Fresh water disinfection by pulsed low electric field

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Fresh water disinfection by pulsed low electric field

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Abstract. In this paper, we describe a pulsed low electric field process for water disinfection. Electric intensity of 0.6-1.7 kV cm^{-1} is applied. Experiments are performed with a 1.2 L axis-cylinder reactor. A bipolar pulsed power source with pulsed width of 25 µs and frequency of 100-3000 Hz is used. Water conductivity of 3-200 µs cm^{-1} is investigated, which can significantly affect pulsed voltage-current waveforms and injected energy. Energy per pulse rises with increased water conductivity. The initial *E. Coli* density and water conductivity are two major factors influencing the disinfection. No disinfection effect is performed with deionized water of 3 µs cm^{-1}. When water conductivity is 25 µs cm^{-1} and bacteria density is 10^4-10^6 cfu ml^{-1}, significant disinfection effect is observed. More than 99% of the cells can be disinfected with an energy density of less than 70 J ml^{-1}, while water temperature is below 30 ℃.

1. Introduction

Pulsed electric filed (PEF) is an emerging non-thermal technology in the field of liquid disinfection and food preservation [1]. Fruit juices, liquid egg and derivatives, milk, grape wines and water are widely tested [2-6]. Comparing to traditional thermal pasteurization for liquid food disinfection, use of this technology can satisfy consumer demand for fresh looking products with minimal losses of nutrients and changes in flavour [7-8]. The effectiveness of PEF technology in reducing microorganisms has been widely demonstrated [9-10]. Disinfection usually depends on a number of factors, such as PEF intensity, pulse shape and duration, PEF energy density, products parameters and microbial characteristics [11]. A peak electric field of around 20-90 kV cm^{-1} is usually applied, while the pulse width is 1-10 µs. The volume of PEF reactor is limited to few millilitres to realize its high intensity electric field, which is a drawback for industrial scale up. Wan recently present a review for liquid food disinfection, the energy density is in the range of 30-7541 J ml^{-1} for achieving 1-6 orders of microbial reduction [12].

This paper presents our recent work on PEF liquid disinfection. Fresh water and *E. Coli* ATCC25922 are selected for fundamental research. We found that electric field as low as 0.5-2 kV cm^{-1} can also effectively inactivate the bacteria.

2. Experimental system

Figure 1 shows the schematic diagram of the PEF reactor. It consists of a grounded stainless steel cylinder and a HV electrode. Its inner diameter and volume are 100 mm and 1.2 L. The diameter of

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HV electrode is 30 mm. It is separated by a ceramic insulator to the grounded cylinder. The distance between the HV electrode and ground is 35 mm. A 10 kW bipolar pulsed power source is used. It can provide a pulsed voltage of 2-6 kV and a pulsed frequency of 100-3000 Hz (200-6000 pps). The pulse width is 25 μs, which is controlled by IGBT. All electrical measurements are recorded with Tektronix oscilloscope (TDS 2014B, 100 MHz). Typical bipolar pulsed voltage waveform is shown as figure 2.

The used *E. Coli* is firstly cultivated for 8-10 hours at 37 ℃ in a prepared LB medium (peptone of 10 g L^{-1}, yeast extract of 5 g L^{-1} and sodium chloride of 10 g L^{-1}). By this cultivation, the cell density usually rises to about 10^9-10^{10} cfu ml^{-1}. The cell number density is obtained by means of heterotrophic plate count (HPC) method. Then, *E. Coli* is harvested by centrifugation and suspended in deionized water for PEF treatment. Water conductivity is adjusted by adding potassium chloride.

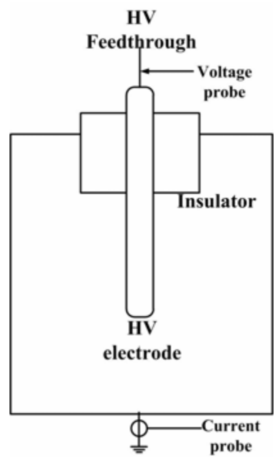

Figure 1. Schematic diagram of PEF reactor.

