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A Study on the Humidity Effect of AC Corona Discharge for a Thin-Wire Electrode Arrangement

by

Try SOBAN[*1] and Ryu-ichiro OHYAMA[*2]

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Abstract

AC corona discharge pulses have been detected in various models in order to investigate the characteristics in electrical insulation systems. In this work, AC negative corona discharge pulses were measured by using a thin wire-plate electrode arrangement while varying the humidity, wire electrode diameter, and applied voltage. This experiment was done to determine the influence of humidity on the intensity of negative corona discharge in thin wire electrodes. The humidity effect is shown by the average magnitude, the maximum magnitude, and the number of pulses of negative corona discharge. This report discusses such details quantitatively.

Keywords: Humidity effect, AC corona discharge, Thin-wire electrode arrangement

1. Introduction

In modern societies due to the increasing of the population and industrials everywhere, the demand of electricity is increased from day to day. So, a huge amount of power is generated, transmitted, and distributed. For example of electricity of Cambodia, the total energy of 122,252 GWh in 2007 gained to 309,797 GWh in 2012. Usually, the load centers and power plants are far from each other, so transmission systems are needed in order to transmit the huge amount of power with long distance. There are two kinds of AC transmission system and DC transmission system. The transmission systems are like the back bone of the power system which carries the huge amount of power with high voltage, extra-high voltage, and ultra-high voltage.

According as the high voltage increases, there are phenomena to become the advantages and disadvantages to the electricity facilities. Corona discharge (as partial discharge) is one of the concern phenomena into the disadvantage [1)]. Taking into consideration the characteristics of corona discharge, there are many influence factors such as conductor arrangements, voltage waveforms, and surrounding environments. The characteristics determined for AC partial discharge are less than those of DC. There are several reports about the characteristics of AC partial discharge with various parameters such as point cup electrode system [2)], point cup electrode arrangement with varies of humidity [3)], bundle conductors with pressure and humidity dependence [4)], point to plate electrode arrangement [5)].

Actually, the phenomena of corona discharge for transmission lines are affected by natural factors such as weather, location or attitude. The weather conditions of raining, snowing, and fogging are easy to cause the corona discharge than fair weather condition. Atmospheric pressure corresponding to altitude affects to the occurrence of corona discharge. In addition, the surface of conductors like bundle configuration effects to the corona discharge [6)]. The transmission lines should be designed to operate below the critical electric field strength of 21.1 kV/cm. Since it is recognized for succeeding the influence of the corona discharge intensity, the evaluation on quantitative characteristic is not well known.

In this study, an influence of humidity on AC corona discharge pulses was experimentally investigated while varying the wire electrode diameter and applied voltage. A wire-plate electrode arrangement was used to determine the characteristic of corona discharge intensity. For the electrode configuration similar to the transmission line system, some thin-wire electrodes were performed in an available voltage

*1 Graduate Student, Course of Electrical and Electronic System
Current work: Electricité du Cambodge (EDC) or Electricity of Cambodia
*2 Professor, Department of Electrical and Electronic Engineering

level less than 50 kV for the laboratory scale and experimental facilities. The characteristics of the average magnitude $q_{ave.}$, maximum magnitude q_{max}, and number of pulses per cycle n of AC negative corona discharge pulses are quantitatively evaluated.

2. Experimental Setup and Procedure

Fig.1 shows the experimental setup to measure the magnitude and number of pulses of corona discharge in AC applied voltage. A copper plate electrode of 260 mm×150 mm was connected to an AC voltage source (50 Hz, 50 kV in the maximum). As an experimental electrode of corona discharge, an aluminum wire (0.20, 0.32, 0.50, and 1.00 mm in the diameter d) was connected to the GND through a resistance R_3 (50 Ω) for detecting the discharge current pulses. The effective length of wire electrode was 260 mm corresponding to the long side of plate electrode. The discharge gap between the plate and wire electrodes was fixed to 30 mm. The applied voltage divided by series resistances (R_1 and R_2) and corona discharge current pulses detected by R_3 were recorded in an oscilloscope (Iwatsu DS-5532, 350 MHz). The electrode system was installed in a constant humidity chamber (220×550×350 mm^3) formed of acrylic resin. The level of relative humidity (RH) was monitored by a humidity meter (SK-110TRH II). The control of RH was conducted by a water-vapor/dry-air circulation system through a water cell or a silica gel cell. The RH level was varied from 20 to 80 %.

