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The Characteristics of Charging Water Spray at Electrostatic Precipitator

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ABSTRACT

The new spray system is proposed by using a pipe with hygroscopic needle electrode in order to develop an air-cleaning ESP with high collection efficiency for submicron particles and high removal efficiency for NO_x, SO_2, NH_3. Fundamental characteristics of charging water spray, which is not an usual wet type, are investigated experimentally. As a result, corona discharging mode and ozone generation rate are significantly affected by the operational conditions, such as the applied voltage and wet condition of the needle electrode.

1. Introduction

Recently, much attention have been paid for indoor air quality concerning for an improvement of living environments. Air-cleaning electrostatic precipitators are widely used to remove dust, smoke, and other particles from indoor air. For the use of air cleaner in home, office, hospital and etc., the well-controlled device is required to operate in safety, and therefore further investigation must be done. Up to now, the conventional air cleaners have the function of particle collection. However, the collection efficiency of submicron particles is low compared to larger particles. Moreover, for new type air cleaner, other functions, such as sterilization and deodorization, have been required in addition to the removal of particles[1].

In a power plant and other industries, various electrostatic precipitators(ESPs) are developed and used. To improve the collection efficiency for submicron particles, a number of methods have been proposed[2,3]. One of the methods is to use water. A wet type ESP[4] and wet scrubber[5] using charged water droplets have been previously studied for industrial use. Moreover, from physical point of view, water spray phenomena generated at the tip of the capillary in capillary-to-plate electrode sys-

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tem have been investigated[6,7].

The wet type system is very effective for removal of submicron particles and dirty gases. One of the problems in wet type ESPs and wet scrubbers is the necessity of after-treatment of slurry disposal. If one uses a wet type ESP for indoor use, the control of the amount of water is very important. Taking into account this point, a semi-wet type plasma reactor has been investigated recently[8]. In this system, a filter paper soaked in saturated $CaCl_2$ solution is introduced into the reactor to stick to the inner surface of glass cylinder. $CaCl_2$ absorbs moisture from air and retains wetness. Higher removal efficiency of NO, NO_x, NH_3 and submicron particles is obtained compared to dry reactor.

In this study, as an alternative approach, a pipe with hygroscopic needle electrode is used as a discharging electrode and water supply source. In order to control fine particulate and gaseous pollutants(NO_x, SO_x, CO_2, etc.) with controlled amount of water simultaneously, charged water spray is generated at the tip of hygroscopic needle electrode. The new technique has several potential advantages to be considered: 1) a small amount of water use and the elimination of slurry disposal compared with wet type ESPs and wet scrubbers, 2) low contamination of the discharging electrode, 3) high collection efficiency of submicron particles and reduction of reentrainment of collected particles by using charging water spray, and 4) enhancement of plasma chemical reactions. This paper describes the fundamental characteristics of the system, such as corona current, discharge mode, particle behavior, ozone concentration. In addition, the discharge electrode without hygroscopic needles is a pipe with nozzles electrode system. This system has been already applied for NO_x removal and high NO_x removal rate can be achieved in streamer corona[9].

2. Experimental Apparatus and Procedure

A schematic diagram of the experimental apparatus is shown in Fig. 1. In order to observe corona discharge and particle trajectory, the apparatus is enclosed in an acrylic vessel. A pipe with hygroscopic needle electrode, as shown in Fig. 1(b), is used as a discharging electrode. Water is intorduced form the pipe electrode and charged water spray is generated by spraying from the hygroscopic needle on the pipe electrode which is connected to a positive dc. high voltage power supply(Max-Elec, model NA-5196). The spacing between the plate electrodes is 30mm and the discharge electrode is placed at the center of two grounded plate. A steady airflow is supplied to the flow channel by using a fan type blower. The air flow velocity is varied in the range of 0-1.2m/s.

