EXPERIMENTAL STUDY OF CORONA DISCHARGE IN WIRE-PLATE ELECTROSTATIC PRECIPITATORS

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Abstract: The electrostatic precipitator widely used in the power plants is the highly-efficient dust collection facility. Parallel wire–plate electrode arrangements are widely used to generate corona discharges in various electrostatic processes. The performance of precipitators can be determined by the current-voltage characteristics. In this work, a laboratory-scale model for prediction of the current-voltage characteristic is presented and experimentally validated for round discharge electrodes in combination with plate type collecting electrodes. The model predicts the effect of electrode configuration such as wire diameter, spacing between wire electrodes, number of discharge wires and distance between collecting plates on characteristics of the corona discharge generated in wire-duct precipitator. Dependence of results and measurements presented in the paper, the onset voltage increases with increasing radius of discharge wires for the same wire-to-wire spacing and collecting plate-to-plate spacing as well. Positive polarity enhances corona current more than negative polarity. In addition, it was experimentally observed that corona current increased by increasing number of discharge wires and also spacing between discharge wires. On the contrary, corona current obviously decreased by increasing spacing between grounded collecting plates and increasing wire diameter as well.

1 INTRODUCTION

An electrostatic precipitator, being abbreviated to ESP, is used as a dust particle collection device in various power plants, steel manufactories, pulp and paper plants, cement plants, food processing, etc., as well as in commercial buildings and home ventilation systems. Wire duct electrostatic precipitators are most commercially used for the removal of solid particulate from combustion of flue gases of industries, thereby preventing the emission of toxic particulate into the atmosphere. The performance of an electrostatic precipitator (ESP) can be determined by the current-voltage (I-V) characteristics. The current-voltage curves under clean air conditions help in diagnosing the electrical problems that occur under various load conditions in an existing precipitator. Also, they play an important role in predicting the performance when the ESP is in the design stage for various mechanical input data such as wire radius, wire-to-wire spacing, wire-to-plate spacing, etc [1]. This paper reports on how the corona current-voltage characteristics in the wire-duct ESP is influenced by electrode configuration and various parameters such as wire diameter, spacing between wire electrodes, number of discharge wires, distance between collecting plates and applied voltage polarity.

2 EXPERIMENTAL SET-UP

As most of industrial electrostatic precipitators are the wire-plate devices, the laboratory-scale of duct-type precipitator was prepared in the high voltage laboratory at Czech Technical University in Prague, Czech Republic. The schematic diagram of experimental set-up is shown in Figure 1. It composed of a duct made from Perspex material, to allow optical observation of the spatial distribution of the corona, has internal dimensions of 100cm length, 30cm width, 30cm depth and 5 x 10^{-3}m thickness. Two stainless steel plates of area 30 x 100cm^2 and 1mm thickness were attached vertically parallel to the walls of the precipitator, one on each side. The ends of the plates were curved as semi-circle to avoid the local discharges. The plate-to-plate spacing of the duct was 30cm and a number of corona discharge electrodes (cylindrical wires) made of stainless steel was hanged symmetrically midway between the grounded metal plates along the length of the precipitator. The corona wires were passed through small holes drilled on the upper and lower surfaces of the Perspex duct. All used wires terminated at both ends by stainless steel hemispherical metallic parts to serve mechanical support to the wire electrodes, reduce vibration of the corona wires due to effects of the corona wind and to reduce sparking or local discharges occurrence at both ends of each discharge wire due to field intensification. The active discharge lengths of the wires were 30cm. Different wire diameters 0.55, 1.1, 1.6 and 1.85mm were used in the performed experiments as single or multi wire electrodes. These corona discharge electrodes energized from a dc high-voltage supply.

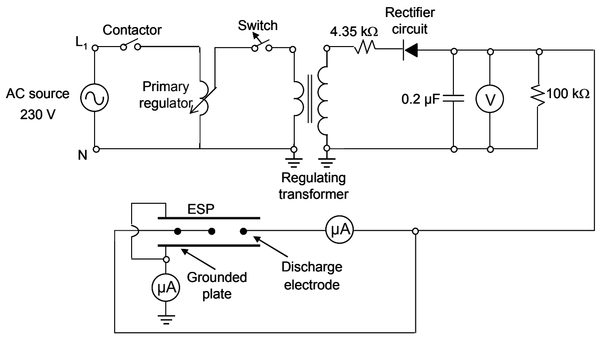

Figure 1: Experimental set-up

An AC voltage source (230V), was applied to step-up regulating transformer (0.2 ~ 100kV, 8kVA) through primary regulator (0 ~ 200V) and contactor switch to provide connecting or disconnecting the power supply. The output voltage of the HV transformer was passed through (4.35kΩ) resistor and then converted to controlled DC voltage using high voltage controlled rectifier circuit (max. 150kV reverse voltage). A high voltage smoothing capacitor bank (0.2µF, 25kVDC), composed of five capacitors connected together in series, was used to smooth DC output current. An Electrostatic voltmeter was used to adjust applied voltage to the high voltage electrode of ESP. A sufficiently large resistor (100kΩ) was connected in parallel with capacitor bank in order to protect the electrical circuit against faults and excessive charging currents at the instant of arc discharge occurrence in ESP.

