Influence of temperature and humidity of the air on discharge processes in electric filters

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Abstract. The article presents the results of an analysis of data sources of information on the use of electric fields in the processes of air purification from small dust particles (aerosols), and it is found that when developing existing devices for air purification from aerosol particles, the influence of the parameters of the purified air on the operation of electric precipitators was not taken into account. There is also no unified methodology for determining the parameters of electric precipitators, which is confirmed by the significant difference in the geometric and energy parameters of the developed electrostatic precipitators. The advantage of using a streamer form of corona discharge in electric gas cleaning processes is described. A methodology for conducting experimental studies to determine the influence of pressure, temperature and humidity is presented. Purified air on discharge processes in discharge gaps when powered by constant voltage and unipolar high voltage pulses with a duty cycle of more than 5. The results of experimental studies are presented.

1. Introduction

To collect dust, devices are used, the operation of which is based on the use of various methods for separating particles from a gas flow. The classification of dust collectors and filters, the basic requirements for them and the areas of application of their various types are given in works [1,2,3,4,5,6]. They provide the following characteristics of dust qualification groups
I – very coarse (cotton dust after the separator);
II – coarse dust (cotton dust from the gin and linter shop);
III – medium-fine dust (cotton dust from the drying and cleaning shop);
IV – fine dust (silk and fibrous);
V – very fine dust (flour and cement).
The principle of operation of dust collectors and filters is as follows:
- devices whose operation is based on the use of gravity - dust chambers, gas ducts;
- devices whose operation is based on the use of centrifugal force: cyclones, louvered and inertial dust collectors;
- wet dust collectors-scrubbers, foam devices, high-speed (turbulent) dust collectors;
- fabric filters; In these devices, dusty gas is passed through the fabric and the dust is retained on them. At low filtration rates, a high degree of gas purification from dust can be achieved. In some cases, to filter dusty gases, they use not fabrics, but papers, special cardboard, cotton wool, layers of fibrous materials, layers of dropped cotton seeds, sand, gravel, and coke;
- vortex hydrofilters (VF) "VORTEKS";
- electric precipitators - devices for separating dust in an electric field.

The widespread use of electric precipitators for collecting solid and liquid particles is due to their versatility and high degree of gas purification at relatively low energy costs. Electric gas purification installations are capable of operating with an efficiency of up to 99%, and in some cases 99.5%, and are capable of capturing particles of any size, including submicron ones, with particle concentrations in gas up to 50 g/m3 and higher.

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Electrostatic precipitators can operate both under vacuum and under pressure of the gases being purified. Dust collection systems using electric precipitators can be fully automated. Electrostatic precipitators have relatively low operating costs. This is explained by the fact that the hydraulic resistance of the electric precipitator does not exceed 100-150 Pa, i.e. is minimal compared to other gas cleaning devices, and the energy costs for creating an electric field are also low and usually amount to 0.1-0.5 kWh per 1000 m3 of gas [7,8].
Of the above methods and dust collection devices, particles of dispersion group V are capable of being captured by electric, water and fiber filters. Of these, the requirements for small dimensions, low pneumatic resistance, low power consumption, low operating costs and low cost are most fully satisfied by electric filters.
The analysis of the parameters of existing electrostatic precipitators revealed that there is no scientifically based choice of such parameters of electrostatic precipitators as the flow rate of the gas being purified, the length of the dust deposition zone, and the power of the high voltage source. In addition, the influence of temperature, humidity, pressure and dust content of the purified gas on the development of electrical discharges in the air is not taken into account. Hence the sharp difference in the parameters of the developed and used electrostatic precipitators
As an example, we will make a selection from the technical characteristics of existing electrostatic precipitators. For convenience of analysis, we introduce the parameter "specific power of the process of cleaning the air flow from dust

$$P_{sp} = P_{con} / \Pi_{pro} \text{ (Vt·s/m}^3\text{)}, \quad (1)$$

P_{con} - power consumed by the electrostatic precipitator, W
Π_{pro} -productivity of the electrostatic precipitator for the purified air, m3/s.

