APPLICATIONS OF HIGH VOLTAGE POWER SUPPLIES IN THE PURIFICATION OF WATER

P.T. Johnstone and P.S. Bodger

Department of Electrical and Electronic Engineering
University of Canterbury, New Zealand
Email: p.bodger@elec.canterbury.ac.nz

Abstract

High voltage treatment technology has been developed by the authors and has shown promise in its effectiveness in reducing microorganisms found in water supplies. Initial testing on a one litre-per-minute (LPM) device found that the high voltage could destroy over 99.9% of the bacteria *S. marcescens*. The device was scaled up to treat flows of 10 LPM and 33 LPM. A high voltage switch-mode-power-supply (SMPS) was also constructed. This supply has a number of significant advantages over the 50 Hz models. The device was successfully tested on a recirculating system and reduced the numbers of bacteria by over 4-log.

1. INTRODUCTION

There is increasing need and awareness for water treatment throughout the world. The most important objective of water treatment is to produce a water supply that is biologically and chemically safe for human consumption. The authors have developed a new water treatment method that uses high voltage to kill suspended microorganisms. This can be used to remove potential pathogens and make the water potable.

The cytoplasmic membrane of living cells acts as a dielectric. The application of a high voltage across water will induce a potential across the membrane of suspended cells according to the equation [1]:

$$V_c = 1.5 E_c a \cos\alpha \pm V_m \qquad (1)$$

where V_m is the resting membrane potential, V_c the critical membrane potential, E_c the critical electric field strength, and α is the angle between the membrane site and field direction.

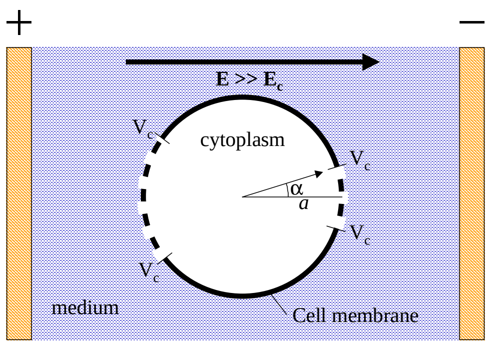


Figure 1 Application of a high magnitude electric field to a spherical cell in an aqueous medium

When the voltage potential exceeds a critical value the membrane becomes permeable, as shown in Figure 1. The increased permeability of the membrane can lead to cell death.

2. WATER PURIFICATION

2.1 One LPM Treatment Device

A high voltage treatment device that works on a one litre per minute (1 LPM) flow rate was constructed and tested. A block diagram of the process is shown in Figure 2. The device applies a constant high voltage directly to deionised water in order to destroy microorganisms.

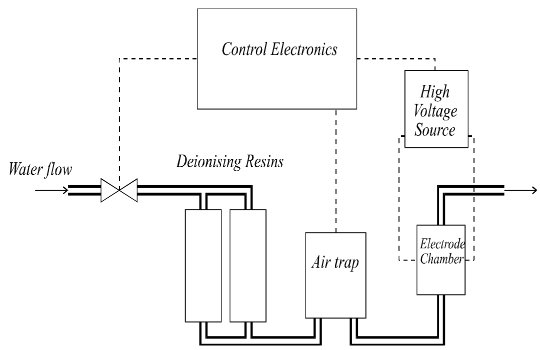


Figure 2 Water treatment device

The deionising resins reduce the conductivity of the water and hence energy requirements. These are readily available commercially. The air trap removes gas bubbles, which may cause arcing if they pass through the electrode chamber. The device was shown to work effectively both electrically and biologically. Initial tests on the bacteria *S. marcescens* showed promise for the technology. A three-log reduction in viability was obtained at an exposure time of 17 msec and an electric field strength of 30 kV/cm (Figure 3).

