Operational Estimation and Application Case of Powdex Pre-coat Filter

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Abstract: Powdex pre-coat filter is the common and important deironing equipment for condensation water. However, some common issues exist in powdex pre-coat filter in a number of Chinese power plants, including low iron removal efficiency, exceeding iron content in effluent water, damaged filter elements, powdex leakage, high operational differential pressure, etc. Researching on these issues, TPRI developed the intelligent estimation system of powdex pre-coat filter, with "Dynamic Simulation Experiment on the Performance of Wound Filter Element and Powdex"and "On-line Intelligent Monitoring" as the core. By determining the removal efficiency of suspended solids and amount of intercepted impurities, this system can provide rapid estimation on the performance of powdex pre-coat filter and diagnose the issue existing in filming process, providing the basis to optimize the operation of powdex pre-coat filter. With application of this intelligent estimation system and the subsequent optimization in some air-cooled power plants, the powdex pre-coat filters are optimized with significant decreased iron content in effluent water, much longer operational cycle and much longer service life of filter elements, meeting the requirement of efficient, safe and economic operation.
Keywords: Powdex pre-coat filter; Dynamic simulation; Performance test; On-line monitoring; Intelligent estimation; Filtering effect

Introduction

In air-cooled units, the condition of high temperature condensation water, much iron corrosion products and high CO_2 brings the strict requirements to prefilter of condensate polishing system. So far, the most common prefilter in air-cooled units is powdex pre-coat filter (short for powdex filter), which has the high content iron corrosion products removal efficiency of higher than 95% and ensure the iron content in boiler feedwater meeting the standard.

At present, the main control index of operation for powdex filter is differential pressure. When differential pressure meets the specified splitting value, the process of pre-coat explosion will be performed and iron corrosion products will be discharged with powdex. Theoretically, there is no iron pollution to filter elements and mixed-bed resins. Additionally, total iron is also the control index of operation for powdex index. The current method (ultraviolet spectrophotometry, atomic absorption method) to

determine iron content is complicated, and power plants only take the determination of iron content for powdex filter once a week, so it is hard to find the problem of exceeding iron content when differential pressure meets the standard.

Investigation and research in over ten air-cooled power plants indicate some main issues in powdex filter, including low iron removal efficiency, exceeding iron content in effluent water, damaged filter elements, powdex leakage, high operational differential pressure, etc. Especially when filter elements damage, powdex leakage will lead decreasing of corrosion ions, together with the issue of exceeding iron content. The worse quality of steam and water is easy to cause corrosion of boiler tube, bringing serious threat to units operation. Concerning about these issues, TPRI developed the technology of operational estimation and optimization for powdex filter.

Technology of Operational Estimation for Powdex Filter

Development Process

In 2008, under the research projects of China Huneng Group, TPRI started to research on the condensate polishing system of large-scale direct air-cooled units. Concentrating on the technical requirements of powdex filter (or elements of prefilter) to condensation water in high temperature and reducing operation differential pressure of powdex filter, TPRI developed “Testbed of Dynamic Simulation Experiment on the Performance of Wound Filter Element and Powdex”, bringing forward the test method of thermostability of filter element, solving the issue of fast increasing of operation differential pressure in powdex filter of one power plant.

With development of research and service in condensate polishing, it is identified the reason of issues existing in powdex filter. TPRI bring forward the index of suspended iron removal efficiency and amount of intercepted impurities in order to represent the operation status of powdex filter, and raise it to the power industry sandard DL/T333.2-2013 “Technical Requirements for Condensate Polishing in Thermal Power Plant, II: Air-cooled Units”. This standard is officially carried out since April 1, 2014, applied for process selection, system configuration, equipment operation and performance evaluation of condensate polishing system in air-cooled units, stating the technical requirements for condensate polishing system in air-cooled units. This standard regulates model selection and operation control of prefilter, and also provides the evaluation index and standard of prefilter operation.

Over the past year, TPRI bring forward the removal efficiency of suspended particles as another technical index, making up the lack of differential pressure and iron

content. Additionally, the intelligent on-line monitoring equipment is developed to real-time monitor the operation status of powdex filter, completing an integral "Intelligent Estimation System of Powdex filter". This system can provide estimation and optimization from key filter elements to equipment operation status for powdex filter.

