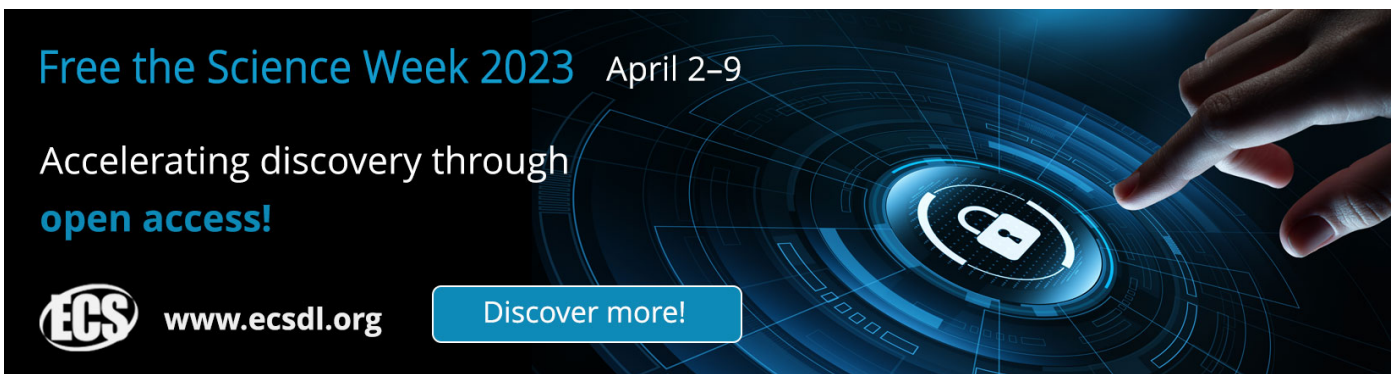**PAPER • OPEN ACCESS**

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Investigation of the cleaning the air flow process from aerosol particles in the electric fields of the corona discharge's streamer form

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Abstract. This article presents the methodology and results of experimental studies of the parameters of the electrode system "Potential plane with corona needles - grounded plane". The parameters of the electrode system were determined for a distance between the electrodes of 0.15 m. The parameters of the electrode system determined on the basis of these studies were verified on the basis of experimental studies of the process of trapping dust particles from an air stream. The methodology and analysis of the results of these studies are given. Based on these studies, the best ratios of the parameters of the electrode system were determined according to the highest degree of purification of the cleaned air. The difference in the distances between the needles in a row located perpendicular to the flow of the cleaned air and between the rows of needles is determined.

1. Introduction

Our studies have revealed the following advantages of the electric field of the streamer form of the corona discharge over those used in the existing electrostatic precipitators of the corona discharge of constant voltage [1-10]:

• stability of the discharge process;

• an increase in the discharge current with a corresponding increase in the power characteristics of the electric field;

• dependence of processes in the electric field on the parameters of the elements of the power circuit.

These advantages, undoubtedly, should increase the efficiency of the process of deposition of aerosol particles in the electric fields of the corona discharge streamer form. The parameters of electrode systems determined in the earlier developments of electrostatic precipitators cannot be used in our studies, due to the difference in the processes in the two types of electric discharges mentioned above.

An essential condition for the use of a streamer form of corona discharge in the processes of electrogas cleaning is the creation of a separating electric field to separate positive and negative space charges formed in the streamer discharge channels and create a flow of unipolar charges. To do this, you can use the electrode system "Potential plane with corona needles - grounded plane" (Figure 1.).
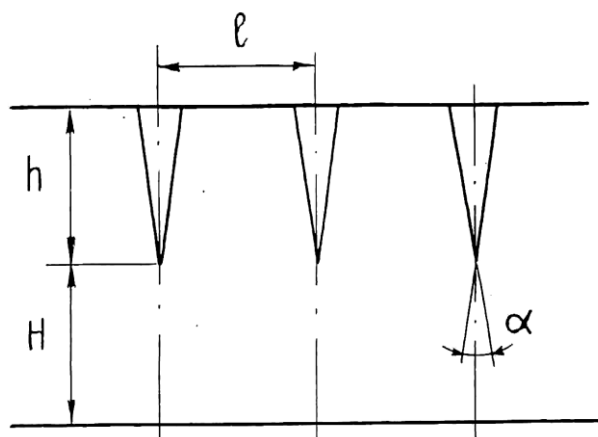
Figure 1. Parameters of the electrode system "Potential plane with corona needles - grounded plane"

The experimental studies of the characteristics of the streamer form of the corona discharge determined the maximum values of the discharge currents for various parameters of the electrode system "Potential plane with corona needles - grounded plane". To determine the parameters of the electrode system that provides the maximum degree of purification of the cleaned air, a series of experimental studies of the process of cleaning the air flow from aerosol particles was carried out, the results of which are given in this article.