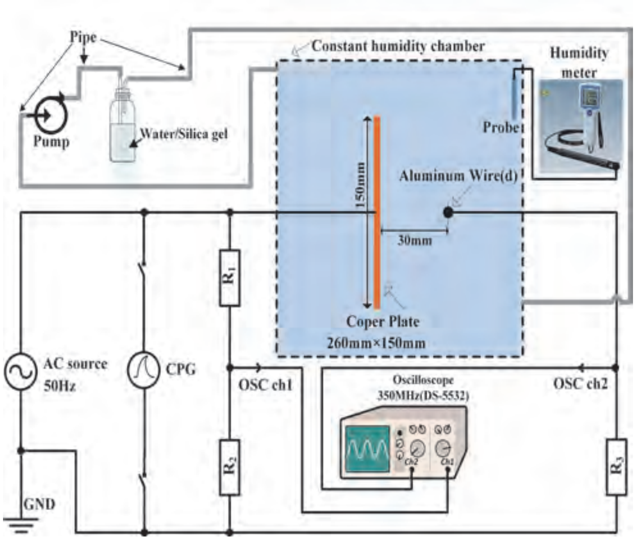

Fig.1 Experimental setup.

The conversion from the detected corona discharge pulses (as the current value) to the quantity of electric charge (as the unit of coulomb) was conducted by a calibration pulse generator (Sokendenki, DAC-CP-2) in the range of 100 to 100,000 pC. The experiment was conducted in the atmospheric pressure while the range of 22 to 34 kV$_{rms}$ in applied voltage.

3. Experimental Results and Discussions

3.1 *Experimental results*

An arrangement of thin-wire and plate electrodes was used, where the different diameters of wire were 0.20, 0.32, 0.50, and 1.00 mm. A lot of negative corona discharge pulses appeared at the surface of wire electrode. With increasing the applied voltage, higher magnitude and more number of discharge pulses were observed. Fig.3 shows the example of AC corona discharge magnitude for different wire diameters, when the applied voltage was 34kV$_{rms}$. Generally, it is well known to be easy to observe the corona discharge pulses while negative polarity cycle in applied voltage than positive polarity. The positive corona discharge pulses could not detect in stability. For the wire electrode diameters of 0.20, 0.32, and 0.50 mm the positive corona discharge did not appear stably. For the wire diameter of 1.00 mm the positive corona discharge was appeared with higher magnitude, but the number of pulses was much less than that of negative corona discharge. The total number of positive discharge pulses was a few to thirty in 50 cycles, while the number of negative discharge pulses was a few hundred to several thousands. The atmospheric corona discharge is usually affected by positive ions. For the positive corona discharge, it is inferred that the space charge formed with positive ions relaxes the electric field strength around the wire electrode. As the results, corona discharge was unstable. For this reason, it was decided to perform the evaluation for the negative corona discharge.

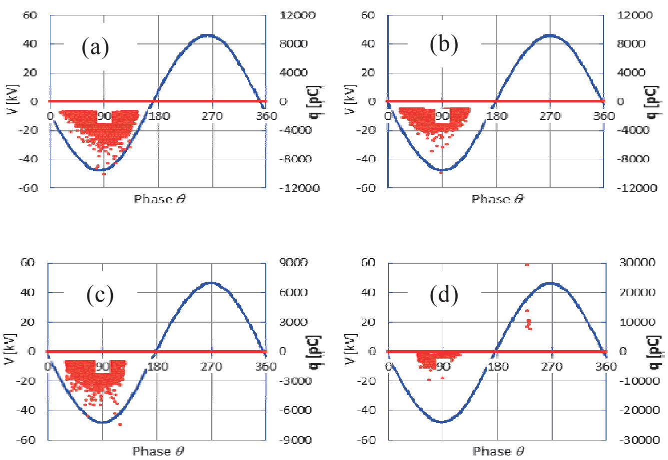

Fig.2 AC corona discharge pulses with gap length of 30 mm, applied voltage V of 34 kV$_{rms}$, and wire electrode diameters: (a) d=0.20, (b) d=0.32, (c) d=0.50, and (d) d=1.00 mm.

