The influence of unburned carbon particles on electrostatic precipitator collection efficiency

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Abstract. Laboratory tests have shown that the chemical composition of fly ash (in that unburned coal) as well as its size distribution has significant influence on the dust cleaning process. Likewise the design of discharge electrodes has shown a strong influence on the dust cleaning. Tests of precipitation efficiency were carried out on a laboratory electrostatic precipitator (ESP) model using fly ash samples of diverse size distribution and unburned coal content collected from several grate boilers. Test results show explicit dependency of the ESP precipitation efficiency on physical and chemical characteristics of the fly ash, design of discharge electrodes and amount of electrical energy delivered to the ESP. Mercury concentration measurements show higher levels in the fly ash than in the fired coal indicating high sorption capacity of the fly ash. Prior observation suggests good mercury adsorption on fine fly ash particles in the presence of elemental coal. Hence the improvement of ESP collection efficiency of fine particles containing unburned coal may help decrease the emission of mercury.

1. Introduction
Studies of the dust separation process in electrostatic precipitators [1, 2, 3] have shown that chemical composition of fly ash – mainly containing unburned coal – has significant influence on precipitation efficiency. New dust emission standards for small power plants using grate boilers as well as introduction of deNOx systems in big power plants – especially with low NOx burners – will require even more efficient precipitation of fly ash because of its high content of unburned coal.

Although theoretic principles of dust separation process in electrostatic precipitators are well known [4, 5], further studies of the influence of construction and electric parameters of discharge electrodes on ESP performance efficiency are essential. Particularly studies on optimal selection of ESP discharge electrode construction seem very important.

2. Experimental
The test bench was comprised of one stage electrostatic precipitator (ESP) model chamber with a set of discharge and collecting electrodes, ESP inlet and outlet air ducts, dust particle feeder, high voltage supply unit (negative polarity) and exhaust fan [3].

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2.1. Fly-ash analysis

Physic-chemical analyses of the fly-ash used in tests are given in table 1. Figure 1 shows results of fly-ash particle size distribution.

| Parameter                  | Units | Fly ash type |
|----------------------------|-------|--------------|
| Chemical composition of ash: | %     | G            | A     | K    |
| SiO₂                       |       | 28.99        | 25.74 | 40.39 |
| Fe₂O₃                      |       | 3.67         | 5.91  | 10.01 |
| Al₂O₃                      |       | 17.14        | 24.31 | 18.09 |
| TiO₂                       |       | 0.86         | 1.24  | 0.96  |
| CaO                        |       | 2.82         | 2.18  | 5.44  |
| MgO                        |       | 1.01         | 0.50  | 1.47  |
| SO₃                        |       | 2.26         | 5.76  | 1.27  |
| K₂O                        |       | 2.68         | 3.58  | 2.08  |
| P₂O₅                       |       | 0.01         | 2.10  |       |
| Na₂O                       |       | 1.14         | 2.82  | 1.47  |
| Unburned carbon in ash:    | %     | 28.60        | 23.31 | 17.92 |
| Density                    | kg/m³ | 2090         | 2320  | 1760  |
| Resistivity                | ohm cm| 5×10⁷        | 1×10⁸ | 2×10⁷ |

The tested fly-ash samples G, A and K characterize high unburned coal contents in a range of 18-28%. The measured fly-ash resistivity in laboratory conditions was 10⁷-10⁸Ω×cm and remained almost steady with temperature changes from 20°C to 215°C.

The particle size distribution of tested fly ashes was measured using a Mastersizers 2000 analyzer of Malvern Instruments, and the resultant distribution curves (figure 1) show characteristic shape of fly ashes from grate boilers.

2.2 Discharge electrodes configurations

The discharge electrode (DE) shape and basic dimensions are depicted by figure 2 and voltage-current characteristics of tested electrode configuration by figure 3.

![Figure 2](image1.png)  
**Figure 2.** Design of the discharge electrodes, dimension in mm.

![Figure 3](image2.png)  
**Figure 3.** Current-voltage curves of discharge electrodes tested under clean air conditions.
The voltage-current characteristics of tested discharge electrodes clearly differentiate construction of electrode for: (1) low-current electrodes and (2) high-current electrodes, so called ‘aggressive’.

