

Reason Analysis and Control Strategy on Operation Corrosion in Direct Air-cooled Condensers (ACC)

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Abstract—The operation corrosion in direct air-cooled condensers (ACC) had been widespread in china. Various water treatment devices were used for condensate water in order to control feedwater iron concentration below the limit according to guidelines, however direct ACC operation corrosion still existed and needed a thorough solution. Ammonia has a lower partition coefficient in the initial condensate, as well acidic anions are concentrated in the initial condensate, thus the initial condensate has lower pH, which results in the above mentioned corrosion. To reduce the direct ACC operation corrosion, methods could be applied, such as dosing higher ammonia in feedwater or dosing some organic alkalizing reagent in exhaust steam as an auxiliary.

Keywords—thermal power plant; direct air cooling unit; air condenser; operating corrosion; corrosion control; alkalizing agent

I. INTRODUCTION

To alleviate the shortage of water resource, air-cooled units are widely used in power construction in North China where is rich in coal and short of water, in accordance with the requirements of the national industrial policy requirements. Therefore, from the beginning of this century, the construction of power plants equipped with ACCs developed rapidly in China, especially in recent years a large number of (ultra) supercritical units with ACCs, which rated power are 600 MW or 1,000 MW, have been built and put into operation, making power per unit and total installed power of ACC units in China leading the world[1][2].

Now in China, the iron content of condensate in the operating units equipped with direct ACC is usually ~ 20 µg/L, for some units it even goes above 100 µg/L, due to the special operation conditions of direct ACCs. In order to reduce the condensate iron pollution on ion-exchange resin, and control feedwater iron concentration in the limit, all the direct ACC in China are equipped with wound powder resin filter, electromagnetic filter, or strong permanent magnetic filter to reduce the iron content of polishing and feedwater system, which can prevent resin iron contamination and slow down scaling rate in the water-steam cycle^{[3][4]}.

However, adding deironization equipment means increasing the investment and operation maintenance cost, but still can't prevent the ACC corrosion effectively. Therefore, analyzing the causes of the operation corrosion in direct ACC, and applying a suitable solution would be the fundamental

strategy for the power plant on the base of balancing the economy and equipment safety.

II. CURRENT CORROSION SITUATION OF DIRECT ACC UNITS

Now, the pH of feedwater in most direct air-cooled units is controlled according to GB/T 12145, which stipulate that feedwater pH is controlled between 8.8~9.6 referring to different boiler parameters. The main purpose of this guideline is to prevent corrosion and scaling in boiler or steam turbine by controlling water-steam quality. Figure 1 is the statistical graph on iron concentration of condensate, feedwater, and main steam, when feedwater pH is controlled in different limits, covering some of the Chinese units equipped with water-cooled condensers (WCC) or direct ACC.

Figure 1 illustrates that although the iron concentration of condensate in units with direct ACC is much higher than that in units with WCC under different feedwater pH conditions, however after effective deironization by condensate treatment devices, the iron concentration in feedwater and main steam in units with direct ACC is almost the same as that in units with WCC, which is within the limit. Thus the direct ACC corrosion problem has not been paid enough attention.

As more units equipped with direct ACC into commercial operation increases in China, and the total operation hours grows a lot day by day, the direct ACC operation corrosion issue gets increasingly prominent. Successively some power plants have experienced partial corrosion leakage in ACC. Figure 2 shows the corrosion of the countervane in steam exhaust pipe, its thickness has been thinned more than 10%; Figure 3 shows the corrosion in entrance of the heat exchange tube, this area is where leakage mostly occurs; Figure 4 and Figure 5 shows respectively the function failure after the deironization of the coiling powder resin filter and strong permanent magnetic deironization device absorbs corrosion products, and also illustrates that there was a large amount of corrosion products in operating direct ACC. As above figures, it is obvious that the direct ACC corrosion has not been prevented effectively^{[3][4]}.

