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JIEC 3076 No. of Pages 10

ARTICLE IN PRESS

Journal of Industrial and Engineering Chemistry xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Journal of Industrial and Engineering Chemistry

journal homepage: www.elsevier.com/locate/jiec

Disinfection performance of adsorption using graphite adsorbent coupled with electrochemical regeneration for various microorganisms present in water

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ARTICLE INFO

Article history:
Received 20 March 2016
Received in revised form 4 August 2016
Accepted 3 September 2016
Available online xxx

Keywords:
Disinfection
Adsorption
Electrochemical regeneration
Graphite intercalation compound

ABSTRACT

The disinfection performance of the process of adsorption using a graphitic material combined with electrochemical regeneration for a range of microorganisms including bacteria, fungi, yeast and protozoa in a laboratory scale sequential batch reactor is demonstrated. The bacterial species studied were *Pseudomonas aeruginosa,Staphylococcus aureus* and *Legionella* pneumophila. A 3.0 $\log_{10}$ reduction in the concentration of *P. aeruginosa* cells was achieved with the adsorbent that was regenerated at 30 mA cm^{-2} with 100% regeneration on each adsorption cycle. The process was quite effective in removing *S. aureus* present in water with a significantly higher reduction in the number of cells (ca. 9-$\log_{10}$ reduction) at relatively low current density (10 mA cm^{-2}). Similarly, *L. pneumophila* were removed from water with a ca. 7.5-$\log_{10}$ reduction in the number of bacterial cells. The SEM images confirmed the adsorption of *L. pneumophila* onto the adsorbent and its electrochemical regeneration at 20 mA cm^{-2} that is considered a refractory pathogen against chlorination. The process was also found to be suitable for disinfecting fungal spores, *Aspergillus* awamori and yeasts including *Saccharomyces cerevisiae* and *Rhodosporidium turoloides* However, the removal of *Cryptosporidium parvum* from water was not demonstrated successfully. The preliminary results suggest that using a chloride free environment and a relatively high current density could be useful in disinfecting *C. parvum*.

Introduction

The purpose of disinfecting water is the elimination of pathogens that are responsible for waterborne diseases. Chlorination is the most commonly used chemical method of water disinfection which is effective for removing a range of microbial pathogens [1]. However, chlorine has been identified as a source of potentially toxic disinfection by-products. It reacts with several organic impurities in water and converts them into trihalomethanes and other halogenated hydrocarbons [2]. Furthermore, significant hazards are associated with the transport and storage of chlorine. In this context, alternative water disinfection technologies have been developed that include chemical and physical processes. Chemical methods employ disinfectants such as ozone [3], chlorine dioxide [4], bromine [5], iodine [6], copper [7] etc. Thermal treatment, ultraviolet irradiation [8], ultrasonication [9], pulsed electric fields irradiation [10] and reverse osmosis [11] are the major physical methods of water disinfection. Amongst physio-chemical systems including photocatalysis using titanium dioxide [12] and photodynamic disinfection [13], electrochemical disinfection of water [14] has emerged as a promising alternative to chlorine providing both primary and secondary disinfection.

Electrochemical disinfection has the potential to be developed as a cost effective and environmentally friendly alternative for the disinfection of water and wastewater [15]. During electrochemical disinfection, the water to be treated is passed through an electrolytic cell which is equipped with a set of electrodes. The

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http://dx.doi.org/10.1016/j.jiec.2016.09.009
1226-086X/

Please cite this article in press as: S.N. Hussain, et al., Disinfection performance of adsorption using graphite adsorbent coupled with electrochemical regeneration for various microorganisms present in water, J. Ind. Eng. Chem. (2016), http://dx.doi.org/10.1016/j.jiec.2016.09.009

effectiveness of the process depends upon cell configuration, electrode material, electrolyte composition, microorganism, water flow rate and current density [14]. One of the main advantages of electrochemical disinfection is the on-site production of disinfectants; thereby the common drawbacks of chlorination including transportation and storage of hazardous chemicals can be avoided [15]. On the other hand, the high cell voltages due to low electrical conductivity of water and the high capital cost are the main bottlenecks for electrochemical disinfection.

Electrochemical disinfection of bacteria adsorbed onto the surface of granular activated carbon (GAC) has already been evaluated [16]. The complete sterilization of the adsorbed bacteria could not be possible without having electrical contact for each GAC particle. However, after the adsorption of bacteria onto the surface of GAC, the electrical contact is disrupted by the formation of a bacterial film on the GAC surface. Greater disinfection could be achieved by utilizing more electrically conductive materials. It was, therefore, anticipated that graphite intercalation compound (GIC) would be effective for electrochemical disinfection as the conductivity of the GIC adsorbent bed has been shown to be over 13 times greater compared with powdered activated carbon [17]. Recently, the disinfection of water by a distinctive process of adsorption using graphite intercalation compound adsorbent with electrochemical treatment has been evaluated [18]. Adsorption of *Escherichia coli* on the GIC adsorbent was followed by electrochemical treatment under a range of experimental conditions in a sequential batch reactor. The adsorption of *E. coli* was found to be a fast process and about 8.5-$\log_{10}$ reduction of *E. coli* concentration was achieved. It was indicated that further work is required to evaluate the treatment of other pathogens including *Pseudomonas*, *Staphylococcus*, *Legionellla* and *Cryptosporidium*. Therefore, the present study is focused on the removal of a number of microorganisms including bacteria, fungi, algae and protozoa by the process of adsorption with electrochemical treatment using graphite intercalation compound.

