PAHs Emission Characteristics and Assessment from the Coal Combustion Process in the Power Plant Boilers

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Abstract

Coal-fired power plant industry plays an important role in the observed PAHs emission process. However, the PAHs emission characteristics and environment impact in coal-fired power plant are still not fully understood. In this study, the PAHs distribution characteristics of the flue gas and fly ash emitted from electrostatic precipitator in two coal-fired power plant boilers with the steam capacity 1000 ton/h and 2000 ton/h have been studied based on USEPA method 0023. PAHs concentrations and PAHs emission factors were determined. And the correlation between PAHs emission and the steam capacity of the power plant boiler was discussed. In addition, the PAHs removal effect of air pollution control devices was also included.

Introduction

Polycyclic aromatic hydrocarbons(PAHs) are mutagenic and carcinogenic and considered as the potential precursors of polychlorinated dibenzo-p-dioxins and polychlorinated dibenzofurans(PCDD/Fs) in waste incineration process, which was one of the most toxic set of compounds in the world[1].

There is also concern about population exposure to PAHs. The recently recommended air quality standard of 0.25 ng/m^3 for benzo[a]pyrene（BaP） is unlikely to be reliably achieved in all parts of the UK[2]. And a target value of air quality standard of 1 ng/m^3 for BaP is recommended by the EU Daughter Directives[2]. The emission of PAHs from various stationary sources, including medical waste incinerators[3] and industrial stacks[4]， lignite-fired power plants boiler[5], and ambient air around them ,were investigated.

Health risk assessment of residential particle pollution and emissions of organic hazardous air pollutants during coal combustion had been done a little in China[6,7]. Distribution and sources of PAHs had been investigated in several cities, such as Beijing[8], Tianjin[9], Guangzhou[10] and Dalian[11].

The main objective of this study was to investigate the concentration and emission factor of 17 individual PAHs from the coal combustion process in a large capacity coal-fired power plant boilers .This information is not only required for PAHs control, but also useful for the performance optimization of the power plant boilers and the emission assessment of large capacity co-fired power plants in future.

Materials and Methods

The two coal-fired power plant boilers located in Southeast China, including a forced circulation subcritical boiler with electrostatic precipitators (ESP) and a nature circulation subcritical boiler with electrostatic precipitators. The combustion systems consist of a feedstock feeder, two superheated chambers, two reheater chambers, an air preheater, an economizer, a main combustion chamber. The installed generating capacity of boiler-1 and boiler-2 are 300 MW and 600MW respectively. Table 1 shows background information of the emission source. Table 2 shows the coal ultimate analysis and elemental compositions used in the power plants.

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Tab.1 The information of emission source

Boiler ID	B-1	B-2
Temperature of sampling probe (^oC)	129	142
Oxygen content in ESP inlet （%）	4.92	5.2
Moisture content in ESP inlet （%）	13.5	8.6
Dust content in ESP inlet(g/dNm^3)	10.5	5
Dust content in ESP outlet (mg/dNm^3)	70	13
Gas flow rate in ESP (m/s)	2.0	1.14
Detention time in ESP （s）	13.0	15.8
ESP Remove efficiency (%)	99.3	99.7

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Tab.2 The coal ultimate analysis and element analysis

	Industrial analysis					Elemental analysis				
	M_{ad}/ %	A_{ad}/ %	V_{ad}/ %	FC_{ad}/ %	$Q_{net, ad}$ /(J/g)	C_{ad}%	H_{ad}%	N_{ad}%	S_{ad}%	O_{ad}%
B-1	7.14	9.9	30.32	52.64	26602	65.26	3.91	0.82	0.24	12.73
B-2	5.02	8.07	32.38	54.53	28027	68.02	4.16	0.9	0.43	13.4

The modification of US EPA method 0023(sample collection part) was adapted for the sampling. The flue gas was sampled from the stack isokinetically by the KNJ sampling system made in Korea. The KNJ sampling system was equipped with a sampling probe with a filter holder, a cooling device, a two stage glass cartridges with XAD-2, a pump, a flow meter, a control unit. The pump in the sampling system was installed after the flow meter to suction the gas sample. A sampling probe with a filter holder was connected to the sampling port of the stack. The sampling points locate in the inlet and outlet chimney flue of the electrostatic precipitators.

The identification and quantification of PAHs was accomplished by using a gas chromatograph (ThermoQuest/Trace GC 2000) with FID using methods based on EPA Method T0-13 and Chinese Standard Method GB86-5119. This gas chromatograph was equipped with a DB-5 capillary column (30m× 0.25mm× 0.25μ m).

