Prevention of Back Corona Discharge in an Electrostatic Precipitator Using Asymmetrical Rectangular AC Voltage

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***Abstract*— The aim of this study is to prevent back corona discharge using asymmetrical rectangular AC voltage. The experimental ESP consisted of a high-voltage application wire electrode and a grounded plate electrode with the gap. Calcium carbonate dust was located on the surface of the grounded plate electrode. DC, symmetric or asymmetric rectangular AC voltages were applied to the wire electrode. The voltage waveform and the current waveform were measured, and a photograph of discharge luminescence on the surface of the dust layer was taken by a digital camera. As a result, the discharge current increased, and the discharge luminescence was observed on the surface of the dust layer at applying DC high voltage due to back corona discharge. On the other hand, the discharge current did not increase and discharge luminescence were not observed, when the symmetrical AC high voltage at the period of 4 ms. However, the application time of the positive polarity was equivalent to the negative polarity, and the period was short. Accordingly, it is expected that the collection efficiency is not high in the symmetrical energized ESP. Thus, the effect of an asymmetrical AC energization was investigated. As a result, it was showed that the back corona discharge was avoided in the asymmetrical rectangular AC energized ESP at the period of 9 ms which the application time of the positive and negative high voltage were 7 ms and 2 ms.**

I. Introduction

Particulate matter included in exhaust gas emitted from a factory or a power station become a problem for the air environment. Therefore, an electrostatic precipitator (ESP) has been extensively used for removal particulate matter. However, the performance depends on the electrical resistivity of the dust. The low resistivity dust less than 10^4 Ωcm causes particle detachment from a collection electrode by an induction charge, i.e. dust re-entrainment, resulting in poor collection efficiency. When the dust resistivity is greater than 10^{10}Ωcm, the collection efficiency decreases due to back corona discharge in the collected dust layer. The corona discharge current increases and the discharge luminescence is observed on the surface of the dust layer on the collection electrode.

For preventing the dust re-entrainment, a hole-type ESP [1] and EHD ESP [2] have been developed, and AC ESP [3] have been put into practical use for road tunnels. A wet type

ESP, a high temperature ESP, an advanced low temperature ESP, an intermittent energization type and a pulse energization type were developed to avoid back corona. In a wet type ESP, the collecting electrode is washed by water spraying or water irrigated [4]. This type is not influenced by electrical resistivity, and dust re-entrainment is also prevented. An electrical resistivity of most dust decreases with increasing the gas temperature at the temperature greater than 150 ^{o}C. Thus, dust is collected in the condition of high gas temperature in the high temperature ESP [5]. In the advanced low temperature ESP, an exhaust gas is cooled to approximately 90 ^{o}C, which is lower than condensing temperatures of water or SO_2, whereby an electrical resistivity decreases [6]. An intermittently a rectified half-wave is applied to discharge electrodes in the intermittent energized ESP [7]. Charges on the surface of dust layer decreases due to the intermittent dormant period, whereby back corona discharge is prevented. A high-voltage pulse with or without a dc high-voltage is supplied in the pulse energized ESP [8]. The corona current can be reduced due to decreasing pulse frequency without reducing voltage to prevent back corona discharge.

In particular, an intermittent and a pulse energized ESPs have a merit that back corona can be prevented by improvement of a high voltage generator. Therefore, these have been widely used. However, these have sometimes a problem that the efficiency is not so improved comparison with that in DC energized ESP [9]. This cause may be that the dominant period is longer than high voltage applied period.

In this study, it is expected that an asymmetrical rectangular AC high voltage is supplied to an ESP, whereby the high voltage applied voltage period is longer than the dominant period. Thus, back corona discharge is going to be prevented with improving a collection efficiency. A symmetrical or an asymmetrical rectangular AC voltages were applied to an experimental ESP. The voltage waveform and the current waveform were measured, and a photograph of discharge luminescence on the surface of the dust layer was taken by a digital camera, and investigated the effect on preventing back corona discharge.

