Research on technical route of flue gas ultra-low emission for coal-fired power plant

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Abstract To meet the requirement of flue gas ultra-low emission in Chinese coal-fired power plants, Two different technical routes basing on low-low temperature ESP technology and WESP technology are utilized. This paper investigated the cooperative removal effect on other pollutants when denitration, dust removal and desulphurization equipments respectively treating NO_x, dust and SO_2. Basing on the research, co-governance technical route which meets the demand of flue gas ultra-low emission in coal-fired power plants was put forward. About the technical route of ultra-low emission, a brief analysis on the main function of key equipment, simultaneous removal effect to pollutants, applicable condition, engineering application and so on was made, and some noteworthy problems and suggestions are provided. This paper could provide some references for flue gas treatment in coal-fired power plant.

Keywords: coal-fired power plant, ultra-low emission, flue gas co-governance, technical route, low-low temperature ESP technology, WESP technology

1. Introduction

Fossil-fuel Power Plant Atmospheric Pollutant Emission Standard (GB13223-2011) further reduced the emission limits of air pollutants in coal-fired power plants . Due to the limited environmental capacity, etc, Jiangsu province, Zhejiang province, Shanxi province, Guangzhou city et. al. have issued relevant policies which request that the emission concentration of dust, SO_2 and NO_X in coal-fired power plants should not be higher than 5 mg/m^3, 35 mg/m^3 and 50 mg/m^3 respectively, under the condition of 6% reference oxygen content. China's National Development and Reform Commission, Ministry of Environmental Protection and National Energy Administration jointly issued *Action plan of upgrading and transformation of energy conservation and emission reduction for coal power (2014-2020)* in September 2014, which claims that the emission concentration of dust, SO_2 and NO_X is not higher than 10 mg/m^3, 35 mg/m^3 and 50 mg/m^3 respectively, under the condition of 6% reference oxygen content for newly-built coal-fired units in eastern region. Meanwhile, it makes demands on the units in central and western regions as well as the active units. On December 11, 2015, Ministry of Environmental Protection, National Development and Reform Commission and National Energy Administration jointly issued *Work program of full implementation of ultra-low emission and energy saving transformation in coal-fired power plants*, pointing out that all of China's coal-fired power plants where modification conditions permit strive to achieve ultra-low emissions by 2020, which means the emission concentration of dust, SO_2 and NO_X should be not higher than 10 mg/m^3, 35 mg/m^3 and 50 mg/m^3 respectively under the condition of 6% reference oxygen content. The newly-built units where conditions permit reach ultra-low emission level. The work program also calls for accelerated ultra-low emission transformation of active units, basically accomplishing ultra-low emission transformation in eastern region before 2017, which was determined to be completed before 2020, expanding the requirement for eastern region to the whole country where conditions permit. The tasks should be respectively accomplished before 2018 and 2020 in central and western regions.

The emission of coal-fired units above is called ultra-low emission in the industry. Considering the increasingly serious situation of air pollution and the present situation that 80% dedusting equipments in coal-fired power plants are ESP in China, studying from developed countries' advanced experience, flue gas co-governance routes with low-low temperature ESP technology and WESP technology as core tasks could be used to achieve ultra-low emission.

2. Flue gas co-governance route with low-low temperature ESP technology as core task

It is worth to note that during the implementation process of existing flue gas treatment technical route in China's coal-fired power plants, one equipment treats one pollutant, not taking full account of synergistic effect of the equipments. When achieving the same efficiency, the system is relatively complicated and needs larger investment and operation costs. And in present actual conditions, regular dedusting equipments are difficult to achieve ultra-low emission.

Flue gas co-governance route with low-low temperature ESP technology as core task is based on taking full account of the performance of existing flue gas pollutants removal equipments in coal-fired power plants or getting proper upgrading and transformation, and is established with the idea of co-governance. The technical route concretely manifests as the overall consideration of synergic relationship among denitration, dust removal and desulfurization systems, in which every system could help remove other pollutants or create removal conditions for other systems when the system is removing its main pollutant.

nFlue gas co-governance route with low-low temperature ESP technology as core task is shown as follows: SCR→WHR→low-low temperature ESP→WFGD→WESP (optional)→FGR (optional), as shown in figure 1.

When dust emission limit is 5 mg/m^3 and WESP is not set, the export dust concentration of low-low temperature ESP should be less than 20mg/m^3, and dust collection efficiency of WFGD should not less than 70%.