The two collecting plate electrodes of the precipitator were earthed through a digital micro-ameter (IWATSU-7411) for measuring the corona current. Another micro-ameter was used for measuring current passing in each discharge wire. Both micro-ameters were totally isolated to avoid local corona that may affects taken measurements. Precipitator current was recorded with the gradual increasing of the applied voltage.

A corona discharge is generated between the wire electrode, which is connected to a dc high voltage supply with negative polarity, and the grounded outer electrode. Negative ions are formed at the discharge wires, which then accelerate to the collecting plates. All the experiments were performed in ambient air (temperature: 22 ± 1°C; pressure: 987.7hPa, absolute humidity: 8.8g/m3) and the precipitator model is working in the absence of dust loading or gas flow conditions. It means that there is no charging and collecting dust particles on the way of discharge zone.

3 RESULTS AND DISCUSSIONS

3.1. Effect of voltage polarity

An initial selection of operating voltage polarity was made on the basis of getting higher precipitator corona current which leads consequently to improvement of ESP efficiency. At negative polarity, beyond a certain threshold voltage, the corona current is higher, in absolute value, than that at a similar high voltage of positive polarity, as can be seen in Figure 2 by examining the current–voltage characteristics for both small and large wire diameters.

It was observed that sparkover for positive polarity occurred at lower voltage compared to negative polarity. Also, corona discharge for positive polarity was very weak and unstable. Figure 2 illustrates that sparkover occurs under positive polarity, for 0.5mm wire diameter, at lower voltage (≥ 30kV) compared to (≥ 45kV) for negative polarity under similar experimental conditions.

The smaller the wire radius, the higher is the corona current and the smaller is the onset voltage under similar applied voltage and plate-to-plate spacing for a single-wire precipitator as shown in Figure 2 and Figure 3. The decrease of the corona onset voltage with the decrease of the wire diameter is attributed to the corresponding field enhancement at the wire surface [2, 3].

For the positive corona case, only positive ions participate in the particle charging process. In the case of negative corona discharge, the interelectrode space consists of neutral molecules, negative molecular ions, and free electrons. The enhanced corona current with negative corona might be due to increased free electron charging [4].