Significance of Estimation

When powdex filter is in operation, the quality of condensation water varies as the change of units load. In addition, the filming effect of filter elements is affected by powdex quality and filming process. Moreover, the damage and pollution of filter element is a slow and long accumulative process. Therefore, the regular and low frequency iron content is not able to indicate the operation status of filter. People will be aware of the matters only when steam and water quality seriously exceeds the standard or operation cycle decreases dramatically. However, it is too late. In order to take preventative measures and solve problems in time, it is supposed to real-time estimate the operation status of powdex filter.

Technical Overview

The operation estimation technology of powdex filter is based on the theory of iron corrosion products removal, with "Dynamic Simulation Experiment on the Performance of Wound Filter Element and Powdex"and "On-line Intelligent Monitoring" as the core. The optimization scheme can be made according to the estimation result.

With real-time and on-line monitoring on suspended solids of influent and effluent water, calculation and determination of performance of filter elements, this technology will give a more accurate result of filter effect, pollution, damage, powdex leakage and filming effect. The entire operation status estimation of powdex filter is the basis to figure out the optimization solution.

Estimation of filter effect

Powdex filter mainly removes suspended iron and colloid iron, so filter effect is estimated by manually determining the removal efficiency of suspended iron or on-line monitoring the removal efficiency of suspended particles. Basically, removal efficiency is lower as a lower suspended particles (iron content) in influent water. Estimation is not performed when suspended particles (iron content) is relatively low.

Estimation of Filter Element Pullution

Operational staff can observe a fast increasing of differential pressure when filter elements are polluted. Polluted level should be estimated by the coefficient of intercepted impurities amount, amount and size distribution of on-line monitored suspended particles. When the coefficient of intercepted impurities amount is less than 0.5, and suspended particles of small size in effluent water is much decreased than regular, it indicates that filter elements are polluted.

Estimation of Filter Element Damage

"Testbed of Dynamic Simulation Experiment on the Performance of Wound Filter Element and Powdex" and on-line particle monitor are applied to test filter elements precision, flowrate and operation differential pressure curve. The damaged level of filter elements is estimated by operation differential pressure, amount and size distribution of suspended particles. When operation differential pressure of filter elements increases slow, and suspended particles of big size increase dramatically, it indicates that filter elements are damaged.

Estimation of Filming Effect

Filming can increase removal efficiency of corrosion products. If filming effect is poor, the overall filter precision will be decreased, resulting in a significant increasing of big size suspended particles in effluent water. The difference between poor filming effect and damaged filter elements is the different size distribution of suspended particles. The size of particle through damaged filter elements is bigger.

Technical Index

Removal Efficiency of Suspended Solids

(1) Removal efficiency of suspended iron

Effect of iron removal of powdex is estimated by determining the removal efficiency of suspended iron, calculated by the following equation

$$N = \frac{C_1 - C_2}{C_1} \times 100\% \qquad \text{(equation 1-1)}$$

With

N —Removal efficiency of suspended iron，%；

C_1 —Suspended iron content in condensation water，μg/L；

C_2 —Suspended iron content in effluent water of powdex filter，μg/L。

(2) Removal efficiency of suspended particles

On-line monitor the amount of suspended particles in influent and effluent water of powdex filter, and calculate the removal efficiency of suspended particles as equation (1-2). It can also analysis the graded removal efficiency in terms of different size distribution as required.

$$\eta = \frac{N_i - N_o}{N_i} \times 100\% \qquad \text{(equation 1-2)}$$

With

η — Removal efficiency of suspended particles，%；

N_i — Amount of suspended particles in influent water of powdex fitler，NO./mL；

N_o — Amount of suspended particles in effluent water of powdex fitler，NO./mL。

Amount of intercepted impurities

(1) Amount of intercepted impurities for one powdex filter is calculated by equation (2-1)

$$S = (C_1 - C_2) \times T \times 10^{-6} \qquad \text{（equation 2-1）}$$

With

S —Amount of intercepted impurities for one powdex filter，kg；

C_1 —Average of total suspended solids in condensation water within one operation cycle，μg/L；

C_2 —Average of total suspended solids in effluent water of powdex filter within one operation cycle，μg/L；

T —Cycle water production，m^3。

Amount of intercepted impurities for one powdex filter can be estimated by calculating the coefficient of intercepted impurities amount, as calculated by equation (2-2)

$$R_s = \frac{S_r}{S_s} \qquad \text{（equation 2-2）}$$

With

R_s —Coefficient of intercepted impurities amount；

S_r —Amount of intercepted impurities at present operation condition，kg；

S_s —Initial amount of intercepted impurities，kg。

When the coefficient of intercepted impurities amount is less than 0.5, in addition to filter elements pollution, the issue of filming process should be also concerned. Filming process should be modified.

