Removal of Escherichia coli via low frequency electromagnetic field in riverbank filtration system.

Rossitah Selamat¹, Ismail Abustan¹*, Mohd Rizal Arshad², Nurul Hana Mokhtar Kamal¹

¹School of Civil Engineering, USM, 14300 Nibong Tebal, Penang, Malaysia.
²School of Electrical Engineering, USM, 14300 Nibong Tebal, Penang, Malaysia.

E-mail: ceismail@usm.my

Abstract. The removal of Escherichia coli (E. coli) via low frequency of electromagnetic field (LF-EMF) with different magnetic field was studied. LF-EMF is known as a high magnetic susceptibility method, which could affect E. coli growth without the usage of chemicals. The aim of this study was to investigate the removal of E. coli by using LF-EMF in water abstraction for the riverbank filtration (RBF) application. The effect of LF-EMF with the intensity of 2 to 10mT and 50Hz on coiled column of 1mm copper wire at 1 to 6 hours was assessed. The removal of E. coli after exposing to LF-EMF on the column model was measured using most probable number (MPN/100mL) and colonies forming unit (CFU/100mL) methods. Water flows into the column were varied up to 6 hours and with flowrate of 100 mL/min. Experimental results demonstrate that 100% of E. coli was removed at 8mT after 6 hours exposure. The magnetic field at 10mT removed 100% of E. coli after 4 hours exposure. The results obtained in this study proved that the LF-EMF was efficient in E. coli removal from RBF system. These finding indicated that the LF-EMF intensities and time of exposure can affect the removal of E. coli.

1. Introduction

One of the most demanding global environmental and health issues nowadays is the demand of clean drinking water. Due to the evolution in technologies, the problems of drinking water supply are being actively addressed around the world through different treatment technologies being developed. One of the growing interest to water utilities is the implementation of riverbank filtration (RBF). Europe uses (RBF) system as a pre-treatment technology preceding more advanced treatment operations for more than 100 years [1]. Moreover, in the United States, RBF systems have been operated for about half a century, and often provide the only treatment other than chlorination and fluoridation prior to consumption [2]. From literature, high potential for removal of fraction of bacteria, organic matters and total suspended solids from surface water have shown high potential by using the riverbank filtration method [3]. Based on the findings of Wang et al [4], magnetic field at induction of 0–20.0 mT had a positive effect on the growth of mixed bacteria in the activated sludge collected. According to the literature as well, the results revealed that the RBF system removal occurs primarily due to the bacterial at the water and media interface [5]. However, due to the persistent problem of exceeding the regulatory limits for bacteria, RBF should be considered a pre-treatment method and combined with conventional disinfection technologies [6]. From this study, LF-EMF is proposed to be introduce on a water column as a new application for bacteria removal/treatment in RBF system.

Gaafar et al [7] find that a decrease in the cell growth an increase of mortality rate on E. coli growth when LF-EMF of 50 Hz with 2 mT for 6 hours and 16 hours exposure. According to Belyaev [8], the
effects of 7–11 Hz EMF with 2 mT affected to cell growth of *E. coli* after 3 hours and 40 minutes exposure [8]. Aslanimehr et al [9] also claimed the effects of LF-EMF of 50 Hz with 2 mT decreased the cell growth of *E. coli* after 6 and 24 hours exposures [9]. In another study by Nafisi et al [10], they found that growth of *E. coli* was decreased after the exposed to 6 hours of 10Hz EMF with 700 miligauss. Akan et al [11], carried out a study concerning the effect of EMFs (50 Hz; 0.5mT) on *S. aureus* and *E. coli*. They found that the growth rate of viability was reduce when the bacterial are exposed to EMF over to 6 hours. Furthermore, Martirosyan et al [12], investigated the LF-EMF (2, 4, 6, 8 and 10 Hz ; 0.4 mT) on stimulated cell growth of *E. coli*. The results showed that the LF-EMF had effects on the bacterial growth. Thus, based on these previous studies, this current study had chosen the frequency of 50 Hz, magnetic field, B, of 9 mT, exposure time ranged between 1-6 hours and a constant water flowrate, Q of 100ml/min to determine the removal of the *E. coli* by using most probable number (MPN) and colony forming unit (CFU) method for river and tube well from RBF water. Standard methods, such as m-TEC agar and IDEXX Colilert-18 used to examine the effect of LF-EMF on *E. coli* [13].

