

Disinfection of *Escherichia Coli* in water using moderate electric and magnetic fields

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ABSTRACT

Bacteria play a key role in both human health and disease. One of the most prevalent harmful bacteria is *E. coli* which is responsible for several illnesses ranging from diarrhea, stomach cramp and fever. In this work we explore the application of moderate electric or magnetic fields for treating distilled and deionized water that is contaminated with *E. coli*. We found that moderate alternating current (AC) electric fields (10 V/cm to 1kV/cm) and moderate static magnetic fields (10 mT to 65 mT) can significantly inactivate *E. coli* by up to 90% or more. This provides the possibilities of developing a low cost and a practical bacteria inactivation technique using electric or magnetic fields.

Key words: bacterial inactivation, drinking water, electromagnetic fields, electroporation, *Escherichia coli*

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1. INTRODUCTION

Microbial contamination of food and water is globally considered to be a major health hazard (WHO, 2015). Waterborne pathogens include *Escherichia coli* (*E.coli*) bacteria (strain O157:H7) which has an infective dose as low as 10 colony forming units (CFU) (Greig, 2010). There are several techniques used for inactivating bacteria and other microbes from water. These include chemical processes such as chlorine disinfection, physical processes such as filtration, UV light treatment, thermal treatment, and the application of electric and magnetic fields (Collivignarelli *et al*, 2017; Johnstone, 1997). There is growing interest in the area of food science on the use of electric and magnetic fields in the decontamination or preservation of liquid food (Vega-Mercado *et al*, 1997; Barbosa-Canovas *et al* 1999; Barbosa-Canovas *et al* and Zhang, 2001; Oziemblowski and Kopec, 2005). There is also a similar interest in the field of medicine to use electric and/or magnetic fields to increase the efficacy of antibiotics against pathogens (Shawki and Gaballah, 2015; Kermanshahi and Sailani, 2005).

Previous studies have shown that (Giladi *et al*, 2008; Yadollahpour *et al*, 2014) there are three main factors that influence the destruction of microbes by electric and/or magnetic fields: (i) physiochemical properties of the media (pH, ionic strength, conductivity, and ambient temperature), (ii) microbial characteristics (microbe type, growth stage, and microbe load), and (iii) properties of the applied electromagnetic (E/M) field (field intensity, frequency of field, and exposure time). For electric fields, another contributing factor is the type of electrodes, whether the electrodes are insulated or not. Low intensity electric fields (less than 10 V/cm) or low magnetic fields (less than 1 mT) inhibit microbial growth and cell division processes through electro-phoresis or magneto-phoresis whereby the cellular ions or charged organelles are forced to flow and align in certain directions (Shawki and Gaballah, 2015; Giladi *et al*, 2008). Moderate electric fields (10 V/cm to 1 kV/cm) or moderate magnetic fields (1mT to 1T) have been found to increase the permeability of the cell membrane (Pillet *et al*, 2016; Trainito, 2015; Puc *et al*, 2004; Gaynor and Bodger, 1995;

Filipic *et al*, 2012; Fojt, 2004). The increased permeabilization affects ion transport into the cells and thus can lead to the loss of viability. When the permeabilization is driven by electric (magnetic) fields, the process is called electroporation (magnetoporation), respectively (Eynard *et al*, 1988; and Rems and Miklavcic, 2016). Electroporation or magnetoporation becomes irreversible at high electric fields (> tens of kV/cm) or high magnetic fields (> 1T). This process explains significant inactivation of bacteria in high electromagnetic fields. For example, (Johnstone and Bodger, 1997) found that the direct current (DC) electric field (about 30 kV/cm) completely inactivates *E. coli* inoculated in deionized water within an exposure time of less 17 ms. AC electric fields at the same intensity reduced the bacteria count by three orders of magnitude from an initial viable bacteria load of $10^5 - 10^6$ cells per cm^3 .

This work investigates the effects and limits of moderate AC electric fields and static magnetic fields on the survival of *E. coli* in deionized water. Our objective is to develop a low cost and practical technique for drinking water disinfection. Previous studies on the use of moderate intensity electric fields were performed with the *E. coli* in liquid foods Vega-Mercado *et al*, 1997) and also with focus on the effects of frequency of AC fields (Giladi *et al*, 2008) . The inhibitory effects of static magnetic fields were found in *E. coli* in a urine sample (Mousavian-Roshanzamir, 2017).