(2) The volume of intercepted impurities is calculated by equation (2-3)

$$S_v = \sum 10^{-6} q_t \left(V_{1,t} - V_{2,t}\right) \nabla T \qquad \text{（equation 2-3）}$$

With

S_v —Amount of intercepted impurities of powdex filter，L；

q_t —Influent flowrate of powdex at moment t，m^3/h；

$V_{1,t}$ —Volumetric concentration of suspended particles in influent water of powdex fitler at moment t，10^{-3}μL/L；

$V_{2,t}$ —Volumetric concentration of suspended particles in effluent water of powdex fitler at moment t，10^{-3}μL/L；

∇T —Time interval between two sampling times of influent and effluent water，h。

Operation differential pressure

When powdex filter is in operation, filter elements pollution will cause the increasing of operation differential pressure, further to decrease the output of equipment and cycle water production, so it is supposed to estimate the operation differential pressure.

When unpolluted filter elements are put into operation, it is supposed to sketch the curve in terms of powdex filter flowrate and the corresponding operation differential pressure as the estimation basis. After a period of time operation, when operation differential pressure is four times higher than the initial condition at the same flowrate, it has to perform chemical clean to filter elements or replace with new one.

Case Introdution

TPRI applied this technology to estimate and optimize condensate polishing system of many power plant in China. The following are some real cases of different issues in powdex filter of air-cooled units, introducing the application of this technology.

Estimation Apparatus

Size distribution of powdex: determined by Microtrac S3500 laser particle size analyzer. Size range is 0.25μm～1400μm.

Amount and size distribution of suspended particles: determined by Chemtrac PC8000 particle counter. Size range is 2~125μm.

Initial operation differential pressure: determined by testbed of dynamic simulation experiment on the performance of wound filter element and powdex. Pressure range is 0~62kPa

Case I: Low iron removal efficiency of powdex filter

A direct super critical air-cooled coal-fired units of 2×660MW in Gansu Province was put into operation in December 12, 2009. The condensate polishing system is consist of three 50%

condensation water flow powdex filters and three 50% spherical mixed-beds. Over the year of 2011, the iron content of steam and water system in both units generally exceed standard. Iron content is showed in Figure 1.

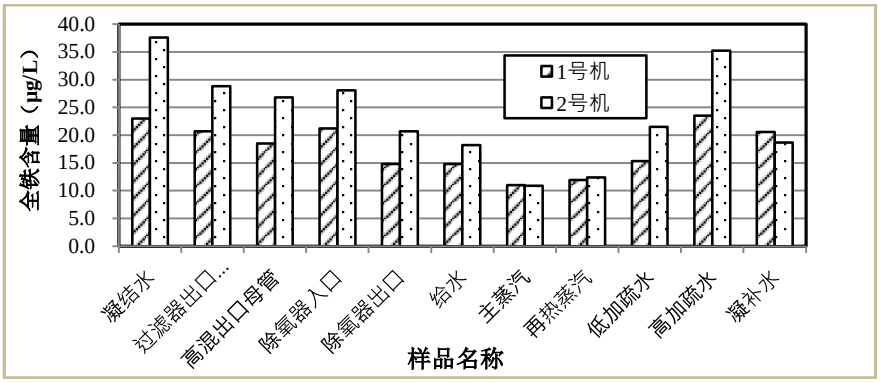


Fig.1 Determination result of iron content

After diagnosed with the two units, it was found that the main reason of exceeding was low iron removal efficiency of powdex filter. The iron removal efficiency of unit 1 and unit 2 is only 23.4% and 11.1%. There are three reasons of low iron removal efficiency, including filter elements passage blocking by corrosion products (see Figure 2), nonuniform filming and incomplete pre-coat explosion. It was detected by the testbed that the performance of powdex and fiber power is poor, resulting in filming like to be nonuniformly and high pressure between film layers after filming. The critical point of filming and pre-coat explosion process is controlled improperly, resulting nonuniform filming and incomplete pre-coat explosion.

