BIOMASS CO-FIRING. NEW CHALLENGE FOR ELECTROSTATIC PRECIPITATORS

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1 Abstract

Power plants are the most important sources of atmospheric contaminants. It refers equally to conventional, coal-fired, as well as biomass co-firing plants. Biomass burning causes new operational problems in electrostatic precipitators. Although there are an increasing number of publications on troubles encountered in biomass co-firing boilers, there is still low number of papers on experimental or operational results regarding the electrostatic precipitators cleaning the flue gases from co-fired biomass. These new problems arising in electrostatic precipitators result from the fact that these precipitators were designed for burning the coal, which is of different chemical composition than the biomass and the physical properties of fly ash are also different. The differences in flue gas composition, particularly variations in particle size distribution in submicron size range, increased emission of CO, and tar leaving the boiler. These new after-burning products, can cause degradation of construction elements of ESP, for example, chlorine or sulfur corrosion of metals, degradation and contamination of HV insulators, etc. Tar present in flue gas after wood burning can, after a longer time, be deposited onto the insulators, changing their electrical properties and causing an increase in leakage current or even the surface breakdown. It was reported in the literature that increased amount of CO in the flue gases can result in fires in ESP. It seems plausible that the same problems will be encountered in ESP cleaning flue gases from biomass burning boilers. The long-term effects of co-firing on the electrostatic precipitator are, however, not known.

There are also met some reports on positive aspects of biomass co-firing for ESP operation. It was noticed that the emission of SO_2 and NO_x is reduced when a small amount of biomass is added to the bituminous coal, due to Ca, K and Na content in the biomass. The emission of SO_3 is also decreased because of high concentration of CaO in the fly ash. However, due to the reduction of SO_3 and low content of unburned coal in fly ash, the flue gas conditioning would be necessary in order to prevent the back discharge in ESP. This effect can be slightly compensated by higher moisture content in flue gas after biomass co-firing.

The purpose of this paper is to outline some new aspects of the effect of biomass co-firing on the short- and long-term operational properties of electrostatic precipitator. The considerations are based on preliminary reports met in the literature and some experimental results of the authors

2 Introduction

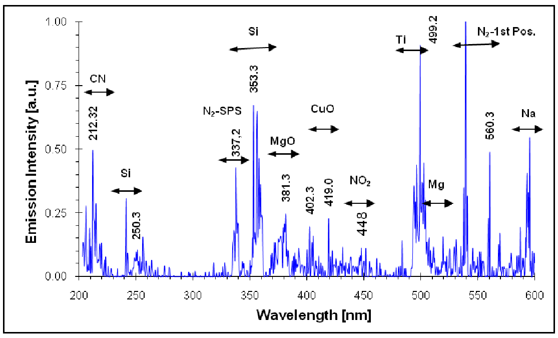
Power plants are one of the most important sources of atmospheric contaminants. It refers equally to conventional, coal-fired, as well as biomass co-firing plants. Recently, biomass is added to coal in order to decrease additional emission of carbon dioxide. To biomass belong all organic products originating from agriculture, forestry or food industry, which are

suitable to be burned. With co-fired biomass, the chemical composition and physical properties of fly ash significantly change that causes new operational problems in cleaning flue gases with electrostatic precipitators. This problem has not been sufficiently extensively dealt in the scientific publications. Some of the reports indicate that current operational properties of electrostatic precipitators do not change significantly when a few percents of sawdust is co-fired with bituminous coal [1], however, a long-term effect on the electrostatic precipitator has not been identified yet.
The effect of biomass co-firing on the short- and long-term operational properties of electrostatic precipitator based on preliminary reports met in the literature and some experimental results of the authors are discussed in the paper.

3 Fly ash properties

Main components of fly ash exhausted from coal-fired boilers are SiO_2 (roughly 1/2), Al_2O_3 (1/4) and Fe_2O_3 (1/8) [2]. Other elements which content is larger than 1 mg/g each, are Ca, Na, Mg, K, Ti, S [3, 4, 5]. These ratios can vary depending on the mine the coal was taken from. In chemical composition of fly ash from biomass co-fired boilers the percentage of these components decreases because the alkaline compounds (CaO, MgO, NaO, K_2O, P_2O_5) originating from co-fired biomass appear [6, 7, 8]. The minerals comprise about 8 wt.% in coal, but about 6 wt.% in straw, 2.8 wt.% in willow, and 0.3 wt.% in beech [9].
The differences in chemical composition can be shown, for example, in the emission spectrum of fly ash subjected to electrical discharge. The results for the fly ash from burned bituminous coal and the coal co-fired with biomass are compared in Fig. 3-1. Intense lines of Na, Mg, Ca, and SO_2 can be noticed in the emission spectrum. Nitriles (CN) are probably an effect of chemical reactions between coal and nitrogen caused by the electric-discharge plasma.

