Optimization of Resin Specifications for Condensate Polishers of Power Plants

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1. Research Background and Purpose

Polisher resin mainly uses ion exchange to treat impurities in condensed water. This condensate polishing process is an important part of water treatment of power plants. In a typical steam condensing cycle, the steam produced from the boiler passes through a series of turbines and expands the volume to perform work while releasing most of the energy, forming high-temperature and low-pressure steam. It is then condensed into water in the heat exchanger. The water or condensate is circulated to the boiler and then converted into steam again to drive the turbine. In this cycle, due to leakage and boiler blowdown, water will be lost during operation. Therefore, the circulation of condensed water can continuously supplement the water source and reduce the operating cost of water treatment. However, if there are traces of soluble impurities in the condensate, a large number of impurities or ions will be sent to the boiler and cause corrosion of the boiler under a high temperature and high pressure environment. Therefore, it is necessary to use a purifier resin to decrease the concentration of soluble and insoluble impurities in water. In this case, we simulate the changes in water treatment capability of different uniformity coefficient resins under the operating conditions of the condensate polisher.

2. Research method and Contents

The cation and anion exchange resins used in the mixed bed of the power plant polisher: AMBERJET 1500H and AMBERJET 4500OH as the control group, and purchased resins with similar specifications except for the uniformity coefficient as the experimental group (Table 1).

To make the operating conditions of the test column approximate to the operation of the power plant, the experimental equipment adopts ASTM D3375 and the simulation operation design for polishers of power plants commonly used abroad (Figure 1).

Table 1 Research Sample Specifications

Brand Amberjet	Cation Resin		Anion resin	
	Product Number	Uniformity Coefficient	Product Number	Uniformity Coefficient
control group	1300H	≦1.10	4500OH	≦1.10
experimental group	1500H	≦1.20	4200OH	≦1.25
experimental group	IRC 120H	≦1.49	IRA402OH	≦1.80

The raw water is pumped from the raw water tank to the polish column containing the mixed bed of cation and anion exchange resin, purified to pure water above 17MΩ-cm, and then mixed with the NaCl injected by the dosing machine in the mixing chamber to 0.5 meq/L as the simulate condensate (64±1 uS/cm). After that, the simulated condensate is passed into the test column containing the mixed bed sample for ion exchange, and the effluent recycled through the pipeline to the original water tank for further purification and use.

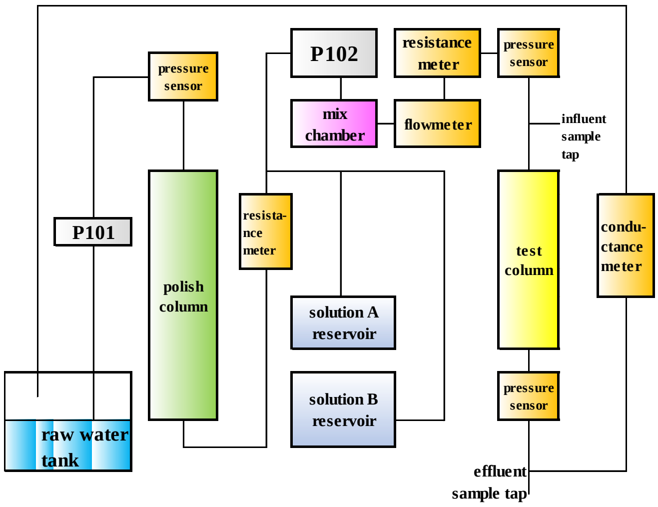

Figure 1 Flow chart of experimental equipment

In addition, to reduce costs and achieve required performance of the polisher during the operation of the power plant, the design and operating conditions of the tank have reached a very high linear flow rate (take a typical polisher as an example, a tank with a design size of φ2800mm × H2200mm, the operating flow can reach 514 m^3/h, and the linear flow rate is 139 cm/min). To make the experimental results comparable with the literature, the linear flow rate in the pipeline is 122 cm/min, which is equivalent to a flow rate of 618 mL/min through a 1-inch test column.

