Investigation the formation of a spark discharge from a layer of deposited dust on a grounded electrode and dependence of air purification degree on the potential electrode voltage

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Abstract. This article presents the methodology and results of experimental studies of the formation of a spark discharge from a layer of deposited dust on a grounded electrode and the dependence of the degree of air purification on the voltage at the potential electrode. Based on the research results, the limiting density of the deposited dust and the need to clean the precipitation electrode from the deposited dust layer, as well as the use of spark protection circuits, were determined. It was also revealed that the level of fluctuation of the mains voltage practically does not affect the degree of purification of the air stream from dust.

1. Introduction

The established technology of primary processing of raw cotton is based on hard mechanical action [1,2]. To increase the efficiency of the primary processing of cotton, while improving the quality of the charged fiber and reducing losses, can be achieved by using the effects of strong electric fields [3].

To clean raw cotton, it is necessary to use homogeneous or slightly inhomogeneous electric fields. In these electric fields, the electric field strength can be set to 6•105 V/m. At this intensity, the interaction force of the charge on cotton particles with an electric field is 3...4 times greater than the mass of a cotton particle [4].

An increase in the force effect of an electric field on cotton particles can be achieved by using pulsed voltages of a large well with an amplitude higher than the electrical strength of the discharge gaps. When using such voltages, the forces of electric fields can be increased by 2.5...3 times compared to constant electric fields.

An increase in the amplitude of pulse voltages above the breakdown value of constant voltages is associated with the regularity of increasing the electrical strength of discharge gaps with a decrease in the time of voltage exposure [5].

Intensive orientation of raw cotton fibers in pulsed electric fields will significantly increase the efficiency of the cleaning process, while reducing mechanical stress and reducing the time of the technological operation.

One of the unsolved problems in cotton cleaning technology is the purification of air used in technological processes from fine dust particles. Currently used cyclones and dust-settling chambers are capable of satisfactorily retaining dust particles up to 50 microns in size. Smaller particles are released into the atmosphere.

The air and gases in industrial buildings used in technological processes can be purified using a variety of techniques and tools, but electrofilters are the most effective because of their high cleaning capacity, high productivity for the gas being cleaned, ability to capture aerosol particles with sizes less than 0.1 microns with any mechanical or physical properties, and lack of aerodynamic drag.

The last century's first fifty to eighty years saw the development of electric gas purification technology [6,7,8,9,10]. Based on the Central Research Laboratory Scientific Research Laboratory for Gas Purification, the State Scientific Research Institute for Industrial and Sanitary Gas Purification, Scientific Research Institute of Gas Purification, was founded in 1949.

The Institute's founding was a turning point in the advancement of residential gas purification research and helped pave the way for a more thorough investigation of the key issues relating to dust collection and gas purification. It has the following tasks: theoretical development and introduction into industry of new methods and the most rational

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technological schemes for cleaning industrial gases from dust and mists; development of methods for monitoring the operation of gas cleaning equipment; experimental verification of new technological schemes and designs of devices, as well as issues related to the reconstruction of existing gas cleaning devices; provision of scientific and technical assistance to industrial enterprises on gas cleaning issues.

Electrofilters have found a wide range of applications due to the development of highly efficient devices that offer a high degree of purification. Large cement production furnaces, high-performance devices for cleaning flue gases from boilers with power units of 300, 500, and 800 MW, and other technological equipment are among the types of devices that fall under the stipulated size range of unified electric filters.

Since the early 80s of the 20th century, the main work on electric gas purification has been mainly related to improving the efficiency and reliability of already developed electric filters. There are now developed power supply units for ATP-type electrofilters. The units' dependability has considerably improved because to the usage of silicon rectifiers, thyristor control, and other semiconductor components. A high level of purification was made feasible by the discovered principles of voltage regulation, which allowed for the maintenance of an enhanced load on the electrofilter electrodes [10].

Taking note of the remarkable advancements in electric gas purification technology, we will examine the barriers preventing the wider application of electric filters for the removal of solid and liquid aerosol particles from the air in commercial, residential, and industrial settings.

