



## Analysis of “desalted water” feedwater oxygenated treatment operation practice in a 350 MW supercritical unit

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### ABSTRACT

“Desalted water” feedwater oxygen treatment dexterously combines the characteristics of water vapor loss in normal operation of unit and the natural saturation of dissolved oxygen in make-up water. It's a new way to implement oxygenated treatment of boiler feedwater, which is more environmentally friendly and economical. Compared to the conventional oxygen bottles or air oxygen methods, the passivation protection mechanism of the heating surface has no difference in essence, but it's further improved in the aspects of simple operation, project investment and cost, and reduce the use of dangerous chemical sources. A 350 MW supercritical unit applied this technology in China, after nearly 2 y operation, the cleanliness of the water vapor system and the stability control of dissolved oxygen has achieved successful results. According to operation statistics, the new technology has saved more than 2 million RMB of economic cost for the power plant, and gradually applied in Henan, Guizhou, Hubei, Inner Mongolia and other regions.

*Keywords:* Desalted water; Feedwater oxygenated treatment; (Ultra) supercritical unit; Operation practice; Stable effect; Economic benefits

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### 1. Introduction

Boiler feedwater oxygen treatment is the better solution to solve the problems of poor cleanliness of water vapor circulation system, flow-accelerated corrosion, advance of corrosion products and short operation cycle of condensate polishing mixed bed exposed in AVT condition of (ultra) supercritical unit, which has reached basal consensus in power industry of the world [1–4]. According to unofficial statistics, more than 60% of the (ultra) supercritical units adopt feedwater OT treatment. Around 2003, the superheater and reheater scale cinder peeling problems occurred in many (ultra) supercritical units with OT treatment of feedwater in China, which triggered the research and debate of researchers [5,6]. There are two opposing views on whether oxygen in superheated steam has an effect on the formation of scale cinder peeling. One view

was that high content oxygen would affect the formation of scale cinder peeling in superheater and reheater tubes, but it was not a necessary and sufficient factor, and they advocated to reduce the dissolved oxygen content of feedwater [5,7]. The other view insisted that superheater and reheater tube scale cinder was not related to the feedwater OT condition [8]. Finally, the main technical route of controlling dissolved oxygen content in feedwater at  $(40 \pm 10)$   $\mu\text{g/L}$  and oxygen content in superheater inlet close to zero is gradually developed [9,10]. In addition, reasonable selection of steel, prevention of overtemperature, slow cooling after brennschluss, prevention of internal leakage of desuperheater, mandatory inspection and regular cleaning of superheater tube scale cinder are also carried out [11–15].

Add compressed air (oxygen) or cylinders oxygen into feedwater are commonly methods in China. After more than 30 y of theoretical research, industrial practice, experience summary, optimization and adjustment stage, the boiler

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feedwater OT technology has been satisfied with the anti-corrosion and anti-scale effect. However, these studies mainly focused on how to reduce the risk of scale cinder peeling through control, such as low-oxygen process, staged oxygenated and fine control, thus paid little attention to oxygenation medium, route and location. Compressed air method requires the use of oil-free air compressor, gas storage tank, safety valve, compressed air flow control cabinet and other equipment, resulting in the disadvantages of complex oxygen system, heavy maintenance workload and high engineering cost [16,17]. Cylinders oxygen method requires the use of high-pressure oxygen cylinders, busbar, oxygen flow control equipment, etc., and there are also problems such as frequent replace of oxygen cylinders, complex oxygen operation and high engineering cost [18,19]. In summary, both way exist the disadvantages such as complex equipments, cumbersome operation, high energy consumption of equipments, and dangerous chemical sources [20].

“Desalted water” feedwater oxygenated treatment based on the advantages and disadvantages of traditional technologies, comprehensive oxygen essence principle, oxygen source equipment, automatic control mode and key technology influence factors and other aspects of research, firstly proposed a new boiler feedwater oxygen treatment method. In November 2020, the China Electricity Council expert group agreed that “desalted water” feedwater oxygenated treatment technology has made an important breakthrough in the field of boiler feedwater oxygenated treatment, which is very subversive and innovative, and identified as the international advanced level.

