Experimental Research on EFIP Technology

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Abstract: In April 2005, the first EFIP system developed by our company is successfully put into operation on Chinese 50MW coal-fired power plant, and since then, after continuous improvement and promotion, this technology is rapidly becoming one of the major dust removal technologies which meets 30mg/Nm3 even below 20mg/Nm3 emission standard for China coal-fired power plant and widely used in 300-1000MW power plants. In the application process of EFIP system, this innovative technology is increasingly matured by experiment research combined with (based on) the engineering practice and continuous technological innovation. With the global environmental protection requirements continue to increase, the EFIP dust removal technology is moving towards to the new direction of technology development of efficient removal of PM2.5, synergy removing mercury metal and its compounds and other multi-pollutant co-processing.

Keywords: EFIP PM2.5 Filter media

Introduction:

Since 2002, the EFIP system has been successively adapted to the boilers of cement plants and coal-fired power plant. As EFIP system has advantages including lower emission, reliable running and energy-saving, as soon as it's come out, it rapidly enjoyed a broadly acceptance. In a few short years, we has designed 300 sets of EFIP systems with the total processing flue gas volume up to 4.7×10^8 m^3/h, among which 180 above has been put into operation with excellent running effect. During this process, in order to stimulate the successful engineering application of EFIP system, serials of reach has been carried out in theory and engineering technology aspect.

1. EFIP Technology Principle

Featuring an electric field area and bag area installed compactly within a casing, the Electrostatic-Fabric Integrated Precipitator (short for EFIP) is new-type de-dusting equipment by combining the advantages of Bag Filter and ESP. FE-type EFIP structure shown as figure 1.

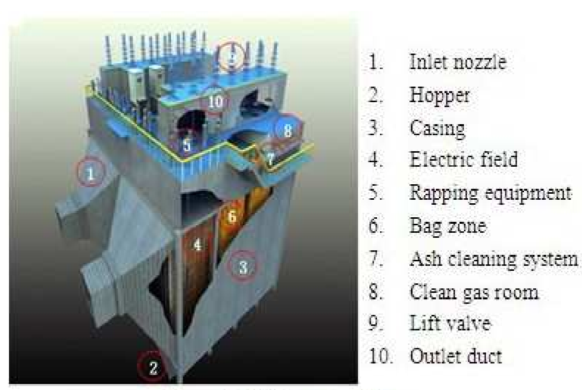


Figure 1 EFIP structure show

During operation, high velocity flue gas enters into the nozzle; it diffuses slowly into even flow streams into the electric field area via the buffering, diffusing and equalization. Under the action of HV corona, more than 80% dust particles will be collected in the electric field area, while the uncollected charged dust particles along with the airflow move into the filter bag area where it's collected by filter bags; the clean gas then passes through clean gas plenum, lift valves, outlet duct and eventual exit to realize the purifying target≤30mg/Nm^3（or≤ 20mg/Nm^3）.

EFIP system synthesizes the complex physical process and related mechanism including particles' charging, collision, diffusion, coagulation, sedimentation, filtration, polarization; coupled peeling and stripping, its inherent law and interaction still require a further profound study.

2. Research on Jet Cleaning

Fig2 Full-scale pulse jet experimental model

Currently pulse jet is the important manner of ash cleaning for filter bags as well as the main cleaning manner of EFIP system. To learn about the basic rules of pulse jet process, an full-scale pulse cleaning experiment model is built in accord with the actual filter bag length shown as fig.2. The filter bag is up to 10m in length, and the greatest line jet amount is within 18 to 35.

A set of pulse jet cleaning process measuring system is established for this experiment by adopting the pressure sensor and microcomputer control technology, figure 3 as shown; and by testing the pressure drop and acceleration distribution to find out the optimum length of filter bags and max amount of jet bags, which is to ensure the ash cleaning effect and for the practical application guidance to save cost and reduce the floor space, finally to improve the overall performance of EFIP.

