Disinfection of deionised water using AC high voltage

P.T. Johnstone and P.S. Bodger

Abstract: A new type of water purification device that uses a high-magnitude electric field to kill micro-organisms has been developed (Johnstone and Bodger, 1997). This device uses a 6000V, 50Hz high-voltage supply applied directly across a flow of deionised water. The area of high-magnitude electric field causes disruption of cellular membranes and leads to a loss of cell viability and infectiveness. This disinfection process required some technical changes to enable its commercial development. A new prototype model of a domestic drinking water device has been constructed with these changes in mind. The initial electrode system and power supply were redesigned to enable them to be easily manufactured. The redesigned system uses a different electrode shape, material and dimensions, although the critical parameters of electric field strength and flow rate remain unchanged. To verify that the electrical and biological performances were still valid, tests were undertaken on the new design. It is shown that the new electrode system is more electrically robust, is easily and cheaply manufactured, and provides a similar disinfection performance. The device was tested on a common bacteria *Serratia marcescens* and proved close to a three log reduction in viability. The device was also tested on a parasitic protozoan *Giardia lamblia*. No viable *Giardia* cysts were detected following treatment.

1 Introduction

In recent years public awareness of the risks of drinking water contaminated with micro-organisms has increased. This is due to knowledge of the spread of actual contamination to previously pure water supplies. There have been many documented cases of large-scale disease outbreaks as a result of contamination of public water supplies throughout the world. As a result there is a rapidly increasing market for domestic point-of-use water treatment units.

The authors have described a new type of water disinfection device [1]. This device uses a high-magnitude electric field to kill bacteria and other micro-organisms in water supplies. It is designed for the domestic drinking water market as a point-of-use device. Being a physical process, it has no residual disinfection in the water. In a similar manner to electric pulse techniques and ultraviolet disinfection, the remnants of killed bacteria remain in the water. The disinfection process involves the dielectric breakdown of the lipid membrane of a micro-organism. This causes the membrane to become permeable to aqueous ions and molecules. This is an extension of a process termed electroporation, which is used for cell gene transfer [2]. Sufficient voltage magnitude and exposure, along with a number of other physical parameters will contribute to a loss of cell viability [3–8].

Conventional electroporation techniques have been applied to the disinfection of various types of fluids, including milk and liquid foods [8–13]. These techniques utilise a high-voltage capacitor discharge system. Disinfection methods that use this technique apply a number of successive discharges (or voltage 'impulses') to the liquid being disinfected. However, relative to the method of this paper, they are complicated and expensive devices.

The water disinfection method cited in [1] is different from conventional methods in that it applies a continuous high voltage across a flow of water. The voltage source is through a 50Hz step-up transformer. A 50Hz supply is used in preference to DC where experiments involving the latter under continuous application showed electrolysis problems. This was not observed to be the case with 50Hz. This method is restricted to fluids of low conductivity. However, it is theoretically applicable over a large range of flow rates. The inventive ideas of this method are protected by patent.

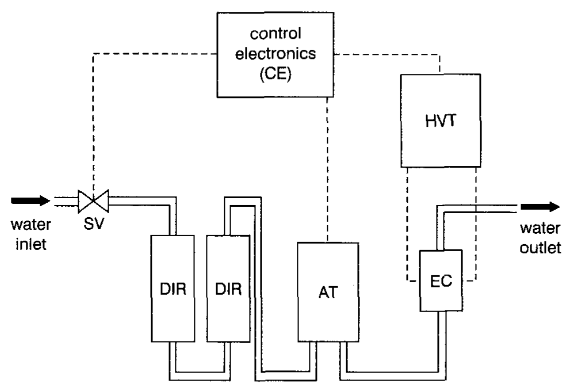

Fig. 1 *Initial disinfection device*

2 Initial development model

An initial working model of the water disinfection device was constructed by Johnstone and Bodger [1]. A block diagram describing the device is shown in Fig. 1. A solenoid valve (SV) at the entry to the device controls the water