The experiment group is designed by the Taguchi method with 4 control factors, including cation (C)/anion(A) resin uniformity coefficient, cation and anion mixed bed volume ratio ($P=V_C/V_A$) and flow rate (V), each with 3 different levels. Use Taguchi Orthogonal Form $L_9(3^4)$ to plan a representative experiment group to conduct the experiment to the specified end point of the effluent conductivity, then sample the effluent for analysis. From the operating exchange capacity Q and the concentration of Na^+ and Cl^- in the effluent, the water treatment capacity of the resin and the trend with the change of the control factor are evaluated.

3. Results and Discussion

（1） Taguchi Analysis results

The operating exchange capacity Q (Figure 2) shows that Q decreases with the increase in the uniformity coefficient of the anion exchange resin (A1→A3), that is, the more uneven the particle size distribution of the resin, the worse the ion exchange capacity. When the mixed bed ratio (P1→P3) increases, the equivalent ratio of cations and anions of the mixed bed resin will deviate from the ratio of the cation and anion equivalents in the influent, resulting in early saturation of the anion resin, acidic effluent and a significant decrease in Q. When the uniformity coefficient of the cation resin (C1→C3) increases, there is no significant change in Q, which will be discussed in (2). When the water flow rate (V1→V3) decreases, the ions in the water have more time for ion exchange on the surface of the resin. Makes Q slightly improved.

（2） Ion concentration in Effluent

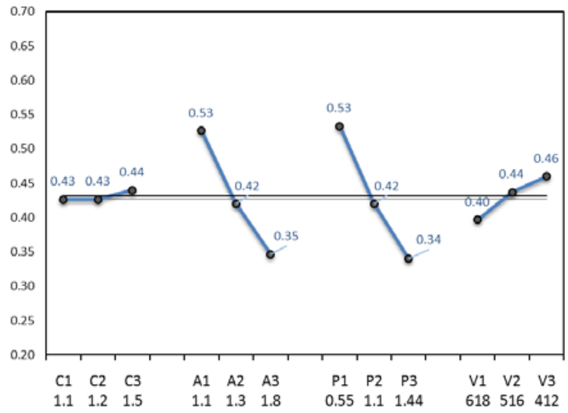

Figure 2 Q vs Control Factor

From comparing the mixed bed formed by cation resins with different uniformity coefficients and the same anion exchange resin, it can be seen from Figure 4 that the mixed bed 1300H/4500OH with a smaller uniformity coefficient of the cation exchange resin has a smaller Na ion concentration in the effluent, indicating the mixed bed has better exchange capability for Na. Figure 5 shows that for the same anion resin 4500OH, the smaller the uniformity coefficient of the matched cation resin, the smaller the Cl ion concentration in the effluent. It is observed that the uniformity coefficient of the cation resin not only affects the exchange capability for Na in the water, but also affects the exchange capability of the anion resin with which it is paired. Even when the resin is not saturated, the ions in the water are not fully exchanged by the bed, in any case, there will still be a small number of ions leaking into the effluent water, but the degree of leakage varies with the environment around the resin. This phenomenon can be used as a direction to improve the kinetics leakage of the anion resin, that is, in a mixed bed prone to kinetics leakage, using a cation exchange resin with a smaller uniformity coefficient should be able to reduce the anion concentration in the effluent.

（3） Mass transfer coefficient (MTC)

With the help of the packed bed model in the tube, the mass transfer coefficient (MTC, m/s) of a single cation or anion resin in the mixed bed resin can be further known, which is equivalent to the speed of ion transfer into the resin surface from the water. The ions in water move in one-dimensional direction in the column as shown in Figure 3, and the mass balance equation can be expressed as

$$D_{eff}\frac{\partial^2 C_i}{\partial x^2}-\frac{u}{\varepsilon}\frac{\partial C_i}{\partial x}=\frac{\partial C_i}{\partial t}+\frac{(1-\varepsilon)R_i}{\varepsilon}\frac{\partial q_i}{\partial t}$$

In the situation of high linear flow rate, the mass transfer coefficient k of a single ion can be obtained by using boundary conditions

$$k=\frac{Vd_p}{6(1-\varepsilon)RAH}ln\left(\frac{C_{inf}}{C_{eff}}\right)$$

The k value can be calculated from experimental data. Taking Fig. 6 as an example, under the same Q value (that is, the same amount of NaCl is provided in the three mixed beds), a mixed bed formed by a cation resin with different uniformity coefficients and the same anion resin is compared, and it shows that the mixed bed with a smaller uniformity coefficient, 1300H or 1500H, with a higher k_{Na}, meaning that the Na ions in the water can be transferred to the resin faster. Figure 7 shows that for the same anion exchange resin, if the uniformity coefficient of the cation resin paired with it is smaller, the k_{Cl} of the anion resin will increase, indicating the faster the anion exchange rate.

