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**Article**

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## Fog dispersion by using electrostatic experimental techniques

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### Abstract

In this work, the fog dispersion was evaluated through three different electrostatic experiments, as well as the environment impact in the *Epipremnum aureum* plants after being exposed to the electric field and to the ozone concentrations generated during these experiments. Fog dispersion was evaluated in function of the optical signal detection times in three sensors located to different heights inside of the fog chamber. Optical signal detection times were measured and analyzed using Python through the t-distribution probability to determine the reliability levels in the data. Electrostatic experiments were carried out applying positive corona discharges through different configurations of the passive electrodes, while that the environment impact in *Epipremnum aureum* plants was evaluated through the transpiration and the absorption spectrum in their leaves by using the LiCOR 6400XT system and the photoacoustic spectroscopy technique. The obtained results show that it is possible to disperse the fog applying positive corona discharges with reliability levels in the data of  $2.306\sigma$  (95%), and that it is possible to reduce the ozone concentrations, if a fan is used during the experiments. The results also show that the photosynthetic activity in the *Epipremnum aureum* plants were not affected during their exposition to the electric field and to the ozone concentrations generated during these experiments.

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**Keywords:** Absorption spectrum; Fog dispersion; LiCOR system; Photoacoustic spectroscopy technique; Positive corona discharge; Transpiration

### 1. Main text

Radiation fog is one of the different types of fog presents in the environment, which consists on a minute water droplets suspended near or above the earth surface that causes restriction in the visibility up to 100 m, so that several accidents occur due to the poor visibility according Croft and Ward also affecting the roads and the crops at the plantations, producing economic losses and interfering with the aerial, maritime and military operations. During

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the last years, many researches have tried to disperse it by using different techniques. Some of the most popular techniques to disperse the fog are: Selective Inverted Sink (SIS) technology (<http://www.frostprotection.com>) and Charged Particle Technique (CPT) by Frost et al. [1] by using corona discharges. The SIS technology consists in to remove the low and cold strata of the atmosphere where the radiation fog is formed by using pneumatic system and the CPT consists in to induce charge in the droplets of fog to disperse it by using corona discharges and electrostatic forces. The SIS technology has been implemented actually in Paraguay while that the CPT still is studied because even it does not exist an adequate system of fog dispersion. Sawant et al. [2] have employed negative corona discharges to disperse the fog; and although these systems of fog dispersion still do not have been successfully implemented in the natural fog, if it exists fog dispersion systems implemented in the environment employing the CPT, as the proposed system by Damak and Varanasi [3] to recollect fog water of electrostatic form or the developed system by Kwon [4] to disperse fog in the roads applying negative corona discharges and the electromagnetic field, among other. The implementation of these systems were possible, because of the fog exhibits an electrical behavior due to the ions present in its water droplets according the studies realized by Anisimov et al. [5] and to that the water droplets can be polarized due to the dipolar nature of the water molecule, so that, the application of the high electric fields into the fog allow to induce charge in its water droplets to disperse it electrostatically the fog. On the other hand, in the research realized by Pontiga et al. [6] was observed that the negative corona discharges minimize the ozone production compared with the positive corona discharges, so that the negative corona discharges are preferred to disperse the fog, because of that the ozone is highly polluting; nevertheless, Bataller-Venta et al. [7] studied the presence of ozone in fog conditions (low temperatures and high relative humidity) and determined, that the ozone under these conditions can be employed as a spermicide and as a sustainable alternative for the crop treatment. However, no system of fog dispersion has been implemented in the environment applying positive corona discharge. Therefore, the goal of this work was to evaluate the fog dispersion and its impact in the plant life of the *Epipremnum aureum* plants through positive corona discharges, measuring the average time of optical signal detection in three optical sensors inside of the chamber, as well as the leaves of these plants to obtain the transpiration and the absorption spectrum by means of the LiCOR system and the Photoacoustic Spectroscopy Technique (PST) according the methodology employed by Calderón et al. [8] and to evaluate if some change occurred in the photosynthetic activity of the plants according with Lincoln and Eduardo [9] and Squeo and León [10]. The obtained results show reliability levels in the data of  $2.306\sigma$  (95%) for the fog dispersion and suggesting us that the fog dispersion system evaluated in this work, it does not significant affect the plant life under the fog conditions considered, and that the fog dispersion is possible by using positive corona discharges with the experimental arrangement adequate.