2. Materials and Methods

The current-voltage characteristics of the streamer form of a corona discharge were studied at a constant length of the corona needles h and different distances between the tip of the needles and the grounded plane H equal to $h + H = 0.1$ m. However, the use of such an interelectrode distance for cleaning an air flow of more than 10 m^3/s will require a significant complication of electrostatic precipitators with both flat and cylindrical electrodes. The most expedient, in this particular case, is to increase the distance between the electrodes to 0.15 m. Therefore, changes were made to the research methodology given in [11]. The studies were carried out at a constant interelectrode distance equal to 0.15 m. The lengths of the corona needles and the distance between the needles were changed. The layout of the test stand with the changes made is shown in Figure 2.
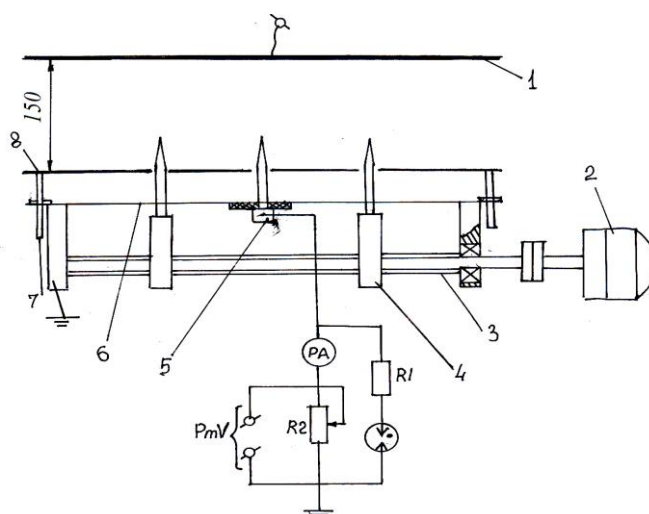

Figure 2. Scheme of the stand for studying the effect of the distance between needles of different lengths in a row on the current of the streamer form of a corona discharge

Compared to the previously developed method, an additional grounded electrode 8 was installed on the stand, which was rigidly fixed at distances of 0.15 m. A mechanism for moving needle electrodes was attached to the grounded electrode on a hairpin 7, which consists of a reactive synchronous electric motor with a gearbox of the RD-2 type, screw shaft 3, from the middle of which a multilateral thread is cut, carriages 4 for fastening movable needle electrodes, measuring needle electrode 5 isolated from the ground by a dielectric plate, mounting plate 6. The measurement circuit consists of a self-recording potentiometer PmV type KSP-4, control microammeter RA, resistor R2 and spark protection circuit R1, FV.
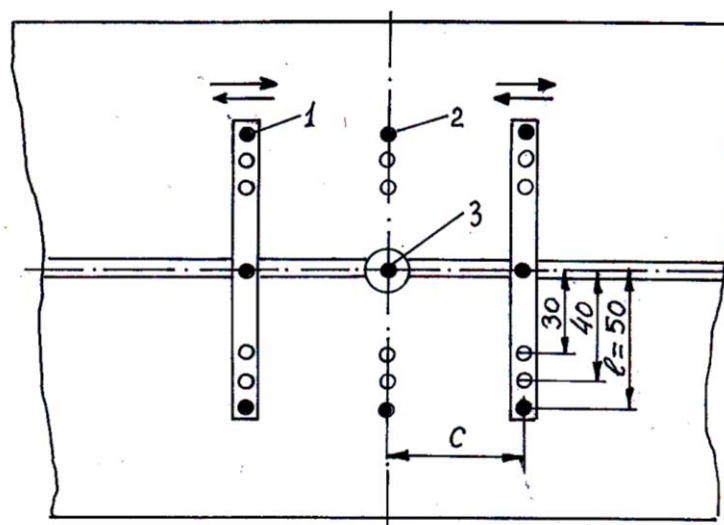