## 2. “Desalted water” feedwater oxygenated treatment

### 2.1. Basic mechanism

“Desalted water” feedwater oxygenated treatment base on the thermal system for coal-fired power units normal steam loss, must be added desalted water (usually add to the condenser, vacuum deoxygenating), select ordinary make-up water as oxygenated medium which carrying natural saturated dissolved oxygen, instead of oxygen cylinders or compressed air. Feed part of the desalted water directly into the condensate pump inlet and deaerator down piping, and close the deaerator exhaust valve, which achieve boiler feedwater OT condition.

The protection mechanism of “desalted water” feedwater OT technology is the same as that of traditional methods. In other words, the micro-dissolved oxygen in water reacts with the iron matrix phase layer or the existing porous  $\text{Fe}_3\text{O}_4$  passivation film to replace and generate a more dense and uniform  $\text{Fe}_2\text{O}_3$  protective layer.

The difference is that how to dissolve oxygen into feedwater, while not used the high pressure oxygen cylinders or air compressor, but a clever combination of boiler operation make-up water (desalted water) moisture loss and the dual characteristics of natural saturated dissolved oxygen in it. Through the theoretical calculation and practical application, to achieve the requirement of the boiler system corrosion anti-scaling treatment.

According to the Henry's law, the solubility of  $\text{O}_2$  in water is proportional to its equilibrium partial pressure under certain conditions:

$$P(\text{O}) = K \times \text{DO}$$

where  $P(\text{O})$  – oxygen partial pressure, Pa, mol/L;  $K$  – Henry's constant, Pa·L/mol;  $\text{DO}$  –  $\text{O}_2$  solubility in water.

The content of dissolved oxygen in boiler make-up water (outlet of condensate refill tank) of some power plants in different provinces of China was investigated. The results are shown in Fig. 1. Affected by temperature and altitude, dissolved oxygen content in water varies, with an average value of about 8,000  $\mu\text{g/L}$  of eight power plants.

### 2.2. Feedwater oxygen control system

“Desalted water” feedwater oxygenated treatment system adopts two-point design: the first is in the condensate pump inlet, the second is in the deaerator down piping. When the system operate normally, keep the deaerator exhaust valve closed and regular intervals open to discharge non-condensing gas ( $\text{N}_2$  etc.).

The system diagram as follows in Fig. 2:

The control system design DCS automatic and local manual modes. The DCS is the main mode and the PID mode as adjustment. The feedback signal includes feedwater pump flow rate (main correlation), on-line DO and cation conductivity instruments at the entrance of economizer, and on-line specific conductivity instruments at the outlet of deaerator (secondary correlation). By coordinating and controlling the dissolved oxygen relationship between the outlet of condensate pump, the outlet of deaerator and the outlet of deaerator, the measured value of the outlet dissolved oxygen of economizer is stably maintained at  $40 \pm 10 \mu\text{g/L}$  and pH  $9.0 \pm 0.1$ . When the linkage correlation signal feedback is abnormal, the control system alarms and prompts the operation personnel to intervene.

## 3. Operation practice effect evaluation

The “desalted water” feedwater oxygenated treatment technology was applied in a 350 MW supercritical unit,

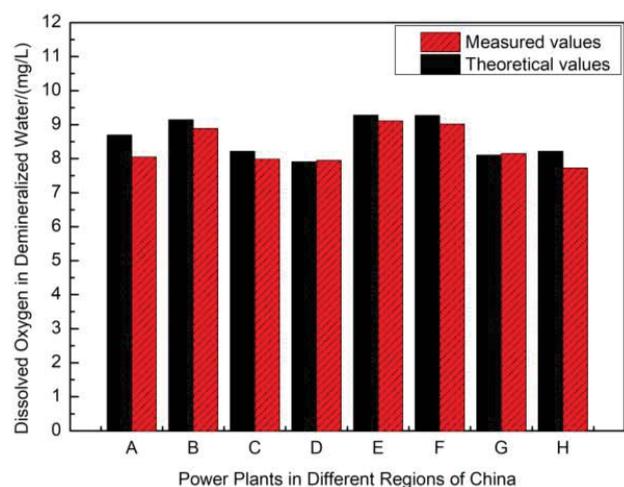


Fig. 1. Dissolved oxygen in desalted water of different power plants in China.

which was operated for over 2 y. The effect evaluation and analysis of the unit were carried out.