II. Model of Preventing back corona

The model of back corona discharge at DC voltage is shown in Fig. 1. When negative DC high voltage is applied to the wire electrode in a wire-plate electrode type ESP, dust in an exhaust gas is charged negatively due to attaching negative ions generated in negative corona discharge, then charged dust is collected on the grounded plate electrode by Coulomb's force. If the electrical resistivity of the dust is high, the amount of charges on the surface of the dust layer increases, and the electric field intensity in the layer becomes stronger. Eventually, the electric field intensity is greater than dielectric strength of the dust layer, and dielectric breakdown occurs, which is back corona discharge. Positive ions are emitted from the back corona discharge points, whereby the collection efficiency decreases.

The model of preventing back corona discharge using a rectangular AC voltage is shown in Fig. 2. The polarity of corona discharge periodically changes in a rectangular AC energized ESP, whereby negative ions accumulated on the surface of the dust layer are neutralized by positive ions generated in positive corona discharge. Therefore, the electric field intensity in dust layer does not become stronger, and back corona discharge is prevented.

III. Experimental setup

The schematic diagram of the experimental system is shown in Fig. 3. The system consisted

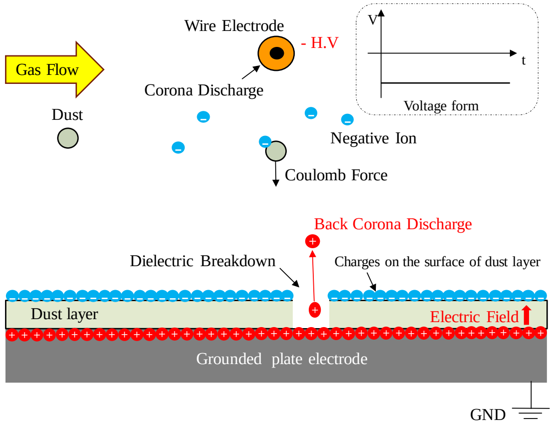


Fig. 1 Model of back corona discharge at DC voltage.

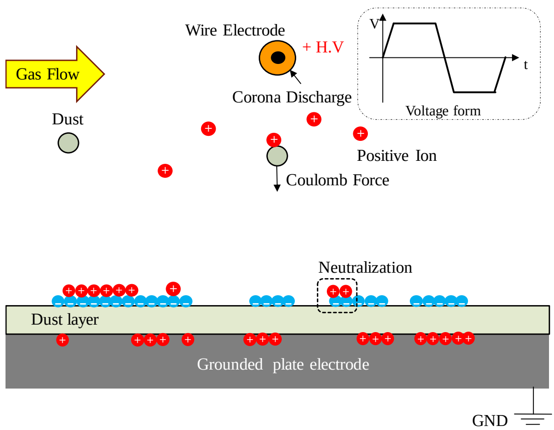


Fig. 2 Model of preventing back corona discharge using a rectangular AC voltage.

of a wire-to-plate electrode, a high voltage amplifier and an oscilloscope. The gap between the wire electrode (Tungsten, ϕ: 0.26 mm. L: 90 mm) and the grounded plate electrode (Aluminum, thickness: 0.4 mm, 150 mm * 90 mm) was 15 mm. The wire-to-plate electrode was in an incubator, and the temperature was controlled to 80 $^{\circ}$C. Calcium carbonate (Wako, 030-00385, 1 g) was located on the grounded plate electrode. The thickness of the dust layer was approximately 0.5 mm. Negative DC, symmetrical or asymmetrical AC High voltage were applied to the wire electrode, and the corona discharge was generated. The resistor (10 kΩ) was connected to between the grounded plate electrode and the earth, and the corona discharge current wave forms were measured by the oscilloscope. The negative DC high voltage was supplied using a high voltage amplifier (SPELLMAN, LS300), and the symmetrical and the asymmetrical rectangular AC high voltage were supplied using a multifunction synthesizer (nF, WF1936A) and a high voltage amplifier (TREK, 20/20C). The back corona discharge luminescence on the surface of the dust layer was photographed by digital camera (Nikon, D40X).