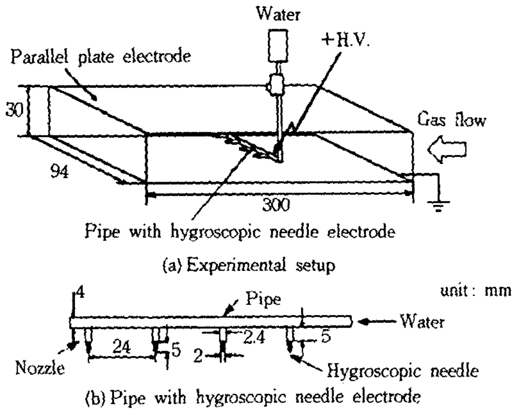

Fig. 1 Schematic diagram of experimental apparatus

In order to observe the collection performance, cigarette smoke, as typical submicron particles, is supplied to the flow channel from the nozzle(ϕ 1.3mm) at 125mm upstream of the pipe electrode. Furthermore, the ozone concentration is measured by ozone monitor(Dasibi, model 1006-AHJ) at the exit of the apparatus.

3. Experimental Results and Discussion

Fig. 2 shows typical corona current charateristics as a function of applied DC voltages for various wet conditions of the needle. Water spray is generated from wet needle electrode at the water evaporation rate of about 14mg/min. For the wet needle electrode, corona onset occurs at 5kV, and corona current increases with increasing the applied voltage. Fig. 3 shows the voltage and current waveforms at 8kV. Corona current consists of dc and pulse components. Observed pulse may be due to the water spray ejected from hygroscopic needles.

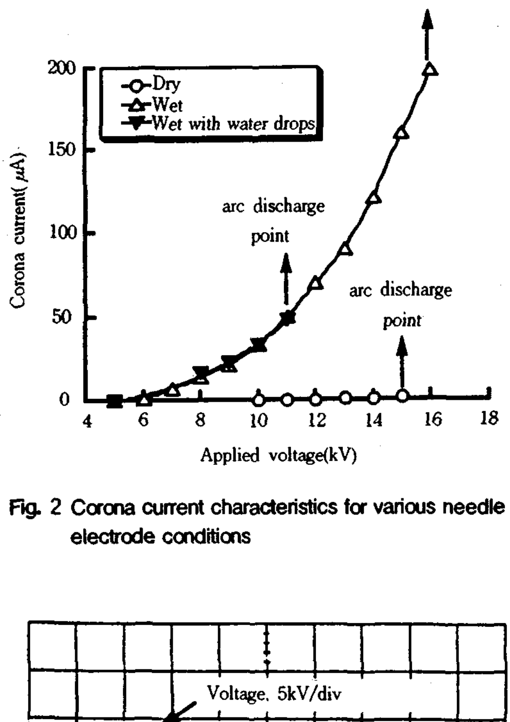

Fig. 2 Corona current characteristics for various needle electrode conditions

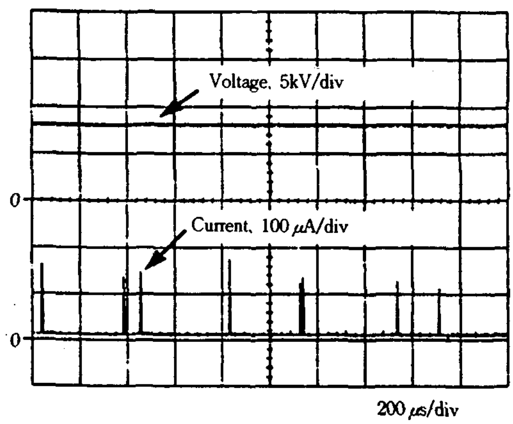

Fig. 3 Applied voltage and corona current waveform for wet needle electrode at 8kV

In the case of wet needle electrode with water drops, which is a condition that water drops form at the tip of wet needles, same features are obtained except for the difference of sparkover voltage. While, in the case of dry needle electrode, no corona is observed because the needle is an insulator under non-wet condition.

Fig. 4 shows typical photographs of corona discharge. Corona discharge below 10kV is a glow at the tip of nozzles, and it becomes streamer as increase the voltage until the transition to spark discharge.

Fig. 5 shows the trajectory of smoke particles for the wet needle electrode at 13kV. The air flow velocity is 1.2m/s. The streamline collides with plate electrode at downstream of needle electrode. Ionic wind influences the smoke particle trajectory near the needle electrode. Therefore, the observed trajectory is caused by both the main gas flow and electrohydrodynamic-induced secondary flow[10]. When the voltage is increased, the collision point moves toward the upstream side. After the experimental run, the deposition of smoke particles on the plate electrode is confirmed.