The weight and size of the electrofilters with high power consumption should be noticed first. The UGZ series electrofilters have dimensions ranging from 18.6 x 12 x 15.4 m to 24.8 x 21.8 x 27 m, and the aerosol particle deposition zone A1 = 15.4... 27 m. The electric filters are powered by power supply that can hold up to 200 kVA. The filtered gas flows at a rate of V1 = 1....1.5 m/s. Electric filters with the same performance will use less power if the deposition zone is lowered to A2 and the gas flow rate is raised to V2. This reduction in power will occur [(V1/V2)•(A1/A2)] times. The electric filters' diameters will shrink in direct proportion to power.

Gas purification in electric fields can be made much more efficient in order to accomplish this goal. The amount of charge on the particles that are collected (Q) and the strength of the electric field between the electrofilter electrodes (E) or the Coulomb force (Fk= QE) are the primary determinants of this process. Pre-charging is one known way to increase the efficiency of electric filters [8], but it does not produce the desired outcome. Our experimental investigations of the dynamics of the force action of homogenous electric fields on the material's particles have led us to this conclusion. In order to conduct these tests, particles were pre-charged with an aqueous aerosol in the corona discharge field. The oscillogram (Fig. 1) shows that the pre-charge's interaction with the electric field results in a brief force pulse that lasts for approximately 0.05 seconds. Following this, the particle charges normally in accordance with the exponential law. The strongest force impulse was seen when using an aqueous aerosol for charging at the same moment. The force pulse is two to three times lower during pre-charging in the corona discharge field.

Based on these studies, a conclusion follows about the "rejection of a foreign charge", after which the electric field informs the particles of its electric charge. It follows that all processes in electric fields are caused by the intensity and type of electric field. However, in existing electrofilters, the electric field strength is automatically maintained at pre-test values, and practically brought to the limit of their capabilities. Therefore, it is necessary to develop a method to increase the intensity of the electric field.

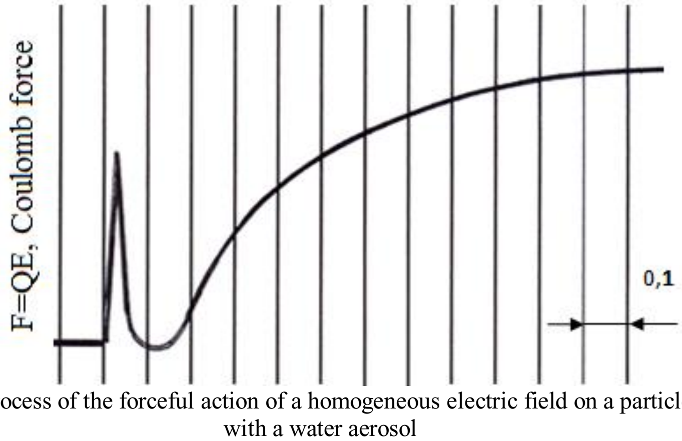

Fig.1. An oscillogram of the process of the forceful action of a homogeneous electric field on a particle of a material pre-charged with a water aerosol

The development of a new method of electric and gas purification is also due to the disadvantages of a constant voltage corona discharge. Being one of the types of independent discharge, various elementary physical processes occur in it at the same time: the appearance, movement and destruction of charged particles. This leads to instability of discharge currents in frequency and amplitude, as well as to locking of the discharge, reverse corona, transition to spark or arc forms. Obviously, while ensuring the stability of discharge processes, it is possible to significantly increase the efficiency of electric and gas cleaning.

Independent discharges in gases are more stable. But to create them, an additional source of ionization is needed. No research has been conducted in this direction due to the significant complication of the electrofilters and the need for an additional high voltage source and a corresponding increase in power consumption. To create electrofilters of a simple design, it is necessary to combine an independent and non-independent discharge in one discharge gap.

Studies have been conducted in the direction of using unipolar high-voltage pulses based on the fact that with a decrease in the time of exposure to voltage, the electrical strength of gas discharge gaps increases [12]. This excess is characterized by an overvoltage coefficient - K_o, which is introduced as the ratio of the amplitude of the voltage pulse Ua to the breakdown constant voltage U_{br} ($K_o = U_a/U_{br}$).