3.1. Feedwater dissolved oxygen control

In the past years, the dissolved oxygen in the feedwater was stably controlled within the range of  $40 \pm 10 \mu\text{g/L}$  in the most time which showed in Fig. 3, and average value dissolved oxygen at the entrance of the economizer was  $35 \mu\text{g/L}$ .

3.1.1. Trend of dissolved oxygen in feedwater section

The change of dissolved oxygen at the boiler feedwater section showed a certain regularity as in Fig. 4. The dissolved oxygen at the outlet of the condensate pump had a good positive correlation with the deaerator inlet, and the deaerator outlet has a good positive correlation with the economizer inlet.

3.1.2. Relationship between dissolved oxygen in feedwater and unit load

There was a certain negative correlation between dissolved oxygen in feedwater section and unit load variation,

when the load was high, the dissolved oxygen in feedwater was low, and when the load was low, the dissolved oxygen was high.

There were some reasons probably: firstly, the sealing water of condensate pump was not switched to the self-sealing water of condensate, but still using desalted water. Under the condition of low unit load, the feedwater flow rate was synchronous low, and the dissolved oxygen additional background had a great influence on the feedwater section, resulted in higher dissolved oxygen [21]. Secondly, the unit load varied synchronously caused the pressure change of the deaerator, which then varied the internal vapor side oxygen partial pressure of the deaerator, and the dissolved oxygen at the outlet of the deaerator varied relatively significantly [22].

3.2. Water vapor system cleanliness improved

Based on the historical datas of SIS, the cation conductivity of the water vapor circulation system were collected. During the normal operation, the vapor cation conductivity was always at a low level (basically  $< 0.08 \mu\text{S/cm}$ ), and the anionic corrosion risk of the thermal system was reliably controlled.

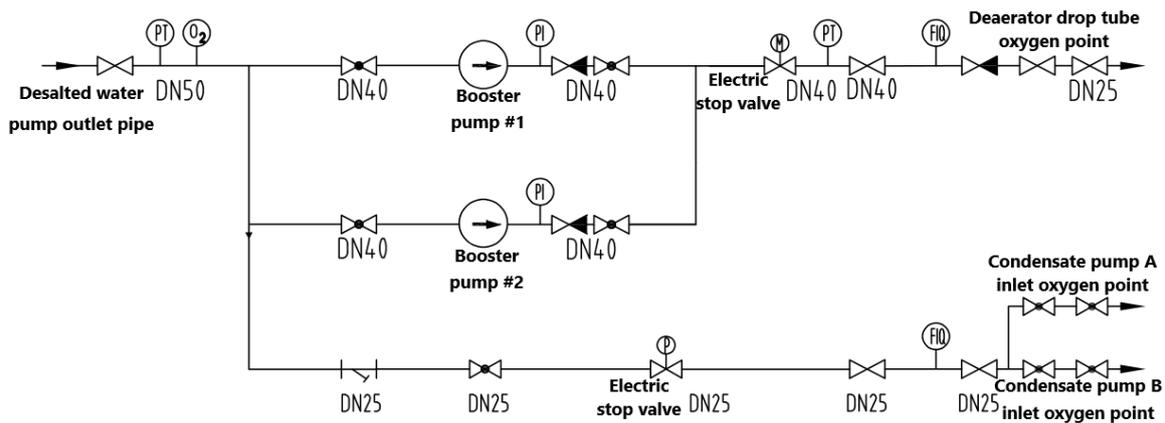


Fig. 2. “Desalted water” feedwater oxygenated treatment system diagram.