Figure 3. Scheme of a stand for studying the effect of the distance between rows of needles of different lengths on the current of the streamer form of a corona discharge

In the second part of the experiment, according to certain distances between the needles in a row, the distance between the rows of needles was determined. Moving rows of needles 1 were installed on the measuring stand (Figure 3). Measuring needle 3 was installed in the center of the fixed row of needles 2. The speed of movement of the carriages of the stand was 1 mm-1. The speed of movement of the chart tape in the self-recording potentiometer KSP-4 is 3 mm-1. The process was recorded until a steady value of the discharge current was established. The minimum distance between the point of the measuring needle and the movable needles is 10 mm.

The optimal ratios of the parameters of the electrode system "potential plane with corona needles – grounded plane" were determined based on the results of experimental studies of the process of trapping dust particles from an air stream.

To conduct experimental studies of the process of capturing aerosol particles from an air stream, a stand was developed (Figure 4) consisting of an assembly table 1, an outlet pipe 2, a grounded precipitation 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 for driving a centrifugal fan 11, an electric motor with a gearbox 9 for driving a dosing conveyor 10, dampers 12 for uniform distribution of air flow velocity with a lock 13.

On the stand, the distance between the potential electrode and the grounded plane is 0.15 m. The length of the dust particle deposition zone on the stand is 0.75 m. This distance is divided into 10 sections of 0.075 m each. The first section of the deposition zone was at the entrance to the deposition zone. The centrifugal fan drive was made from a series-excited DC motor. The speed of air flow through the stand was regulated by changing the voltage supplied to the electric motor. The maximum air flow rate in the stand is 9 m/s.
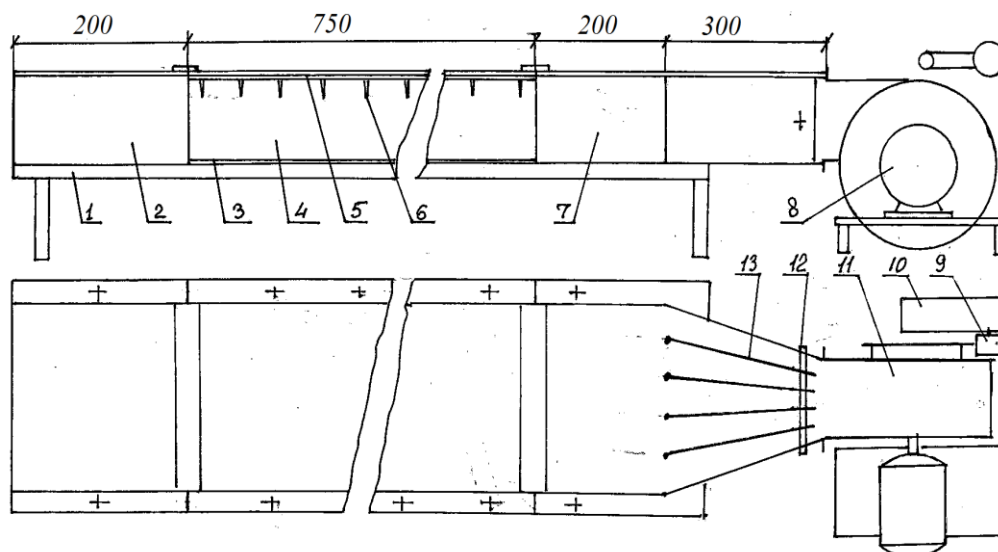
Figure 4. Scheme of the stand for researching the process of capturing aerosol particles from an air stream

The experiments were carried out on fine dust taken from a cotton gin and sieved on a 50 μm calibration sieve. Experiments with cotton dust were carried out for the reason that there are more than 100 cotton gins in the Republic of Uzbekistan. At these plants, the primary processing of raw cotton is carried out, the technology of which involves the use of a large amount of air (more than 50 m3 / s). The air exhausted in the technological process is cleaned by cyclones of various sizes and dust settling chambers. These devices work satisfactorily when capturing dust particles larger than 50 microns. With a decrease in the dispersion of dust particles, the trapping ability decreases sharply. A huge amount of fine dust (tens of thousands of tons) is released into the environment. The concentration of dust in the workshops and premises of factories, as well as on their territory, significantly exceeds the MPC. Accordingly, the ecology is disturbed in the areas where cotton ginning plants are located.

