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# The Continuous Non-Thermal Sterilization of Drinking Water Using Low Electric Field

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**Abstract**

A continuous non-thermal sterilizer of drinking water using low electric field was designed, manufactured and tested in food engineering laboratory, food science department, Basrah University. It consists of tank, electrodes made from stainless steel and valve. Three electric field intensities have applied in this study are 40, 70 and 100 $Vcm^{-1}$. The complete randomize design has been used to analyze data statistically. The parameter studied were electric Conductivity, total aerobic bacteria count, total coliform Bactria, *E. coli*, calculation of survival microorganism's ratio to total ($C/C_T$), rate of microorganisms' destruction and reducing microorganism percentage. The results showed that the electric conductivity of water ranged from 0.127 - 0.159 $Sm^{-1}$. Moreover, total count bacteria, total coliform Bactria, *E. coli* and survival microorganism's ratio to total were decreased significantly with the increase of the electric field intensities. As well as, rate of microorganisms' destruction was ranged between -281 to -2.81 CFU/L $s^{-1}$ and the reducing microorganism percentage has ranged between 99.94 – 99.99% at range of electric field intensities from 40 – 100 $Vcm^{-1}$ respectively. On the other hand, equation of calculation $C/C_T$ has been developed by adding the electric field intensity effect in it which produced a new equation for the first time in this field.

**Keywords:** drinking water, sterilization, electric field, non-thermal treatment

## Introduction

Water is one of essential elements for surviving human because the life has begun through the water. Water covers three quarters of the planet earth. Dry lands have two types of water, the first is a surface water and the second is a ground water. Drinking water is a not harmful for human. In another meaning, drinking water has not pathogenic microbes and unpolluted (Hammer, 1975). Drinking polluted water (without purification) leads to spread of many diseases such as poliomyelitis, typhoid, cholera, Bilharziasis and Bacillary dysentery (Abdullah, 2015). Sterilization is used to eliminate of all microbes from water. There are many methods for sterilizing water are physical and chemical methods. Physical methods such as heating water at temperature more than 75 $^{o}C$ for several minutes, as well as using ultraviolet ray with range of 240 – 280 nm. UV ray attacks DNA of all bactria types directly, where bactria loss it is ability on the reproduction and damages then dies after that. The last type of physical methods is filtration, in this way, sand filter is used to eliminate of a high percentage of microorganisms reaches to 90 %. Also, the membranes made of cellulose with pores of 0.001 µm diameter, and which called reverse osmosis technology (Aladawi, 1990). Machado et al. (2010) found that the *E. coli* was incapacitated by 3 $log_{10}$ cycles when used the moderate electric field of 220 V $cm^{-1}$. Chemical methods are widely used to sterilize drinking water such as chlorine, dioxide chlorine (Darwesh, 1997). Al-Manhel et al. (2016) have used the chitosan as a non-thermal treatment for eliminating microorganism from drinking water, and they found that the chitosan was eliminated completely of fecal coliform bactria, total coliform bactria, Staphylococci and count of total bactria. .

This study aimed to applicate of new system for sterilizing water by low electric field as a non-thermal treatment and evaluation of it is efficiency in elimination of all microorganisms from drinking water.

## Materials and methods

### Non-thermal sterilizer of water

The continues non-thermal sterilizer of water consists of stainless steel tank with capacity of 5 letters, four electrodes (the distance between each other was 1cm) were made from stainless steel of 0.4 cm diameter and 2 cm length, valve (tap) and voltage regulator works with range of 0 to 230 V. the apparatus is shown in figures 1 and 2. The apparatus works by the continuous method with mass flow rate of 0.08 $kgs^{-1}$. Three electric field intensities have applied in this study are 40, 70 and 100 $Vcm^{-1}$.

### Electric Conductivity

 

Electric conductivity means how water transfers the electric charge and is affected by the chemical composition of water. The electric conductivity increases with the increase of ionic, such as salts (NaCl) (Anderson, 2008). Electric conductivity is given by equation (1) (Wang and Sastry, 1993; Icier et al., 2008):

$$\sigma = \frac{I\ d}{V\ A} \tag{1}$$

Where, is the electric conductivity ($Sm^{-1}$) and $A$ is the sectional area ($m^2$), $d$ is the distance between electrodes (cm) and V is the voltage (V).