3. Results and discussion
Performance tests were conducted on a bench scale laboratory ESP with fly ash samples described in table 1 and figure 1. The test results are presented as a function of ESP applied voltage for different ash samples on figure 4 and figure 5 for discharge electrode type (2) and (3) respectively. For all tests the air flow velocity in the ESP was held constant at 0.8 m/s and the dust concentration at 0.2 g/m$^3$.
For each level of the supply voltage three collection efficiency tests were carried out.

![Figure 4. Collection efficiency as a function of applied voltage for discharge electrode type (2).](image1)

![Figure 5. Collection efficiency as a function of applied voltage for discharge electrode type (3).](image2)

Collection efficiency of fly ash type A for both tested discharge electrodes shows a typical shape (the increasing tendency with increase of applied supply voltage). In a case of fly ash type K the influence of applied voltage on collection efficiency is negligible although with type (2) discharge electrode the results were better. Collection efficiency of fly ash type G and discharge electrode (2) decreases when applied voltage over crosses a level of 40 kV, but for discharge electrode (3) presents slight increase only but at lower values. It should be mentioned that this fly ash contains more than 28% of unburned coal. It seems that there is a certain applied voltage level above which further collection efficiency will not be possible.

The above observations show that besides the unburned coal contents of fly ash and its resistivity other factors also affect the precipitator collection efficiency. It calls on further investigation on such fly ashes with special consideration to its chemical composition and unburned coal content for respective particle size distribution ranges.

4. Studies on Mercury contents in fly ashes
The study of mercury content in fly ash at the ESP inlet has shown that it is several times higher than the mercury contents of the fired coal (for hard coal it is in a range of 50 to 150 ppb), suggesting a high sorption capacity of the fly ash [6]. Typical samples of fly ash G taken at power plant conditions have shown the following mercury content values:
- from ESP inlet: 1.0925 mg/kg (ppm)
- inside ESP: 0.6615 mg/kg (ppm)
- from ESP outlet: 7.5303 mg/kg (ppm)
Additionally the mercury content for respective particle size distribution ranges of fly ash sample G collected from typical ESP has been measured and the results presented in table 2.

| Fly ash sample | Dust diameter (µm) | Mercury content (ppm) |
|----------------|--------------------|----------------------|
| (G)            | 0-3                | 9.0827               |
|                | 3-10               | 6.2917               |
|                | 10-24              | 3.6420               |
|                | 24-45              | 1.0657               |

The above experimental results confirm professional literature suggestion about mercury accumulation in fine particles emitted from coal combustion processes [7]. Therefore a serious improvement of fine particles collection efficiency becomes critically necessary for also reducing the mercury emission after combustion processes.

5. Summary
Analysis of experiment results showed some problems in collection of fly-ash from stocker-fired boilers:
- decrease of collection efficiency for high content of unburned carbon in the fly ash,
- no clear relationship between the supply voltage and collection efficiency of fly ash,
- the improvement of bulk fine particle collection efficiency which may significantly reduce the mercury emission into atmosphere.

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References
[1] Barranco R, Gong M, Thompson A, Cloke M, Hanson S, Gibb W, Lester E 2007 The impact of fly ash resistivity and carbon content on electrostatic precipitator performance, Fuel 86 2521-2577
[2] Senneca O 2008 Burning and physico-chemical characteristics of carbon in ash from a coal fired power plant Fuel 87 1207-1216
[3] Jeđrusik M and Świerczok A 2009 The influence of fly ash physical & chemical properties on electrostatic precipitation process Journal of Electrostatics 67 105-109
[4] White H J 1990 Industrial Electrostatic Precipitation (prep.), (International Society for Electrostatic Precipitation, Library of Congress Catalog Card No 62-18240)
[5] Parker K R 1997 Applied Electrostatic Precipitation (London: Blackie Academic & Prof.)
[6] Hower J C, Senior C L, Suuberg E M, Hurt R H, Wilcox J L 2010 Mercury capture by native fly ash carbons in coal-fired power plants Progress in Energy and Combustion Science 36 510-529
[7] Sung-Jun L, Yong-Chil S, Ha-Na, J, Kyu-Shik P, Jeom-In B, Hi-Soo A, Kwang-Chul S 2006 Speciation and mass distribution of mercury in a bituminous coal-fired power plant, Atmosph. Envir. 40 2215-2224