Studies of the process of trapping aerosol particles from an air stream at an interelectrode distance of 0.15 m, which will be used in electrostatic precipitators for cleaning process air, were carried out at an initial dust content of 560 mg/m3. To do this, a sample of dust weighing 0.003 kg was poured over a length of 0.05 m of the dosing conveyor. The initial contamination of the air was determined by the formula:

$$Z_0 = m_0 / [h \cdot b \cdot V(d/v)] , \qquad (1)$$

where m_0 – dust weight, mgr;

   h - interelectrode distance, m;

   b = 0.2 m - stand pipe width;

   V is the air flow rate, m/s;

   d - the length of the dosing conveyor on which the dust sample is located, m;

    v = 0,0015 m/s – dosing conveyor speed.

The air flow rate during experimental studies was 8 m/s.

The degree of purification was determined after summing up the masses of deposited dust over all 10 zones of the collecting electrode according to the formula:

$$W_0 = \Sigma m_n \cdot 100) / m_0, \% \qquad (2)$$

To reveal the dynamics of the process of deposition of dust particles from an air stream in the electric fields of a streamer corona discharge, the results of experimental studies were processed according to

the following method described below. The results for the most rational scheme of the electrode system were processed.

The residual mass of non-deposited dust was determined by the zones of the stand:

$$\Delta m_n = m_0 - \Sigma m_1 + m_2 + \cdots + m_n \tag{3}$$

where $m_1 + m_2 + \cdots + m_n$ – mass of dust deposited in 10 zones of the stand.

Dust content of air by booth zones:

$$Z_n = m_n / [h \cdot b \cdot V(d/v)]. \tag{4}$$

The degree of air purification by booth zones:

$$W_n = m_n \cdot 100) / \Delta m_n, \% \tag{5}$$

In the experiment, potential electrodes were used on which corona needles were installed with the parameters given in Table 1. For comparison, potential electrodes were also made with the same distances between the needles in a row and rows of needles. The pulse voltage frequency in the experiment was 500 imp-1. The results of the experiment were compared with the degree of purification obtained with a DC corona discharge. The degree of purification was determined after summing up the masses of deposited dust over all 10 zones of the collecting electrode according to formula (4.2).

In order to exclude the entrainment of deposited dust on the surface of the collecting electrode after switching off the high voltage, the experiment was carried out in the following sequence:

• The dust sample was placed on the feeding conveyor:

• A high voltage was applied to the stand, which increased to a spark breakdown of the interelectrode gap:

• The voltage was reduced by 20% of the breakdown value;

• Turn on the centrifugal fan motor and set the voltage corresponding to the air flow velocity equal to 8 m/s;

• At the same time, the dosing conveyor drive motor and the stopwatch were turned on;

• After 40 seconds of stand operation, the fan and dosing conveyor were turned off. After the fan stopped completely, the high voltage was turned off;

• The residual charge was removed from the high voltage source and grounded its exit;

• The box of the stand was removed, the dust deposited in each zone was removed with a brush and weighed on a torsion scale with a limit of 1000 mg and a division value of 2 mg.

After weighing the mass of soap deposited in zones, the mass of all trapped dust was determined. To determine the deposition zone required for 100% capture, an additional experiment was carried out according to the following method:

• The mass of uncollected dust was determined by the formula:

$$m_{oct} = m_0 - \Sigma m_n. \tag{6}$$

• The clogging of the air flow was determined in the presence of a residual mass of dust according to the formula

$$Z_{oct} = m_{oct} / (hbV); \tag{7}$$

• The length of the dosing conveyor on which the mass of uncaptured dust was located:

$$d = (m_{oct} v) / (Z_{oct} hbV); \tag{8}$$

To clarify the results of research on the parameters of the electrode system "potential plane with corona needles - grounded plane", the pattern of dust spots deposited on the collecting electrode was studied. Initially, a pattern of deposited dust from single corona needles of various lengths was observed. To do this, corona needles 15,20,25,30,35,40 mm long were alternately mounted in the center of the potential electrode. Then the picture of dust deposition at the same distance between the needles in the rows and between the rows of needles, and with the distance between the rows of needles twice as large as the distance between the needles in the row. In these studies, the air flow velocity is 2 m/s.

