Fuel 185 (2016) 863–871

Contents lists available at ScienceDirect

Fuel

journal homepage: www.elsevier.com/locate/fuel

Full Length Article

Fine particulate matter emission and size distribution characteristics in an ultra-low emission power plant

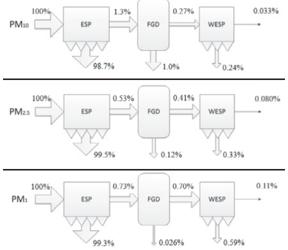
Zifeng Sui [a], Yongsheng Zhang [a,*], Yue Peng [a], Pauline Norris [b], Yan Cao [a,b,*], Wei-Ping Pan [a,b]

[a] *Key Laboratory of Condition Monitoring and Control for Power Plant Equipment, Ministry of Education, North China Electric Power University, Beijing 102206, PR China*
[b] *Institute of Combustion Science and Environmental Technology, Western Kentucky University, Bowling Green, KY 42101, USA*

HIGHLIGHTS

- The PM emission from a ULE coal-fired power plant in China was less than 1 mg/Nm^3.
- Over 99.7% of the fine PM was captured by the retrofitted ESP, FGD and WESP.
- The fine particulate matter was mostly ash and gypsum.

GRAPHICAL ABSTRACT



(a) mass distribution

(b) number distribution

Fine PM distribution in ESP, FGD and WESP

ARTICLE INFO

Article history:
Received 26 June 2016
Received in revised form 9 August 2016
Accepted 12 August 2016

Keywords:
Ultra-low emission
Fine PM emission
Coal-fired power plant
WESP
ELPI+

ABSTRACT

The pollution emitted by power plants is a continuing environmental problem around the world. Recently, China has proposed new regulations limiting emissions. The new regulations include a reduction in particulate matters (PM) emission to less than 5 mg/Nm^3 to reach Ultra-Low Emission (ULE) standards. This research examines the PM emission from a ULE power plant. The power plant was equipped with a low-temperature economizer, a wet electrostatic precipitator (WESP), a retrofitted electrostatic precipitator (ESP) and a flue gas desulfurization (FGD) system. The PM_{10}, $PM_{2.5}$ and PM_1 emissions were 0.36 mg/m^3, 0.36 mg/m^3 and 0.09 mg/m^3, respectively. The capturing efficiencies of the retrofitted ESP and WESP were over 98.7% and 80.5%, respectively. The FGD did not significantly capture $PM_{2.5}$ and PM_1. The PM collected from the Electrical Low Pressure Impactor (ELPI+) was analyzed using scanning electron microscope/energy dispersive spectrometer (SEM/EDS). The SEM/EDS data showed small limestone/gypsum particles. These particles probably entered the flue gas from the FGD. This research shows that WESP can effectively capture PM greater than 0.3μm and particles of limestone and gypsum.

1. Introduction

In 2013, a nation-wide haze appeared in China. Approximately 30% of the haze was attributed to emissions from coal-fired power generation [1]. Coal-fired power plants are a major source of power generation in China so the emission of PM from coal-fired power plants can't be ignored. The newly released emission standards have decreased the SO_2, NO_X and PM emission limits to 100 mg/Nm^3, 100 mg/Nm^3 and 30 mg/Nm^3, respectively [2]. In 2014, a new concept of energy-saving and environment-protection called "Ultra-Low Emission (ULE)" was proposed with

---

* Corresponding authors at: Institute of Combustion Science and Environmental Technology, Western Kentucky University, Bowling Green, KY 42101, USA (Y. Cao).
E-mail address: yszhang@ncepu.edu.cn (Y. Zhang).

http://dx.doi.org/10.1016/j.fuel.2016.08.051
0016-2361/

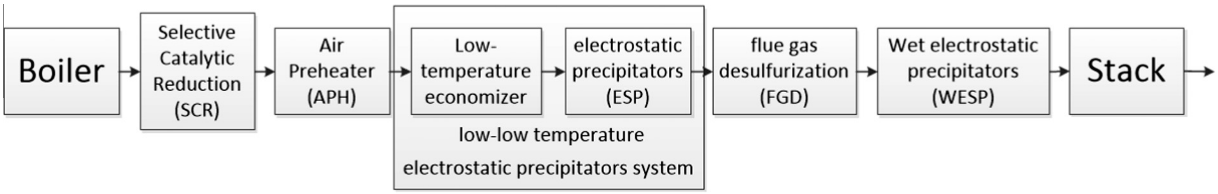


Fig. 1. Technology route for ULE retrofitting.

even lower standards. Emissions of SO_2, NO_X and dust for ULE were limited to 35 mg/Nm^3, 50 mg/Nm^3 and 10 mg/Nm^3, respectively [3]. In December 2015, the executive meeting of the Chinese state council decided that before 2020, coal-fired power plants should be retrofitted to meet ULE standards. Capturing fine particulate matter (PM) is a very difficult task [4]. Improvements, such as retrofitting the ESP and installing a WESP, could help solve this problem. The suggested technology route is shown in Fig. 1.

