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Electrical sterilization of *Escherichia coli* by electrostatic atomization with a photo-chemical catalyst

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ABSTRACT

The inactivation of *Escherichia coli* (*E. coli*) was studied to find the optimal sterilization conditions using electrostatic atomization with a near ultraviolet light-emitting diode (near UV-LED) and TiO_2 nanofiber films. Three types of near UV-LEDs of different wavelengths (365 nm, 375 nm, 385 nm) were used in this investigation. In order to enhance the LED performances, TiO_2 nanofiber films were utilized for the production of a photo-chemical catalytic effect. In these studies, the flow rate condition of the *E. coli* mixture was varied from 2 ml/h to 10 ml/h for the purposes of measuring the capabilities of the proposed sterilization method. During these electrostatic atomization experiments, Each LED irradiated a TiO_2 nanofiber film and atomized *E. coli* mixture. The results of these experiments were compared with electrostatic atomization performed without the use of photo-chemical catalyst effects. The experimental result shows that the optimal sterilization effect of *E. coli* is 375 nm wavelength with a TiO_2 nanofiber employed during electrostatic atomization.

1. Introduction

In 1985, Matunaga et al. reported for the first time the microbiotical effect of the titanium dioxide (TiO_2) photo-catalytic reaction [1]. Huang et al. also reported the basic sterilization mechanism of *Escherichia coli* treated with TiO_2 and near UV light [2]. In this research TiO_2 is of interest because of it is highly active, photostable, non-toxic and of low cost. The principle is very simple. When TiO_2 is irradiated by UV light that has a higher energy than the TiO_2 band-gap energy, inter-band transitions result in the creation of electron-hole pairs. Excited electrons and created holes, which migrate to the TiO_2 surface generate superoxide anions radical ($O_2^{\bullet -}$) and hydroxyl radicals ($^{\bullet}OH$), respectively. Those strong oxidative radicals can decompose organic compounds and this is called the TiO_2 photo-catalyst effect [3]. Furthermore, many researchers have been interested in sterilization methods that are environment friendly and without secondary pollution [4,5].

In 2001, a new type of water sterilization method has been introduced by Lee et al. who demonstrated an electro-hydrodynamic approach to the inactivation of *E. coli* [6,7]. In Lee's experiments, an electrostatic spraying system is utilized for liquid atomization in order to inactive the *E. coli*. The electrostatic spraying system consists of a syringe, a high voltage DC power supply, a needle electrode and a ring electrode [8,9]. These experiments show that the electrostatic atomization mechanism can be used for sterilization in water treatment. In an electrostatic atomization mechanism, if sufficient charge is induced over the surface of the water drop during its separation, further atomization into finer droplets occurs due to an instability between the surface tension of the water, which acts to hold the separating drop together, and the repulsive force of the induced charge, and sometimes gravity, which act to break the separating drop apart. A droplet ionized and atomized by high voltage, as arises in electric-field water treatment, becomes electrically polarized whilst it moves from a needle electrode to a ring electrode. The atomized droplet is de-ionized when it passed through the ring electrode. This polarization phenomenon can be used to inactivate bacteria and, effective when supplied high voltage and had smaller droplet. These experiments demonstrate the survivability rate of *E. coli* as a function of variations in the supplied voltage and electrode conditions. However in these experiments, the flow rate must also be considered because of the use of a syringe system. The *E. coli* mixture flows from the high voltage needle to the harvesting dish.

The electrostatic spraying system has advantages for water sterilization such as being applicable under controllable water flow conditions and droplet size (controllable sterilization efficiency). Moreover, the surface area of the liquid increases rapidly during electrostatic atomization. If the UV sterilization method is applied

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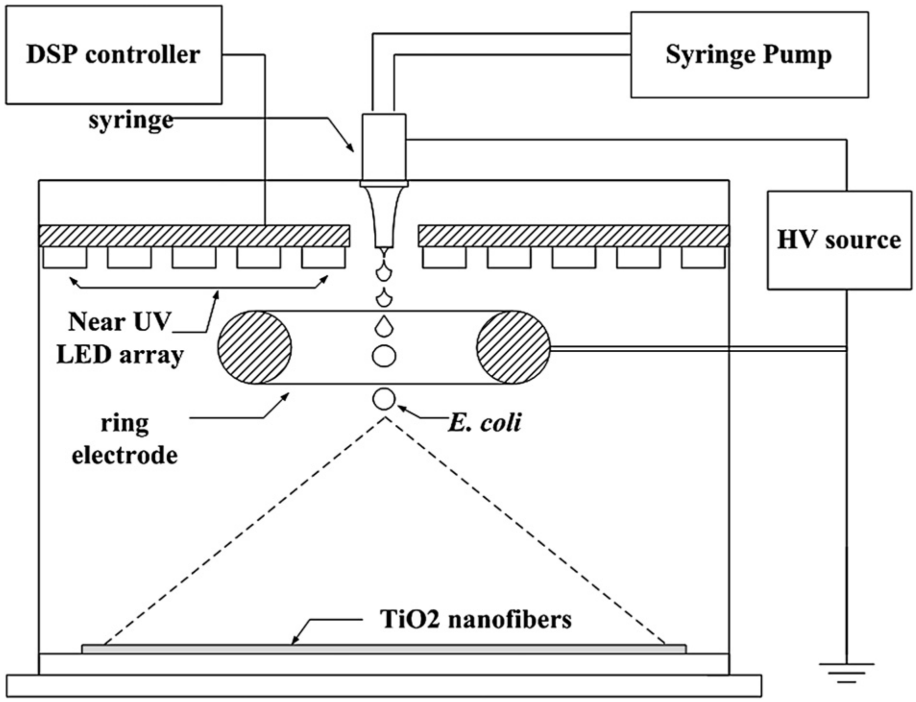

