Application of on Line Chemical Cleaning for Stainless Steel Tube Condenser in a Power Plant

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Abstract: According to the characteristics of stainless steel material and scale composition of condenser in a power plant, nitric acid was used as cleaning medium, and corrosion inhibitor was added to inhibit the corrosion of nitric acid on stainless steel. On line chemical cleaning was carried out on the condenser without shutdown. The scale removal efficiency and corrosion rate met the requirements of DL/T957-2017, and the terminal difference of condenser recovered to the optimal value after cleaning.

1. Introduction
Condenser is one of the important auxiliary equipment in thermal power plant. Long term operation of condenser will cause dirt accumulation on the water side, resulting in the decrease of vacuum degree, which has an important impact on the economy and safety of steam turbine operation[1]. At present, the commonly used cleaning technologies at home and abroad mainly include: high pressure water jet cleaning, condenser rubber ball automatic cleaning, condenser projectile cleaning, ultrasonic descaling and chemical cleaning[2]. Chemical cleaning technology is mainly based on the principle of chemical reaction. Some calcium carbonate and magnesium carbonate scales produced by the condenser are chemically reacted to generate water-soluble salts and carbon dioxide, and finally these scales can flow out of the pipeline[3]. The commonly used chemical cleaning media include hydrochloric acid, amino sulfonic acid, nitric acid, alkaline solution and degreaser. The cleaning media are usually selected according to the comprehensive analysis of the scale composition, condenser equipment structure and material[4]. The condenser online cleaning does not need a huge temporary system, the equipment can operate normally, the cost is much lower than the traditional pickling, the operation is simple, the production is not affected, and the economic benefit is significant[5]. In this paper, through the experimental study, using nitric acid as the cleaning medium, a complete set of online chemical cleaning scheme for stainless steel tube condenser is designed, which has guiding significance for the condenser cleaning work of power generation enterprises.

2. Project background
The condenser of a 150 MW unit in a power plant is taken as the research object. the vacuum degree of the condenser has gradually decreased Since the last cleaning, and the terminal difference has gradually increased to 10℃, which has a serious impact on the safety production. Through the vacuum system leak detection and circulating water system inspection, it is determined that the phenomenon is caused by the scaling of the stainless steel pipe of the condenser. Main technical parameters of condenser are shown in Table 1.

| Table 1 | Technical Parameters of Condenser |
|---------|----------------------------------|
| Parameter | Value |
| Vacuum degree | 10℃ |
| Condenser area | 400 m² |
| Condenser material | Stainless steel |
| Condenser type | Tubular |
| Condenser diameter | 200 mm |
| Condenser length | 500 m |
| Condenser material thickness | 5 mm |

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Table 1: Main technical parameters of condenser

| number | equipment name | specification | data |
|--------|----------------|---------------|------|
| 1      | Model          | N-17000-3     |      |
| 2      | Steel pipe grade | TP304 stainless steel | |
| 3      | Number of steel pipes |             | 21212 |
| 4      | Steel pipe specification mm |   | 0.25 |
| 5      | cooling water m³ |             | 36211 |
| 6      | cooling area m² |             | 17000 |

It was found that the appearance of scale inside the condenser tube was mud color after inspection. A layer of white scale was found after stripping the outer layer. After cleaning the scale, no corrosion pits were found on the surface of the tube. The composition and quantity of scale are analyzed by experiment. The analysis results are shown in Table 2, which is mainly calcium scale.

Table 2: Analysis results of scale components

| Analyse analysis | Fe₂O₃ | CuO | CaO | MgO | P₂O₅ | SiO₂ | ZnO | Al₂O₃ | K₂O | SO₃ |
|------------------|-------|-----|-----|-----|------|------|-----|-------|-----|-----|
| Include quantity (%) | 6.63  | 0.03 | 80.18 | —   | 4.02 | 3.6  | 0.01 | 0.24  | 0.45 | 1.09 |

3. Scheme design

3.1. Selection of corrosion inhibitor

Stainless steel equipment will rust and scale in varying degrees in the process of use. Nitric acid, as a cleaning agent, has a good removal effect on calcium magnesium scale and silicate scale attached to stainless steel equipment. However, corrosion inhibitor needs to be added in the process of use to prevent nitric acid from corroding stainless steel during cleaning, inhibit hydrogen absorption ability of stainless steel during pickling, and avoid "hydrogen embrittlement" of stainless steel.