2. MATERIALS AND METHODS

For the study *E. coli* strain O157:H7 ATCC 35150 pellets were purchased from the American Type Culture Collection (ATCC) company. Bacteria were cultured in eosin methylene blue agar. To obtain a uniform *E. coli* suspension, 0.15 g of *E. coli* concentrate was dissolved in 250 mL of distilled and deionized water. 100 mL of this solution was poured in a beaker and two carbon electrodes were placed inside it on opposite sides (Fig.1). Another 100 mL of this solution was retained as a control. The temperature of both treated and control samples was maintained at $23 \pm 1^\circ\text{C}$. To study the inhibition /growth rate of the *E. coli* in the presence of applied electric and/or magnetic fields, the following procedure was carried out.

2.1 Alternating (AC) electric field

The electrodes were connected to an alternating voltage source as shown in Fig. 1. The AC voltage at a frequency of 50 Hz, was increased from 5.0 V to 50.0 V in steps of 5.0 V. For each voltage applied, the *E. coli* suspension was exposed to the electric field for a period of one hour and the *E. coli* colony count was measured. Thereafter the time interval was increased in steps of one hour up to a maximum period of eight hours and the colony count was done for each voltage. The colony count enumeration was performed using the Colisure test at the Eswatini Water Services Corporation laboratory in Mbabane, Eswatini. This is an ISO 17025 accredited laboratory. The influence of the E/M fields we obtained from calculating the change in *E. coli* count that is defined by the following ratio:

$$(N_t - N_c)/N_c \quad (1)$$

where N_t and N_c represent the number of the *E. coli* colonies in the treated sample and control sample, respectively.

2.2 Static magnetic field

The procedure is similar to one applied in the AC electric field experiment (Section 2.1) but the count rate was measured against static magnetic field strength. The data obtained were: (a) colony count versus magnetic field strength for a fixed time interval (2 h) and (b) colony count versus time of exposure for a fixed magnetic field strength (65 mT).

3. RESULTS AND DISCUSSIONS

Variation of *E. coli* count with applied AC electric field for 2 hours is shown in Fig. 2. For AC electric fields with strength between 11 V/cm to 1.1 kV/cm, the bacteria inactivation of 25% to 100% observed. An extremely high decrease in bacteria count was obtained at the lower electric field intensity of 11 V/cm, though these results also depend on the exposure time. For example, at the electric field intensity of 1 kV/cm, decrease in the bacteria count was at least 50% or more for exposure time of above six and half hours as shown in Fig. 2. The effectiveness of electric field of lower intensities, in our study, can be attributed to the electro-mechanical effect that

is dependent on the conductivity of the medium (Shawki and Gaballah, 2015; Giladi et al, 2008). Higher electric field intensities can lead to Joule heating effect (Lee et al, 2012) that can affect the bacteria deactivation mechanism.

Variation of *E. coli* count in a sample exposed to various static magnetic fields for two hours is shown in Fig. 3. Again, our results show that magnetic fields between 10 mT and 65 mT have an inhibitory effect on *E. coli*. The maximum reduction in bacteria count occurred

at 60 mT with the count declining by 77%. We found that for exposure time greater than one hour, the bacteria count declined by between 40% and 90% at 65 mT limit as shown in Fig. 3. Our results indicate an insignificant decline in the bacteria count for magnetic fields at 20 mT and 30 mT. However, in a recent study (Mousavian-Roshanzamir et al 2017) found that a static magnetic field (20 mT) produced a significant decline in survival rate of *E. coli* bacteria in urine samples. This conflicting evidence might be a result of the different physiochemical properties of the media .

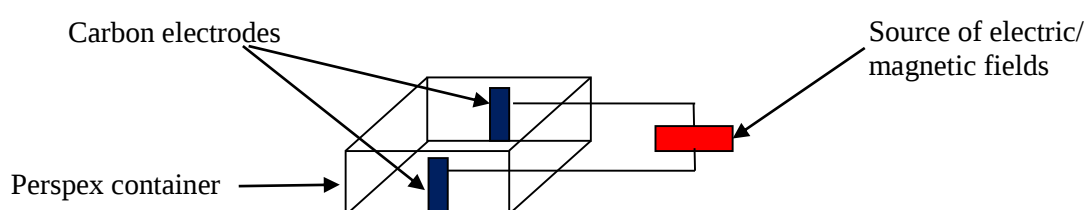


Fig. 1. Schematic diagram of the experimental setup.

