Article citation info:
MACHNIK R, NOCUŃ M. Effect of anti-corrosion coatings of corona electrodes on selected operating parameters of industrial electrostatic precipitators. Eksploatacja i Niezawodnosc – Maintenance and Reliability 2014; 16 (1): 56–60.

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EFFECT OF ANTI-CORROSION COATINGS OF CORONA ELECTRODES ON SELECTED OPERATING PARAMETERS OF INDUSTRIAL ELECTROSTATIC PRECIPITATORS

WPŁYW POWŁOK ANTYKOROZYJNYCH ELEKTROD ULOTOWYCH NA WYBRANE PARAMETRY EKSPLOATACYJNE ELEKTROFILTRÓW PRZEMYSŁOWYCH*

The problem of corrosion protection of electrostatic precipitators used in the energy industry, during its construction or modernization is of vital importance. Several months construction period and the period of time elapsed from the end of construction to operation promotes corrosion of its components. Significant impact on the electrical parameters of an electrostatic precipitator performance has the corrosion phenomena of its emission components, which are the corona electrodes. Manufacturers do not apply any corrosion protection coating on electrostatic corona electrode for fear of worsening their emissivity. This paper presents the results of comparison of emission properties of corona electrodes with and without corrosion protection coatings. Rode and mast type electrodes were studied. The analysis of the results was performed using a statistical method based on the time-series model. The obtained results clearly show that the use of anti-corrosion coating does not impair the electrical parameters of corona electrodes. Corrosion protection can be used both during the modernization as well as during the construction of new electrostatic precipitators.

Keywords: *anti-corrosion coatings; electrostatic precipitators; corona electrodes.*

Problem ochrony antykorozyjnej ma istotne znaczenie w okresie budowy lub modernizacji urządzeń odpylających stosowanych w przemyśle energetycznym. Wielomiesięczny okres budowy elektrofiltru oraz okres czasu upływający od zakończeniu montażu do momentu uruchomienia instalacji odpylającej powoduje nieuniknioną korozję jego elementów. Istotny wpływ na elektryczne parametry eksploatacyjne elektrofiltru ma, występujące w tym okresie, zjawisko korozji jego elementów emisyjnych – elektrod ulotowych. Producenci elektrofiltrów nie stosują ochrony antykorozyjnej elektrod ulotowych w obawie przed pogorszeniem emisyjności elektrod. W artykule przedstawiono wyniki badań emisyjności elektrod ulotowych bez zabezpieczeń oraz zabezpieczonych powłokami antykorozyjnymi, dla elektrody prętowej oraz wybranej elektrody przemysłowej typu masztowego. Analizę wyników przeprowadzono z zastosowaniem metod statystycznych opartych na modelu szeregów czasowych. Uzyskane wyniki badań jednoznacznie wykazały, że stosowanie powłok antykorozyjnych nie pogarsza parametrów elektrycznych elektrod ulotowych. Ochrona antykorozyjna może być stosowana zarówno podczas prac modernizacyjnych elektrofiltrów, jak i na etapie budowy nowych urządzeń.

Słowa kluczowe: *powłoki antykorozyjne; elektrofiltr; elektrody ulotowe.*

1. Introduction

Electrostatic purification methods of gases generated during the combustion of fuels in energy production are currently the only economically justified way to protect the air. The main part of the line of extraction of dust aerosols, resulting from combustion of fuel in the boiler energy, is electrostatic precipitator (ESP). Electrostatic precipitators are large-size devices. The volume of the chamber of currently used industrial electrostatic precipitators may be up to 40 thousand of m^3, with a total working area of collecting electrodes of up to 160 thousand m^2. The number of emission electrodes is up to 14 thousand.

Electrostatic precipitators are unique devices, designed for the purification of exhaust gas of a specific power boiler. Fuel type and its physical and chemical properties are set up on the stage of the implementation of the project both power boiler, as well as cooperating with it dust extraction system. Implementation of the investment, such as a gas extraction line usually takes several months, and naext few months elapses after the completion of the construction to begin the operation. The reason for this is the need for the supplier to accomplish a numerous tests of the finished device, as required by the investor. Studies, carried out by the manufacturer, include both the determination of electrical parameters, the distribution of exhaust gas velocity in selected sections of ESP, as well as issues related to the security service. Such a long period of time, when the electrostatic precipitator is not in operation causes corrosion of its construction components. The most important is corrosion of the corona electrodes, as the basic parameters of an electrostatic precipitator performance like corona starting voltage and current density on the surface of the collecting electrodes depend on their condition.