Corrosion inhibitor A is an excellent surfactant with low toxicity, hard water resistance, foaming and good emulsification. It has a good inhibition effect on the corrosion of strong acid solutions such as sulfuric acid, hydrochloric acid, hydrofluoric acid and nitric acid. It is widely used in daily chemical industry, textile printing and dyeing, chemical fiber, medical and health care, petroleum mining and other fields. Corrosion inhibitor B is a chemical, colorless acicular crystal, slightly soluble in cold water, ethanol, ether, can be used with a variety of scale inhibitors, bactericides and algaeicides. In this cleaning, a small-scale test was carried out with corrosion agent A and B combined with chemical agent C, taking TP304 stainless steel sheet as the research object. The test results are shown in Table 3.

Table 3: Test results of adjusting pH=1.59 with 3‰ compound inhibitor C solution

| Material | initial weight (g) | Weighing (g) | weight reduction (g) | test piece area (m²) | test time (h) | corrosion rate (g/m²·h) |
|----------|-------------------|--------------|----------------------|----------------------|---------------|-------------------------|
| TP304    | 22.5646           | 22.5645      | 0.0001               | 0.002889             | 2             | 0.0173                  |

Table 3 test results show that the slow-release effect of inhibitor C on TP304 is qualified. Inhibitor C can effectively inhibit the corrosion of stainless steel in nitric acid solution and can be used for cleaning.
3.2. **Cleaning process design**

Compared with off-line cleaning, the on-line cleaning isolation measures are less, a large number of temporary systems do not need to be installed, and the labor cost is reduced. The unit can be shut down for cleaning, and it can also be cleaned in the running state, which does not affect the power generation task. At the same time, it has the advantages of short cleaning period, fast system recovery after cleaning, simple operation and so on. The online cleaning process system diagram is shown in Figure 1. The medicine is added into the cellar of the forebay of the circulating water pump. The research shows that the cleaning indexes such as the online cleaning descaling efficiency can meet the requirements of the standard.

![Figure 1. Online cleaning process system diagram.](image)

3.3. **Determination of cleaning scheme**

The dynamic simulation test was carried out on the condenser tube sample to determine the cleaning scheme. The process is divided into desliming process and cleaning process. The sludge cleaning agent is composed of desliming agent, defoamer and wetting agent. The concentration is controlled at 200 ~ 300mg /L, and the dynamic desliming time is 6 hours. During the cleaning process, the cleaning solution consists of nitric acid, corrosion inhibitor and auxiliary agent, and the dynamic cleaning time is 6 hours. The test results are shown in Table 4.

| Test steps | process conditions | test phenomena and results | remarks |
|------------|--------------------|----------------------------|---------|
| Desliming  | Desilting agent: 100mg/L  
Wetting agent: 100mg/L | After dynamic desilting for 6h, the corrosion product sludge on the inner surface of the pipe sample was completely cleaned, and the surface of white scale was exposed. | The test pipe sample is the condenser extraction pipe sample. |
| wash       | nitric acid: pH= 2  
Corrosion inhibitor: 0.3%  
Cleaning aids: 100mg/L | After dynamic cleaning for 6h, the inner surface of the tube sample was completely cleaned without any residue, and the metal surface was metallic gray. corrosion rate: 20 steel test piece: 0.4969g/m².h, 304 stainless steel test piece: 0.0523g/m².h. |         |
According to the results of dynamic simulation cleaning in laboratory, both desliming and cleaning processes have achieved good results. This scheme can be used for on-line chemical cleaning of stainless steel tube condenser.