**Electric Field Intensity**

Electric field intensity was calculated from equation (2) (Toepfl et al., 2001):

$$E = \frac{V}{d} \tag{2}$$

Where: $E$ is the electric field intensity ($V\ cm^{-1}$), $d$ is the distance between electrodes (cm).

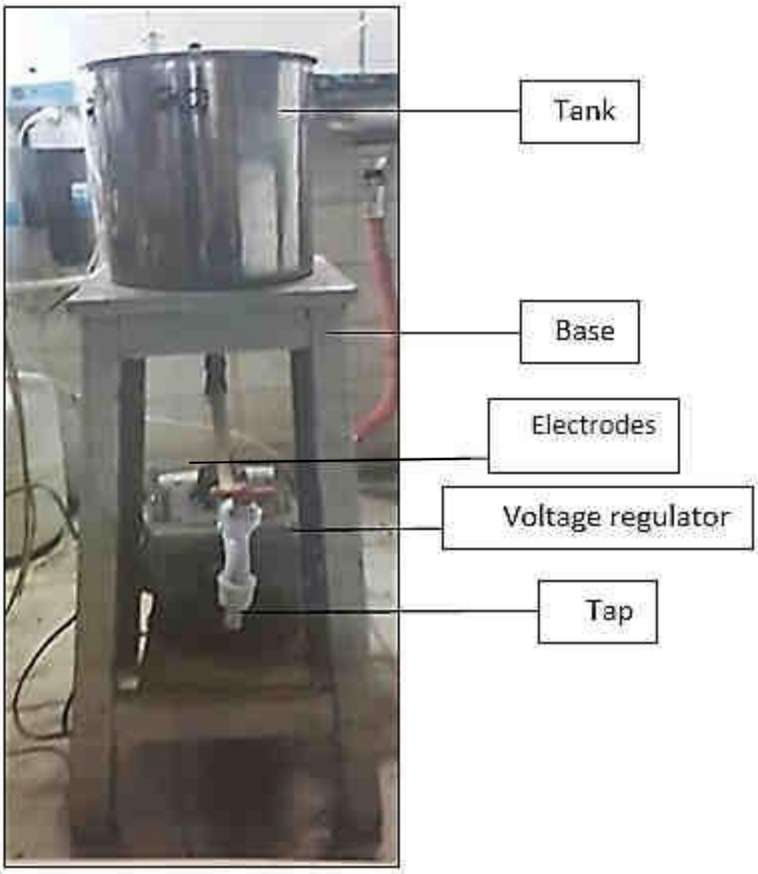


Figure 1. Photograph of non-thermal sterilizer

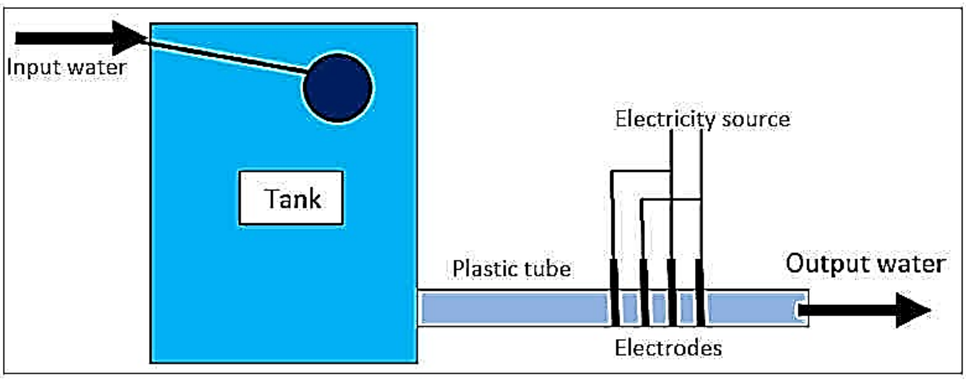


**Figure 2. Schematic of continues non-thermal water sterilizer.**

**Microbial tests**

Four samples of water treated by electric field of 50, 70 and 100 $Vcm^{-1}$ have been prepared in sterilized test tubes. Coliform and *E*. coli were enumerated in water samples by using 3M™ Petrifilm™ Coliform/*E. coli* Count Plates (3M Microbiology, USA) while 3M™ Petrifilm™ Aerobic Count Plates AC (3M Microbiology, USA) were used for the enumeration of total aerobic plate count. One mL of each of the diluted water samples was placed on to Petrifilm™ Plates and incubated at 37°C for 24 h for coliform and *E. coli* Petrifilm3M™ Petrifilm™, Aerobic Count Plates AC were incubated for 24 – 48 h.

**Calculation of survival microorganism's ratio to total:**

Survival microorganism ratio to total ($C/C_T$) can be calculated by the equation (3) (Ferna'ndez-molina et al., 2001):

$$\left(\frac{C}{C_T}\right) = exp.\left(kV\frac{t}{Q}\right) \qquad (3)$$

The relationship between outlet microorganisms and time is exponential (Esplugas et al., 2001).

Because our study has focused on the effect of electric field on the destruction of microorganisms, so the k in equation (4) can be expressed by $1/Vcm^{-1}$ instead $s^{-1}$, as well as we have entered the electric field in equation (4) as follow:

$$\left(\frac{C}{C_T}\right) = exp.\left(\frac{-kVE_f t}{Q}\right) \qquad (4)$$

Equation (4) is a new equation can describe the effect of electric field on the Survival microorganisms' ratio. Where, $E_f$ is the electric field ($Vcm^{-1}$), V is the treatment chamber volume ($m^3$), k is the constant ($s^{-1}$), t is the treatment time (s) and Q is the discharge ($m^3/s$). The constant k has been predicted by using solver program in excel 2013.

**Rate of microorganisms' destruction**

Rate of microorganisms' destruction was calculated from the following equation (Esplugas et al., 2001):

$$r = -kc \qquad (5)$$

Where, r is the rate of microorganisms' destruction (CFU $ml^{-1}$)/L $s^{-1}$). C is the microorganisms' numbers (CFU $ml^{-1}$).

