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Design and construction of the experimental plasma water activation system

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HIGHLIGHTS

- The PAW activity is due to the plasma reactive species.
- Discharge time affect the PAW properties.
- PAW play an effective role in different fields, such as food industry, agriculture, and healthcare.
- By increment of the treatment time, Nitrite and nitrate concentrations of PAW are increased and pH is decreased.

ABSTRACT

Design, construction, and experimental investigation of the plasma water activation device have been presented in this article. In this design, one of the electrodes, which is plate ss316, is placed in water. The other electrode which is made from tungsten is placed inside a glass tube and immersed in water. Air is also blown into the water through a constant rate air pump of 5 $L.min^{-1}$. An AC power supply with voltage and current of 15 kV and 30 mA has been used to create plasma in water. The results of the analysis of nitrite, nitrate, and pH in three water samples that have been irradiated with plasma for 10, 20, and 30 minutes showed a very significant change compared to the control sample. The pH of PAW is drastically decreased with an increase in treatment time due to the formation of strong acids. Nitrite and nitrate concentrations of PAW are increased with an increase in treatment time.

KEYWORDS

Plasma activated water
Nitrite
Nitrate
pH

HISTORY

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1 Introduction

Freshwater is a scarce commodity that makes up only 2.5% of the earth's total water, and less than one percent of that amount can be readily available as terrestrial and surface water resources. At present, this vital commodity of life has been affected by population growth and overdevelopment, which has also led to the destruction of groundwater resources (Foster, 2017). According to available statistics, up to 10.6 billion cubic meters of surface water in Iran, including saline and brackish water. Also, despite the drought in recent decades, which has brought the country's water resources to a critical level, as well as the high need for water in agriculture and green space, much attention has been paid to the use of lower quality water resources. For example, one of these unconventional sources of water is gray water, which is effluent from household uses other than toilets (Pan et al., 2018). It is also important to develop new innovative strategies that are more effective and efficient in combating bacterial infections, with increasing concerns about the emergence of antibiotic-resistant bacteria in the health and food industries (Sakudo et al., 2019; Oh et al., 2017). Using plasma is a very cheap solution to this problem. The use of plasma technology is very effective in eliminating biological contaminants of water (fungi, bacteria, viruses). The method is simple: water is processed with electric plasma before it reaches its target. Plasma activated fluid (PAL), including PAW, is antibacterial against several microorganisms.

Previous studies showed that low-temperature plasmas can be used to generate plasma-activated water (PAW) by treating water under specific conditions, which has the

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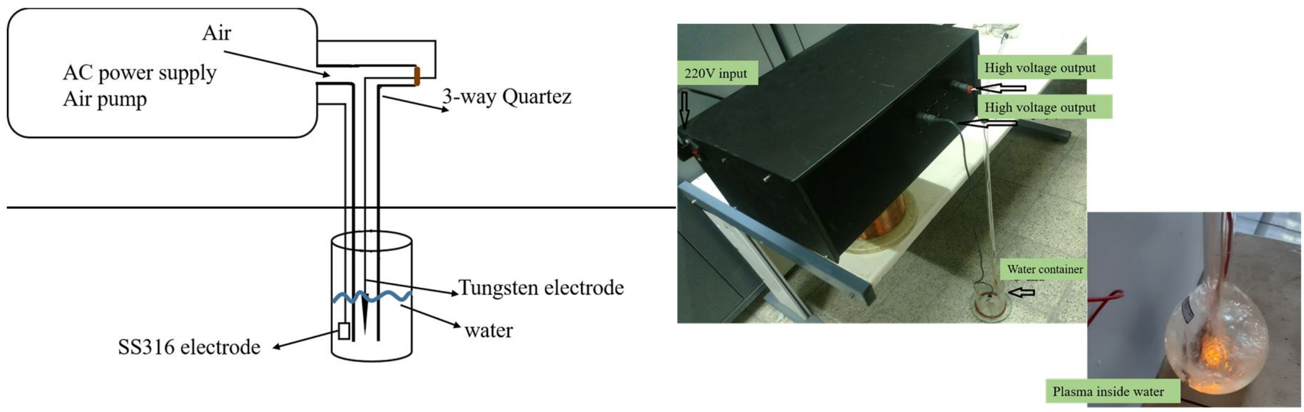

Figure 1: Left: Schematic diagram of PAW device. Right: experimental setup of PAW device.

capability of bacterial and fungi inactivation on contaminated solid surfaces or liquids (Bormashenko et al., 2012; Chen et al., 2018). Also, PAW can be used as fertilizer because it is a rich source of nitrogen oxide.