Materials and methods

Adsorbent

The adsorbent used was an unexpanded graphite intercalation compound (GIC) in the form of flakes supplied by Arvia Technology Ltd., UK. The material was non-porous as indicated by Mercury porosimetry and therefore did not acquire internal surface area. However, the BET surface area of the particles was found to be around $1.0\,m^2\,g^{-1}$ by nitrogen adsorption technique. Laser diffraction (Mastersizer-2000, Malvern Instruments, UK) have indicated that the mean particle diameter of particles was around 480 μm.

All the chemicals used in this work were of analytical grades.

Microorganisms

Bacteria

Three bacteria including *Pseudomonas aeruginosa*, *Staphylococcus aureus* and *Legionella pneumophila* were studied in this work.

Pseudomonas aeruginosa: *Pseudomonas aeruginosa* (*P. aeruginosa*) is a gram-negative rod shaped free living bacterium that is ubiquitous in the environment [19]. It may cause a variety of infections including endocarditis, osteomyelitis, pneumonia, urinary tract and gastrointestinal infections [20]. *P. aeroginoas* is frequently found in natural waters including lakes and rivers. However, high concentrations of *P. aeruginosa* can also be found in swimming pools and hot tubs. This is due to the relatively high temperatures and aeration; both of these factors favour the growth *P. aeruginosa* [20]. Epidemics have also been reported from exposure to *P. aeruginosa* in swimming pools and water slides [21]. In addition, it has resistance to many antibiotics and disinfectants [22]. *P. aeruginosa* used in this work was obtained from School of Chemical Engineering and Analytical Sciences, The University of Manchester.

Staphylococcus aureus: *Staphylococcus aureus* (*S. aureus*) is a gram positive bacterium usually arranged in grape like irregular clusters. While it occurs widely in the environment, it is found mainly on skin and the mucous membranes of animals. *S. aureus* can be released into swimming pools, spa pools and other recreational waters by human contact. *S. aureus* is one of the main causes of pyogenic infections including boils, skin infections, abscesses, osteomyelities, septic arthritis, endocarditis and food poisoning [23]. *S. aureus* has been found to be more resistant to chlorination than *E. coli* or *P. aeruginosa* [23]. A culture of *S. aureus* (on nutrient agar plate) was obtained from the School of Chemical and Engineering and Analytical Science, University of Manchester, UK.

Legionella pneumophila: *Legionella pneumophila* (*L. pneumophila*) is a gram negative rod shaped bacterium. It is one of thewaterborne pathogens responsible for about 90% of all the cases of legionnaires, a fatal infectious disease [23]. It occurs naturally in rivers and lakes. However, *L. pneumoplila* also live in cold storage tanks, cooling towers, fire-fighting equipments and spa baths. Stagnant warm water provides an ideal environment for the growth of this bacterium [24]. Inhalation of contaminated aerosols formed by showers, air conditioning systems and cooling towers can spread the disease. Therefore, it is essential to eliminate *L. pneumophila* from water systems associated with public usage in order to prevent such outbreaks. *L. pneumophila* strain ATCC 33152 serogroup 1 was obtained from School of Pharmacy and Bimolecular Sciences, University of Brighton, UK.

Fungi

Fungi occupy a wide spectrum of habitats in animal and plant environments, and they are important both as harmful or useful microorganisms. They can contaminate foods and feeds [25]. By contrast, they are also frequently used in the fermentation industry for the production of organic acids, enzymes, vitamins, and antibiotics [26]. Therefore, water is not a primary route for acquiring human fungal infections. However, some fungi including *Fusarium* can produce toxic substance in water that are associated with a variety of respiratory, neurological and other systemic symptoms [27]. Low concentrations of some of the fungi present in raw water supplies can pass through both sand filtration and disinfection and thus can occur in drinking water leading to potential health problems [28]. In order to investigate whether adsorption using GIC adsorbents with electrochemical regeneration is effective in disinfecting fungal spores in water, *Aspergillus awamori* (*A. awamori*) was selected as a model species for water disinfection. A strain of *A. awamori* (2B. 361 U2/1) classified by the Commonwealth Mycological Institute as in the *Aspergillus niger* complex, was obtained from the School of Chemical Engineering and Analytical Science, University of Manchester, UK.

Yeast

Saccharomyces cerevisiae: In order to investigate the effectiveness of adsorption using GIC adsorbents with electrochemical regeneration to disinfect yeast in water, *S. cerevisiae* was selected since this species has been intensively studied as a model eukaryotic organism in microbiology. It was obtained from the School of Chemical Engineering and Analytical Science, University of Manchester, UK.

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