2.1 Determine on Pulse Valve Jet Capacity

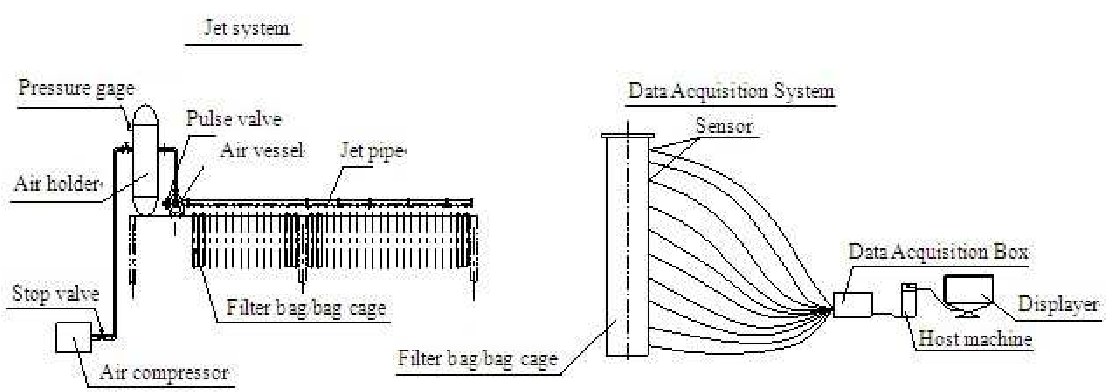


Fig 3 Jet system and data collection system

Pulse valve jet capacity is the important data for pulse jet cleaning process. Usually the pulse valve jet capacity is not only related to pulse valve specification, but also the structure of jet system. Therefore, the sampling parameters used for test is in accordance with the practical system structure.

Firstly, this experimental model can be used to test and analyze the pulse valve jet capacity under different structure and parameters, such as manufactured by different suppliers; varying length of jet pipe, different specifications of pulse valves（3＂、4＂）, different jet pressure（0.25MPa、0.3MPa、0.35MPa、0.4 MPa) and pulse width（100ms、150 ms 、200ms）; and find out the best match relationship between each parameter by test.

Taken 3 " pulse valve of factory A as example: when the pulse width is 150ms, under different jet pressure, the jet compressed air volume of pulse valve is recorded, refer to fig.1.

Fig 1 relation between jet capacity and jet pressure

Pulse pressure(Mpa)	0.25	0.3	0.35	0.4
Pulse capacity(L)	293.8	352.5	398.7	443.5

2.2 Research on Pressure Distribution during Jet

The pressure distribution on the jet pipe reflects the pressure of air jet into each filter bag along the jet pipe length, while the pressure of filter bag reflects the ash cleaning strength of air to filter bag. This paper only introduces the pressure distribution situation of jet pipe and filter bags under a certain condition.

Selected condition as follow:

3 " pulse valve of factory A; jet pressure is 0.3MPa; jet pipe length is 4571mm; eighteen jet nozzle with 250mm jet nozzle spacing, 50mm in length and 26mm diameter; correspond to 18 pcs filter bags respectively; the bag is PPS with 160mm diameter and 8m in length; an protective casing, 243mm in length, is used for bag cage.

2.2.1 Pressure Distribution on Jet Pipe

To measure the pressure distribution situation on jet pipe in jet process, 10 pressure sensor measure points is set up on jet pipe, shown as fig 4.

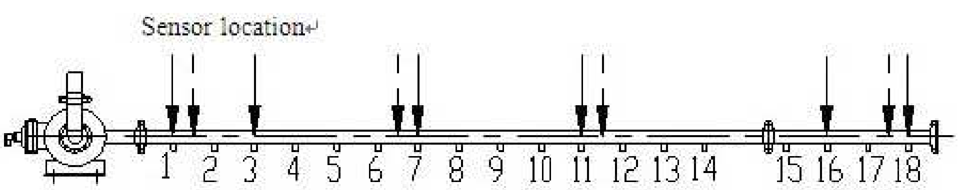
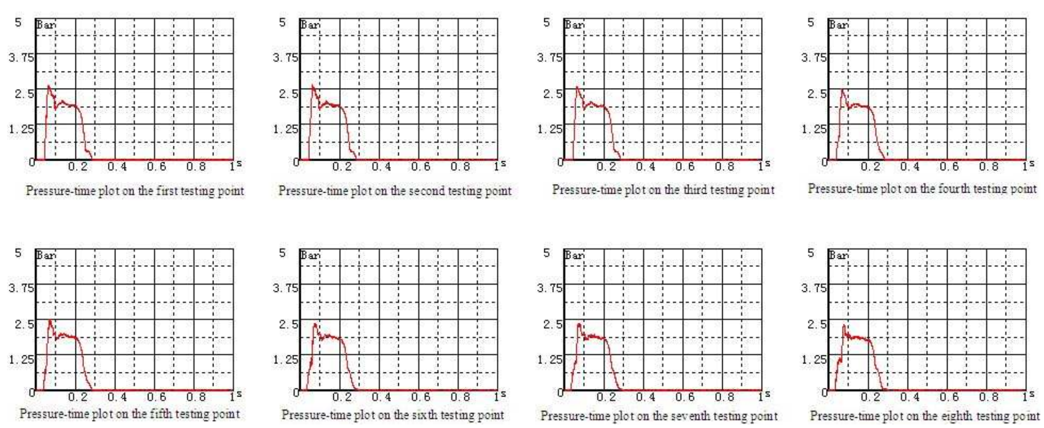