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The authors are with the Department of Electrical and Electronic Engineering, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

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flow. The water then flows through two deionising resin cartridges (DIR), which reduce the conductivity of the water. An air trap (AT) removes any bubbles present in the water to prevent air reaching the electrode chamber. The electrode chamber (EC) consists of two square parallel plates, 10 × 10mm, separated by a distance of 2mm. The plates are made of titanium because of its hardness and resistance to corrosion, and serve as electrodes with the flow of water passing in between. The high voltage transformer (HVT) increases the mains voltage from 240 to 6000V RMS, and the high voltage side is applied to the electrodes. The control electronics (CE) provide control of the solenoid valve and power to the HVT.

A series of experiments were undertaken on a common bacterium *Serratia marcescens* to test the killing effectiveness of the electrodes. In these experiments, the deionising stage was removed from the procedure as the resin was found to filter out large numbers of the bacteria. Instead, the Serratia were first washed and resuspended in deionised water, then pumped through the electrode chamber. The treated sample S was collected at the water outlet while the high voltage was turned on. The control samples So were collected with the high voltage turned off [1]. The results of this testing are plotted in Fig. 2. All samples and controls were undertaken within a small time-frame relative to the bacteria being suspended in deionised water. Also all culturing was undertaken simultaneously, thus the effect of suspension time on the viability of the bacteria in deionised water was effectively eliminated.

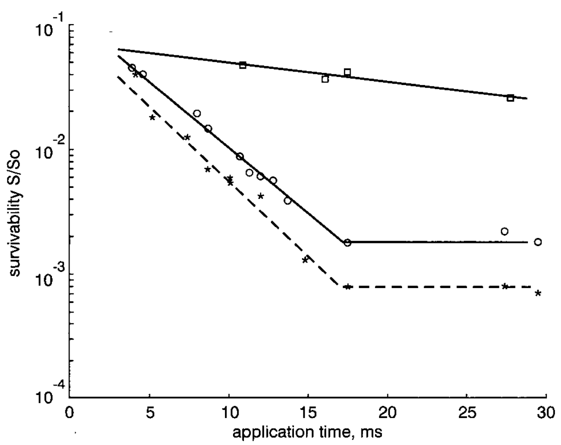

Fig. 2 *Survivability of Serratia marcescens for initial development model*
Lysing rate of 50Hz HV on *Serratia*, 30kV/cm RMS
□ 21kV/cm
○ 27kV/cm
✳ 30kV/cm

The critical design parameters for killing micro-organisms were found to be electric field and application time. Application time is defined as the average length of time a particle in the water takes to pass through the region of high electric field strength. Increasing either of these parameters increases the micro-organism lysing rate.

As a result of the biological testing on *Serratia*, the initial development model used an electric field strength of 30kV/cm RMS, and an application time of 17ms. At these levels the electrodes provide a greater than three log reduction of *Serratia*. This is equivalent to a 99.9% kill rate.

3 Commercial prototype design

The initial development model was redesigned to allow for commercial production. A block diagram describing the new process is shown in Fig. 3. The main design changes are the combination of the air trap and electrode chamber and the use of a mechanical air release valve, a change in electrode shape and construction, a change in the high-voltage transformer specifications, and the incorporation of an electrical/mechanical flow switch. These changes are described in more detail in Sections 3.1–3.3.

