Investigating the reliability of needle-plane experiments with dust layer

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Abstract:

Parameter correlations and phenomena associated with electrostatic precipitators are often investigated using laboratory models. In the literature, there are many measurements on dusts, which are used to determine, e.g., current-voltage curves. In our research, we investigate corona currents in a needle-plane arrangement covered with dust and further consider the validity of these measurements.

Introduction

Human activity significantly increases atmospheric particulate matter pollution, which is clearly visible in large cities. Some technological processes result in solid atmospheric emissions that cannot be used without filtration [1,2]. The main problem with these emissions is not that they deposit pollution on houses, vehicles, and electronic equipment but that they can severely affect health [3]. There are several dust separation technologies, the efficiency of separation of which may vary according to their function. One of the well-known industrial-size devices used for dust precipitation is electrostatic precipitator (ESP). It filters the dust from the flowing gas by electrically charging, mixing small particles, and using the Coulomb force. The primary design consideration for ESPs is to maximize efficiency, but several operating parameters can adversely affect the collection efficiency of the precipitation [4,5].

Detailed studies of particular phenomena are often conducted in laboratory arrangements because the cause and effect correlation can be studied more in-depth. The most commonly used arrangement is the needle-plane arrangement [6,7,8], which can be extended, as this is indeed how the ESP corona electrodes behave locally during discharge. Depending on the different electrode types, an existing piece of corona electrodes can also be used. The needle-plane arrangement is also used in numerical models, not only for discharge but also for flow and separation efficiency studies [9,10].

Typical diagnostic tests can be traced back to corona current and voltage characteristics, for which several models and developments have been made [11,12]. In recent years we have had industrial projects where the combustion technology has changed. In addition to the particle size, the temperature of the gas stream has also changed, resulting in a reduction in separation efficiency. Temperature changes also affect the resistance, charge and relative permittivity of the particles moving with the airflow [13, 14]. Our previous papers investigated the effect of the change in diameter size [15]. The first part of this research is the continuation of the paper [14], which includes the dust heating processes, temperature dependence, and other parameter calculations. In this research, during the application of the needle-plane arrangement to determine I-U characteristics, we were confronted with the phenomenon that the high voltage causes the dust particles to charge and start moving. The initial measurements may therefore give erroneous results. The second half of this paper deals with the investigation of the phenomenon.

Needle-plate measurements

Before being tested in the needle-plane electrode arrangement, the dust samples were heated in an oven to 200°C. The dust came from an existing ESP where the operating temperature was 150°C. The composition of the dust was sodium sulfate with chaff. The ratio of the particle sizes to each other is known and is illustrated in the literature [15]. The dust samples were collected from the first zone. The electrical parameters of the dust in the oven could be determined and are summarized in [14]. The dust samples were heated in two different ways: in a dry medium and at 100% humidity. Depending on the circumstances, the dust's electrical conductivity and relative permittivity changed. The 100 % humidity was ensured by inserting a tank full of water, which boiled due to the high temperature. The measurement condition was suitable because the samples holding the dust were also heated in the oven during the tests.

After the simple examinations, we could put this dust on the arrangement, as seen in the first figure. A dust-covered needle can be perceived as a corona discharge in concentrated dust, which is initiated in the dust but has not yet fully penetrated it. The Rogowski-electrode was initially clean, but during the measurements, the dust adhered to the high-voltage electrode as well. This is also acceptable, as it also sticks to the corona electrode in a full-scale ESP. Above the needle, the height of the dust layer locally was circa 2 mm. The width of the Rogowski-electrode was 30 cm, and the distance 'H' was 9 cm.