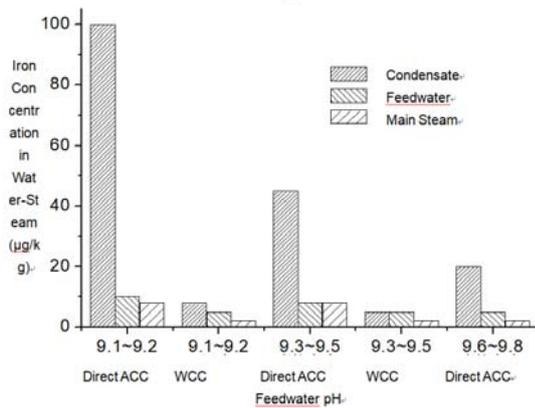


FIGURE I. IRON CONCENTRATION IN WATER-STEAM IN DIFFERENT FEEDWATER CONDITIONS



FIGURE II. THE COUNTERVANE IN STEAM EXHAUST PIPE



FIGURE III. ENTRANCE OF THE HEAT EXCHANGE TUBES



FIGURE IV. THE COILING POWDER RESIN FILTER



FIGURE V. THE MAGNETIC DEIRONIZATION DEVICE

III. ANALYSIS ON DIRECT ACC OPERATION CORROSION

Exhausted steam from low pressure turbine is cooled down in direct ACC, it condensates gradually, thus forms a lot of two phase flow areas, the corrosion occurred in the areas of direct ACC is defined as “Steam/Water Two phase Flow Accelerated Corrosion” in some foreign literatures^[6]. The root cause of corrosion in direct ACC is, that water steam cycle corrosion is prevented by conditioning feedwater pH using ammonia, and ammonia is volatile with a much larger partition coefficient in steam. Direct ACC is a heat exchanger which water / steam side is nearly vacuum, all leading ammonia and pH in initial condensate where is in two phase flow in local areas far lower than that in steam. According to the ammonia physicochemical parameters as ionization constant, relative volatility, etc., the formula on the basis of thermodynamic equilibrium is proposed:

$$y = \frac{\alpha x}{1 + (\alpha - 1)x} \quad 1$$

$$pH = 14 + \lg \sqrt{\frac{1000 \cdot \rho_{mix} \cdot k \cdot y}{18(y + \alpha - \alpha y) + m_{ammonia} \cdot y}} \quad 2$$

in which:

- α = Relative Volatility of Ammonia/Amine;
- k = Ionization Constant of Ammonia/Amine;
- $m_{ammonia}$ = Molar Concentration of Ammonia/Amine
- y = Molar Fraction of Ammonia/Amine in steam phase;
- $\rho_{mix} \approx \rho_{water} \approx 1$

With different feedwater ammonia concentration, calculated ammonia and pH in initial condensate is shown in Figure. 6. Also Figure. 6 shows that even if significantly increase the ammonia dosing amount in feedwater, the ammonia concentration and pH in initial condensate in local areas is not obviously increasing. Especially when corrosive ions such as SO_4^{2-} , Cl^- exists in water-steam cycle, they may highly concentrate in initial condensate to lead the pH of condensate close to neutral or even weakly acidic. Table 1 is the measured ion content and pH in initial condensate in direct ACC of a power plant in China. Figure 7 is solubility curve of the magnetite in water as a function of temperature at various ammonia concentrations. It is shown the pH has a positive effect on the iron concentration in condensate in the ACC operation temperature range ($\sim 50^\circ C$)[6][7]. Thus elevating feedwater pH does not help much in elevating initial condensate pH in local areas. According to the iron ion

potential-pH diagram, in the corrosive condition with low pH and high ion concentration in initial condensate in local areas of direct ACC, synergistic effected by high velocity steam flow, porous magnetite layer can be only formed and then it gets stripped away from metal surface, and exposed metal matrix. Therefore, corrosion rate is relatively high in direct ACC, iron concentration in condensate continues high.