Fig4 Sketch map for the arrangement position of pressure sensor on jet pipe

Under the working condition described above, ten measure points are arranged from left to right in accord with figure 4. The experimental curves refer to figure 5.



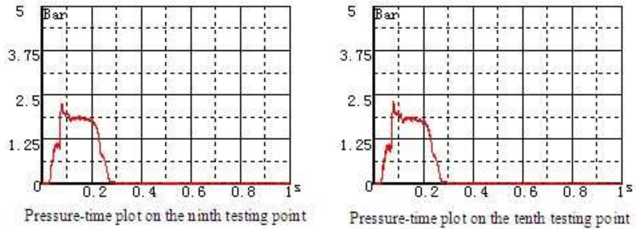


Fig5 Pressure changing curve of ten test points on jet pipe

Table2 Pressure distribution on jet pipe

Measure Point	1	2	3	4	5	6	7	8	9	10
Arrival time of pressure(ms)	28.8	30	30.4	32	32.4	36	36.6	41.2	42	42.8
Arrival time of pressure peak(ms)	75.4	76.4	75.4	71.8	71	67.2	66.4	63	62	62
Pressure peak(kPa)	232.2	228.4	236.4	239.8	237.8	252.4	249.1	259.6	263.2	264.8

The experimental results indicate that:

(1)The pressure in the jet pipe will increase gradually along the airflow direction when reaching the testing point. It can be calculated that the average velocity in the jet pipe is about 300m/s based on the distance between the first jet nozzle to 18^{th} jet nozzle as 4250mm and the duration of 14ms.

(2)The pressure in the jet pipe will decrease gradually along the airflow direction when passing each pressure testing peak point. It can be considered that the compressed air in the jet pipe reach the bottom of pipe in a way of high-speed jet and the airflow will move in the reverse direction against the airflow when the air is compressed in the bottom of pipe and expand. The kinetic energy convert to pressure energy gradually and the expanded air will go back the first jet nozzle in just 14ms.

(3)It is suggested that the pressure peak value will increase gradually from the first jet nozzle to the 18^{th} jet nozzle. The pressure peak value at the 18^{th} jet nozzle has extra 32KPa compared with the first nozzle and the deviation is just 10%.

2.2.2 Pressure Distribution on Bags

The clean bag experiment: the 18 jet nozzles is matching to 18 bags respectively and the one close to the pulse valve will be marked as the first and the following will be 2 to 18 along the airflow direction.

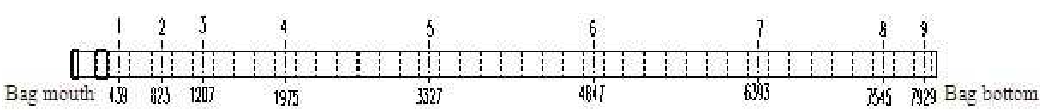
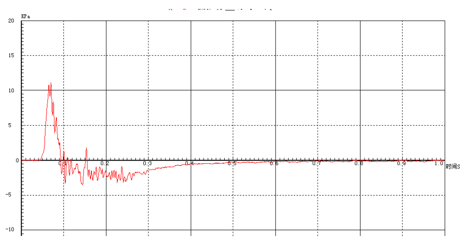


Fig 6 Distance Schematic Diagram from the Testing Point to Bag Mouth of 8m Bags

It can be concluded from the Picture7, 8, 9 that the pulse airflow can not reach the bottom of bag bottom in an instant after entering the bags and the bags are not expanded simultaneously with the airflow. The pulse airflow forms a kind of bubble in the bags and moves downward and the bags will be expanded due to the pressure of the bubble which makes the dust layer deform and fall apart by the deformation of bags. Then the dust clean aim can be achieved by this process. Picture 10 shows the different pressure value in the different positions which indicate the pressure of bag will decrease gradually in the downward movement due to the air leakage of bags. Then the bags with dust layer are chosen as object for the experiment. From the different pressure values of bag in Picture 11, it can be concluded that the deviation of pressure in the bag is quite small due to the little leaking air in the process.