3. Results and Discussion

The dependences of the current of a single corona needle electrode on the distance to neighboring corona needle electrodes at a distance between the planes of 0.15 m were taken for an effective value of the pulse voltage of 5.4x104 V and a frequency of 500 s-1. The spark breakdown of the gap took place at a voltage of 5.8x104 V. The resulting diagrams were combined for comparison on one graph (Figure 5). The graphs show a significant dependence of the current of a single discharge electrode on the distance to adjacent discharge needle electrodes, as well as on their length.

The distances between the needle electrodes in a row were determined from the inflection points of the curves, marked with dots on the graphs.
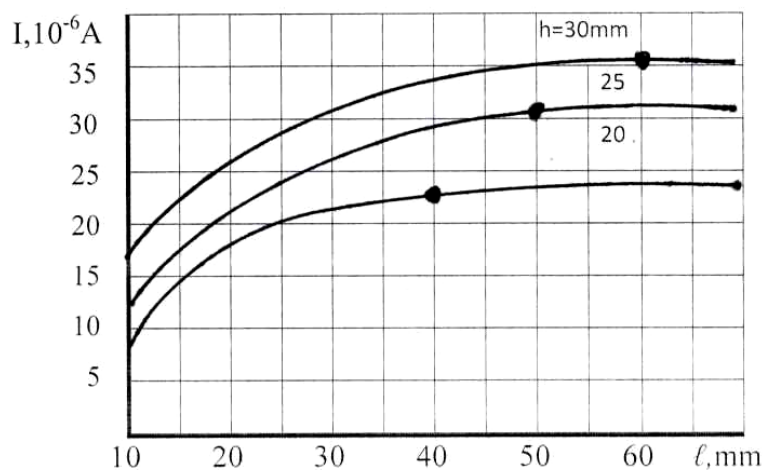
Figure 5. Dependences of the currents of single corona needles of various lengths on the distances to neighboring corona needles at H+h=0.15m
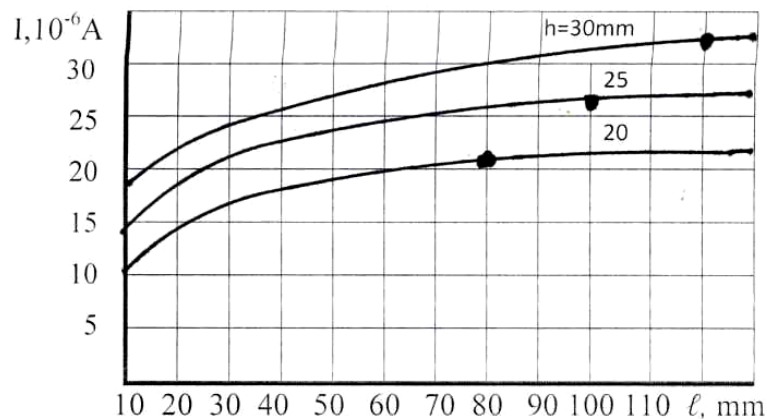
Figure 6. Dependences of the currents of single corona needles of different lengths on the distances between rows of corona needles at H+h=0.15m

In the data obtained, the relationship is clearly traced that the distance between the corona needles in the rows is two times less than the distance between the rows of needles (Table 1). Analytical analysis of this ratio is not amenable. The reason was found out during experimental studies of the process of capturing aerosol particles from an air stream. Of the certain parameters of the electrode system "potential plane with corona needles - grounded plane", the most optimal ones were chosen on the basis of experimental studies of the process of capturing aerosol particles from an air stream.

Table 1. Parameters of the electrode system "potential plane with corona needles - grounded plane" with a distance between the planes of 0.15 m

Needle electrode length, mm	20	25	30
Distance between needles in a row, mm	40	50	60
Distance between rows of needles, mm	80	100	120

3.1. Process of capturing aerosol particles from an air stream

Of interest are the patterns of spots of deposited dust from corona needles 25 mm long, with their staggered arrangement and the same distance between the needles in rows and between rows of needles and the pattern of spots of deposited dust from corona needles 20 mm long, with their corridor the location and distance between the needles in the rows is twice as large as the distance between the needles in the rows (Figure 7).