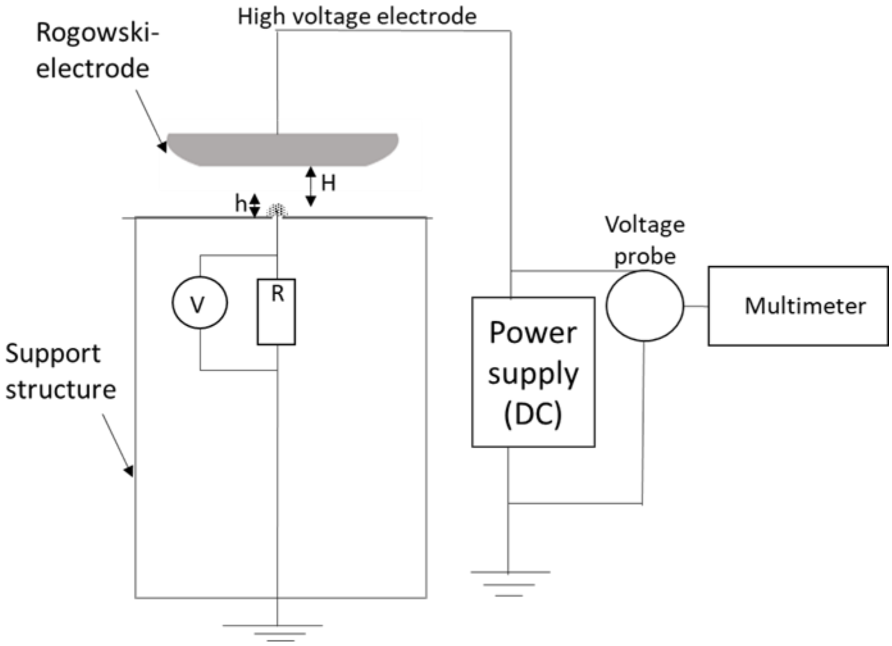

Figure 1 Examination arrangement for the effect of a dust layer

The arrangement consists of a needle, a Rogowski electrode, DC power supply, voltage measuring devices, a voltage probe, and a resistor. The resistor is connected in series with the needle, so the corona current makes a voltage drop on the resistor, which we could measure. The resistance was 1500 Ω. The current was calculated from these results. The needle goes through a conductive plate with a hole in the center. Above the plate, a Rogowski electrode provides a similar electric field that can appear in an ESP. The voltage probe was connected directly to the output of the DC power supply. There was a protective couple of diodes in parallel to protect the measurement devices.

We removed the dust from the needle, earthed the plate in a pyramid structure, and started the experiment.

We have done research in three categories: measuring with dry dust at circa 200°C, room temperature dust, and wet dust at circa 200°C. Accurate measurement was distorted because the dust had to be removed from the oven for the measurement so that it cooled during the measurement. The constant parameters throughout the measurements and, therefore, comparable were the temperature of the oven (initial temperature of the dust removal) and the measurement duration. In all cases, if the measurement exceeded one minute, the process started from the beginning.

The reference measurement was a current-voltage characteristic, without any dust on the arrangement. The results can be seen in the second figure.

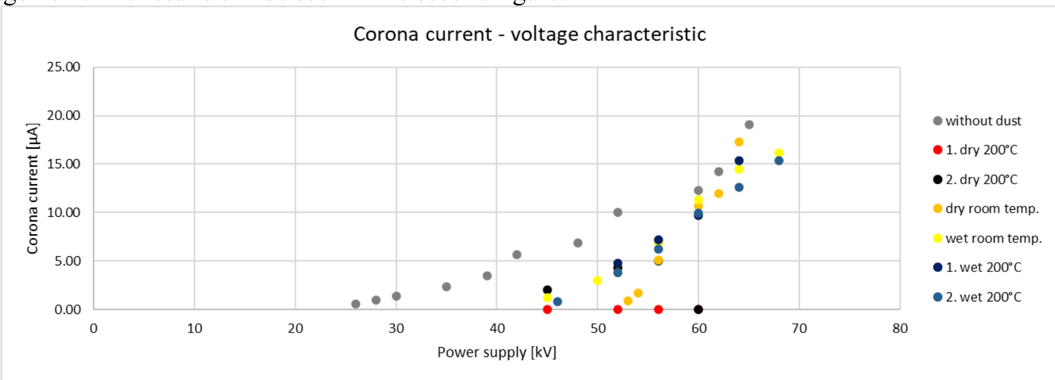

Figure 2 Current – voltage characteristic in the needle-plane electrode arrangement

There were three kinds of dust conditions that we can see. It glances that the highest corona current was with the measurements without dust. Discharge can be developed sooner because the maximum electric field strength in the vicinity of the top of the electrode was much higher than on the surface of dust. Dust at room temperature is not precisely a concrete case because most ESP operates within the range between 150-300 °C. We had shown it like as a reference value. Secondly, when the dust was wet at 200°C or measurements were taken out at room temperature, a decreased value of current has experimented. The dry sample showed lower values in the early part of the discharges, but the current increased exponentially in the vicinity of the breakdown voltage. When we made measurements with dry dust at 200°C, the total current disappeared. Corona discharges pulses were not developed as well. There can be two important issues to explain the phenomenon. There could be a high number of charges placed on the dust layer's surface. The same electric field polarity has changed the maximum electric field strength between the electrodes, resulting in less corona discharge. Another explanation is related to the difference between the relative permittivity. The electric field strength is inversely proportional to the different values of relative permittivity. The dust had higher permittivity, which was calculated from [14]. The higher electric field was between the dust surface and the Rogowski plate. Less field has developed on the top of the needle, which is why the voltage of electrical breakdown was reached before the corona current detection. Moreover, the explanation for the difference in the corona currents can be explained by the grounded metal plate; the charges on the surface of the dust can also conduct the current to the ground. We observed that the dust particles had started moving to the corona electrode or out of the two-electrode system in the higher voltage range.

When the particles moved away from the original location on the top of the needle, it meant that there was an error during the measurement because the initial condition was not the same at the breakdown. Improved arrangement necessary.