(a)



(b)

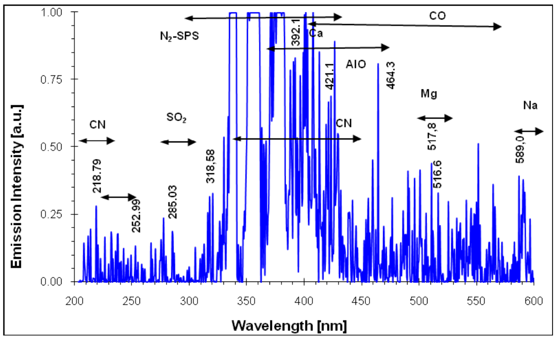


Fig. 3-1: Emission spectra of fly ash from bituminous coal (a) and the coal co-fired with biomass (b). Pulverized-fuel boiler in Gdansk Power Plant EC-2, year 2002 (a), year 2009 (b). Electrode distance 20 mm, voltage 25 kV

The elemental composition of the fly ash from biomass co-fired boiler is shown in Fig. 3-2. Main elements, of weight percentage larger than 1%, found in the fly ash are Oxygen, Carbon, Potassium, Silicon, Sodium, Aluminum, Sulfur, Phosphorus, Iron, Calcium. Similar results were obtained for the fly ash from coal fired boiler. Trace elements like heavy metals were not identified with this method. It should be noted that high content of carbon can originate from carbon tape used in SEM as substrate for the fly ash.

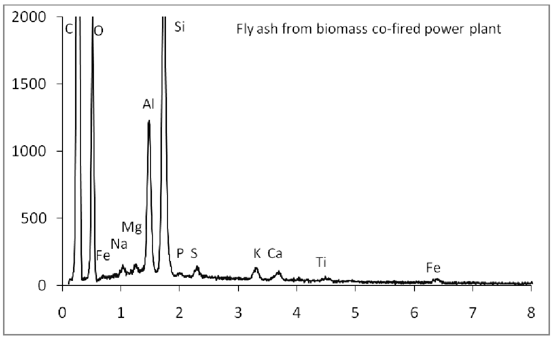


Fig. 3-2: Elemental composition of fly ash from the coal co-fired with biomass. Pulverized-fuel boiler in Gdansk Power Plant EC-2, year 2009

The size of fly ash particles from the coal-fired boilers is in the range of 20 nm to 200 μm [10]. It was also noticed that total emission of particulate matter decreases when biomass is co-fired, but, at the same time, increases the number of submicron particles, which are difficult to be removed by electrostatic precipitators [11, 12]. The submicron particles are mainly formed from the compounds of Ca, Fe, Al, Mg, Si [7], and small amounts of compounds of K, S, Mn, Cl [8]. Two distinctive ranges in particle size from coal can be distinguished: smaller than 1 μm, which constitute only 1% of total mass but 99% in number size distribution, and larger than 1 μm [13]. The mean mass density of fly ash is about 2.45×10^3 kg/m^3 [2, 14], and is close to the density of main component of fly ash - SiO_2 (2.2×10^3 kg/m^3). Submicron particles are formed as a result of bursting of larger ones due to the gas explosion present within the mineral components of the fuel. These particles absorb volatile elements before condensing and bear most of the metals released from the fuel [4]. The emission of biomass-burned particles decreases when the moisture content in the fuel is in the range of 15-25% (sawdust) [15]. Higher moisture content causes a decrease in the temperature in boiler that results in not complete burning of biomass and higher emission of fly ash and tar. Lower water content causes volatilization of lighter hydrocarbons which are exhausted to the atmosphere [15].