**Calculation of reducing microorganism percentage**

Percentage of reducing microorganism has been calculated from the following equation:

$$SR\ (\%) = \frac{(N_1 - N_2)}{N_1} \times 100 \qquad (6)$$

**Statistical analysis**

The complete randomize design has been used to analyze data statistically. Least significant differences test at 0.01 significant level was used to compare among treatments (Al-Rawi and Khalfallah, 2000). The statistical analysis was carried out by using one way ANOVA in SPSS statistical program (SPSS, 2009).

**Results and discussion**

**Electric conductivity**

Figure 3 shows the relationship between the electric conductivity ($Sm^{-1}$) and electric field ($Vcm^{-1}$), as well as current (A). Electric conductivity was insignificant decreased with the increase of the electric field. This simple influence because of the voltage has increased with the increase of electric field where led to decrease the electric conductivity, as shown in the following equations:

$$\sigma = \frac{I\ d}{V\ A} \qquad (1)$$

$$\sigma = \frac{I}{E_f A} \quad (7)$$

The electric conductivity has an important role in an inactivation of microorganisms. (Machado et al., 2010). Castro et al. (2004) have found that the differences between electric conductivity for strawberry-apple sauce and strawberry at different electric fields were not significant at temperature range of 22 – 100 °C, but they found a significant effect of electric field on the electric conductivity of strawberry filling. The variations in the electric conductivity values with electric field depends on the salts, temperature, current, voltage, pH, food properties. Castro et al., (2003) have stated that the electric conductivity decreases with the increase of the electric field due to presence of air bubbles at increase of electric field. When the air bubbles increase, the electric conductivity decreases (Icier and Ilicali, 2005).

The results also have showed that the electric conductivity has ranged between 0.127- 0.159 $Sm^{-1}$ and the electric current ranged between 0.20 – 0.40 A. There is no studies about effect of electric field on the electric conductivity of water as a non-thermal treatment. There are many researches have studied the electric conductivity versus electric field such as Castro et al. (2004) for strawberry-apple sauce, Icier et al. (2008) for milk, Mohsin, (2012) for milk, Abdulsattar, (2014) for milk and Al-Hilphy et al. (2015) for wheat bran.

