding

After on-site observation and investigation, it was found that the manual ammonia feeding method requires the laboratory staff to notify the duty staff of the chemical feeding department by phone. The operator then goes to the chemical feeding room to adjust the metering pump until the pH value of the feed water is stabilized. The lag time during this period is about 20 to 30 minutes. This will easily cause the untimely adjustment and lead to the fluctuation of feed water pH value, which may even exceed the standard range within this period of time. Therefore, it can be initially determined that the end factor is a main factor.

4) Malfunction of chemical feeding valve

Through on-site verification, the chemical feeding valve did not show obvious failure. It was also regularly maintained. Therefore, the end factor is not a main factor.

5) Failure to strictly follow the procedures

Through the on-site verification, the employees on the production line are working in strict accordance with the procedures, and there are skilled employees to carry out on-site inspection to ensure that the process meets the procedures. Therefore, this end factor is not a major factor.

6) Lack of work instructions

Through on-site verification, the department of the power plant has a special operation guideline, DLT 805.4-2004 Steam and Water Chemistry Guidelines for Thermal Power Plants Part 4: Boiler Feedwater Treatment. Therefore, this end factor is not a major factor.

7) Ambient temperature change

Through on-site verification, the boiler structure of the power plant is complete and can ensure uniform heating in the furnace tube. There does not exist the influence of temperature. Thus, this end factor is not the main factor.

8) Lack of deaeration in feed water

Through on-site confirmation and review of the operation records of the process, it is found that the dissolved oxygen content in the feedwater is within the controlled range and does not affect the pH value of the feedwater. In the meantime, there is no potential hazard of high oxygen content in the water leading to pot wall corrosion. Therefore, the end factor is not a main factor.

9) Remaining oxygen in the deaerator

Through site investigation, there is no important defect in the deaerator, and there is regular maintenance. It is found that the dissolved oxygen content in the feed water is within the controllable range, which does not affect the pH fluctuation of the feed water. In addition, there is no potential hazard of high oxygen content in the water which leads to the corrosion of the pot wall. Therefore, the end factor is not a main factor.

After examining all of the above factors individually, it can be initially determined that the main factor affecting the pH value of feed water is the delay in emergent chemical feeding.

3.2. Analysis of Water Quality Variables in the Power Plant by Multiple Linear Regression

The indicators to be monitored in the boiler feedwater are hardness, oil content, dissolved oxygen, hydrazine, pH, total carbon dioxide, silicon content, conductivity, iron content and copper content, etc. Combining with the geographical location and actual condition of the power plant, the historical data of furnace water and steam vapor quality of unit 3 provided by the power plant laboratory team focused on pH, dissolved oxygen, hardness, conductivity, silicon content and hydrazine. The six indicators were analyzed by SPSS software to find out the most critical variables affecting the pH change.

The output multiple regression results are shown in **Tables 3-5**.

Based on the regression results, the multiple linear regression equation of pH with dissolved oxygen, conductivity and silicon content in feedwater was obtained as:

$$\hat{y} = 0.9531 - 0.408x_1 + 0.829x_2 - 0.002x_3$$

Therefore, as long as the problem of delay in emergent chemical feeding is solved effectively, so that the dissolved oxygen, conductivity and silicon content of boiler feedwater can be stabilized, the pH fluctuation of boiler feedwater can be avoided.

Table 3. Summary of model.

Model	R	R^2	Adjusted R^2	Error in standard estimation
1	0.770[a]	0.593	0.585	0.06358

a. Predicted variables: (constant), SiO_2, dissolved O_2, conductivity; R = 0.770, which indicates that 77.0% of the predictions can be made with this model.

Table 4. Variance analysis table of the model.

Model		Sum of squares	df	Average square	F	Sig.
1	Regression	0.896	3	0.299	73.854	0.000[b]
	Residual	0.614	152	0.004		
	Total	1.510	155			

a. Predicted variables: (constant), SiO_2, dissolved O_2, conductivity; b. Dependent variable: pH; Sig = 0.000 < 0.05, which proves that the linear relationship between the dependent variable and the independent variable is significant and a linear equation can be established.

Table 5. Estimation and test of model parameters.

Model		Non-standardized coefficient		Standardized coefficient	t	Sig.
		B	Standard Error	Beta		
1	(constant)	9.531	0.028		345.676	0.000
	Dissolved oxygen	−0.408	0.029	−0.770	−14.162	0.000
	Conductivity	0.829	0.258	0.216	3.215	0.002
	SiO_2	−0.002	0.001	−0.183	−2.636	0.009

Since the Sig. values are less than 0.05, it can be concluded that dissolved oxygen, conductivity and silicon content in the feedwater have significant effects on the pH of boiler feedwater.