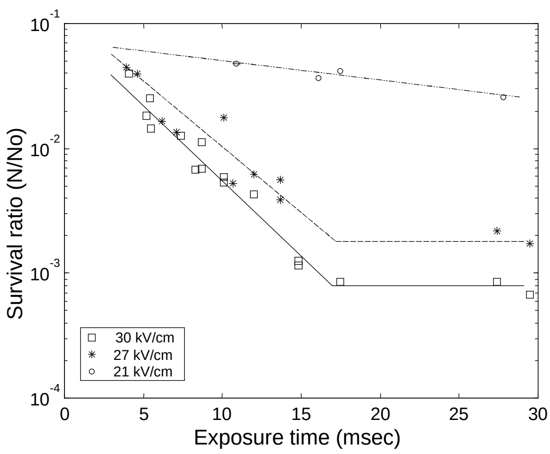


Figure 3 Reduction in survival ratio for treated *S. marcescens*

The resistance of the water load is directly dependent on the water conductivity, according to the equation:

$$R_L = \frac{g}{\kappa A} \quad (2)$$

where g is the gap between electrodes (0.2 cm), A the area of the electrodes (1 cm^2) and κ is the conductivity of the water (µS/cm). The load power may be calculated from:

$$P_L = \frac{V_L^2 \kappa A}{g} \quad (3)$$

where V_L is the load voltage (6 kV rms). The power to treat water with conductivity 1 µS/cm is thus 180W. Assuming that the transformer is 90% efficient, then this is the maximum conductivity the 200 VA transformer can continuously treat.

The device was tested in an independent laboratory on a waterborne parasite, *Giardia intestinalis*. The high voltage was effective on this organism, destroying over 99.9% of *Giardia* cysts [2]. The initial 1 LPM demonstration model was subsequently redesigned to allow for commercialisation and mass production.

2.2 Higher Flow Rate Devices

The high voltage treatment technology was scaled up to higher flow rates. Devices with flow rates of 10 LPM and 33 LPM were constructed. These larger flow rates required a design change of the electrode chamber. Pairs of concentric cylinder electrodes were used instead of parallel flat plates. This minimises the electrode size and eliminates side edges, which can adversely affect the electric field. Construction of the 33LPM electrodes is shown in Figure 4.

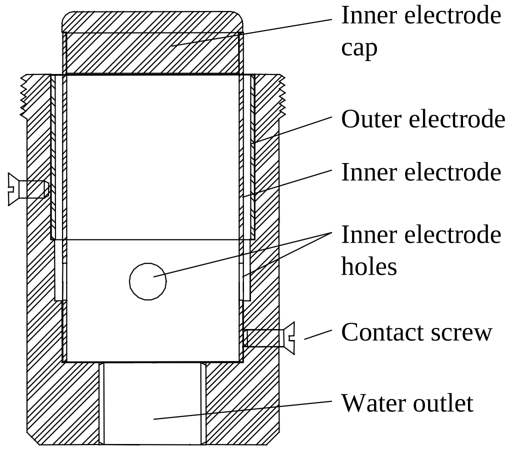


Figure 4 Concentric cylinder electrodes for higher flow rates

2.2.1 Problems in the Scale-up of Technology

Some practical problems in the scale-up of the technology were discovered. Due to the high electric field strength and increased electrode surface area, the larger sized electrodes were more prone to electrical arcing. Electrode design must be careful to minimise sharp edges and surface imperfections that may lead to electrical breakdown. The electrode chamber shown in Figure 4 is connected directly into the larger air trap to minimise the formation and trapping of air bubbles near the electrode vicinity.

The devices monitor the high voltage transformer primary current so that if arcing or overcurrent occurs, the high voltage may be turned off. However this means that the transformer may often be turned off in a highly excited state. The residual magnetism of the transformer may then cause large inrush currents when the transformer is re-energised. Inrush current can also be a problem at turn on under normal conditions, depending where in the voltage waveform the transformer is energised. Thus the transformer was made to only switch on at zero current (full voltage), and a soft start circuit is necessary to avoid the residual magnetism problems.