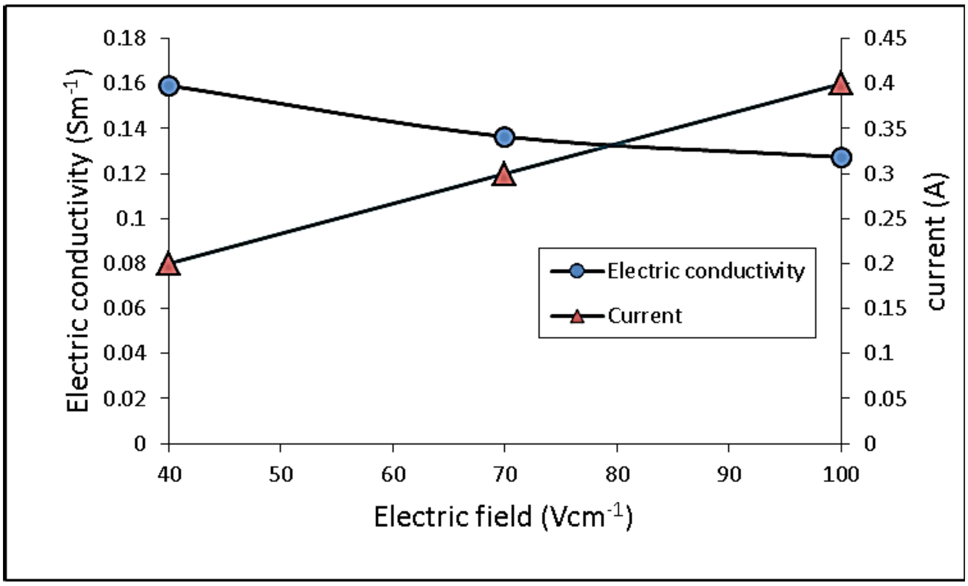


Figure 3. Electric conductivity of water vs. electric field.

**Total Bactria count**

Figure 4. Illustrates the Log of total Bactria count ($CFUml^{-1}$) has reduced with the increase of the electric field ($Vcm^{-1}$). This is because of electroporation on the cells membranes by the electric current and electric field. Moreover, electroporation happens due to exceed of the specific dielectric strength in the cells membranes because of the increase of the electric field. Specific dielectric strength of cells membranes is bounded to the quantity of lipids in the membrane (lipids make the membrane as an insulator).forming varied pores in size on the cell membrane due to the applied electric field intensity, but the pores can be closed after a little period. when the cell membrane is exposure to electric field for long time, the leakage occurs in the cell membrane and leads to death of cells (Lee and Yoon, 1999).These results have agreed with Cho et al. (1999); Wouters et al. (2001); Gowrishankar et al. (2005) Pereira et al. (2007); Huixian et al. (2008); Luis Machado et al. (2009) and Al-Hilphy (2013) who stated that the reduction in numbers of microorganisms happens by the moderate electric field. Abdulstar (2014) has noticed that the total count of bacteria in milk decreased significantly with increasing electric field intensity, where number of Bactria is decreased to zero by using electric field.

The results also indicated that the relation between Log of total Bactria count and electric field is exponential with $R^2$=0.9938 as shown in figure (4) and the equation (8):

$$Log(CFU\ ml^{-1}) = 6.4255e^{-0.017Ef} \qquad (8)$$

Where, $E_f$ is the electric field ($Vcm^{-1}$).