New model for testing the transport of dust particles

The arrangement was similar to the previous one; the only difference was that the dust layer covered not only the vicinity of the needle but also a 25*25 cm range. However, the new examination aimed not to draw new characteristics; but to determine the electrode distance and applied voltage in which the particles start to move. We made measurements with positive and negative DC and set 3 different electrode distances: 30, 42, and 94 mm. The values of characteristics related to the electrode difference can be seen in Table 1 and Figure 3.

TABLE I Measured voltage and calculated current function of electrodes distances

ID / Electrode distance	30 [mm]	42 [mm]	94 [mm]
U_{dc}^{-} [kV]	21.4 ; 28	34.1	45
$I_{calculated}^{-}$ [μA]	62.89 ; 121.86	143.87	79.4
U_{dc}^{+}[kV]	18.9	32	42
$I_{calculated}^{+}$[μA]	27.52	81.76	47.96

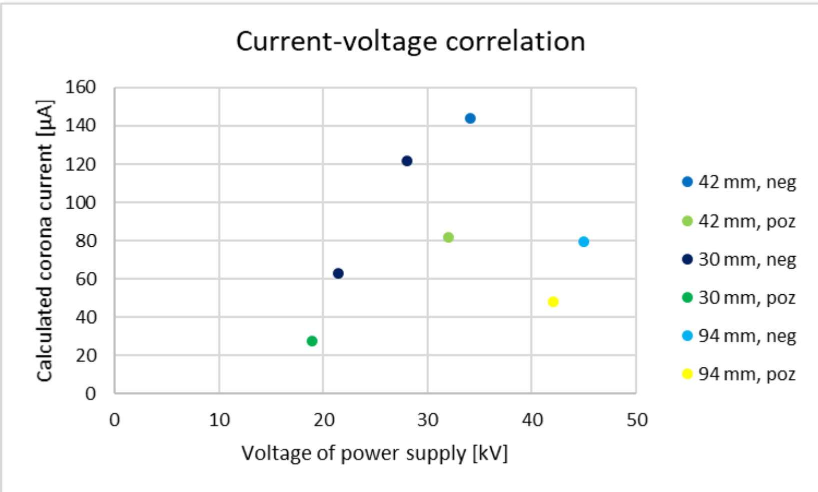

Figure 3 Current-voltage characteristics function of electrode distances

The observation was that the corona currents were developed later if the electrode distance was increased. The needle was already inside the dust layer, meaning the behavior was like the first part of a developed back corona discharge. After a critical value, charges could come from the needle to the volume of the dust layer, and the charges from up-per Rogowski could transfer and stay on the dust surface. We should consider that the difference in relative permittivity is still high between air and dust particles, so a higher electric field was developed between the dust surface and the Rogowski plate. However, the conductive needle inside the dust could help in the process of leakage current, and the top of the covered needle has also formed a high electric field area. In

Fig 3, the reaction differs in positive and negative polarity. However, in general, the particles start to move sooner, in a lower voltage supply than the positive one.

Interestingly, we could observe the moving particles during the examination, but craters did not form. With increasing further, the supply voltage and movement of particles were denser and denser after a breakdown happened. The result of the breakdown can be observed in Fig4.

Figure 4 Dust explosion after breakdown in the vicinity of the needle

The result needs consideration. It can be seen that the breakdown location was at another point than the needle, where we expected. The phenomenon can be explained that on the dust surface, charges accumulate in that amount, making the electric field distribution relatively homogeneous. This was enough, or a higher block of dust came from another location which was the cause of the breakdown. However, it was also important that the dust particles disappear in the vicinity of the needle. These particles were dispersed on the surface, moved outside, or reached the high-voltage Rogowski electrode. Unfortunately, we cannot tell the exact value when the particles move away around the needle. Also a finding that the breakdowns happened in different locations, not the same place. However, it should be in the range of immediate vicinity of the breakdown voltage.

Conclusion

The summary of this paper is the measurement of a needle-plane electrode arrangement, starting from the measurement of the I-V characteristics of dust at different temperatures. We have found that wet and room-temperature dust currents show similar results. Both can be traced back to the amount of humidity at high temperatures in the form of vapor trapped on the surface of the dust particles and at room temperature contained in the form of a base. In the case of dry dust, moisture disappeared, and a breakdown occurred sooner than current measurements. To explain this, the difference in relative permittivity between air and dust is given. Accordingly, the field strength in the air was much higher than in the covered dust layer (despite the smaller distance).

Because of the movement of the dust, we asked whether it was possible to measure it under similar conditions. In the new model, we tried determining the voltage or the distance needed to start the dust movement. From the results, we can conclude some cases: at a distance of 3cm, the dust starts to move at 18.9 kV, 4.2cm at 32kV, and 9.4cm at 42 kV. From the results, we can conclude that the voltage is higher for similar distances, or for a given voltage, the distances are smaller, and the dust will move, distorting the results. It can also be seen that as the distance increases, the voltage that induces the dust movement is not directly proportional but follows a curve of decreasing slope. The exact correlation requires further measurements and the definition of a data set, which is currently under investigation. All this shows that measurements on dusts are susceptible; designing an accurate measurement setup is critical.

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