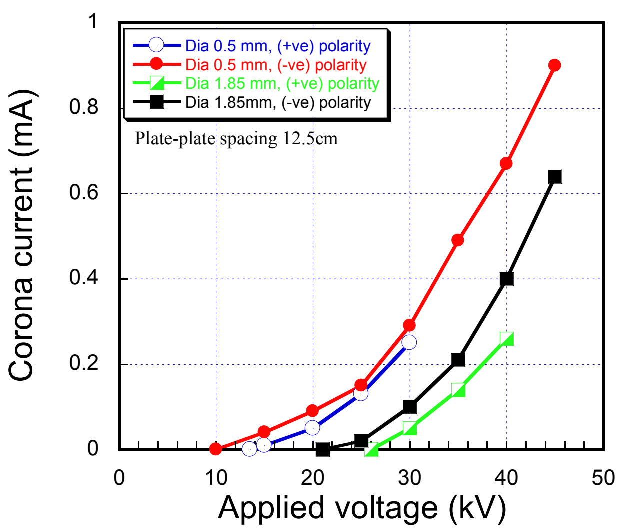

Figure 2: Effect of voltage polarity on precipitator corona current

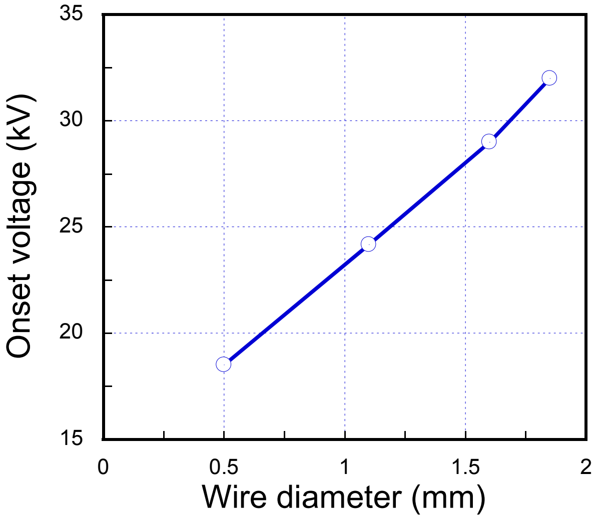

Figure 3: Dependence of corona onset voltage on wire diameter

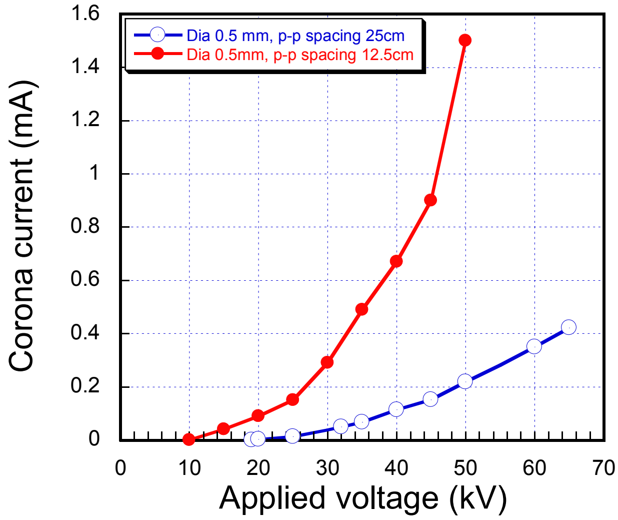

Figure 4: Effect of spacing between grounded plates on precipitator corona current

It is assumed that the electric field is more intensive, and hence, the corona current density is higher for negative polarity in each point at the surface of the collector grounded electrode. This is why the negative polarity is preferred in most electrostatic precipitation applications for which the corona discharge was more stable.

3.2. Effect of plate-to-plate spacing

Spacing between collecting electrodes of ESP plays an important role on the characteristics of wire-plate precipitators. In order to show the effect of spacing between collecting plates on I-V characteristics of ESP, two different spacing between grounded plates were employed for comparison. The obtained results clarified that increasing of plate-to-plate spacing led to decreasing the corona current and increasing the onset voltage, under the same applied voltage and wire diameter for a single-wire precipitator, as shown in Figure 4.

This is simply explained by the resulting decrease of the electric field along the flux lines, where the corona ions are convicting between the discharge wires and the collecting plates. The more of plate-to-plate spacing, the more decreasing of the electric field along the flux lines with subsequent decease of the corona current for the same applied voltage. It is quite clear that corona current for smaller spacing between plates was much higher, more than seven times, than wider spacing between plates at the same operating voltage. In other words, I-V characteristics as well as precipitator efficiency could be improved by decreasing spacing between collecting plates without the need of increasing applied voltage.

3.3. Effect of number of discharge wires

In this section, three different wire configurations (single wire, 3-wires and 7-wires) were employed, under similar experimental conditions, in order to clarify effect number of discharge wires on ESP characteristics. Figure 5 shows the corona current-voltage characteristics of the precipitator model as influenced by the number of discharge wires at the same plate-to-plate spacing, wire diameter and spacing between wires. It was found that onset voltage increased by increasing number of discharge wires, as the shielding effect becomes more pronounced with increasing of the number of discharge wires. The measurements revealed that corona current increased obviously by increasing number of corona wire electrodes. This may attributed to increasing electric field between adjacent discharge wires and also between collecting plates and wires as well.

3.4. Effect of wire diameter

In particular, cross sectional area of wire electrodes is an important factor that has a direct effect on current-voltage characteristic of wire-duct precipitators. Therefore, two different sizes of wire diameters were used in the experiments in order to describe the influence of wire diameter on I-V characteristics.

The current-voltage characteristics using multi-wires arrangements, 3-wires and 7-wires, are shown in Figure 6 and Figure7, respectively. On the other hand, Figure 2 gives clarification for the precipitator characteristics when using single-wire precipitator. It was observed that the smaller the wire diameter, the smaller the onset voltage and the higher is the corona current at the same applied voltage and plate-to-plate spacing.

