Operation Optimization of Condensate Polisher and Effect Analysis on Improving Quality and Efficiency in Dingzhou Power Plant

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Abstract: Researches show that when feedwater pH is up to 9.6～9.8 in direct air-cooled supercritical unit, flow accelerated corrosion (FAC) in condenser could be prevented effectively, reducing iron content tremendously in water-steam cycle. However, it will result in a shorter operation cycle of mixed bed (MB) as adding more ammonia, only 3～4 days for shortest. With researches in Dingzhou Power Plant, TPRI found solution to this issue. First, adjust the ratio of cation to anion resin from 1:1 to 3:2, increase filling volume of cation resin by 0.77m^3 , extending the operation cycle by 20%. Second, develop an instrument of image recognition and intelligent control of resin transportation (IRIC), which can improve the accuracy of resin transportation, avoid cross-contamination of cation and anion resins, ensure a higher resin regeneration degree, meanwhile, modify the defects of water distribution plate in MB, improving the water distribution effects Then the working exchange capacity is raised from 1396 to 1967 mol/m^3R with a corresponding increment of operation cycle by 41%. After these measures applied to Dingzhou Power Plant, operation cycle of MB is raised up to more than 7 days, resulting in 69% more cycle water production. Irons content in effluent is lower than 3 μg/L, and the concentration of chloride and sodium ion are both lower than 1 μg/L, without salt deposits, corrosion and scaling ever occurred on steam turbine.

Keywords: air-cooled units; mixed bed; high pH; operation cycle; resin ratio of cation and anion; image recognition and intelligent control of resin transportation

Introduction

Direct air-cooled supercritical units are developed quickly for water-reducing and energy-saving in water-deficient areas of northern China recent years. It is required very high water quality for direct air-cooled supercritical units. The main water quality indicators, like sodium ion, chloride ion, silicon dioxide and iron, are all strictly controlled. For direct air-cooled units, the cooling area of air cooling island is very large, leakage of CO_2 and O_2 are likely to happen, and corrosion products content is high. If there are problems with condensate polishing, it is likely to have salt deposit, corrosion and scaling on steam turbine, which is a serious security threat.

In Dingzhou Power Plant, 4 months after the 660MW NO.3 direct air-cooled supercritical unit put into operation, scaling rate of economizer was up to 124.5 $g/m^2 \cdot a$ high, boiler pressure difference increased from 1.44 MPa to 2.09 MPa. In July 2010, in order to inhibit flow accelerated corrosion (FAC) in water supply and drainage system, and decline the scaling rate of boiler heating surface, Dingzhou Power Plant requested the international known chemical expert to come up with the solution. He researched and found that the problem would be resolved if change the feedwater treatment mode from AVT (O) to oxygenated treatment in high pH, with pH ranging from 9.6~9.8. With this solution, total iron content in condensate water dropped off dramatically, from 30μg/L to less than 10μg/L. However, with a higher pH feedwater, more ammonia should be added to the system, resulting in a frequent resin regeneration in MB, an obviously decline in operation cycle of MB, a shorter resin service life, a higher operational cost and that the use of regeneration apparatus is close to saturation. Therefore, for oxygenated treatment to boiler feedwater in high pH, it is desirable to extend the operation cycle of MB.

Concerning about the new issue, TPRI estimate the spherical MB of the condensate polishing system in supercritical 2×660MW direct air-cooled unit, and found that water quality met the expectations of DL/T 912-2005 after treated by condensate purification or polishing system (CPP) system, which satisfied the requirement of operation, while the operation cycle was relative short, not meeting the requirement of long cycle operation. Therefore, it is necessary to concentrate on the theory and technology of long operation cycle. According to the estimation result, there are two main reasons related to short operation cycle of CPP, which are short of cation resin and low working exchange capacity of cation resin. TPRI proposed solution, including adjustment of resin ratio, application of IRIC and optimization procedure of regeneration, elimination of MB defects. By implementation of this solution, MB issue in Dingzhou Power Plant was completely resolved.