The sampling results are summarized in table. 1. Analysis of the table shows a significant difference in the specific power of the air purification process from dust - from 144 to 4285 W·s/m3. If we take into account that the speed of the purified gas in the active zone of electric precipitators is maintained within 1-1.5 m/s, then the specific power of the gas purification process from dust should be proportional to the productivity of the electrostatic precipitator for the purified gas [9-11].
However, this proportion is not observed. This situation is not the only incident in the theory of electrostatic precipitators. When studying technical information on the research and development of electric precipitators, it was discovered that there were no clearly substantiated recommendations for the selection of such technological parameters of electric precipitators as the length of the dust deposition zone and the flow rate of the gas being purified. The dynamics of the dust deposition process along the length of the deposition zone has not been studied.

Table 1. A selection from the technical characteristics of existing electrostatic precipitators

Electrical type Filter	Dimensions, m (length,height, width)	Speed gas flow, m/s	Performance by air, m3/s	Power consumption, W	Specific power, Wt•s/m^3
EF Sfu	Diameter 1 m, deposition zone, 1 m	8,0	6,2	200	33
EFVA 20-10	0,7 x3x1,5	1,0	5,56	800	144
EFVA 40-11	0,75x3x3	1,0	11,12	1600	144
EFVA 1-08	1,3x0,65x0,6	1,0	0,28	1200	4285
EFVA 1.5-09	0,8x1,4x0,7	1,0	0,36	1200	3333
FIBERBOARD-2x25		1,0	3,3	8000	242
ORP-2x30		1,0	33,8	18000	532
PGDS 3x24		1,0	24	40000	1667

Note: drum-type electrostatic precipitator using a streamer form of corona discharge.
The electric precipitator power unit is one of the most important components of an electric gas treatment plant. The achieved significant increase in the efficiency and reliability of the installations was facilitated by the creation of modern automatic power units, which made it possible to automate the operation of electrical gas purification installations. The specific features of technological processes in industries where electrostatic precipitators are used have led to the creation of devices of various designs.

A large amount of research work on the creation of power systems for high-voltage gas purification devices based on electron beam valves and gas-discharge devices was carried out at the Federal State Unitary Enterprise "All-Russian Electrotechnical Institute" [12, 13, 14, 15, 16, 17].

Until recently, the use of alternating and pulsed voltages in electric gas cleaning processes was not considered possible for widespread practical application due to serious technical difficulties in designing power supply units capable of providing reliable switching of high voltages with a sufficiently high frequency. Recently, thanks to the development of electronics, powerful high-voltage semiconductor switching devices have been created that make it possible to solve the technical problems of creating reliable switching power supply units.

It should be noted that developments were carried out to improve the efficiency of existing electrostatic precipitators. Therefore, the issue of reducing weight, dimensions and power consumption was not considered in them. The disadvantages also include the fact that the pulses were formed on the high-voltage side of the sources, which led to a significant increase in their dimensions and a decrease in reliability.

The main disadvantage of the listed studies is the erroneous choice of the frequency of pulse voltages equal to the frequency of the discharge processes of a constant voltage corona discharge, equal to 30,000...40,000 s-1. As studies have shown [18, 19], stabilization of the streamer-shaped corona discharge current is limited to a frequency not exceeding 1000 s-1. In addition, the flow speed of the purified air can be increased to 10 m/s, and the deposition zone can be reduced to 1 m.

The article presents the results of studies of the influence of temperature, humidity, pressure and the degree of dust content of the purified gas on the process of development of electrical discharges in the air at constant and pulsed high voltages.

2. Research Methods

2.1. Methodology for experimental studies of the influence of temperature and air humidity on discharge processes in electric precipitators

Experimental studies were carried out using a climatic chamber, the general view of which is shown in (Fig. 1), and the arrangement of elements inside the chamber is shown in (Fig. 2.1., 2.2.). When developing the methodology, the Interstate standard was used: "Chambers of non-injection type for obtaining constant relative humidity" (GOST 28237-89. IEC 260-68). This standard specifies the performance and design requirements for forced air chambers that may be used for moisture testing of apparatus or similar products. The relative humidity of the air in the chamber is regulated using saturated solutions of salts or mixtures of glycerin and water. This standard applies to cameras operating at a constant nominal temperature ranging from ambient temperature to 60 °C. and at constant relative humidity. Chambers designed to operate at temperatures below or equal to ambient temperature. must be equipped with a cooling system

To do this, the camera was installed in the blowing zone of a BK-2000 household air conditioner. In addition to the standard for operation at temperatures above ambient temperature, a water radiator with forced airflow was installed in the chamber. Water for the radiator was heated in a boiler using a tubular electric heater (TEH) with a power of 1000 W.