2 Experimental setup

2.1 Preparation of the materials

The fundamental method of generation of PAW involves operating a plasma generator inside the water to generate the ions, which lead to reactive species for bacterial inactivation (Soni et al., 2021).

The major components of the system included a high-voltage power supply, an air pump, and electrodes. Shematic diagram and the real picture of the experimental setup have been presented in Fig. 1. The device was specifically designed to activate water by inserting an electrode beneath the water's surface. The working gas for the plasma was normal air that was pumped by an air pump. Based on the preliminary study, the water volume, voltage, frequency, and airflow rate were set at 100 mL, 15 kV, 50 kHz, 30 mA, and 5 L.min^{-1}, respectively. Plasma-activated time was (10, 20, and 30 min). When plasma is applied to water-based liquids, it changes their characteristics (pH and electrical conductivity) and the resulting liquids are named as plasma-activated water (PAW) or plasma-activated liquid (PAL). After inactivation, the PAW was stored at room temperature.

3 Results and Discussion

Nitrite, nitrate, and pH levels of plasma-activated water have been measured. The results show that the production of plasma inside water along with aeration could significantly increase nitrite and nitrate and decreases pH as shown in Table 1.

Depending on the nature of the discharge gas, reactive oxygen species (ROS–ozone, O_3, H_2O_2, $^{\bullet}OH$) and reactive nitrogen species (RNS–ONOO–, NO_3–, NO_2–, and the corresponding acids, nitrogen oxides NO_x) are generated in the PAW (Thirumdas et al., 2018). After the treatment pH of the solution was measured using a pH meter.

Nitrite concentration in PAW was determined using standard USEPA diazotization method and absorbance was read by spectrophotometer at 507 nm (Punith et al., 2019). Nitrate concentrations were measured photometrically by using the Spectroquant nitrate assay kit (Merck Chemicals) adapted to a 96-well plate format, as described in (Tsoukou et al., 2020).

Table 1: pH, nitrate, and nitrite levels of plasma-activated water.

Water sample	pH	Nitrate (mg.kg^{-1})	Nitrite (μg.kg^{-1})
Untreated water	7.58	6.16 ± 0.31	10.12 ± 0.21
10 min	7.28	25.2 ± 0.9	30.56 ± 0.72
20 min	3.46	40.6 ± 1.3	45.5 ± 1.2
30 min	3.16	45.92 ± 1.33	52.32 ± 1.3

The pH value of PAW dropped significantly from 7.58 to 3.16 during 30 minutes of treatment as shown in Table 1, implying that the water has undergone acidification. The reactions taking place between the chemical species formed in the plasma and water result in acidification. In addition, it was known that acidic solutions are highly effective in bacterial inactivation (Soni et al., 2021). Several researchers have studied the impact of acidification to reduce bacterial colony formation (Lin et al., 2019; Soni et al., 2021; Chen et al., 2018). The results show that the concentration of nitrate increases with treatment time (Tabel 1). It is known that a solution containing a nitric ion with a pH below 4 to 5 is antimicrobial. Detection of nitrites and nitrates ions in the PAW is the main evidence for the formation of RNS. Besides ROS, reactive nitrogen species (RNS) such as nitrite and nitrate also play important role in bacteria inactivation. This solution would be a good candidate as fertilizer. Reactions between water gas-phase species lead to the formation of aqueous species like nitrite, nitrate, and hydrogen peroxide.

4 Conclusions

Design and construction of the plasma water activation device have been presented in this article. By creating plasma in water along with aeration, the amount of nitrate and nitrite increases significantly, and also the pH decreases. This solution can be used as fertilizer in agriculture and greenhouses and also as a disinfectant solution that can have many applications in agriculture, medicine, and daily life. Nitrate concentration of PAW increased from 6 for control to 25, 40, and 46 for 10, 20, and 30 minutes of treatment, respectively. The acidity of the solution along with generated ROS and RNS is central to its effectiveness in bacterial inactivation. This result suggests that PAW has suitable characteristics for the inactivation of bacteria and as a medium for the sterilization of medical devices.

Conflict of Interest

The authors declare no potential conflict of interest regarding the publication of this work.

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