Waldemar SOBIESKI[1], **Andrzej ŁASICA**[2]

Rafako (1), Warsaw University of Technology (2)

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Determination of insulation gaps in electrostatic precipitators – laboratory testing

***Abstract**. The article describes a study to verify the existing requirements used in the production process on insulating distances inside the ESP. The results confirmed the correctness of the distance used, in some cases, made it possible to reduce them. Additionally, checked during the test or the introduction of new or changed structurally elements will not adversely affect operating voltage ESP.*

***Streszczenie.** W artykule opisano badania mające na celu zweryfikowanie dotychczasowych wymogów stosowanych w procesie produkcyjnym dotyczących odległości izolacyjnych wewnątrz komory elektrofiltru. Wyniki badań potwierdziły poprawność stosowanych odległości, a w kilku przypadkach pozwoliły na ich zmniejszenie. Dodatkowo sprawdzono podczas badań czy wprowadzenie nowych lub zmienionych konstrukcyjnie elementów nie wpłynie negatywnie na napięcie pracy elektrofiltru. (Wyznaczenie odstępów izolacyjnych w elektrofiltrach – badania laboratoryjne).*

Keywords: Electrostatic Precipitator, Gas Cleaning, Insulations Gaps.
Słowa kluczowe: elektrofiltr, odpylanie, oczyszczanie powietrza, wytrzymałość napięciowa.

Introduction

Thanks to the simplicity of design, low cost of operation and high-efficiency of dust removal electrostatic precipitators have become the principal equipment applied for dust removal from gases originating from industrial processes. Despite the fact that the efficiency of dust removal in electrostatic precipitators exceeds 99%, more and more stringent environmental standards trigger even further increase of dust removal efficiency. This may be achieved, inter alia, via increase of the dust deposition area of collecting electrodes in the electrostatic precipitator, which is associated with the increase of mass of the equipment resulting in obvious price increase. Other method of achieving the highest possible efficiency of dust removal is the application of increasingly higher discharge voltage values in the process of electrostatic dust removal from gases.

The first electrostatic precipitators

The phenomenon of electrostatic dust removal from gases has been observed already in 1771 by the Italian scholar G. Beccaria, but more detailed studies on this phenomenon were conducted several decades, in the first half of the 19th century. The precursor to this research was the German mathematician M. Hohlfeld. He made a simple electrostatic precipitator consisting of a pipe and the electrode installed inside the pipe, along the axis thereof. This device, upon initiation of the corona discharge between the electrodes, has precipitated the smoke contained in the pipe.

Similar examination with precipitation of the tobacco smoke was performed by Guitard in 1850.

In 1884, a British Olivier-Lodge conducted further research on electrostatic precipitation of solid particles. He applied the electrostatic machine as a source of high voltage. The electrostatic precipitator constructed on the basis of his ideas proved successful in cleaning of flue gases from lead smelter. Lodge presented the results of his research at a conference held in Liverpool in 1886 [1].

The attempts of industrial application of electrostatic precipitators carried out at the end of the 19th century in Germany and England did not bring the positive results. The main problem was the lack of an appropriate high voltage source. In the laboratory environment satisfactory results were achieved using the electrostatic machine, but the voltage and power values thus generated proved to be insufficient for industrial applications.

Another milestone was reached with the application of high voltage transformer with mechanical rectifier for powering the ESP. The originator of this solution, Professor F.G. Cottrel performed in 1904 a successful attempt to clean the gases containing the sulfuric acid anhydride using the high-voltage transformer with a mechanical rectifier developed by Goldshmidt as a high-voltage source.

Theory

Dust removal efficiency is the main parameter for evaluation of electrostatic precipitator as a device for separation of dust or liquid particles from the gases. This parameter is described in Deutsch's equation (1). [2, 3]

$$\eta = 1 - e^{-A\omega/V}, \tag{1}$$

where: η – ESP dust removal efficiency, A – collecting electrodes surface, ω – charged particle migration velocity, V – gas flow rate.

In the equation above, the migration velocity is the sole parameter reflecting the impact of electrostatic phenomena on the efficiency of dust removal.

The dependence describing the theoretical velocity of migration is shown in the equation (2).

$$\omega_{th} = \frac{E^2 \cdot \varepsilon_0 \cdot d_p \cdot C_o}{\eta}, \tag{2}$$

where: ω_{th} – velocity of movement of a precipitated (charged) particle, E – electric field (proportional to the voltage applied to the electrodes of electrostatic precipitator), d_p – diameter of a precipitated particle, C_o – Cunningham's correction parameter, η – gas viscosity, ε_0 – permittivity of vacuum.

