The research results of cleaning air stream process from aerosol particles in electric fields of corona discharge stream form

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Abstract. In article the method and results of experimental researches of electrode scheme parameters is given “Potentional plane with corona’s needles – landed plane (earthed)”. The parameters of electrode scheme is determined for distance between electrodes which equal for 0,05 m, 0,1 m and 0,15v determined on the basis of these researches the electrode scheme parameters is checked on the basis of experimental researches, process of catching dust particles from air stream. Method and the results of these researches the best correlation of electrode scheme parameters in the best degree of cleaning air is determined. Difference of distance between needles in line, which situated perpendicularly to stream of cleaning air, and between needle’s lines is defined.

I. Introduction
Various methods and devices are used to treat process gases, the most preferred of which are electrostatic precipitators with their distinctive features such as high clean ability, high treated gas capacity, ability to catch less than 0.1 µm aerosol particles with any physical and mechanical properties, and lack of aerodynamic drag.

Development of electrical gas cleaning techniques falls on the 50…80’s of the last century [1, 2, 3]. Apparatuses, ensuring high degree of cleaning, have been created; the application domain of electrostatic precipitators has extended significantly. Production of unified dimension-type electrostatic precipitators has been set, a number of which include high-production apparatuses that ensure cleaning of flue gases emitted from the boilers of large 300, 500 and 800 MW power units, large cement production furnaces and other processing apparatuses.

From the 80’s of the 20th century, main works on gas cleaning are mainly associated with increasing the effectiveness and reliability of already developed electrostatic precipitators. Owing to application of tyristor control, silicon rectifiers and other semiconductors, reliability of generating units has improved greatly. The developed principles of voltage control enabled to maintain an increased load on electrostatic precipitators’ electrodes, which ensure a high degree of cleaning [1].

However, the use of electrostatic precipitators is constrained by a number of factors.
It is important to note here first of all the significant sizes and mass of electrostatic precipitators under high power consumption. The sizes of GFD-series electrostatic precipitators range from 18.6x12x15.4 m to 24.8x21.8x27 m, the deposition zone of the aerosol particles being \( A_i = 15.4 \ldots 27 \) m. Power sources of up to 200 kVA capacity are used to feed the electrostatic precipitators. Flow rate of the cleaned gas is \( V_j = 1 \ldots 1.5 \) m/s.

If the settling zone \( A_i \) is reduced up to the magnitude \( A_2 \) and the gas flow rate \( V_i \) is increased up to the value \( V_2 \), then power consumption of electrostatic precipitators under same cleaned gas treatment capacity will reduce \( \frac{1}{(V_i/V_2)} \cdot \left( \frac{A_i}{A_2} \right) \) times. The sizes of electrostatic precipitators will reduce pro rata to the capacity.

The gas cleaning effectiveness can be increased by using pulse voltages of low duty cycle, using the regularity of an increase in electric gas strength when voltage dwell time reduces [4, 5, 6].

Powerful high-voltage commutating semiconductors have been created recently, which enable resolution of technical problems of creating reliable pulse power supply units [7, 8]. However, the information given in literature does not provide any practical recommendations as to design industrial apparatuses, what is more – lack of pilot research recurrence and discord of the results cast doubt on expediency of switched power supply. This happens due to lack of a convincing physical model explaining the very impact mechanism of the switched power supply on dust collection effectiveness. It should be noted that these supply sources were used to increase the effectiveness of the electrostatic precipitators operated. Moreover, they provide for commutation of pulse voltages under high voltage of 12-24 kHz frequency.

Several original devices have been proposed in the field of gas purification over the past 5-6 years. These include electret filtering materials with a low pressure drop and high filtration efficiency [9]. The disadvantage of this device is a low electric field strength and inability to regulate the process.

Electrostatic filters have been developed for cleaning gaseous media from radioactive materials [10]. In these filters, the use of electric pulsed cleaning devices is proposed for shaking off the deposited layer of coal dust from the precipitation electrode. However, such periodic cleaning devices lead to secondary entrainment of already deposited dust.

In many applications, electrostatic precipitators are particularly attractive for the thermal treatment of radioactive materials [11]. In these studies, to increase voltages above breakdown voltage, the use of new power sources combining direct voltage with pulse voltage is proposed. In this case, the high-voltage power supply circuit becomes much more complicated, where it is necessary to use two high-voltage sources: direct and pulse.

The proposed electrostatic filter is an ozone generator consisting of a plate corona discharge and a high voltage direct current generator [12]. The experimental results showed that the more ozone generators used as electrostatic filters, the faster the concentration of particles decreases. However, studies on the processes of ozone electrosynthesis showed that they have very low energy indices, and efficiency ozone output does not exceed 2%.