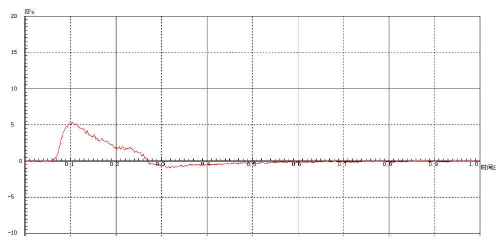


Fig7 Pressure drop changes with the time on the upper point (439 mm from the bag inlet)

Fig8 Pressure drop changes with the time on the middle point (3327 mm from the bag inlet)

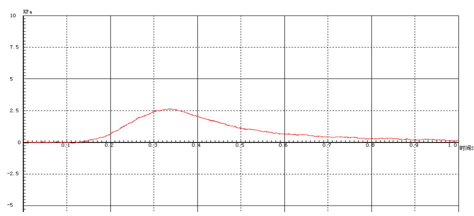
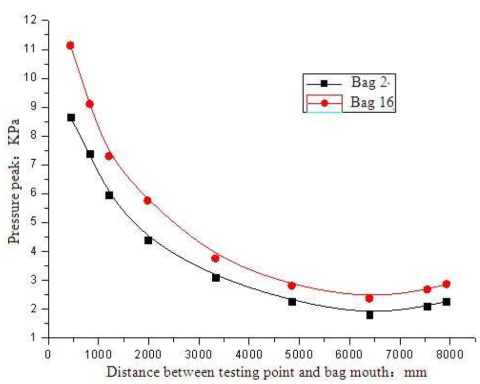


Fig9 Pressure drop changes with the time on the bottom point (7545 mm from the bag inlet)



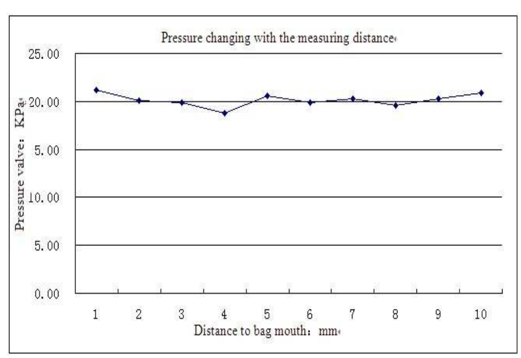


Fig10 Comparison of pressure drop distribution of no.2 and no.16 filter bags

Fig11 Pressure drop distribution map of filter bags

Picture 10 shows the different pressure drop value in the different positions which indicate the pressure of bag will decrease gradually in the downward movement due to the air leakage of bags. Then the bags with dust layer are chosen as object for the experiment. From the different pressure drop values of bag in Picture 11, it can be concluded that the deviation of pressure drop in the bag is quite small due to the little leaking air in the process.

Secondly, we also carried out the experiment on the filter bags glued with ash. Figure 11 shows the pressure drop value at the different positions of filter bags, which includes the small change of pressure drop from top to bottom as the gas volume exiting from the bags is very small.

3. Research and Development of High Strength Filter Media

The filter bags, important components of EFIP system, its filter media property will directly affect the flue gas emission concentration and equipment operation. Several main factors as follow shall be taken into account when select the filter media:

(1) Flue gas temperature;

(2)Flue gas composition (0_2、NO_X、SO_2、SO_3 content、H_2O etc) or coal composition;

(3)Chemical composition, grain composition and concentration of flue gas;

(4)Boiler type

(5)Emission requirements for flue gas

(6)Cost performance and enterprise’s economic capability

Currently the alternative filter media when handling the flue gas of coal-fired boiler is shown in table 4.