Definition of terms used in the methodology:

- working volume – part of the chamber in which the conditions necessary for this test are established (the working volume does not include the space located at a distance of 3 cm from the walls and lid of the chamber);
- chamber temperature – temperature in the center of the working volume;
- temperature deviation – the difference between the chamber temperature and the temperature at any point in the working volume at any time;
- temperature fluctuation - short-term change in temperature at any point in the working volume.

2.2. Methods for obtaining the required relative humidity using saturated salt solutions

Saturated salt solutions have a great ability to absorb or release moisture without affecting the relative humidity of the air. The air above a saturated saline solution at a constant temperature retains a certain relative humidity characteristic of a given salt solution and a given temperature. The saturated solution must have excess salt. When using a saturated saline solution for testing, do not use salts, which can create a corrosive atmosphere that is hazardous to the samples.

Adding 1% - 2% sodium tetraborate solution slows down discoloration and reduces the relative humidity equilibrium by 1% at 200C.

Ammonium salts, for example, are not suitable for testing samples containing copper or its alloys. Avoid salt crystallizing or creeping onto the walls. The names of the salts and their corresponding relative humidity used in the experimental studies are given in Table 2.

If there is excess salt, the solution can release and absorb large amounts of moisture, which does not affect its ability to regulate the relative humidity of the surrounding air. Therefore, the solution can be used for a long time and should be changed only when dirty.

Table 2. Relative humidity of air over various saline solutions

Saturated saline solution	**Relative humidity, %, at temperature, °C**									
	5	10	15	20	25	30	35	40	50	60
Potassium sulfate K2SO4	98	98	97	97	97	96	96	96	96	96
Sodium chloride* NaCl	76	76	76	76	75	75	75	75	75	75
Sodium dichromate Na2Cr202 2H20	59	58	56	55	54	53	51	50	47	-
Potassium acetate CH3 SOOC	20	21	21	22	22	22	21	20	-	-

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The range of relative humidity that can be adjusted in this way is limited to salts and mixtures for which reliable data are available. When using brine solutions there is no need to measure the relative humidity in the chamber.
Some salts are difficult to use due to the solution sliding down the walls of the vessel. The use of other salts is limited due to their high cost.
Unless otherwise specified, a saturated solution prepared from distilled water and sodium chloride of a known analytical composition is poured into the pan. It is important that the saturated solution contains a slight excess of solid salt. If necessary, you can use a liquid suspension (mixture) obtained by adding a pre-prepared saturated solution to solid salt having particles of the appropriate size until the required consistency is obtained.

2.3. Precautions when working with cameras

The permissible loading of the chamber depends on the quantity and type of absorbent materials from which the test samples are made. Overloading a small chamber can reduce the rate of humidity rise so much that it takes too long to reach steady state. Since the loading limit of the chamber depends on the material of the test specimens, it cannot be established. Care must be taken to ensure that moist air has free access to all samples.
To prepare saturated salt solutions or mixtures of glycerin with water, distilled water is used.
To prepare a brine solution, salt crystals are stirred into boiling water until it is almost saturated, then the solution is cooled to room temperature to obtain a homogeneous solution. Otherwise, a layer of lower concentration may form on the surface of the solution, and when such a solution is used to obtain a relative humidity of 80-90%, the relative humidity exceeds the specified one.

2.4. Requirements for the design of a climatic chamber

General provisions. The chamber must be constructed of appropriate materials, and electrical and other fittings must be accessible during operation. The interior of the chamber must be made of corrosion-resistant, non-absorbent material. The connections must be free of leakage and free from corrosion.
The design of the chamber must provide free access for cleaning internal surfaces. When closing, the door frame and the front wall of the chamber must be pressed tightly enough to ensure the necessary tightness of the chamber.
Prevents condensation. The design of the chamber must exclude the possibility of moisture condensation on the inner surface of the chamber or on the surfaces of a cooling device that may be built into the chamber.
Note: At a relative humidity of 90% and above, small streams of water are allowed on the chamber walls if this does not affect the average relative humidity in the working volume and if drops of water do not enter the working volume of the chamber. If the chamber is equipped with any additional heater to prevent condensation on the viewing window, then it should not have an adverse effect on the temperature and relative humidity in the working volume of the chamber.
Air circulation. The chamber is equipped with a fan that creates the necessary air circulation in all parts of the working volume of the chamber. The speed of air circulation on the surface of the solution must be sufficient to quickly transfer

moisture from the solution to the atmosphere or vice versa, and must be such that relative humidity can be measured with the required accuracy.