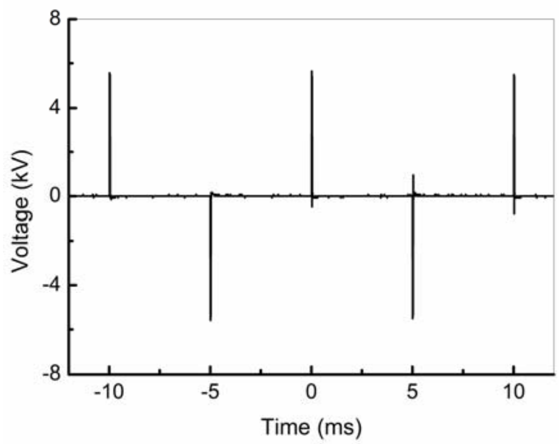

Figure 2. Typical bipolar pulsed voltage waveform when frequency is 100 Hz (200 pps).

3. Results and discussion

3.1. Effect of water conductivity on pulsed waveforms

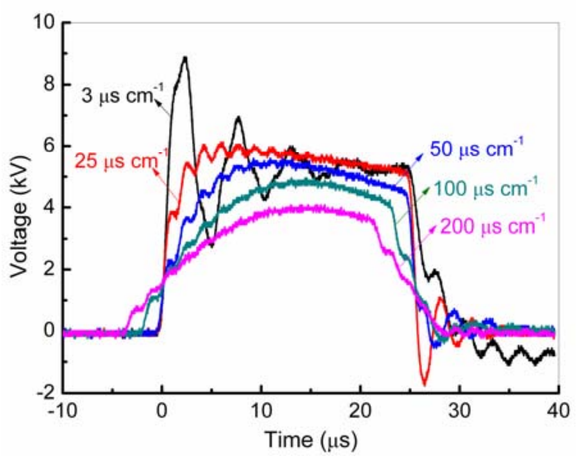

Figure 3. Pulsed voltage waveforms under water conductivity of 3-200 μs cm^{-1}.

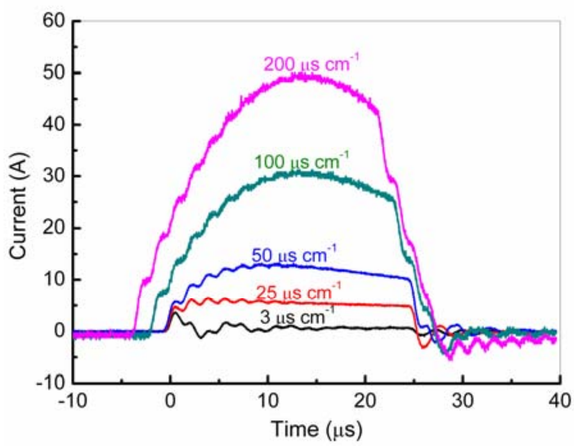

Figure 4. Pulsed current waveforms under water conductivity of 3-200 μs cm^{-1}.

Water conductivity can significantly affect pulsed waveforms. When the pulsed power source has the same output, figure 3 and figure 4 show the variation of voltage-current waveforms under different water conductivities within 3-200 μs cm^{-1}. As water conductivity rises, the pulsed voltage decreases slowly and corresponding current increases sharply. When water conductivity is 25 μs cm^{-1}, the pulsed peak voltage and current are 6 kV and 6 A, respectively. At the same time, both its voltage and current waveforms are fine square waves. When conductivity rises to 200 μs cm^{-1}, its peak voltage is 4 kV, but the peak current is as high as 50 A. Meanwhile, the waveforms become smooth.

From voltage-current waveforms in figure 3 and figure 4, we can obtain the single pulse energy under different water conductivities, as results shown in figure 5. As water conductivity rises from 3 μs cm^{-1} to 200 μs cm^{-1}, injected energy per pulse increases from 0.09 to 3.5 J.

3.2. Variation of water temperature during PEF treatment

Water temperature rises during PEF processing. When initial water temperature is 20 ℃, water volume is 1.2 L, pulsed waveforms are as figure 3 and figure 4, pulsed frequency is 200 pps and treatment time is 10 min, the increment of temperature is detected as shown in figure 6. If water conductivity is 3 μs cm^{-1}, it is 1 ℃. From figure 5, we can calculate the corresponding injected energy density is 9 J ml^{-1}. As water conductivity rises, both the injected energy density and temperature persistently increase. When water conductivity is 200 μs cm^{-1}, the energy density and temperature increment are 350 J ml^{-1} and 18 ℃, respectively.