Currently built electrostatic corona electrodes are made of general purpose construction steel. The use of steel with high corrosion resistance is not desirable due to financial reasons. Despite the problems arising from the corona electrode corrosion, producers do not protect them by appling antycorrosion coatings containing a rust inhibitor. This is due to the fear of the danger of electrostatic precipitator working disturbance caused by changes in the electrical parameters of corona electrodes coated with high resistivity coating. This study aimed to determine the influence of corrosion protection coatings of the corona electrode on their electrical parameters. Consequently, they should give the ansever whether the effect of the corrosion protection is so unfavorable that prevent its use.

(*) Tekst artykułu w polskiej wersji językowej dostępny w elektronicznym wydaniu kwartalnika na stronie ***www.ein.org.pl***

2. Research methodology

The most important parameters characterizing the electrical corona electrodes are [4, 15, 16]:

- Current-voltage characteristics, and initial corona voltage determined on its basis,
- Current density at the surface of collecting electrode

The first parameter, defined as the emissivity of the electrode, provides the intensity of the electric field produced by the corona electrode. Electric field strength influences the time of obtaining the charge by the dust grains allowing the migration and deposition on the collecting electrode. The second parameter affects the mechanical properties of the deposited dust layer on the surface of the electrode. The current density on the surface of collecting electrode is affected by the emissivity of corona electrode and conductance of a medium (gas-dust aerosols) present in the space between electrodes [18], at the given configuration of the electrodes. In the process of operation, both electrostatic parameters are set at the required level by selecting the corona electrode voltages and operation regime of high voltage power supplier to prevent the phenomenon of migration of dust grains separated from the collecting electrode to the further zones of electrostatic precipitator.

Research equipment constructed by the authors to study the electrical parameters of corona electrode (Fig. 1.) depending on its configuration, allows the determination of current-voltage characteristics or the current density on the surface of the collecting electrode.

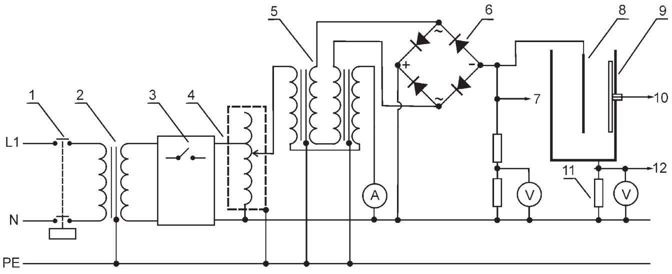

Fig. 1. Scheme of the equipment to test corona electrode parameters 1– circuit of power supply switch, 2– isolation transformer, 3– circuit for overcurrent protection, 4– high voltage control loop, 5– set of high voltage transformers, , 6– set of HV rectifiers, 7– circuit for measuring HV, 8– corona electrode, 9– colleting electrode, 10– current measuring circuit (current density at the surface of collecting electrode), 11– decade resistor, 12– current measuring circuit (I–U characteristic)

The measuring station have an active collecting electrode h = 1.0 m hight and with a maximum division of collecting electrodes H = 0.6 m allows the study of industrial corona electrodes up to 0.8 m. The measuring station consists of a supporting frame to which the collecting electrodes with the total area of 4 m^2. Tested corona electrode (8) is attached to the support frame and supplied with a DC high voltage (6). Power supply voltage allows the continuous adjustment in the range from 0 to 75 kV. The collecting electrodes (9) are connected to ground via a resistors decade box (11). The tolerance of the resistors value is 0.05%. Measuring the voltage present on the resistor and measuring the voltage on the corona electrode allows to determine the current-voltage characteristics of the collecting electrode.