2. Materials and Methods

2.1 Study Area

The study area was situated in Lubok Buntar, Kedah. The source water was from Sungai Kerian. Sungai Kerian is a main tributary of Kerian basin in Perak. This river is providing potable water for residents of Parit Buntar, Nibong Tebal and Bandar Baharu in Kedah. This river originated from the hilly headwaters at Mahang, Kedah, and flows through Lubok Buntar area and down to Kerian Valley in Parit Buntar, Perak. Sungai Keria is also the main water body that acts as a boundary between the states of Perak, Kedah, and Penang.

2.2 Electromagnetic Field

The magnetic fields were generate from the coiled column as shown in figure 1. A magnetic field power generating system transformed the magnetic field from the coil. The maximum of effective current was 2A at 50 Hz frequency. The magnetic generator consisted of a pair of solenoid coils, a current amplifier and a waveform generator controller. The samples were exposed and placed in column pipe where uniformity of the magnetic field is optimal. The magnetic field distributions inside the coil was applied at different current values. The magnetic field of solenoid coils was employed with 80mm mean radius. In each coil, the number of turns were 600 with 1 mm diameter copper wire. The resulting of resistance was at 1Ω and 2-10 mT inductance as shown in figure 1.

![Figure 1. Electromagnetic Field Circuit](image)

a. Sampling

Eighty-one samples were collected during wet and dry seasons from Sungai Kerian and tube well
starting on February 2016, to December 2016. The water samples were collected, transported and stored in strict accordance with the guidelines described by Standard Methods WHO [14]. Sterile glass flasks were used to collect the samples. These samples were preserved in accordance with Water and Wastewater Standards and then stored at a temperature of less than 4°C. All laboratory apparatus used in this study were prewashed with 5% nitric acid (HNO₃) and rinsed with deionized water prior to testing base on the standard Method for Water and Wastewater, APHA [15].

2.3 Column set-up and operation
Column set-up for the experiment in this study presented in table 1. The plastic column with a 80 mm diameter and 500 mm height were used. The column was exposed to LF-EMF generated by solenoid coils with mean radius of 50 ± 0.5 mm. In each set of coils, the number of turns was 600 from the copper wire wound giving a resulting resistance of 1Ω and an inductance of 2-10 mT. The set-up of this column was composed by using controls of alternating current (AC) generator. The generator generated an effective magnetic field in the range 0–10mT, with a sinusoidal wave of frequency of 50Hz. The constant and steady flow rate of 100 ml/min of water sample was maintained using peristaltic pumps connected to horizontal column.

| Table 1. The parameter of magnetic column for LF-EMF generated system. |
|---------------------------------|
| Diameter of column, \( D_{column} \) | 80 mm |
| Length, \( L \) | 500 mm |
| Number of turn, \( N \) | 600 |
| Diameter of wire, \( D_{coil} \) | 1 mm |

2.4 Modified m-TEC Membrane Filter (Standard Method 9213D)
The original m-TEC Agar enumeration method for \( E. coli \) [16] was used. The 81 water samples has collated and filtered through the membrane filter for retains the \( E. coli \). The membrane filter containing the \( E. coli \) was place on a selective and differential medium of m-TEC Agar plate after filtered. The filter was transfer to modified m-TEC agar plate and the plate was initially incubate for 2 hours at 35°C and then 22 hours at 44.5°C. Magenta-coloured colonies visible after incubation was counted as \( E. coli \) and reported as colony-forming units (CFU) per 100 millilitres (USEPA, 2002) [17].