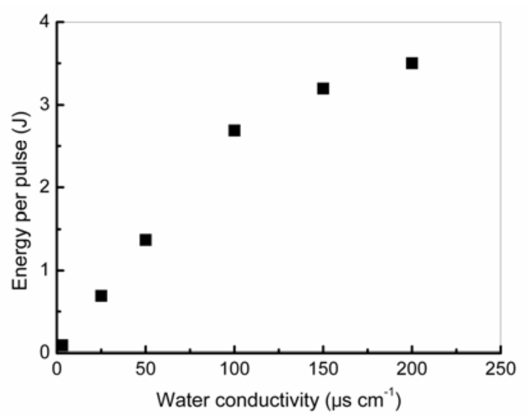

Figure 5. Injected energy of single pulse under water conductivity of 3-200 μs cm^{-1}.

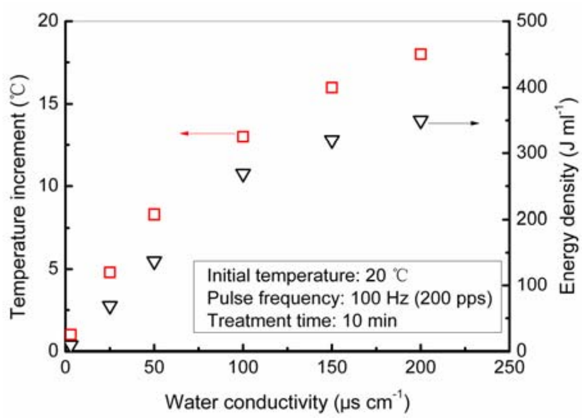

Figure 6. Increment of water temperature and injected energy density under water conductivity of 3-200 μs cm^{-1}.

3.3. Effect of water conductivity on PEF disinfection

Water conductivity can affect the PEF disinfection. When *E. Coli* is suspended in deionized water of 3 μs cm^{-1}, no disinfection effect is observed. If water conductivity is 25-200 μs cm^{-1}, the cell survival curves are shown in figure 7. The initial cell density, pulsed frequency and treatment time are 2×10^5 cfu ml^{-1}, 200 pps and 10 min, respectively. It is found that best disinfection effect is performed when water conductivity is 25 μs cm^{-1}. More than 99% of the cells can be disinfected, while the temperature is around 25 ℃. Disinfection efficiency decreases with raised water conductivity. Meanwhile, the corresponding PEF intensity is decreased from 1.7 kV cm^{-1} to 1.1 kV cm^{-1}, which can be seen from figure 3 and figure 4. Figure 8 shows the relationship between injected energy density and order reduction of cell density, which is defined as the logarithm ratio of the initial cell density over its survival value. When water conductivity is raised, the injected energy density increases obviously but without improved disinfection efficiency. The higher the water conductivity, the lower the energy efficiency of disinfection. Major of the energy is dissipated for water heating. We think that PEF disinfection efficiency is depend more on electric intensity and pulsed waveforms than injected energy density in present experiments. Square wave is supposed better than smooth one for disinfection.

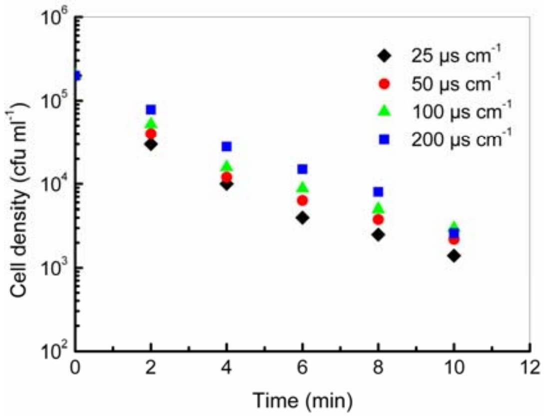

Figure 7. Effect of water conductivity on PEF disinfection.

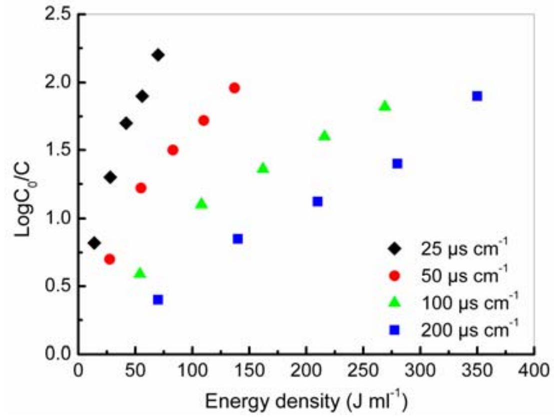

Figure 8. Effect of injected energy density on PEF disinfection under different water conductivities.