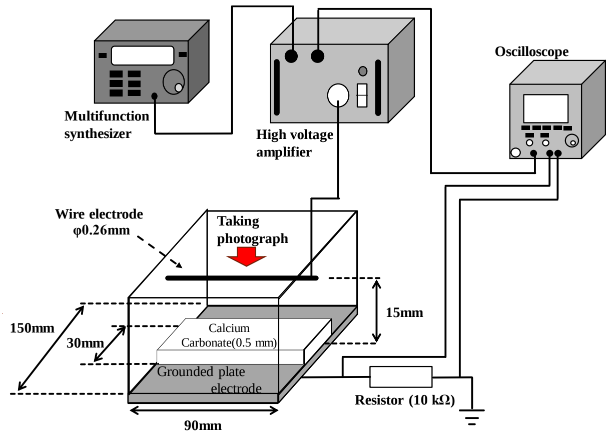


Fig. 3 Schematic diagram of experimental system.

IV. Result and Discussion

A. Current form at DC high voltage

V-I characteristic at positive DC high voltage without and with the dust is shown in Fig. 4. The corona onset voltage without the dust was approximately +11.5 kV. The current increased with increasing the applied voltage and spark at approximately +15 kV. The corona onset voltage with the dust was approximately +9.5 kV. The current increased as the voltage increased, and spark at approximately +12 kV. The corona onset voltage with the dust was lower, and the current was greater than those without the dust. This cause is that back corona discharge expand the surface of the dust layer [10].

The current wave form at positive DC high voltage without and with the dust is shown in Fig. 5. The applied voltage of the current form without the dust is +15 kV, and that with the dust is +12 kV. The current form without the dust was almost constant. The form with the dust had many pulses, and the current value was greater than that without the dust due to back corona discharge.

V-I characteristic at negative DC high voltage without and with the dust is shown in Fig. 6. The corona onset voltage without the dust was approximately -10 kV. The current increased with increasing the applied voltage and spark at approximately -19 kV. The corona onset voltage with the dust was approximately -11 kV. The current increased as the voltage increased, and spark at approximately -12.5 kV. The corona onset voltage with the dust was lower, and the current was greater than those without the dust due to back corona discharge.

The current wave form at negative DC high voltage without and with the dust is shown in Fig. 7. The applied voltages of the current forms were -12 kV. The current form without the dust has pulses by superimposing DC voltage. The current wave form with the dust has many pulses, and the current value was greater than that without the dust due to back corona discharge.

The back corona discharge luminescence, which is an overhead image, at the applied

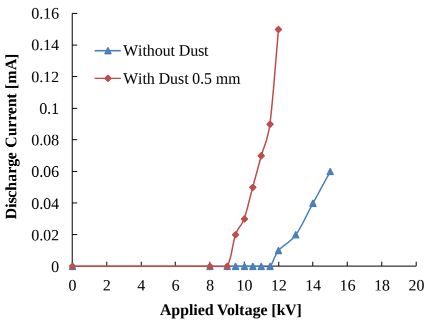


Fig. 4 V-I characteristic at positive DC voltage.