Fig. 1. Experimental apparatus for sterilizing *E. coli*.

with an electrostatic system, the sterilization efficiency will be increased. In this paper, the effect of the *E. coli* mixture flow rate on the efficiency of sterilization by electrostatic atomization, was considered During the experiments, three types of near UV-LED were used in the study of the enhancement of sterilization performance and their effectiveness was considered in terms of ease of applicability and economy of power consumption. TiO_2 ninofibers are also considered because of their photo-catalytic effect in the sterilization process.

2. Experiments

2.1. Electrostatic spinning procedure of the TiO_2 nanofiber films

The TiO_2 nanofiber film was prepared by an electrostatic spinning technique. The precursor solutions were prepared as follows. Initially, 1 ml of Titanium (IV) Isopropoxide was slowly added into 4 ml of ethanol under stirring followed by the addition of 0.5 ml of acetic acid. Finally 1 g of polyvinylidine pyrole (PVP) of molecular weight 120000 was added and stirred at 550 rpm by a magnetic stirrer (MS300TSD) for 45 min at 40 °C. These solutions for the production of an electrostatic spray were loaded into a syringe pump (KDS100, KD Scientific) and connected to a high voltage power supply. An electric potential of 13 kV was applied between the spray nozzle and the substrate over a collection distance of 15 cm. The diameter of the spray nozzle was 0.02 mm. The F-doped SnO_2 (FTO, 8 Ω/square, 50mmØ, Solaronix) were successively cleaned ultrasonically by acetone, ethanol and de-ionized water and were used as substrates to coat nanofiber TiO_2 thin films at a 0.1 ml/h flow rate. Finally, the film was left in the atmosphere for 12 h to complete the hydrolysis reaction and then annealed at 450 °C for 2 h at the heating rate of 2 °C/min.

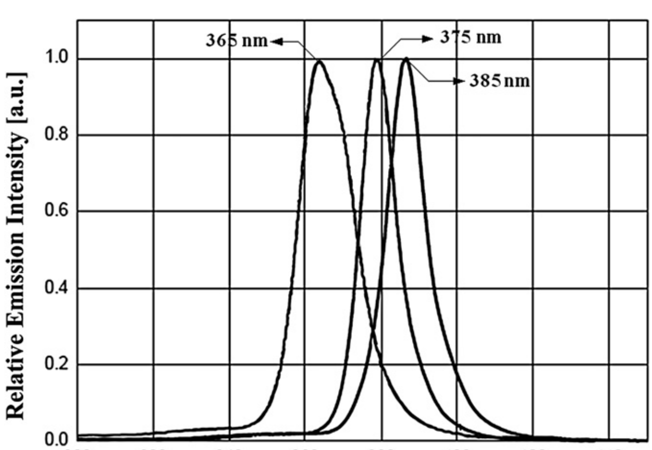

Fig. 2. Wavelength spectrum of the near UV-LEDs.

2.2. Artificial E. coli preparation

Water artificially contaminated by *E. coli* was used for this experimental investigation. The *E. coli* strain DH5α was cultured in a Luria-Bertani (LB) medium at 37 °C. The cultured DH5α *E. coli* has

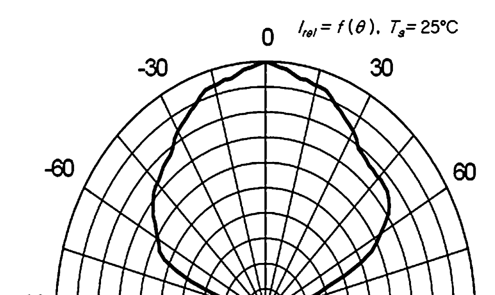

Fig. 3. Radiation characteristic of near UV-LEDs.