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Discoloration of the solutions in the foaming environment

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The influence of electrical discharge on the discoloration of solution in the foaming apparatus was observed. The pure water or indigo blue solutions in various concentrations were used as substrate liquids. Foam was formed without the addition of foaming agents in the strict flow regime or with the addition of common surfactant. Performed measurements confirmed the presence of 40 mg/l hydrogen peroxide, OH radicals, dissolved ozone and gaseous ozone, which were generated by the electrical discharge.

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Key words: foaming column, electrical discharge within foam, removal of color

1 Introduction

Presently, the electrical discharges, which take place on the gas and liquid interphase (aerosols, bubbling systems), gain a lot of interest [1–4]. In this paper, the experiment of removal of indigo blue color by the electrical discharge within foam is reported. In the case of foam in the static state, foam drainage process was induced by the electrical discharge. Foam, in its dynamic flow state, consisting of the huge amount of gas in the liquid matrix might be formed with the addition of surface active components or without any foamable additives but in a strict and constant gas flow regime using the diffusers. The theoretical aspects of foam formation and drainage are already widely known [5, 6]. After first reports about the phenomenon of electrical discharge in foaming environment using the Blumlein pulse power source [7], the possible applications and advantages for environmental techniques were suggested [8]. The electrical discharge in the foaming column caused formation of various oxidants, which could be directly applied to treat pollutants in gaseous or liquid phase introduced to the reactor. Thus, it is possible to construct small, compact apparatus and to avoid loses of oxidants during the transportation process.

2 Experimental Setup

The main reactor of the foaming system, which is depicted in Fig. 1A, was a cylindrical, polyacrylate column ($D_{\mathrm{in}} = 50$ mm, $L = 200$ mm). A ceramic diffuser (type IA–500 of mainly aluminum oxide) was placed perpendicularly to the flow direction of media. The electrodes were located in homogenous foam zone, above the diffuser. The central electrode (stainless steel electrode, which was made of horse needle $d_{\mathrm{out}} = 1.5$ mm) was placed inside the inner electrode (stainless steel tube $d_{\mathrm{in}} = 40$ mm, $l = 30$ mm).

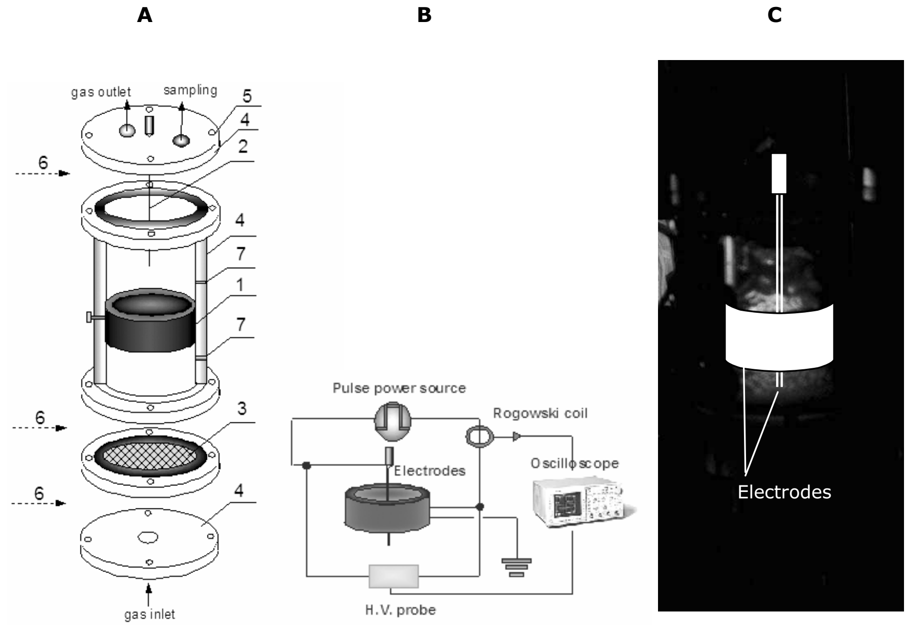

Fig. 1. (A) Cylindrical foaming column. 1,2– electrodes, 3–ceramic diffuser, 4–housing, 5–bolts, 6–orings, 7–foam level control. (B) The electrical circuit with commercial pulse power source. (C) The photograph of electrical discharge within foam.