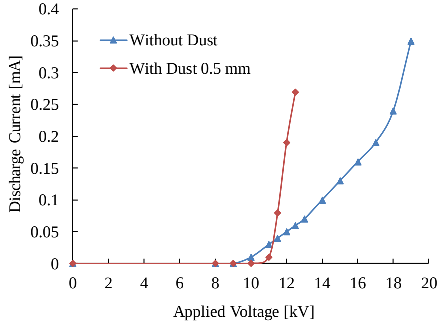
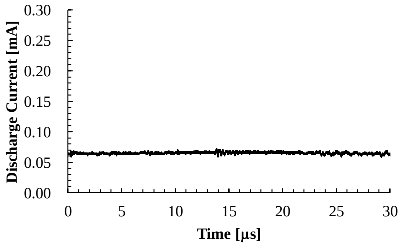
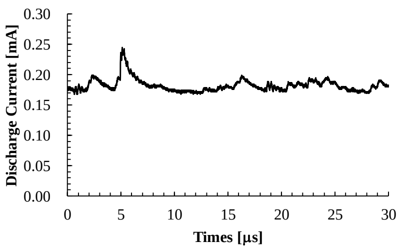


Fig. 6 V-I characteristic at negative DC voltage.

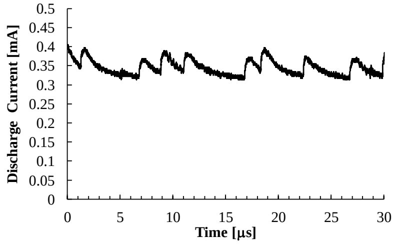


a) without dust (V = +15 kV)

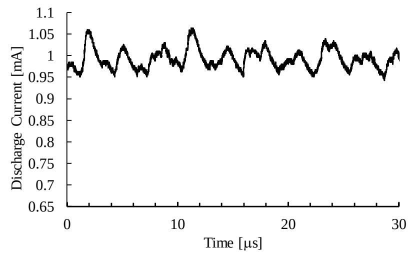


a) with dust (V = +12 kV)

Fig.5 Current wave form at positive DC voltage.



a) without dust(V = -12 kV)



b) with dust(V = -12 kV)

Fig. 7 Current wave form at negative DC voltage.

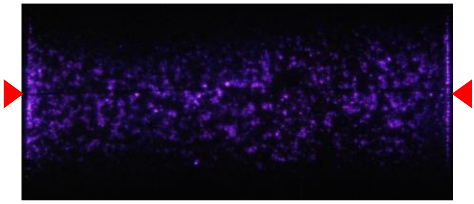
voltage of 12 kV with the dust is shown in Fig. 8. As a matter of course, the luminescence on the surface of the grounded plate electrode did not observed at the case without the dust. The back corona discharge luminescence at the positive corona was generated uniformly along the wire electrode, whereby the luminescence at the positive high voltage was observed on the entire surface of the dust layer as shown in Fig. 8-b. The luminescence at the negative corona was mottled pattern as shown in Fig. 8-c. This cause is considered that tuft corona discharge is generated on the surface of the wire electrode in the negative corona discharge.

These result indicated that the positive and negative corona discharge currents increased due to back corona discharge.

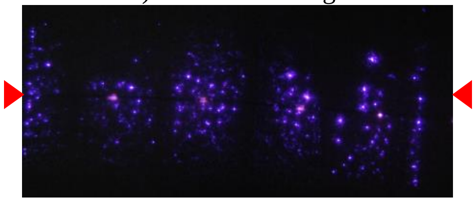
B. Effect of symmetrical AC energization

The current and the voltage wave forms when the symmetrical rectangular AC high voltage at the period of 25 ms is applied to the ESP is shown in Fig. 9. The rapid rising

a) Condition of dust on the surface of electrode



b) Positive voltage



c) Negative Voltage

Fig. 8 Back corona discharge luminescence on the surface of dust.

currents at 0 and 12.5 ms are induced current due to changing the voltage polarity. During the positive polarity, the current increased after 10 ms due to back corona discharge, while it was approximately 8 μA until 10 ms. During the negative polarity, the current was approximately 20 μA at 15 ms, and increased to approximately 58 μA with elapsing the time. The reason why the current increases is back corona discharge.

The current and the voltage wave forms at the period of 8 ms is shown in Fig. 10. The current did not increase in the positive polarity due to preventing back corona discharge, although that increased with the time in the negative polarity.