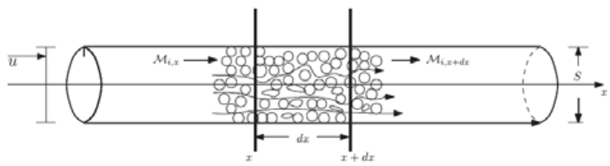

Figure 3 packed bed model

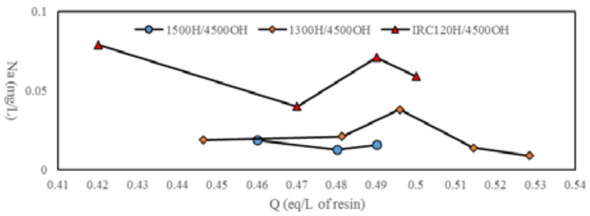

Figure 4 Na^+ concentration in effluent vs Q

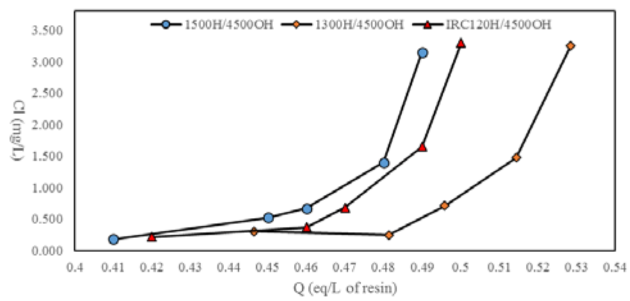

Figure 5 Cl^- concentration in effluent vs Q

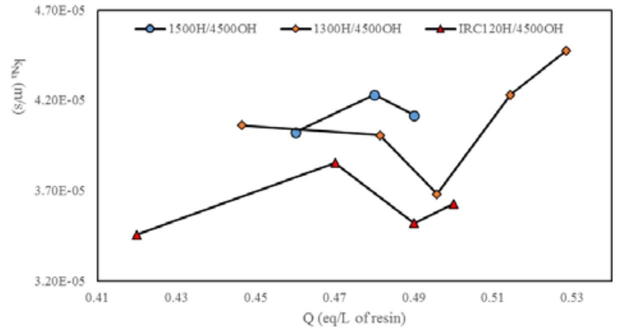

Figure 6 MTC k_{Na} vs Q

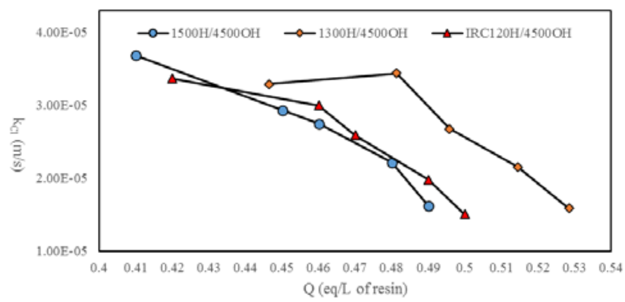

Figure 7 MTC k_{Cl} vs Q

（4） Conclusion

i. The effect of uniformity coefficient of anion resin on exchange capacity is more dramatic than that of cation resin.

ii. The cation/anion resin exchange capacity of the mixed bed will be affected by the uniformity coefficient of the anion/cation resin paired with it. Using a paired resin with a smaller uniformity coefficient can effectively reduce the degree of kinetics leakage.

iii. Regularly check the cation and anion composition and concentration of the inlet, and calculate the total equivalent of cation and anion to adjust the volume ratio of the mixed bed, so that the exchange capacity of the mixed bed can reach the maximum utilization rate.

iv. Without affecting the normal operation of the condensed water purifier, the lower linear flow rate allows the ions to stay in the mixed bed for a longer time, so that the ion exchange reaction with the mixed bed is more complete, thereby improving the mixed bed's efficiency and increasing the capacity of mixed bed further.