The differences in fly ash morphology from burned bituminous coal and the coal co-fired with biomass are compared in Figs. 3-3 and 3-4. Scanning electron microscope photographs of the fly ash from bituminous coal taken from the third stage of electrostatic precipitator in Gdansk Power Plant EC-2 show that particles larger than 1 μm are spherical (Fig. 3-3). Particles smaller than 0.1 μm are irregular in shape and firmly adhere to the larger ones. The larger particles are formed from fused silica with alumina. In the fly ash from the bituminous coal co-fired with biomass, there are irregular, basket-like particles originating from the burned biomass of the size of 100 μm or larger (Fig. 3-4b). These baskets are frequently filled with smaller particles, which are the mineral components of coal. The aerodynamic density of the basket particles is much lower than the mineral components, mainly SiO_2 and are difficult to be removed in first and second stages of ESP.

In boilers co-firing biomass, Na and K released during burning are volatilized in high temperatures and are deposited onto boiler inner surfaces that results in faster corrosion of the boiler parts. An effect of Na, K and Cl on the corrosion in electrostatic precipitators has not been investigated yet.

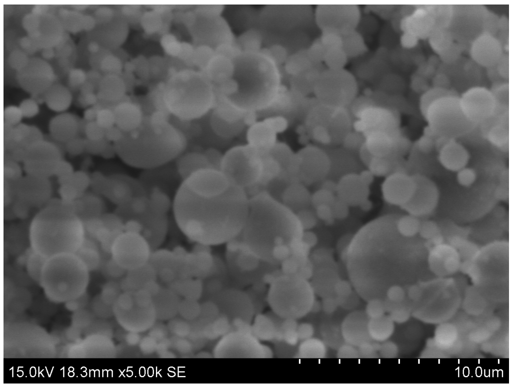
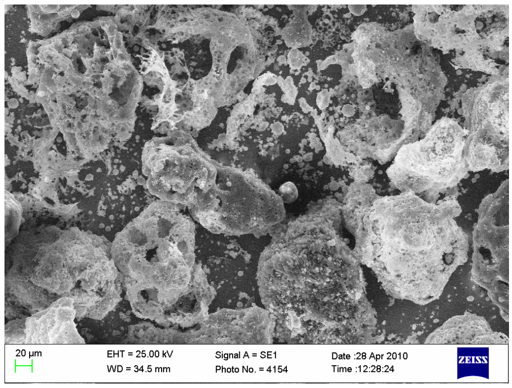


Fig. 3-3: SEM micrographs of fly ash from bituminous coal. Pulverized-fuel boiler in Gdansk Power Plant EC-2, year 2002

(a)



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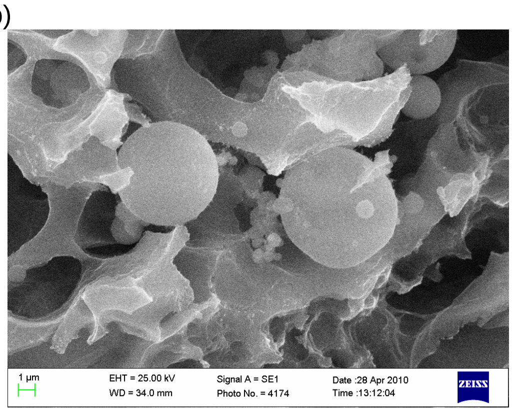

Fig. 3-4: SEM micrographs of fly ash from bituminous coal co-fired with biomass. Pulverized-fuel boiler in Gdansk Power Plant EC-2, year 2009

The equilibrium of Stokes drag force and electrostatics force on a fly ash particle charged to the Pauthenier limit in the electric field E gives the terminal velocity of the particle:

$$w = \frac{2r\varepsilon_0 E^2}{\eta}\frac{\varepsilon_r}{\varepsilon_r + 2} \qquad (1)$$

From this equation results that the velocity is proportional to the particle radius that should speed-up the migration of such particles towards collection electrode and increase the collection efficiency compared to small fly ash particles. However, equation (1) is valid for smooth solid particle or undistorted droplet. Particles emitted after biomass firing are not smooth, have many voids and for this case the drag force has not been determined yet. Also the process of charging of such irregular particles has also not been recognized. The charge of biomass-burned particles would also be changed because of different dielectric constant of the material.