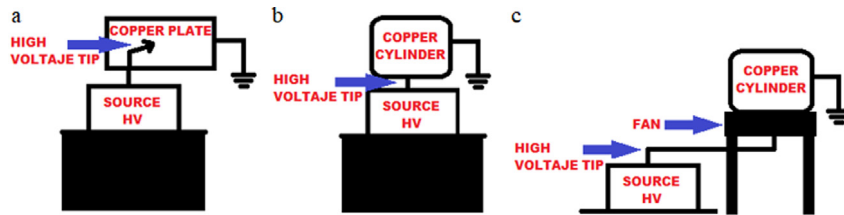
### 1.1. Experimental configuration for fog dispersion

In the early paper developed by Leal del Río et al. [11] was described the experimental fog chamber and the methodology used to evaluate the fog dispersion under the influence of electric field generated by the flyback transformer. The Table 1 shows the main operating characteristics inside of the chamber.

**Table 1.** Main operating characteristics inside of the experimental fog chamber.

Symbol	Constant	Value
$T$	Temperature (°C)	22.00
$RH$	Relative humidity (%)	99.98
$a$	Water steam droplet size ( $\mu\text{m}$ )	10.00
$V_o$	Applied voltage intensity (kV)	3.98
$v$	Water steam coming from ultrasonic humidifier (oz.)	2.36
$v_c$	Amount of condensed water by the fan (oz.)	0.45
$O_3$	Ozone concentrations (ppm)	0.02–0.05
$t_i$	Water steam filling time (min)	30
$t_f$	Natural water steam dispersion time (min)	30

The data of fog dispersion were obtained by using an electronic system designed for our own and analyzed through t-distribution probability to determine of the reliability levels by means of Python language. Data of interest were related with the optical sensor 2 and optical sensor 3, because these sensors are located closed at the surface of the chamber, where it is supposed that the radiation fog is formed inside of the chamber. Fig. 1 shows the



**Fig. 1.** Experimental configuration used to evaluate the fog electrostatic dispersion applying positive corona discharges for different configurations of passive electrodes at the height of the optical sensor number 2. (a) Experiment 1 using a copper plate (Exp1\_PC) as passive electrode; (b) Experiment 2 using a copper cylinder (Exp2\_CC) as passive electrode; (c) Experiment 3 using a copper cylinder in presence and in absence of a fan (Exp3\_CCF).

experimental configuration used to evaluate the fog electrostatic dispersion inside of the chamber at height of the optical sensor 2. Each configuration corresponds to a different experiment. In the first experiment (Fig. 1a), the corona discharge was performed between a copper plate tied to ground and high voltage tip, in the second experiment (Fig. 1b), the corona discharge was performed between a copper cylinder tied to ground and mounted above the high voltage source with a separation around 5 cm between both. The high voltage tip was fixed inside of the cylinder. Finally, the third experiment (Fig. 1c), was performed by a similar way to the second experiment, with a difference that the cylinder was mounted on a wood base at 32 cm from the bottom of the chamber and a fan fixed below of the cylinder. Each experiment was made in two parts: in the first part, the chamber was filled with steam water while that in the second part, the dispersion of the water steam was evaluated by registering the time of the optical signal detection for each sensor inside of the chamber. In all the experiments, eight trials were made with a total of the 874 data samples. During each experiment, the high voltage was applied (since the beginning until the end of the trial) to generate a continuous positive corona discharge between the electrodes (active and passive) and producing the greater number of ionized particles inside of the water steam. Variables as temperature, relative humidity, time (per sample) and voltage were registered on each trial for all the experiments. Also, a flyback transformer was used as the high voltage source for generating the positive corona discharge with a peak voltage of 3 kV. Each part of the experiment was completed in a half of an hour.

### 1.2. Determining of the reliability levels in the data

**Table 2.** Averages time of optical signal detection for each experiment of fog dispersion.

Experiment	Sensor 1		Sensor 2		Sensor 3	
	$X_1$	$\sigma_1$	$X_2$	$\sigma_2$	$X_3$	$\sigma_3$
Exp1_PC	239.75	165.71	249.88	33.00	977.12	283.38
Exp2_CC	144.50	85.85	315.25	38.61	734.12	154.50
Exp3_CCF	298.38	1115.14	111.87	80.70	469.25	172.88

For the analysis of the data, a population of sample means was obtained from the 874 samples of data recorded on each trial for each type of experiment. The size of the new sample of data was of eight for each experiment. T-distribution probability was used to determine the reliability levels, due to that the sample size of the data was less than 30. Values of mean ( $X$ ) and standard deviation ( $\sigma$ ) of the averages time of optical signal detection of the new population of data are showed in Table 2. Data of Table 2 were used to determine the reliability level in the experiments of fog dispersion, where it was obtained a reliability level of  $2.306 \sigma$  (95%) in the data. This analysis in the data were performed to validate the repeatability in the acquisition of data of the different experiments performed with the system of fog dispersion proposed in this work.