Fig. 6 shows a ozone concentration as a function of applied voltage. Generally, it is considered that the major mechanism of the ozone generation is expressed as follows[11]:

$O_2+e \rightarrow O+O+e$ ······························ (1)

$O_2+O+M \rightarrow O_3+M$,

where M is a third body. ····················· (2)

Hence, in well designed ozonizer, ozone concentration increases with increasing corona current[12,13]. Water vapor also affects the ozone concentration. If water vapor exists in the discharge space, ozone dissociation process takes place[14]:

$O+H_2O \rightarrow 2OH^*$ ······························ (3)

$OH^*+O_3 \rightarrow HO_2+O_2$ ························ (4)

$HO_2+O_3 \rightarrow OH^*+2O_2$. ······················ (5)

In Fig. 6, as the discharge mode is glow corona below 10kV, ozone generation increases with increasing applied voltage, and then decreases against

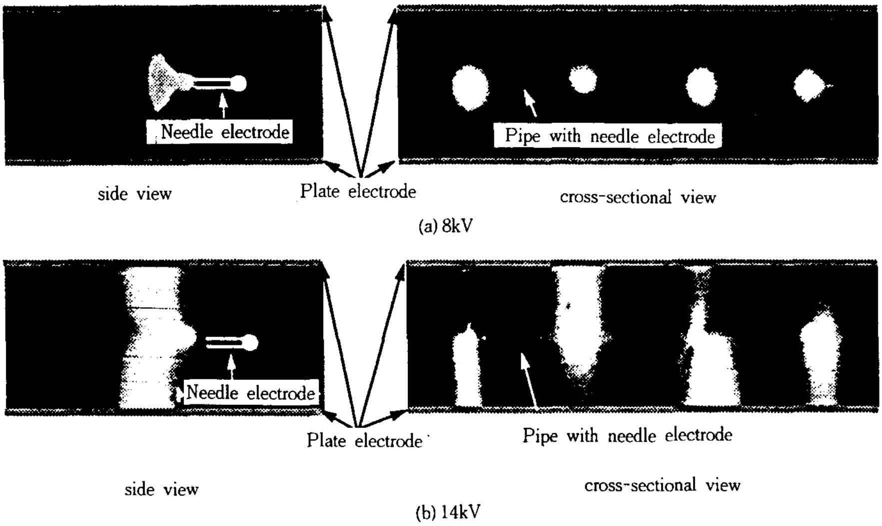

Fig. 4 Photographs of corona discharge

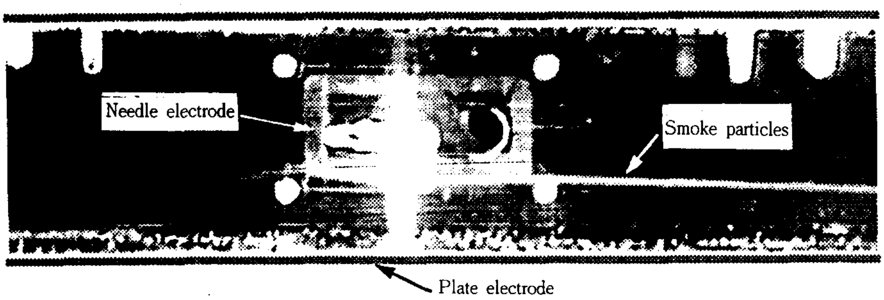

Fig. 5 Smoke particle trajectory at 13kV

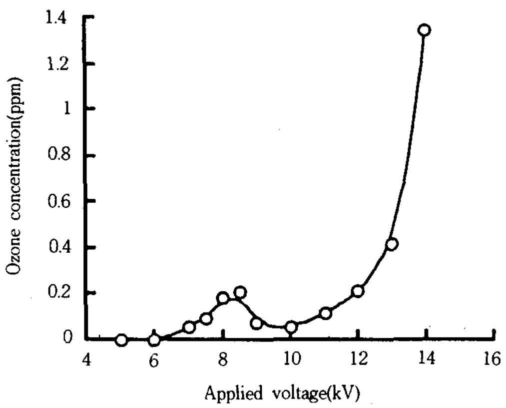

Fig. 6 Ozone concentration as a function of applied voltage for the wet needle electrode

the increase of the voltage. These phenomena are due to the both effects of ozone generation and decomposition. Especially, water evaporation rate may be enhanced by the increase of applied voltage. Therefore, non-monotonic ozone generation characteristic appears. When the corona mode changes to streamer corona, discharge space is enlarged as shown in Fig. 4. and a relatively high ozone concentration compared with the glow mode-(less than 10kV) is produced. However, the generated ozone would be able to enhance the plasma chemical reaction, such as decomposition of gaseous pollutants.