4 Heavy metals emission

The emission of heavy metals is another issue in coal burning. The heavy metals detected in bituminous coal are Se, As, Cd, Hg, Ni, Pb, Cr, Sr, Be, V and U. They are mainly in the form of submicron particles, which are particularly difficult to remove [3, 5, 14, 16, 17, 18]. In the case of biomass co-firing, the heavy metals are chemically bounded in the bottom ash at the temperature of 700ºC or higher. For example, only 0.8-4 % of cadmium has been volatilized (at 830ºC) while the rest was bounded within the fly ash particles. Lead and cooper are bounded in the bottom ash (Cu: 28-30%, Pb: 14-16%). Volatilized Zn was at the level of 0.1-0.3%. The results of investigation on the effect of biomass co-firing on heavy metals emission are not conclusive: an addition of biomass can increase or decrease the heavy metals emission, depending on many circumstances, including the content of Cl and S in the biomass [19].

5 Gaseous compounds emission

In pulverized-fuel boilers, the NO_x compounds are formed from the nitrogen originating from the fuel. It is emitted as HCN after coal burning or NH_3 after biomass burning [19]. The emission of SO_2 and NO_x decreases after the addition of biomass to the coal due to the content of alkali metals, such as Ca, K, Na, in biomass [1]. In the case of firing of coal and biomass, the conversion of sulfur to the SO_2 is inversely proportional to biomass percentage, and decreases for coarser biomass particles because of part of sulfur remains in the bottom ash [19]. However, flue gas conditioning would be required at too low concentration of SO_3 and SO_2, which is reduced by CaO and MgO, in order to increase the fly ash conductivity, and prevent decreased collection efficiency and back discharge in ESP.
The effect of biomass on the CO emission, and the role of CO on the collection efficiency of electrostatic precipitators are still controversial. The results presented by Kruczek et al. [19] indicate a decrease in the CO emission in boilers co-firing forest-wood waste. Wiltsee [20] reports that biomass causes an increase of CO concentration. Probably the differences depend on the kind of biomass. Fires within the ESP due to too high concentration of CO have also been reported. The effect of CO concentration on the collection efficiency and operational parameters of ESP still require further investigations.

6 Tar emission

Tar is a class of organic compounds (mixture of condensable hydrocarbons) of molecular weight larger than molecular weight of benzene [21]. Electrical-discharge generated plasma can be favorable to the condensation of light hydrocarbons to the heavier ones. Such heavy hydrocarbons can form a coating on the insulators and electrodes, which is difficult to be removed. However, there lack sufficient data on the tar emission on operational properties of ESP. Van Paasen et al. [22] reported on the results of operation of a wet ESP cleaning a biogas, and concluded that the contamination of electrodes was insignificant after 200 h of operation. The inlet concentration of tar was from 0.9 to 2.2 g/m^3 and at the outlet 400-800 mg/m^3. The dew-point of the tar from biogas varied from 111ºC to 148ºC, and for polycyclic aromatic hydrocarbons it was about 20ºC. However there lack investigations of months-long operation of ESP for similar tar loading.
Incomplete burning of wood will form a difficult-to be removed deposit on insulators and electrodes of ESP. Results of experimental investigation indicated that the collection efficiency of ESP cleaning flue gas after wood combustion decreased from about 80% to below 20% after 5 hours of operation due to high tar content [23]. Most of the particles were deposited just under the discharge electrode as a result of high electric field at this place. Novel inventions which could solve this problem are an urgent need.

7 An effect of biomass co-firing on the collection efficiency of electrostatic precipitators

Preliminary laboratory tests have been carried out by Jędrusik et al. [24] on a laboratory model of electrostatic precipitator with various discharge electrodes and for fly ash from coal-fired fluidized boiler (sample C), the same coal with 10% co-fired biomass (sample B), and 50% of biomass (sample W). The size distributions of fly ash particles and their chemical composition do not differed much, with only increased percentage of K_2O (by about 1 wt.%) and SiO_2 (by about 4 wt.%) in the fly ash from co-fired biomass.