When dust emission limit is 10 mg/m^3 and WESP is not set, the export dust concentration of low-low temperature ESP should be less than 30 mg/m^3, and dust collection efficiency of WFGD should not less than 70%.

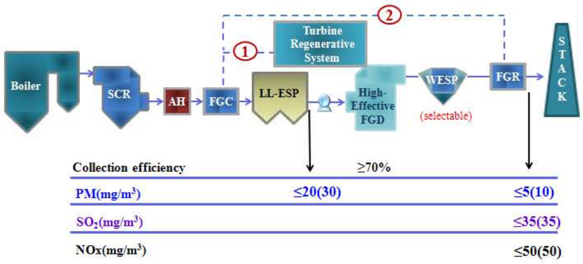

Figure 1. roadmap of flue gas co-governance route with low-low temperature ESP technology as core task

Note: If FGR is not set, heat exchange capacity in WHR should be recycled to turbine regenerative system according to route 1. Otherwise, heat exchange capacity should be recycled according to route 2.

2.1. Main functions of key equipments

1) Selective catalytic reduction (SCR)

The main function of SCR is to remove NO_X. With the addition of efficient mercury oxidation catalyst in denitration system, the oxidation efficiency of elemental mercury will be increased, contributing to the mercury removal in dust removal and desulfurization equipments.

2) Waste heat recoverer (WHR)

The main function of WHR is to lower the flue gas temperature below the acid dew point, which is generally about 90°C. In this case, the majority of SO_3 is coagulated during the temperature-fall period of flue gas. With flue gas has not entered ESP, so the dust concentration is high and the specific surface area is large, the condensational SO_3 can be adsorbed sufficiently. Low-temperature corrosion phenomena will not occur in the equipments downstream, at the same time waste heat is utilized and clean flue gas before stack is heated.

3) Low-low temperature ESP

Its main function is to realize the efficient removal of dust and collaborative removal of SO_3 at the same time. The temperature of flue gas reduced to less than acid dew point when flue gas passes WHR, then SO_3 condensates into sulfuric acid mist and will be adsorbed on dusty surface, making dust properties change a lot, not only reducing dust specific resistivity, but also improving the breakdown voltage and reducing the flue gas flow, thus improving the dust removal efficiency. Its SO_3 removal rate is generally not less than 80% and could reach a maximum of 95%. Additionally, the export dust particle size of low-low temperature ESP will increase, significantly improving the cooperative dust removal effect of WFGD.

Currently issues talked about most on low-low temperature ESP are the problems such as low temperature corrosion, dust reentrainment and so on.

D/S ratio, the ratio of dust concentration (mg/m^3) and SO_3 concentration (mg/m^3), is the evaluation criterion to judge whether corrosion will occur in the equipment or not. D/S ratio of low-low temperature ESP which Mitsubishi Heavy Industries practically adopted is generally larger than 100. There is no corrosion problem in the low-low temperature ESP delivered by Mitsubishi Heavy Industries in coal-fired power plants. America Southern Company also evaluates corrosion degree by D/S ratio. Study shows that when the sulfur content is 2.5%, corrosion can be avoided if D/S ratio is 50~100. Based on the comprehensive analysis of D/S ratio of low-low temperature ESP in coal-fired power plants abroad, and the calculation of D/S ratio of six different power plants and six kinds of typical coal in China, generally, there is no low temperature corrosion risk when D/S ratio is greater than 100, and the adaptability of low-low temperature ESP to Chinese coal is satisfactory.

The lower flue gas temperature is, the lower dust resistivity and electrostatic adhesions between dusts and anode plates it has, the more serious dust reentrainment it will happen, so applicable measures should be taken. Appropriately increasing the capacity of ESP and adopting the rotating electrode electrostatic precipitation or offline vibration technology are the main measures. While one of these two methods above is taken, reasonable vibration cycle should be set. If there is no back corona at the last electric field, vibration is needless. When dust thickness reaches 1mm~2mm, vibration begins, the frequency normally is 1 time per 2 days. Speed of vibrating motor should be adjusted. For example, speed of vibrating motor at the last electric field is adjusted from 60 spr to 247 spr. Reasonable vibration system should also be made. Vibration of chambers at the last electric field should not be carried out at the same time, as well as the vibration at the last two electric fields and the vibration of collection plate and discharge electrode at the last electric field. Meanwhile, other aiding methods could be taken, channel plate can be installed in outlet header, for re-collecting part of the dusts.