During the measurement of the current–voltage characteristic of corona electrode, signal voltage of corona electrode (7) and the current flowing between the collecting electrodes and groung electrode (12) are applied to the analog inputs of 16-bit measurement card NI USB-6039 connected to the computer. The data acquisition is performed by software specially developed for this purpose in LabView programme. Measurement is carried out for the corona electrode voltages in the range of 0 to 65 kV. Each data points were measured in increment of ΔU = 500 V by the card working with a sampling rate 2KS/s. The average value of measured value was recorded and written to a file to be subjected to further analysis.

Measurement of the current density distribution on the surface of the collecting electrode is realized with 16 fields spread over the length of the measuring electrode (along the x–axis) with a constant space Δx = 0.05 m. Due to the relatively low value of the current flowing between measureing fields (10) and ground electrode of the system, the signals were sent to the, specially designed for the purpose, high stability amplifier circuit realized on INA 114 Burr–Brown using multiplexer 1 of 16. The amplified voltage signal was recorded by the data acquisition NI USB–6039 using a computer. Specially developed software enables data acquisition and control the operation of the multiplexer. Recorded value of the voltage is obtained by averaging 2000 measurements for each measurement field. The measurement data are recorded in a series of five measurements, which means that the measured value corresponding to the current value of the current flowing through each of the fields is the average of 10 thousand measurements. Such a high number of measurements are taken to minimize the influence of AC component of the high voltage transformer. The measured data are stored in the form of ASCII files to enable further analysis.

The study involved 5 cylindrical electrodes, in the form of rods of Ø = 6 mm made of steel S275 and four mast type electrodes. Carrying mast of the electrodes on the study, was made of steel pipe with a diameter of Ø = 10 mm. Emission elements made of steel strip were welded at equal intervals. The essence of this type of electrode structures is the presence of tips with a small radius of curvature being the source of the corona. Different manufacturers use similar electrostatic electrodes design solution, but the diameters of the mast and shape of the carrier emission elements (such as nail, elements in a shape Δ or U made of a wire with a diameter of 3 to 5 mm) are different. The geometry of the blades are selected depending on the desired emissivity of the electrode [11]. An example of the mast type electrode is shown in Figure 2.

Fig. 2. Mast type discharge electrode

Current-voltage characteristics and current density distribution on the collecting electrode was carried out for the electrodes without corrosion protection and with anti–corrosion coating. Anti–corrosion coating has a thickness of 50 to 65 μm, and was applied by pneumatic spraying technique. Tests were performed for three anti-corrosion agents: “Unikor C” with filler containing iron oxide (III), water-soluble polydispersion of acrylic resin with an organic filler and a polyurethane varnish without filler. The condition of the measurements were as follow: the temperature t = 22°C, the relative air humidity w = 53%, atm pressure p = 987.9 hPa.

3. Methodology for the statistical analysis of the current density distribution on the collecting electrode

Analysis of recorded value of the current flowing in the space between electrodes of electrostatic precipitator is difficult due to possible deviations from classical assumptions of normal population distribution of the results and the lack of correlation of the random sample results. Therefore, for the analysis of this phenomenon, the methodology belonging to the group of non–classical statistical methods was applied [8]. For the analysis of the distribution of current density on the surface of collecting electrode a method based on time–series model formalism was used [3]. This method is widly applied to the analysis of acoustical phenomena [7, 13], and is increasingly used in other fields such as genetics [5, 6]. In the analysis process the measurement data {*x1, x2, ..., xn*} are the time series of random value of variable *X* representing a further observations {*x1, x2, ..., xn*} describing the current density at the collecting electrode. It is assumed that the probabilistic structureot the measured data can be described by the equation:

$$X_t = \mu_t + \varphi_t + \xi_t \text{ ; } t = 1,2,...,n \tag{1}$$

It was father assumed that the structure of the analyzed phenomenon is created by: trend μ_t associated with factor enforcing the level of the analyzed values, cyclic component φ_t corresponding to the periodically recurring changes and residual component ξt, satisfying the conditions of the normal distribution of noise and resulting from random noise. The classic model of a random sample probe assumes the conditions of a normal distribution for the next observation. Model applied to the analysis of the phenomenon, differs from the classical model by the assumption of the presence of a enforce mechanism changing the results, the recorded signal is subjected to random disturbances (noise signal), satisfying the conditions of the normal distribution with zero expected value and variance σ_ξ^2. In this case, the estimation problem of expected value and variance of the measured data comes down to identification of the structure of the time series.