Fig.2 Contaminated filter

图 3 After cleaning filter

According to the reason of issues, optimization is proposed as following. First, clean the polluted filter elements by Off-line Filter Elements Clean Technology (OFECT), the cleaned filter elements are showed in Figure 3. Second, apply the better performance powdex, XTW-C developed by TPRI. Third, optimize the critical parameters of filming and pre-coat explosion by the dynamic simulation testbed. With the optimized parameters and test, figure out the optimum process of filming and pre-coat explosion to ensure the best effect operationally (see filming effect in Figure 4).

Fig.4 Optimized dynamic membrane effect

Case II: Exceeding iron content in effluent water of powdex filter

In a subcritical air-cooled power plants in Xinjiang Provoince, condensate polishing system is consist of two 100% condensation water flow powdex filters (short for single powdex system). The issue of condensate polishing is that iron content in effluent water always exceeds standard (18 μg/L in maximum) and operation cycle is relatively short (2 ~ 4 days under high load).

After Unit 1 start up on June 8, 2015, TPRI traced the operation. Figure 5 is the monitored particles number of filter influent and effluent number.

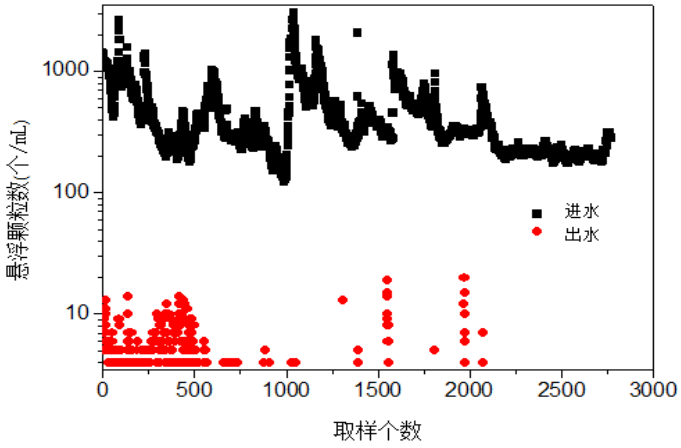


Fig. 5 Suspended particulate monitoring results in water

Figure 5 showed that the range of particle number distribution in influent water is large (120 ~ 3000/mL). The range of effluent water is relatively constant (0~20/mL), with the particle size of less than 3μm;The removal efficiency of suspended particles in Unit 1 is at least 90%. Additionally, the powdex of less than 3μm is no more than 0.5% in total, which means there is no damage, leakage of the filter elements. However, even there is no damage to the filter elements, the iron content in effluent water still exceeds standard. With further investigation, it was found the reason is that dissolved iron content is high (about 4μg/L), which is a large proportion of total iron (30%~40%). On the other hand, according to the transfer test, the iron corrosion products is mainly from air-cooled condenser. Besides, the short operation cycle is mainly resulted from large iron content of condensation water, low powdex filming and filter elements pollution.

Apply the dynamic filming test by the dynamic simulation testbed (Figure 6). Based on the present

amount of powdex for filming and filming process in this power plant, this test is helpful to observe the whole filming process. Estimate the effect of filming from by film forming effect and initial operation differential pressure. The relationship between initial differential pressure and flowrate after filming is showed in Figure 7 (before optimization). The dynamic filming effect shows the poor effect of present filming process, which means some improper setting of critical parameters in filming process.

Fig.6 Simulation tester

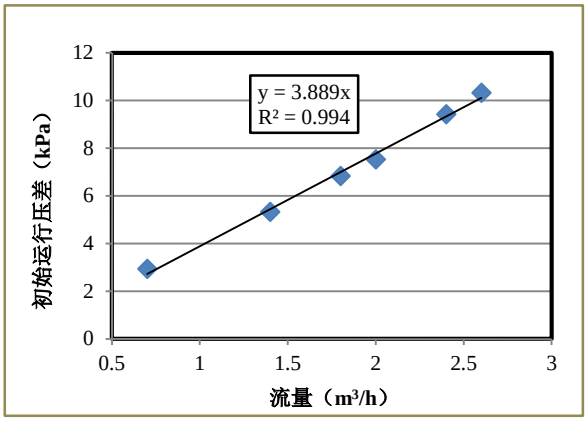


Fig.7 Membrane filtration after the initial pressure difference and flow diagram (optimization) before

Concerning about these reasons, the optimization scheme is given as the following. Increase the pH of feedwater to decrease the iron content; Modify the overflow pipe of filming auxiliary tank to ensure the filming flowrate meets the requirement; Change the type of cation resin, adjust the ratio of cation and anion resin and increase the amount of powdex for filming in order to increase the iron removal efficiency of powdex filter and cycle water production; Optimize the filming process to improve filming effect and increase the removal efficiency of suspended iron.

