SERIES ON CLEAN ENERGY TECHNOLOGY

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Jinsong Zhou · Zhongyang Luo
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Mercury Emission and its Control in Chinese Coal-Fired Power Plants

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Preface

Coal-fired mercury emission is one of the main factors causing global mercury pollution problems. The United Nations Environment Program (UNEP) pointed out that coal-fired power plants are the biggest human mercury emission source. In China, coal consumption is huge. And mercury emission pollution was gradually revealed in recent years. Actively developing coal-fired mercury pollution emission control research and exploring reasonable, effective and economic mercury control methods and approaches, are important topics for Chinese sustainable development in light of the current use of coal as main energy source.

This book mainly introduces Zhejiang University's experiences and achievements in the research field of coal-fired mercury emissions and control during the last decade. All these studies were funded by the Chinese National Natural Science Foundations: Transformation Mechanics and Emission Reduction of Mercury in Coal Combustion (No. 59906010, 2000-2002), and Stabilization Mechanisms of Mercury During Its Control in Coal-Fired Flue Gas (No. 50476056, 2005-2007); the Chinese National Basic Research Priorities (973) Program: Mercury Transformation and Its Control for Coal-Fired Utilization (No. G1999022212-08, 1999-2003); the Chinese High Tech Research and Development (863) Program: Advanced Mercury Control Technology on the Basis of Semi-Dry Method (No. 2001AA529040, 2002-2004), and Estimation of Mercury Emission from Coal Use in China (No. 2005AA520080, 2005-2007), and the Chinese Doctor Station Foundation: Mercury Speciation Transformation and Removal in the Conventional Combustion Pollutants Control Process (No. 20050335057, 2006-2008).

This book is the technical report to introduce mercury emission and its control from coal-fired power plants in China. The book focuses on coal consumption and air pollutant control in coal-fired power plants, and the ongoing research status of mercury emission and its control in China. The book mainly describes the mercury sampling methods and measurements of coal-fired flue gas, the estimation of mercury emission from coal-fired power plants in China, the research into mercury speciation transformation during coal combustion, the research of mercury control and mercury stability in byproducts.

The preparation of this book has been made possible thanks to the

contributions of Dr. Changxing Hu, Dr. Sheng He, Dr. Hongliang Gao, Dr. Jianli Ren, Dr. Jianming Zheng, Dr. Xiaoyu Hua, Xujie Wu, Xiangjian Shi, Guangkai Wang, Le Zhang, and Qiankun Li, etc.

The authors
Hangzhou, China
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1

Controlling Pollutants in Coal-Fired Power Plants in China

1.1 Introduction

Coal is an important source of energy in China. According to the data from the National Bureau of Statistics of China, 3,570 million tons coal was consumed in 2011, which was about 72.8% of the primary energy used in China. Although new sources of energy are now being used, it is estimated that the use of coal will still be above 60% of the total primary energy production by the year 2020. The typical way of utilizing coal is through burning. Emissions such as sulfur oxides (SO_x), nitrogen oxides (NO_x), and trace mercury (Hg), etc., from burning coal have caused serious pollution problems. In fact, coal-fired power plants are the main sources of mercury emissions[1]. In 2005, about 495 tons of mercury came from coal-fired power plants and other sources. Considering the rapid economic growth and industrial expansion of China, the annual growth of mercury emissions is expected to reach 20 – 30 tons[2]. Hu estimated that there were about 193.6 tons of mercury emissions from coal-fired power plants in China in 2005. This figure amounts to 12% of global mercury emissions[3].

More than 140 countries, including China, reached an agreement under the Environment Program Management Committee of the United Nations in February 2009. Through this agreement, the participating countries pledged to a treaty on reducing global mercury pollution. At present, a few developed countries plan to fix limit standards on mercury emissions in future. The United States Environmental Protection Agency (US EPA)[4] proposed new mercury emissions control rules in March 2011.