3.4. Cleaning process and effect inspection
The circulating water system of the unit maintains normal operation, and the water level of the circulating water tower basin is controlled to a lower level. The sludge cleaning agent, such as desludging agent, defoamer and wetting agent, should be added at 7:00, the control concentration should be 200-300 mg/L, and the desludging time should be 6 hours. 0.3% corrosion inhibitor and additives were added to the system at 13:00, and the system was operated for 1.5h, Carring out pre corrosion inhibition. adding nitric acid at 14:30. During the whole process of adding acid, the pH and calcium concentration at the inlet and outlet of the condenser were controlled, and corrosion test pieces were hung at the inlet, the cleaning time was extended to 9 hours. The acid concentration and calcium concentration are analyzed. The test data of pickling process are shown in Fig. 2 and Fig. 3.

Fig. 2: pH curve of inlet and outlet water during cleaning

Fig. 3: Hardness change curve of inlet and outlet water during cleaning
In order to judge whether the cleaning has reached the terminal point, the acidity or calcium ion content of the cleaning solution is generally detected. When the calcium ion content gradually increases and basically remains unchanged, it indicates that the cleaning terminal point has been reached[6]. Stable acid concentration can also be used as the judgment of pickling terminal point[7]. It can be seen from Figure 2 that when the cleaning time reaches 5 hours, the acid concentration at the inlet and outlet is basically balanced, and the acid concentration remains stable for two hours, indicating that the cleaning terminal point is near. It can be seen from Figure 3 that after 6 hours of pickling, the descaling reaction speed is faster, the calcium ion concentration in the acid solution rises rapidly, the cleaning time reaches 7 hours, the calcium ion content at the inlet and outlet keeps balance, and the calcium ion content basically remains unchanged, indicating the end of cleaning.

After the chemical cleaning of the condenser, open the manhole door of the condenser, and comprehensively check and evaluate the chemical cleaning effect of the condenser, as shown in Table 5.

Table 5: quality inspection results of chemical cleaning of condenser

| Inspection items                                      | Standard provisions (DL/T 957-2017)                          | Actual inspection and test results                                                                 |
|-------------------------------------------------------|----------------------------------------------------------------|---------------------------------------------------------------------------------------------------|
| Whether there are residual oxides and over washing on | After cleaning, the metal surface should be clean without      | (1) There is no residual oxide and metal coarse crystal precipitation in the surface of condenser;  |
| the inner surface of condenser metal                   | residual carbon film and hard scale.                           | (2) There is no carbon film and hard scale on the surface of condenser, and the passive film is     |
|                                                       |                                                                | uniform.                                                                                          |
| Removal rate of corrosion products in condenser        | ≥85% qualified                                                 | After cleaning, the surface of stainless steel tube of condenser is uniform silver gray, and the   |
|                                                       | ≥95% excellent                                                 | scale removal rate is 99%.                                                                       |
| Whether the fixed equipment of condenser is damaged    | There is no damage to the fixed equipment, valves and          | After inspection, the fixed equipment, valves and instruments of the condenser body are not       |
|                                                       | instruments of the condenser.                                  | damaged.                                                                                          |
| Average corrosion rate                                 | <1 g/m²·h                                                     | 20 steel test piece: 0.5653g/m²·h 304 stainless steel test piece: 0.0581g/m²·h                  |

4. Conclusion
The chemical cleaning basically eliminated the attachment of the condenser, and the relevant data of the condenser were significantly improved. The terminal difference of the condenser decreased from 9.6℃ to 5℃, it has returned to below the design value. The on-line cleaning technology reduces the installation and removal of off-line cleaning temporary equipment, which has strong flexibility and shortens the construction period by 15 days. Due to the reduction of coal consumption, the unit saves about 2 million a year. Due to the reduction of construction period, the unit saves about 1.44 million a year. The economic benefit is significant.

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