Analysis on MB Effluent quality

Test the concentration of cation and anion at the end operation stage. The water & steam quality is also tested in order to estimate the impact of leaking impurities, as shown in Table 1 and Table 2.

Table 1. Tested result of effluent cation concentration（μg/L）

NO.	Sampling Time	Na^+	NH_4^+	K^+	Mg^{2+}	Ca^{2+}`
1	4 h	0.36	79.9	0.2L	0.1L	0.2L
2	3 h	0.42	98.3	0.2L	0.1L	0.2L
3	2 h	0.57	117.3	0.2L	0.1L	0.2L
4	1 h	0.59	134.0	0.2L	0.1L	0.2L
5	0 h	0.75	162.7	0.2L	0.1L	0.2L

Table 2. Tested result of effluent anion concentration（μg/L）

NO.	Sampling Time	F^-	CH_3COO^-	$HCOO^-$	Cl^-	NO_2^-	SO_4^{2-}	NO_3^-	PO_4^{3-}

1	4 h	0.1L	0.1L	0.42	0.1L	0.1L	0.2L	0.1L	0.39
2	3 h	0.1L	0.11	0.35	0.1L	0.1L	0.2L	0.1L	0.41
3	2 h	0.1L	0.19	0.50	0.1	0.1L	0.2L	0.1L	0.37
4	1 h	0.1L	0.44	1.04	0.1L	0.1L	0.2L	0.1L	0.3L
5	0 h	0.1L	0.20	0.97	0.1	0.1L	0.2L	0.1L	0.3L

Note: Effluent hydrogen conductivity maintains at 0.080~0.086μS/cm from 4 hours before splitting to splitting; "L" means below the limit of detection (LOD), the value before "L" means the value of the corresponding LOD, the same below; For sampling time, "x h" means x hours before splitting, the same below.

According to Table 1 and Table 2, ammonia-breakthrough occurs when MB being exhausted, and the concentration of sodium ion also increases. When ammonia-breakthrough occurs and cation resin is exhausted, concentration of chloride and sodium ion are both less than 1μg/L, meeting the expectations of DL/T 912-2005 《Quality criterion of water and steam for supercritical pressure units in fossil fuel power plant》.

Analysis on approaches to improve operation cycle of hydrogen MB

Condensed water is low in ionic impurities, so the main substance exchanged in resin is ammonia. Therefore, with the resin exchange capacity to ammonia, the operation cycle of hydrogen MB can be calculated, as shown in formula (1).

$$H = Vc \cdot Ec / (Qc \cdot C_{NH_3}) \tag{1}$$

where： H —operation cycle of MB, h;

Vc —filling volume of cation resin, m^3;

Ec —working exchange capacity of cation resin, mol/m^3R;

Qc —average influent flowrate of MB，m^3/h;

C_{NH_3} —average concentration of NH_3 in condensed water, mmol/L.

According to formula (1), with a constant influent flowrate of MB, the external facotr is ammonia content (pH) in condensed water while the internal factors affecting MB operation cycle are cation resin volume and working exchange capacity.Ammonia content has a great impact to MB operation cycle. For instance, when pH of cendensation water is 9.4, the ammonia content is 1.0mg/L; when pH of cendensation water is 9.6, the ammonia content is 2.2 mg/L. This means that operation cycle at pH of 9.4 is 2.2 times longer comparing to at pH of 9.6, under the condition of equal working exchange capacity of cation resin, equal volume of cation resin and equal MBcapacity.The filling volume of cation resin is direct propotional to operation cycle with other factors being equal. Without changing MB structure, the only way to increase cation resin volume is to increase the proportaion of cation resin.Working exchange capacity of cation resin is affected by some points, including accuracy of resin transportation, transportation percentage of exhausted resin, resin separation and mixing coefficient, separation percentage of exhausted resin,rationality of process control procedure and integrity of water distribution device in MB.