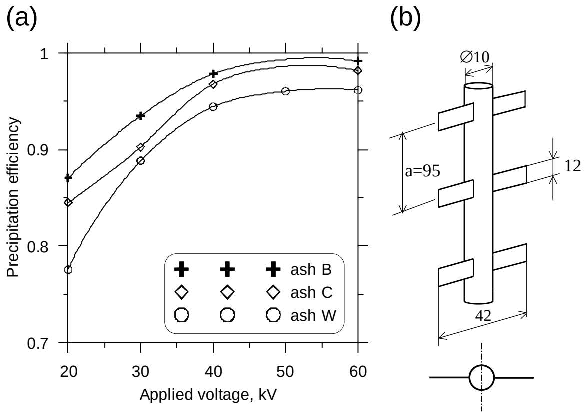

Fig. 7-1: a) Collection efficiency of laboratory-scale ESP vs. voltage of discharge electrode for various fly ash sources: fly ash C from burned bituminous coal, fly ash B from bituminous coal with 10% of co-fired biomass, fly ash W from bituminous coal with 50% of co-fired biomass; b) Scheme of the double-spike discharge electrode

Measurements of the collection efficiency of laboratory-scale electrostatic precipitator with double-spike discharge electrode (shown in Fig. 7-1b) are presented in Fig. 7-1a. The collection efficiency depends on electrical parameters of the discharge and the biomass percentage. The collection efficiency increases with an increase of the voltage supplying the discharge electrode, but it is saturated for a certain voltage magnitude, of about 50 kV, in this specific case. Further increase in the voltage can even cause a slight decrease in the collection efficiency. It was also determined, that small addition of biomass (10%) to bituminous coal causes an increase in the collection efficiency, whereas for higher content of biomass, 50% or larger, the collection efficiency decreases. These preliminary results indicate that further research on the effect of co-fired biomass content on the collection efficiency is required in order to optimize the operational parameters of electrostatic precipitator.

8 Conclusions

The effect of biomass co-firing on the operational parameters of electrostatic precipitator has been considered in the paper. There still lack sufficient data to answer the question which properties of flue gases cause a decrease of the collection efficiency of electrostatic precipitator and which help to improve the quality of exhaust gases. Another issue is the effect of chemical composition of flue gas, different from that from the coal fired boilers, on the contamination and degradation of electrostatic precipitator construction elements. The research in this field is also poor. The paper has indicated new directions in the investigations of the electrostatic precipitator operation when biomass is co-fired with coal in traditional boilers.

The positive and negative effects of the biomass co-firing on the electrostatic precipitators are summarized in Table 1. The further research should be aimed at the effect of biomass co-firing on the collection efficiency of electrostatic precipitator, emission of submicron particles, heavy metals and tar as well as contamination and degradation of electrodes and insulators due to increased production of tar, chlorine and sulfur compounds.

Table 1
Biomass co-firing
Positive and negative effects on electrostatic precipitator

Positive
1. Reduced emission of SO_2 and NOx (due to Ca, K, Na content, lower content of N and S in biomass). 2. Increased collection efficiency (larger particles, ease of agglomeration). 3. Reduced emission of mineral particles (due to lower content of minerals in biomass).
Negative
1. Chlorine and sulfur corrosion. 2. Electrodes and insulators contamination (due to increased tar emission). 3. Back-discharge ignition (due to reduced content of SO_3). 4. Reduced collection efficiency (because of too high resistivity of the fly ash). 5. Possible fires in ESP (due to increased emission of CO). 6. Increased emission of PM2.5 (due to higher concentration of submicron particles).

Acknowledgements: The research was supported by Polish Ministry of Science and Higher Education within the projects No. NR06-0014-06 and No. 3180/B/T02/2010/38. The authors are grateful to the Gdansk Power

Plant EC-2 for delivering fly ash samples for research purposes.

9 Literature

[1] Savolainen K.; *Co-firing of biomass in coal-fired utility boilers;* Appl. Energy 74**;** 2003; pp. 369-381

[2] Ylätalo S.I., Hautanen J.**;** *Electrostatic precipitator penetration function for pulverized coal combustion;* Aerosol Sci. Techn. 29; No.1;1998; pp.17-30

[3] Coles D.G., Ragaini R.C., Ondov J.M., Fisher G.L., Silberman D., Prentice B.A.; *Chemical studies of stack fly ash from a coal-fired power plant;* Envir. Sci. Technol. 13; No.4, 1979; pp. 455-459

[4] Smith R.D., Campbell J.A., Nielson K.K.; *Characterization and formation of submicron particles in coal-fired plants*; Atmosph. Environ. 13, 1979; pp. 607-617