4) Wet flue gas desulfurization device (WFGD)

The principal function of WFGD is to effectively remove SO_2, as well as the dust and SO_3. The collaborative dust removal efficiency can reach above 70%.

WFGD takes a series of measures to improve the desulfurization efficiency, such as adopting single-tower or modular partition absorption technology, changing the balance conditions of gas-liquid mass transfer, and optimizing serosity pH value, serosity atomizing particle size, calcium sulfur ratio, liquid gas ratio, and optimizing the flue gas flow field in the tower, improving the spray layer design and demister performance.

The droplets at WFGD export contain solid particles like gypsum. Some measures as follow were conducted to achieve ultra-low emission of particles and improve the cooperative dust removal efficiency.

a) Better air flow distribution;
b) Appropriate velocity for absorption tower;
c) Optimizing the design of the spray layer;
d) Using high-performance demister, the export droplet concentration of demister is designed between 20 mg/m^3 and 40 mg/m^3;
e) Appropriate liquid gas ratio.

Gypsum slurry is suspension slurry. Research shows that, in gypsum slurry, the weight of particles with a diameter under 26.5 µm accounts for less than 37.57% of the total weight, and the limit size of weir-type demister is about 22 µm ~ 24 µm, so the droplets which surpass the limit size are captured by the demister. In general, the solid-containing content of gypsum slurry in absorption tower is 20%, if the particles in small particle size section are equally distributed, which means the particles at small particle size section in big and small droplets are equal in concentration. Small droplet passing the demister can only contain gypsum particle at small particle size section, so the theoretical value of solid-containing content of droplets passing the demister should be 20% × 37.35% = 37.35%, not the solid -containing content of gypsum in tower which is accepted in the industry. When the demister manufacturer can guarantee the concentration of desulfurization outlet droplet is less than 75 mg/m^3, 40 mg/m^3, 20 mg/m^3, the contribution of droplets to dust is only 5.6 mg/m^3, 3mg/m3 and 1.5 mg/m^3, respectively.

5) WESP

WESP can effectively capture the pollutants which other flue gas treatment equipments can not acquire high removal efficiency, such as $PM_{2.5}$, etc. WESP eliminates the 'gypsum rain', achieving a extremely low emission limit which is hard for other pollution control equipments to reach, for example, the particulate matter emission value is less than or equal to 3 mg/m^3. In general, the SO_3 removal rate can reach about 60%. WESP is optional according to the requirement of the pollutant emission concentration at stack outlet in special project.

6) Flue gas reheater (FGR)

The main function is to heat the wet flue gas from 50°C to 80°C, improving the operating condition of stack, at the same time, avoiding white smoke occurring in stack and raising the diffusivity of effluent pollutants. FGR is optional according to environmental impact assessment statements or economic comparison in special project.

2.2. Cooperative removal effect among typical pollutants treatment technologies

While denitration, dust removal and desulphurization equipments treats their own pollutants respectively, they have cooperativly removal effect on other pollutants. The typical cooperative removal effect among the pollutant treating technologies is as shown in table 1.

2.3. Application condition

1) D/S ratio > 100;

2) The type of coal contains medium or low sulphur content and low ash content, and the type of coal has high burning stability.

2.4. Engineering application situation at home and abroad

1) Engineering application abroad

Flue gas co-governance route with low-low temperature ESP technology as core task in Japan, has an applied history of nearly 20 years. Over 20 power plants take advantage of this technology, with a total installed capacity of 15 000 MW. The typical engineering cases are as shown in table 2. Generally, Japan's dust concentration design value of low-low temperature ESP outlet is 30 mg/m^3, but the actual operation value is lower than this. In addition, the comprehensive dust removal effect of WFGD is up to 70% ~ 90%, and dust emission value is generally less than 5 mg/m^3.

2) Engineering application in China

From 2009, China's environmental protection enterprises began to strengthen research of low-low temperature ESP technology. According to incomplete statistics, environmental protection enterprises have signed low-low temperature ESP with a total installed capacity of 50 000 MW by April 2015, and there is an operation performance of unit with an installed capacity of 1000 MW.

