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Sensitivity analysis on the maximum ash resistivity in terms of its compositions and gaseous water concentration

X. Li, X. Zhang, J. Zhu, W. Feng, K. Yan*

Industrial Ecology and Environment Research Institute, Zhejiang University, Hangzhou 310028, China

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ABSTRACT

Fly ash resistivity is one of the critical factors influencing its collection efficiency of electrostatic precipitators (ESPs). This paper discusses the resistivity in terms of ash compositions and water concentration and evaluates available resistivity models with over 120 groups of ashes. The analysis shows that the available models hardly match each other for predicating the resistivity. With regard to ash compositions, only Li_2O plus Na_2O and Fe_2O_3 have obvious effects on the maximum resistivity. A new simplifying model is proposed for approximating the maximum ash resistivity in terms of the ash compositions and the water concentration, which is used to size ESPs and to predicate the collection efficiency.

1. Introduction

Today, electrostatic precipitators (ESPs) have been widely applied in industries, and a number of ESPs need to be upgraded for matching the latest emission standards. Our knowledge for predicating ESP performances, however, is still poor because of lack of reliable ESP models. Many factors do influence ESP performance, such as flue gas velocity, gaseous temperature and compositions, electrical power sources, ESP configuration and fly ash characteristics [1–5]. Ash resistivity is one of the critical parameters to affect ESP's collection efficiency and power consumption. For higher than 10^{12} Ω cm and smaller than 10^4 Ω cm ashes, ESP performance significantly deteriorates due to ash reentrainment. A small value of resistivity leads collected ash too fast losing its charge. A higher value, however, hardly leads to discharge its charges but to the so-called back corona [1,6]. As a result, ash reentrainment occurs in such cases. Many investigations have been performed to limit the reentrainment and/or back corona by optimizing electrode rapping [7], electrode construction [8], flue gas conditioning [9,10] and upgrading the power sources [11,12] for energy saving and emission reduction.

Ash resistivity models have been very useful for selecting and/or blending coals and sizing ESPs in order to achieve a better ESP performance. Ash and gaseous compositions, electric field strength and temperature play key roles for determining its value. As a pioneer, R.E. Bicklhaupt proposed one analytical model to derive the resistivity in terms of ash compositions, electric field and gaseous temperature [13]. V. Arrondel and G. Bacchiega recently reported a comprehensive ESP model and also developed the so-called ORCHIDEE, by which the ash resistivity and the particle grade collection efficiencies can be evaluated in terms of coal characteristics and ESP specifications [14]. After Bicklhaupt's model, Chandra proposed a revised one with new coefficients according to Indian utilities [15]. These three empirical models present the state of the art of theoretical investigations on the ash resistivity. Unfortunately, those models hardly match each other when considering ash effects on the resistivity. As part of our investigations on fine particle collection [19,20], this paper discusses those models and also proposes a new one by considering sensitivity analysis on the maximum resistivity with over 120 types of Chinese ashes. Its final objective is to develop an industrial ESP model for upgrading ESPs to control fine particle emissions.

2. Ash resistivity models

As an example, Table 1 lists three selected ash compositions used in this paper for discussing those available models. Their resistivity values were obtained in laboratory without considering effect of gaseous SO_3. The ash compositions are presented in terms of their weight percentage. The first sample is selected according to

* Corresponding author. Fax: +86 571 88210340.
E-mail address: kyan@zju.edu.cn (K. Yan).

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Table 1
Typical ash composition.

Composition	Sample1	Sample2	Sample3
$Li_20 + Na_2O$ (%)	9.72	0.15	7.84
K_2O (%)	0.60	1.34	7.84
MgO (%)	3.70	0.71	0.76
CaO (%)	17.30	2.57	10.70
Fe_2O_3 (%)	8.70	6.58	7.80
Al_2O_3 (%)	19.30	31.03	19.00
SiO_2 (%)	28.90	51.61	42.10
TiO_2 (%)	1.90	2.60	2.60
P_2O_5 (%)	1.00	0.13	0.26
SO_3 (%)	5.70	0.23	2.40

the Bickelhaupt database [13], which is for US coal. The second sample is based on Chandra's model [15], which is for Indian coal, and the third sample is from the IEEE Std 548-1984 [17] as a reference.

2.1. Bickelhaupt's model

Bickelhaupt's model consists of three parts, i.e. volume resistivity ρ_v, surface resistivity ρ_s and acid resistivity ρ_a as expressed by Eqs. (1)–(3), respectively. When there is no significant amount of sulfuric acid vapor, its total resistivity ρ_{vs} is derived as the Eq. (4). If significant amount of the acid vapor exists, the total resistivity ρ_{vsa} is then calculated with Eq. (5) via ρ_{vs} and ρ_a [13].

