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DESIGNATION AND SIMULATION OF EQUIPMENT INTEGRATED PM2.5 AND MERCURY REMOVAL

[1]XIAOWEN HAO, [2]WEILONG ZHAO AND [3]YI'E ZHAO

[1] School of Automotive Engineering, Harbin Institute of Technology at Weihai, 2 Wenhuaxi Road, Weihai, 264209, P. R. China

[2] Zhucheng Advanced Technical School, Peaceful North Street, Zhucheng, 262200, P. R. China

E-mail: haoxiaowen@sohu.com

ABSTRACT

PM2.5 and Mercury in the atmosphere is mainly from the coal-fired power plants. But the PM2.5 and Mercury removal efficiency for most of the power plants is not high enough to satisfy the newest national standard. A new technology named Equipment Integrated PM2.5 and Mercury Removal with low investment and high removal efficiency is developed and simulated. The equipment comprises bag filter to control PM2.5 in upstream of the flue gas and AC absorber to absorb mercury in downstream. We optimized the flow in the equipment. For the outer filtering bags and inner filtering bags in bag filter, the uniformity of flow is got with guide plates. The resistance is lower with guide plates than without them. Flow in the AC absorber is uniform along the height from simulation. So it can equally absorb mercury. One AC absorber can operate for many days and can be replaced easily for regeneration. So the equipment suits the request of the PM2.5 and mercury removal and has better foreground.

Keywords: *Integrated PM2.5 And Mercury Removal, Bag Filter, Activated Carbon (AC) Absorber, Uniformity, Outer Or Inner Filtering Bag*

1. INTRODUCTION

Mercury (Hg) has the character of persistence, migratory aptitude, highly biological accumulation and strong toxicity in the atmosphere. One of the main sources of Hg emission is artificial [1]. And the amount of Hg from coal combustion account for about 40% of the artificial Hg emission. Hg in the flue gas from coal combustion has three states: divalent mercury (Hg^{2+}), elemental mercury (Hg^0), and particulate mercury (Hg (p)). The pollutants control technologies can reduce the Hg^{2+} and Hg (p) concentration in certain extent [2,3]. But these technologies have little effect on Hg^0.

A new Emission Standard of Air Pollutants for Thermal Power Plants of P. R. China was unveiled in 2011 [4]. The emission standard for particle concentration is reduced from 50mg/Nm^3 to 30mg/Nm^3. Only bag filter and electrostatic bag filter can satisfy the new standard in the long time running by capturing PM2.5. The emission standard for Hg concentration is firstly put forward to be 0.03 mg/Nm^3. The thermal power plants have to remove the PM2.5 and Hg, especially Hg^0, from the flue gas with additional technology except the pollutants control technologies in use.

The activated carbon (AC) can strongly adsorb Hg^{2+}, especially Hg^0, and there are two AC technologies: the AC injection (ACI) technology and the activated carbon filter (ACF) technology. The ACI is used in power plants [5,6]. This technology with particle control equipment can remove Hg^{2+}, Hg^0 and Hg (p) besides particle. This technology injects AC into the boiler tail flue. There are two injection ways. The first way injects AC into the flue gas upstream of the particle control equipment [7]. But for this injection way, the collected particle includes most of fly ash and a few AC. Separation of the AC from fly ash is hard. So the AC is abandoned and cannot be regenerated. The operation cost of this way is very high. The other way injects AC into the flue gas downstream of the particle control equipment [8]. But an additional particle control equipment must be installed in order to collect the AC. The AC can be regenerated. But the additional particle control equipment brings more investment and more system resistance. Meanwhile the distribution of AC in the cross section of the tail flue is non-uniform. The

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ACF can be used to make bags remove Hg [9]. But the AC of ACF saturates quickly. Changing the ACF will be frequent and need much investment. So the new AC removing technology with low resistance and investment fitting power plants are imperative.

Equipment Integrated PM2.5 and Mercury Removal is put forward. It comprises bag filter and AC absorber in the unified equipment. Bag filter firstly removes almost all of the fly ash (including PM2.5) and Hg (p). Then the AC absorbs Hg^{2+}, Hg^0 and other gas pollutions. The AC is fixed in absorber. Additional particle control equipment is not needed. The AC can be replaced from the absorber when the Hg concentration at the absorber outlet is beyond the national standard. So the AC can be regenerated for several times. The investment of the absorber is lower than the ACI and ACF. The absorber resistance is low without additional particle control equipment.