Case III: Powdex leakage of powdex filter

Fast increasing of hydrogen conductivity of boiler water

In a direct subcritical air-cooled units of 2×330MW in Ningxia Province, condensation water is treated by medium pressure polishing system of 100% water flow. Powdex filters of 2×100% condensation water flow are set for each polishing system, with 100% bypass system.

Since November 2013, the hydrogen conductivity of boiler water would be fast increased after several minutes operation of powdex filter, increase from 0.3~0.5μS/cm to 2.5μS/cm at serious condition. It will take three days to back to the normal hydrogen conductivity even with continuous draining. This phenomenon is resulted from the powdex leakage. Basically, there are two reasons for powdex leakage. First one is that the size of powdex is too small, which can be determined by the size distribution test. Second one is that filter elements are damaged. Usually, one or several filter elements are randomly selected out after splitting, then test the integrity and precision of filter element to estimate if it is damaged. However, this process is complicated and can’t avoid contingency, so the result is not representative.

Therefore, on-line particle counter is applied to test suspended particles of influent and effluent water and size distribution to estimate if filter elements are damaged. In this way, it is not required to open filter and take sample, which is more convenient. The result will be accurate, reliable and representative.

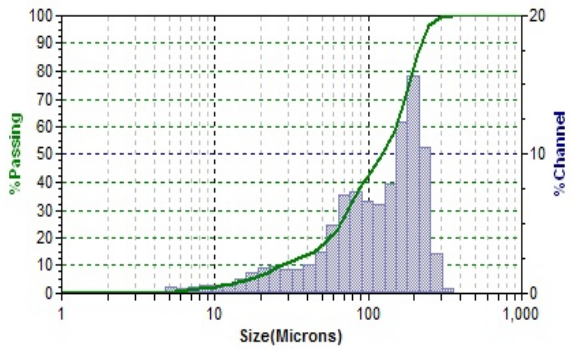


Fig.8 Suspended particulate monitoring results

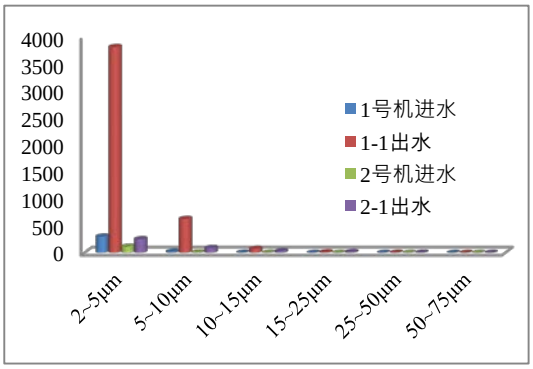


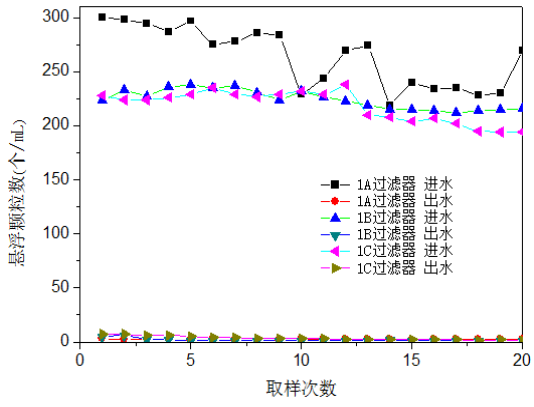
Fig.9 Suspended particulate monitoring results

From Figure 8, the minimum and maximum particle size of this powdex is 4μm and 350μm. The particle of less than 5μm is 0.4%, and particle of less than 15μm is 3.8%. Figure 9 shows, after 15 min operation of filter 1-1 and 2-1, the suspended particle of 2~5μm are increased by 11 times and 1 time compared to condensation water. Particles of 5~10μm are increased by 26 times and 9 times, and particles of 10~15μm are even increased by over 30 times.

The suspended particle size of two filters are both less than 15μm, but there are suspended particles of 15μm~50μm existing in the effluent water. Considering about the test result of size distribution (particles of less than 15μm is 3.8%), it indicates that particles of 15μm~50μm are all leaked powdex, resulted from the loose and fracture winding of filter elements.