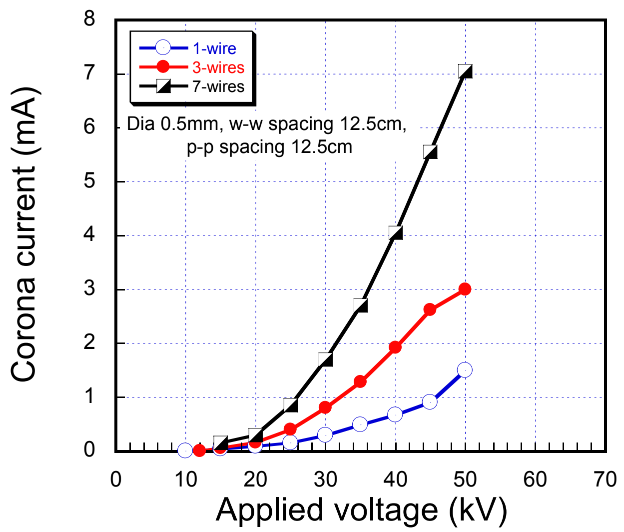

Figure 5: Effect of number of discharge wires on precipitator corona current

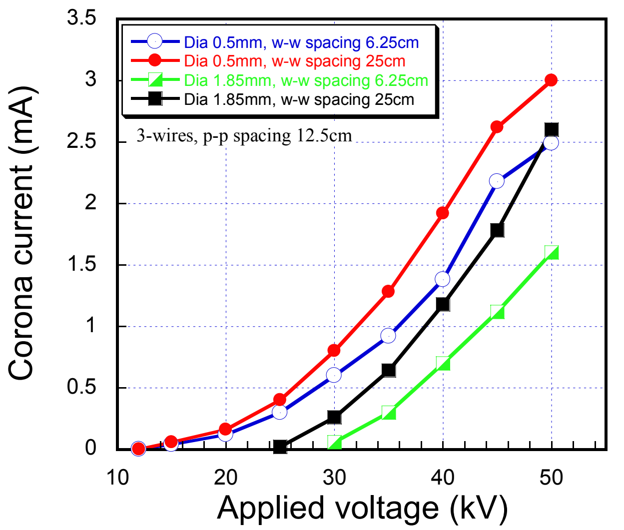

Figure 6: Effect of wire diameter on precipitator corona current (in case of 3-wires)

The decrease of the corona onset voltage with the decrease of the wire diameter is attributed to electric field enhancement at the surface of smaller wire diameter [2, 3]. This is why the corona current under the same applied voltage increased significantly with decreasing cross sectional and surface area of wire electrode diameter.

3.5. Effect of wire-to-wire spacing

In this section, the dependency of corona characteristic of ESP on spacing between high voltage electrode wires was investigated. It is shown from Figure 6 and Figure 7 that corona discharge current and also sparking voltage increased remarkably by increasing spacing between discharge wires under the same experimental conditions with both 3 and 7 wires arrangement. This may corresponded to shielding

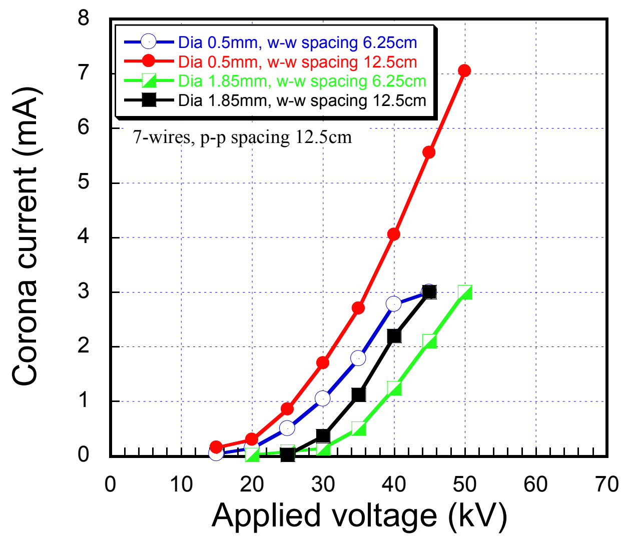

Figure 7: Effect of wire diameter on precipitator corona current (in case of 7-wires)

effect on discharge wires in the case of denser spaces between high voltage electrode wires. The sparking voltage may increase with wider spacing between wires, due to the loss of ionized charges from the current channels by convective charges transporting [5].

4 CONCLUSION

In conclusion, this study reported that corona current-voltage characteristics of a laboratory-scale model of electrostatic precipitator could be dramatically affected by various essential parameters. Dependence of results and observations in the paper, the corona current for negative polarity enhanced much higher than positive polarity under similar high voltage. Also, sparkover voltage occurred at higher voltage when applying negative polarity other than positive polarity. In addition, I-V characteristics as well as precipitator efficiency could be improved by decreasing spacing between collecting plates without the need of increasing applied voltage. The measurements revealed that corona current increased obviously by increasing number of corona wire electrodes. Also, it was observed that the smaller the wire diameter, the smaller the onset voltage and the higher is the corona current at the same applied voltage and plate-to-plate spacing. Finally, it was experimentally observed that corona discharge current and also sparking voltage increased remarkably by increasing spacing between discharge wires under the same experimental conditions.

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