Both the diameter of a charged particle and the viscosity of gas are the parameters remaining beyond control of the manufacturers of electrostatic precipitators. Therefore, the electric field appears as the sole adjustable parameter. It is directly proportional to the voltage of discharge occurring between the collecting electrode and the discharge electrode. Due to the fact that the electric field, in the formula for ω_{th}, is raised to the second power, it is important that, for the efficiency of dust removal, the voltage between the electrodes is the highest possible. The upper achievable limit of discharge voltage is the voltage triggering the spark discharge between the elements positively and negatively polarized. In theory, the spark discharge shall occur between the discharge electrode and collecting electrode.

The complexity of issues related to electric discharge as well as the number of internal elements of electrostatic precipitator cause the occurrence of spark discharges in other places thus reducing the discharge voltage which is so important for dust removal efficiency.

The electrostatic precipitator features the “blade – plate” arrangement of electrodes where the discharge electrodes are “blades” and the collecting electrodes are “plates”. The discharge electrodes (blades) are negatively polarized and the collecting electrodes (plates) are positively polarized. The system with such a polarity has the low voltage at the beginning of discharge and the high breakdown voltage (spark-over). The figure 1. shows the current-voltage characteristics of nail-type and wire-type discharge electrode at both negative (a) and positive (b) polarity.

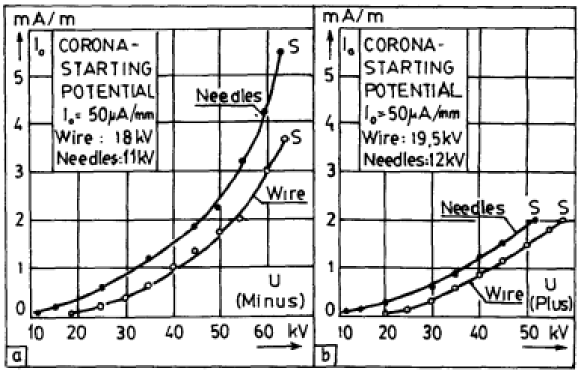

Fig.1. Current-voltage characteristics of selected discharge electrodes with negative (a) and positive (b) polarity [3]

The figure 1 demonstrates clearly that the positive polarity has the higher voltage at the beginning of discharge and the lower breakdown voltage. For instance, in case of wire-type electrode the voltage at the beginning of discharge in case of negative polarity amounts to c.a. 18 kV and in case of positive polarity to c.a. 19,5 kV. For the nail-type electrode these values amount respectively to 11 kV and 12 kV.

In case of electrostatic precipitator the breakdown voltage is more important since the ESP is operated with the highest possible voltage limited only to the value of breakdown voltage. In case of wire-type electrodes and the ESP pitch of 400 mm, the breakdown voltage with negative polarity is approximately 64 kV and 58 kV in case of positive polarity. For the nail-type electrode these values amount respectively to 63 kV and 52 kV.

In view of the above, the systems with positively polarized blades inside the electrostatic precipitator are to be avoided since they are capable of generating the sparkovers inside the electrostatic precipitator at voltages lower than the achievable ones thus dramatically reducing the migration velocity and adversely affecting the dust removal efficiency. This results in necessary application of larger deposition surfaces, which in turn increases the weight and the price of electrostatic precipitator. Therefore, all positively polarized elements (earthed elements in the ESP) located near the positively polarized elements shall have the largest possible radii or, if the use of large radii is impossible, the distance between the positively and negatively polarized elements shall be properly dimensioned. Too small distance between the elements reduces the electrostatic precipitator operating voltage while too large distance causes the unnecessary increase of dimensions of electrostatic precipitator and the undesired increase of the mass and the price thereof.

Laboratory testing

Continuous increase of the pitch between the electrodes applied in the electrostatic precipitators imposes the application of increasingly higher insulation gaps in crucial structural nodes. The increase of the gap applied is not always directly proportional to the increase of pitch. Each node has to be approached individually. In addition, the use of new ESP internal equipment elements that may cause the reduction of electrostatic precipitator operating voltage also requires determination of the correct insulation distance.