Large increasing of suspended particles in effluent water of filter

In a direct supercritical air-cooled units of 2×660MW in Gansu Province, three medium pressure powdex filters of 50% water flow are equipped for each unit. In the normal operation of unit 1 and initial operation of filters, on-line monitoring is performed to the number and size distribution of suspended particles at the influent and effluent water sampling opening of powdex filter, as Figure 10 and 11.



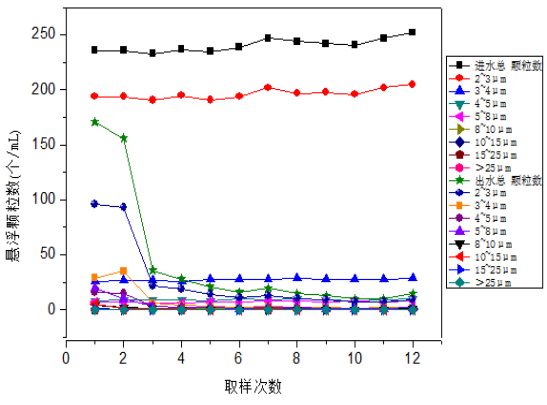


Fig.10 #1 suspended particulate monitoring results

Fig.11 1B Suspended particulate monitoring results

As Figure 10 shows, the suspended particles of influent water in 3 powdex filters are about 200~300/mL, while the suspended particles of effluent water are about less than 10/mL, giving the suspended particle removal efficiency of higher than 95%. In Figure 11, the suspended particles of 1B powdex filter at initial operation are about the same as at normal operation, while the suspended particles in total and in each size range are obviously increased, and decreased to normal level in the end, with duration of 20 min. The reason to these issues are mainly caused by poor filming process and short cycle time, resulting in incomplete filming of powdex, partial powdex leakage and large ratio of small size powdex.

Concerning about these issues, the “Intelligent on-line Monitor of Prefilter” (Smart Filter, SF, developed by TPRI) can automatically switchover among multi water passages, monitoring multi water passages by single on-line particle counter. The optimum sampling and distribution system can be designed for each specific power plant, with the communication mode or independent software system compatible to the automatic control system of power plants. SF can provide real-time monitoring to the operation status of prefitler. SF is already applied in several power plants, system scheme and real equipment are showed in Figure 12 and 13.

The basic functions of SF includes on-line monitoring of suspended particles removal efficiency, the equivalent filter precision of filter elements and the integrity of filter elements. Based on these basic functions, there are still some practical expanding functions.

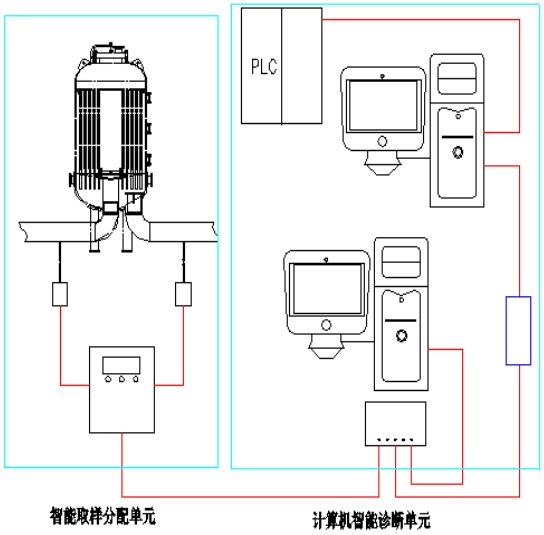


Fig.12 Smart Filter System

Fig.13 Smart Filter

Conclusion

According to the theory and characters of iron corrosion products removal, on the basis of research and field services, TPRI develop this technology from theory to practice, bringing forward the new index to represent the operation status of powdex filter in order to make up the lack of differential pressure and iron content. The intelligent estimation system developed for

estimating the operation status of powdex filter, can quickly estimate the operation status of powdex filter and diagonose the effect of filtering and filming, providing the basis for optimization. After applying the intelligent estimation system and subsequent optimization, many air-cooled power plants resolve the problems existing in powdex filters. “Intelligent On-line Monitor of Prefilter” can be the “intelligent housekeeper” of water treatment in power plants, guaranteeing the safe, effective and economic operation of condensate polishing.