Table 1 shows the partial discharge inception voltage (PDIV) and partial discharge extinction voltage (PDEV) in the negative corona discharge determined for wire diameters. The PDIV was increased with increasing the wire diameter. The tendency indicating the value of PDEV lower than PDIV was similar to corona discharge phenomena in the dry air condition. For influence of humidity, the PDIV or PDEV obtained from the present experiment was approximately constant in the range of 20 to 80 % in RH.

Table1 PDIV and PDEV for diameter of wire electrode.

Diameter of wire electrode (mm)	Air gap (mm)	PDIV (kV_{rms})	PDEV (kV_{rms})
0.20	30	14	13
0.32	30	17	16
0.50	30	21	20
1.00	30	29	28

Figs.3, 4, and 5 show the average magnitude $q_{ave.}$, the maximum magnitude q_{max}, and number of pulses per cycle n as a function of RH for the negative corona discharge, respectively. These figures represent for wire diameters of 0.20, 0.32, 0.50, and 1.00 mm, respectively. The values of $q_{ave.}$, q_{max}, and n were increased with increasing the applied voltage. As a characteristic trend obtained from the experiment, the magnitude and generation frequency of corona discharge were decreased with increasing RH. The humidity effect of corona discharges was indicated as the same tendency in the range of experimental conditions.

For dependence of wire diameters of 0.20, 0.32, 0.50, and 1.00 mm, Figs.6, 7, and 8 show the average magnitude $q_{ave.}$, the maximum magnitude q_{max}, and number of pulses per cycle n as a function of RH, respectively. These figures represent for the applied voltage of 22, 26, 30, and 34 kV_{rms}, respectively. The values of $q_{ave.}$, q_{max}, and n were decreased when the wire diameter was enlarged. For the dry air conditions of wire-plate electrode system, the same dependence of wire diameters is also mentioned in many papers [7-12]. In the wire-plate electrode system, the surface of the wire electrode takes the maximum electric field strength. The electric field strength depends on the diameter of wire electrode, and decreases with increasing the diameter. Therefore, the magnitude ($q_{ave.}$, q_{max}) and generation frequency (n) of corona discharge relatively decreased when the size of wire electrode was enlarged.