The physics of pulsed breakdown of gases separates the areas of development of discharges in the air according to the Townsend or streamer mechanism. In the technique of using the corona discharge electric field, gaps from 0.05 to 0.15 m are used at pressures close to normal, which corresponds to pd = 38...80 torr.m. Hence, already at Kp > 0.02, the streamer breakdown mechanism [8], or corona discharge in streamer form, manifests itself.

Studies on the use of the streamer form of the corona discharge have been published in [11-18]. These studies have established the following advantages of the streamer form of the corona discharge:

- The discharge processes are stabilized;
- the electrode system "potential plane with corona needles – grounded plane" has been developed;
- the geometric parameters of the developed electrode system for interelectrode distances of 0.05, 0.1 and 0.15 m are determined;
- power supply circuits with high-voltage voltage pulses have been developed;
- machine and electronic generators of periodic voltage pulses have been developed;
- electrofilters have been developed and tested in production conditions for air purification in industrial premises and purification of air used in technological processes from fine dust;
- it has been established that in the electric fields of the streamer form of the corona discharge, the discharge currents do not depend on atmospheric pressure, humidity and temperature of the purified air.

This article presents the results of the following studies:

1) investigation of the process of formation of a reverse corona and the resulting spark discharge from a layer of deposited dust on a grounded electrode;
2) investigation of the VAC streamer shape of the corona discharge with positive polarity of the corona electrodes;
3) investigation of the degree of purification of the air stream from dust depending on the voltage value;
4) investigation of voltage fluctuations at the output of a high voltage source from a change in voltage in the network.

2. Research Methodology

The study of the effect of the degree of dustiness of the purified air on the magnitude of the discharge current was carried out on a stand developed for experimental studies of the process of capturing aerosol particles from the air stream (Fig. 2) [12]. The stand is mounted on a mounting table 1 and consists of an outlet pipe 2, a sedimentary grounded electrode 3, a removable box 4, a potential electrode 5, corona needles 6, inlet pipe 7, fan motor 8, electric motor of feeding conveyor 9, feeding conveyor 10, centrifugal fan 12, fixing device and regulating the uniformity of the air flow velocity along the cross section of the stand of plates 13.

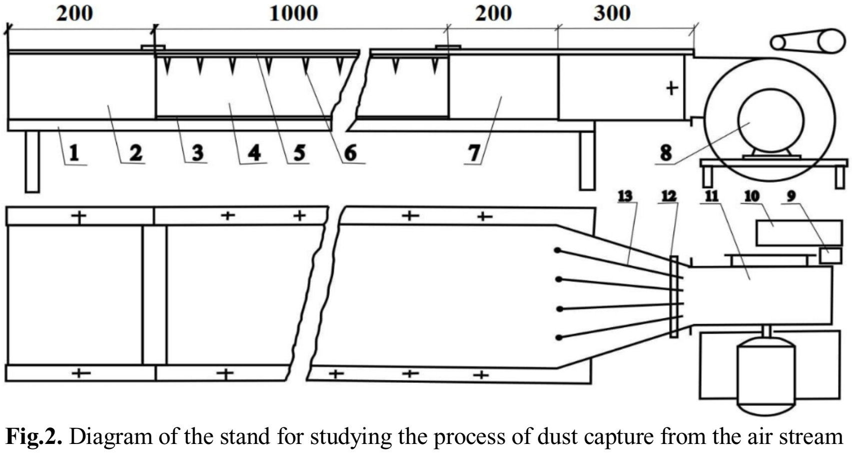

Fig.2. Diagram of the stand for studying the process of dust capture from the air stream

The length of the dust particle deposition zone on the stand is 1.0 m. This distance is divided into 10 sections of 0.1 m each. The first section of the deposition zone was located at the entrance to the deposition zone. The centrifugal fan was driven by a DC motor of sequential excitation. The air flow rate through the stand was regulated by changing the voltage supplied to the electric motor. The maximum air flow velocity in the stand at an interelectrode distance of 0.1 m is 12 m/s.

The experiments were carried out on fine dust selected at a cotton gin and sieved on a calibration sieve with cells of 50 microns.

