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Effects of high-voltage power sources on fine particle collection efficiency with an industrial electrostatic precipitator

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ABSTRACT

This paper presents industrial investigations on fine particle grade collection efficiency of an industrial electrostatic precipitator (ESP). Experiments are performed with a hybrid ESP and fabric filter (FF). Gas flow rates, mass inlet concentration, gaseous temperature and the ESP plate–plate distance are 20,000–40,000 Nm^3/h, 15 g/Nm^3, 110 °C, and 400 mm, respectively. The ESP specific collection area ranges from 10 to 20 m^2/m^3/s. Both single-phase and three-phase transformer-rectifiers (TRs) are used for energizing the ESP. When changing the single-phase TR to the three-phase TR, the maximum average secondary voltage is increased from 55 kV to 71 kV and average corona current rises from 31 mA to 62 mA without spark breakdown. As a result, both fine particle grade collection efficiency $\eta(r)$ and their migration velocities are significantly increased. With the single-phase TR, the velocity is around 17 cm/s for all particles. With three-phase TR, its maximum value is about 35 cm/s. For particles within 0.03–0.1 μm and 0.1–2.5 μm in diameter, the efficiencies rise from about 85% to 95% and 92, respectively. For particles of around 2.5–8.0 μm, they rise from about 87% to about 98%. Moreover, experiments show that a revised Deutsch equation $\log(1-\eta(r))/\beta = -\alpha E_a^2 S$ gives a good approximation via the average electric field E_a, the specific collection area S and two correction coefficients α and β, which depend on particle size.

1. Introduction

Over the past century, electrostatic precipitators (ESPs) have been widely used in industries for particle collection due to their high efficiency and low cost [1,2]. Its state of art of fundamentals and mechanical design, models, electrical operation and power sources, conditioning, hybrid precipitation techniques, and industrial applications can be referred to the latest ESP proceedings [3]. Today, world-wide evaluation on health impact of fine particles have promoted a number of campaigns for understanding particulate matter (PM) emission from combustion sources and their concentration in air. For examples, Ehrlich et al. reported PM emission from 303 plants and domestic stoves in Germany [4]. Zhao et al. estimated Chinese PM emission after evaluation of ten Chinese coal-fired power plants [5]. Khan and Sun et al. presented PM characteristics around Yokohama and Beijing, respectively [6,7]. On the other hands, world-wide ESP upgrading has obtained significant achievements for reducing PM emission and/or saving energy consumption. With regard to Chinese utilities [5,8], almost all ESPs need to be upgraded by considering PM2.5 emission (particles with a diameter of less than 2.5 μm). Industrial observations have indicated that a poor ESP performance is always related to either back corona or insufficient particle charging at the inlet field of the ESP or both of them. Retrofitting usually includes resizing ESP itself, changing it to hybrid ESP & FF (Fabric Filter) precipitator [9], replacing high-voltage (HV) and/or low-voltage (LV) power sources [10,11], coal switching, flue gas conditioning or using pre-charger [12]. A number of literature are available for those individual applications [3]. Among them, one of the most cost effective techniques is to upgrade the HV power sources by using the latest automatic voltage controller (AVC) and/or new types of HV techniques, such as by using switch-mode power supplies [3]. For 400 mm gap ESPs, typical used output voltage and current of three-phase TRs are 82 kV and 2.0 A, respectively, which are beyond switch-mode power sources. Our industrial applications to 125 MW, 300 MW and 600 MW Chinese coal-fired boilers have confirmed that after retrofitting traditional single-phase TRs at the inlet ESP field, both the corona discharge power and the particle

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collection efficiency significantly rise. The specific collection area of the inlet field is usually around 10–20 $m^2/m^3/s$ [13]. Detailed principles for upgrading ESP to reduce emission and save energy consumption, however, are not available yet due to our poor knowledge on PM2.5 emission in terms of specifications of ESP collection area, particle characteristics and the high-voltage power sources.

This paper reports our continuous work on ESP upgrading by using the three-phase TR and fine particle grade collection efficiency. Its main objective is to get deep insights on the fine particle migration velocities and to provide simplifying collection approximations in terms of the applied electric field, the specific collection area and particle size for upgrading industrial ESPs.