Table 3 Property of different filter media

Fiber	Abb.	Operating Temp. (□)	Hydrolysis Resistance	Acids Resistance	Alkali Resistance	Oxygen Resistance
Polyphenylene sulfide	PPS	160	Excellent	Excellent	Excellent	Ordinary
Polyimide	P84	220	Better	Better	Better	Better
Polytetrafluoroethylene	PTFE	250	Excellent	Excellent	Excellent	Excellent
fiber	Glass fiber-fi	260	Excellent	Excellent	Poor	Excellent

Jointly cooperate with relevant parties, the Gradient Filter Media research and engineering application have been carried out. The so-called Gradient Filter Media is to adopt the small diameter fiber to the dust attaining surface of filter bag while the negative side adopts coarser diameter fiber, which will not only improve the filter fineness but also reduce the filtering resistance. Besides, in recently years, the composite filter media, Eg. P84+PPS, PPS+PTFE, PTFE base fabric, have been widely used to meet the requirements of different coal type and flue gas conditions. Following are the composite filter media available for different situations.

Table 4

No	Flue Gas Temp. (□)	Oxygen level	Sulfur in Coal(%)	Filter Media		Weight	Emission Concentration mg/Nm^3	
				Fiber	Base cloth	g/m^2	＜30	＜20
1	t≤120-160	≤6%	＜1.0	PPS	PPS	550/580/600	Surface impregnation	PTFE Film
2			＜1.0	15%P84+85%PPS	PPS	580/600	Surface impregnation	
3			1~1.5	PPS	PTFE	580-600	Surface impregnation	PTFE Film
4			1.5~2.5	50%PPS+50%PTFE	PTFE	600	Cover coat	PTFE Film
5	t=170-240		1~2.5%	25%P84+75%PTFE	PTFE	650	Cover coat	PTFE Film
6	t=170-260		＞2.5%	PTFE or glass fiber	PTFE	750	Cover coat	PTFE Film

4. Research on Air-Flow Distribution Technology

In order to ensure the application of EFIP technology to projects including 300MW～1000MW power units, jointly work with Tsinghua University and Tianjin University, we has developed the airflow distribution technology of EFIP system, which is in the leading place with regard to its technology and science research.

The study found that, after equipment scaled up, the big volume of flue gas will bring about many technical problems, especially the airflow distribution of equipment scaled up. When the flue gas volume is big, the distribution of flow field, temperature field, concentration field, pressure field tends to be uneven. So it’s particularly important to ensure the even flow field and temperature field etc.

Through a great deal of foundation work, experimental research and site test, we found that, in order to ensure the uniformity of flow field, firstly to guarantee the uniformity of flue gas entering into the precipitator from each inlet nozzle, then the reasonable design of airflow distribution plate to attain even airflow distribution of electric field. The technology has already been mature in this aspect, while the key is how to make the airflow distribution even. Reach on an EFIP system found that, the max. flow deviation between chambers is up to 25%, which will aggrandize the pressure drop and lower the service life of filter bags.

To ensure the uniformity of flue gas distribution, base on the modern CFD technology, we use the large-scale computer for the 1:1 optimized design to guarantee the flue gas distribution to achieve the following targets:

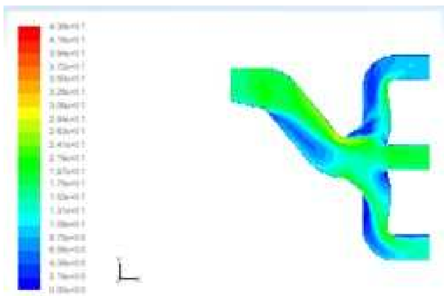
1)Flow deviation between chambers is less than 5%.

2)The flow of each filter bag is square root deviation σ <0.25.

$$\sigma = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left[\frac{v_i - \bar{v}}{\bar{v}}\right]^2}$$

Therefore, when carry out the large-scale design of EFIP, reasonably arrange the internal airflow by use of CFD simulation technology to hammer out the optimal bag layout manner and guiding device, so that the airflow uniformity of electric field, the scouring rate and ascending velocity of dust will be within an advisable range.

The best structure design of flow field has been preceded in line with test results. Dozens of EFIP airflow distribution test is completed through engineering application. Followings are the CFD simulation diagrams for the inlet duct before and after partial remolding. Based on the test results, the optimal structure is designed to ensure the flow deviation of each passage within ± 5%.