The concentrations of the following seventeen PAHs were determined: Naphthalene(NaP), Acenaphthylene(AcPy), Acenaphthene(AcP), Fluorene(Flu), Phenanthrene(Phe), Anthracene(AnT), Fluoranthene(Fla), Pyrene(Pyr), Benz(*a*)anthracene(BaA), Chrysene(CHR), Benzo(*b*).fluoranthene(BbF), benzo(*k*)fluoranthene(BkF), Benzo(*e*)pyrene(BeP), Benzo(*a*)pyrene(BaP), Indeno[1,2,3,-cd]pyrene(IND), Dibenz[a,h]anthracene(DBA), and Benzo[*ghi*]perylene(BghiP)[12,13].

Results and discussion

The 17 PAHs can be classified by their numbers of aromatic ring as follows: lower molecular weight PAHs (LM-PAHs) containing 2-ring and 3-ringed PAHs, middle molecular weight PAHs(MM-PAHs) containing 4-ringed PAHs and higher molecular weight PAHs(HM-PAHs) containing 5-ring, 6-ring PAHs.

Tab.3 The Emission factors of total PAHs and toxic equivalency factors in different operating condition

PAHs Emission factors (μg/kg of consume fuel)	B-1 flue gas				B-2 flue gas			
	ESPs inlet		ESPs outlet		ESPs inlet		ESPs outlet	
	A	B	A	B	A	B	A	B
Two-rings	0.147	0	0	0.441	0	0	0.0407	0
Three-rings	3.7632	1.1172	0.4116	0.9702	1.1396	0.5291	0.407	0.2035
Four-rings	30.87	28.7238	1.617	2.6166	6.0643	1.3431	2.6455	1.3838
Five-rings	7.6734	1.9698	3.9102	14.112	10.4192	6.3899	1.8722	1.3431
Six-rings	0.2058	0.4116	0.6174	0	6.7155	0.0814	0	0
Total－PAHs	42.6594	32.2224	6.5856	18.1692	24.3793	8.3028	4.9247	2.9304
Toxic equivalency factors	9.0258	1.029	0.9702	4.5864	3.663	1.5873	1.1396	0.3663

A－low load period (approximated 70 percent of normal capacity)

B－Normal capacity load period

Total-PAHs concentration in the flue gas of eight measured data for these two boiler stacks ranged between 2.24 and 14.51 μg/m^3 and averaged 8.37 μg/m^3. The mean Emission factors of PAHs for the two boilers presented by the unit of μg PAHs /kg of consumed fuel are shown in Table 3. The mean Emission factors of total-PAHs were 12.3774 μg/kg of consumed fuel in electrostatic precipitators outlet of bolier-1, and 3.9276 μg/ kg of consumed fuel in bolier-2. It is known that the emission factors were strongly affected by the feedstock feeding rates that were specified for the two types of boilers. In particular, if the higher feedstock feeding rate was specified then a lower emission factor could be expected. The feedstock feeding rates were examine specified for two boilers (=102.5t/h, and 189t/h, respectively), it is further confirmed that the results obtained from this study could be theoretically plausible.

The mean toxic equivalency factors were 5.0288 μg/kg of consumed fuel in the electrostatic precipitators inlet of bolier-1, and 2.6252 μg/kg of consumed fuel in bolier-2.But in the electrostatic precipitators outlet, the mean toxic equivalency factors were 2.7783 and 0.7530 μg/kg. The above results indicate that air-pollution control devices used in the above two boilers were feasible to control the emission of gaseous PAHs. This is consistent with the results reported by You Xiaofang that PAHs emission factors are affected by fuel[14], combustion temperature, air flow ,and air pollution control devices. The fuel for combustion or pyrolysis processes is the major sources of PAHs emission. The fuel of the power plant in this study was bituminous coal, which is by far the largest group and is characterized as containing many high-ring PAHs.

It can be seen that MM-PAHs were the most dominant species in the flue gas of the bolier-1 electrostatic precipitators (ESPs) inlet (accounted for 72.37% and 89.14% of total-PAHs in low load and normal capacity load period , respectively). MM-PAHs and HM-PAHs was the highest PAHs about 90.83~ 96.53% in total PAHs emission factors among 17 PAHs .For all ringed PAHs, emission factors of 4-ring and 5-ring PAHs were higher than others PAHs. Despite the concentration differences, the composition of PAHs in two boilers showed similar patterns dominated by PAHs with four or more rings. BkF, BeP and BaP are the most predominant PAHs occurring in the stack flue gas. Generally, it is thought that the LM-PAHs formed mainly as a result of incomplete combustion of gaseous fuel HM-PAHs formed from high temperature pyrolysis process of fossil fuels. PAHs form from coal combustion can be considered as complex way of two reaction mechanism .The latter PAHs mechanism from coal combustion in large capacity power plant is even more dominance .