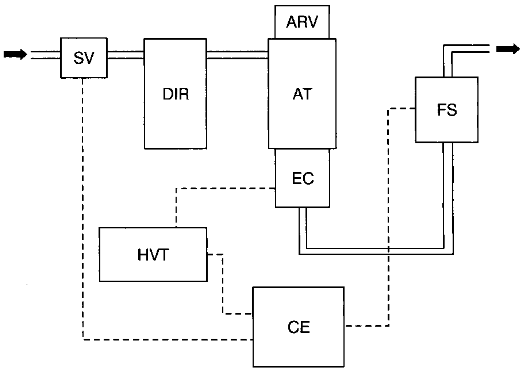

Fig. 3 *Commercial prototype block diagram*

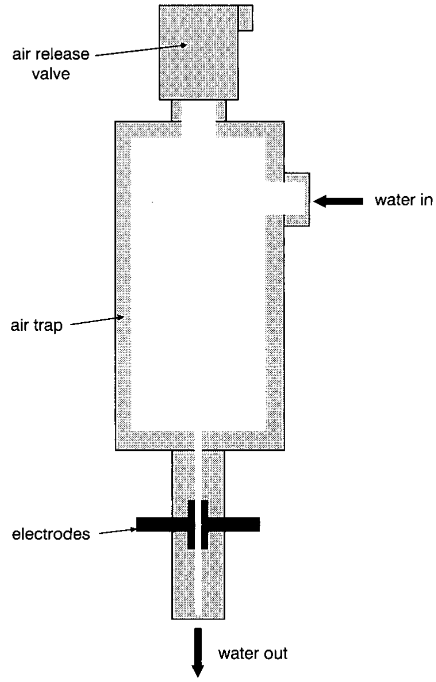

Fig. 4 *Electrode/air trap construction*

3.1 Electrode and air trap combination

The electrode chamber and air trap were incorporated into one complete unit (Fig. 4). This combination was mainly for ease of manufacture. The air trap and electrode chamber were both constructed from plastic and lend themselves to being injection moulded. It was convenient to combine these components and thus avoid the need for two separate chambers with associated plumbing attachments. The combined AT/EC chamber was injection moulded in two pieces that were then heat jointed together.

Another important reason to combine them is that the air trap is a necessary prerequisite to the electrode chamber. If air bubbles are allowed to reach the electrode chamber, electrical arcing and electrode degradation will occur. The air trap is designed around the same operating characteristics as the electrode chamber. The two components are matched for any given flow rate.

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3.2 Electrode dimensions and construction

The dimensions of the electrodes are different from the initial development model. Since the electrodes are to be inserted into an injection mould, the electrode face must be of circular cross-section to allow for rotation in the moulding process. A sketch of an electrode is shown in Fig. 5*a*, showing its shape. It was machined out of 316T stainless steel. This is different to the initial development model that uses titanium. Stainless steel is more common, easier to work with, and less expensive than titanium. It has been found that this grade of stainless steel does not degrade significantly over time. A unit has been on trial for over six months without a significant change in performance. The design of the commercial electrodes is such that they can easily be replaced and recycled. Material costs are minor relative to the overall unit.

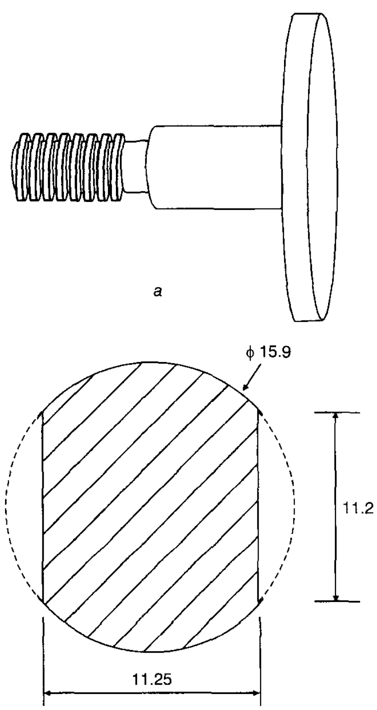

Fig. 5 *Electrode*
a Shape
b Effective electrode area. Dimensions in mm

Fig. 5*b* shows the effective electrode area in contact with the water. This area can be calculated to be $1.62 cm^2$.

3.3 High-voltage transformer

The gap between the electrode surfaces has been reduced from 2 to 1.5mm. To obtain a similar electric field strength of 30kV/cm RMS, the voltage magnitude applied to the electrodes is 4.75kV RMS. A suitable transformer with a 240:4750 voltage ratio was designed and manufactured by an existing transformer winding company. The design is suitable for large scale automated production.