Bearing in mind the importance of the problem, the ESP Division of Rafako decided to conduct the laboratory testing focused on application of rectified high voltage on the crucial points of internal equipment and determination of their breakdown strength. For this purpose a structure was developed enabling the application of rectified high voltage on the crucial structural points of electrostatic precipitator. This structure enables the relative movement of individual elements of the nodes being tested so as to make possible the determination of the optimum distances between them.

Tests

The tests were carried out in the High Voltage Laboratory of Electrical Engineering Faculty, Warsaw University of Technology, where the system enabling the simulation of crucial structural nodes occurring in the electrostatic precipitator was installed. The system is shown on figure 2.

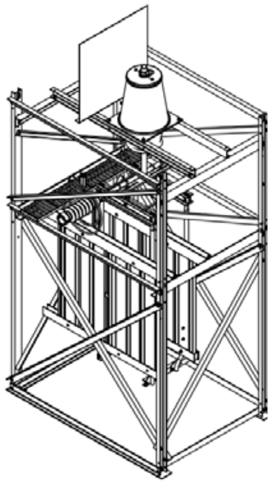

Fig.2. The sketch of testing array

Due to the possibility of relative movement of individual elements of the testing array it was possible to simulate the actual solutions in any configuration. Power supply system diagram is shown on figure 3.

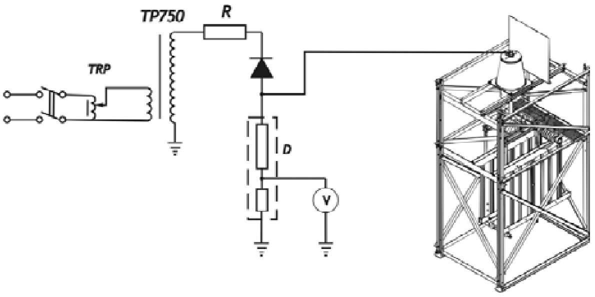

Fig.3. Power supply system diagram of a model of electrostatic precipitator. TRP – regulating transformer, TP750 – test transformer, R – limiting resistor, D – voltage divider

Constant voltage with negative polarity adjustable by means of a brushless regulating transformer was applied on discharge electrodes. Constant voltage was achieved via half-wave rectification of the voltage originating from TP750 test transformer with a voltage of 750 kV and the power of 750 kVA. The system is equipped with R resistor limiting the current in case of a sparkover in the model of ESP chamber.

The measurement of constant voltage supplied to the discharge electrodes was made using the voltage divider connected to a reference voltmeter Hameg HM-8112.

The testing was carried out in an open system (in atmospheric air). Thus the appropriate approach to the testing methodology was imposed because the breakdown voltage in the atmosphere of gases normally flowing through the electrostatic precipitator occurs at much lower voltage than in the air.

As far as possible, the testing was carried out with the system of discharge and collecting electrodes connected in parallel to the system being tested. The system in which the spark-over occurred between the electrodes and not between the elements of the node subject to testing was considered as a system demonstrating the distance sufficient for a tested node. Where it was impossible to assure the simultaneous power supply for the node subject to testing and for the system of electrodes, the breakdown voltage between the electrodes was determined followed by searching for such a distance of the tested node, at which the breakdown voltage is 10% higher than the breakdown voltage determined for the electrodes.

Testing as described above was carried out with simulation of electrostatic precipitator pitch amounting to 400 mm and 500 mm. In some cases, in order to determine the trend, the testing was performed also for a pitch amounting to 300 mm.

Results

The following presents the values of breakdown voltages for the three ESP pitches (300 mm, 400 mm, 500 mm). The tests were performed in three consecutive measurement days. Weather conditions prevailing these days are presented in table 1. For each of ESP pitch, the value of three measurements of breakdown voltage (U_p) was performed. Then average value of these measurements (U_{p_av}) was calculated. The resulting breakdown voltages were converted to normal atmospheric conditions (U_{pn}) in accordance with the requirements of PN-EN 60060-1 High-voltage test techniques - Part 1: General definitions and test requirements [4]. The combination of these voltages includes table 2. Graphic interpretation of this results is shown in figure 4.

In the next step, the influence of mechanical processing of collecting electrode suspension beam on breakdown voltage inside the electrostatic precipitator has been examined. The measurement results are shown in table 3. The measurements were performed in three different beam machining methods. Under option 1, suspension beam had edges polished using files and sandpaper. In option 2, the suspension beam was raw, not polished - directly from production. Under option 3 the suspension beam was slightly revised shape and sharp edges was removed using sandpaper.