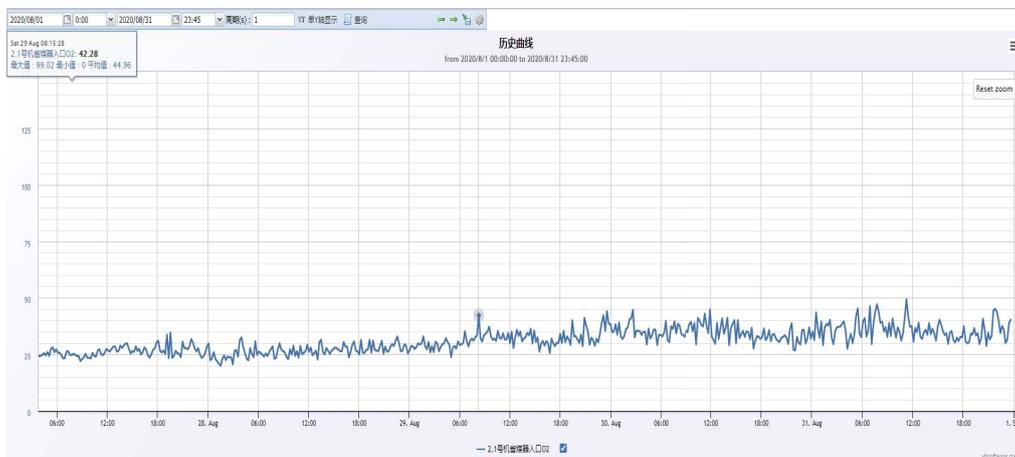


Fig. 3. The typical historical curve of the feedwater.

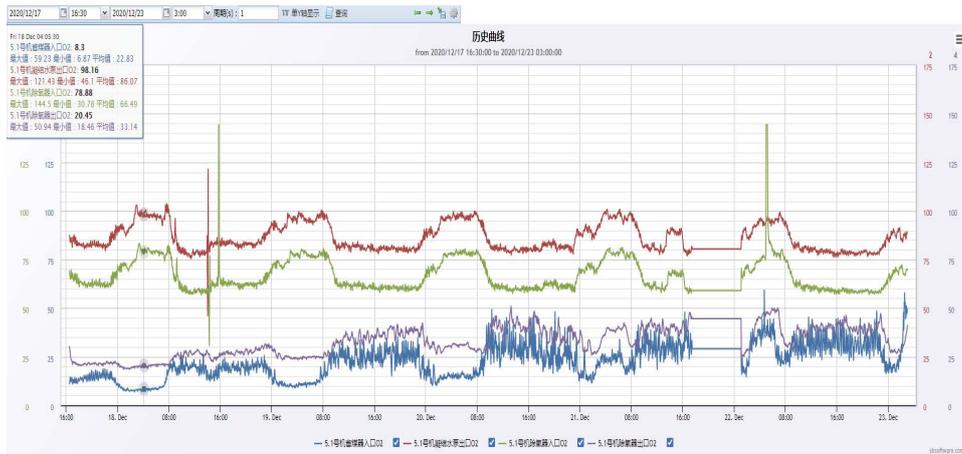


Fig. 4. Trend of dissolved oxygen in feedwater section.

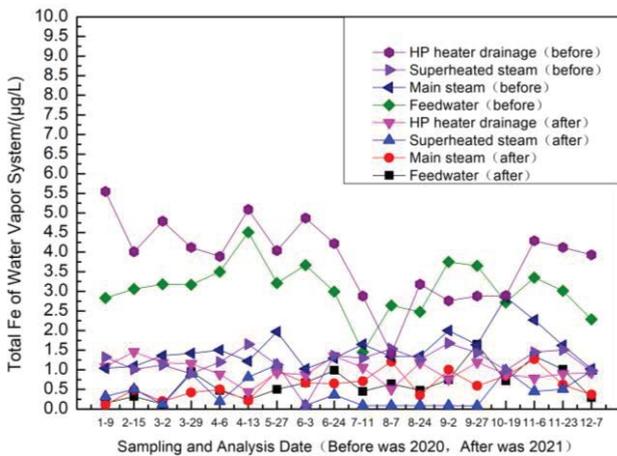


Fig. 5. Total Fe content in water vapor system.