2. Pilot experimental setup

The pilot hybrid precipitator as shown in Fig. 1 consists of two parts, namely the first-stage ESP and the second-stage FF. The precipitator is installed in-parallel to a full-scale FF in order to adjust the gas flow rate from 20,000 Nm^3/h to 40,000 Nm^3/h. Flue gas firstly enter the ESP and then the FF. The hybrid precipitator was carefully designed by considering gas flow distribution and system pressure drop. The same type of precipitator has been used for up to 600 MW coal-fired generator. The system has been in operation for over two years with a local 30 MW coal-fired power generator. The gap between ESP plates is 400 mm. The length and height of ESP are 2500 mm and 4200 mm, respectively. The ribbed strike type electrode is used for the corona wire. The maximum gas velocity at 110 °C inside the ESP is 1.15 m/s under 40,000 Nm^3/h. The specifications of the experimental setup are listed in Table 1.

An in-situ electrical low-pressure impactor (ELPI) is used to analyze particle concentration and size distribution. The ELPI is a 13-stage low-pressure cascade impactor. The size range is from 30 nm to 10 μm. The technique has been widely used for studying PM emission [5]. Its detailed diagnostic principle was early reported [14]. Particle sampling ports are located at the ESP and FF outlets, respectively. All experimental data are obtained between two rapping cycles. The initial inlet particle specifications are obtained by means of the measurement at the ESP outlet when switching off the power source. Particle natural collection inside the ESP is excluded for evaluation of the collection efficiency. Particle concentrations are obtained by averaging individual sampled data across these outlet sections. Within this study, the total inlet mass concentration is around 15 g/Nm^3 with an average diameter of 11.2 μm and a specific dust resistivity of 3.09×10^{10} Ω cm at 110 °C. Detailed evaluation of dust resistivity was reported in Ref. [15].

Both single-phase and three-phase TRs were used in order to carry out a series of comparison experiments. For each observation, experiments were usually performed within a week. And then the collected data were analyzed according to operation conditions. Fig. 2 shows circuit diagrams of the traditional single-phase and three-phase TRs. Both primary and secondary voltage and current were automatically measured with an equipped AVC [16]. The single-phase TR is based on a couple of anti-parallel silicon controlled rectifiers. Its operation principle and various control methodologies have been very well described [2]. The three-phase TR is based on three couples of anti-parallel silicon controlled rectifiers. The technique has been known for many years. Few reports, however, are available for discussing its performances on particle grade collection efficiency. As far as we know, the work by Boyle and Paradiso is the only available literature to discuss the issue by means of an opacity monitor. The comparison experiments of three-phase TR with single-phase TR were also performed under the same industrial conditions [17].

Table 1
List of the specifications of the precipitator.

Unit	Value
Flow gas	
Gas flow rate (m^3/h)	40,000
Inlet gas temp (°C)	110 (max.120)
Inlet dust (g/Nm^3)	15
ESP	
Total cross area (m^2)	9.6
Total ESP length (mm)	2500
Total ESP height (mm)	4200
Plate–plate distance (mm)	400
Total collector surface (m^2)	120
Total length of corona wire (m)	120
Gas velocity inside ESP (m/s)	1.15
Specific collecting area (SCA)	10.9
FF	
Fabric filter	PPS
Total cloth area (m^2)	333
Filter velocity	2 m/min

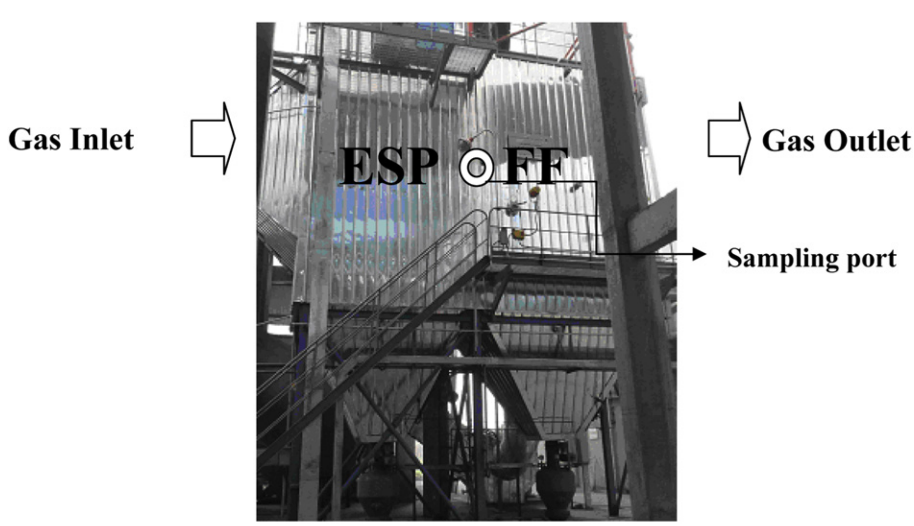

Fig. 1. Photo of the pilot experimental setup.