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Application of accelerated electron beam and microwave irradiation to biological waste treatment

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Abstract

The comparative results obtained by applying separate electron beam (EB) irradiation, separate microwave (MW) heating and combined (successive and simultaneous) electron beam irradiation and microwave heating to reduction of viable cells of *Escherichia coli*, *Salmonella typhi*, *Staphylococcus intermedius*, *Pseudomonas aeruginosa*, and *Trichinella spiralis* are presented. The results of studies concerning the disinfection by separate and combined EB and MW irradiation of sewage sludge performed from a food industry wastewater treatment station (vegetable oil plant) are also presented. The research results demonstrated that the simultaneous EB and MW irradiation produces the biggest reduction of microorganisms.

Keywords: Electron beam; Microwaves; Sterilization; Microorganisms; Sewage sludge

1. Introduction

Electron beam and microwave treatments are two of the most interesting and emerging sterilization techniques [1]. The food residuals, plastics, paper, various organic materials and hospital wastes could be landfilled as municipal refuse after a suitable sterilization treatment. The electron beam process uses the Coulomb interaction of the accelerated electrons with atoms or molecules of the gases, liquids or solids. By this interaction ions, thermalized electrons, excited states and radicals are formed. The free radicals react with cell membranes, enzymes and nucleic acids to destroy microorganisms [2,3]. The microwave processing of materials is a relatively new technology that provides new approaches to improve the sterilization process compared with

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classical methods. The frequency range of microwave (300 MHz–300 GHz) corresponds to quantum energies ($W = hv$, where h is Planck's constant and v is the radiation frequency) which are small ($1.2\,\mu eV \leqslant W \leqslant 1.2\,meV$) as compared to that for ionizing radiation. Hence microwaves cannot interact with atoms by generating transitions between principal energy levels, e.g., between a base state and an excited state. Instead of this, microwaves couple to transitions within the hyperfine structure of the dynamical state. Hyperfine splitting of the principal energy levels may be due to the interaction of magnetic moments of the electron shell and of the nucleus [4]. The effect of microwaves is explained by their heating property on the polar or polarizable molecules of biological systems. Most reports suggest that for various microorganisms, the death rate is enhanced by microwave heating more than by conventional heating and the more intense the microwave electric field the more is the death rate enhancement [5–10]. A comparative analysis of the application of the electron beam irradiation and microwave heating to the sterilization process has led to the following main conclusions. Electron beam radiation processes are very effective for sterilization but the required radiation dose and the process cost are high. Also, the ionizing radiation requires expensive shielding and higher costs for maintenance. Microwave radiation processes are less effective for sterilization than electron beam processes but the cost of microwave systems is considerably smaller than ionizing radiation systems. Water is known to be a component of every biological system and a constituent present in most chemical processes. Due to the presence of water, both electron beam irradiation and microwave irradiation can enhance the microorganism's death rate. Thus, the irradiation by the electron beam of water produces radicals such as e^-_{aq}, OH^*, H^*, H^*_2, $H_2O^*_2$, OH^{-*}_{aq}, H_2O^* and O^{-*}_2. The fact that the interaction by the radicals is effective to a wide range of pollutants is one of the advantages of the electron beam irradiation. The various products formed during radiolysis of water may, in this way, influence directly or indirectly the chemical processes and biological effects occurring in the individual compounds dissolved in water. Because to the presence of water, which absorbs microwave energy very strongly due its exceptional polarizability, it is possible to pump vibrational modes of DNA leading to unwinding and strand separation.

The main idea of this work is to combine the sterilizing effects of both electron beams and microwaves on the survival of microorganism in order to reduce the required absorbed dose level and irradiation time to a minimum as well as to decrease the sterilization process costs. The combined effects of microwave (MW) heating with electron beam (EB) irradiation could decrease the average microwave power level while keeping the temperature increase as low as possible.

2. Experiment

Experiments were carried out using a system consisting mainly of the following units: an accelerated EB source of 6 MeV and 75 mA current peak intensity (ALIN-10 electron linear accelerator built in Romania), a 2.45 GHz MW source of controlled power up to 0.85 kW (2.45 GHz-MWS), and a specially designed irradiation chamber (IC). The irradiation chamber consists of a MW multimode cavity of $0.45\,m \times 0.245\,m \times 0.245\,m$ inner dimensions in which the ALIN-10 scanned EB is introduced perpendicular to its upper-end plate through a 100 μm thick aluminum foil while the MW power is coupled to one of its lateral walls via a slotted waveguide used as radiating antenna. The research comprised of the investigations on the influence of separate and combined EB and MW irradiation of the following biological materials: culture fluids of different microorganisms, guinea-pig muscle samples of 0.002 kg and sewage sludge samples of 10^{-4} m^3 performed from a food industry wastewater treatment station (vegetable oil plant). Culture fluids of four kinds of microorganisms were used: *Escherichia coli*, *Salmonella typhi*, *Staphylococcus intermedius* and *Pseudomonas aeruginosa*. 90 ml of nutrient broth fluid (solution of 0.037 kg powder of Brain Heart Infusion dissolved in 1000 ml distilled water) was inoculated with 1 ml culture fluid of *Escherichia coli*, *Salmonella typhi*, *Staphylococcus intermedius* or *Pseudomonas aeruginosa* and incubated at 37 °C for 24 h. After incubation,