According to the statistical reports of water vapor test in the power plant of the recent 2 y, the total Fe content of corrosion products in the water vapor circulation system remained at a relatively low level after supplied, which basically remained at <1.0 µg/L, significantly decreased compared to that before, and the water vapor cleanliness was significantly improved. We could find that from Fig. 5.

### 3.3. Feedwater dosing and condensate polishing system optimization

When under AVT condition, the hydrogen type operation cycle of condensate polishing mixed bed was about 1 week, frequently resin regeneration put forward high requirements on resin service life and operation intensity, and a large amount of acid and alkali regeneration wastewater discharge causes great environmental pressure.

During the OT operation, the amount of ammonia in feedwater decreased greatly, control pH value decreased from 9.40 to 9.07 (SC 2.88 µS/cm). According to the calculation, the average amount of ammonia added was 292 µg/L, which was about 3 times lower than the original

860 µg/L. The periodic water production of single high-speed mixed bed increased from about 120,000 tons to about 360,000 tons, the resin regeneration frequency was extended from 1 week to 3 weeks, the consumption of acid and alkali hazardous chemicals used for regeneration and the discharge of wastewater were reduced by 2/3, which effectively reduced the workload of operators.

### 3.4. Furnace tube inspection of protective film

Fig. 6 shows the microscopic morphology of waterwall (Spiral front wall #4 corner burnout air upper elevation 37 m, upper part, the material is 15 CrMo) under SEM. Under different mesh (×100 µm and ×1,000 µm), it can be seen that the inner surface of the waterwall was mainly round particles with relatively close arrangement and no angular loose structure.

From the energy spectrum analysis of waterwall, the main elements of corrosion products are Fe and O, and iron oxides account for more than 94%. The Fe/O molar mass ratio in the table is 2.33, which can confirm that the dense and good passivation effect of Fe<sub>2</sub>O<sub>3</sub> (Fe/O molar mass ratio is 2.33) protective film has been generated, rather than the loose porous and easy fall off Fe<sub>3</sub>O<sub>4</sub> (Fe/O molar mass ratio is 2.62) protective film.

## 4. Analysis of economic and social benefits

### 4.1. Economic analysis

- (1) It greatly reduced the dosing of caustic alkali, hydrochloric acid, ammonia and other chemicals investment more than 2/3, include the chemical dosing of feedwater, the acid and alkali consumption of condensate polishing resin regeneration, roughly saved about 350,000 RMB/y.
- (2) It saved the cost of 300 tons coal burning resulted by heat transfer efficiency of furnace tube, while maintaining the same efficiency, the cost of corrosion products removal while reduce the deposition rate of corrosion products in thermal equipment. The two items can save 400,000 RMB/y.