The electrical circuit is shown in Fig. 1B. The commercial pulse power source was operated at variable frequencies (maximal pulse repetition rate 200 pps), pulse length was 100 ns. The central electrode was the high voltage one and the inner electrode was the grounded one. The discharge voltage and current were measured using the high voltage probe Tektronix: model P6015A and the Rogowski coil Pearson: model 110, respectively with an oscilloscope Tektronix: model TDS 350. The discharge pictures were taken using the digital camera Olympus Camedia X–2.

3 Results and discussion

Average diameter of the single bubble within foam ranged from 1 mm to 5 mm. The addition of surfactant increased the diameter of the bubbles and changed slightly their structure from spherical to polyhedral one. It was not possible to obtain totally uniform electrical discharge (Fig. 1C). The strong light emission took place at higher applied voltages. In the performed investigations 50 ml of substrate liquid was dosed. Liquid medium were pure water or pure water mixed with indigo blue. Initial concentration of indigo was 50 mg/l. Substrate gas was oxygen. Flow rate ranged from 1 l/min to 3 l/min. The presence of oxidants was measured. The hydrogen peroxide concentration was determined using Hydrogen Peroxide Test Kit (HACH, Model HYP–1). After 5 minutes of the electrical discharge application within foam generated in the batch reactor, the gas flow was cut off and the liquid remained after the foam decomposition was collected and analyzed. The hydrogen peroxide concentration in dependence on the pulse repetition rate is shown in Fig. 2A.

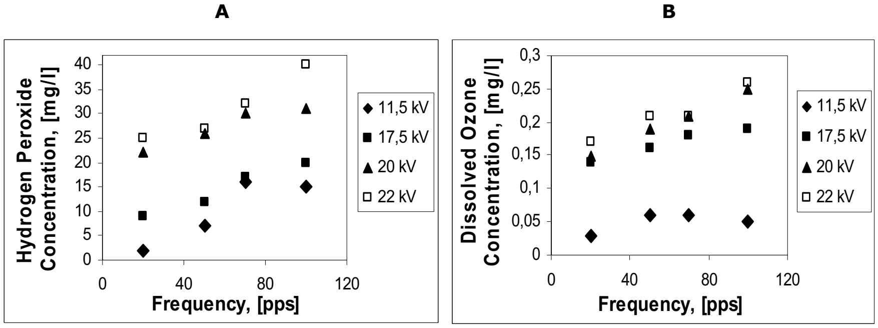

Fig. 2. Hydrogen peroxide concentration (A) and dissolved ozone concentration (B) in dependence on frequency.

The maximal obtained value without addition the surfactant ranged 40 mg/l. It rapidly decreased to about 12 mg/l when the surface active substance was dosed to improve foaming. Some of generated oxidants immediately took part in the decomposition process of the surfactant, thus dosing of such additives should be carefully considered even with the low gas flow rate or liquid with poor foamability. Further disadvantage is that surfactant should be added constantly. The by–products of its decomposition may eventually become the secondary pollutants so they should be precisely analyzed. Addition of surface active compounds would be reasonable if the purified medium consisted of a substance of hydrophobic nature and longer holdup within foam was required. The dissolved ozone concentration in the outlet gas was measured using the HACH spectrometer with the same sampling procedure as in the case of hydrogen peroxide. The maximal concentration for 22 kV of applied voltage and 100 Hz ranged 0,26 mg/l. The slight decrease in concentration was observed when the surfactant was introduced to the system. The concentrations of all oxidants increased with the increasing of applied voltage and frequency as it was expected. A Photonic Multichannel Analyser (Hammamatsu) connected to PC with PMA Windows software was used in order to take emission spectra of discharge within foam (Fig. 3.). Time exposure for the dimmer of the equipment's sensor was from 5 to 10 seconds. Sensor was located by the glass cover from the topside of apparatus. Emission bands of $\mathrm{OH}(\mathrm{A}^2\Sigma^+-\mathrm{X}^2\Pi)$ range from 300 to 335 nm. The $\mathrm{OH}(\mathrm{A}^2\Sigma^+)$ and $\mathrm{OH}(\mathrm{X}^2\Pi)$ radicals in the foaming conditions can be generated by the electron collisions with water molecules.

