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FOAMING ENVIRONMENT- ANALYSIS OF ADVANTAGEOUS CONDITIONS FOR ADVANCED OXIDATION TECHNOLOGIES

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A b s t r a c t. In this paper the foaming system was presented. Foam was formed in a very strict gas flow conditions. The electrical discharge leaded to the oxidants formation. The low amount of gaseous and dissolved ozone was detected. The high concentration of hydrogen peroxide was measured. Presence of OH radicals was confirmed. The foaming system is an example of the modern AOT reactor with the expanded contact area between gaseous phase and thin liquid film.

K e y w o r d s: foaming system, discharge in foam, AOP, ozone, hydrogen peroxide, OH radicals.

INTRODUCTION

The necessity of the protection of natural environment requires more rigorous standards for the wastes treatment involving the development of new technologies of utilization.

The main way of the treatment using Advanced Oxidation Technologies (AOT) concentrated on the separate oxidants formation and then, on the sequential addition of generated substances to the polluted medium. Eventually, UV or electron beam treatment were the other steps besides chemical oxidation.

In this paper a foaming system was proposed. Despite of the small amount of water required, this system could be applied not only for the polluted gas treatment but also for the specific type of water and wastewater treatment. The electrical discharge might be applied directly in foam, partly consisted of pollutant. Foaming column became the various oxidants' generator and the reaction vessel in the same time. The losses of oxidants in the providing system could be reduced.

FOAMING SYSTEM

Foam itself belongs to a group of the colloidal structures. The properties of foam and the size of the bubbles depend on several factors, e.g. composition of the solution, eventual surfactant, eventual contaminants, method of foam formation and environment.

Foam can be easily created using the dispersion technique, with shaking or whipping liquid with gas, which is immiscible in that liquid. Without continuous flow such foam is decomposed in very short time. The increasing of liquid density or addition of surfactants to make the liquid layer more elastic and not so easy to break can slow down the decomposition process. To obtain the constant foaming phenomena, orifice or shelf techniques are applied.

Foams can be divided into two categories depending on the method of generation and its features [1]:

-Homogenous, (standing) foams,

-Pneumatic (dynamic) foams.

In the case of pneumatic foams, there is a certain gas velocity level beyond which steady sate height will not be attained.

Pneumatic foams are always in contact with the foaming solution; in the static foams there is a time lag before some liquid appears in the lowest part of the column.

Pure liquids cannot foam unless the foaming agent is added in case of typical static foams. An exception is pneumatic foam, which is very unstable and can be performed without the addition of any surfactants- using only the gas kinetic energy, keeping the strict conditions of the medium flow and using the diffusers in the apparatus of special construction. Co-current flow, where gas and liquid flow through the same diffuser's hole, was used in our case. It allowed for the appropriate inside-area usage [2].

The general rules concerning the flow and the apparatus-construction limits for the creation of foam environment are presented below [3]:

- Linear velocity of substrate gas for whole apparatus cross-section (V_C): 0.1-4.0 m s^{-1},
- Gas velocity in the diffuser hole (V_D): 10-20 m s^{-1},
- Diffuser's perforation level: 5-20% of whole shelf area.

EXPERIMENTAL APPARATUS

Experimental set-up consisted of the following sub-systems:

- Foam generation,

- Discharge generation,
- Data analysis.

Foam was generated in the main reactor called the foaming column, presented in Fig.1. The apparatus was constructed as a rectangular parallelepiped. The main dimensions were 365 mm (height) and 170 mm (length). Two porous, ceramic diffusers' shelves type IA-500 of mainly aluminium oxide were placed perpendicularly to the flow direction of media and parallely to each other in the housing. The electrodes were located in the homogenous foam zone, above the second diffuser. The plate-to-plate, needles-to-plate, alumina dielectric-to-plate and alumina dielectric-to-needles stainless steel electrodes were tested.

Pure water was used as a substrate liquid and air and oxygen as the substrate gases in the performed investigations.

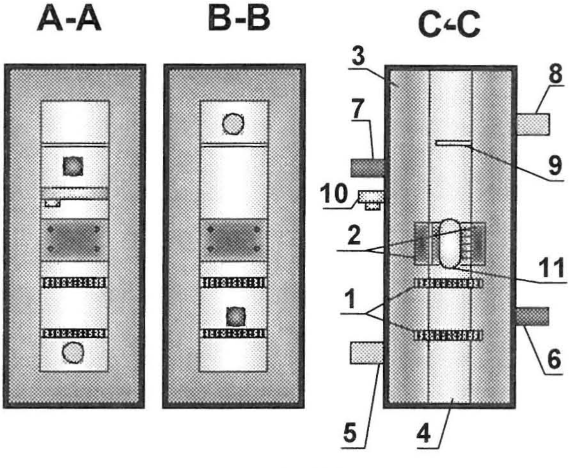


Fig. 1. Foaming column. (1-diffusers, 2-electrodes, 3-housing, 4-spacer, 5-gas inlet, 6-liquid inlet, 7-liquid outlet, 8-gas outlet, 9-drops' grabber).