In China, government and related agencies have focused on measures to control mercury emissions from coal-fired power plants in the country. The government has started funding research on finding ways to control mercury emissions. In 2010, the State Environmental Protection Department explicitly requested carrying out atmospheric mercury pollution control pilot projects in coal-fired power plants from 2011 to 2015. China has announced emission standards of air pollutants for thermal power plants (GB 13223-2011), including mercury emission control standards, in July 2011. This chapter discusses the coal consumption and air pollution control devices of coal-fired power plants in China, and the current status and control of mercury emissions in the country.

1.2 Coal Consumption and Air Pollutant Control in Coal-Fired Power Plants in China

For a long time, the use of coal as the main source of energy has played a key role in the structure of energy consumption in China. The percentage of coal consumption in total energy in China from 1990 to 2007[5,6,7] is shown in Fig. 1.1.

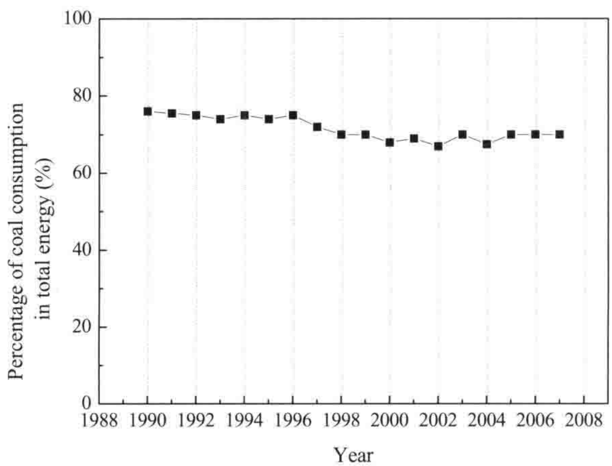

Fig. 1.1 Percentage of coal consumption in total energy from 1990 to 2007 in China

As can be seen, coal consumption occupied a high proportion of total energy in China. The percentage of coal consumption was lowest at 65.6% in 2002, increasing to 68.7% in 2009. It is estimated that coal consumption can reach 62.6% in 2015 and continue to reach levels above 50% in 2050. So, not only now, but also for quite a long period, though the proportion of coal in the energy consumption structure will drop year by year, the role of coal as the main source of energy in China shall remain.

The capacity and coal consumption of electric power generation in China are shown in Fig. 1.2. Coal-fired power plants are the most popular type of electric power generation in China. The average installed capacity of coal-fired power plants was about 75.2% of the total installed capacity from 1990 to 2008. In 2008, the capacity of electric power generation was 792.5 GW, including 601.3 GW from coal-fired power plants, which was about 75.9% of the total. In all, these plants have consumed a total of 1.34 billion tons of coal.

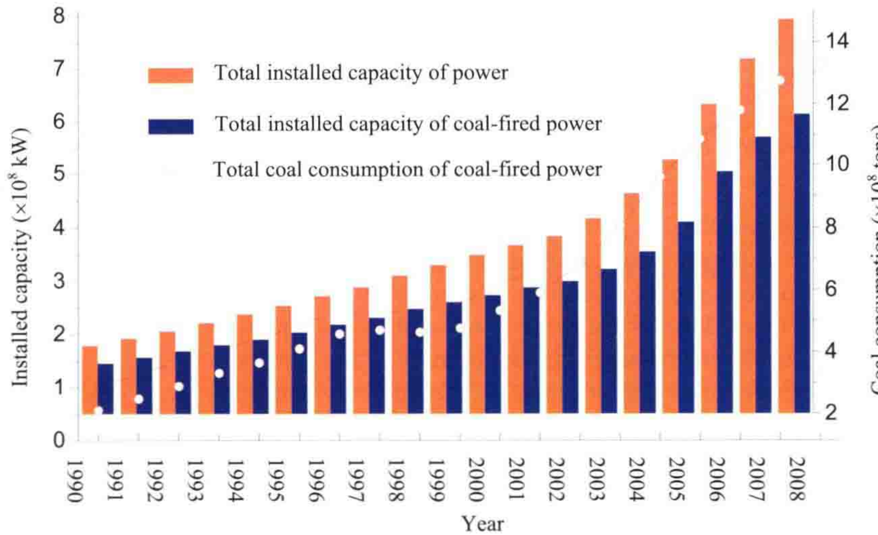

Fig. 1.2 Capacity and coal consumption of electric power generation in China from 1990 to 2008