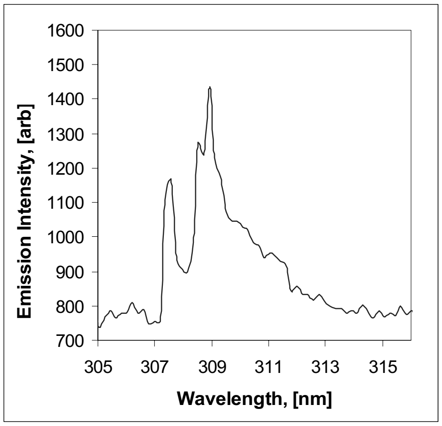

Fig. 3. The emission spectrum in foam. Substrate gas: oxygen, substrate liquid: pure water.

The experiments of removal of indigo blue with foaming systems were performed. The intensive blue color of indigo blue solutions appeared due to the complicated double bounded structure called chromophor (Fig. 4A). Color disappeared after decomposition of the indigo molecule onto the isatin and further onto more simple by–products.

The measurements of the UV absorption to confirm the indigo blue removal were performed using HACH spectrometer. The light absorption peak of indigo at the wavelength of 612 nm was analyzed. The indigo blue decomposition during the application of the electrical discharge within foam was observed also visually. The results of the experiment with decomposition of indigo blue in dependence on the gas flow rate, applied voltage and the discharge frequency are presented in Fig. 3 (B)–(D). The light emission peak decreased significantly with time. Increasing of the pulse repetition rate and of applied voltage (especially above 14 kV) caused the improvement of the treatment's effects till the occasional arc discharge occurred with the constant application of 150 pps. Dissolved and gaseous ozone had the main influence on the discoloration process and according to the literature data; H_2O_2 played just a minor role [9–11]. Visually, the full discoloration was observed after about 30 minutes of treatment.

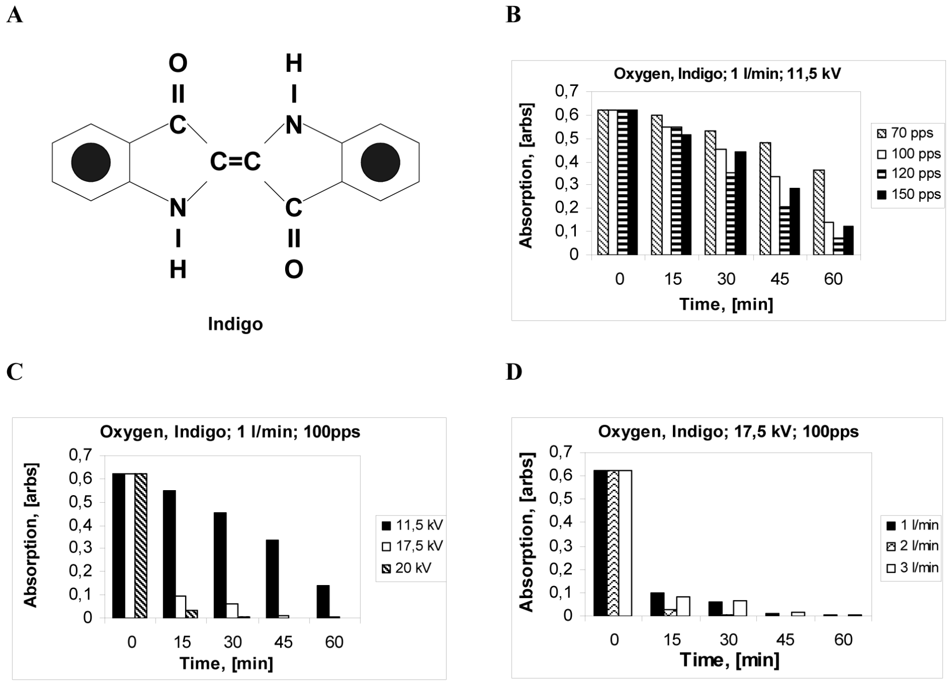

Fig. 4. (A) Chemical structure of indigo blue molecule. (B), (C), (D) The indigo blue decomposition versus time.

4 Conclusions

An apparatus based on the discharge in the foam was designed. Hydrogen peroxide, hydroxyl radicals, gaseous and dissolved ozone were generated in the same reaction vessel using the electrical discharge within foam. Indigo blue was relatively easily decomposed in the foaming environment. The higher amount of oxidants was formed and visually full removal of color was attained at the higher frequencies and applied voltages.

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