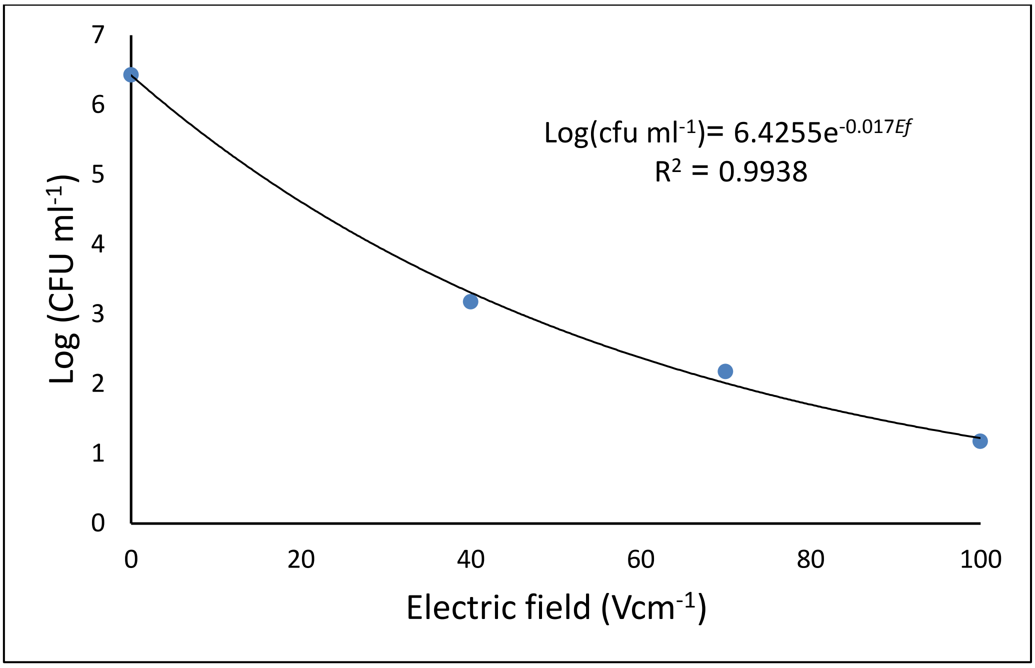


Figure 4. Total Bactria count vs. electric field.

**Total Coliform bactria and *E.coli*.**

Table 1 shows effect of electric field on the total coliform bactria and *E.coli* (CFU $ml^{-1}$). The results have showed that the total coliform bactria and *E.coli* were $4\times10^2$ CFU $ml^{-1}$ and $1\times10^1$ CFU $ml^{-1}$ respectively for control treatment, then reduced to nil at electric field of 40, 70 and 100 $Vcm^{-1}$. This influence because of passing electric current into the water and generated electric field led to eliminate all the microorganisms due to the electroporation on them. These results have agreed with Machado et al.( 2010) who stated that the alternative current eliminated *Escherichia coli* at 25 $^oC$. also, they found that the *Escherichia coli* has decrease with the increase of the electric field because the electric field causes changes into the cell membrane ranged between 0.1 – 50 μm.

Table 1. Effect of electric field on the total coliform Bactria and E.coli.

| Electric field ($Vcm^{-1}$) | Total coliform Bactria (CFU $ml^{-1}$) | E.coli (CFU $ml^{-1}$) |
|---|---|---|
| Control | $4\times10^2$ | 10 |
| 60 | Nil | Nil |
| 80 | Nil | Nil |
| 100 | Nil | Nil |

**Mathematical modeling of survival microorganism ratio to total**

The relation between the survival microorganism ratio to total ($C/C_T$) and electric field has shown in figure (5). The experimental and predicted of survival microorganism ratio to total has significantly decreased with the increase of electric field. Reducing $C/C_T$ ratio is due to the electroporation of microorganisms by the electric field. The results also showed that the experimental $C/C_T$ ratio was convergent with predicted $C/C_T$ ratio. Moreover, Values of statistical parameters have a goodness fitting between the mathematical model data and the experimental fitting, i.e. the determination coefficient ($R^2$), root mean square error (RMSE) and chi square ($x^2$) were reached 0.991591, 0.00010503 and $5.52\times10^{-9}$ respectively. On the other hand, the constant k was 0.1259124 ($1/Vcm^{-1}$) as shown in table 2. Equation (4) can be written as follow:

$$\left(\frac{C}{C_T}\right) = exp.\left(-0.1259124\frac{VE_f t}{Q}\right) \quad (9)$$

The proposed equation (9) is a novel equation used to describe the effect of the electric field intensity on the $C/C_T$ ratio. Results of the new equation (9) at Q=0.00008 $m^3s^{-1}$, V=0.000157 $m^3$ , t=0.5 s, k=0.1259124 1/$Vcm^{-1}$ and $E_f$ has ranged between 0-230$Vcm^{-1}$ are given in table 3.