Analysis of the distribution of current density on the collecting electrode surface were done using a program, for this purpose developed, and containing advanced statistical functions TSA (Time Series Analysis) of LabView programme. This program allows after preprocessing of the measured data (resampling, smoothing), calculate the following values for the analyzed quantity:

- The average value $\mu = \frac{1}{n}\sum_{i=0}^{n-1} X_t(i)$ after elimination of extreme values
  where: μ - arithmetic mean value, n – the number of elements of the time series *Xt*,
- Value of mean RMS (Root Mean Square) $\psi = \sqrt{\frac{1}{n}\sum_{i=1}^{n}|x_i|^2}$
  where ψ_x – RMS value, n – the number of elements of *X*,
- Magnitude of power spectrum PS (Power Spectrum) FFT (Fast Fourier Transform) of the current density at the collecting electrode (in the form of squares RMS)
- Power spectrum density PSD (Power Spectrum Density) FFT of the time series *Xt* (in the form of squares of the RMS per unit of x-axis of collecting electrode).

PDS describes the frequency distribution of a registered signal (or time series). and is defined as: $P(t) = f(t)^2$ for the signal *f(t)*. Average (or expected) value of *P(t)* is the sum of power spectral density calculated for all values of frequency or time. Using the Fourier transform:

$$\hat{f}_T(\omega) = \frac{1}{\sqrt{T}}\int_0^T f(t)\exp(-i\omega t)dt \tag{2}$$

where:

$\hat{f}_T(\omega)$ – Fourier transform in the frequency domain,
ω – circular frequency (2πf)
i – the imaginary unit ($i^2 = -1$),

power spectral density can be defined as [1, 2]:

$$PSD\ (\omega) = \lim_{T\to\infty} E\left[\ \left|\hat{f}_T(\omega)\right|^2\ \right] \tag{3}$$

where:

PSD (ω) – power spectral density,
E – the expected value of a random variable.

Alternatively, assuming a stationary nature of the studied phenomenon, which takes place in this case, according to the theorem of Wiener-Chinczyn, the power spectral density of such a process is the Fourier transform of the autocorrelation function $R(\tau) = \langle f(t)\cdot f(t+\tau)\rangle$ [15]:

$$PSD\ (f) = \hat{f}_T(R(\tau)) \tag{4}$$

where:

R(τ) – autocorelation function,
τ – signal delay time.

The procedures for the calculation of the power spectrum and power spectral density are included in the LabVIEW function libraries.
To analyse electrical parameters of electrodes tools for time series analysis available in the Advanced Signal Processing module – Time Series Analysis Tools of the LabVIEW was used [14].

The tested electrodes satisfy the condition of similarity in terms of geometry and material characteristics [9, 12]. They are objects whose properties can be determined by comparing the magnitudes: the power spectrum and power spectral density analysis of the measured values. The use of statistical methods for the analysis of time series simplifies the analysis of the results obtained by measuring electrical parameters of tested electrodes. It also provides information about the object uner test, which can not be obtained by other methods. This allows the construction of mathematical models of the phenomena occurring in the space between electrodes of electrostatic precipitator depending on the shape of the applied corona electrode. This information can be used for utilitarian purposes.

4. The results

Based on measured data recorded for each of the tested electrodes the current-voltage characteristics was determined and based on then specific initial voltage corona was calculate[4, 16]. The results for the mast type electrode are shown in Figure 3.
The initial corona voltage of corona electrode without coating and with anti-corrosion coatings, determined on the basis of current-voltage characteristics, are provided in Table 1.

The results confirm that the initial corona voltage and current-voltage characteristics of the corona electrode made of steel, are affected only by their geometrical parameters and the presence of anti-corrosion coating does not affect their electrical parameters.