4. Comparison of Boiler Feedwater pH before and after Improvement

A total of 180 feedwater pH values were selected before and after the improvement, as shown in Table 6, and a $\overline{x}-MR$ (Charlie control) chart was drawn, as shown in Figure 2.

According to the criterion of the control chart, among the 180 pH values tested before improvement, a total of 6 criterion points, 4, 16, 62, 78, 69 and 89, were detected at more than 3 standard deviations from the center line. According to the criterion of the control chart, the improved pH data were stable.

From Figure 2, it can be seen that the fluctuation amplitude of the points before and after the improvement is significantly reduced, and all the points are within the control limits, reaching the control steady state, which allows the process capability analysis to be performed, as shown in Figure 3.

The improved process capacity reached 1.42, and the boiler water quality was in ideal condition according to the evaluation criteria in Table 7, indicating that the measures taken were effective in improving the boiler feedwater quality.

Applying the analysis results to practice, the pH fluctuation of boiler feedwater is effectively avoided by controlling the "delay of emergent chemical feeding", that is, controlling the main factors affecting the fluctuation of pH: dissolved oxygen, conductivity and silicon content, which ensures the safety of boiler in thermal power generation.

Table 6. pH value of boiler water before and after improvement.

	pH									
Before	9.25	9.48	9.58	9.00	9.35	9.33	9.31	9.41	9.47	9.58
	9.48	9.54	9.46	9.11	9.37	9.33	9.32	9.59	9.26	9.23
	9.23	9.26	9.20	9.24	9.32	9.34	9.25	9.21	9.21	9.29
	9.27	9.30	9.35	9.36	9.30	9.27	9.38	9.37	9.36	9.36
	9.40	9.36	9.37	9.40	9.40	9.42	9.41	9.42	9.43	9.27
	9.42	9.43	9.42	9.41	9.40	9.42	9.42	9.38	9.38	9.42
	9.45	9.62	9.46	9.40	9.44	9.43	9.42	9.42	9.44	9.43
	9.56	9.59	9.47	9.58	9.21	9.58	9.60	9.63	9.61	9.56
	9.54	9.53	9.54	9.52	9.52	9.57	9.28	9.27	9.00	9.23
After	9.47	9.47	9.48	9.39	9.51	9.48	9.38	9.49	9.52	9.53
	9.48	9.45	9.50	9.50	9.50	9.49	9.45	9.47	9.46	9.40
	9.35	9.46	9.36	9.46	9.47	9.34	9.46	9.47	9.46	9.53
	9.47	9.45	9.53	9.45	9.35	9.36	9.38	9.36	9.46	9.36
	9.38	9.45	9.45	9.45	9.54	9.43	9.36	9.46	9.38	9.41
	9.42	9.42	9.32	9.32	9.39	9.34	9.46	9.35	9.30	9.40
	9.32	9.31	9.34	9.40	9.42	9.46	9.35	9.47	9.38	9.45
	9.45	9.37	9.54	9.46	9.35	9.33	9.34	9.35	9.45	9.35
	9.54	9.45	9.54	9.35	9.36	9.40	9.50	9.45	9.48	9.45

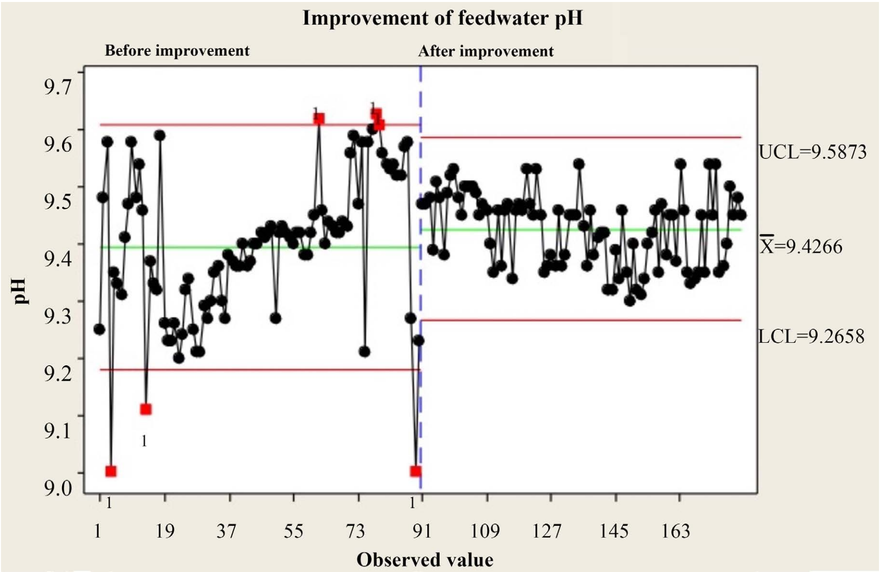

Figure 2. Comparison of water quality improvement.