The two-stages, 5 m length Blumlein pulse power source made from RG/8-U coaxial cable as a capacitance was used for the electrical discharge. Blumlein generator worked in a single shot mode or a repetition mode with 10 and 15 Hz repetition rate, regulated by an oscillator (Kenwood, AG-204D). The discharge was triggered by triggering system connected to the discharge gap switch and to Blumlein serially.

The discharge voltage and current were measured by the high voltage probe (Tektronix, model P6015A) and the Rogowski coil (Pearson, model 110) with the oscilloscope (Tektronix, model TDS 380), respectively.

The pictures of the discharge were taken by the ICCD camera (HAMAMATSU Photonics, PMA-11) with minimal shutter speed 10 ns and minimal duration time 50 ns.

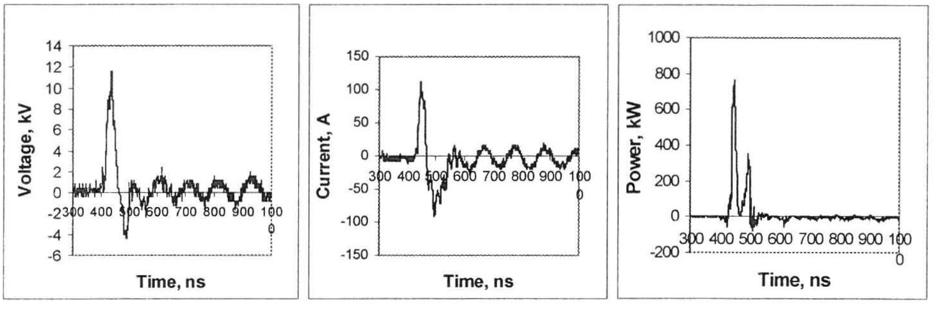
Spectroscopic measurements were performed to observe the generation of OH radicals. The hydrogen peroxide concentration was determined using Hydrogen Peroxide Test Kit (HACH, Model HYP-1). The standard titration method was used to determine the ozone concentration in the outlet gas. The dissolved ozone concentration was determined using a spectrophotometer (HACH, DR/4000) and indigo method in an acidic (pH=2.5) environment.

RESULTS AND DISCUSSION

It was noticed that too large and too small widths of diffuser and spacer had a negative influence on the foam formation and rather bubbling conditions occurred than foaming [4].

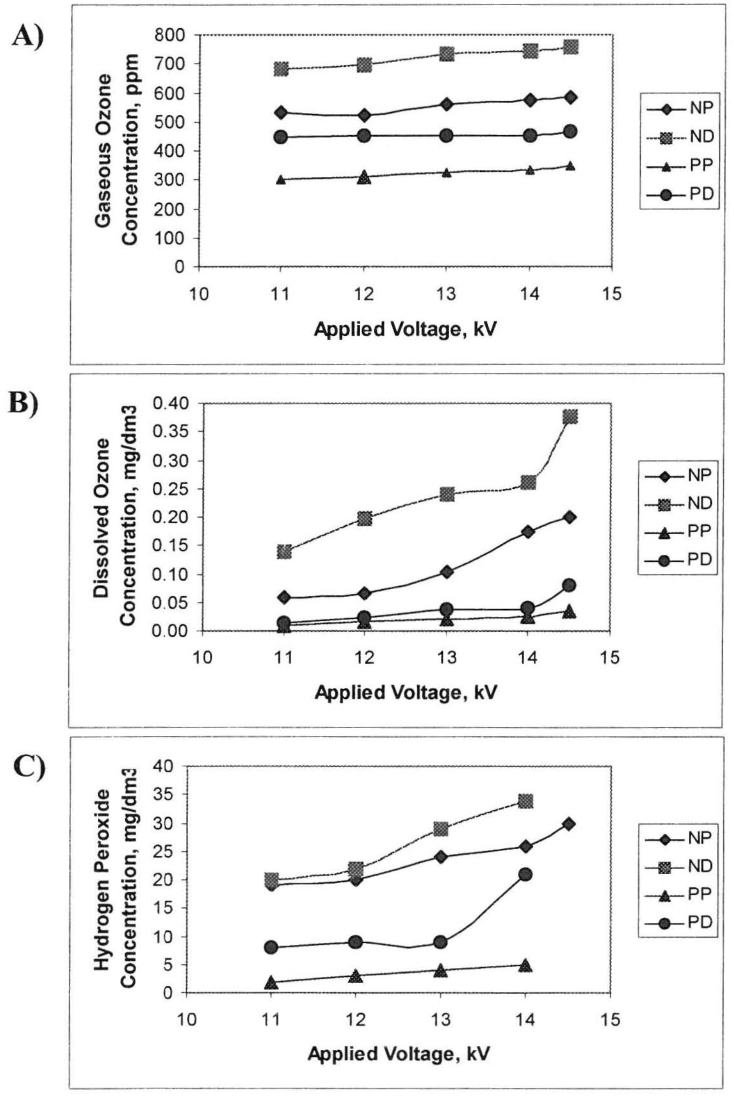
For the most ideal condition from the foam creation point of view, the diffuser's width should be decidedly wider than 5 mm. On the other hand, in too large diffuser's width it is difficult to achieve the expected foam level and higher gas flow rate must be applied to keep the foaming conditions. For this reason, in the further experiments 15 and 25 mm width spacers were used.