In studies conducted by [13], an attempt was made to functionally treat the surface of a discharge electrode to reduce the level of ozone generation from a corona discharge. Industrial ozone generators were based on a barrier discharge powered by an alternating current source, while the voltage on the ozone generator significantly exceeds the discharged voltage without a barrier. Our studies have established that the concentration of ozone at the outlet of the electrostatic precipitators does not exceed the maximum permissible concentration (MPC).

Filtration of dust treated with an electric field, without and with corona discharge, was investigated on a laboratory scale [14]. An increase in the pressure drop across the dust crust was detected when an electric field was applied without a corona discharge. If a corona discharge exists, the pressure drop decreases. The influence of dust pre-charging was indicated on the pressure drop after regeneration of the filter at low filter loads.

In the study [15], a new electrostatic air filter system (EEAF) was proposed, which could increase the efficiency of filtering the fibrous filter for small particles without increasing a pressure drop.
Indoor air quality was improved by monitoring particulate matter (PM), consisting of components such as house dust and bacteria, using atmospheric pressure plasma [1]. Fedorov et al. [16] presented materials for studying detachment with impact for dust deposited in the field of an electric corona discharge on filter electrode plates. It was found that a significant factor determining the level of acceleration required to separate dust from the electrodes is the weight of dust accumulated on the electrodes before shaking.

A new electrostatic air filter system (EEAF) was proposed by Feng et al. [17], which could increase the efficiency of filtering a fibrous filter for small particles without increasing a pressure drop. However, in the aforementioned works, the goal was not to increase the efficiency of the electric gas treatment process, reduce the weight, dimensions and power consumption, and increase their productivity in the cleaned air. The listed parameters are the determining technological parameters, but in many studies they are simply not even mentioned. An important drawback in these works is also the lack of developments in the management of the processes for operation of electrostatic precipitators and their automation.

2. Methods
The studies conducted by the authors have revealed the following advantages of the electric field of corona discharge of streamer form over the electric field of corona discharge of constant voltage, used in existing electrostatic precipitators [18, 19, 20]:

- the stability of the discharge process;
- an increase in discharge current with a corresponding increase in the power characteristics of electric field;
- the ability to control processes in electric field by changing the parameters of the power circuit elements.

These advantages make it possible to increase the efficiency of the process of aerosol particles deposition in electric fields of streamer form of corona discharge.

An indispensable condition for using the streamer form of a corona discharge in electric gas cleaning processes is the creation of a separating electric field to separate the positive and negative space charges generated in the streamer discharge channels and the creation of unipolar charges flow. To do this, an electrode system “potential plane with corona needles – an earthed plane” can be used (Figure 1).

![Figure 1. Parameters of electrode system of “a potential plane with corona needles – earthed plane”: 1 – earthed plane; 2 – potential plane; 3 – corona needles](image-url)
installation. In our studies, the choice of parameters was carried out according to the maximum current from a single isolated corona needle [18, 19, 20]. The studies were carried out for interelectrode distances $H$ of 50, 100 and 150 mm. The choice of these distances was determined by the amount of air to be cleaned. The layout of a stand is shown in Fig. 2. An additional earthed electrode 8 was installed on the stand, fixed at distances of 50, 100 and 150 mm from the potential plane. A mechanism for moving needle electrodes was attached to an earthed electrode with a pin 7, the mechanism consisted of a synchronous reactive electric motor with an RD-2 type gearbox, a helical shaft 3 in which a many-sided, thread is cut from the middle, carriages 4 for attaching the movable needle electrodes, a measuring needle electrode 5 isolated from the earth by dielectric plate, a mounting plate 6. The measurement circuit consists of a PmV potentiometer of KSP-4 type, a control ampermeter PA, a trimming resistor R2, and a spark protection chain R1, FV.

![Figure 2. The layout of a stand for studying the influence of the distance between the needles of different lengths in a row on the current of corona discharge of streamer form.](image)

In previous studies on the use of needle-shaped corona electrodes [1, 2] the parameters were selected according to the specific current per unit length of the corona electrodes at different steps of needle installation. In our studies, the choice of parameters was carried out according to the maximum current from a single isolated corona needle [18, 19, 20, 21, 22]. The studies were carried out for interelectrode distances $H$ of 50, 100 and 150 mm. The choice of these distances was determined by the amount of air to be cleaned. The layout of a stand is shown in Figure 2. An additional earthed electrode 8 was installed on the stand, fixed at distances of 50, 100 and 150 mm from the potential plane. A mechanism for moving needle electrodes was attached to an earthed electrode with a pin 7, the mechanism consisted of a synchronous reactive electric motor with an RD-2 type gearbox, a helical shaft 3 in which a many-sided, thread is cut from the middle, carriages 4 for attaching the movable needle electrodes, a measuring needle electrode 5 isolated from the earth by dielectric plate, a
mounting plate 6. The measurement circuit consists of a PmV potentiometer of KSP-4 type, a control ampermeter PA, a trimming resistor R2, and a spark protection chain R1, FV.