### 1.3. Measurements in the *Epipremnum aureum* plants

To evaluate if the electrostatic experiments had some negative impact in the plant life of the *Epipremnum aureum* plants, it was measured and analyzed the photoacoustic activity of these plants before and after being exposed to

the electric field and the ozone concentrations generated by the positive corona discharges inside of the chamber. The photoacoustic activity in the plants *Epipremnum aureum* plants was analyzed through the transpiration and the spectrum absorption by using the LiCOR 6400T system and the spectroscopy photoacoustic technique. For these experiments, the *Epipremnum aureum* plants were selected because of that they live in places where the temperature variate from 17 °C to 30 °C and they do not need to be exposed a lot a sun, so that these characteristics in general, were similar to the conditions inside of the chamber, which allowed us to evaluate the effect of the electrostatic experiments in these plants without they were affected by the experimental conditions inside of the chamber. For this analysis, the Exp2\_CC and the Exp3\_CCF experiments were selected.

To measure the transpiration, six *Epipremnum aureum* plants was selected and divided into three groups. First group (called Reference) was taken as reference for the Exp2\_CC and Exp3\_CCF experiments and was not exposed to the corona discharges generated inside of the chamber, while that the second (Group 2) and third (Group 3) group were taken as reference for the Exp2\_CC and Exp3\_CCF experiments and were exposed to the corona discharges generated for their own experimental configuration. The Exp1\_PC experiment was not considered for this analysis. For each plant of each group, three leaves were selected and measured with a sample size per leaf of 74 data, for a total of 1332 samples of data for all the considered plants groups. The measurement area was of two per two cm. Plant were monitored during 12 days after being exposed to the electric fields and the ozone concentrations generated for the corona discharges of each group. Exposition time of these plants to the experimental conditions was of 60 min. Plant were maintained in an indoor control environment with an amount of luminous flux between 200 and 600 lux, and a temperature between 22 °C. The photoacoustic spectroscopy technique was used to obtain the absorption spectrum in the plants. The absorption spectrum was measured in the plants for the same groups of the plants used for the analysis of the transpiration. This spectrum was measured in the visible spectrum in the range from 400 to 700 nm where the photosynthetic pigments are located. Each spectrum is formed by 600 points that corresponding to the amplitude of the absorption bands. For the experimental procedure, the following equipment were used: a xenon lamp of 700 W, a monochromator, a mechanical modulator (chopper) configured to 17 Hz, an optical fiber, C300 line cell, a lock-in amplifier and an acquisition system of data implemented in LabVIEW.

## 2. Results and discussions

The Fig. 2 shows the average times of optical signal detection for the fog electrostatic dispersion in each sensor. The optical signal was measured in function of the time for the water steam dispersion applying positive corona discharges for each experiment (see Fig. 1) inside of the chamber. When the positive corona discharge was generated in each experiment, a high electric field was generated near to the high voltage tip of the flyback transformer, the which accelerated any free electron toward the conductor, causing the productions of additional electrons, positive ions and photons upon impact with other particles near to them, generating heat and air dry in this region, which

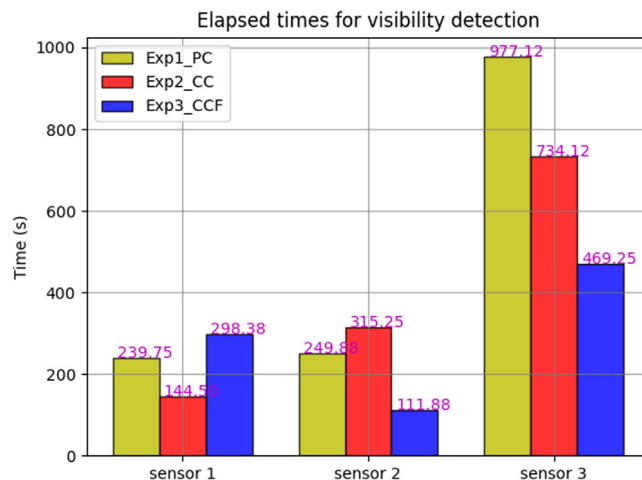
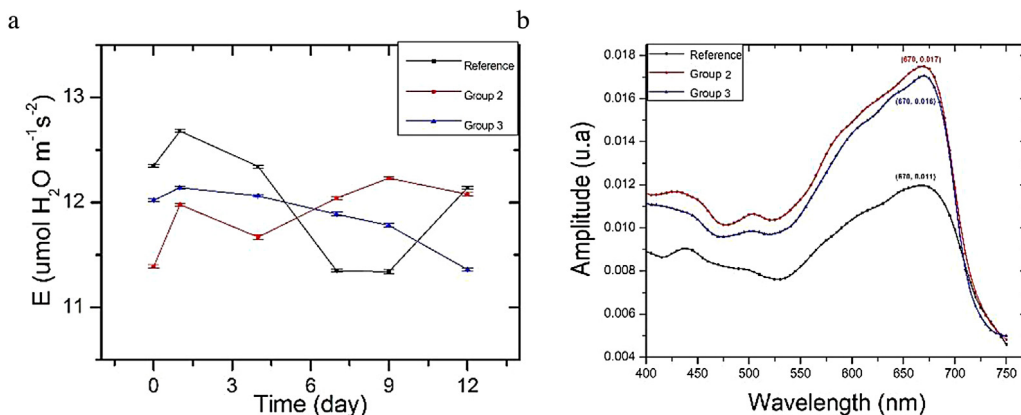