Table 1. Weather conditions during test

Day of tests	Temprature [°C]	Atmospheric pressure [kPa]	Humidity [%]
1	34	101,4	52
2	37	101,3	55
3	28	101,6	68

Table 2. Results of breakdown voltage for the various ESP pitches

ESP pitch H [mm]	Breakdown voltage U_p [kV]			U_{p_av} [kV]	U_{pn} [kV]
the first day of testing					
400	160	153	152	155	159,6
500	172	174	174	173	179,6
the second day of testing					
300	131	128	129	129	135,8
400	147	146	153	149	154,5
500	174	174	173	174	179,5
the third day of testing					
300	120	121	121	121	125,4
400	155	156	150	154	159,0
500	171	171	169	170	174,1

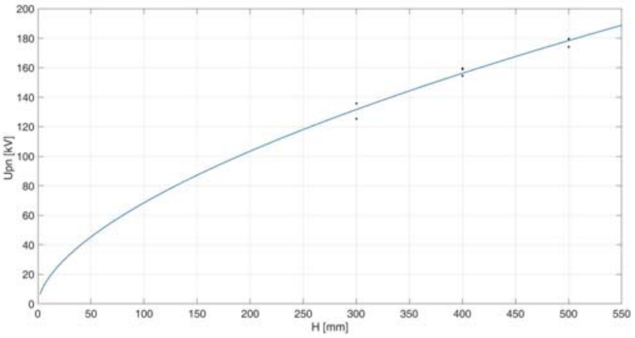

Fig.4. Breakdown voltage as a function of ESP pitch

Table 3. Breakdown voltage for different beam suspension

Type of beams	Breakdown voltage U_p [kV]	U_{p_av} [kV]
1	195	191,3
	188	
	193	
	189	
2	196	189,4
	191	
	192	
	188	
	180	
3	189	191,0
	192	
	192	

The system used to examination the breakdown voltage is also well suited to determine the current-voltage characteristics of different systems of discharge and collecting electrodes. In this case, the ESP chamber must be separated electrically from the ground reference and grounded through the shunt resistance, allows to measure

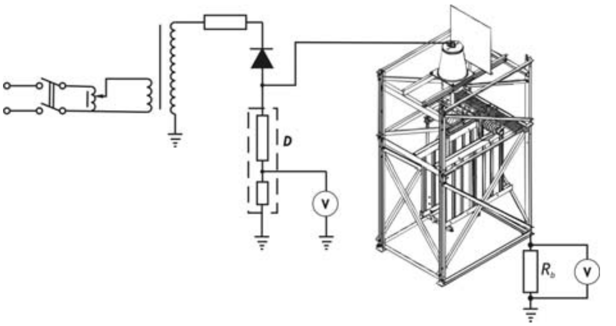

Fig.5. Modified power supply system diagram of a model of electrostatic precipitator for determining current-voltage characteristic; D – voltage divider, R_b – shunt resistance

corona current, such as that shown in Figure 5.

The advantage of this arrangement is that the characteristics are measured in the system with the actual electrodes. For example, in this type of system we can determine influence of anticorrosion coating of the discharge electrodes (still for a certain period of time after installation in the electrostatic precipitator) on the corona current. Such studies have been performed in the past. The results of these tests are given in tables 4 and 5, and the sample discharge electrodes and the characteristics shown in figures 6-8.

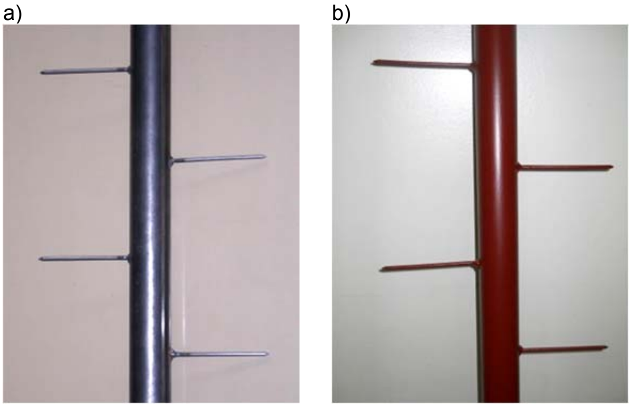
a) b)

Fig.6. Nail-type discharge electrode a) without anticorrosion coating b) with anticorrosion coating