Tray for salt solution. The brine tray must be made of an appropriate material that will not crack or deteriorate when exposed to the saturated brine solutions listed in

Temperature regulation. Temperature control is carried out manually from the outside of the chamber using a temperature relay PTR-2-03. The sensitivity of the control system must ensure that the temperature is maintained at a certain point in the chamber with an accuracy of ± 2 C. The temperature measurement accuracy of a direct-reading device should be ± 2 “C.

2.5. Camera tests

Camera. The chamber must be tested unloaded with samples, but with shelves installed in it (if any). The saturated sodium chloride solution in the pan should reach the operating level unless otherwise specified in the test conditions. The environmental conditions and operating voltage but test time must be within the limits that the chamber is designed for.

2.6. Test to check the relative humidity conditions in the chamber

The chamber should be operated for 2 hours at the upper end of the operating temperature range using a saturated sodium chloride solution poured into a tray. Relative humidity measurements are taken at a specific point in the working volume over a 2-hour period as follows. Relative humidity is measured using a multi-junction differential thermocouple with dry and wet. Measurements are made using a recording device or other method that allows the maximum change in relative humidity to be determined during the entire test.

2.7. Design of the developed climatic chamber

The chamber consists of a cubic box with sides of 0.5 m, the walls of which are made of organic glass 3 mm thick, a water radiator, a fan, a boiler heated by a heating element with a power of 1 kW, a piping system, measuring equipment, and an automatic control system.

The temperature in the room is controlled by a thermal relay KK (Fig. 1) type PTR-2-03. Emergency shutdown of the heater in the boiler is carried out using relay SK type RT-200. This relay is mounted directly into the boiler. The temperature of the water in the boiler is controlled by a thermometer. The air temperature in the room is measured using the Sh69006 device. There is a window in the lid of the model for ventilation. The activation of the KK and SK relays is signaled by the signal lamps HL1 and HL3, and HL2 – when the fan is turned on

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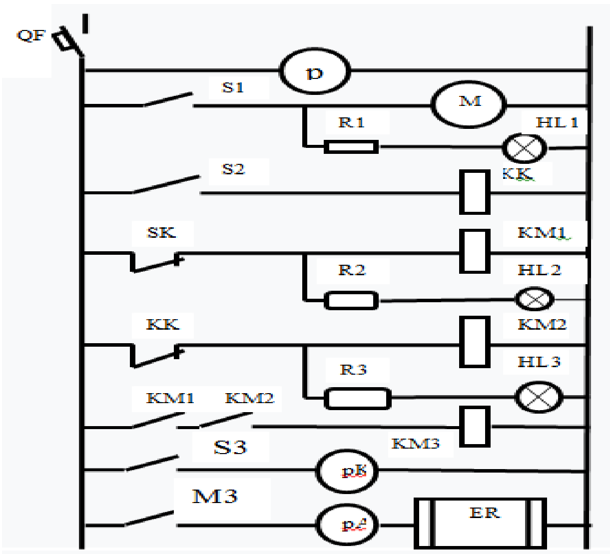
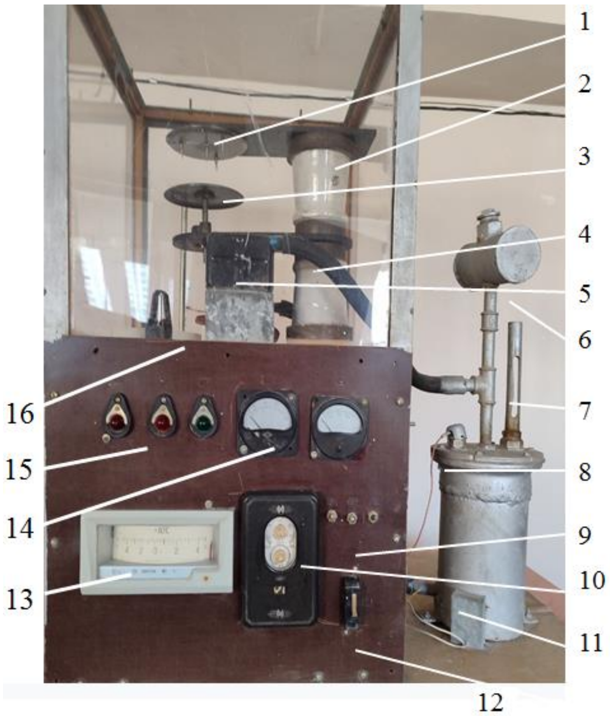


