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Development of back corona discharge in a wire-cylinder electrostatic precipitator at high temperatures

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ABSTRACT

High-temperature electrostatic precipitation is a potential method for hot gas clean-up that is hindered by the issue of back corona discharge (BCD). This paper reports on the development of BCD at 350–700 °C in a wire-cylinder electrostatic precipitator (ESP). As the output voltage of power supply increases, BCD begins at the surface of the ash layer, and then it extends toward the electrode gap space, forming consecutive discharge channels that bridge the two electrodes, ultimately leading to spark breakdown (SB). The discharge process that follows BCD can be classified into different stages: the NCD & BCD stages, the weak NCD, BCD & glow discharge stage, and the BCD & SB stages. At high temperatures (500 °C or above), BCD is likely to convert to SB. In the NCD & BCD stages, the collection efficiency of the electrostatic precipitator is not affected, i.e., the collection efficiency is ~99.65%, regardless of whether BCD exists or not at a temperature of 350 °C and a port voltage of ~17,200 V. In the BCD & SB stages, the collection efficiency is greatly reduced, i.e., it is ~88.35% in the NCD-only stage at a temperature of 500 °C and a port voltage of ~14,000 V, whereas it is only ~67.42% in the BCD & SB stages. It should be noted that BCD results in an increase in the power consumption of the ESP for all stages. A physical model is proposed to explain the processes that initiate, maintain, and develop BCD.

1. Introduction

The integrated gasification combined cycle (IGCC), and poly-generation systems are advanced power generation technologies, which promise electricity generation with substantially greater thermodynamic efficiencies and reduced environmental impacts [1–4]. Hot gas clean-up is a key issue for IGCC systems and poly-generation systems [5, 6]. Table 1 lists some IGCC power plants in the world, and the operating temperature of dust removal is usually below 500 °C [7–10]. Ceramic filter is the most popular method for hot gas clean up in IGCC plants, which can easily be clogged and then has an unacceptable pressure drop across the filter [11,12] or unexpected break during long-term tests [13]. Smid et al. [14] regarded the development of advanced power systems were aimed toward the use of particulate collection temperatures of 370 °C to 595 °C for IGCC. Particles should be separated from gas at a temperature of ~500 °C or above in order to recover tar for poly-generation systems. It is because tar would become liquid and mix with particles at low temperatures, which is very hard to deal with [4].

High-temperature electrostatic precipitation is considered to be a potential method for dust removal in hot gas. The characteristics of negative corona discharge at high temperatures have been reported in our previous studies [15–17], and a particle mass collection efficiency of greater than 99.6% has been obtained experimentally [18]. It should be noted that back corona discharge represents a great obstacle to high-temperature electrostatic precipitation if the deposited particles on the earthed electrode cannot be cleared in time.

In an electrostatic precipitator (ESP), charged particles are collected on the earthed electrodes, where a porous ash layer is formed, and the ionic current passes through the ash layer. Electric charges accumulate on the surface and within the ash layer if the resistivity of the ash is sufficiently high, i.e., greater than 10^{12} Ω·cm [19]. With the accumulation of electric charge, the voltage drop across the ash layer increases until electrical breakdown occurs, a phenomenon known as back corona discharge (BCD) [20,21]. BCD is always a challenge for electrostatic precipitators, regardless of whether an ESP operates at conventional temperatures or high temperatures. Various studies have reported on the BCD phenomenon [22–30] and its effect on the performance of an ESP [31–33]; BCD has been observed to increase the electric current in the circuit. Cross [22] considered that the increased current was due to the increase in the frequency of the Trichel pulses at the cathode when BCD occurred. Masuda and Mizuno [23–26] classified BCD into three modes, namely the space streamer, surface streamer and mixed streamer modes. Czech et al. [27], Rajch et al. [28] and Jaworek et al. [29] investigated BCD in a point-plane configuration with fly ash as the dielectric layer using a diagnostic method involving optical emission spectroscopy, and they observed that the characteristic intensity of emission lines of active species induced by BCD was different from that of the emission lines of active species induced by corona discharge; this result was also confirmed by Krupa [30]. Patel et al. [31] and Krupa

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Table 1
Representative IGCC plants in the world.

Power plants	Methods of dust removal	Operation temperature
Demkolec, Netherlands	Cyclone & ceramic filter & water scrubbing [7]	235 °C for ceramic filter, and 165 °C for water scrubbing [7]
Elcogas, Spain	Ceramic filter & water scrubbing [8]	236 °C for ceramic filter, and 165 °C for water scrubbing [8]
Wabash River, USA	Candle ceramic filter [9]	371 °C [9]
Tampa, USA	Water scrubbing [10]	371–427 °C [10]

et al. [32] reported that BCD has a negative effect on particle collection efficiency because positive ions produced by BCD enter the electrode gap space, thereby decreasing the negative charges on particles and the force driving the particles toward the collection electrode. Chang and Bai [33] indicated that BCD increased the power consumption of an ESP due to the increase in the discharge current.

There are rare fundamental studies regarding how BCD is maintained after it occurs, how BCD interacts with normal corona discharge (NCD), and how BCD affects spark breakdown (SB). This paper reports on a study of the development of visible BCD at 350–700 °C in a wire-cylinder electrostatic precipitator and the effects of BCD on the particle collection efficiency.