In studies of the effect of the specific gravity of the layer of dust deposited on the grounded electrode on the formation of a reverse corona discharge and the occurrence of spark discharges from the grounded electrode, a dust suspension equal to 30 g was placed on the feeding conveyor.

In the experiment, the parameters of the electrode system were used, for which the maximum degree of purification of the air flow was obtained at an interelectrode distance of 0.1 m:

- length of corona needles is 20 mm;
- the distance between the needles in a row located across the flow of purified air is 40 mm;
- the distance between the rows of needles is 80 mm.

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

Before conducting experiments on the stand, without turning on the fan and the feeding conveyor, a pulsed voltage was applied and increased to a spark breakdown of the discharge gap. Then the voltage decreased by 20%. The current breakdown voltage of the discharge gap is 55 kV. A voltage of 44 kV was applied to the stand. The discharge current at this voltage is 60 μA. After that, the fan and the feeding conveyor were turned on.

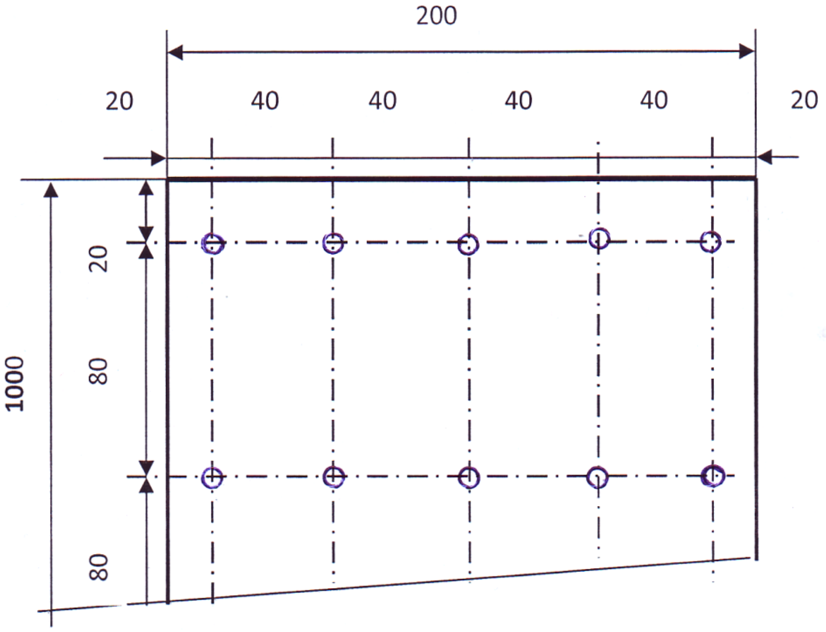

Fig. 3. Diagram of the installation of corona needles on a potential electrode of the stand for studying the process of dust capture from the air stream at an interelectrode distance of 0.1 m

2.1. Investigation of the VAC streamer form of a corona discharge with positive polarity of corona electrodes

The study of the VAC of the streamer form of the corona discharge with positive polarity of the corona electrodes was carried out on a stand (Fig. 3). For comparison, the VAC of the DC corona discharge and the VAC of the streamer form of the corona discharge of negative polarity were removed.

The measuring stand consists of a potential 1 and a grounded electrode 3. The diameter of the electrodes is 145 mm. The ends of the electrodes are curved with a radius of 10 mm to reduce the edge effect and eliminate ionization processes from the edges of the electrodes. A corona needle with a length of 25 mm and a taper of 8° was installed in the center of the potential electrode. The distance between the electrodes is 75 mm. The discharge current was measured by an M - 93 type microammeter with a measurement limit of 200 μA and an accuracy class of 1.5. To protect the microammeter from spark discharge currents, a resistor R with a resistance of 3 mOhm and a dissipation power of 5 W was connected in series to the microammeter, and an RD - 350 type spark gap was turned on in parallel with the R – RA chain. The voltage was measured with a C - 100 type RV kilovoltmeter with measurement limits of 25, 50, 75 kV and an accuracy class of 1.5.