The newly-built project, 2 × 660 MW unit in Huaneng Changxing power plant, adopts the following process route: denitration + WHR + low-low temperature ESP + WFGD. Each furnace is assorted with 2 double-chamber and five-electric-field ESP, with a design flue gas temperature of 90°C and a design value of the outlet dust concentration of 15 mg/m^3. The outlet dust concentration is required to be below 5 mg/m^3 after WFGD. ESP has been utilized in the middle of December 2014. During December 16 to 18, Zhejiang province environmental monitoring center conduct a test, With result showing that, under full load working condition the emission value of dust, SO_2 and NO_X of unit 1 is 3.64 mg/m^3, 2.91 mg/m^3 and 13.6 mg/m^3, respectively, while the emission value of unit 2 is 3.32 mg/m^3, 5.91 mg/m^3 and 15.8 mg/m^3. ESP outlet dust concentration of unit 1 is about 12 mg/m^3, and the cooperative dust removal efficiency of WFGD is about 70%.

Table 1. Typical cooperative removal effect among the pollutant treating technologies

pollutants	denitration	WHR	low-low temperature ESP	WFGD	WESP
PM	o	▲	√	●	√
SO_2	o	o	o	√	o
SO_3	★	▲	√	●	√
NO_x	√	o	o	●	o
Hg	▲	▲	●	●	●

note：√- Direct effect，●- Direct cooperative effect，▲- Indirect cooperative effect，**o**- No effect essentially or no effect，★- Reaction。

Table 2. Application situation of low-low temperature ESP in Japanese typical power plants

power plants	Tokyo electric power company Hirono plant ＃5 unit	Nippon Steel Kashima Plant	Tachibanawan Thermal Power Station #2 unit	Binan Plant #4, #5 unit
manufacturers	Mitsubishi Heavy Industries	Ishikawajima-Harima	EPDC	Japan Hitachi
unit capacity	600 MW	507 MW	1050 MW	1000 MW
inlet flue gas temperature of low-low temperature ESP	~ 90°C	93°C	designevalue：90°C measured value：96°C	designevalue：80°C～90°C
outlet flue gas concentration of low-low temperature ESP	design value：30 mg/m^3 measured value：16.4 mg/m^3	design value：30 mg/m^3 measured value：15 mg/m^3	design value：24 mg/m^3 measured value：3.7 mg/m^3	measured value：＜30 mg/m^3
outlet dust concentration of WFGD	design value：5 mg/m^3 measured value：3.4 mg/m^3	design value：5 mg/m^3 measured value：2 mg/m^3	measured value：1.0 mg/m^3	measured value：3.0 ~ 5.0 mg/m^3
dust removal efficiency of WFGD	measured value：79.27%	measured value：86.67%	measured value：72.97%	measured value：83.33% ~ 90%
commissioning time	July 2004	2007	December 2000	2001, 2002

3. Flue gas co-governance route with WESP technology as core task

The main function of WESP is to further realize the cleaning treatment of flue gas pollutants, including $PM_{2.5}$ and SO_3, etc. It is mainly used for solving the problem of dust emissions after desulfurization towers. As an equipment using microprocessing technique to treat and control combined pollutants of flue gas in coal-fired power plants, WESP is usually applied in combination with precipitator and WFGD, and it is not limited by the coal and can be applied to newly-built project and modification project.

When the contaminants need to achieve ultra-low emissions in coal-fired power plants, flue gas co-governance route with WESP technology as core task can be used, as shown in figure 2. When using low-low temperature ESP, the main function of the key equipments, synergistic removal between the typical technologies of pollutants, and so on, which is the same to "Flue gas co-governance route with low-low temperature ESP technology as core task".

When the dust emission limit is below 5 mg/m^3, the concentration of inlet dust of WESP should be less than 20 mg/m^3. To reduce the investment of pre-stage pollution control equipments, and considering the dust removal efficiency which WESP can reach, the capacity of WESP could be increased appropriately, and the concentration of inlet dust can be extended to 30 mg/m^3.

When the dust emission limit is below 10 mg/m^3, the concentration of inlet dust of WESP should be less than 30 mg/m^3. To reduce the investment in pre-stage pollution control equipments, and consider about the dust removal efficiency which WESP can reach, the capacity of WESP could be increased appropriately, and the concentration of inlet dust can be extended to 60 mg/m^3.