Conventional pollutant emission control technologies for particles SO_2 and NO_x has progressed in recent years in China. Currently, most coal-fired power plants are equipped with dust-cleaning equipment, such as electrostatic precipitators (ESP) or fabric filters (FF). Desulfurization technology has also rapidly developed[8]. In 2005, the capacity of coal-fired power plants equipped with a desulfurization unit was 12.3%. However, in 2009, this capacity was about 78% (about 470.0 GW). In addition, SO_2 emissions from coal-fired power plants appeared to have decreased for the first time. Wet limestone-gypsum desulfurization is mainly used as flue gas desulfurization technology in China. By 2007, 26 sets of flue gas NO_x-controlled devices had been installed in coal-fired power plants in China, with a total capacity reaching 11,250 MW. Most power plants used selective catalytic reduction (SCR) technology, except four units of 600 MW that adopted selective non-catalytic reduction (SNCR). At present, nearly 200 sets of NO_x-controlled devices for 105.0 GW capacity have passed environmental assessments[9]. Given the rapidly increasing demands for environmental protection requirements, more coal-fired units must be equipped with flue gas desulfurization and NO_x-controlled devices. However, although these conventional pollutant control technologies can affect gaseous mercury ($Hg_{(g)}$) emissions, the ability to control $Hg_{(g)}$ depends on mercury speciation.

1.3 Research of Mercury Emissions and Their Control in China

1.3.1 Mercury Emissions in China

According to the UNEP report released in 2008, China, the United States and India are the three countries with the largest mercury emissions, with an aggregate rate of about 57% of total global emissions. It is said that by 2008, mercury emissions in China were twice those of the United States and India combined, with nearly 50% of mercury emissions coming from the burning of fossil fuels in China.

Some reports show that in China average mercury concentration in coal is 0.22 mg/kg, which is more than 0.13 mg/kg of the world average. Many scholars used different methods to estimate mercury emissions from coal-fired plants in China. Feng *et al.*[10] estimated mercury emissions in the atmosphere to be 296 tons; if the present pollution control facilities are maintained, the annual amount of mercury emissions can increase by 5.3%. Wang *et al.*[11] studied the mercury concentration in Chinese coal and the emissions of mercury from coal-fired industries and estimated the mercury emissions in the atmosphere in China in 1995 to be about 213.8 tons. Mercury emissions from coal-fired industries reached 2493.8 tons in the years 1978–1995, with emissions growing at an average annual rate of 4.8%. David and Streets *et al.*[12] analyzed the national statistical yearbook data for 1999 and estimated the mercury emissions to be 536(±236) tons, 38% of which came from coal-fired industries. Meanwhile, Jiang *et al.*[13] divided mercury emission sources into 65 various types according to the following criteria: economic sector, flue type, method of burning and pollutant emission control technology. They established a mercury emission inventory of coal-fired industries in the provinces according to coal consumption, mercury concentration in coal and the mercury emission factor in China. The two sets of data released by the US Geological Survey (USGS) showed that the average mercury concentration in Chinese coal was 0.15 and 0.20 mg/kg, respectively. Both were higher than the global average mercury concentration of 0.13 mg/kg. In addition, the two data sets also indicated $Hg_{(g)}$ emissions from coal-fired industries in 2000 at 161.6 and 219.5 tons, respectively. At present, about 35% of total mercury comes from electric power industries. China has an unequal distribution of mercury emissions from coal-fired industries, and provinces with major emissions include Henan, Shandong, Guizhou, Guangdong and Jiangsu.