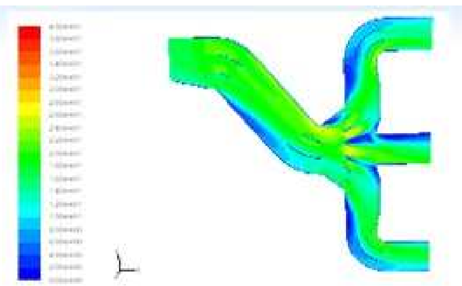


Fig12 Speed cloud picture without guide plates

Fig 13Speed cloud picture after guide plates installed

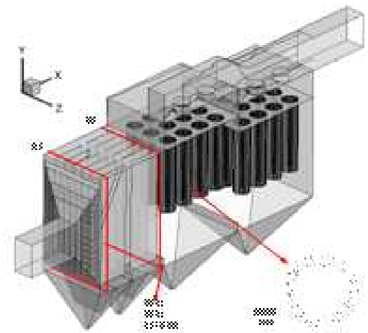
When the flow deviation of each passage is within ± 5%, proceed the airflow distribution test inner EFIP to guarantee the deviation of each chamber is within certain limits.

The EFIP airflow distribution technology has gone through three research stages; the best comprehensive performance is attained through several innovations.

Phase one: initial R&D phase, the dominant idea is to study the airflow contact and distribution between electric area and bag area, and explore the flow distribution device that guarantee the even distribution in electric area, namely equip the even flow distribution device between electric area and bag area. This research has been awarded as patented technology and had been applied to over 10 sets of EFIP project. Engineering practice shows that, this flow distribution device will greatly affect the charging effect of dust particles; most dust particles will lose the electric charge when pass through this device; and with obvious distribution diversity of pressure drop in bag area. For this purpose, we start to explore updated flow distribution technology.

Phase two: study the airflow distribution technology of filter bag. The dominant idea is to study the multidimensional intake air of filter bag to guarantee the air enter into the filter bag from lateral and bottom. The excellent distribution effect has gained through the engineering practice and test of EFIP applied to large-type units.

Phase three: joint with University to study the flow distribution technology of upsizing EFIP system for 1000mw units. Base on the 1:14 physical model test of EFIP of a 1000MW power unit, the microcomputer CFD model has established, and gain optimal upsizing airflow distribution result.



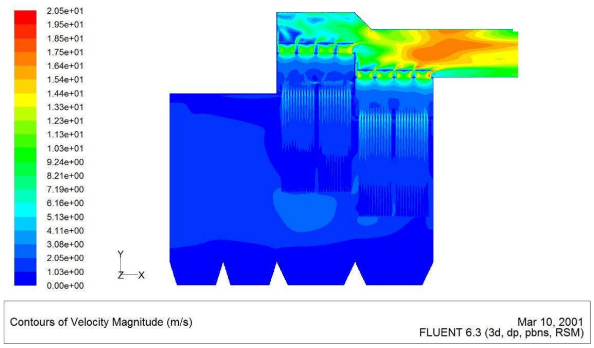


Fig14 Physical model of a 1000MW power unit; CFD model and velocity nephogram

After many years, various practice and research on the airflow distribution technology of EFIP has been completed . The EFIP projects that have been put into operation conclude that, good de-dusting efficiency and excellent charging effect in electric field area; small and even operation pressure drop in bag area, without any bag breakage or abnormal spoilage caused by the uniformity of airflow distribution. Following is upgrade project of 600MW units. The overall airflow uniformity is realized by means of CFD test, guiding on bag arrange manner, position and spacing, several guiding device settings and outlet lift valve control, as well as multiple control of many factors.