According to Figures 7 and 8 clearly show the shielding effect of the corona needles, which leads to a distortion of the shapes of the deposited dust spots. The validity of these data was confirmed by the following results of studies of the process of dust particle deposition by electrode systems with different parameters.

Figure 7. Pattern of spots of deposited dust from corona needles 25 mm long, with their staggered arrangement and the same distance between the needles in the rows and between the rows of needles

Figure 8. Pattern of spots of deposited dust from corona needles 20 mm long, with their in-line arrangement and the distance between the needles in the rows is twice as large as the distance between the needles in the rows (cells on a substrate 2x2 mm)

The results of experimental studies of the process of deposition of dust particles from an air stream for potential electrodes with the same distance between needles in a row and rows of needles are shown in

Table 2. According to the results of the experiment, it can be seen that the bulk of the deposited dust falls on 3,4,5,6,7 and 8 sections of collecting electrodes. The highest degree of purification was observed with a length of corona needles of 20 mm, but it is also equal to 65.87%. The total discharge current ranges from (50 ... 60) · 10-6 A

Due to the low performance of potential electrodes with the same distance between the needles in a row and the rows of needles, further studies were carried out for electrodes with an increased distance between the rows of needles (Table 2).

For comparison, studies at constant voltage were carried out only with a length of corona needles of 25 mm. The average value of the degree of purification at a constant voltage was 46.33%, and at an impulse voltage - 68.77%. With a pulsed voltage, the deposition process is more stable than with a constant voltage.

The highest degree of purification was obtained for needles 25 mm long. The average degree of purification was 90.36% with a dispersion of ±2.98%.

Of interest is the dynamics of the process of cleaning the air flow in the zones of the stand. To do this, the results of experimental studies obtained for the most rational parameters of the electrode system were processed using formulas 3, 4 and 5. Based on the results of these calculations (Table 3), it can be seen that a stable degree of purification begins from 5 to 8 zones of the stand and averages 30.1%. This means that the limiting ionic charging of dust particles proceeds in a time equal to: $t_{limit} = 4 * 0.075 / 8 = 0.0375$ s.

Table 2. The process of dust deposition from the air flow at the distances between the corona needles in rows 2 times greater than the distances between the rows of needles (air flow velocity 8 m/s)

h, mm	ℓ, mm	c, mm	U, 10^3V	I, 10^{-6}A	f, imp^{-1}	Total mass, mg	W, %	W_{cp} ±σ, %
20	40	80	56	120	500	1990	66.35	68.87±2.95
20	40	80	56	120	500	2092	69.7	
20	40	80	56	120	500	2018	67.27	
25	50	100	58	110	500	2682	89.4	90.36±2.98
25	50	100	58	110	500	2618	87.27	
25	50	100	58	110	500	2832	94.4	
30	60	120	55	100	500	2048	68.27	71.47±2.26
30	60	120	55	100	500	2190	73.07	
30	60	120	55	100	500	2192	73.07	

Table 3. Dynamics of the process of dust deposition by the zones of the bench

Booth zone numbers	1	2	3	4	5	6	7	8	9	10
Mass of deposited dust by test bench zones, mg	191.3	187.3	314.7	408	422	341.3	280	193	189	183
Residual dust weight by stand zones, mg	2808	2621	2306	1898	1476	1135	855	662	472	289
Dust content of air by stand zones, mg/m^3	524	489	430	354	275	211	159	123	88	54
Degree of air purification by booth zones, %	6	7	14	22	29	30	32	29	40	63

In the 9th and 10th zones of the stand, there is a sharp increase in the degree of purification to 40.03 and 63.32%. 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/m^3, which is much less than the amount of 150 mg/m3 allowed for process air emissions from cotton ginning plants.

Let us calculate the dust content of the air at the outlet of the electrostatic precipitator under the condition of increasing the deposition zone to 1.05 m, i.e. in the presence of additional 4 zones of dust deposition. In this case, the total number of zones will be 14 pieces. Let us assume that in zones 9…12 the degree of purification is 30%, and in zones 13 and 14, respectively, 40 and 63%. As a result of calculations (Table 4), the residual concentration of dust at the stand outlet is 20.15 mg/m^3, which is 7.44 times less than the permissible maximum concentration.