Estimation of MB operation

For Dingzhou Power Plant, 45% operation cycle reduction at least was caused by high pH. The only way to extend operation cycle is to increase the cation resin volume and improve working exchange capacity.

Table 3 is the actual resin volume in Dingzhou Power Plant. Table 4 is the actual working exchange capacity of cation resin in Dingzhou Power Plant.

Table 3. Actual resin volume

MB NO.	Actual Value (m^3)	
	Cation Resin	Anion Resin
3-1	3.77	3.32
3-2	3.58	3.37
3-3	3.87	3.76
4-1	3.90	3.86
4-2	3.90	3.62
4-3	3.54	3.93

Table 4. Actual working exchange capacity of cation resin

MB NO.	Cation resin volume （m^3）	Operation cycle （h）	Cycle water production （kiloton）	Average ammonia concentration in condensed water （mg/L）	Working exchange capacity of cation resin （mol/m^3R）
4-3	3.54	103	45	2.1	1496
4-3	3.90	108	52	2.1	1569
3-2	3.90	58	30	3.2	1448
3-2	3.90	53	28	3.2	1351
3-3	3.60	63	32	2.4	1255
3-3	3.87	93	43	2.0	1242
average					1393

The design cation resin volume is 3.84m^3, while the volumes of three sets of resin are lower than the design value dramatically; the average working exchange capacity of cation resin is 1393 mol/m^3R, not meeting the standard DL/T333.1-2010《Technique requirements of condensate polishing in thermal power plant Part 1:Water-cooled units》 of 1750~2000mol/m^3R.

It is still possible to have more filling catoin volume and cation working exchange capacity in Dingzhou Power Plant. Therefore, TPRI will estimate the factors affecting cation resin volume and working exchange capacity of CPP system in Dingzhou Power Plant.

1. Factors affecting MB operation

Factors affecting MB operation include accuracy of resin transportation, transportation percentage of exhausted resin, resin separation and mixing coefficient, separation percentage of exhausted resin, rationality of process control procedure and integrity of water distribution device in MB.

(1) Accuracy of resin transportation

Estimating the accuracy of resin transportation, when there is a deviation between actual and design is up to 13.5%, operation cycle will be affected inevitably. Additionally, when there is a large difference in resin volume and ratio, resin transportation and procedure of separation and mixing will be easily confused, causing adverse impact to resin transportation percentage, separation percentage and mixing effect, which further impact the effluent quality and operation cycle adversely. The main reason of low resin transportation accuracy is inappropriate working of photoelectric apparatus of interface inspection. Resin separation and transportation node are controlled by operating personnel, resulting a poor accuracy on resin transportation control.

(2) Transportation percentage of exhausted resin

There is no resin leftover in MB. The exhausted resin is thoroughly transported, meeting the required standard of more than 99.9%.

(3) Resin separation and mixing coefficient

Under hydrogen operation, resin separation coefficient is 0.68 meeting the requirement of more than 0; mixing coefficient is 2.12, meeting the requirement of more than 3. This means, resin has good separation performance, which can be easily separated in backwashing.

(4) Separation percentage of exhausted resin

After exhausted resin separated, there are 0.08% cation resin contained in anion resin, and there are 0.07% anion resin contained in cation resin, both meeting the standard DL/T333.1-2010 of less than 0.1%.

(5) Rationality of process control procedure

Some critical points are not controlled rationally, resulting in resin leakage during regeneration.

(6) Integrity of water distribution device in MB

Transport the exhausted resin to high-tower separation system, and inspect the inner condition of MB. Figure 1 shows gap between water distribution plates, Figure 2 is single-speed strainer.