Research was carried out in two stages. At the first stage, the distance between the needles of various lengths in a row was determined on the stand (Figure 2), by the inflection point of the dependence 1=f(ℓ). In the second part of the experiment, the distance between the rows of needles was determined according to certain distances between the needles in the row. Moving rows of needles were installed on the measuring stand. An insulated measuring needle was installed at the center of the fixed row of needles. The motion velocity of the carriages on the stand was 1 mm⁻¹. The motion velocity of the chart tape in the recording potentiometer KSP-4 was 3 mm⁻¹. The process was recorded until the steady-state value of the discharge current was reached. The minimum distance between the tip of the measuring needle and the moving needles was 10 mm. The experiments were conducted for the needles 10, 15, 20, 25, 30 mm long, the results are given in Table 1.

| Table 1. Parameters of the electrode system "potential plane with corona needles – an earthed plane" |
|-----------------------------------------|
| Name of parameters                      |
| The distance between the planes - H, mm |
| 150                                     |
| 100                                     |
| 50                                      |
| The length of needle electrodes - h, mm |
| 20                                      |
| 25                                      |
| 30                                      |
| 15                                      |
| 20                                      |
| 10                                      |
| 15                                      |
| 20                                      |
| The distance between the needles in the row - ℓ, mm |
| 40                                      |
| 50                                      |
| 60                                      |
| 30                                      |
| 40                                      |
| 50                                      |
| 25                                      |
| 30                                      |
| 40                                      |
| The distance between the rows of needles - c, mm |
| 80                                      |
| 100                                     |
| 120                                     |
| 60                                      |
| 80                                      |
| 100                                     |
| 50                                      |
| 60                                      |
| 80                                      |

From Table 1 the parameters providing the greatest degree of air flow purification from dust particles were determined. These studies were conducted on the stand (Fig. 3) which consists of a mounting table 1, an outlet pipe 2, a precipitating earthed electrode 3, a removable box 4, a potential electrode 5 on which corona needles 6 were installed, an inlet pipe 7, an electric motor 8 of a centrifugal fan drive 11, an electric motor with gearbox 9 of the drive of the metering conveyor 10, the dampers 12 for uniform distribution of the air flow rate with a lock 13. At the stand, the distance between the potential electrode and the earthed plane varied within 150, 100 and 50 mm.

The experiments were conducted with the samples of fine dust taken at a ginnery and sifted on a calibration sieve with 50 μm cells. The air exhausted in the technological process was cleaned by cyclones of various dimensions in dust precipitation chambers. These devices work satisfactorily when catching the dust particles larger than 50 microns. With a decrease in dust particles dispersion, the catching capacity decreases sharply and a great amount of fine dust is released into the environment.

Investigations of the process of aerosol particles catching from an air flow were carried out at an initial dust content of 500 mg/m³. To do this, a dust sample weighing 3,000 mg was poured onto the metering conveyor. The length of the metering conveyor onto which a dust sample was poured was determined by the formula:

\[ d = \frac{m_0 v}{Z_d H b V} \]  

where  
- \( m_0 = 3000 \) mg is the weight of a dust sample;  
- \( H \) = inter electrode distance, mm;  
- \( b = 200 \) mm - stand pipe width;  
- \( V \) = the air flow rate, m/s;  
- \( d \) - the length of the metering conveyor on which the dust sample is located, m;  
- \( v = 1.5 \) mm/s is the velocity of the metering conveyor. 

Depending on \( H \), the air flow rate was taken as: for \( N = 150 \) mm \( V = 9.5 \) m/s; for \( H = 100 \) mm \( V = 8 \) m/s; for \( H = 50 \) mm \( V = 3.8 \) m/s.
The degree of purification was determined by the formula:

$$W_0 = \left( \frac{\sum m_n \cdot 100}{m_0} \right) \%, \quad (2)$$

where $m_n$ is the total weight of deposited dust, mg.

Potential electrodes were used in the experiment, the corona needles with the parameters given in Table 1 were installed on them. The frequency of pulse voltage in the experiment was 500 imp$^{-1}$. A dust sample was placed on the feed conveyor.

3. Results and Discussions

The results of studies of the dependence of the maximum current of a single isolated needle on the distances between the needles in a row and the distances between the rows of needles are presented in Table 1. According to these data, the relation is clearly observed that the distance between the corona needles in the rows is two times less than the distance between the rows of needles. Of the certain parameters of the electrode system "potential plane with corona needles – an earthed plane" the most optimal ones were selected on the basis of experimental studies of the process of aerosol particles catching from the air flow; for results see Tables 2, 3 and 4.