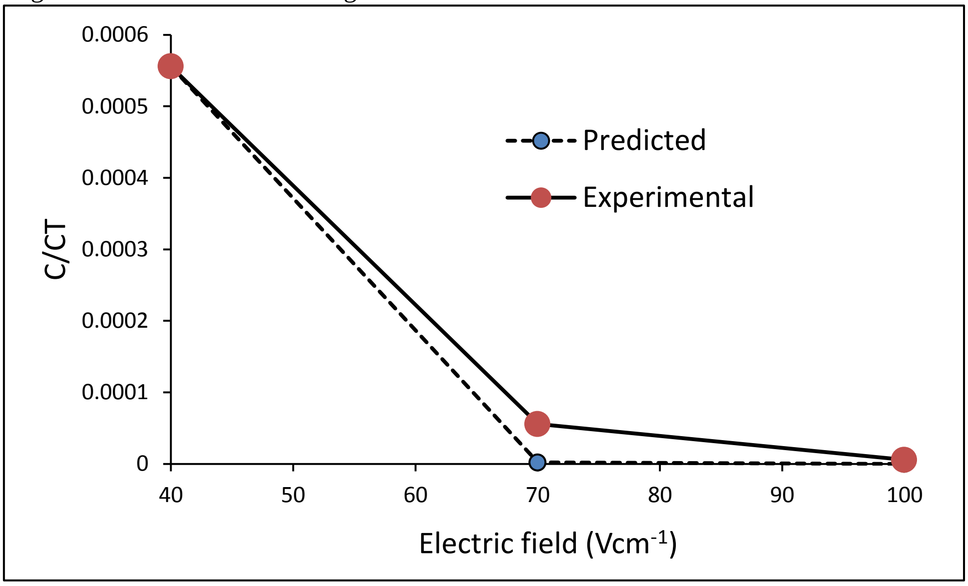


Figure 5. Survival microorganism ratio to total vs. electric field.

Table 2. Statistical parameters for fitting the mathematical model data with the experimental

| k (1/$Vcm^{-1}$) | RMSE | $X^2$ | $R^2$ |
|---|---|---|---|
| 0.1259124 | 0.00010503 | $5.52\times10^{-9}$ | 0.991591 |

Table 3. Results of the new equation (9) at Q=0.00008 $m^3s^{-1}$, V=0.000157 $m^3$ and t=0.5 s.

| $E_f$($Vcm^{-1}$) | $C/C_T$ |
|---|---|
| 0 | 1 |
| 10 | 0.290685 |
| 20 | 0.084498 |
| 30 | 0.024562 |
| 40 | 0.00714 |
| 50 | 0.002075 |
| 60 | 0.000603 |
| 70 | 0.000175 |
| 80 | 5.1E-05 |
| 90 | 1.48E-05 |
| 100 | 4.31E-06 |
| 110 | 1.25E-06 |
| 120 | 3.64E-07 |
| 130 | 1.06E-07 |
| 140 | 3.08E-08 |
| 150 | 8.94E-09 |
| 160 | 2.6E-09 |
| 170 | 7.55E-10 |
| 180 | 2.2E-10 |
| 190 | 6.38E-11 |
| 200 | 1.86E-11 |
| 210 | 5.39E-12 |
| 220 | 1.57E-12 |
| 230 | 4.56E-13 |

 

**Rate of microorganisms' destruction**

Figure 6 shows the relationship between the rates of microorganisms' destruction (CFU/L $s^{-1}$) and electric field ($Vcm^{-1}$). The rates of microorganisms' destruction ranged between -281 to -2.81 CFU/L $s^{-1}$ when the electric field ranged between of 40 to 100 respectively. The negative sign refers to reduce of microorganisms. The reduction occurs by electric field effect. It can be seen from Figure 7 that the electric field has significantly effect on the reduction percentage of microorganisms. Range of reduction was 99.94 – 99.99% for electric field range of 40-100 $Vcm^{-1}$.