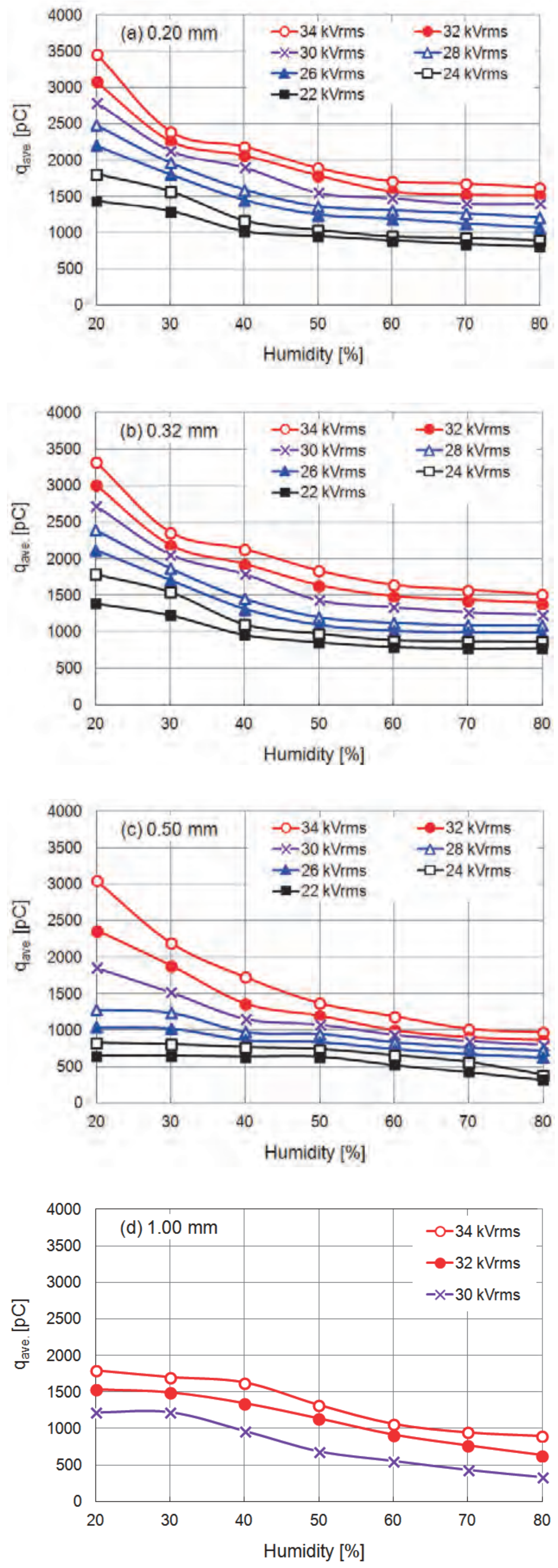

Fig.3 Average magnitude $q_{ave.}$ of negative corona discharge as a function of humidity for wire electrode diameters: (a) 0.20, (b) 0.32, (c) 0.50, and (d) 1.00 mm.

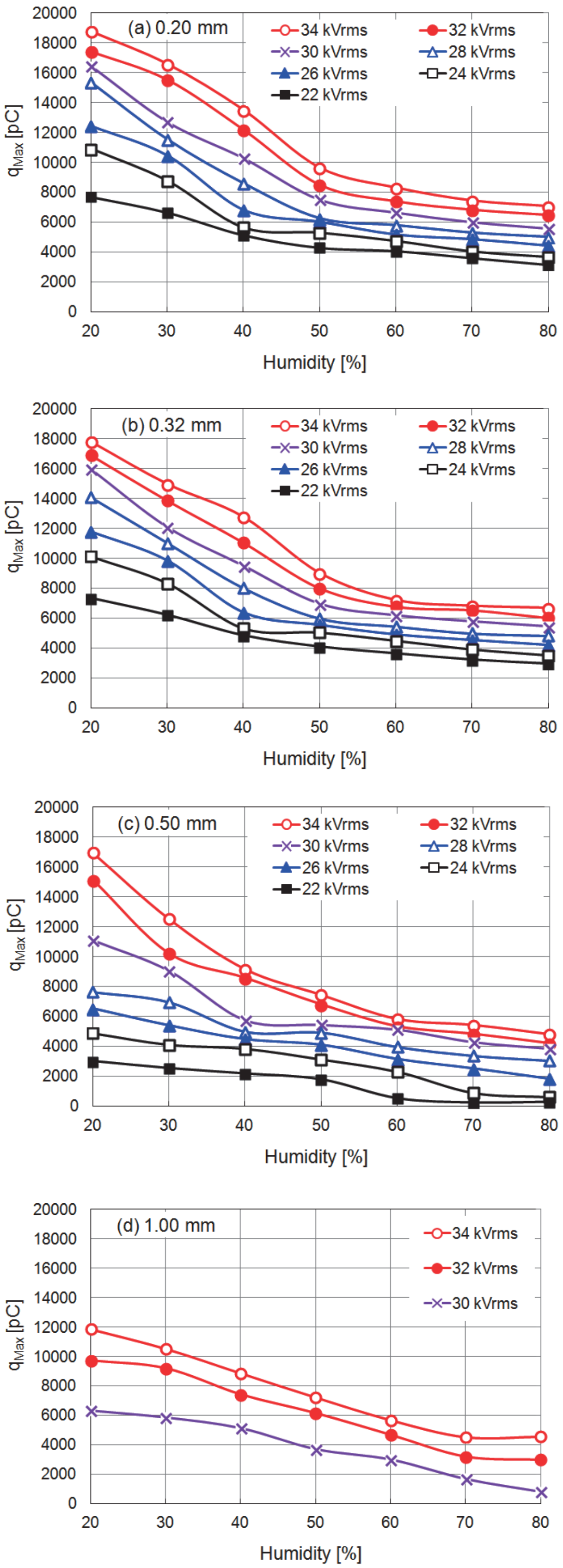

Fig.4 Maximum magnitude q_{max} of negative corona discharge as a function of humidity for wire electrode diameters: (a) 0.20, (b) 0.32, (c) 0.50, and (d) 1.00 mm.