The design of the Equipment Integrated PM2.5 and Mercury Removal is firstly proceed. Then the flow field in the equipment is simulated and optimized.

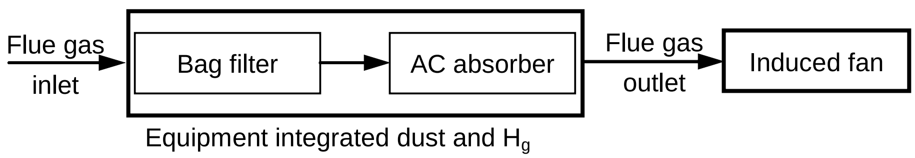
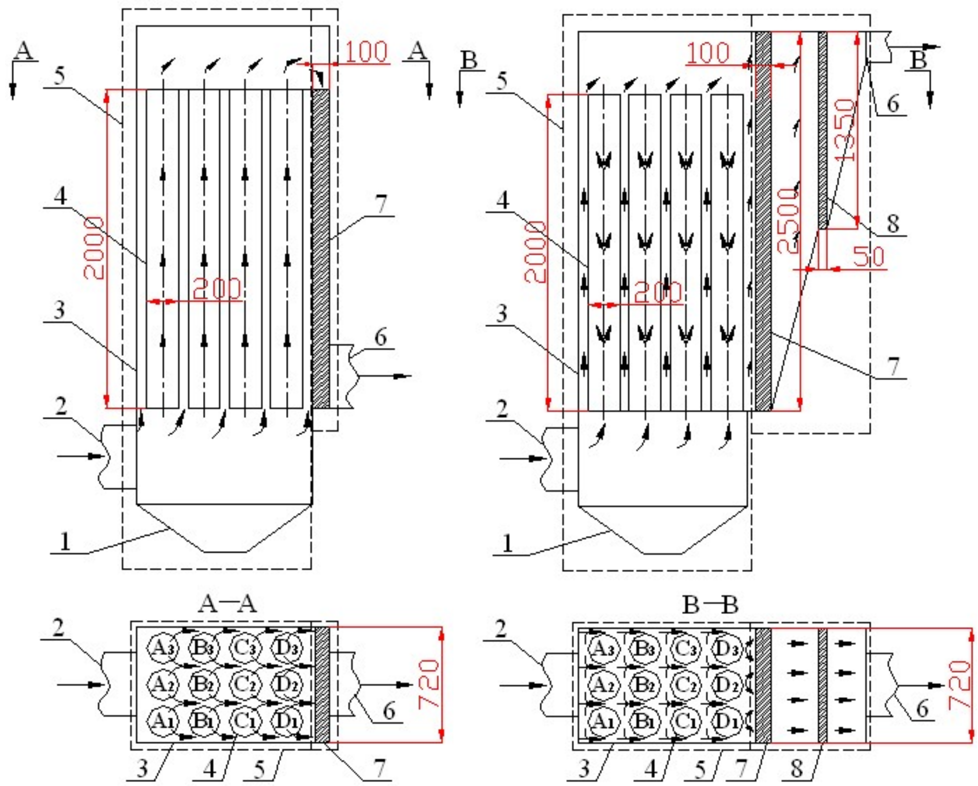


Figure 1. Flow chart of the equipment.



(A) Bag Filter With Outer Filtering (B) Bag Filter With Inner Filtering

Figure 2. System Of Equipment Integrated PM2.5 And Mercury Removal.(1. Ash Bunker, 2. Flue Gas Inlet, 3. Cabinet, 4. Filter Bags, 5. Bag Filter, 6. Flue Gas Outlet, 7. AC Absorber Ⅰ, 8. AC Absorber Ⅱ).

2. EQUIPMENT SETUP

Flue gas flux of a coal-fired boiler is set as 500 Nm^3/h, whose temperature in the tail flue is 120 ℃. Along the gas flowing direction, the former part of the equipment is bag filter, and the latter part is AC absorber (Fig. 1). The bags from the gas inlet to the outlet number A1-A3, B1-B3, C1-C3, and D1-D3.