Another problem occurs if the devices are used intermittently. Deionised water is a strong solvent and leaches ions from any metal components in the system, causing a rise in water conductivity and hence operating power. This may cause a surge of power for several seconds until the higher conductivity water has exited the system, and is especially evident after the device has been idle for more than a few hours. These power surges may be minimised by eliminating metal plumbing components in the system. Also for devices that are used intermittently it may be necessary to first flush the system to drain before the high voltage is turned on.

Results of testing these devices on *S. marcescens* showed a significant decline in effectiveness, even at similar electric field strengths (30 kV/cm) and higher exposure times when compared to the 1 LPM device, as shown in Figure 5. Possible reasons for this low performance were experimentally tested, but no obvious explanation could be found.

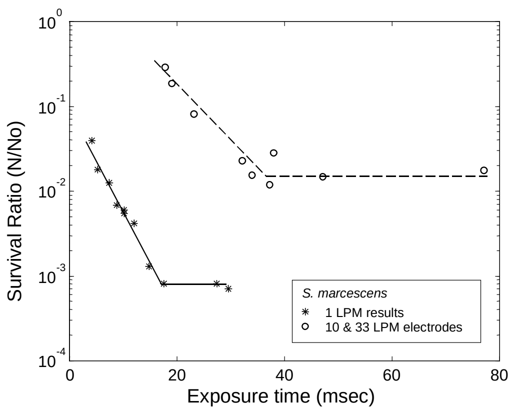


Figure 5 Results of testing on S. marcescens for larger flow devices

2.3 High Voltage Switch-Mode Power Supply

A high voltage SMPS has many advantages over a 50 Hz waveform. It enables the exposure time to be significantly reduced since the duration of areas of low electric field strength has also been reduced. Thus, the energy required to treat deionised water may be also reduced by over 90%. This reduction in energy requirements enables water of higher conductivity to be treated. The reliance on the deionising resin may be reduced or even eliminated.

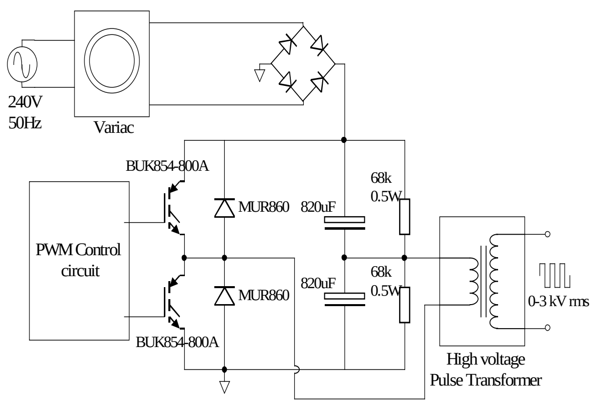
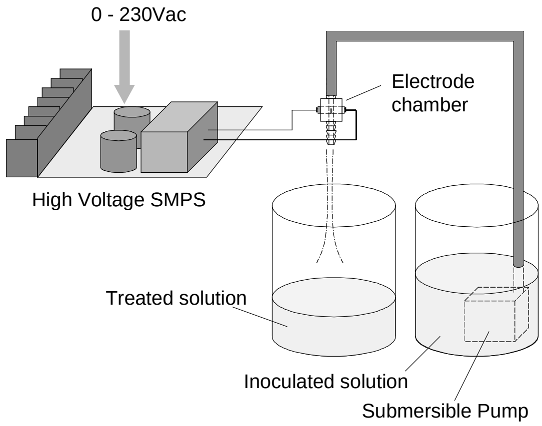
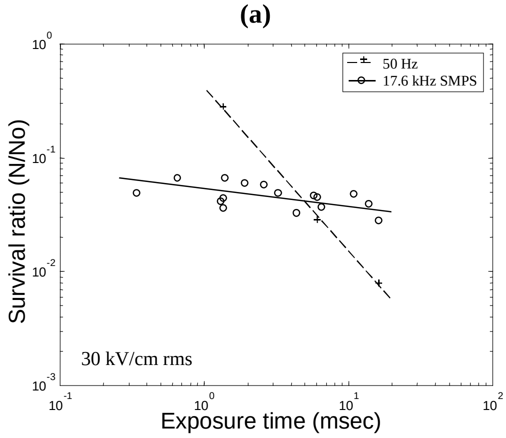