Table 4. Discharge current for nail-type discharge electrode with and without anticorrosion coating for the ESP pitch of 400 mm

without anticorrosion coating		with anticorrosion coating	
U [kV]	I [mA]	U [kV]	I [mA]
28,28	0,03	30,09	0,06
40,81	0,11	40,54	0,13
55,58	0,25	56,28	0,28
69,23	0,43	70,21	0,46
84,28	0,69	84,28	0,70
97,93	0,99	97,65	0,99
112,69	1,42	113,11	1,45
124,53	1,85	124,67	1,91
135,82	2,34		

Table 5. Discharge current for nail-type discharge electrode with and without anticorrosion coating for the ESP pitch of 500 mm

without anticorrosion coating		with anticorrosion coating	
U [kV]	I [mA]	U [kV]	I [mA]
29,67	0,02	28,28	0,03
41,51	0,03	41,79	0,10
55,44	0,10	55,30	0,19
69,93	0,28	68,81	0,32
84,69	0,43	85,53	0,53
98,21	0,64	97,51	0,72
112,83	0,88	111,86	0,98
125,79	1,17	124,81	1,27
139,44	1,52	133,59	1,51

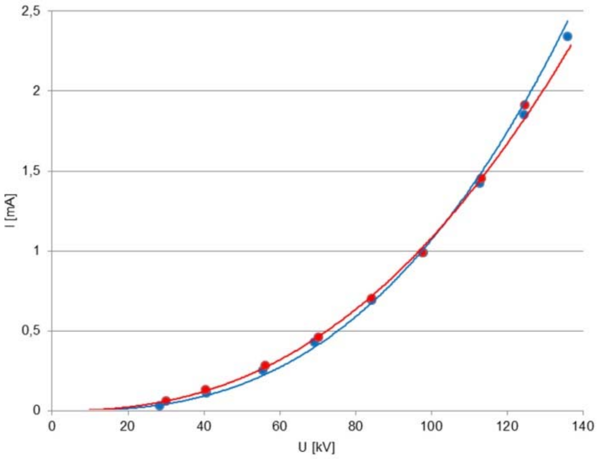

Fig.7. Current-voltage characteristics for 400 mm ESP pitch; red – without anticorrosion coating, blue – with anticorrosion coating

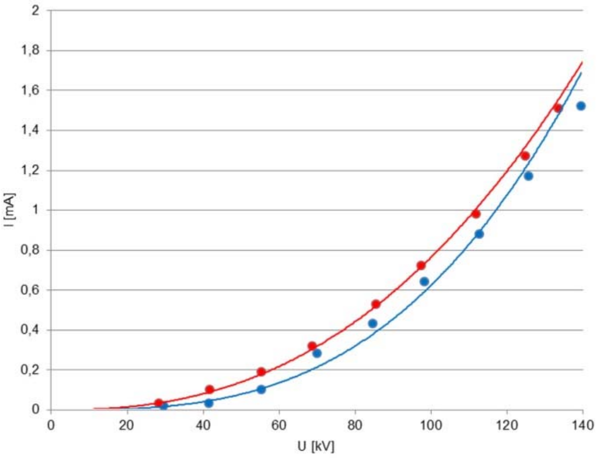

Fig.8. Current-voltage characteristics for 500 mm ESP pitch; red – without anticorrosion coating, blue – with anticorrosion coating

Conclusions

The purpose of testing was to verify the existing requirements for insulation distances inside the ESP chamber applied in manufacturing processes. Test results have confirmed the correctness of the distances applied and, in some cases, enabled the reduction thereof. In addition, the impact of new or structurally changed elements on the operational voltage of electrostatic precipitator was checked during the testing. Such testing shall be carried out at each implementation of changes to the internal equipment of electrostatic precipitator that may reduce its operational voltage in an uncontrolled way.

***Authors**: mgr inż. Waldemar Sobieski, Rafako, Zakład Instalacji Odpylania Spalin, ul. Górnośląska 3a, 43-200 Pszczyna, waldemar.sobieski@rafako.com.pl; dr inż. Andrzej Łasica, Politechnika Warszawska, Instytut Elektrotechniki Stosowanej i Systemów Informacyjno-Pomiarowych, Zakład Wysokich Napięć i Kompatybilności Elektromagnetycznej, ul. Koszykowa 75, 00-662 Warszawa, alasica@ee.pw.edu.pl.*

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