The current and the voltage wave forms at the period of 4 ms is shown in Fig. 11. The currents both positive and negative polarities did not increase with the time. Therefore, the back corona discharge was completely prevented.

The back corona discharge luminescence for various periods is shown in Fig. 12. As shown in Fig. 12-a, the back corona discharge luminescence was observed on the entire surface of the dust layer at the period of 25 ms. However, the luminescence was prevented at the period of 8 ms. Furthermore, the luminescence was completely avoided at the period of 4 ms.

These result shows that the symmetrical rectangular AC voltage can prevent back corona discharge in the ESP.

C. Effect of asymmetrical AC energization

As describe so far, the effect of symmetrical rectangular AC energized ESP on preventing back corona discharge was indicated. However, the application time of the positive polarity was equivalent to the negative polarity, and the period was short. Accordingly, it

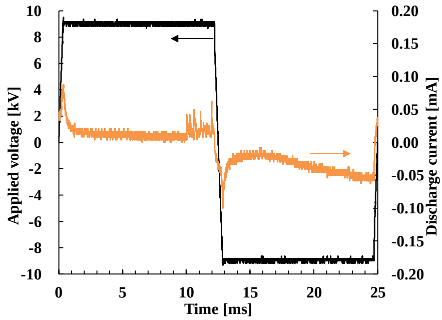


Fig. 9 Current and voltage wave forms.
(Symmetrical AC voltage. Period: 25 ms)

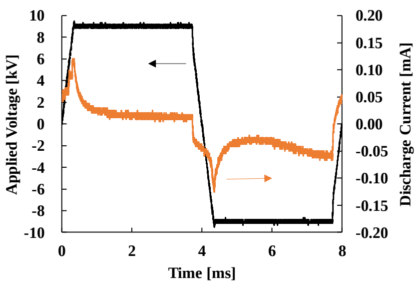


Fig. 10 Current and voltage wave forms.
(Symmetrical AC voltage. Period: 8 ms)

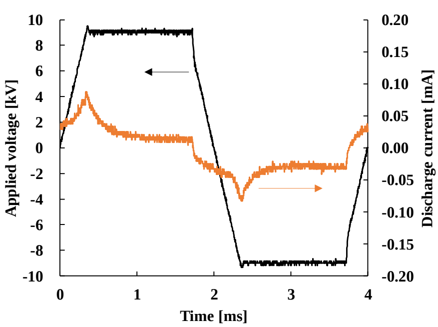
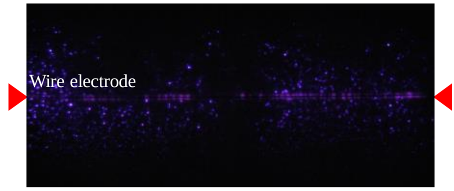
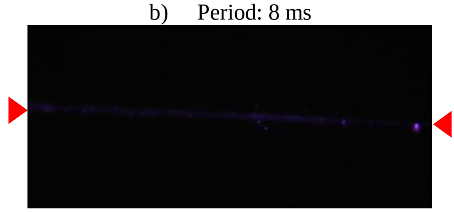


Fig. 11 Current and voltage wave forms.
(Symmetrical AC voltage. Period: 4 ms)



a) Period: 25 ms

b) Period: 8 ms



c) Period: 4 ms

Fig. 12 Back corona discharge luminescence at symmetrical voltage.

is expected that the collection efficiency is not high in the symmetrical energized ESP. Thus, the effect of an asymmetrical rectangular AC energization is investigated.

The current and the voltage wave forms at the period of 16 ms in the asymmetrical AC energization is shown in Fig. 13. The application times of the positive and the negative polarities are 12 ms and 4 ms, respectively. These application times were set while referring to the results in Fig. 9. During the positive polarity, the current was approximately 13 μA until 6 ms, and increased with elapsing time. The current during the negative polarity was approximately 60 μA until 15 ms, and increased as the time elapsed. The increasing current was observed in both the positive and the negative polarities, therefore back corona discharge was not prevented in this condition.