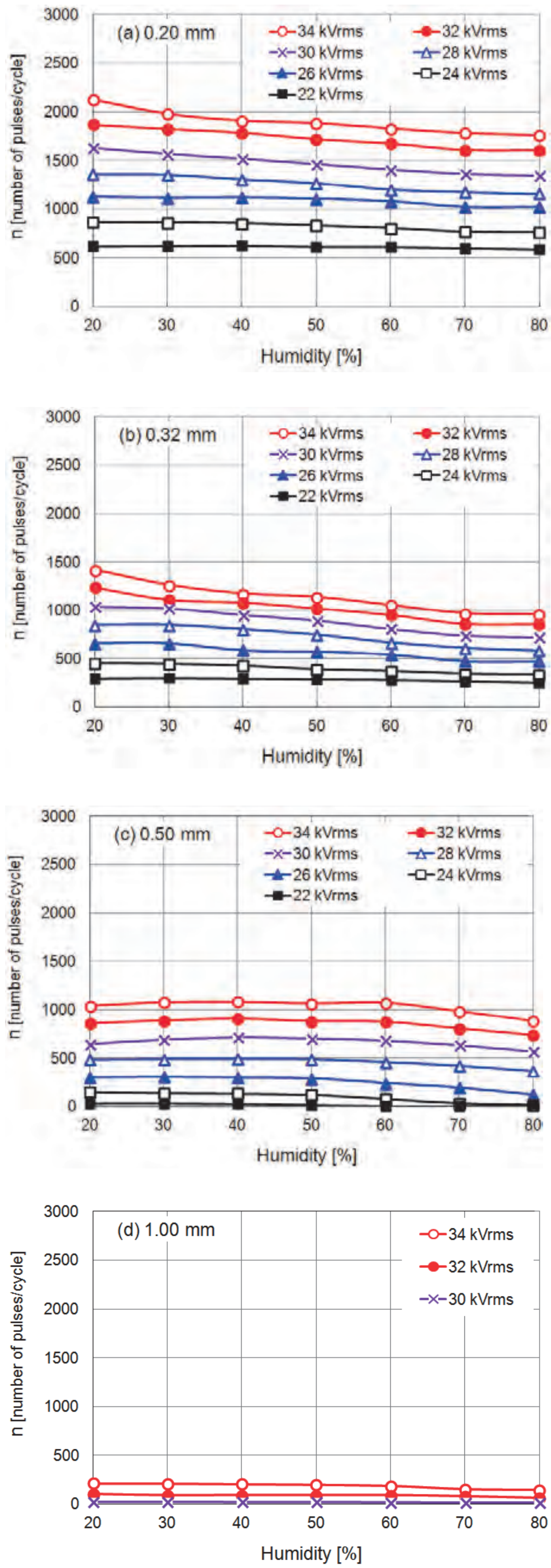

Fig.5 Number of pulses per cycle n of negative corona discharge as a function of humidity for the wire electrode diameters: (a) 0.20, (b) 0.32, (c) 0.50, and (d) 1.00 mm.