The measuring stand was powered by unipolar pulses of high voltage of positive and negative polarity (Fig. 4, b) and constant voltage of negative and positive polarity (Fig. 4, c).

The high-voltage unipolar pulse power supply circuit consists of a machine generator of periodic acute-angle voltage pulses with 20 pairs of pronounced poles on the rotor and stator G. The generator was driven by a DC motor M. The motor was powered by a three-phase RLNO type T1 autotransformer and a rectifier V1...V2. The voltage at the output of the generator was regulated by changing the excitation voltage and was supplied from the autotransformer T2 through the rectifier bridge V4.

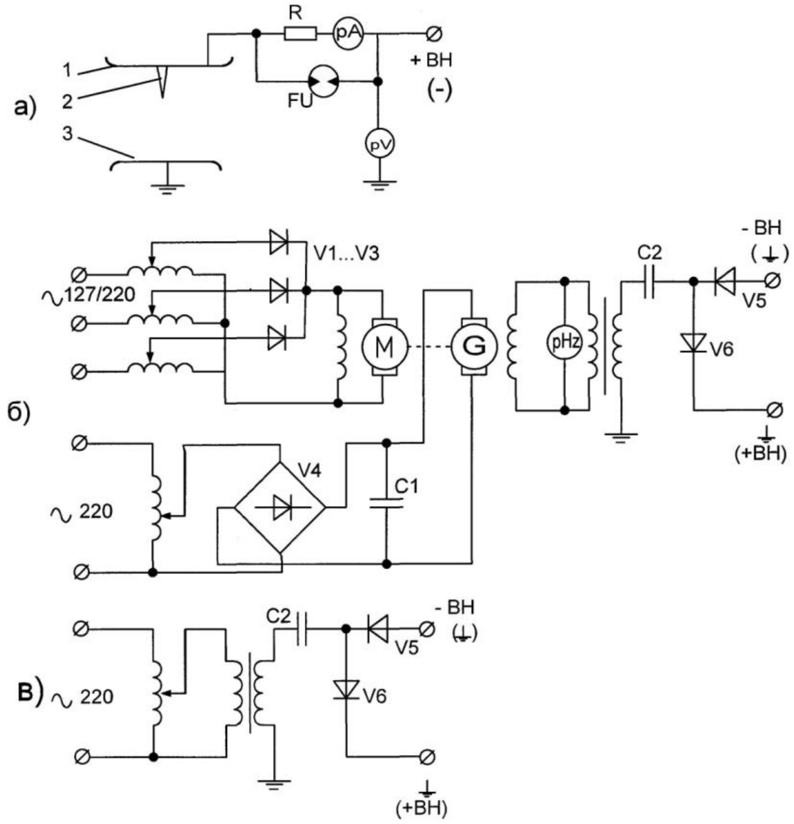

Fig. 4. Schematic diagram of the stand for studying the characteristics of the negative and positive streamer forms of the corona discharge

To smooth out the voltage ripple, a 10-mF filter was turned on in parallel with the rectifier. The frequency at the output of the generator was measured by a frequency meter of the Ph type Ch3 - 33. The voltage from the generator output was increased by a 600 W transformer T4 with a transformation coefficient of 250. The increased voltage was rectified by a voltage multiplication rectification circuit consisting of a capacitor C2 and diode arms V4, V5. To change the polarity of the high voltage, the connection of the diode arms was changed. The pulse voltage was fixed according to the current value. Experimental studies were carried out when the voltage was increased to a spark breakdown of the interelectrode gap.

3. Results and Discussion

Of interest is the value of the specific gravity of the deposited dust at which spark discharges from the grounded plane are observed. For this purpose, the stand was put into operation before the first spark breakdown from the deposited dust in the direction of the potential electrode, this phenomenon is a consequence of the reverse corona discharge from the deposited dust layer.

To determine the specific mass of the deposited dust layer, the trace with the largest mass of deposited dust was selected from the dust traces on the grounded electrode. The specific mass of the deposited dust layer was determined as the ratio of the mass of the dust trace to the area of this trace, approximately representing an ellipse (Fig. 5) was determined by the formula:

$$\Pi = m_{tr}/\pi[(d_1+d_2)/4]^2 , \qquad (1)$$

where msl is the mass of dust in the trace, g;
d1 – larger footprint diameter, m;
d2 – smaller footprint diameter, m .