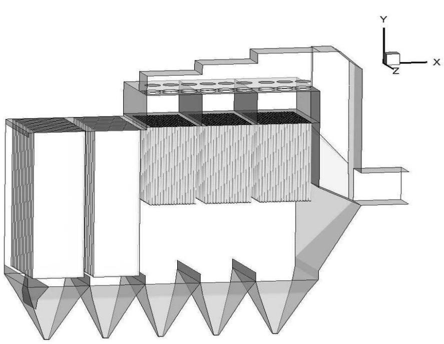


Fig 15 3d sketch for the single passage of 600MW unit

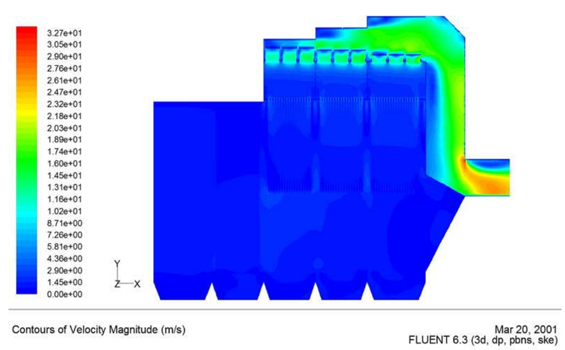


Fig16. Corresponded speed cloud

Through the CFD test and site test of EFIP for a mass of 600MW and 300MW units, we have mastered a full set of even airflow distribution technology.

5. PM2.5 Removal

As the massic volume of PM2.5 is pretty small, its single particles are hard to be collected by conventional de-dusting methods. So two type technical measures are taken in general to collect PM2.5, that is firstly make the smaller particles agglomerated into larger particles to enlarge its equivalent diameter, then collect them[2]. PM2.5 particle agglomeration technology includes electric agglomeration, acoustic agglomeration, magnetic agglomeration, phase change and condensation, turbulence agglomeration. The electric agglomeration is the most simple and effective way for the product industrialization. And the agglomeration effect of electric field in EFIP has been confirmed. According to the test results, compared with the uncharged dust particles, the dust particles after charging and agglomeration is arranged in root rules, figure 17 as shown. Therefore, as EFIP has the charging function of electric field which enable the dust particles entering into the back bag area attract together and smaller particles are agglomerated into larger particles, thus benefits the collection of PM2.5, while the conventional Bag Filter does not possess this function [2].

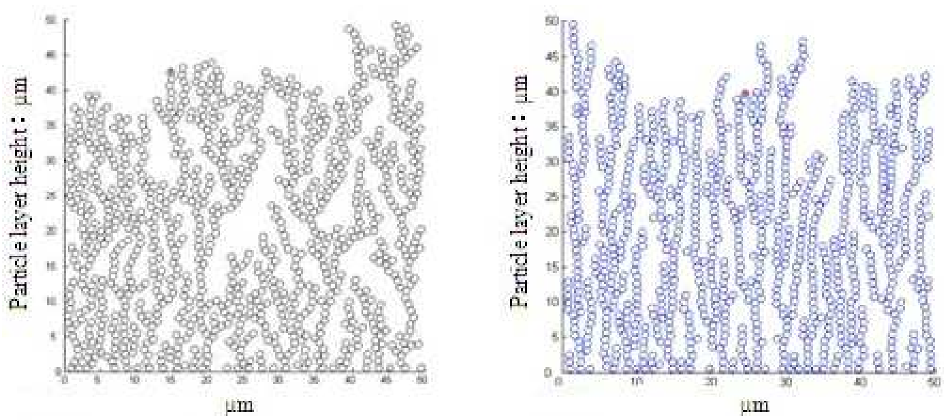


Fig17 Comparison chart for the arrangement of charged and uncharged dust particles (charged dust particles is on the right)

De-dusting equipment for PM2.5 particles comprises ESP, Bag Filter, and EFIP. Research (experimental data) carried out by some university indicates that, compared with the 13% PM2.5 in the total emission particles of filtration type de-dusting equipment, the same of ESP is as high as 40%. As the EFIP system has the electric agglomeration effect, the PM2.5 emission is much lower.

EFIP is one of the best de-dusting methods for collecting PM2.5 dust particles. Practical tests of a university show that the PM2.5 collecting efficiency of EFIP applied to 600MW units is 98.1%.

EFIP technology for PM2.5 collection possesses following peculiarities:

(1)Highly efficient electric field is furnished to strengthen the charging effect, so as to improve the electric agglomeration of PM2.5 dust particles.

(2)Choose proper filter medium to improve the filtration efficiency.

(3)Based on the advanced airflow distribution technology, guarantee the overall distribution effect of

EFIP to improve the filtration efficiency.

(4)Based on the advanced pulse cleaning technology to ensure the timing sequence of pulse to form an effect of dust particles filtrated by dust particles.

(5)Extend the ash cleaning cycle to reduce the penetration probability of fine particles.