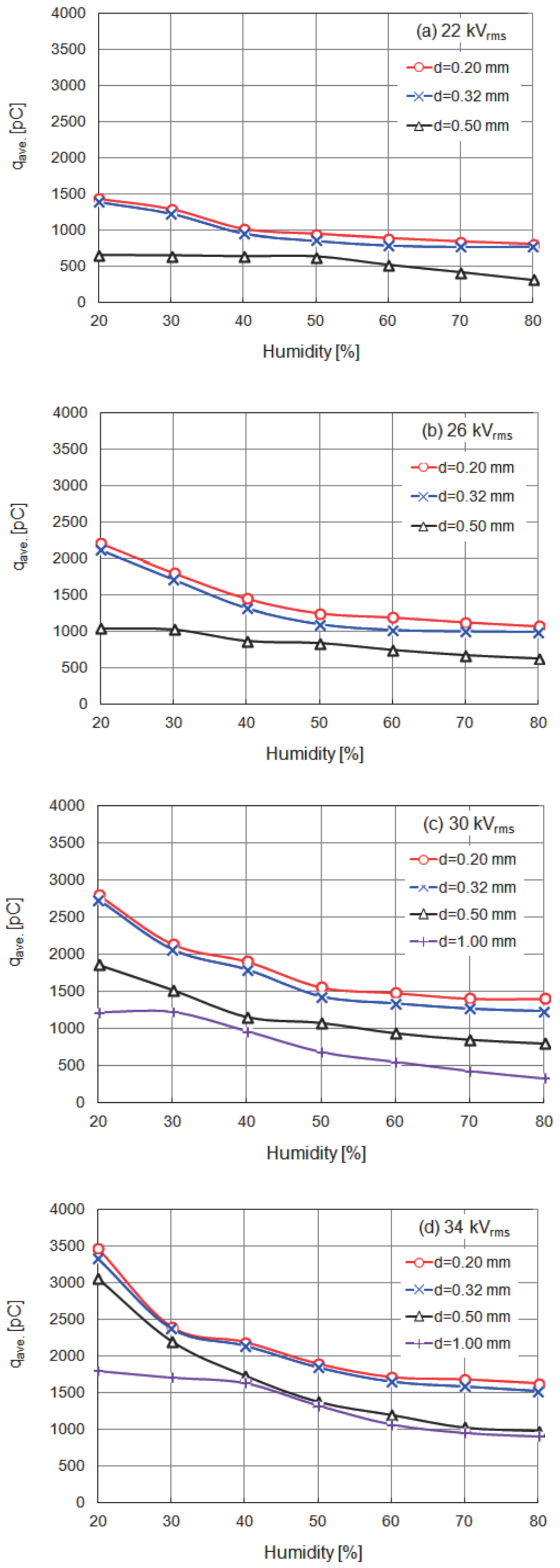

Fig.6 Average magnitude $q_{ave.}$ of negative corona discharge pulses as a function of humidity for applied voltage: (a) 22, (b) 26, (c) 30, and (d) 34 kV_{rms}.