Fig.1. Schematic diagram of a climatic chamber for studying the influence of temperature and air humidity on corona discharge processes



1 – potential electrode; 2 – support insulator; 3 – grounded electrode; 4 – pipeline; 5 – radiator; 6 – expansion tank; 7 – control thermometer; 8 – thermal relay RT-200 for water in the boiler; 9 – switches; 10 – thermal relay PTR-2-03 for air in the chamber; 11 – boiler; 12 – automatic switch; 13 – thermal relay M-1006; 14 – measuring instruments for network voltage and current of the heating element of the water heating boiler; 15 – signal lamps; 16- thermal resistance for PTR-2-03

Fig. 2. General view of the chamber for studying the influence of temperature and air humidity on the corona discharge current at constant and unipolar pulse voltages

17 – needle electrodes; 18 – clamp for regulating the interelectrode distance; 19 – thermal resistance for M-1006; 20 – fan; 21 – tray for saturated saline solution

Fig. 3. Chamber for studying the influence of temperature and air humidity on corona discharge current at constant and unipolar pulse voltages

3. Results and Discussion

Experimental studies were carried out in two stages:

• study of the magnitude of the discharge current at different air temperatures and power supply with direct and pulsed voltages;

• study of the magnitude of the discharge current at different relative air humidity and power supply with direct and pulsed voltages.

In the experiment, the distance between the potential and grounded planes was set to 0.075 m. The length of the corona needles was 25 mm. A constant and pulsed voltage equal to 35 kV according to the effective voltage value, which corresponds to 467 kV/m, was alternately applied to the potential electrode. Pulse voltage frequency 120 c^{-1}.

The first part of the experiment was carried out using a saturated solution of sodium chloride (NaCl), which corresponds to 75% relative humidity. During the experiment, the temperature relay PTR-2-03 was set to the required temperature, the value of which was automatically maintained. The experiment was carried out after one hour of exposure to achieve the required equilibrium humidity. After removing the discharge current value, the next temperature value was set on the thermal relay. The measurement results are presented in Fig. 3 in the form of a dependence graph.

The results of the experiment show (Fig. 4) that when powered with a constant voltage, an increase in the corona discharge current is observed with increasing air temperature. When the temperature increases from 10 0C to 60 0C, an increase in the discharge current is observed from 120 to 270 µA.

When powered by pulsed voltage, the value of the discharge current practically does not change with increasing temperature and is on average 450 µA. Compared to constant voltage, the magnitude of the discharge current with pulsed voltage increases by 1.67. 3.75 times.

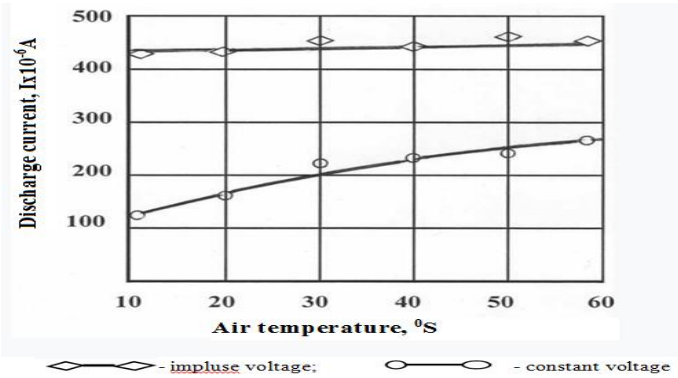


Fig.4. Dependence of the discharge current on air temperature at a relative humidity of 75% and an effective voltage value of 35 kV (electric field strength 467 kV/m)

The second part of the experiment was carried out using four types of saturated salt solutions. Depending on the type of salt, the relative air humidity had the following values: 97%, 75%, 54%, 22%. The temperature in the climate chamber was maintained at 25 0C, which was set on the PTR-2-03 temperature relay. After installing a tray with another saturated salt solution in the chamber, the fan was turned on for 1 hour to evenly distribute humidity throughout the entire volume of the chamber. The source of direct and pulsed voltages was turned on alternately and the microammeter reading was taken.

