Removal of Organic Dye by High-Voltage Pulsed Streamer Discharge in Gas Bubbling Water

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Abstract—This paper details how high-voltage pulsed discharge was generated in water with different types of bubbling gases as well as no gas in a reactor with a point-mesh electrode configuration. Acid orange 7 organic dye solution was treated as wastewater sample to elucidate chemical efficiency of bubbling gas types in discharge reactor. Experimental results showed that, oxygen bubbling gas effectively removed 84.35% of acid orange 7, while corresponding removal rates were 70.40%, 64.67%, 58.36% and 50.81% with argon, air, nitrogen and with no bubbling gas, respectively. Our research clarifies that chemical efficiency of the discharge reactor is significantly influenced by bubbling gases. A magnetic compression pulsed power modulator at 25kV, 100pps was used as a high voltage pulse source to initiate discharge in reactor.

Keywords—discharge, streamer, acid orange 7, oxygen, argon, air, nitrogen, bubble, Magnetic pulsed compression

I. INTRODUCTION

Water pollution occurring in tandem with rapid development of the textile industry and other such factories causes serious environmental problems. Different kinds of organic dyes of complex composition and strong biologic toxicity are synthesized subsequently producing dye wastewater [1-5]. Development of an advanced dye wastewater treatment method is very important to determine environmental pollution. Discharge plasma generated directly in water using high-voltage pulses is known as an effective waste water treatment method [6-10]. Discharge in the form of corona or streamer initiates dissociation and ionization of water molecules, forming various reactive species such as radicals (hydroxyl, atomic hydrogen and oxygen, etc.), ions and reactive molecules (hydrogen peroxide, ozone, etc.) [1-10].

In previous works, several common organic dyes such as acid orange 7 [2, 5-6], indigo [7], methyl orange [8], Chicago sky blue [8], direct red 79 [9], direct blue 106 [9] and basic blue [9] were treated using pulsed discharge in water. These studies confirmed that dye molecules breakdown due to the efficiency of OH radicals, O radicals, ozone [7, 9, 10] and dye removal rates increased with the addition of hydrogen peroxide in discharged water [8]. Li et al showed above 85% of dye removal is possible using TiO2 photocatalyst with streamer discharge [5]. Shen et al reported that acid orange 7 removal was higher for spark discharge (57.2%) than for streamer discharge (40.4%) and corona discharge (27.6%) [2].

The application of external bubbling gas in water can influence plasma chemical activity as well as the production of radicals or reactive molecules. In addition, bubbling gas in water lowers electric field required to initiate discharge, thus reducing electrode erosion, a common problem in the direct discharge method. Different bubbling gases are thus anticipated as a positive influence on the removal of organic dye from polluted water. Burlica et al evaluated effects of various gases (N2, O2, air and argon) on the removal of reactive blue 137 dye using GlidArc reactor, finding that degradation was higher for N2 and O2 gases [6]. Clements et al confirmed ozone production and removal of indigo dye with oxygen bubbling gas in a reactor, finding that removal increased with O2 gas flow rates [7].

In this work, we observed the removal of acid orange 7 organic dye using pulsed streamer discharge in bubbling water. Four different types of gases were used to generate bubble in water: air, nitrogen, oxygen and argon; also a no gas condition was evaluated. A point-mesh electrode configuration and a magnetic pulsed compression (MPC) pulsed power modulator at 25kV, 100pps were employed to generate discharge across electrodes in reactor. A non-conductive porous ceramic filter was used to generate bubbles in the presence of applied gases in water. The effects of bubbling gas on the chemical efficiency of the reactor were evaluated by treatment of acid orange 7 organic dye solution.