Table 4. Calculation results of the predicted process of air purification from dust with the number of stand zones equal to 14 and the total deposition zone of 1.05 m

Booth zone numbers	9	10	11	12	13	14
Mass of deposited dust by test bench zones, mg	463.4	264.8	185.36	129.75	90.83	54.5
Predicted degree of cleaning by stand zones,%	30	30	30	30	40	63
Mass of deposited dust by test bench zones, mg	198.6	79.44	55.61	36.33	34.35	20.15

However, a noticeable increase in the degree with an increase in the zones of deposition of purification is not observed. This is due to the fact that 78.8% of the total mass of dust is deposited in the first 8 zones of the stand.

Table 5. Results of studies of the air purification process with residual dust content

h, mm	25		
ℓ, mm	50		
c, mm	100		
U$_\text{д}$, kV	48		
I, 10^{-6} A	110		
Zoned mass of deposited dust, mg			
Residual mass of dust, mg	325	354	326
5 zone	115	117	110
6 zone	74	77	74
7 zone	47	54	48
8 zone	32	37	33
9 zone	31	36	34
10 zone	25	28	24
General	324	349	323
W%	99.7	98,59	99,08
W$_\text{average}$	99,12		

According to the results of studies of the dust deposition process, it was found that the highest degree of cleaning was observed with a needle length of 20 mm, a distance between the needles in a row of 40 mm, a distance between the rows of needles of 80 mm, and was equal to 90.33%. From an initial sample weight of 3000 mg, the uncaptured mass is approximately 300 mg. To determine the total length of the dust deposition zone, an additional experiment was carried out according to the method described in Section 3. To eliminate the effect of the charging time of dust particles flowing in the first three deposition zones, an additional 100 mgy of dust was added to a dust sample of 300 mgy, taking into account the fact that about 25% of the dust is deposited in the first three zones of the stand. The

residual clogging and the length of the feed conveyor, on which the mass of the uncaptured dust sample was located, were determined by formulas 6, 7 and 8. The results of the experiment are given in Table 5. The dust deposited in the first three zones of the stand was not taken into account in the calculations. An analysis of these results shows that almost complete air purification from aerosol particles occurs in the dust deposition zone not exceeding 1 m.

Based on the results of the experiments, the following shortcomings were identified that require additional research:

- the value of the breakdown voltage of the interelectrode gap of the stand is significantly lower than the breakdown voltage of disk electrodes with a single corona needle;
- breakdown of the interelectrode gap of the stand flows from the grounded plane.

The latter conclusion is based on the fact that the shape and structure of the spark discharge of the interelectrode gap of the stand is similar to the spark discharge from the tip of the needle when the latter is powered by a pulsed voltage of positive polarity.

4. Conclusions

1. The most acceptable interelectrode distances between the potential and collecting electrodes of electrostatic precipitators are: for electrostatic precipitators designed to clean the air and gases exhausted in technological processes 0.1 m; for electrostatic precipitators intended for air purification in dusty industrial premises 0.05 m.

2. It has been experimentally established that the distance between the rows of needles should be twice as large as the distance between the needles in the rows. In this case, the rows of needles should be located across the flow of the purified gas, and the length of the needle is equal to half the distance between the needles in the rows.

3. The spot of deposited dust from a single corona needle is a circle of almost perfect shape. With a constant distance between the potential and ground planes, an increase in the length of the needle leads to an increase in the diameter of the circle. Spots of deposited dust from groups of corona needles with different parameters show a strong mutual shielding effect of the needles on each other.

4. It has been established that the highest degree of air purification is observed with the following parameters of the electrode system "potential plane with corona needles - grounded plane": for an interelectrode distance of 0.1 m - the length of the needles is 20 mm, the distance between the needles in a row is 40 mm, the distance between the rows of needles is 80 mm, the length of the deposition zone is 1 m; for an interelectrode distance of 0.05 m - the length of the needles is 15 mm, the distance between the needles in a row is 30 mm, the distance between the rows of needles is 60 mm, the deposition zone is 0.5 m.

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