Table 1. Initial corona voltage of corona electrode

Anti–corrosion coating type	Initial corona voltage [kV]	
	mast type electrode	cylindrical electrode Ø=6 mm
without coating	17,0	48,0
acrylic resin	16,8	51,4
Unikor C	17,4	48,0
polyurethane varnish	17,0	48,0

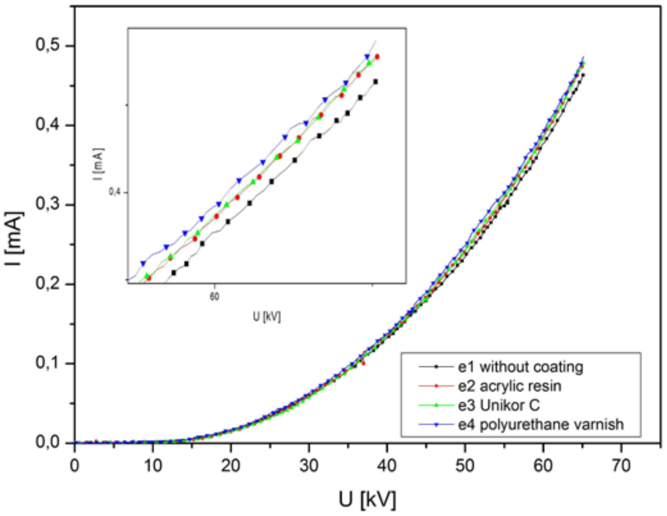

Fig. 3. Current-voltage characteristics of the mast type spike corona electrode

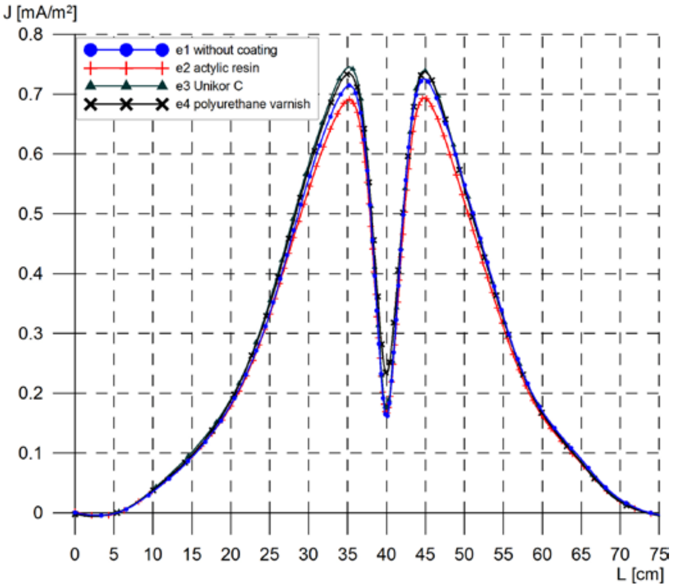

Fig. 4. Current density distribution of on the surface of the collecting electrode for a mast type spike corona elektrode

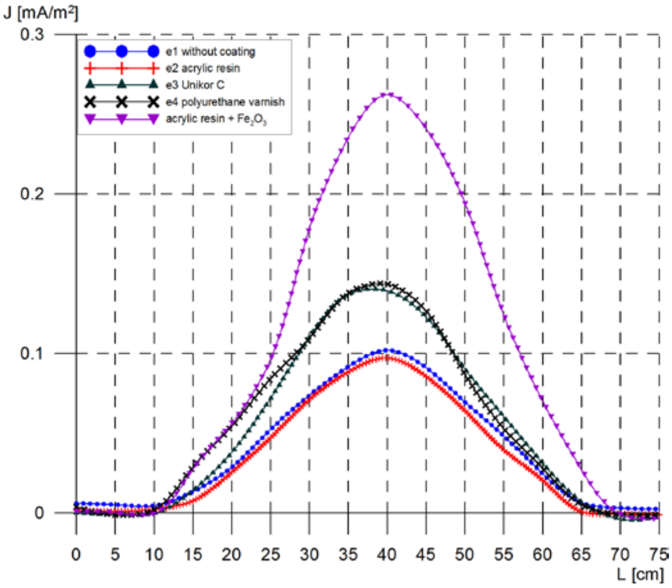

Fig. 5. Current density distribution of on the surface of the collecting electrode for a cylindrical corona electrode

The results of measurements of the current density distribution on the collecting electrode in case of spike electrode without coating and with anti–corrosion coatings are shown in Figure 4.