Cylindrical bags are made by PPS in the bag filter. The bags' diameter and height are 200 mm and

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2000 mm, respectively. The bag filter is divided into two types: outer filtering bags with pulse-jet cleaning technology and inner filtering bags with reverse gas blowing cleaning technology. Their filtration velocity is set as 0.83 m/min, the deduced filter bags number is 12.

The spherical AC is selected. Its bulk density ρ_p is 580 kg/m^3, its porosity Φ is 0.595, its void fraction ε is 0.359, its mean diameter D_p is 20 mm, respectively [10]. The saturated adsorption capacity of the AC is set as 306.55μg/g [11].

It can be seen from Fig. 2a that the AC absorber corresponding to outer filtering type is design as a fixed bed with size of 720×100×2000 mm^3. The absorption from inlet to outlet of the fixed bed often comprises three regions: saturation region, mass transfer region and unsaturation region. But the uniform absorption is supposed during calculation. The absorption efficiency is set as 75%. The H_g emission standard is 0.03 mg/Nm^3, and the flue gas flux is 500 Nm^3/h. So the calculated replacement cycle is of 24 days. The saturated AC will be released and fresh AC is injected into the fixed bed.

The AC absorber corresponding to inner filtering is enclosed by filter screen, whose diameter is 1 mm. The AC is put into the filter screen. Gas flow through the inner filtering bags is not uniform. So it can be seen from Fig. 2b that two AC absorbers are installed. The size of AC absorbers is 720×100×2500 mm^3 and 720×50×1350 mm^3, respectively. The calculated replacement cycle is of 38 days. The filter screen with saturated AC will be replaced by new filter screen with fresh AC.

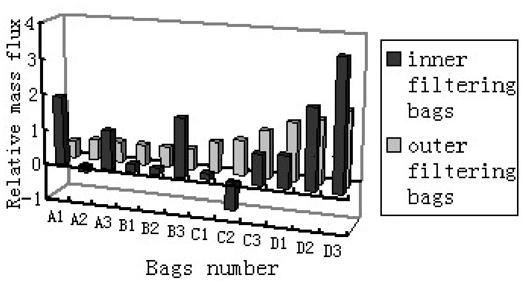

Figure. 3. Relative gas mass flux in each bag without guide plates.

3. SIMULATION SETUP

The inlet was set as velocity-inlet and the outlet was of pressure-outlet. The Standard k-ε model and discrete particle model (DPM) were used to simulate the flow field. The simulation conditions of flue gas were: uniform inlet velocity distribution, fully developed outlet, unsteady flow field, ignored heat transfer, and standard wall function.

The air was used to substitute the flue gas in simulation. So the density and the viscosity of the flue gas were set as 0.898 kg/m^3 and 2.45×l0^{-5} Pa · s at 120 ℃, respectively. The slip velocity of flue gas and particle was ignored. Their velocity at the inlet was set as 1.59 m/s. The pressure at the outlet was set as -860 Pa. The particle concentration was set as 0.18 kg/s. The particle diameter fit Rosin-Rammler diameter distributions, which was shown in Table 1. The mean fly ash diameter D_f was 91 μm after calculation. The discrete phase BC type of particle at the inlet and outlet was set as escape. This type on the apparatus bottom and filters was set as trap. The boundary condition of filters was set as porous jump, whose parameter was from Wang [12].

Table 1. Fly Ash Diameter Distribution.

Fly ash diameter d （μm）	Mass fraction Y （%）
0～45	8.91
45～60	19.47
60～80	16.81
80～105	35.33
>105	19.48

Table 2. Calculated Porous Media Parameters Of AC.

	Symbol	Units	Parameters
Permeability	α	m^2	3.00×10^{-7}
Inertial resistance factor	C_2	1/m	2.42×10^3
Viscous resistance coefficient	D	1/m^2	3.33×10^6

Table 3. Flux Nonuniformity Coefficient Of The Bags, ζ.