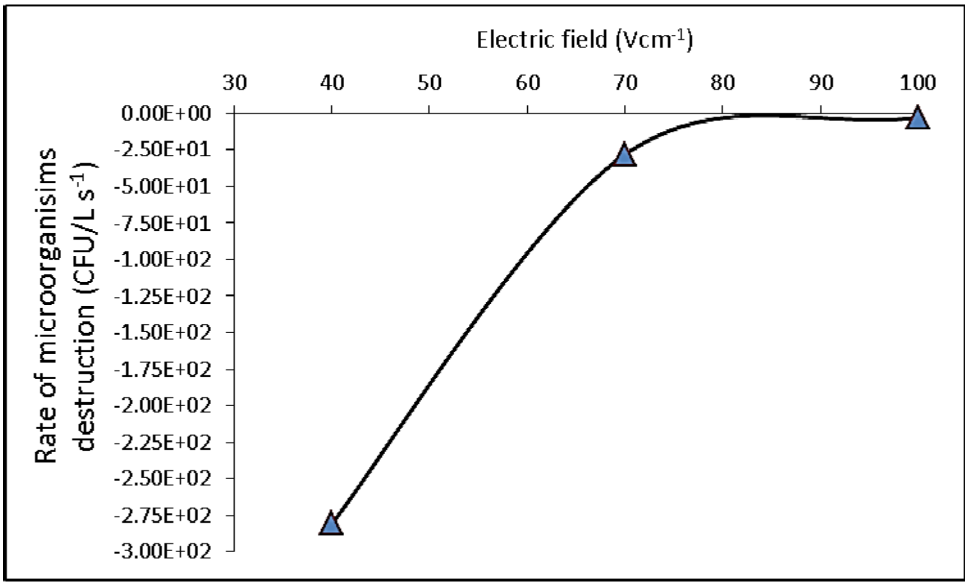


Figure 6. Rate of microorganisms' destruction vs. electric field.

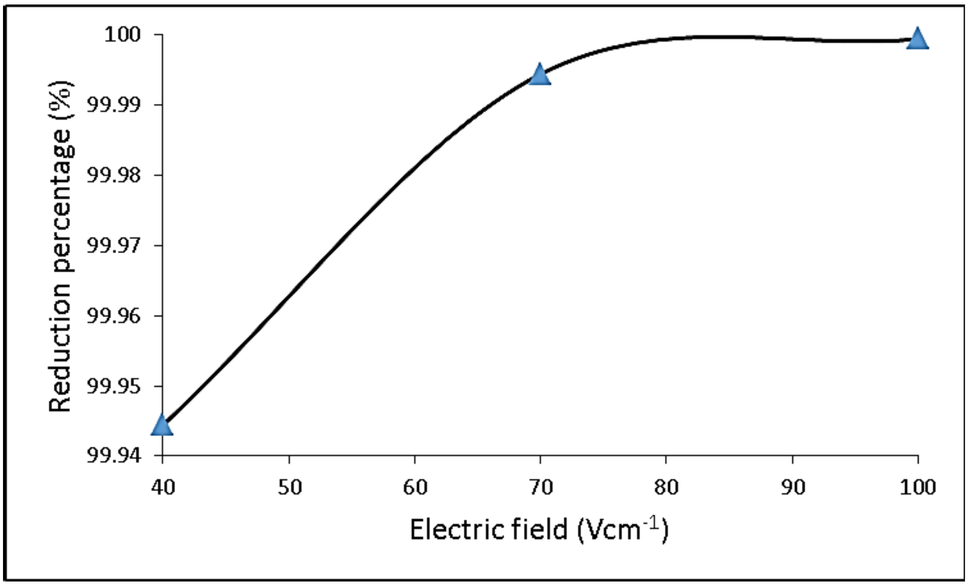


Figure 6. Reduction percentage of microorganisms vs. electric field.

## Conclusions

In conclusion, the electric field has a significantly effect on elimination of microorganisms. The new proposed equation has a goodness fitting with experimental data and it can be used to predict the survival microorganism ratio to total at any electric field value. The continuous non-thermal sterilizer for drinking water has a high efficiency to eliminate microorganisms.

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