Fig. 2. Average times of optical signal detection in seconds in the fog electrostatic dispersion.

avored the ozone production. The energy present in the corona region, it is lost while flowing toward the water steam and the grounded collector as heat, while that the charged particles were transported into the fog by the flow of energy and by the fan (when this was used) forming a cloud of charged particles around of this region. So that, the fog was dispersed through the displacement of water droplets toward the walls and the grounded conductor inside of the chamber, because of the action of the electrostatic forces. The action of the gravitational force there was not much influence in the precipitation of the water droplets, due to that the electric field applied was not so high enough to produce larger droplets.

Fig. 2 shows that the registered Exp3\_CCF experiment the lower times of fog dispersion for the second and the third sensor compared with the other experiments, so that this experimental configuration was more efficient in the production of charged particles. Also, the ozone production was lower in this experiment than in the other experiments because of the action of the fan. Time in the first sensor is not very important for us, since the water steam inside of the chamber is not constant for this area. The results of Fig. 2 show that it possible to disperse the fog applying positive corona discharges with a low production of ozone, if a fan is used.



**Fig. 3.** Photosynthetic activity in the *Epipremnum aureum* plants. (a) Water molar concentration in function of the time for the variable of transpiration in each considered plants group. (b) Absorption spectrum evaluated in the visible range spectrum from 400 to 750 nm for each considered plants group.

The Fig. 3a shows the water molar concentration in function of the time for the each group of considered plants before (black circles) and after (blue squares, group 2 and red triangles, group 3) being exposed to the experimental conditions inside of the chamber. The obtained results show no significant variations in the transpiration for the plants of the group 2 and group 3 compared with the reference group, even though there is a decreasing tendency in this variable for the plants of the group 3, of agreement with Bataller-Venta et al. [7] and to the results shown in Fig. 3a, no significant change it was observed in the physiology of the considered plants that it indicate a change in the transpiration by dehydration and turgor because of experimental conditions inside of the chamber. The Fig. 3b shows the absorption spectrum in function of the time for each plants group measured by using the photoacoustic spectroscopy technique, where the black squares correspond to the reference group, the red circles to the group 2 and the blue triangles to the group 3, which represents the contribution of the photosynthetic pigments present in the plants for the visible range spectrum (400–750 nm) according Bidwell [12]. The three maximum peaks in the absorption spectrum of Fig. 3b correspond to the chlorophylls for each plants group. This absorption spectrum also shows that the photosynthetic activity in the *Epipremnum aureum* plants was not affected by the experimental conditions inside of the chamber because of there were not significant differences between the amplitude and the shape of the spectrum for each group of plants.

### 3. Conclusions

The obtained results shown that it is possible to disperse the fog applying positive corona discharges by means of proposed experimental arrangements in this paper (see Fig. 1). The electrostatic fog dispersion experiments carried out inside of the experimental fog chamber without used the fan, produced ozone molecules in concentrations from 0.02 to 0.05 ppm, because of that in the corona discharges region was produced and kept a zone of dry air due to the energy losses in form of heat, so that, when the fan was used, a continuous flow of water steam was



generated and passed through of corona discharge region, avoiding the formation of dry air and minimizing the ozone production through the displacement of the ionized particles inside of the artificially generated fog. The use of the fan also contributed to condense 0.45 oz. of water steam compared with the 2.36 oz. used to fill the chamber with the water steam. On the other hand, the variable of transpiration and the absorption spectrum measured on the leaves of the *Epipremnum aureum* plants, do not reveals significant changes in their physiology and in their photosynthetic activity, because of theirs exposition to the electric field and to the ozone concentrations generated during the experiments carried out inside of the chamber, so that, the proposed fog dispersion system in this work, does not significantly affected the plant life of the *Epipremnum aureum* plants under the considered experimental conditions.

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