$$\log\rho_v = -1.8916\log A_{ls} - 0.9696\log A_i + 1.237\log A_{mc} - 0.03E + \frac{4334.515}{T} + 1.57595 \quad (1)$$

$$\log\rho_s = -2.233348\log A_{ls} - 0.000764C_W - 0.03E - 0.000321C_W\exp\left(\frac{2303.3}{T}\right) + 11.98555 \quad (2)$$

$$\log\rho_a = 25.65278 - 0.371201C_{SO_3} - \frac{5667.313}{T} - 0.03E \quad (3)$$

$$\frac{1}{\rho_{vs}} = \frac{1}{\rho_v} + \frac{1}{\rho_s} \quad (4)$$

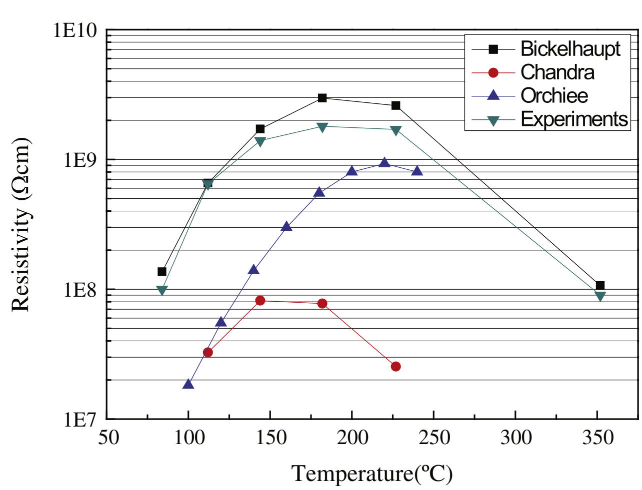

Fig. 1. Theoretical and experimental resistivities for the ash sample 1 under 2 kV/cm and 9% of H_2O.

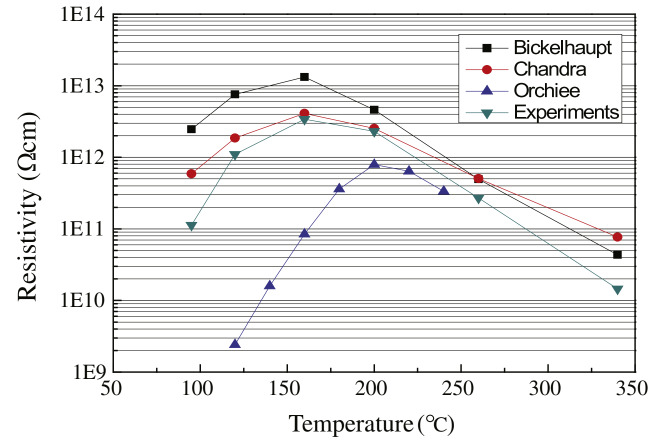

Fig. 2. Theoretical and experimental resistivities for the ash sample 2 under 4 kV/cm and 9% of H_2O.

$$\frac{1}{\rho_{vsa}} = \frac{1}{\rho_{vs}} + \frac{1}{\rho_a} \quad (5)$$

Where, A_{ls}, A_i, and A_{mc} are the atomic concentrations of lithium plus sodium, iron, and magnesium plus calcium in unit of percentage, respectively. E is electric field intensity in unit of kV/cm. T is absolute temperature in K. C_w is water concentration in %. C_{SO_3} is SO_3 concentration in dry volume in parts per million (ppm).

2.2. Chandra's model

Chandra's revised model is based on Bickelhaupt's one. The used coefficients are, however, revised and corrected according to the ash samples from Indian power plants. The sulfur concentration is usually low for Indian coals, so the acid resistivity is ignored in the Chandra's model [15]. The revised volume ρ_v, surface ρ_s and total ρ_{vs} resistivity values are expressed by the following Equations.

$$\log\rho_v = -3.6695\log A_{ls} - 2.1861\log A_i + 2.5514\log A_{mc} - 0.058847E + \frac{3394.117}{T} + 1.461271 \quad (6)$$

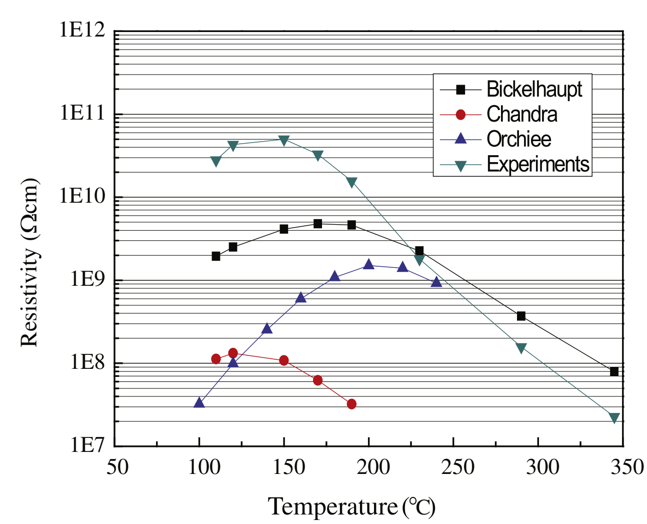

Fig. 3. Theoretical and experimental resistivities for the ash sample 3 under 4 kV/cm and 6% of H_2O.