Ren *et al.*[14] reported that the average annual growth rate of $Hg_{(g)}$ emissions coming from the coal-fired power plants in China from 1999 to 2003 was 9.59% and that for non-$Hg_{(g)}$ emissions was 8.49%. There were 86.8 and 28.94 tons of $Hg_{(g)}$ and non-$Hg_{(g)}$ emissions, respectively, from coal-fired power plants in 2003. Wang *et al.*[15] estimated that the mercury emission was about 256 tons from the coal-fired industry in 2003. According to actual test data of coal-fired power plants, Hu *et al.*[3] estimated the total mercury emissions from coal-fired power plants in 2005 to be 193.6 tons, including 147.0 tons of $Hg_{(g)}$.

The assumptions made by Wang, however, have yet to be proven by field test or research. To date, the accuracy of such estimations still awaits validation. Thus, it is important to study the mercury emission characteristics of the typical coal-fired sources in order to establish a thorough, comprehensive, and accurate mercury emission inventory of coal-fired power plants in China.

1.3.2 Mercury Emission Control Technologies in China

Coal-fired mercury control technologies have developed gradually in recent years. Various mercury pollution control technologies used in coal-fired power plants are presented in Fig. 1.3. Mercury pollution control technologies of coal-fired plants can be roughly divided into three types: those done before, during, and after the burning of coal.

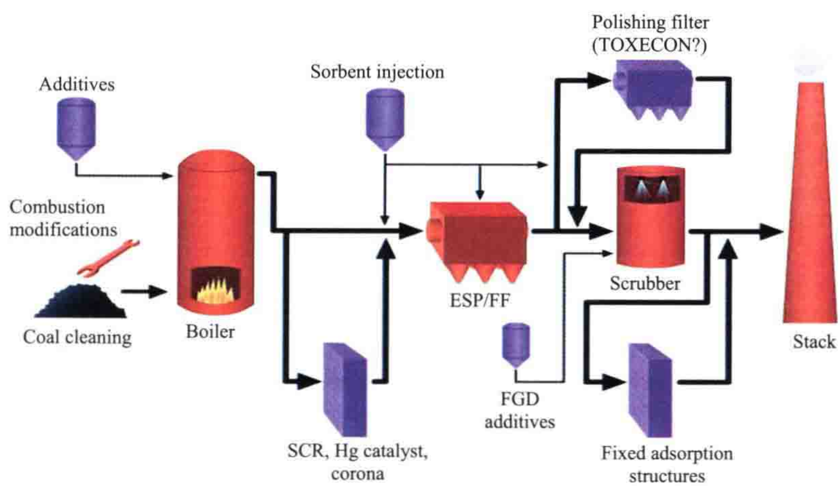

Fig. 1.3 Mercury pollution control technical methods for coal-fired power plants

Examples of mercury control technology applied before burning include coal washing, coal drying technologies, etc. Coal washing is an effective mode of reducing $Hg_{(g)}$ emissions. In general, the mercury removal rate of flotation technology is between the ranges of 21%–37%. This technology is applied depending on the coal type, method of washing, separation technology, and mercury concentration in coal[16]. The coal washing technology is a relatively old technology, whereas the application of coal heating dry technology is fairly recent. Coal drying technology, on the other hand, can remove about 70% of mercury in the coal before burning. However, the rate of washed coal in China is still low and most coal-fired power plants have not yet adopted the use of "washed" coal.

At present, studies of mercury control during burning have focused on the improvement of the combustion mode and additive combustion method. Research shows that the circulating fluidized-bed coal combustion method is helpful in reducing mercury emissions. In fact, only 4.5% of mercury in coal is emitted to the atmosphere when burning high chlorine bituminous coal[17]. Incorporating the additive during the burning process changes the distribution of mercury speciation in the flue gas. Currently, brominated additive is used to control mercury emissions. On-site application research shows that total mercury removal efficiency can reach 80% when 4 ppm bromine is added to the coal[18].

Mercury control technology after burning refers to the removal of mercury from the coal-fired flue gas. This technology can be divided into several methods explained below. First, it uses sorbent to adsorb mercury in flue gas. However, the mechanism involved in adsorbing mercury is unclear, and there are many arguments surrounding its effectiveness. The popular absorbents are activated carbon, coal fly ash, calcium material, zeolite, and so on.