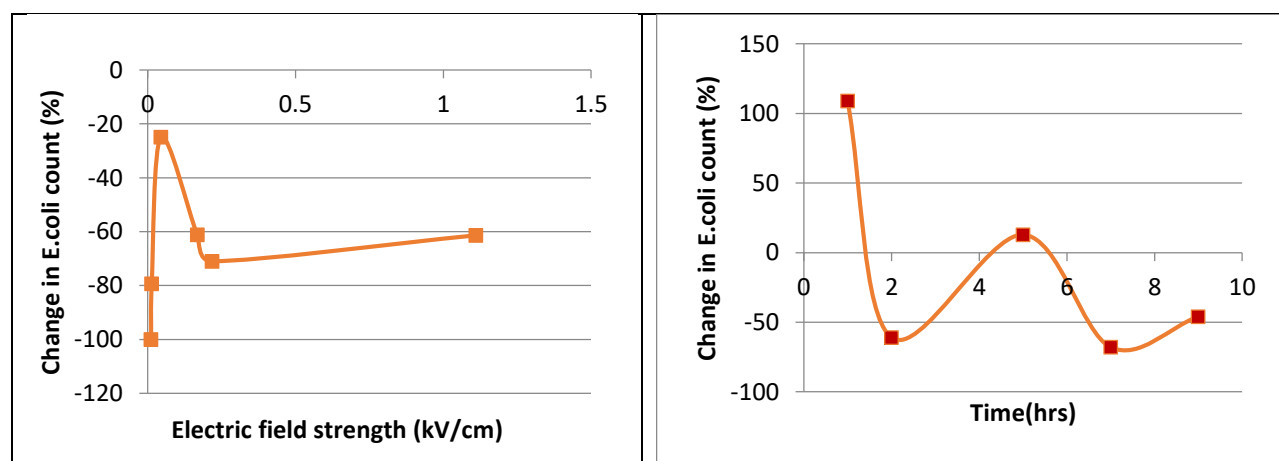


Figure 2: The change in *E. coli* bacteria count (Vs.) exposed AC electric field for 2 hours (left panel). The electric field applied ranged from 0.011 to 1.1 kV/cm. Changes in *E. coli* bacteria count in a sample exposed in AC electric field (1 kV/cm) for different exposure periods (right panel).

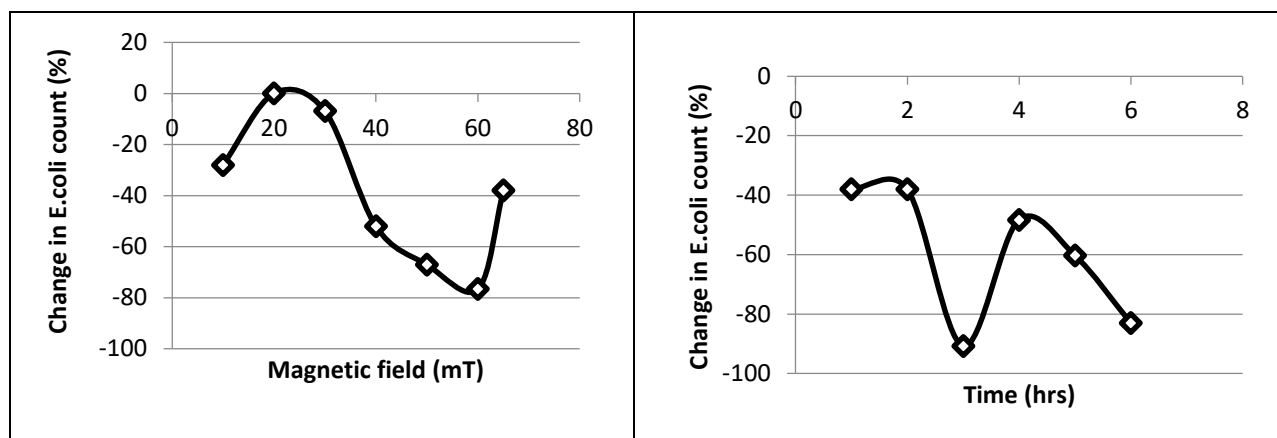


Figure 3: The change in *E. coli* bacteria count exposed to static magnetic fields for 2 hours (left panel). Changes in *E. coli* bacteria count in a sample exposed to a static magnetic field (65 mT) for different exposure periods (right panel).

4. CONCLUSIONS

In summary, the results obtained in this study show that exposing distilled and deionized water contaminated with *E. coli* bacteria to moderate AC electric or moderate static magnetic fields leads to the decline in bacteria count. While previous studies have shown that a high intensity electric field may be more effective as a decontamination of liquid foods, moderate fields are more practical for developing domestic disinfection devices.

It is suggested that more elaborate studies, both on the experimental and theoretical aspects of the subject are needed, placing emphasis on the importance of an ion-free environment for the microorganisms.

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