Filtering type	Bag filter	Nonuniformity coefficient
Outer filtering bags	Without guide plates	0.28
	With guide plates	0.06
Inner filtering bags	Without guide plates	1.33
	With guide plates	0.24

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The porous media model was use to simulate the AC. Porous media are modeled by the addition of a momentum source term to the standard fluid flow equations. The source term is composed of two parts, a viscous loss term (Darcy, the first term on the right-hand side of Eq. 1), and an inertial loss term (the second term on the right-hand side of Eq. 1):

$$S_i = -\left(\sum_{i=1}^{3} D_{ij}\mu\upsilon_j + \sum_{i=1}^{3} C_{ij}\frac{1}{2}\rho|\upsilon|\upsilon_j \right) \quad (1)$$

where S_i is the source term for the *i*th (*x*, *y*, or *z*) momentum equation, and *D* and *C* are prescribed matrices.

To recover the case of simple homogeneous porous media

$$S_i = \frac{\mu}{\alpha}v_i + C_2\frac{1}{2}\rho|v_j|v_j \quad (2)$$

where α is the permeability and C_2 is the inertial resistance factor, simply specify *D* and *C* as diagonal matrices with $1/\alpha$ and C_2, respectively, on the diagonals (and zero for the other elements).

The α and C_2 of the porous media in each component direction may be identified as

$$\alpha = \frac{D_p^2}{150}\frac{\varepsilon^3}{(1-\varepsilon)^2} \quad (3)$$

$$C_2 = \frac{3.5}{D_p}\frac{(1-\varepsilon)}{\varepsilon^3} \quad (4)$$

The calculated porous media parameters of AC are shown in Table 2.

4. RESULT AND DISCUSSION

The relative gas mass flux is defined as the simulated gas mass flux of every bag divided by the average gas mass flux. As shown in Fig. 3, mass flux in each bag is nonuniform for the two filtering types. Flux in two outer filtering bags is even negative. So guide plates are necessary. Based on Deng [13] and many times of simulation, two guide plates of 200mm are installed in the cabinet near the gas inlet in Fig. 4. Their angle between plates and the horizontal plane is both 60°.

As shown in Fig.5, gas flux in each bag is more uniform when guide plates are installed.

The axial velocity nonuniformity coefficient is used to analyze gas mass flux uniformity. Smaller nonuniformity coefficient means more uniformity. The nonuniformity coefficient is defined as the root-mean-square of the mass flux along the tower height (Eq. 5):

$$\zeta = [\frac{1}{n}\sum_{i=1}^{n}(\frac{c_i - \bar{c}}{\bar{c}})^2] \quad (5)$$

where ζ is the flux nonuniformity coefficient, c_i is the flux in each bag, $\bar{c}$ is the average flux of the bags, and *n* is the number of bags.

As shown in Table 3, the nonuniformity coefficient of bag filter with guide plates is smaller than that without plates. The mass flux in the bags is more uniform for the bag filter with guide plates.

Fig. 6 is axial velocity distribution of filter with guide plates in the center section. It can be seen in Fig. 6a that flow between each outer filtering bag is relative uniform. Axial velocity between the bags near the gas inlet is a little larger than the ones far from the inlet. Axial velocity on the higher horizontal surface between the bags is larger than that on the lower surface. The same regulation can be seen in Wang [12]. The flow in the AC absorber is uniform. So the Hg^{2+} and Hg^0 can be equally absorbed.

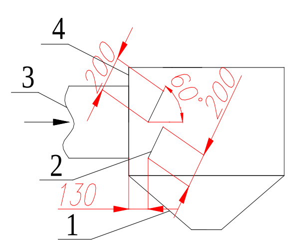

Figure 4. Guide Plates In The Cabinet (1. Ash Bunker, 2. Guide Plates, 3. Flue Gas Inlet, 4.Cabinet).

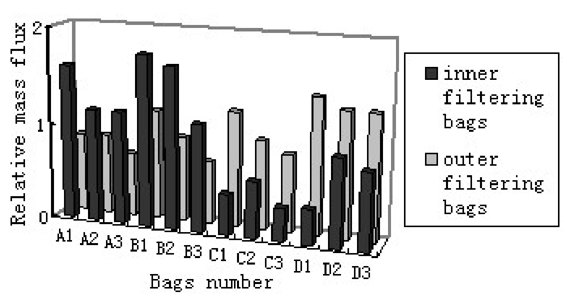

Figure 5. Relative Gas Mass Flux In Each Bag With Guide Plates.

