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Evaluation of process parameters of ultrasonic treatment of bacterial suspensions in a pilot scale water disinfection system

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ABSTRACT

In this study, several process parameters that may contribute to the efficiency of ultrasound disinfection are examined on a pilot scale water disinfection system that mimics realistic circumstances as encountered in an industrial environment. The main parameters of sonication are: (i) power; (ii) duration of treatment; (iii) volume of the treated sample. The specific energy (E_s) is an indicator of the intensity of the ultrasound treatment because it incorporates the transferred power, the duration of sonication and the treated volume. In this study, the importance of this parameter for the disinfection efficiency was assessed through changes in volume of treated water, water flow rate and electrical power of the ultrasonic reactor. In addition, the influences of the initial bacterial concentration on the disinfection efficiency were examined. The disinfection efficiency of the ultrasonic technique was scored on a homogenous and on a mixed bacterial culture suspended in water with two different types of ultrasonic reactors (Telsonic and Bandelin). This study demonstrates that specific energy, treatment time of water with ultrasound and number of passages through the ultrasonic reactor are crucial influential parameters of ultrasonic disinfection of contaminated water in a pilot scale water disinfection system. The promising results obtained in this study on a pilot scale water disinfection system indicate the possible application of ultrasound technology to reduce bacterial contamination in recirculating process water to an acceptable low level. However, the energy demand of the ultrasound equipment is rather high and therefore it may be advantageous to apply ultrasound in combination with another treatment.

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1. Introduction

A cooling tower is an important part of many industrial processes. In such a system, microbial growth can be substantial due to the presence of nutrients, high residence time, high ratio of surface area to volume, etc. A cooling tower furthermore provides ideal circumstances for microbial growth, because it provides air, heat and light [1]. This makes cooling water systems highly sensitive to fouling (biofilm) through the accumulation of microorganisms on piping and equipment surfaces. The major economic impact of biofilms in cooling water systems is through energy losses due to increased fluid frictional resistance and reduced heat transfer in power plant condensers and process heat exchangers. Biofilms accumulating on the surfaces of heat exchange tubes significantly reduce the heat transfer rate because the thermal conductivity of biofilms is significantly less compared to metal heat transfer surface materials [2].

A variety of chemical and physical techniques are routinely used for water disinfection including chlorination, ozonation and UV irradiation [3,4]. However, these disinfection methods suffer from severe drawbacks. Chemical techniques, like chlorination and ozonation, are often not environmental friendly. Chemical disinfection can lead to the formation of mutagenic and carcinogenic agents in the treated water. In addition to this formation of non-acceptable residual compounds, chemical methods are also limited by severe mass transfer limitations resulting into decreased disinfection rates [5]. Also, certain species of microorganisms produce colonies and spores, which agglomerate in spherical or large clusters. Chemical treatment may destroy the microorganisms on the surface of these clusters but leaves the innermost intact [6]. Furthermore, chlorination has been causing the appearance of resistant microorganisms [7]. The potency of certain physical techniques, such as UV irradiation, is limited in highly light

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scattering or absorbing solutions or when microorganisms are capable of photoreactivation (self-repair) [8,9]. Due to the inherent disadventages of traditional water disinfection techniques, there is still a need for alternative disinfection methods.

In this study, we investigated the potential of ultrasound as an alternative for more traditional techniques for the disinfection of water. Acoustic cavitation generated by ultrasound, offers potential as an effective tool for water disinfection [10–12]. Ultrasound is able to disinfect bacterial suspensions through a number of physical, mechanical and chemical effects arising from acoustic cavitation without the production of any hazardous by-product. Cavitation can be defined as the phenomenon of formation, growth and subsequent collapse of microbubbles occurring in an extremely small time interval (milliseconds). During the collapse of the microbubbles or so-called cavities, large amounts of energy are released. The local effects of the cavitation phenomena are described as generation of very high temperatures (of the order of 1000–5000 K) and pressures (100–50,000 bar) as well as release of free radicals due to pyrolysis of water [13]. In addition, ultrasound is capable of deagglomerating bacterial clusters or flocs.

The exact mechanism by which cavitation results in inactivation of the microorganisms has not been conclusively established. Nevertheless, it is recognized that the antimicrobial effect of ultrasound is caused by a combination of the following simultaneously acting mechanisms [5]: (1) Mechanical effects caused by the cavitation phenomena; (2) Chemical effects of cavitation phenomena including generation of active free radicals; (3) Heat effects, i.e. generation of local hot spots (condition of very high temperature and pressure locally). It has been generally observed that the mechanical effects are more responsible for the microbial disinfection and the chemical and heat effects play only a supporting role [14,15].