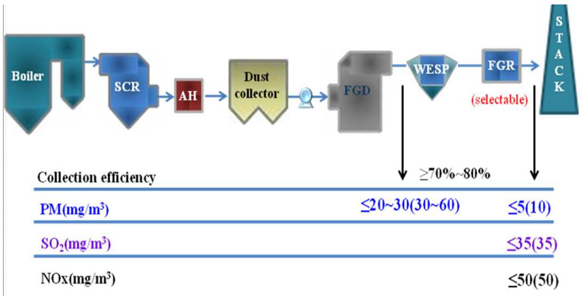

Figure 2. flue gas co-governance route with WESP technology as core task

3.1. Working principle and technical features

WESP dust removal principle is the same with dry ESP, the difference is that WESP uses water to flush the dust on electrode surface.

Technical features of WESP are as follows:

1) It can provide corona power several times than dry electrostatic precipitator;

2) It is not affected by dust resistivity, and it can effectively capture pollutants of which other fume treatment equipments have a lower working efficiency (such as $PM_{2.5}$);

3) It can trap the pollutants of WFGD, and eliminate the gypsum rain;

It can achieve a very low dust emission limit that other dust removal equipments are difficult to achieve. (Such as < 3 mg/m^3).

3.2. Application condition

1) The inlet flue gas of WESP should be saturated wet flue gas;

2) For new project, when the concentration of dust emission limit is below 5 mg/m^3;

3) For improvement project, when the modification of wet desulphurization equipments and dust removal equipments are difficult or expensive，dust emission can not meet the standard demand，especially when dust emission limit is 10 mg/m^3 or lower, and spaces were allowed.

4) When boilers use middle or high-sulphur coal.

3.3. Engineering application situation at home and abroad

In America and Japan, WESP technology has been applied in power plants for nearly 30 years, dozens of WESP have been utilized in large-scale coal-fired power plants. 2 sets of 1000 MW units and 3 sets of 700 MW units in Binan power plant all adopte WESP, which are still in good condition, and dust emission has kept in the range of 2 mg/m^3 ~ 5 mg/m^3 for a long time. If the coal quality is good, the minimum concentration of dust emission can reach 1 mg/m^3, and it never found any problem in shell and internal parts during 20-year operation.

According to incomplete statistics, China's WESP contract orders have exceeded far than the total number of other countries' WESP which has been put into operation. By the end of May 2015, there are about 200 contracts, with the total installed capacity is about 120 000 MW, and there are about 50 sets which have been put into operation, in which includes 1000 MW units, and the metal plate WESP accounts is about 50% among them.

In the new project No.4 unit of Shenhua Guohua Zhoushan power plant (350 MW), which has been tested by the Zhejiang Provincial Environmental Monitoring Center in June 2014, the emission concentration of PM, SO_2 and NO_X is 2.55 mg/m^3, 2.86 mg/m^3, 20.5 mg/m^3, respectively; The improvement project No.9 unit of Guangzhou HengYun thermal power plant (330 MW), which has been tested by the Guangzhou Jianyan environmental monitoring co., LTD in July 2014, of which the emission concentration of PM, SO_2 and NO_X is 1.94 mg/m^3, 4 mg/m^3, 25 mg/m^3, respectively; The improvement project No.2 unit of Shanghai Caojing power plant (1000 MW), which has been tested by the third party in July 2014, the emission concentration of PM, SO_2 and NO_X is 1.45 mg/m^3, 13.9 mg/m^3, 21.6 mg/m^3, respectively. Among which No.4 unit of Shenhua Guohua Zhoushan power plant has passed stability assessment by Ministry of Environmental Protection of PRC.

4. Noteworthy problem and suggestion of ultra-low emission technology

1) Local conditions, coal condition and furnace condition, should be taken into consideration when utilizing ultra-low emission technology and then take appropriate measures, if it is necessary, we can take measure of „a strategy corresponding to the boiler", at the same time, we should also take the synergies which are between every equipment into consideration.

2) Now there are many WESP technologies in China, while technology levels of enterprises which participate in the competition are uneven, each technology has its

own advantages and disadvantages, which one can running stablely for a long time, have high efficiency, and become the mainstream technology?

3) Ultra-low emission technique route has applied for less than three years in China, unit operation time is short, workers lack of experience on operation and maintenance, and whether the unit could running stablely for a long time needs to be tested. We should consider in combination with the practical situation of Chinese coal plants, and continue tracking, analysising, evaluating and making improvement.

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