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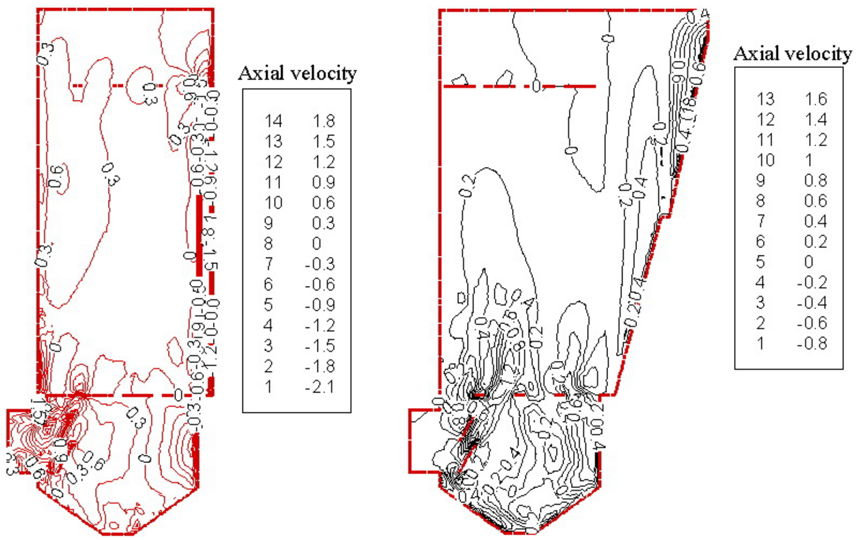

(A) Bag Filter With Outer Filtering. (B) Bag Filter With Inner Filtering.

Figure 6. Axial Velocity Distribution Of Filter With Guide Plates In The Center Section.

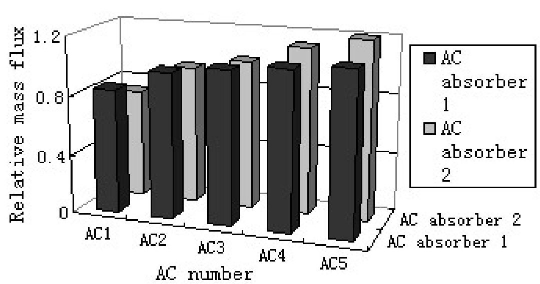

Figure 7. The Relative Gas Mass Flux For AC Absorbers With The Inner Filtering Bags.

It can be seen in Fig. 6b that the axial velocity within each inner filtering bag on the lower horizontal surface is larger than the higher one. The AC absorbers are divided equally into fifth parts along the height. Their numbers are AC1 - AC5 from the bottom to the top. It can be seen from Fig. 7 that the mass flux gradually increases from the bottom to the top. But the nonuniformity coefficient is of 0.008 and 0.027 for the AC absorber Ⅰ and Ⅱ. So the flow in the absorbers is uniform. The H_g^{2+} and H_g^0 can be equally absorbed. The design of the AC absorber is optimal.

From simulation, the resistance for the bag filter with guide plates is about 2% smaller than that without guide plates. Guide plates in the bag filter can reduce resistance. The same regulation can be seen in Hu [14].

5. CONCLUSION

The Equipment Integrated PM2.5 and Mercury Removal were designed. The flow field in the equipment was investigated. The following results were obtained:

1) The Equipment Integrated PM2.5 and Mercury Removal comprise bag filter and activated carbon (AC) absorber. Structure and dimension of the equipment are given at 500Nm^3/h.

2) Bag filter, which can removed PM2.5 and particulate mercury with high efficiency, is composed by outer or inner filtering bags. The AC absorber, which can absorb divalent and elemental mercury, is designed to fit the filtering types.

3) The structure of the equipment is optimized. Two guide plates near the gas inlet are installed. The flow in the bag filter is much more uniform with guide plates than without plates. The resistance is lower with guide plates meanwhile.

4) The flow in the AC absorber is uniform from simulation not only for the outer filtering type but also for the inner filtering bags type.

The Equipment Integrated PM2.5 and Mercury Removal has the advantage of simple structure and highly removal efficiency. The transformation from original bag filter to the equpement is easy to accomplish. This equipment is easy to popularize after designation and simulation. Future work will be dedicated to select proper AC for this equipment and optimize the equipment by experiment.

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