The current and the voltage wave forms at the period of 9 ms is shown in Fig. 14. The application time of the positive and the negative polarities are 7 ms and 2 ms, respectively. The currents in both positive and negative polarities did not increase with the time. Therefore, the back corona discharge was completely prevented.

The back corona discharge luminescence for the periods of 16 ms and 9 ms is shown in Fig. 15. As shown in Fig. 15-a, the back corona discharge luminescence was observed on the surface of the dust layer along the wire electrode at the period of 16 ms. However, the luminescence was prevented at the period of 9 ms.

These result showed that the asymmetrical rectangular AC voltage prevented the back corona discharge. The effect of the asymmetrical rectangular AC energization on the collection efficiency in an ESP will be investigated in the future.

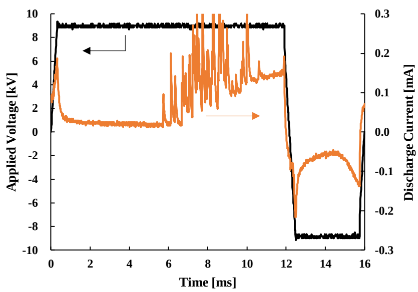


Fig. 13 Current and voltage wave forms.
(Asymmetrical AC voltage. Period: 16 ms)

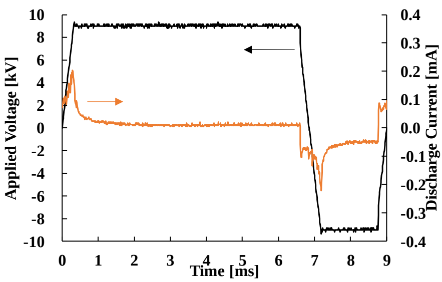
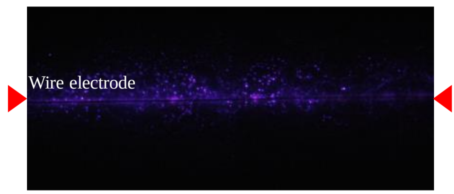
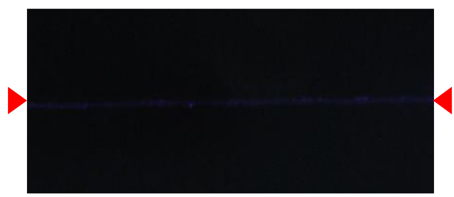


Fig. 14 Current and voltage wave forms.
(Asymmetrical AC voltage. Period: 9 ms)



a) Period: 16 ms



b) Period: 9 ms

Fig. 15 Back corona discharge luminescence at asymmetrical voltage.

V. Conclusion

A symmetrical or an asymmetrical rectangular AC voltages were applied to the experimental ESP, and investigated the effect on preventing back corona discharge. As a result, the discharge current increased, and the discharge luminescence was observed on the surface of the dust layer at applying DC high voltage due to generating back corona discharge. On the other hand, the discharge current did not increase and discharge luminescence were not observed, when the symmetrical rectangular AC high voltage at the period of 4 ms. Therefore, the back corona discharge was prevented using the symmetrical AC energized. However, the application time of the positive polarity was equivalent to the negative polarity, and the period was short. Accordingly, it is expected that the collection efficiency is not high in the symmetrical rectangular AC energized ESP. Thus, the effect of an asymmetrical AC energization is investigated. As a result, it was showed that the back corona discharge was avoided in the asymmetrical rectangular AC energized ESP at the period of 9 ms which the application time of the positive and negative high voltage were 7 ms and 2 ms.

The effect of the asymmetrical rectangular AC energization on the collection efficiency in an ESP will be investigated in the future.

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