3.4. Effect of initial cell density on PEF disinfection

Figure 9 shows cell survival curves in terms of the treatment duration and/or the PEF energy density. Experiments are performed in water conductivity of 25 μs cm^{-1}. Its PEF intensity is 1.7 kV cm^{-1} and pulsed frequency is 200 pps. All the *E. Coli* cells can be inactivated in 10 min or under 70 J ml^{-1} when initial density is below 1.3×10^4 cfu ml^{-1}. Disinfection becomes less efficient when initial density rises. The orders reduction is 2.3 after 10 min when initial cell density is 4.5×10^4 cfu ml^{-1}. For an initial density of 1.6×10^6 cfu ml^{-1}, only 0.9 order reduction can be achieved.

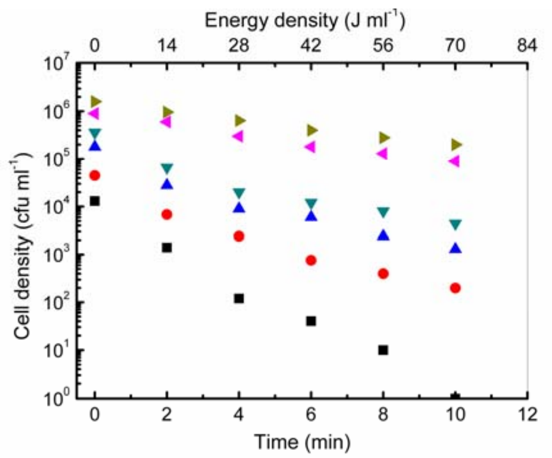

Figure 9. Effect of initial cell density on PEF disinfection.

3.5. Effect of PEF intensity on disinfection

Figure 10 shows the effect of PEF intensity on disinfection. The water conductivity, initial cell density, pulsed frequency and treatment time are 25 μs cm^{-1}, 1.3×10^4 cfu ml^{-1}, 200 pps and 10 min, respectively. PEF intensity is controlled by adjusting the output of the power source. The waveforms are all fine square waves as figure 3 and figure 4 but with different amplitudes. If PEF intensity is 0.6 kV cm^{-1}, only 0.5 order reduction can be achieved after 10 min. Disinfection efficiency rises with increased PEF intensity. The order reductions are 1.0 and 2.2 when PEF intensity are 0.9 kV cm^{-1} and 1.3 kV cm^{-1}, respectively. All the cells can be disinfected under a PEF intensity of 1.7 kV cm^{-1}. The energy per pulse for PEF intensity of 0.6 kV cm^{-1}, 0.9 kV cm^{-1}, 1.3 kV cm^{-1} and 1.7 kV cm^{-1} are 0.10 J, 0.22 J, 0.45 J and 0.70 J, respectively. When re-plotting the curves shown in figure 10 in terms of the PEF energy density and the order reduction as shown in figure 11, the disinfection efficiency is mainly dependent on the energy density.

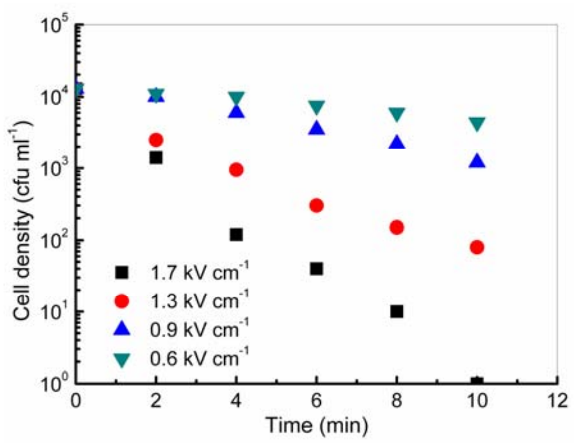

Figure 10. Effect of PEF intensity on disinfection.

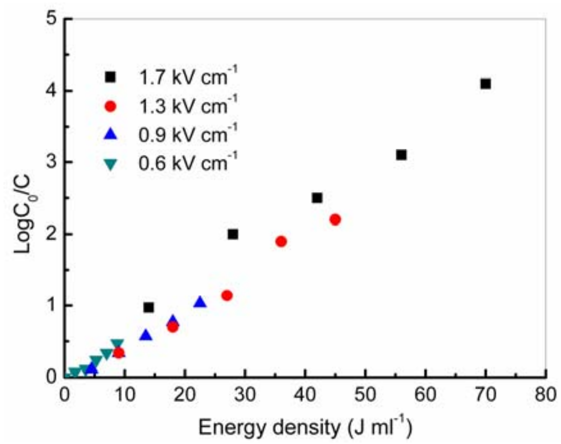

Figure 11. Effect of injected energy density on PEF disinfection under different electric intensity.