The results of analogous measurements corresponding to a cylindrical electrode (having a diameter of Ø = 6 mm), are shown in Figure 5. For these electrodes, the differences in a current density depending on the presence and the type of anti-corrosion coating are much more visible than in the case of a spike electrodes.

Influence of the coating with filler in the form of iron dioxide (III) on the electrical parameters of the discharge electrode, it was confirmed by introducing into the waterborne anticorrosive formulation, 15% by weight of Fe_2O_3. The measurement results confirmed that the presence of iron dioxide (III) in the coating, applied to the surface of the discharge electrode, significantly changes its electrical characteristics by increasing the emissivity.

Effect of the presence of the iron oxide (III) as a filler in the coating on the electrical parameters of corona electrode was studied by applying water-based anti-corrosion paint filled with 15 wt.% Fe_2O_3. The results confirmed that the presence of iron oxide (III) in the coating applied to the corona electrode significantly changes its electrical characteristic by increasing the emissivity.

Table 2. The results of the statistical analysis of the current density distribution on the surface of collecting electrode

Electrode	Anti–corrosion coating type	Mean Value	Root Mean Square (RMS) Value	Magnitude	
				Power Spectrum (PS)	Power Spectral Density (PSD)
mast type	without coating	0,2047	0,3469	0,3440	16,949
mast type	acrylic resin	0,1990	0,3343	0,3208	15,8545
mast type	Unikor C	0,2106	0,3568	0,3652	18,057
mast type	polyurethane varnish	0,2136	0,3561	0,3722	18,667
cylindrical Ø = 6 mm	without coating	0,0341	0,0525	0,0090	0,46689
cylindrical Ø = 6 mm	acrylic resin	0,0295	0,0491	0,0080	0,4210
cylindrical Ø = 6 mm	Unikor C	0,0441	0,0728	0,0176	0,9183
cylindrical Ø = 6 mm	polyurethane varnish	0,0471	0,0746	0,0182	0,9427
cylindrical Ø = 6 mm	acrylic resin + 15 wt.% iron oxide (III)	0,0817	0,1338	0,0596	3,0957

Table 2 presents the summary of the statistical analysis results using TSA model.

The test results show that the use of anticorrosion coating with the filler in the form of dioxide of iron (III), does not worsen of the emissivity parameters of corona electrodes protected from corrosion, but even increases it. One can assume that this is due to the physicochemical properties of the compound, but the cause of this phenomenon has not been determined. A different situation occurs in the case of rod electrodes secured by a polymer coating (polyurethane resin). The intensity of the corona discharge of rode type electrode dependents on the radius of curvature of the electrode. It is believed that the thin layer (~ 50 μm), applied by spraying has local discontinuities or areas with a lower thickness, which are the source of the corona. This increases the emissivity of the rod electrode similar to the spike electrodes, having blades with a small radius of curvature. That interpretation is borne on the electrical properties of polyurethane polymers such as high value of the resistivity [19].

5. Conclusions

The results of emissivity tests of corona electrodes used in the electrostatic precipitators showed that the use of anti-corrosive coatings does not adversely affect their electrical parameters. The presence of anti-corrosion coating does not infuence the current-voltage characteristics of the respondents corona electrode. Analysis of the results of the current density distribution on the surface of collecting electrode using TSA indicates that the corrosion protection in the form of coatings deposited on the electrode surface does not decrease in corona current density. Research has also shown that the anti-corrosion filler in the form of iron oxide (III), commonly used due to their low price, have a positive influence on the electrical characteristics of corona electrode. This responds to the concerns of electrostatic manufacturers if corrosion protection used during manufacturing and testing, will not adversely affects the operational performance of dust extraction system. The study showed that the corona electrode corrosion protection can and should be used at the assembly stage, prior to entry into service. It was also found that the anti-corrosion coating containing iron oxide as a filler (III) is the best choice for corona electrode protection against corrosion.

Acknowledgement: *The research work financed with the means of Polish National Science Center grant nr 7041/B/T02/2011/40 as a research project.*

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