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Development of automatically controlled corona plasma system for inactivation of pathogen in hydroponic cultivation medium of tomato

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ABSTRACT

A nutrient solution treatment system using corona plasma is developed for practical use in hydroponics. A gas-liquid separated reactor and a high voltage power supply based on a 20 kHz inverter neon-transformer are developed to archive the treatment with high energy efficiency, a low initial cost and a low running cost. The performance of the system on bacteria inactivation in the nutrient solution is evaluated in a continuous treatment system operation. The results show that the standard plate count for background microflora and *R. solanacearum* is drastically reduced by the plasma treatment and is not detected after 8 days treatment. The nutrient solution is decontaminated by 4 log cycle with plasma treatment under the continuous operation condition.

1. Introduction

Agricultural applications of electric field and plasma have been widely investigated and have become one of the most attractive research topics in plasma science [1–3]. Atmospheric pressure plasma can produce various types of chemical active species [4–6], which have various effects on the cell membrane of bacteria [7–9], biochemical activity of a living plant body [10] and chemical structure of organic compounds [11]. These effects contribute to germination enhancement [12], preservation of crops [13,14], plant growth enhancement [2], and increases in production of crops by improving the plant cultivation environment [15,16].

In recent years, hydroponics, which is the method of growing plants without soil using nutrient solution, has been widely used in agriculture [17,18]. In hydroponics, the nutrient solution is re-circulated in a closed system in order to reduce the cost and the environmental load. This re-circulation system can save up to 40% of fertilizer compared with other run-to-waste system [19], and has become popular for the high growth rate of vegetables and fruits in green house cultivations [19,20]. However, plant diseases caused by microbial contamination of the artificial nutrient solution rapidly spread in the circulation system and cause serious damage to the entire plant [21,22]. During the entire period of plant growth, contamination with pathogens can never be excluded, since the pathogens are introduced in the nutrient solution via the irrigation water supply, by air and directly from the grower [21]. Furthermore, if the nutrient solution contains undesirable organic compounds originate from the water and root exudates, the crop yield can also be seriously lost [23,24]. Therefore, the nutrient solution should be remedied by continuous water treatment system operation during the cultivation period.

The nutrient solution is commonly treated with conventional sterilization technologies such as heat treatment, ultraviolet exposure processing, and membrane filtration [25–27]. These methods have various limitations such as low oxidation power, high running cost and periodical cleaning maintenance. Discharge plasma in water has been attracting much attention as a promising technology for sterilization and environmental remediation in water [28,29]. The discharge plasma enables the instantaneous production of a non-thermal plasma which produces various chemical species, such as hydroxyl radicals and ozone. These chemical species play an important role in sterilization effect, [8,15,16,28,30] and the decomposition of organic compounds in the solution [29]. The discharges also produce nitric acid in the solution, which acts as a fertilizer and increases the plant growth rate [15,31,32]. Thus, the discharge plasma treatment has several advantages, however, a cost of discharge plasma system and its stability in continuous operation are a major obstacle in agricultural applications, which is still an open question. In this study, the novel nutrient solution treatment system using corona plasma is developed for practical use in hydroponics. The system is based on high-efficient gas-liquid separated reactor [29] with a compact and substantial high-voltage generator to