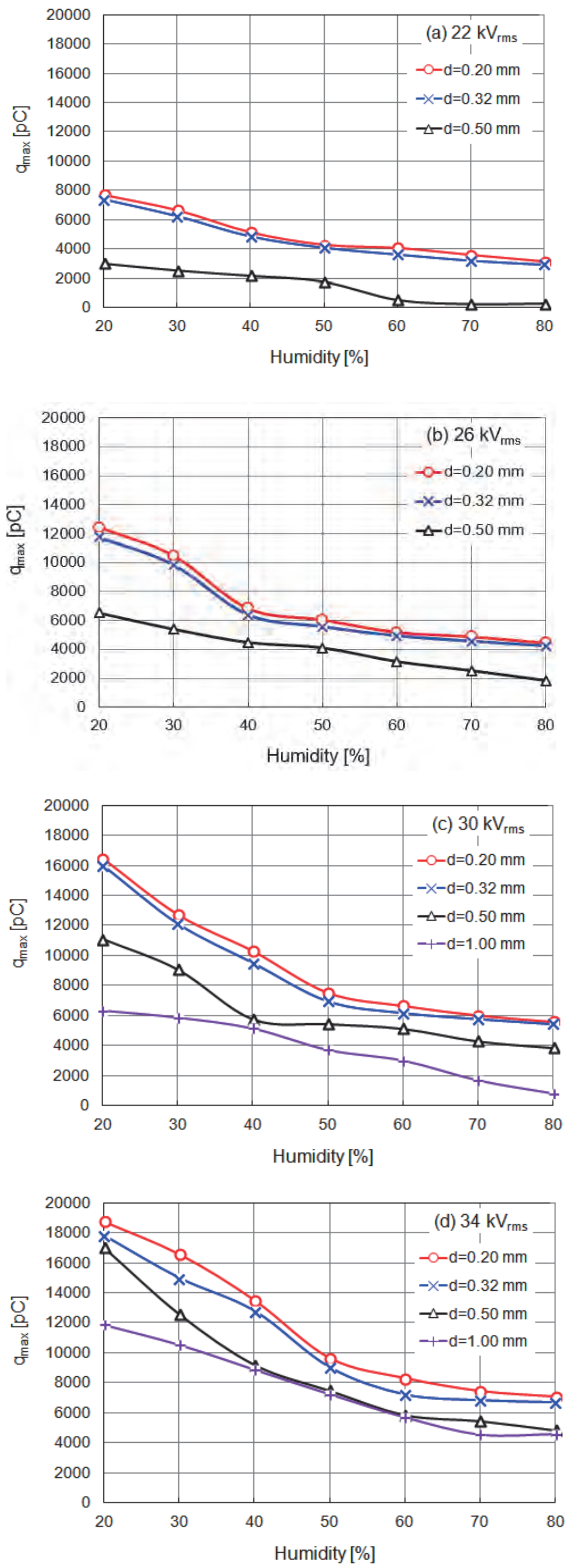

Fig.7 Maximum magnitude q_{max} of negative corona discharge pulses as a function of humidity for applied voltage: (a) 22, (b) 26, (c) 30, and (d) 34 kV_{rms}.