The visible discharge appeared at about 11-12 kV of applied voltage in not transparent, white color foam. In lower voltage some faint discharge proceeded what was confirmed by the low concentrations of oxidants. The discharges however, were not totally uniform in all mentioned cases. Typical applied voltage and current waveforms with calculated power for the most frequent quasi-arc discharge in the needle-to-metal plate electrode set-up are presented in Fig. 2.



Figs. 2. Electrical characteristics and absolute power of the discharges in needle-to-metal plate electrode set-ups. Airflow rate: 8 l/min, 14 kV of applied voltage.

The UV emission spectra from the discharge region, taken with argon and oxygen or air as a substrate gases and pure water as a substrate liquid of foam were captured using UV spectroscope. In both cases, some peaks corresponded to the OH radicals' emission were resolved around 313 nm. The emission intensity increased significantly with the increasing of applied voltage.



Figs. 3. The comparison of the oxidants concentrations obtained in the foaming system in dependence on applied voltage at constant 8 $dm^3\ min^{-1}$ oxygen flow rate. A) gaseous ozone, B) dissolved ozone, C) hydrogen peroxide.

The oxidant's concentration for H_2O_2, DO_3 and O_3 in dependence on the applied voltage was investigated for various electrode set-ups. The results of the absolute comparison during the test at constant velocity of 8 dm^3/min for various electrode set-ups are presented in Fig. 3. The following abbreviations were made for electrodes: NP for needles-to-metal plate electrode, ND for needles-to-dielectric covered metal plate electrode, PP for metal plate-to-metal plate electrode and PD for metal plate-to-dielectric covered metal plate electrode.

The dominance of efficiency in the needles-to-dielectric covered plate electrode was easily recognized.

CONCLUSIONS

A new technological solution based on the discharge in the foaming system was designed. Foam was created without the addition of foaming agents.

Quasi-arc discharge obtained in the humid environment was partly homogenous.

The formation of various oxidants such as gaseous ozone, dissolved ozone, hydroxyl radicals and hydrogen peroxide in the apparatus with needles-to-metal plate, needles-to-dielectric covered plate, metal plate-to-metal plate and metal plate-to-dielectric (alumina) plate set-ups were confirmed.

OH radicals were detected by the spectroscopic measurements in foam. High concentrations of hydrogen peroxide and low concentrations of gaseous and dissolved ozone were measured. The combination of various kinds of oxidants makes foam belong to the Advanced Oxidation Processes.

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FAZA PIANY – ANALIZA KORZYSTNYCH WARUNKÓW DO PRZEBIEGU ZAAWANSOWANYCH TECHNOLOGII UTLENIANIA

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S t r e s z c z e n i e. W pracy przedstawiono możliwości wykorzystania fazy piany w procesach AOT (zaawansowane techniki utleniania). Wyładowania elektryczne w pianie powodują powstawanie takich czynników utleniających jak ozon (niskie stężenie), nadtlenek wodoru (wysokie stężenie), rodniki OH. System pianowy jest przykładem nowoczesnego reaktora AOT z ułatwionym kontaktem fazy gazowej i cienkiej warstwy ciekłej.

S ł o w a k l u c z o w e : system pianowy, wyładowania w pianie, AOP, ozon, nadtlenek wodoru, rodniki OH.