Given all that, EFIP system has the integrated function of charging and agglomeration and highly effective de-dusting, meanwhile EFIP technology application is pretty matured, which is one of the most effective de-dusting methods for controlling the PM2.5 emission. With the development and application of coated microporous filter technology, EFIP not only possesses the collecting ability for single PM2.5 particles, but also can effectively avoid the pressure drop increasing caused by the fine particles penetrating into bag, so that the comprehensive function of PM2.5 particles collection is improved.

6. Collaborative Mercury Removal of EFIP

Among all researches on mercury removal by using existing refining plants, the most noteworthy is EFIP system which is still in research and development in the present China. Research on mercury removal by using EFIP system to realize the multi-pollutant removal is of great significance. The arrangement structure refers to figure 18.

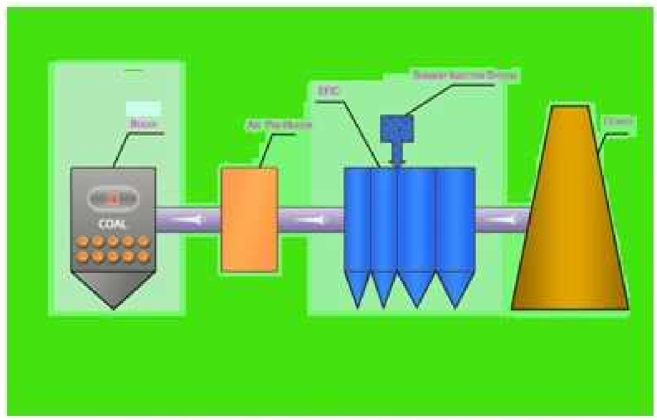


Fig 18 Multi-pollutant's collaborative treatment process of EFIP system

Currently, Activated Carbon Injection (ACI) is one of the mercury control technology widely researched. This technology is that inject the activated carbon into the flue gas at the upstream position of precipitator to absorb the mercury during its moving process; then collected with the fly ash when go through the downstream de-dusting device, to complete the mercury removal [3]. ACI technology has entered into the Industrialization demonstration stage so far. However, adopting ACI technology into the single stage flue gas de-dusting system still is put in a lot of problems. Firstly, the great activated carbon consumption leads to high operation cost; secondly, the activated carbon mixed in fly ash will affect the Fly ash utilization value. Besides, the key problem is that using common ACI technology to remove the zero-valent mercury is in low efficiency.

For this purpose, some studies also adopt the combinatorial methods for the hierarchical collection of dust and carbon to have the problems including activated carbon circulation and fly ash utilization settled; While as two sets of de-dusting system is adopted, the de-dusting process is complex and the equipment investment is too high. The EFIP system is expected to provide an opportunity for the use of ACI technology. If minor reform can be put forward in EFIP system, to a certain extent the separation of dust and carbon can be achieved, and realize the cyclic utilization of adsorbing material including activated carbon to bring new energy to the application of mercury removal technology by using activated carbon. The EFIP cooperating with the mercury removal technology now under development of Longking has the following advantages:

(1)EFIP has a higher collecting efficiency of fine dust PM2.5, as well as the impalpable mercury particles.

(2)The long ash cleaning cycle extends the action time of adsorbing material and mercury to improve the collection efficiency of mercury.

(3)The aerosol effect of charged dust and charged adsorbing material will help to the adsorption of particle mercury and elemental mercury, and improve the collection efficiency of mercury.

(4)The front electric field collects the most dust particles, few dust particles enter into the back bag area; the adsorbing materials injected is affected by dust particles slightly, which can improve the effect of adsorbing material and mercury absorbing, meanwhile reduce the injecting amount of adsorbing material.

(5)EERC has carried out the mercury removal test by using EFIP system with mercury removal efficiency up to 90% above.

Conclusion

EFIP technology has become a new technology in recent years. In order to promote this technology and meet environmental protection of coal-fired power plant, we has developed EFIP technology including cleaning process research; R&D of strong filter material; R&D of air distribution; PM2.5 dust collecting; heavy metal mercury coordination treatment etc. Those researches have brought many important achievements, which not only enrich the EFIP technology theory but also solve many urgent engineering problems. Along with the further advance of research work, we believe, EFIP technology will be highly improved by efforts of all the R&D crew.

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