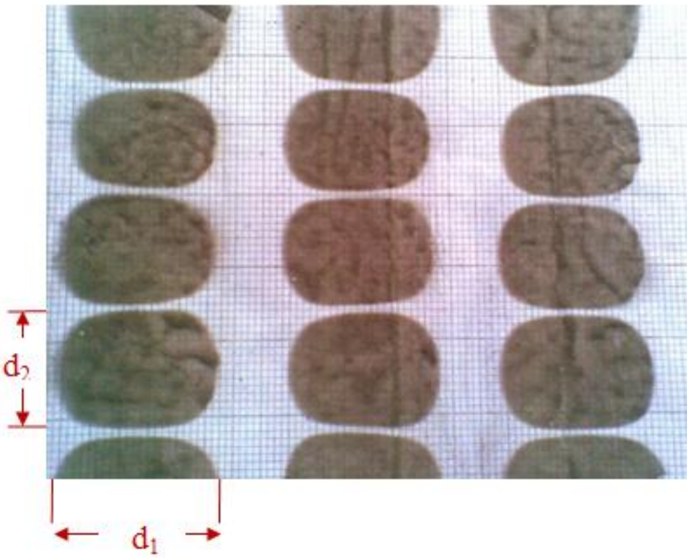

Fig. 5. Traces of deposited dust on a grounded electrode (dimensions of the coordinate substrate 2x2 mm)

The experiment was conducted before the first spark breakdown of the discharge gap. After that, the mass of the dust trace was determined in the fifth zone of the stand, in which the largest mass of trapped dust was deposited.

As a result of the experiment, it was determined that the first spark breakdown from the grounded plane in the direction of the potential plane occurs at a specific mass of the deposited dust layer equal to 24 g/m^2.

It was also found in the experiment that spark breakdowns lead to a sharp decrease in the degree of purification of the air flow. Therefore, it is of interest to study the streamer shape of the corona discharge with positive polarity of the corona electrodes.

The study of the volt-ampere characteristics of the streamer form of the corona discharge with positive polarity of the corona electrodes was carried out on a stand (Fig. 3). For comparison, the volt-ampere characteristics of the permanent corona discharge and the volt-ampere characteristics of the streamer form of the corona discharge were removed.

To smooth out the voltage ripple, a 10 mF filter was turned on in parallel with the rectifier. The frequency at the output of the generator was measured by a frequency meter of the PHz type ChZ - 33. The voltage from the generator output was increased by a 600 W transformer T4 with a transformation coefficient of 250. The increased voltage was rectified by a voltage multiplication rectification circuit consisting of a capacitor C2 and diode arms V4, V5. To change the polarity of the high voltage, the connection of the diode arms was changed. The pulse voltage was fixed according to the current value. Experimental studies were carried out when the voltage was increased to a spark breakdown of the interelectrode gap.

The VAC of the positive and negative streamer forms of the corona discharge, as well as the VAC of the negative and positive DC corona removed for comparison, are shown in Fig. 6.

The analysis of the research results showed that with a negative streamer form of corona discharge, the dependence of the discharge current on the voltage is almost linear.

The corona discharge of negative DC voltage is characterized by a sharper increase in the discharge current with an increase in voltage, which causes a significant dependence of the dust-collecting properties on changes in the applied voltage. The voltage characteristics with a positive polarity of the corona needle show that the discharge is ignited at a higher initial voltage: 20 kV for constant voltage and 30 kV for pulse voltage. The breakdown occurs at a voltage of about 36 kV. At constant voltage, the positive corona exists in the voltage range of 20...36 kV, and positive pulses are only in the range of 30 - 36 kV.

The practical use of the streamer form of a positive polarity corona discharge in technological processes is impossible. However, it is necessary to develop ways to eliminate the occurrence of the positive streamer form of the corona discharge from the deposited dust layer, the pointed edges of the grounded electrode and the irregularities on its surface, and the designs of the electrofilters should ensure continuous cleaning of the surface of the precipitation electrodes from the deposited dust.