[5] Hower J.C., Robertson J.D.**;** *Chemistry and petrology of fly ash derived from the co-combustion of western United States coal and tire-derived fuel*; Fuel Proc. Technol. 85; 2004; pp. 359-377

[6] Ruth L.A.; *Energy from municipal solid waste: a comparison with coal combustion technology*; Prog. Energy Combust. Sci. 24; 1998; pp.545-564

[7] Lighty J.S., Veranth J.M., Sarofim A.F.; *Combustion aerosols: Factors governing their size and composition and implications to human health;* J. Air Waste Manag. Assoc. 50**;** 2000; pp. 1565-1618

[8] Sippula O., Hokkinen J., Puustinen H., Yli-Pirila P., Jokiniemi J.; *Comparison of particle emissions from small heavy fuel oil and wood-fired boilers;* Atm. Envir. 43; 2009; pp. 4855-4864

[9] Golec T.; *Biomass co-firing in power-plant boilers;* Energetyka i Ekologia; 2004; pp. 437-445 (in Polish)

[10] Nielsen M.T., Livbjerg H., Fogh C.L., Jensen J.N., Simonsen P., Lund C., Poulsen K., Sander B.; *Formation and emission of fine particles from two coal-fired power plants;* Comb. Sci. Technol.; 174, Iss. 2; 2004; pp. 79-113

[11] Strand M., Bohgard M., Swietlicki E., Sanati M.; *Method for characterisation of fly ash particles at high temperatures;* J. Aerosol Sci. Suppl. 1; 2003, pp. S1321-S1322

[12] Lind T., Hokkinen J., Jokiniemi J.K.; *Electrostatic precipitator collection efficiency and trace element emissions from co-combustion of biomass and recovered fuel in fluidized-bed combustion;* Environ. Sci. Technol. 37; 2003; pp. 2842-2846

[13] Oglesby S. Jr.; *Future directions of particulate control technology;* A Perspective. J. Air Waste Manage. Assoc. 40; No.8, 1990; pp. 1183-1185

[14] Giere R., Carleton L.E., Lumpkin G.R.; *Micro- and nanochemistry of fly ash from a coal-fired power plant;* Am. Mineralog. 88; No.11-12; 2003; pp. 1853-1865

[15] Chau J., Sowlati T., Sokhansanj S., Preto F., Melin S., Bi X.; *Optimizing the mixture of wood biomass for greenhouse heating;* Int. J. Energy Res. 33; 2009; pp. 274-284

[16] Dinelli G., Bogani V., Rea M.; *Enhanced precipitation efficiency of electrostatic precipitators by means of impulse energization*; IEEE Trans. Ind. Appl. 27; No.2; 1991; pp.323-330

[17] Snadelin K., Backman R.; *Trace elements in two pulverized coal-fired power stations*; Environ. Sci. Technol. 35; 2001; pp. 826-834

[18] Pavageau M.P., Pecheyran C., Krupp E.M., Morin A., Donard O.F.X.; *Volatile metal species in coal combustion flue gas;* Environ. Sci. Technol. 36; No.7; 2002; pp.1561-1573

[19] Kruczek S., Skrzypek G., Muraszkowski G.; *Firing and co-firing of biomass with fossil fuels*; Czysta Energia; czerwiec 2007 (in Polish)

[20] Wiltsee G.; *Lessons learned from existing biomass power plants*; National Renewable Energy Laboratory - Report. Feb; 2000

[21] Tippayawong N., Inthasan P.; *Investigation of light tar cracking in a gliding arc plasma system;* Int. Chem. Reactor Eng. 8; 2010;Article A50, pp. 1-14

[22] van Passen S.V.B., Rabou L.P.L.M., Bär R.; *Tar removal with a wet electrostatic precipitator (esp); A parametric study*. 2nd World Conf. and Technology Exhib. on Biomass for Energy, Industry and Climate Protection. Rome, Italy, 10-14 May 2004

[23] Ruttanachot Ch., Tirawanichakul Y., Tekasakul P.; *Application of electrostatic precipitator in collection of smoke aerosol particles from wood combustion;* Aerosol and Air Quality Research, 11; 2011 pp. 90-98

[24] Jędrusik M.; *Electrostatic precipitators: development of techniques in the increasing of dust collection efficiency;* Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław; 2008; (in Polish)