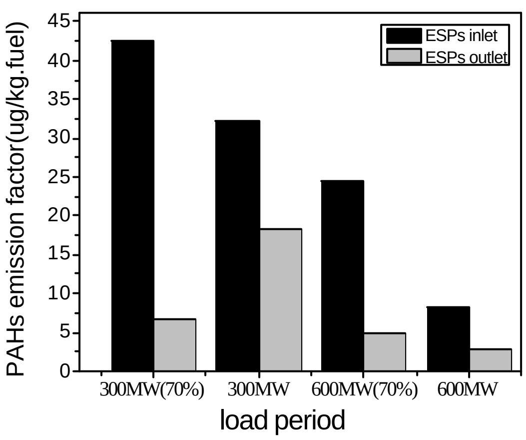

Fig.1 The PAHs emission factor in the flue gas in different boiler load **period**

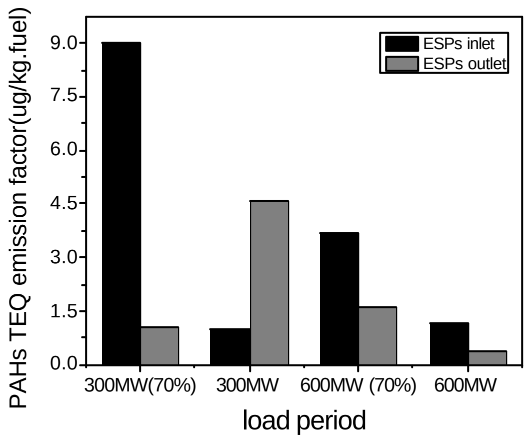

Fig.2 The PAHs toxic equivalency factors in the flue gas in different boiler load **period**

Figure1 showed the measured total-PAHs emission factors in the flue gas during different boiler load periods. Generally, a change of the boiler steam load would definitely change the flue gas temperature, also, backpressure in stack, and the blower operating point moves along the Q-H curve (flow vs height). In this paper, the steam and generating capacity of the low load period is assumed as the 70% of the normal capacity .The total PAHs content in the flue gas of electrostatic precipitator inlet decrease with the boiler load increasing. This can be owing to the higher feedstock and higher combustion efficiency in higher boiler load period. Coal is mainly composed of a wide variety of organic structures such as aromatic clusters, aliphatic bridges and rings, side chains, functional groups. PAHs formation during coal combustion process may occur through complex pathways.

Figure 2 showed the PAHs toxic equivalency factors in the flue gas in different boiler load period. The trend of PAHs toxic equivalency factors is similar with the trend of the total-PAHs emission factors. The high toxic equivalency factors at the ESP outlet in boiler-1 in normal load period can be due to the more high toxic equivalency factors species in the product, which can be forming from the low toxic equivalency factors and high molecule species on the effect of the electric field. But the reaction route is still unknown. PAHs resulting from boiler-1 are more toxic than boiler-2.It indicated that the higher capacity and more large-size incineration facility type can focus on organize of combustion process to reduce pollutes emission.

In general, it is thought that PAHs form as a result of incomplete combustion of organic compounds. And the total-PAHs Emission factors in the flue gas of electrostatic precipitators outlet is lower than electrostatic precipitators inlet, which is the effect of air pollution control devices to the PAHs forming process. The electrostatic precipitators can remove the fly ash particle in the flue gas. Then PAHs will be removed because during the cooling of coal emissions from combustion processes, PAHs are incorporated onto particles, and the fly ash can adsorb some PAHs particles. And the electric field of the electrostatic precipitators can decompose some PAHs based on the plasma theory, because the flue gas moisture content in ESPs inlet can reach 10% which would promote the plasma state forming .

Conclusion

(1) The above studies show that the pollution level of the large capacity coal－fired power plant studied was low to the data obtained from municipal solid waste power plant . Total-PAH concentration in the flue gas of the electrostatic precipitators outlet ranged between 2.24 and 14.51 μg/m^3, averaged 8.37 μg/m^3. The mean emission factors of total-PAHs ranged between 3.9276 and 12.3774 μg/kg of consumed fuel in the electrostatic precipitators outlet.

(2) The relationship between PAHs emission factor and power plant capacity were determined from elution analysis. It was shown that the total PAHs content in the flue gas of electrostatic precipitator inlet decrease with the boiler load increasing.

(3) The total-PAHs emission factors in the flue gas of electrostatic precipitators outlet is lower than Electrostatic precipitators inlet，electrostatic precipitators can remove PAHs in the flue gas.

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