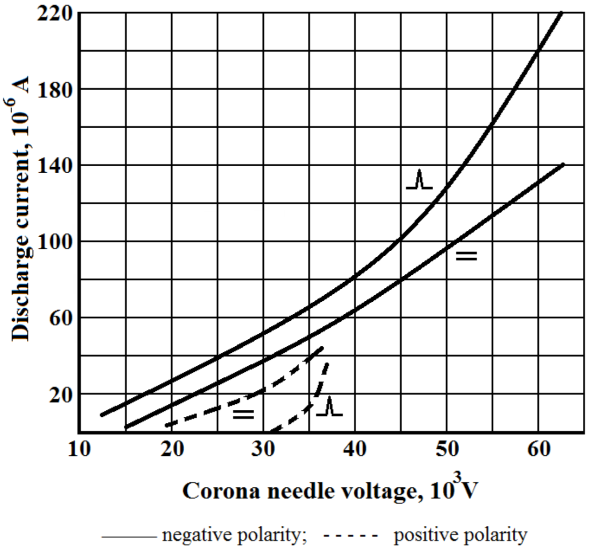

Fig.6. Voltage characteristics of positive and negative streamer forms of corona discharge and corona discharge of constant voltage

Previously conducted research has developed an electrofilter system for HOP. The system includes electrofilters for cleaning the air at the outlet of cyclones, for cleaning the air at the outlet of dust chambers and for cleaning the air in workshops and premises.

In existing electrofilters, shaking is the main way to clean the precipitation electrodes from dust. This is due to the significant dimensions of the existing electrofilters. The method of washing off the deposited dust with water is relatively rarely used.

The electrofilters developed by us, which use the streamer form of a corona discharge, have significantly smaller dimensions compared to previously developed electrofilters, which used a constant voltage discharge. This made it possible to develop electrofilters with direct cleaning using brush pullers. To use this method, rotational motion was reported to the drum deposition electrodes. As shown by production and laboratory tests of these electrofilters, the purification process must be carried out as a certain amount of dust accumulates on the precipitation electrodes, which manifests the effect of a reverse corona and the appearance of spark discharges from the precipitation drums towards potential electrodes.

3.1. Investigation of the dependence of the degree of purification of the air stream from dust at different voltages of the potential electrode

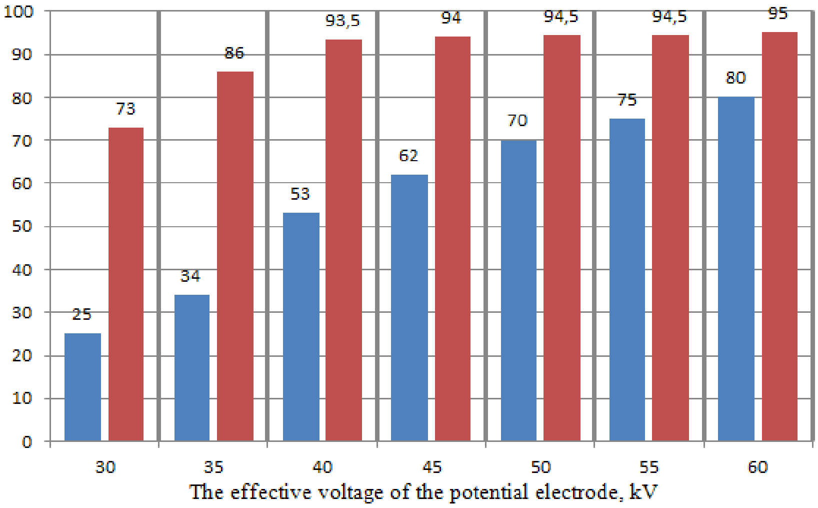

Fig.7. The degree of purification of the air stream from dust at different voltage values at the potential electrode

The studies were carried out when connecting a constant and pulsed voltage from 30 to 60 kV to a potential electrode with intervals of 5 kV. The voltage fluctuation on the substation tires during the day ranges from 210 ... 230 V (Fig. 7). Taking into account the fact that a voltage equal to 50 kV is applied to the potential electrodes of the electrofilters, with an input voltage of 220 V, the transformation coefficient of the power supply is 227.3. Therefore, the voltage fluctuation at the output of the source will be equal to 52.3 - 47.7 = 4.6 kV, or 9.2 kV.
Such a voltage fluctuation when using constant voltage leads to fluctuations in the degree of purification from 70 to 80%. At pulsed voltage, the degree of purification will vary between 94.5 -95% (Fig. 8).