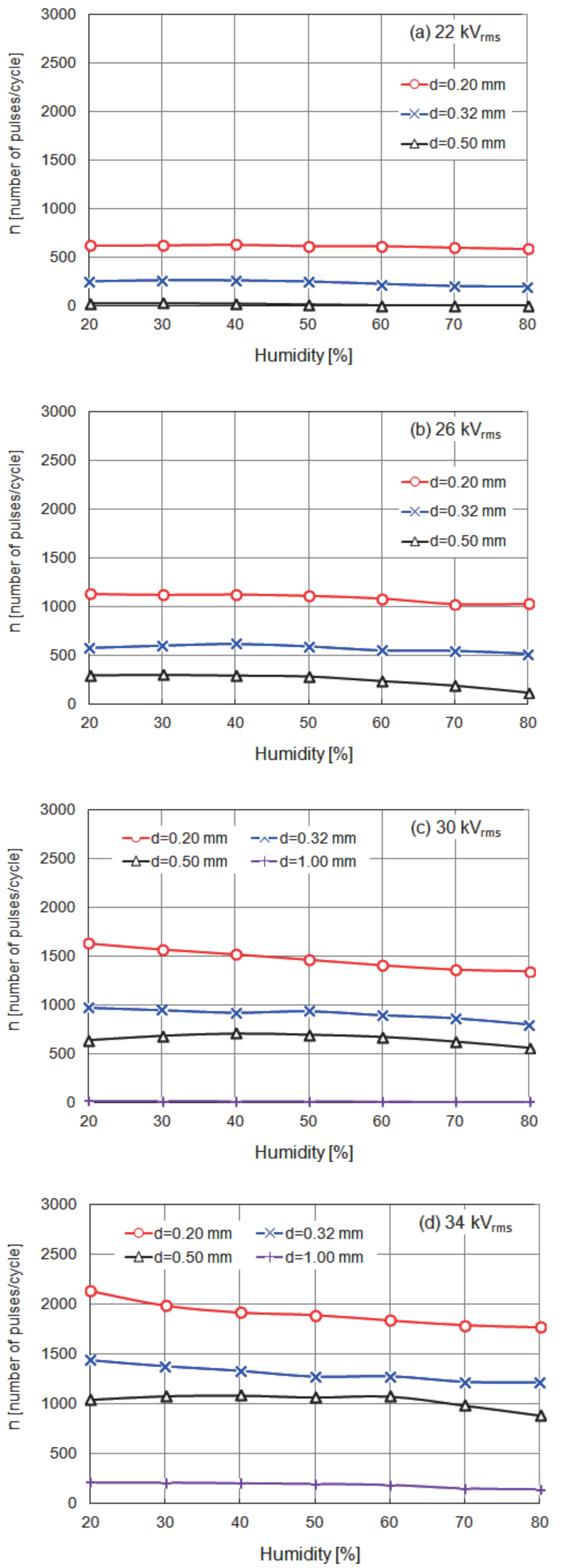

Fig.8 Number of pulses per cycle n of negative corona discharge pulses as a function of humidity for applied voltage: (a) 22, (b) 26, (c) 30, and (d) 34 kV_{rms}.

3.2 *Discussions*

The basic characteristic of negative corona discharge is Trichel pulse corona and pulseless corona. For the range of PDIV, Trichel pulse corona of the slightly long discharge path occurs around the wire electrode. With increasing voltage, it becomes pulseless corona of the longer discharge path and finally shifts to spark discharge [13,14]. The corona discharge characteristics as shown in Fig.3 to Fig.8 were the humidity dependence on Trichel pulse corona and pulseless corona. Usually, in the ionization process higher than PDIV, when the electric field intensity is enhanced, free electrons move from the higher electric field (wire electrode side) to lower electric field (plate electrode side). During the movement for lower RH, the electron collides or attaches with neutral gas molecules (N_2, O_2, etc.). As a result it produced two free electrons and a positive ion or negative ion per one electron action. This process develops to the higher electric field domain where an electron avalanche is generated as shown in Fig.9.

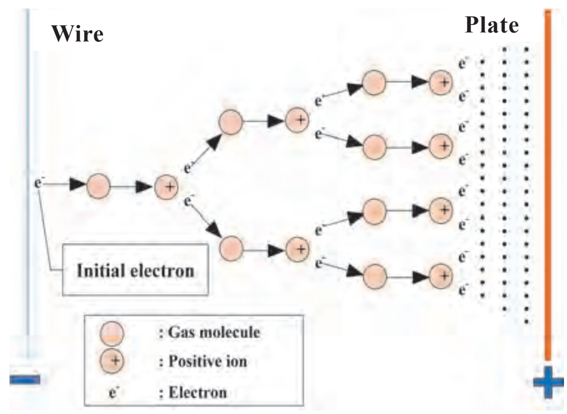

Fig.9 Ionization process by electron collision with neutral gas molecules.

The existence of oxygen molecules with the electronegativity characteristic tends to form negative ions due to the free electron attachments. For higher RH condition, water molecules in vapor phase tend to enhance the negative charge formation of water cluster $(H_2O)_n^-$, which is well known as negative ion or anion, and the range of subscript n is more than 5 [15,16]. Another water molecules in the gas phase can be attached with electron to form the negative ion clusters $(H_2O)_n^-$ [17]. It is considered as the humidity effect involved the space charge formation above negative ion process of water clusters.

While the applied voltage is negative cycle, the electric field on the surface of wire electrode relaxes to lower strength, because the space charge of negative polarity forms as surrounding the wire electrode [3,18]. Thereby, the discharge progress from Trichel pulse corona to pulseless corona will be weakened. This characteristic behaves so that the diameter of wire electrode becomes larger. The humidity effect of AC corona discharge was able to know that it was remarkable with increasing RH.

4. Conclusion

In this work, negative corona discharge for AC applied voltage was investigated by using a wire-plate electrode arrangement. The measurements have been done inside a constant humidity chamber where the relative humidity was varied from 20 to 80 %. From this experimental investigation, the average magnitude $q_{ave.}$, the maximum magnitude q_{max}, and the number of pulses per cycle (generation frequency) n of negative corona discharge were determined. The majority of parameters was the relative humidity dependence. According to the experimental result, it was concluded that $q_{ave.}$, q_{max} and n were decreased when the relative humidity was increased and wire electrode diameter was enlarged. With increasing the relative humidity from 20 to 80 %, the magnitude of negative corona discharge pulses was reduced until 50 to 60 %.

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