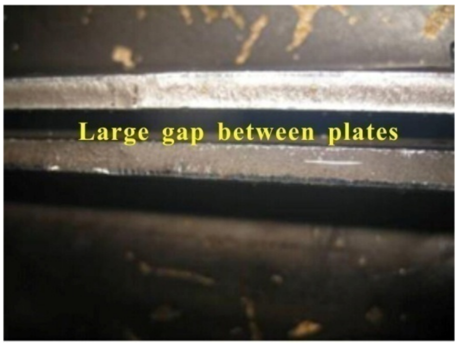

Figure 1. Gap between water distribution plates (Influent)

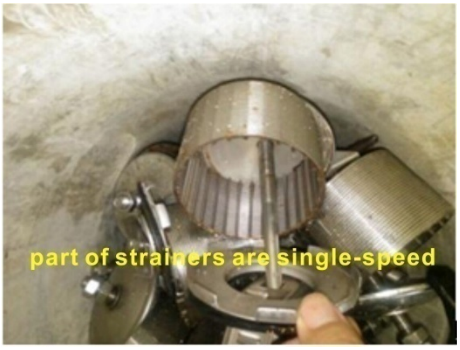

Figure 2. Strainers (Effluent)

Water distribution plate is consisted of 6 parts. Gap between plates is obviously large, which is 6 mm for maximum. During operation, it results in high flowrate in the gap, and resin exchange layer will be rushed and confused, leading to bias flow. Part of strainers are single-speed, resulting in more water flow out. This might be a reason of the short operation cycle.

Cation resin volume is affected by factors of (1), (2) and (5), working exchange capacity of cation resin is affected by factors of (1) through (6).

3. Result summary

Summarizing the estimation result, the optimization scheme is provided for long safe operation, as shown in Table5.

Table 5. Summary of diagnostic result

NO.	Diagnostic Content	Standard Requirement	Actual Situation	Satisfied or Not
1	Accuracy of resin transportation	No deviation	Deviation-13.5%~0.5%	N
2	Transportation percentage of exhausted resin	＞99.9%	＞99.9%	S
3	Resin separation and mixing coefficient	Separation coefficient＞0	Separation coefficient 0.68 Mixing coefficient 2.12	S

		Mixing coefficient < 3		
4	Separation percentage of exhausted resin	Cation resin in anion < 0.1% Anion resin in Cation < 0.1%	Cation resin in anion 0.08% Anion resin in Cation 0.07%	S
5	Rationality of process control procedure	No resin leakage	Some critical points are not controlled rationally, resulting in resin leakage during regeneration	N
6	Integrity of water distribution device in MB	No gap；Strainers are double-speed	Maximum gap is 6mm； Part of strainers are single-speed	N

4. Analysis of the estimation result

According to the inspection result, the main problems are listed as following:

(1) Inappropriate resin ratio of cation and anion, less filling volume of cation resin result in a short operation cycle.

(2) The photoelectric inspection apparatus of interface cannot be normally operated, resulting that the actual resin volume is deviated from designing and resin ratio is confused. Inappropriate procedure of operation, resin leakage occurs in resin regeneration, further leading the confusing of resin ratio.

(3) There are some defects in the inner Mb, easily leading to bias flow and disturbance of resin layer, and then adversely impacting the cycle water production.

The 3 problems above are interactive. Photoelectric apparatus of interface inspection cannot work properly, leading to the deviation of resin filling volume and resin ratio confusion; resin leakage further confuses the resin ratio. Then resin ratio confusion and inappropriate operational procedure result in the poor effect of resin mixing, reducing the resin regeneration percentage. Then, in the condition of low resin regeneration percentage, less filling volume of cation resin and inner defects of MB, cycle water production is obviously reduced.

Optimization schemes

1. Adjust the filling volume and ratio of resin

For hydrogen mixed bed, the principle of determining resin filling volume and ratio is to have the most cycle water production and operation cycle with the guarantee of water quality. For Dingzhou Power Plant, the feedwater treatment mode is oxygenated treatment in pH of 9.6. It is unable to have a higher cycle water production with the given resin filling volume and ratio. In order to have more cycle water production and operation cycle, the proportion of cation resin should be increased. Taking into account all aspects, adjust the cation to antion ratio from 1:1 to 3:2.