Dry electrostatic precipitators (ESP) have been the primary particle emission control devices (PECD) in Chinese power plants for the past twenty years. While they effectively capture large particles, they can do little to help with fine particles such as $PM_{2.5}$ (PM less than 2.5 μm at the aerodynamic diameter) or lower. Power plants are primarily concerned with $PM_{2.5}$ because of the low capture efficiency and because it is a health hazard [5]. A low-low temperature (LLT) ESP system and a high frequency electric source in the ESP were used to improve ESP capture efficiency [6,7]. A LLT ESP system consists of a low temperature (LT) economizer and LLT ESP. The low-temperature economizer reduces the flue gas temperature from 120–160 °C to 85–95 °C. Reducing the flue gas temperature increases the breakdown field strength (which is the electric field strength when the dielectric breakdown phenomenon occurs) and gas density while reducing the specific resistance of fly ash (the specific resistance of the dust layer, when the area is 1 cm^2 and the thickness is 1 cm) and flow velocity [8]. These parameters will influence the ESP operating conditions and the capture efficiency of fly ash. The results of Wang et al. [9] show that the PM_{10} (PM less than 10 μm at the aerodynamic diameter) and $PM_{2.5}$ in the LLT ESP outlet are respectively decreased 81% and 86% with a decrease in flue gas temperature from 160 °C to 110 °C. Similar results were found in other studies [10,11]. Thus, a LLT ESP system has better capture efficiency than the traditional ESP. A high-frequency electric source can also decrease the mass-concentration of $PM_{2.5}$ significantly and improve ESP efficiency [8,12]. The combined effect of the LT-economizer and the high-frequency electric source ESP can effectively improve $PM_{2.5}$ control [7] and help to meet the ULE PM standards. Studies by Zukeran et al. [13] show a decrease in the amount of particles exiting the ESP larger than 0.04 μm when the ESP is operated at 18 kV dc.

Wet limestone-gypsum flue gas desulfurization (FGD) installed after the ESP is the typical final pollution control device in Chinese power plants. However, under low load capacity or other unstable operating conditions, FGD cannot reach the rated efficiency and some of the gypsum can be carried out in the flue gas. This causes the problem known as “gypsum rain” [14,15]. In a typical Chinese power plant, Lu et al. found that the mass concentration of PM in the flue gas increased significantly after passing through the FGD due to the release of fine particles and some volatile metals from FGD slurry [16]. Wang et al. concluded that limestone and gypsum particles account for 47.5% and 7.9% of the PM mass concentration, respectively, in the flue gas at the FGD outlet [14]. Clearly, controlling the PM concentration in the flue gas at the FGD outlet is another key factor to achieving PM control in ULE power plants.

Table 1
Coal analysis of SH #4 unit (wt.%, dry basis).

Proximate analysis			Elemental analysis				
Volatile	Ash	Fixed Carbon	C	H	N	S	O
29.04	18.58	52.38	63.22	4.18	0.89	0.74	12.39

Table 2
Air pollution control device retrofit of SH #4 unit.

	LT-economizer	ESP	FGD	WESP
Action	New construction	LLT ESP, high-frequency electric source retrofitted	Integrated desulfurization and dedusting retrofitted	New construction

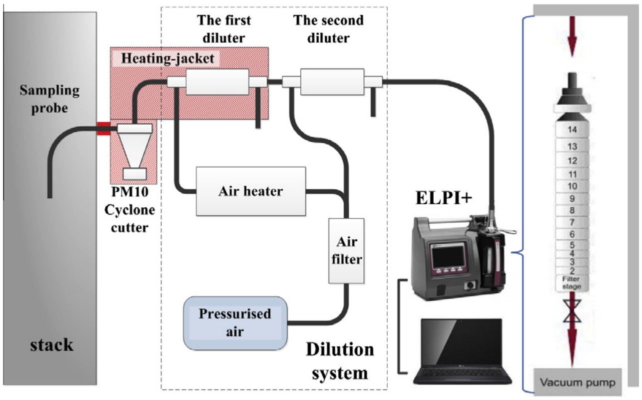


Fig. 2. ELPI+ sampling and analysis system.

The installation of a wet ESP (WESP) after the FGD system can reduce the PM concentration in the flue gas [17]. Compared with a dry ESP, WESP is particularly suitable in the following situations: (1) the moisture content of the flue gas is high and the temperature is close to the dew point temperature of the flue gas; (2) the flue gas contains sticky particles and droplets (such as sulfuric acid mist); (3) the fine particles need to be effectively captured due to stronger corona power generated than in traditional ESP [18]. In addition, the adhesive force between dust and water prevents the dust in the WESP from reentering the flue gas. In conclusion, a WESP is very suitable for installation after the WFGD as the final device to control fine particles.

Previous work on PM emissions from ULE power plants have focused on final emissions and the effect of the WESP. Zhang et al. [19] studied particulate emission in a 1000 MW ULE power plant. The capture efficiency for $PM_{2.5}$ was only 57.2%. This indicates that WESP did not effectively control ultrafine PM. Liu et al. [20] studied the $PM_{2.5}$ concentration before and after the WESP in a ULE power plant using Electrical Low Pressure Impactor (ELPI). They found that WESP decreased the PM_{10} mass concentration from 8.42 mg/m^3 to 1.62 mg/m^3. The $PM_{2.5}$ capture efficiency in the WESP was 78.77%. Zhao and Zhou [4] studied particle emission in a 300 MW ULE power plant. They determined that the PM