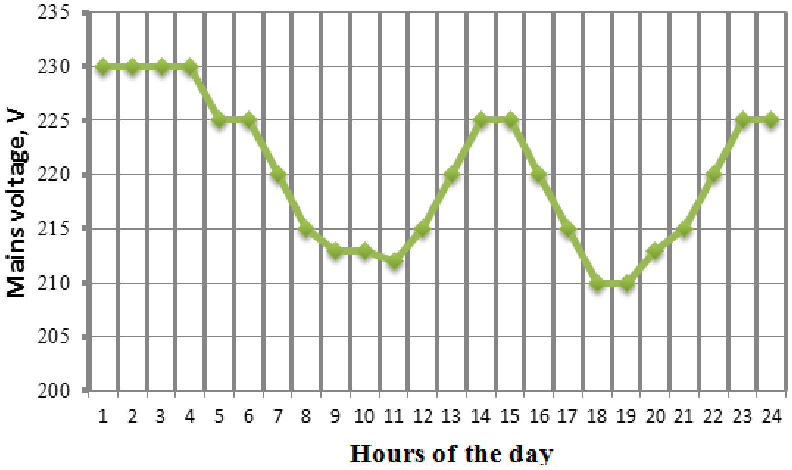

Fig.8. Diagram of voltage fluctuations on the input tires of a cotton gin substation

4. Conclusions

1. When the specific gravity of the deposited dust exceeds more than 24 g/m3, spark breakdowns are observed from the grounded plane to the potential one. Therefore, it is necessary to include spark-proof elements in the automatic control circuit that turn off high voltage to clean the grounded electrode.
2. Investigation of the process of formation of the reverse corona and the resulting spark discharge from a layer of deposited dust onto a potential electrode by a spark breakdown from a grounded plane in the direction of the potential plane occurs at a specific mass of a layer of deposited dust equal to 24 g/m2. It was also found that spark disruptions lead to a sharp decrease in the degree of purification of the air flow and secondary entrainment of deposited dust from the grounded electrode.
3. A study of the VAC streamer form of a corona discharge with a positive polarity of corona electrodes has shown that a corona discharge of negative DC voltage is characterized by a sharper increase in the discharge current with an increase in voltage, which causes a significant dependence of the dust-collecting properties on changes in the applied voltage. The voltage characteristics with a positive polarity of the corona needle show that the discharge is ignited at a higher initial voltage: 20 kV for constant voltage and 30 kV for pulse voltage. The breakdown occurs at a voltage of about 36 kV. At constant voltage, the positive corona exists in the voltage range of 20...36 kV, and positive pulses are only in the range of 30 - 36 kV.
4. The practical use of the streamer form of a positive polarity corona discharge in technological processes is impossible. However, it is necessary to develop ways to eliminate the occurrence of the positive streamer form of the corona discharge from the deposited dust layer, the pointed edges of the grounded electrode and the irregularities on its surface, and the designs of the electrofilters should ensure continuous cleaning of the surface of the precipitation electrodes from the deposited dust.
5. The study of the dependence of the degree of purification of the air flow from dust at different voltages of the potential electrode showed that the voltage fluctuation on the substation tires during the day ranges from 210 ... 230 V. Taking into account the fact that a voltage equal to 50 kV is applied to the potential electrodes of the electrofilters, with an input voltage of 220 V, the transformation coefficient of the power supply is 227.3. Therefore, the voltage fluctuation at the output of the source will be equal to 52.3 - 47.7 = 4.6 kV, or 9.2 kV. Such a voltage fluctuation when using constant voltage leads to fluctuations in the degree of purification from 70 to 80%. At pulsed voltage, the degree of purification will range from 94.5 -95%.

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