4 Performance of commercial prototype

A new commercial prototype that incorporates the changes mentioned in Section 3 was constructed and tested. The commercial prototype electrode chamber and air trap combination was found to work well. It was found to be more robust to the problem of air bubbles and electrode stability i.e. it exhibited less arcing and was able to better withstand the injection of large amounts of air bubbles upstream.

The commercial prototype is much simpler to manufacture. The electrode chamber in the initial development model was machined out of solid plastic with five different parts and rubber O-rings to prevent water leakage. The new EC/AT combination may be easily injection moulded and produced quickly in mass quantity. The costs of producing the new EC/AT combination would be much lower. For an initial run of 1000 units the cost per piece is estimated at 1/50th the cost of producing the separate development model pieces.

The commercial prototype was tested on *Serratia marcescens*, using an identical method as explained for the development model (Section 2). A comparison of results is graphed in Fig. 6. It can be seen that the commercial model provides a similar disinfection characteristic to the development model. The slight general decrease in kill rate may be attributed to the change in electrode dimensions and associated tolerances. The similarity in disinfection characteristic suggests the biological performance of the device has not been compromised by the change in design parameters listed in Section 3.

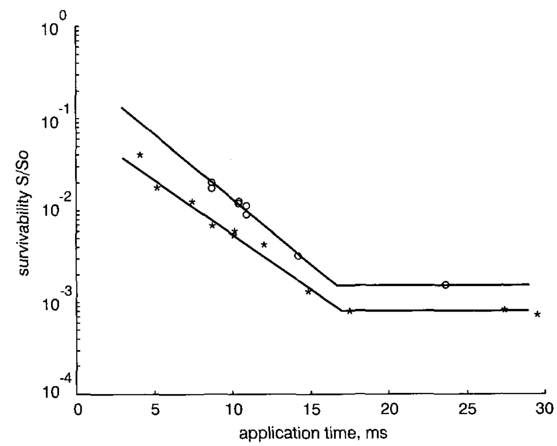

Fig. 6 *Survivability of Serratia marcescens for commercial prototype, compared with initial development model*
Lysing rate of 50Hz HV on *Serratia*, 30kV/cm RMS
* initial development model
O commercial prototype

Table 1: Viability of *Giardia* in development model

	Untreated	Treated
Cysts examined	408	1131
No. viable	396	0
No. nonviable	14	1131
% viable	96.6	0

Table 2: Viability of *Giardia* in commercial prototype

	Untreated	Treated
Cysts examined	200	100
No. viable	54	0
No. nonviable	146	100
% viable	27	0

The commercial prototype was also tested on live cysts of *Giardia lamblia*. A summary of results shows the number of viable and nonviable cysts before and after treatment.

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Table 1 shows the results from the initial demonstration model. Table 2 summarises the results for the commercial prototype. It can be seen from the results that after passing through the electrode chamber with the high voltage on, all cysts studied were nonviable. This is true for both the demonstration model and the commercial prototype. For the demonstration model a total of 1000 nonviable cysts were counted to give a greater than three log (99.9%) decrease in viability. The commercial prototype test confirmed that all treated cysts were nonviable. The low untreated cyst viability was due to a poor initial cyst culture. The two experiments were performed at different dates on different cyst cultures.

5 Conclusions

A commercial prototype of a high-voltage water purification device has been constructed. This device has a one litre per minute flow rate and is designed for use in domestic households. Critical design parameters had to be changed from the initial development model to allow ease of manufacturing for the commercial prototype. These changes were in the electrode material, electrode shape and dimensions, high-voltage magnitude and the air trap and electrode chamber combination. Despite these design changes, the commercial prototype had a similar disinfection performance as the demonstration model.

The combination of the air trap and electrode chamber into one component also increased the electrical robustness of the device. The whole component may be injection moulded, decreasing the cost and time of manufacture.

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