Figure 6 High voltage Switch-Mode Power Supply

A high voltage switch-mode power supply (SMPS) is shown in Figure 6. This supply is in a half bridge configuration and provides a bipolar square waveform at 3 kV, 17 kHz, and 400 VA. The demonstration SMPS was tested on *S. marcescens*. The experimental procedure is shown in Figure 7(a), and the corresponding results in Figure 7(b).



(a)



(b)

Figure 7 Testing the SMPS on *S. marcescens*, **(a)** experimental procedure **(b)** results compared to the 50 Hz device.

The SMPS is less effective in reducing the survival ratio than 50 Hz at higher exposure times. However, it is more effective at lower exposure times. This is because of the higher frequency minimises areas in the voltage waveform where the electric field is low (surrounding zero crossings) [3]. At low exposure times with the 50 Hz waveform a certain amount of bacteria may pass through the electrodes during a period of low field strength and thus be untreated. The viability of *S. marcescens* is reduced by over 90% with one application of SMPS at an exposure time of only 0.4 msec. This can be equated to an energy reduction of over 97% when compared to a similar 50 Hz device. Thus the SMPS is remarkably more energy efficient than 50 Hz treatment. The lower effectiveness of the SMPS may be increased by multiple applications.

Other advantages of using a SMPS are apparent. The SMPS is much more robust to electrode arcing. The SMPS is controlled by a Pulse Width Modulation (PWM) control chip (SG3526, Motorola). This chip contains current sensing pins and can shut-down the output on a cycle-by-cycle basis, thus providing quick and effective protection against arcing or overcurrent situations. Hence, the SMPS is current limiting and can easily cope with air bubbles passing through the electrode chamber. The air trap can be eliminated thereby reducing size and manufacturing cost.

The significant reduction in power and energy requirements means that the SMPS may be used to treat water with higher conductivity, reducing the reliance on deionising plant. A future goal is to eliminate the need for deionising resins and be able to treat existing water supplies with high voltage SMPS.

2.4 Recirculating Systems

A recirculating system is shown in Figure 8. This system consists of a large body or volume of water either in storage or continuously used in some process. This system could be, for example, an air conditioning plant or spa pool. Both of these systems are open to a source of outside contamination. If a continuous side stream with flow rate Q (m^3/s) is treated at an efficiency of S % (S % of bacteria in the side-stream is destroyed), then the survival ratio of the overall bacteria in the tank may be written as:

$$\frac{N}{N_0} = e^{-\left(\frac{QS}{100V}t\right)} \qquad (4)$$

where N is the number of bacteria in the tank after recirculation time t (s), and N_0 is the number of bacteria in the tank at time t=0. This equation assumes uniform mixing within the tank and that the growth rate of the bacteria within the tank is zero. These assumptions are valid if the side-stream flow rate Q is high compared to the total volume V.