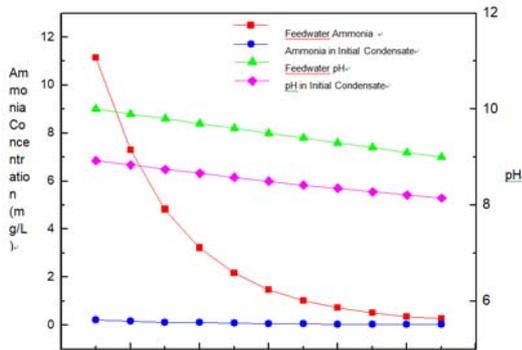


FIGURE VI. THE VARIATION OG AMMONIA AND PH IN INITIAL CONDENSATE WITH DIFFERENT AMMONIA IN FEEDWATER

TABLE I. MEASURED ION CONTENT AND pH IN INITIAL CONDENSATE

Ion Content in Feedwater($\mu\text{g}\cdot\text{kg}^{-1}$)				Measured pH
NH ₃	Cl ⁻	SO ₄ ²⁻	Na ⁺	
3463	<0.1	0.2	<0.1	9.73
1823	0.2	0.4	<0.1	9.22
Ion Content in Initial Condensate($\mu\text{g}\cdot\text{kg}^{-1}$)				Measured pH
NH ₃	Cl ⁻	SO ₄ ²⁻	Na ⁺	
557.6	110.9	59.8	199.2	7.46
306.5	165.3	42.1	107.3	6.84

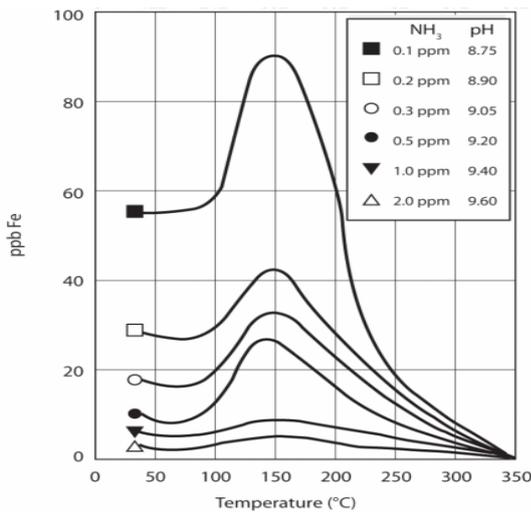


FIGURE VII. MAGNETITE SOLUBILITY RELATING TO TEMPERATURE AND PH

IV. OPERATION CORROSION PREVENTION STRATEGY IN DIRECT ACC

In order to reduce the direct ACC operation corrosion, some domestic and foreign power plants chose to operate with feedwater pH more than 9.8^{[8][9]}. But from Figure. 6&7 it is seen that elevating feedwater ammonia to elevate initial condensate pH in local areas is not fulfilling the corrosion prevention optimum condition. Higher feedwater ammonia concentration makes the regeneration circle of condensate polishing plant (CPP) shorter, makes CPP maintenance load heavier, and acid/base consumption amount for ion-exchange resin regeneration larger.

According to direct ACC operation corrosion analysis, so long as the pH in initial condensate in local areas is elevated higher than 9.0, the iron concentration in condensate and the direct ACC corrosion rate can be reduced significantly. Thus on the technique research in direct ACC corrosion prevention, some foreign materials introduce to add ETA or DMA as alkalinizing reagent into feedwater. For the ETA/DMA relative volatility is much higher than ammonia, its partition coefficient in the liquid phase is much higher too (as shown in Table 1), leading to elevate the initial condensate pH in local areas and to slow down the material corrosion obviously^[9]. However ETA and DMA are amines, they decompose into low molecular weight organic acids under high temperature and high pressure conditions in supercritical units, causing the water steam quality such as cathodic conductive exceeding the limits according to the guidelines, and undecomposed ETA has a potential pollution effect on the performance of ion-exchange resin which is still needed to be demonstrated. Therefore, technology using ETA or DMA into feed water to prevent direct ACC corrosion is limited applied, only experienced in some subcritical units and nuclear power plants.

On the basis of the foreign reseaches, it is thought to be feasible applying an amine which is a strong base with high partition coefficient in liquid phase, and has no effect on the performance of ion-exchange resin, to elevate the initial condensate pH in local areas and prevent the direct ACC operation corrosion. However, the alkalinizers should not be dosed directly into feed water to prevent the decomposition of organic alkali at high temperature. It could be considered to be designed to dose the amine into the exhaust steam pipe in the direct ACC.

