Decomposition of Benzene with Periodic Excitation of Cavitation

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Abstract – For treatment of the benzene-containing wastewater, it is proposed to carry out their cavitation treatment in a cyclic mode. For periodic excitation of cavitation, the process of decomposition of benzene (both under adiabatic and under isothermal conditions) continues even during exposure to the medium.

Keywords – cavitation fields, benzene, decomposition, ultrasonic magnetostrictive emitter, periodic treatment.

Introduction

Industrial waste water from chemical and petrochemical enterprises contains aromatic compounds (both mono- and polycyclic) and their derivatives that exhibit carcinogenic, mutagenic and teratogenic properties, and therefore difficult to biodegradate by microorganisms. Therefore, the promising direction of the treatment of such sewage is the use of cavitation fields to generate high-level compounds [1] (hydroxyl, peroxide radicals, atomic Oxygen, oxygen, hydrogen peroxide, ozone, etc.), which are directly involved in the decomposition and oxidation processes of arenas and their derivatives.

The degree of transformation (mineralization) of arenas in the cavitation fields depends on the intensity of the development of cavitation phenomena, which, in turn, is determined by the technological parameters of the processing process (the values of pressure at the entrance to the cavitator, the temperature of the reaction medium, the frequency of its circulation, the pH value, the concentration of the pollutant), and structural features of cavitation generator (shape, size of cavity elements, their number and spatial configuration, etc.) [2, 3].

It has been established that the cavitation efficiency (the ratio of the mass of the pollutant destroying in the cavitation fields to the energy expended on the implementation of this process depends on the structural features of the sonochemical reactors (cavitation generators)) for the degree of destruction of toluene about 80% increases by 8 times (from $4{,}02\cdot10^{-3}$ to $32{,}2\cdot10^{-3}$ mg/J) in the transition from the device with openings to the vortex diode [4]. This is due to the fact that for the occurrence of cavitation in the vortex diode a much smaller pressure difference is required than in a device with openings.

An increase in the degree of transformation of benzene in cavitation fields at a temperature of 303 K from 73.8% to 84.2% was found during the transition from the stationary treatment regime (specific power of treatment - 68 kW/m^3) to the mode of initiation of the reaction (specific power of cavitation treatment - 22,7 kW/m^3). That is, initiating the process of sonolysis of water molecules allows to reduce energy costs for cavitational transformation of benzene at least 3 times while increasing the degree of its transformation [5]. At the same time, the rate constant of benzene decomposition in the mode of reaction initiation is 2.2 times higher than in the stationary mode (($17{,}4\cdot10^{-4}$ and $7{,}94\cdot10^{-4}$ s^{-1}, respectively).

The purpose of the research was to study the process of decomposition of benzene in the cyclic mode of excitation of cavitation.

Research Results

The cyclic mode of excitation of cavitation provides a periodic introduction of acoustic energy, which contributes to the periodic formation of radicals and, as a consequence,

prolongation of the decomposition and oxidation of benzene. Investigations with periodic excitations of cavitation were performed under adiabatic and isothermal (T = 298 K) conditions. The content of benzene in the system of imitation wastewater was determined by its maximum solubility in water under given conditions (temperature, pressure). An ultrasonic magnetostrictive emitter "Ultrasonic Disintegrator UD-20" with a frequency of 22 kHz was used to generate cavitation phenomena. The concentration of benzene in the immitate was determined by UV / Viz spectroscopy on the SPECORD M40 Carl Zeiss JENA two-beam spectrophotometer using a quartz cuvette in the thickness of 10 mm in the wavelength range 200-400 nm. The medium of comparison is distilled water.

In the case of the process of adiabatic conditions, depending on the concentration of benzene from time to time there are four areas with different angles of inclination (Fig. 1). Areas with a relatively large angle of inclination, that is, at which speed the process grew, correspond to periods when the cavitation was excited in the system. At these very periods there was a rise in temperature by 4.5 ... 5 K. A slight decrease in temperature in the periods of exposure to the solution is due to certain losses of heat in the environment. The process speed during cavitation is about twice as high as during exposure periods. Thus, in the I and III periods (excitation of cavitation), the rate of benzene decomposition is equal to $4{,}13 \cdot 10^{-3}$ and $3{,}13 \cdot 10^{-3}$ mol/(s·m^3), while during the exposure (periods II and IV) - $1{,}32 \cdot 10^{-3}$ and $1{,}63 \cdot 10^{-3}$ mol/(s·m^3). An increase in the rate of expansion of benzene in the IV period, as compared with II, that is, during exposure, can be explained by an increase in the temperature of the reaction medium to about 298 K [5].