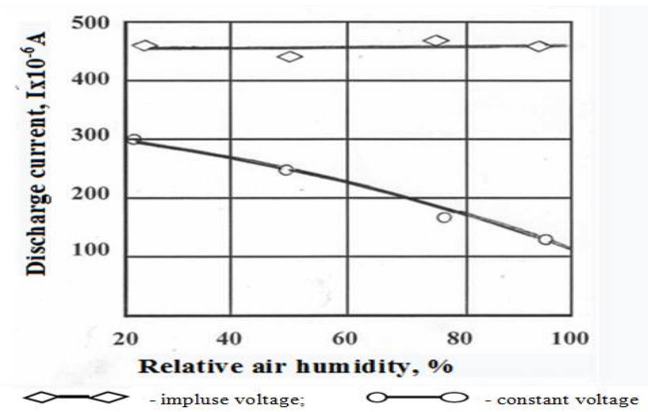


Fig. 5. Dependence of the discharge current on the relative humidity of the air and the effective voltage value of 35 kV (electric field strength 467 kV/m)

According to the results of the experiment, it can be seen (Fig. 5) that when powered by a constant voltage, with an increase in the relative humidity of the air, a decrease in the corona discharge current was observed. When the relative humidity increased from 22% to 97 0C, a decrease in the discharge current was observed from 300 to 110 μA.
When powered by pulsed voltage, the value of the discharge current practically did not change with increasing temperature and was on average 460 μA. Compared to pulse voltage, the discharge current at constant voltage decreased by 1.53-4.18 times.
Based on the results of an experimental study of the corona discharge current, it was revealed that when powered with a constant voltage, the discharge current significantly depends on humidity and air temperature. However, in previously developed electrostatic precipitators this factor was practically not taken into account, but was compensated by an increase in the dust deposition zone and a decrease in the flow rate of the gas being purified.
When powered by pulse voltage, the amplitude of the voltage pulse is 40% higher than the breakdown voltage of direct voltage and is equal to

$$U_a=U_{work}/(0,8\cdot 0,6)=35/(0,8\cdot 0,6)=73 \text{ Kv}. \quad (2)$$

From which it can be seen that the amplitude of the pulse voltage is 40% higher than the breakdown voltage of the constant voltage. The amplitude value of the pulse voltage leads to significant ionization of the discharge gap, which leads to an increase in the conductivity of the gas discharge gap, which in turn leads to a significant increase in the discharge current and a decrease in the influence of temperature and humidity of the air gap.

4. Conclusions

1. When powered with a constant voltage, an increase in the corona discharge current is observed with an increase in air temperature. When the temperature increases from 10 0C to 60 0C, an increase in the discharge current is observed from 120 to 270 μA. When powered by pulsed voltage, the value of the discharge current practically does not change with increasing temperature and is on average 450 μA. Compared to constant voltage, the magnitude of the discharge current with pulsed voltage increases by 1.67...3.75 time
2. When powered by a constant voltage, with an increase in relative air humidity, a decrease in the corona discharge current was observed. When the relative humidity increased from 22% to 97 0C, a decrease in the discharge current was observed from 300 to 110 μA. When powered by pulsed voltage, the value of the discharge current practically did not change with increasing relative air humidity and was on average 460 μA. Compared to pulse voltage, the discharge current at constant voltage decreased by 1.53...4.18 times
3. In the developed and operated electrostatic precipitators, where constant high voltages are used, a big omission in the selection of parameters and development is ignoring the influence of temperature and humidity of the air being purified. However, with an increase in temperature from 10 0C to 60 0C, the value of the discharge current increases by 2.25 times, and the flow of space charges in the discharge gap and the amount of charge on dust particles change accordingly. The opposite picture is observed when the relative air humidity changes, where an increase in relative humidity from 22% to 97 0C, an almost threefold decrease in the discharge current is observed. However, this phenomenon was practically not taken into account in the studies, but was compensated by increasing the dust deposition zone to 28 m, using numerous processing fields, and the low speed of the purified air.
The opposite picture is observed when using a streamer form of corona discharge, where the amplitude of the voltage pulse is 40% higher than the breakdown voltage of the discharge gaps at constant voltages. At such voltages, the strongest ionization of the discharge gaps occurs, approaching the values of the phenomenon of low-temperature plasma. In this case, there is no need to regulate the parameters of electric precipitators based on the temperature and humidity of the processed air.

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