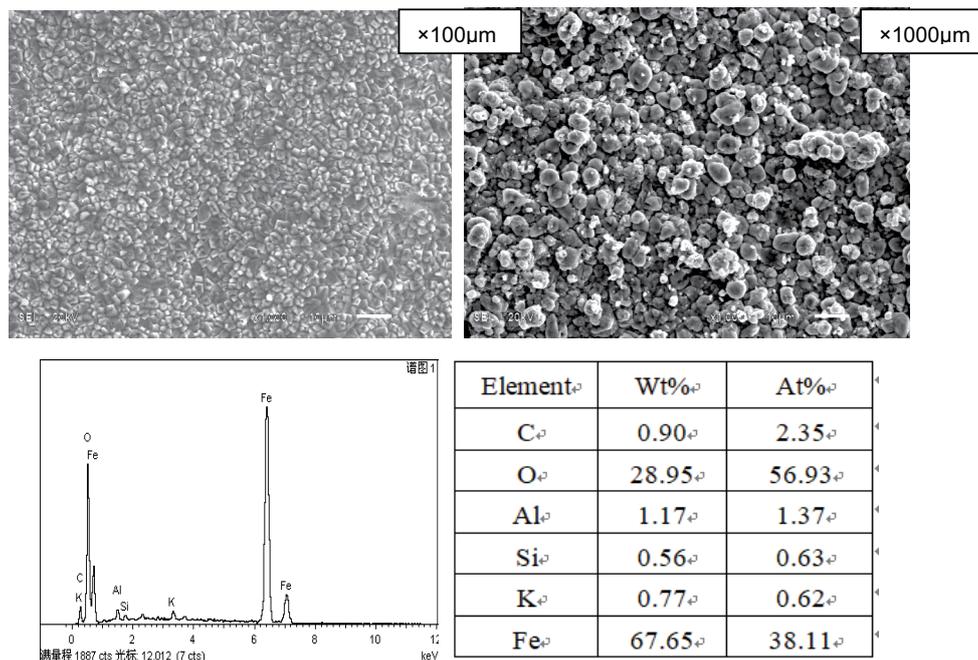


Fig. 6. SEM and energy spectrum analysis of waterwall samples.

- (3) It significantly shortened the start-up time of the unit, and realized the quick response of grid-connection. Compared to AVT condition, the time was shortened by 1/3. The unit increased power generation, saved the cost of water and energy about 400,000 RMB per time, which can save about 800,000 RMB/y.
- (4) The whole process avoided oxygen cylinders, oil-free air compressors, gas storage tanks and other equipment maintenance costs, can save economic cost of more than 100,000 RMB/y. Compared to the conventional system, the equipment investment can directly save 400,000 RMB. The economic cost saved by the two items were more than 500,000 RMB.

#### 4.2. Social benefit analysis

- (1) It improved the water vapor system cleanness of the unit, effectively reduced the harm of corrosion and scale formation of equipment, avoided the non-stop accident of tube explosion caused by water vapor degradation, and improved the operation safety and economy.
- (2) Compared to the traditional technology, it avoided the use of complex equipment, greatly reduced the workload of operation and maintenance, and reduced the human input caused by frequent replacement of oxygen cylinders.
- (3) Not use high-pressure cylinders and high-pressure air storage in the whole process, reduced the dangerous risk caused by chemicals agent and pressure vessels, which significantly improved the working environment.
- (4) Compared to AVT working condition, the time of start-up rinsing and grid-connection shortened by 1/3, realized the quick response of grid-connection of generating units and promoted the improvement of power supply guarantee level.

#### 5. Conclusion

After the implementation of “desalted water” feedwater oxygenated treatment technology, the feedwater system control of dissolved oxygen situation overall is stable and reliable, obviously improve the cleanness of water vapor system, feedwater dosing and hazardous chemicals is greatly reduced, the condensate polishing mixed bed output significantly increased, and obtain better economic and social benefits, achieve the expected effect of supercritical unit feedwater OT objective.

“Desalted water” feedwater oxygenated treatment technology belongs to “resource-saving and environment-friendly”. It infinitesimally changes the original official system, add the conventional oxygenated position by the condensate pump export to the entrance of condensate pump, keep the second add oxygen point (deaerator drop piping) unchanged, select a part of the normal ordinary desalted water as the feedwater oxygenated medium, through intelligent operating system, precise control feedwater OT working condition.

In essence, dissolved oxygen content in the water vapor circulation system can be easily controlled by using low-content dissolved oxygen desalted water instead of oxygen cylinders or air compressor. The overall process equipment investment is less, the daily operation cost is low, no need to manually replace oxygen cylinders, reduce labor cost input, significantly reduce the boiler feedwater oxygenated daily operation and maintenance work intensity. The safety of the working environment on site is significantly improved, avoiding the use of high pressure vessels and reducing the use of dangerous chemicals. The invention of this technology significantly reduces the technical difficulty in the implementation of conventional feedwater OT, greatly reduces the risk points and

workload in the daily operation of feedwater OT, and plays a significant role in promoting the industrial progress of boiler feedwater OT technology.

At present, 4 units of 2 × 660 MW and 2 × 350 MW supercritical units have been put into operation, and another batch of units are being implemented and planned.

#### About the author

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#### Fund projects and major research projects

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