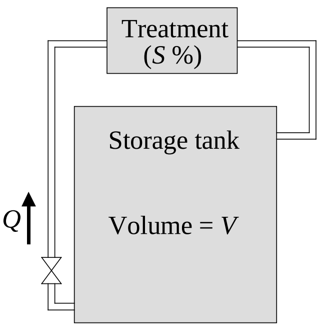
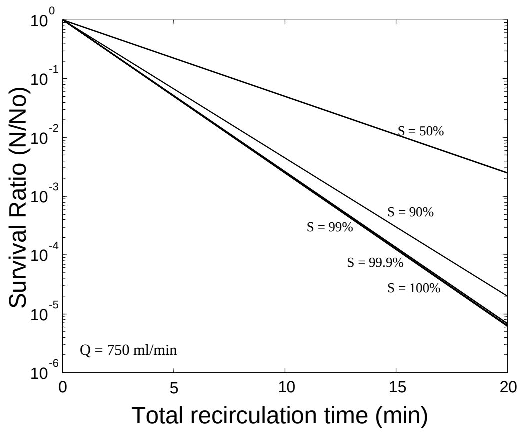
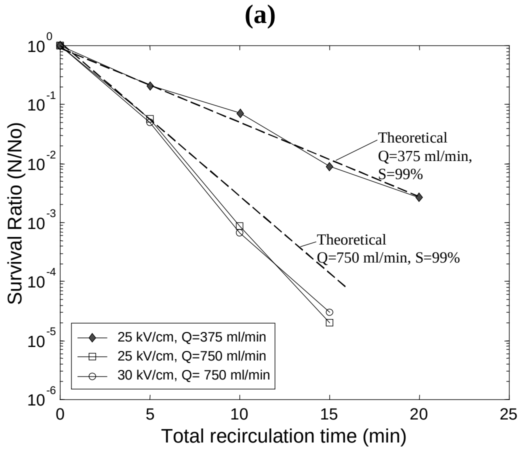


Figure 8 Recirculating system

Equation (2) is plotted in Figure 9(a). This shows that the reduction in survival ratio of bacteria is essentially the same for any treatment efficiency >99%. There is no advantage in using a treatment system with a higher than 99% efficiency. Thus, a recirculating treatment system may be operated at higher flow rates and lower treatment effectiveness, and still be more effective in reducing overall numbers of bacteria within the system. This is counter-intuitive, but has been verified by experimental testing using *E. coli*. An overall reduction in the viability of *E. coli* during some of these tests was greater than 4-log after a recirculation time of 15 minutes, as shown in Figure 9(b).



(a)



(b)

Figure 9 (a) Theoretical curves for recirculation systems **(b)** Experimental results on *E. coli*.

2.5 Effects of Cell Growth Phase

The effect of cell growth phase on the treatment effectiveness was examined using *S. marcescens* and *E. coli*. It was found that bacteria harvested in the early logarithmic stage of growth were most susceptible to the electric field treatment. Bacteria harvested in the late stationary phase were much more resistant. Since the state of most naturally occurring bacteria in water supplies is that of low growth, they will be mostly resistant to high voltage treatment.

3. CONCLUSIONS

Water treatment using high voltage has shown promise as an exciting new method in water purification. A one litre per minute device that uses a 50 Hz waveform has been successfully constructed and tested. This device was able to destroy 99.9% of the bacteria *S. marcescens* at an electric field strength of 30 kV/cm and exposure time 17 msec. It has also been successfully tested in destroying the waterborne parasite *Giardia intestinalis*.

The technology was scaled-up to larger flow rates of 10 and 33 litres per minute. This increase in size presented a few problems with the interaction of the high voltage and water. These problems were overcome with some design changes.

A switch-mode power supply (SMPS) was built to replace the 50 Hz high voltage. The SMPS offers many advantages over 50 Hz. The size and cost of high voltage supply is reduced. The SMPS is more robust to electrode arcing and air bubbles, eliminating the need for a large air trap. Due to the reduction in low electric field areas of the waveform, the SMPS is over 97% more energy efficient and thus may be used to treat water with higher conductivity.

Recirculating systems such as air conditioning systems or cooling towers may benefit from this technology. In these systems a water treatment device need only be 99% effective. Under these conditions, an overall reduction in the viability of *E. coli* during some recirculating tests was greater than 4-log after an operation time of 15 minutes. This needs now to be trialed on a larger scale.

4. REFERENCES

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[3]. Johnstone, P.T. and Bodger, P.S., "Applications of a high-voltage SMPS in water disinfection", *IEE Proc. Science, Measurement and Technology*, March 2001, Vol. 148, No. 2, pp 41- 45.