Table 2. The process of dust deposition from an air flow at an inter electrode distance of 150 mm and an air flow rate of 9.5 m/s

| h, mm | f, mm | c, mm | U, $10^3$V | I, $10^6$A | f, s$^{-1}$ | Total weight, mg | W, % |
|-------|-------|-------|------------|------------|----------|----------------|------|
| 30    | 60    | 120   | 46         | 120        | 500      | 2091           | 69.7 |
| 25    | 50    | 100   | 48         | 110        | 500      | 2772           | 92.4 |
|       |       |       |            |            |          | 2046           | 68.2 |

Table 3. The process of dust deposition from an air flow at an inter electrode distance of 100 mm and an air flow rate of 8 m/s

| h, mm | f, mm | c, mm | U, $10^3$V | I, $10^6$A | f, s$^{-1}$ | Total weight, mg | W, % |
|-------|-------|-------|------------|------------|----------|----------------|------|
| 25    | 50    | 100   | 46         | 120        | 500      | 2319           | 77.3 |
| 20    | 40    | 80    | 48         | 110        | 500      | 2832           | 94.4 |
| 15    | 30    | 60    | 50         | 100        | 500      | 1911           | 63.7 |

Of interest is the dynamics of the process of cleaning the air flow in the zones of the stand. For this, the results of experimental studies obtained for the most rational parameters of the electrode system were processed in order to determine the degree of purification of the air flow over 10 zones of the bench. According to the results of these calculations, a steady degree of cleaning starts from 5 to 8 zones of the stand and averages 30.1%. Mean limiting ionic charging of dust particles occurs over a time equal to 0.0375 s.

In 9 and 10 zones of the stand, a sharp increase in the degree of purification to 40.0 and 63.3% is noted. This is due to a decrease in the shielding effect between the corona needles. The dust content of the air at the outlet of the stand is 54 mg / m³, which is significantly less than the contamination allowed for the emission of technological air from the ginnersies - 150 mg / m³.

An analysis of these results shows that the predicted degree of air purification is confirmed by the results of experimental studies and almost complete purification of air from aerosol particles occurs on the dust deposition zone not exceeding 1 m. This parameter was adopted when developing electrostatic precipitators for purifying process air.
Table 4. The results of studies of the process of dust deposition from an air flow at an inter electrode distance of 50 mm and an air flow rate of 3.8 m/s

| h, mm | l, mm | c, mm | U, $10^4$ V | I, $10^5$ A | f, s$^{-1}$ | Total weight, mg | W, % |
|-------|-------|-------|-------------|-------------|-----------|-----------------|-----|
| 10    | 25    | 50    | 26          | 120         | 500       | 2091            | 69.7|
| 15    | 30    | 60    | 28          | 110         | 500       | 2772            | 92.4|
| 20    | 40    | 80    | 30          | 100         | 500       | 2048            | 68.7|

Electrofilters with a distance between electrodes of 50 mm will be used for air purification in workshops and premises of enterprises. Therefore, the length of the dust deposition zone was chosen equal to 400 mm. For such a cleaning zone, it is necessary to reduce the flow rate of the cleaned air. It was experimentally established that this speed should not exceed 3.8 m/s. At this speed, studies were conducted (Table. 4).

4. Conclusions
The most acceptable inter electrode distances between the potential and precipitation electrodes of electrostatic precipitators are: for electrostatic precipitators designed to clean exhaust air and gases in technological processes - 100 and 150 mm; for electrostatic precipitators designed for air purification in dusty industrial premises - 50 mm.

It was experimentally stated that the distance between the rows of needles should be two times greater than the distance between the needles in the rows. In this case, the rows of needles should be located across the flow of the gas being cleaned, and the length of the needle should be equal to half of the distance between the needles in the rows.

It was stated that the greatest degree of air purification is observed with the following parameters of the electrode system "potential plane with corona needles – an earthed plane": for the inter electrode distance of 150 mm, the length of the needles is 25 mm, the distance between the needles in the row is 50 mm, the distance between the rows of needles is 100 mm, the deposition zone length is 1 m; for the inter electrode distance of 50 mm, the length of the needles is 15 mm, the distance between the needles in the row is 30 mm, the distance between the rows of needles is 60 mm, the deposition zone length is 0.5 m; for the inter electrode distance of 100 mm, the length of the needles is 20 mm, the distance between the needles in the row is 40 mm, the distance between the rows of needles is 80 mm, and the deposition zone length is 1 m.

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