2. Apply the Instrument of image recognition and intelligent control of resin transportation (IRIC) and optimize the process control procedure

The accuracy of separation and transportation are relatively low in Dingzhou Power Plant. IRIC can be used to better control the end of transportation and have a more accurate transportation control for Dingzhou Power Plant.

3. Eliminate inner defects of MB

For the defective MB, install angle steel at the gap between water distribution plates to change the flow direction not rush down directly, avoiding bias flow. Also replace part of the single-speed strainers, as shown in Figure 3 and 4.

Figure 3. Installation of angle steel at plates gap (Influent)

Figure 4. Replacement of strainers (Effluent)

3. Optimization the procedure of MB operation and regeneration

Additionally, optimize the procedure of MB operation and regeneration. Install and debug the optimized procedure, resulting in no maintenance required for middle drainage in regeneration tower, avoiding problems of resin leakage and so on, improving the resin mixing effect, consolidating the optimization of MB.

The four optimization schemes are linked each other. First, increasing cation resin volume and adjusting the resin ratio make every set of resin are all identical in volume and ratio. Additionally, in order to accurately control resin in the process of separation and transportation after adjusting resin ratio, it is necessary to install IRIC developed by TPRI. IRIC can not only accurately control the resin separation and transportation, but also reduce cross contamination of resin to improve the resin regeneration percentage. Optimizing the operation and regeneration procedure of MB can enable automation of procedure and modify effect of resin reparation and mixing. Finally, eliminating defects of MB and improving uniformity of water distribution solve the problem of bias flow and resin layer disturbance fundamentally, ultimately achieving the objective of increasing operation cycle with guarantee of water quality.

Implementation effect

Optimization was completed in April 2013, the field operation data shows that the MB performance is obviously improved and under stable operation.

1. Increment of cycle water production

Cycle water production increases 69% on average after optimization.

2. Increment of working exchange capacity of cation resin

Working exchange capacity of cation resin is 1967 mol/m^3R on average after optimization, increasing 41%, meeting the requirement of DL/T 333.1-2010.

3. Standardized effluent quality

After optimization, under normal operation, in effluent of condensate polishing, the average concentration of SiO_2 is less than 6μg/L, the concentration of total iron is less than 3μg/L, and hydrogen conductivity is less than 0.09μS/cm; at the end of operation, the concentration of sodium increases as increasing of ammonia, with no change of chloride; when splitting, the concentration of sodium and chloride are all less than 1μg/L in effluent, meeting the expectations of DL/T 912-2005, resulting in a further improvement of water quality.

4. Increment of direct economic benefit

After optimization, regeneration cycle is longer, make-up water is less required for regeneration, consumption of acid and base are reduced; service life of resin is longer; annual supplement resin is reduced; treatment cost of waste water is reduced. The resulted annual direct benefit is about 1.68 million RMB (274,000 USD).

Conclusion

(1) The main problems in Dingzhou Power Plant are inappropriate resin ratio, inappropriate working of photoelectric apparatus of interface inspection, resin leakage in resin regeneration and defects of inner MB.

(2) By optimization of resin ratio and application of IRIC, the cycle water production increases 69%, the working exchange capacity of cation resin increases 1967 mol/m^3R, the concentration of chloride of sodium are all less than 1μg/L and total iron is less than 3μg/L in effluent. In addition, problems of resin leakage, inaccurate of resin separation and transportation are all resolved, achieving the objective of long

cycle safe operation of condensate polishing under the condition of high pH.

(3) After implementation of the project, a significant benefit can be brought to Dingzhou Power Plant. The resulted annual direct benefit is about 1.68 million RMB (274,000 USD).

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