4. Conclusions

The new air-cleaning ESP using a hygroscopic needle electrode is proposed and basic characteristics of the system is investigated experimentally. The pipe with hygroscopic needle electrode plays an important role in the generation of charging water spray. The total amount of required water is very small. The stable streamer corona can be generated by adjusting the water supply rate. The behavior of particles is affected by electrohydrodynamic gas flow near the needle electrode. Ozone generation for streamer corona is considerably larger than that for glow corona.

References

1) S. Masuda, S. Hosokawa, X. L. Tu, M. Tsutsumi, T. Ohtani, T. Tsukahara and N. Masuda : The Performance of an Integrated Air Purifier for Control of Aerosol, Microbial, and odor, *IEEE Trans. Ind. Appl.*, Vol. 29, No. 4, pp. 774-780, 1993.
2) The Inst. Electrostatics Japan ed., : *Handbook of Electrostatics*, Ohm Co., p. 543, 1981.
3) S. Kanazawa, T. Ohkubo, Y. Nomoto and T. Adachi : Submicron Particle Agglomeration and Precipitation by Using a Bipolar Charging Method, *Proc. Inst. Electrostatics Japan*, Vol. 16, No. 4, pp. 323-331, 1992.
4) T. Adachi : Experimental Discussion on Removal Functions of SO_2 Gas by a Wet type Electrostatic Precipitator, *Trans. Inst. Elec. Eng. Japan*, Vol. 97, No. 6, pp. 521-528, 1977.
5) H. Hara, S. Sumiyoshitani, Y. An-no, S. Fujimoto and M. Akazaki : Experimental Study on Highly Effective Collection of Fine Particles by a Charged Water Droplet, *Proc. Inst. Electrostatics Japan*, Vol. 6, No. 4, pp. 239-247, 1982.
6) N. Yoshida, R. Ishimaru and T. Adachi : On the Coulomb Force for Water Drop at the Tip of Capillary Tube Electrode, *Proc. Inst. Electrostatics Japan*, Vol. 6, No. 1, pp. 41-47, 1982.
7) A. Watanabe : *Oyo Buturi*, Vol. 37, p. 314, 1968.
8) A. Chakrabarti, A. Mizuno, K. Shimizu, T. Matsuoka and S. Furuta : Gas Cleaning with Semiwet type Plasma Reactor, *Conf. Record of IEEE IAS*, part. Ⅲ, pp. 1989-1994, 1993.
9) T. Ohkubo, S. Kanazawa, Y. Nomoto, J. S. Chang and T. Adachi : NO_x Removal by a Pipe with Nozzle-Plate Electrode Corona Discharge System, *IEEE Trans. Ind. Appl.*, Vol. 30, No. 4, pp. 856-861, 1994.
10) T. Ohkubo, T. Murakami and T. Adachi : Analytic and experimental study of flow field for wire-duct type electrostatic precipitator, *Trans. Inst. Elec. Eng. Japan*, Vol. 106-A, No. 8, pp. 377-383, 1986.
11) M. Horvath : *Ozone*, Amsterdam, The Netherlands, Elsevier, 1970.
12) Y. Nomoto, T. Ohkubo, S. Kanazawa and T. Adachi : Improvement of Ozone Yield by a Silent-Surface Hybrid Discharge Ozonizer, *Conf. Record of IEEE IAS*, part. Ⅲ, pp. 1995-1999, 1993.
13) J. D. Moon : High Efficiency Ozone Generation Using a Pyramidally Embossed Rod-to-Cylinder Electrode and a Pulse Corona Discharge, *Proc. Inst. Electrostatics Japan*, Vol. 16, No. 3, pp. 224-229, 1992.
14) A. S. Viner, P. A. Lawless, D. S. Ensor and L. E. Sparks : Ozone Generation in dc-Energized Electrostatic Precipitators, *IEEE Trans. Ind. Appl.*, Vol. 28, No. 3, pp. 504-512, 1992.