3.6. Effect of pulsed frequency on PEF disinfection

Figure 12 shows the effect of PEF frequency on disinfection. Water conductivity, PEF intensity and initial cell density are 25 μs cm^{-1}, 1.7 kV cm^{-1} and 5.0×10^4 cfu ml^{-1}, respectively. All experiments are performed with 120000 pulses. The treatment duration drops to 1 min when pulsed frequency is 2000 pps. Results show that PEF disinfection is not depends on pulsed frequency but depend on the total pulse number. 2.1-2.2 orders reduction is achieved after 120000 pulses. If we raise the pulsed frequency to the maximum of 6000 pps, few seconds is enough for the process.

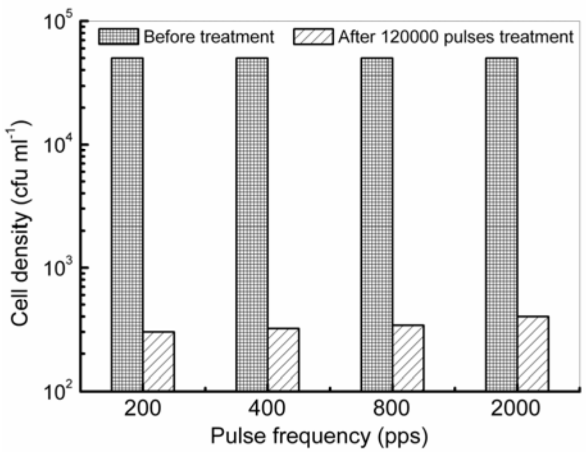

Figure 12. Effect of pulse frequency on PEF disinfection.

4. Conclusions

This paper gives a preliminary investigation on pulsed low electric field process for liquid disinfection. Based on present experiment on the *E. Coli* disinfection, we can conclude as follows:

1. PEF intensity of 0.6-1.7 kV cm^{-1} has disinfection effect. Disinfection efficiency rises with increased PEF intensity and energy density.

2. Water conductivity significantly affects the PEF waveforms and disinfection efficiency. When conductivity is within 3-200 μs cm^{-1}, best disinfection efficiency is performed under the water conductivity of 25 μs cm^{-1} and its fine square wave.

3. All the cells can be disinfected under an energy density of 70 J ml^{-1} after 120000 pulses when initial bacteria density is below 1.3×10^4 cfu ml^{-1}. Disinfection efficiency drops as initial cell density rises.

References

[1] Zhang Q H, Barbosa-Canovas G V and Swanson B G 1995 *J. Food Eng.* **25** 261
[2] Mosqueda-Melgar J, Raybaudi-Massilia R M and Martin-Belloso O 2007 *Int. J. Food Microbial.***117**192
[3] Sampedro F, Rodrigo D, MartInez A, Barbosa-Canovas1 G V and Rodrigo M 2006 *Food Sci. Tech. Int.* **12** 397
[4] Jaeger H, Schulz A, Karapetkov N and Knorr D 2009 *Int. J. Food Microbial.***134** 154
[5] Bermudez-Aguirre D, Yanez J A, Dunne C P, Davies N M and Barbosa-Canovas G V 2011*Food Res. Int.* **43** 2201
[6] Puertolas E, Lopez N, Condon S, Raso J and Alvarez I 2009 *Int. J. Food Microbial.* **130** 49
[7] Aguilo-Aguayo I, Oms-Oliu G, Soliva-Fortuny R and Martin-Belloso O 2009 *Food Chemistry* **116** 59
[8] Jia M, Zhang Q H and Min D B 1999 *Food Chemistry* **4** 445
[9] Heinz V, Toepfl S and Knorr D 2003 *Innov. Food Sci. Emerg.* **4** 167
[10] Huang K, Tian H, Gai L and Wang J 2012 *J. Food Eng.* **111** 191
[11] Wouters P C, Alvarezb I and Rasob J 2001 *Trands Food Sci Tech.***12** 112
[12] Wan J, Coventry J, Swiergon P, Sanguansri P and Versteeg C 2009 *Trands Food Sci. Tech.* **20** 414