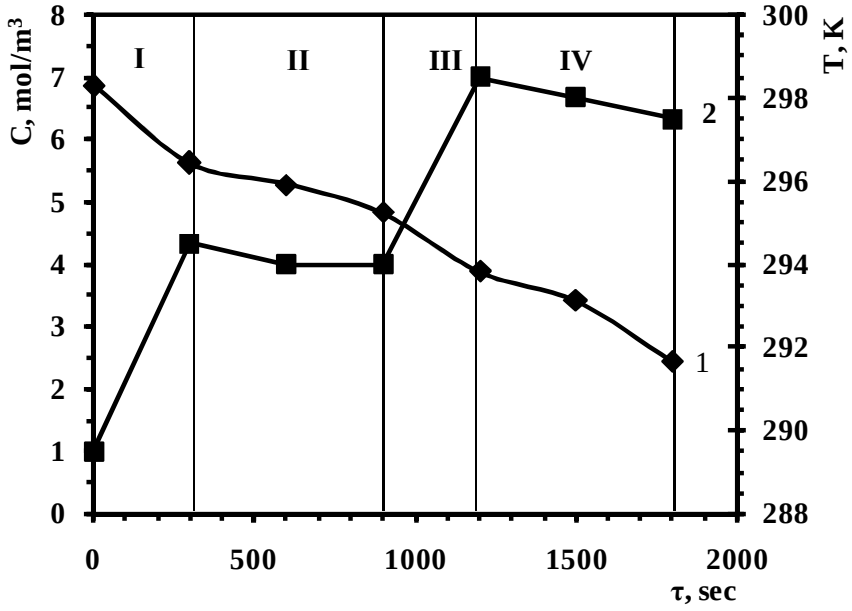

Fig.1. Dependence of benzene concentration (C, mol/m3) (1) and ambient temperature (T, K) (2) on time (τ, sec) under adiabatic conditions; periods: I, III - excitation of cavitation; II, IV - exposition of the environment

Within 30 minutes it was achieved the degree of conversion of benzene, which was 64.4%. The estimated duration of the process until the maximum permissible concentration of benzene is reached is 48 minutes. The comparatively small value of the degree of conversion and the rather long duration of the process, probably due to the fact that the process started at a rather low

temperature - 288 K. At this temperature, the value of the constant of speed is 6.3 times less than 303 K (for stationary mode).

In isothermal conditions at a temperature of 298 K (Fig. 2) in periods I and III (excitation of cavitation) the rate of the benzene decay is equal to $3{,}10 \cdot 10^{-3}$ and $0{,}77 \cdot 10^{-3}$ mol/(s·m^3), and under time of exposure (periods II and IV) - $6{,}40 \cdot 10^{-3}$ and $0{,}95 \cdot 10^{-3}$ mol/(s·m^3).

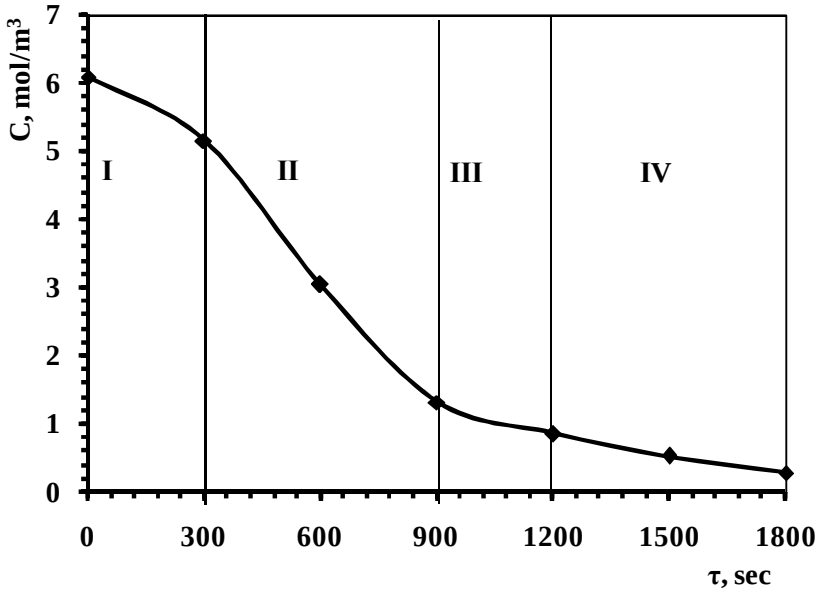

Fig. 2. Dependence of benzene concentration (C, mol/m3) on time (τ, sec) under isothermal (298 K) conditions; periods: I, III - excitation of cavitation; II, IV - exposition of the environment

The rate of expansion of benzene during exposure (period II) is almost twice as high as during the period of cavitation excitement (period I); in the fourth (exposure) period the speed is also greater (almost 20%) than during the cavitation (III period).

Obviously, the lower velocity of the process during the course of cavitation is due to the accumulation in the liquid of isothermal conditions of significant amounts of mechanically and diffusely stable bubbles that are split during the medium exposure (due to the pressure drop) with the formation of a large number of radicals that significantly intensify the process of benzene decomposition.

Conclusion

Consequently, for the periodic excitation of cavitation, the process of decomposition of benzene (both in adiabatic and in isothermal conditions) continues even during exposure to the medium. This indicates that the processes of decomposition and oxidation of benzene in cavitation fields are radical and occur in a chain mechanism.

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