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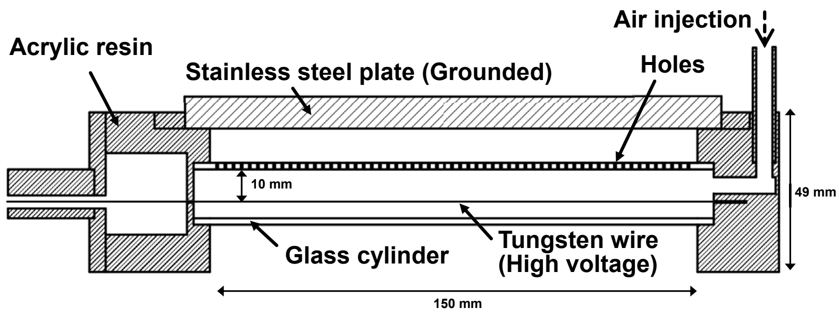
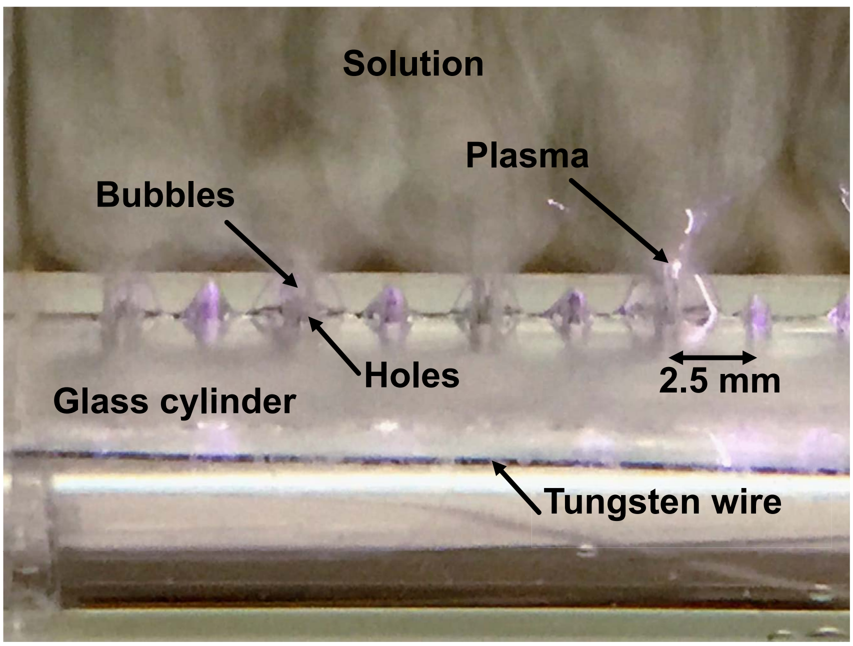


(a)



(b)

Fig. 1. (a) Schematics of the corona plasma reactor and (b) typical photograph taken with an exposure time of 1/30 s.

achieve a low cost and a long time stability treatment for practical use. The performance of the developed system on the sterilization effect is evaluated by counting the bacterial *Ralstonia solanacearum*, which is plant pathogenic bacterium, in the nutrient solution. The evaluation is performed with cultivating tomato plants in a greenhouse for approximately 5 month continuous operation.

2. Development of a water treatment system using corona plasma

2.1. Corona plasma reactor

Various types of plasma reactors for water treatment have been developed by many research groups, and their energy efficiency has been evaluated [33,34]. In general, the electrical conductivity of the nutrient solution is relatively high because of the high concentration of ionic nutrients such as nitrate ion dissolved into the solution [35]. The energy efficiency for water treatment using plasma discharge decreases with increasing conductivity of the solution, because of an increase in energy dissipation by the ohmic loss in the conductive solution, which does not contribute to the production of the chemical species [36,37]. To overcome this problem, gas–liquid separated reactors have been proposed [38,39]. The gas-liquid separated reactors consist of a high-voltage electrode surrounded by a gas layer to insulate from the surrounding solution and a grounded electrode immersed in the solution. In this study, the gas-liquid separated reactor with a wire electrode and a glass cylinder with many tiny holes is used to extend the corona plasma area and reduce the ohmic energy dissipation [16,38,39].

Fig. 1 (a) shows the schematics of the corona discharge reactor. The reactor consists of a tungsten wire with a diameter of 0.5 mm which is placed in an insulating glass cylinder with an outer diameter of 19 mm, and a stainless steel (SUS316) plate outside the cylinder outside. The tungsten wire and stainless steel plate are used as the high voltage and grounded electrodes, respectively. The distance between the wire electrode and the inside wall of the cylinder is approximately 10 mm. The reactor is immersed in the solution. Atmospheric air is injected into the cylinder using a gas pump with a gas flow rate of 15 L/min. The air is released though 60 holes of the cylinder. The hole diameter is approximately 0.5 mm and the distance between holes is 2.5 mm.

2.2. High voltage power supply

A high voltage is applied to the wire electrode in the cylinder to generate corona plasma in the gas phase area. After breakdown occurs, the plasma propagates from the wire electrode into the bubble [29,40] as shown in Fig. 1 (b). The size of the bubbles is measured by taking photographs using a high-speed camera (DegiMo, VCC-H1200) at frame rate of 1000 frames per second and is ranged from 4.7 to 5.2 mm. The size of the bubbles increases with increasing gas flow rate. The increase of the size of the bubbles affects the streamer development and increases yield of chemical species [39]. Moreover, increase of gas flow