In spite of extensive research on laboratory scale and immense potential of ultrasound for water disinfection, there is hardly any research on an industrial scale [5,16]. In this study, several process parameters that may contribute to the efficiency of ultrasound disinfection are examined in pilot scale water disinfection system experiments. The influence of changes in specific acoustic power (kW L^{-1}), specific acoustic energy (kJ L^{-1}) and residence time in the ultrasonic reactor on the efficiency of ultrasonic treatment were assessed through changes in the volume of treated water, water flow rate and electrical power of the ultrasonic reactor. In addition, the effect of the initial bacterial concentration on the ultrasonic treatment efficiency and the operational cost of ultrasonic treatment were discussed. The effect of these process parameters were investigated on two different types of ultrasonic reactors, the Telsonic and the Bandelin ultrasonic reactor.

2. Materials and methods

2.1. Design and construction of the pilot scale water disinfection system

A pilot scale water disinfection system was constructed to asses the potential benefits of using ultrasound. This system consists of four subsystems each entailing one water container (maximal volume of 200 L), a pump (370 W), 100 m of piping, a disinfection unit, two ball valves and a rotameter (Figs. 1 and 2). The pumps are centrifugal pumps with a maximal flow rate of 5400 L/h. The flow rate to the disinfection unit was adjusted via a ball valve to between 60 and 1000 L/h. Through the bypass connection, water within each container is mixed.

Ultrasound was applied to water using two different commercially available ultrasonic technologies: (i) The Bandelin ultrasonic technology is a flow-through system with a reactor volume of 0.98 L and includes the Sonorex Technik Sonobloc (SB 5.1–1002) consisting out of a reactorbloc (rectangular pipe dimension: 80 (h) ×20 (w) ×750 (l) mm; material: stainless steel) (Fig. 3) and an ultrasonic generator (LG 1001 T). The system has a fixed frequency of 25 kHz, and a variable power output with a maximum of 1000 W (1020 W/l); (ii) The Telsonic ultrasonic technology (generator type SG-22-1000G, resonator type SRR 46/42-St, reactor type SRH 100/374 (diameter: 100 mm; material: stainless steel) (Fig. 4)) has a fixed frequency of 20 kHz, a variable power output between 700 and 1000 W, and a reactor volume of 2.28 L.

Two types of experiments were conducted. In the first type water passes only once through the disinfection unit (single-pass treatment). In these experiments, water is treated by pumping it from the container through the ultrasonic cell. After passage through the ultrasonic cell, the water is collected in another water basin and samples are taken for bacterial enumeration. The second type is a recirculation experiment (closed loop configuration) where the water is circulated continuously through the pilot scale water disinfection system during a period of 180 min. During the experiments, the water was pumped from the water container, through the disinfection unit and the piping system and was

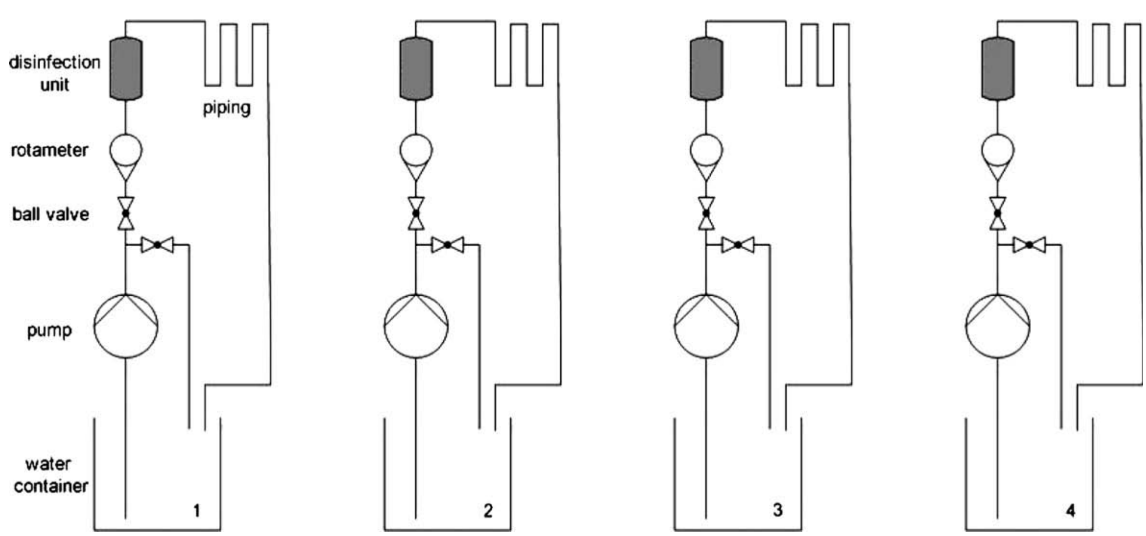

Fig. 1. General scheme of the pilot scale water disinfection system. This system consists of four subsystems each entailing one water container, a pump, 100 m of piping, a disinfection unit, two ball valves and a rotameter.

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