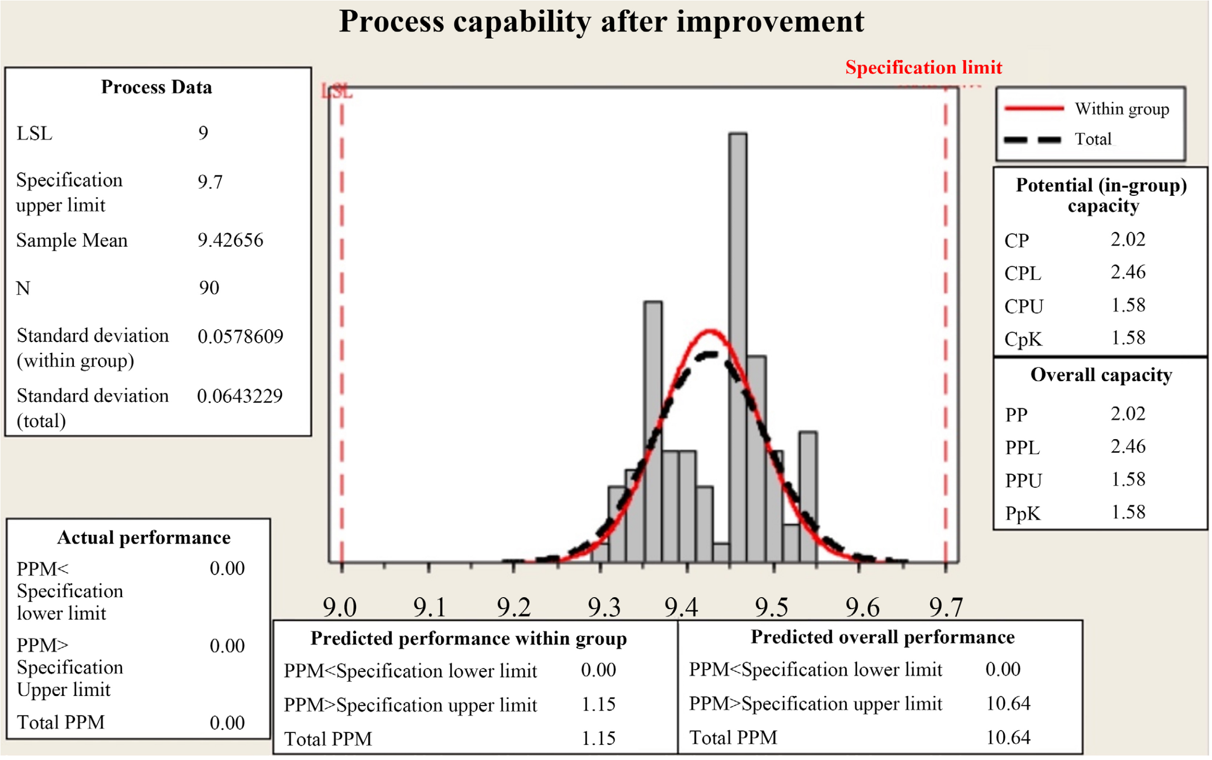

Figure 3. Process capability analysis diagram after improvement.

Table 7. Evaluation criteria of C_p value of process capability index.

C_p (C_{pk})	Process capability	Treatment
$C_p \geq 1.67$	Excessive	Process capability is far too good. The specifications could be reduced as appropriate, or consider simplifying quality inspection to simplify management and reduce costs.

Continued

$1.67 > C_p \geq 1.33$	Ideal	An ideal state. The process should be standardized, monitored by control charts or other means.
$1.33 > C_p \geq 1.00$	Warning	Keep the process in a controlled state, otherwise there is a risk of non-conformity in the product, which requires attention.
$1.00 > C_p \geq 0.67$	Poor	Existence of non-conformity products, requiring full speed inspection or tightened inspection, and the need for proper management and improvement of the process.
$0.67 > C_p$	Very poor	Urgent measures should be taken to improve the quality and investigate the causes.

5. Conclusion

This paper takes boiler feedwater quality of a thermal power plant as the research object. Firstly, by using the cause-effect diagram, the cause of deviation of boiler feedwater quality was confirmed. Secondly, by applying the multiple linear regression method, the variables that have significant influence on pH value (dissolved oxygen, conductivity and silicon content) in feedwater were identified. Improvement measures were implemented accordingly. Finally, the Charlie Control Chart and process capability analysis were conducted to compare and verify the effect of pH value before and after improving the water quality of the power plant, and relevant improvement suggestions and countermeasures were proposed.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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