2. Experimental setup

Fig. 1 shows a schematic of the wire-cylinder electrostatic precipitator considered in this study. The system consists of a blower, a gas flow-meter, a particle feeding device, connecting pipelines, programmable heating devices, an electrostatic precipitator and a high-voltage electric circuit.

The particle feeding system includes an electromagnetic vibrating feeding device, a vibration controller and a Venturi tube. The mass flow of particles is adjusted by the vibration controller. The mass concentration of particles is detected using a Dekati PM10 impactor and an electronic balance. The gas stream is heated by a heating furnace, which is connected to a programmable temperature controller. Six tubular heating elements are installed around the electrostatic precipitator to maintain the gas temperature. The high-voltage electric circuit consists of a negative high-voltage DC power supply, a protecting resistor, a high-voltage probe, a Keithley 6514 electrometer, an oscilloscope and the wire-cylinder ESP. An adjustable mirror is placed under the ESP to observe BCD. The gate at the bottom of the ash silo is closed during the electrostatic precipitation experiment, whereas it is opened to obtain images of BCD, which are reflected in the mirror.

An extendable stick is used to measure the thickness of the ash layer on the anode tube. As shown in Fig. 2(a), a pin is fixed at one end of the extendable stick perpendicular to the axis of the stick. Apiezon-L (a type of glutinous grease) is painted onto the tip of the pin. By plunging the pin into the ash layer deposited on the anode tube, the ash adheres to the pin, and then the thickness of the ash layer is measured using a vernier caliper under a magnifier, as shown in Fig. 2(b).

Chemical compositions of two kinds of fly ash from Hangzhou and Jiaxing coal combustion power plants are shown in Table 2. Fig. 3 displays the resistivities at 100–800 °C for the two kinds of fly ash. The resistivities at 350–700 °C are similar and are in the ranges of 9.32×10^7 to ~1.23×10^{10} Ω·cm and ~3.44×10^7 to ~7.46×10^{10} Ω·cm, respectively, which are both within the proper resistivity range for electrostatic precipitation, i.e. 10^6–10^{10} Ω·cm [34]. Ash from Hangzhou power plant is used in this work.

3. Results

3.1. BCD development and discharge stages

It should be noted that the following data regarding BCD development were obtained in an operating ESP and that some of the operating conditions discussed are listed in Table 3. The ash layer thickness is different indifferent parts of the earthed electrode during operation, and the characteristics of BCD are mainly determined by the greatest

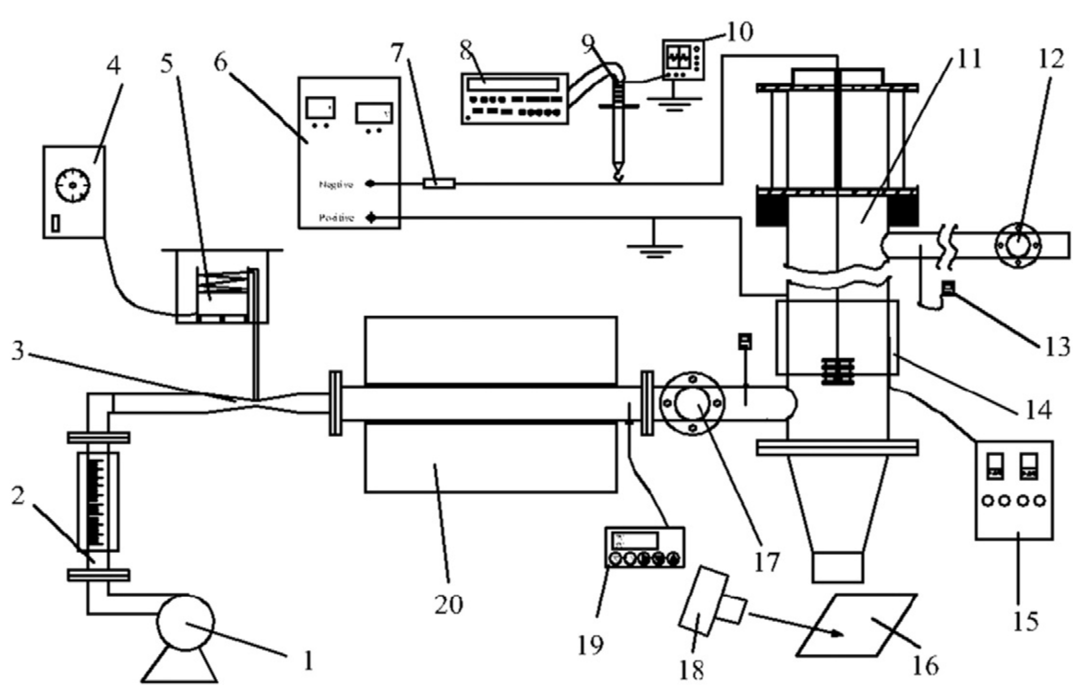

Fig. 1. Schematic of the wire-cylinder electrostatic precipitator: 1—blower; 2—gas flow-meter; 3—Venturi tube; 4—vibration controller; 5—electromagnetic vibrating feeding device; 6—high voltage power supply; 7—protection resister; 8—6514 electrometer; 9—P7400 high-voltage probe; 10—oscilloscope; 11—electrostatic precipitator; 12—sampling port 1; 13—thermocouple 2; 14—tubular heating elements; 15—programmable temperature controller 1; 16—mirror; 17—sampling port 2; 18—camera; 19—programmable temperature controller 2; and 20—heating furnace.