II. EXPERIMENTAL

A schematic of the experimental setup is shown in Fig. 1. A cylindrical glass jacket reactor (volume: 200 ml) filled with water solution was used as a discharge reactor. The initial concentration of acid orange 7 organic dye solution, was 20 mg/l (C9H4N2NaO5S, molecular weight: 350.32 g/mol) prepared from deionized water. Absorption spectra of dye solution were measured using a spectrophotometer (AMTOH, FL-2000, U-2900). A discharge sample of 3 ml was used to measure at the range of 200–800nm. The concentration of

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degraded dye was then determined at maximum peak of initial dye at 484 nm.

The solution conductivity was adjusted by mixing a desired amount of potassium chloride (KCl) with dye solution at 100µS/cm as measured by a conductivity tester (CD5021A, Custom). Four different gas types - air, nitrogen, oxygen and argon - were used as feeding gas; a ceramic filter (φ25x30mm) was used to generate bubbles in water. Bubble initial size was about 0.1mm, growing to 4-5mm before dispersing and finally collapsing. The flow rate of gas injection was 1.0 l/min at 0.2 MPa. A magnetic pulse compression pulsed power modulator was used as the high voltage source (Suematsu Elect. Co. Lt., Japan) to supply 25kV at 100Hz. Electrical measurement was performed using a digital oscilloscope (DPO4054B, Tektronix) with a high voltage probe (P6015A, Tektronix) and current monitor (model no. 3972, Pearson).

III. RESULTS AND DISCUSSION

Visualizations of discharge streamer propagation from the high voltage needle tip to water under (a) Oxygen bubbling gas and (b) no bubbling gas are shown in Fig 2. When the high-voltage pulse was applied across the electrodes, discharge initiated as a streamer from the needle tip and then propagated with good branching in water. There was no significant variation of discharge under the bubbling gas and no gas conditions. During propagation, streamer branches passed through bubbles. Fig. 3 shows typical waveforms of voltage and current during discharge under (a) oxygen bubbling gas and (b) no bubbling gas. The amplitude of current is seen to be a little higher and the pulse width is lower under the bubbling gas water than no bubbling gas condition. In order to evaluate effects of bubbling gases on the chemical efficiency of reactor, the removal of acid orange 7 organic dye was studied. This dye is characterized by an azo group consisting of two nitrogen atoms (-N=N-), which is very sensitive to OH radicals and ozone (O₃) [2-4]. Typical UV-visible absorption spectra of treated dye at oxygen bubbling gas in water are shown in Fig 4. The pulse was applied for 60 min. It is seen that the absorption spectra of acid orange 7 dye decreases with time in discharge water, where the absorbance peak is mainly around 484nm for azo double bond (N=N). The reduction of these peaks indicates the breakdown of azo double bond after pulse treatment.
Experimental results of dye removal rate using oxygen, argon, air, nitrogen and no bubbling gas are shown in Fig 5, where the removal rate was much faster for the case of oxygen bubbling gas than others.

It is suggested that the breakdown process of acid orange 7 mainly occurs due to direct action of OH radicals or ozone generated during discharge in solution. The possibility of the formation of O₃, OH and O radicals are higher during oxygen bubbling gas than others in water; subsequently, these radicals react with dye molecules to break them down. Respective removal ratio were 84.35%, 70.40%, 64.67%, 58.36% and 50.81% under oxygen, argon, air, nitrogen and at no bubbling gas. The study confirmed the byproducts of acid orange 7 dye after pulse treatment consist of acetic acid, p-benzoquinone, phenol, 2-naphthalone, coumarin, benzoic acid, phthalic anhydride [2-6].

IV. CONCLUSION

It can be concluded that, the removal rate of acid orange 7 is significantly influenced by the discharge of bubbling water. Production of radicals and reactive molecules are higher in the case of oxygen bubbling than for the others tested, argon, air, nitrogen and no bubbling gas. Therefore, the removal rate of dye was higher for oxygen bubbling gas and was reduced for others. It is seen that the removal rate is more than 50% in all conditions. Finally, it is clear that bubbling gas types are an important parameter of discharge reactors to improve chemical efficiency of waste water treatment methods.

REFERENCES