Figure. 8 is pH elevation effect according to the calculated amine dosing amount in the exhaust steam pipe on the basis of the ionization equilibrium constant and vapor/liquid distribution coefficient of one kind of amine, and Formula 1&2. From this figure, it can be concluded that dosing amine into exhaust steam can effectively elevate the initial condensate pH in local areas. As a result, choosing an amine, which can elevate initial condensate pH in local areas obviously, has no effect on the ion-exchange resin, and can be totally absorbed by ion-exchange resin not transporting into feedwater system decomposing at high temperature, can be the solution for effective direct ACC corrosion prevention.

Figure 9 is the comparison on the iron concentration in condensate tested by the filter film before and after dosing amine into a direct ACC in a domestic power plant. It can be

seen from the diagram that the iron content in condensate after dosing amine is significantly reduced, and the corrosion prevention effect of the direct ACC is excellent.

Table 2 is the statistical comparison based on the result of operation corrosion prevention experiment, that is, the economic and corrosion prevention effects comparison between using amine and dosing only ammonia in feedwater. It can be seen from the table that dosing amine has a significant economic and corrosion prevention effect, than conventional methods.

TABLE II. LOG RV OF SECCRAL AMINE IN FIRRERENT TEMPERATURE

amine	Log RV		
	25°C	50°C	100°C
Ammonia	1.41	1.28	1.08
Dimethylamine	0.83	0.90	1.04
Ethanolamine	-2.10	-1.72	-1.13
Morpholine	-0.98	-0.77	-0.44

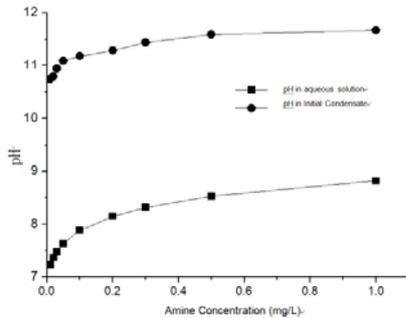


FIGURE VIII. PH AND DIRRERENT AMINE CONCENTRATION



(a) Feedwater pH 9.2~9.4, Iron Concentration 46.8µg/L



(b) Feedwater pH 9.6~9.8, Iron Concentration 19.3µg/L



(c) Feedwater pH 9.2~9.4 dosing amine, Iron Concentration 4.4µg/L
FIGURE IX. CONDENSATE IRON CONCENTRATION TESTED BY FILTER MEMBRANCE

TABLE III. THE ACC OPERATION PARAMETERS AND ECONOMY DATA

Item	Feedwater Ammonia	Feedwater Ammonia +Amine	Feedwater Ammonia +Amine
Average ammonia dosing amount, mg/L	≈0.8	>3.0	≈0.8
Average amine dosing amount, mg/L	0	0	<1
Feedwater pH	9.20~9.30	>9.7	9.20~9.30
Feedwater CACE, µS/cm	≤0.10	0.1~0.2	≤0.10
Condensate Iron Concentration, g/L	>30	10~20	≤10
CPP Cation bed production capacity, 10 ⁴ m ³	≥9.8	<3.2	≥9.0
Carbon steel corrosion rate	High	Intermediate	Relatively Low
Influence on boiler or turbine scaling	High	Intermediate	Relatively Low
Contamination degree of ion exchange resin	High	Intermediate	Relatively Low
Iron scaling trend in ACC outlet	Intermediate	Intermediate	Relatively Low
Operation Cost	Filter operation cost high	Mixed-bed operation cost high	Amine cost added

V. RECOMMENDATIONS

a) The key to prevent the operation corrosion in direct ACC is to elevate the initial condensate pH in local areas, it is recommended the power plants choose high feedwater pH (pH >9.8), or feedwater pH controlled as normal (pH 8.8~9.3) dosing amine into the exhaust steam pipe as an auxiliary, according to the power plant balance. Both way has the effect on elevating the initial condensate pH, and to reduce the operation corrosion rate in direct ACC.

b) Obvious advantage can be seen in water-steam quality maintaining, corrosion prevention effect, and economical efficiency, if dosing amine into the exhaust steam pipe as an auxiliary is applied. However the amine chosen should not have an effect on the performance of ion-exchange resin, and if it transports into the feedwater system, it should not decompose into a substance affecting water-steam quality.

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