Second, it uses existing flue gas pollution control devices of coal-fired power plants to reduce mercury emissions. At present, existing flue gas pollution control devices include particle-control equipment (ESP or FF), NO_x-control equipment (SCR), and flue gas desulfurization equipment (WFGD). It can simultaneously control mercury, particulates, SO_2, and NO_x pollutants using the existing pollutant control devices.

Third, it develops new mercury pollution control technologies, such as corona discharge plasma technology and electrocatalytic oxidization combined treatment technology, for comprehensive control.

Currently, except for the mercury emissions control technology used in the laboratories, there is no particular technology being used for coal-fired power plants in China. However, ESP, WFGD, and SCR pollutant control equipment that has certain mercury control functions is widely used. The mercury removal efficiency of such equipment depends on the speciation distribution of mercury in flue gas, which is mainly affected by coal type. Table 1.1 shows the average mercury removal efficiency rates of existing pollutant control technologies with different coal types[19,20].

Table 1.1 Mercury removal efficiency of existing pollution control technology with different coal types

Existing pollution control technology	Mercury removal efficiency (%)		
	Bituminite	Sub-bituminite	Lignite
Particle control			
Cold-ESP	46/36	16/3	0/04
Hot-ESP	12/9	13/6	-/-
FF	83/90	72/72	-/-
Wet dust removal	14/-	0/9	33/-
SO_2 control			
Dry spray+FF	98/98	3/24	17/0
Hot-ESP+WFGD	55/49	33/29	-/-
Cold-ESP+WFGD	81/75	35/29	44/44
FF+WFGD	96/98	-/-	-/-

1.4 Outline of the Book

The aim of this book is to introduce mercury emissions and their control in coal-fired power plants in China. The whole book is divided into 5 chapters. Chapter 1 discusses the controlling pollutants in coal-fired power plants in China, including coal consumption and air pollutant control in coal-fired power plants, and the ongoing research status of mercury emissions and their control in China. Chapter 2 describes mercury sampling methods and measurements in coal-fired power plants, including the introduction of sampling objects in coal-fired power plants, the process of mercury sampling, results of mercury sampling and measurement, mercury balance analysis, mercury removal with current pollutant control devices, and so on. Chapter 3 presents an estimation of mercury emissions from coal-fired power plants in China, including mercury emission factor, mercury emission estimation from coal-fired power plants, the future development trend forecasts, and so on. Chapter 4 touches on mercury speciation transformation during coal combustion, including experimental research on the release of mercury from coal combustion, mercury speciation transformation after coal combustion, modeling research on mercury speciation transformation during coal combustion, and so on. Chapter 5 discusses mercury control and mercury stability in byproducts, including experimental research on the absorption of $Hg_{(g)}$, mercury absorption with normal sorbents and mercury absorption with treated sorbents, as well as the absorption mechanism on the active carbon surface, mercury stability in desulfurization gypsum, mercury stability on the active carbon surface, and so on.

1.5 Summary

The hazards of mercury pollution have attracted growing public interest in recent years. Thus, the effective control of mercury emissions from coal-fired power plants has also gained worldwide interest. Mercury emission and control are significantly related to the energy consumption structure of a country. In line with this, the current chapter presents the structure of the coal consumption and mercury control technology in China, and other related issues.

In China, coal is one of the main sources of energy, occupying a high ratio of the total energy consumption in the country. This coal-based energy consumption structure is expected to continue well into the future. Control methods of coal-fired mercury emission pollution can be divided into three categories: mercury control technologies before burning, such as coal washing technology and heat treatment technology, that are not commonly used in China; mercury control technologies during burning, which are focused on improving combustion methods and additive combustion means; and mercury control technologies after burning, such as using sorbents to achieve the adsorption removal of mercury and existing pollution control devices of coal-fired power plants in order to control $Hg_{(g)}$ emissions.

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