2.5 Colilert-18 / Quanti-Tray 2000 (MPN method 9223B)
The \( E. coli \) quantity was also determined by using the Colilert-18 method that was approved by the USEPA (2002) for used of \( E. coli \) detection in drinking water. The most probable number (MPN) test was applied to test the \( E. coli \) concentration in water using Quanti-Tray recommended by the IDEXX package insert. In this method, \( E. coli \) was measured by calculating the occurrence of one or more bacteria colonies in small- and large-discrete wells of the Quanti-Tray that caused colour development in those wells. The density of bacteria is determine by positive wells statistically. Reaction of the chemical based on defined substrate technology. Undiluted water samples of Sungai Kerian was used to estimate the number of \( E. coli \) using Quanti-Tray 2000 trays that divides the sample into 49 large and 48 small wells. The \( E. coli \) enzyme reacts with a fluorogen, which caused the medium to fluoresce under a long-wave ultraviolet (UV) light (366 nm). The samples were incubated for 18 to 22 hours at 35°C. The sample was then examined under UV lamp to observe the fluorescent well. From the observation, wells in only yellow colour indicated coliform bacteria existence, while the wells are in yellow and fluorescent, indicated the presence of \( E. coli \).
2.6 Statistical Analysis
All results were presented as data recorded in concentration of \( E. coli \) removal (MPN/100mL) and were statistically analysed using one-way ANOVA. In order to compare the analysis method m-TEC and colilert®-18, a paired t-test was performed. Regressions liner between CFU/10 mL and MPN/100 mL were drawn in order to determine the removal of \( E. coli \) by ANOVA and t-test. Parametric and non-parametric statistics provided the similar results and conclusions. From the results, a significantly different at \( p<0.05 \) were considered.

3. Results and Discussion

3.1 Comparison of Colilert-18® and Modified m-TEC
Result from statistical analysis was indicate the concentration of \( E. coli \) removal has no statistical significant difference (\( p=0.5 \)) and has a strong positive correlation (\( R^2=0.96 \)) in the \( E. coli \) enumeration result between the Colilert-18® and Modified m-TEC method. The significant correlations and linear relations of \( E. coli \) removal between the two results were essential equal and statistically equivalent performances in this study as illustrated in figure 2. Furthermore, correlation coefficients of \( E. coli \) removal showed strong significant relationship between these two methods. From these results, both Colilert-18® and Modified m-TEC method can be applied to enumerate for \( E. coli \) densities in water treatment. The Colilert-18® method provided the most similar assessment of recreational water quality to m-TEC method. In a similar finding, Francy et al. [18] Colilert-18® and m-TEC method provided the same assessment of water quality in the low- and middle-range groups, although the biggest difference in range and the false-negative rate for correctly assessing recreational water quality was greater than 5%.

![Figure 2. Correlations of E. coli removal using Colilet-18® and m-TEC agar](image)

3.2 Growth of \( E. coli \)
From the observation, it shows a decrease of \( E. coli \) MPN/100mL (figure 3) and CFU/100mL (figure 4) for exposed samples. Different effects on the growth of \( E. coli \) after exposure to LF-EMF can be seen at magnetic field of 10mT, 8mT, 6mT and at different time exposure. It was shown that \( E. coli \) growth after LF-EMF exposure was more visible at 2mT and 4mT of magnetic field.
Figure 3. Concentration of *E. coli* removal in the treated and control samples at the frequency of 50Hz and 2, 4, 6, 8, and 10 mT of EMF, using IDEXX colilert-18.

Figure 4. Concentration of *E. coli* removal in the treated and control samples at the frequency of 50Hz and 2, 4, 6, 8, and 10 mT of EMF, using m-TEC agar method.

From the experiment, the results showed that as the exposed samples of raw water from Sungai Kerian had high initial *E. coli* concentration values. In this case, after 4 hours of LF-EMF expose, it shows a significant increase in the percentage (16-92%) of *E. coli* removal. Percentage of *E. coli* removal was 100% for 8mT after 6h exposure and 10 mT after 4 hours exposure. It is show that with longer time...
of exposure, more on *E. coli* were removed. From one-way ANOVA analysis, it was proven that the LF-EMF had significantly remove the concentrations of *E. coli* (*p*<0.05). The results obtained in this current study proved that LF-EMF was effective in controlling *E. coli* growth.

In a similar finding by Fojt et al. (2004), concerning the LF-EMF effect (50 Hz; 10 mT) on *E. coli*, the concentration was 95% reduced when the *E. coli* exposed to LF-EMF for more than 30 min and the highest reduction observed for *E. coli* [19]. In another study, application of LF-EMF with 10 Hz after 6 hours had proven that the growth of *E. coli* was decreased with 110 kHz of frequency applied[10]. Another previous study also proved the oscillating magnetic field affected different bacterial strains in lag-phase of their growth according to the expose time [20]. The results of this study showed that LF-EMF has positive effects on growth rate of *E. coli*. From the *E. coli* removal data, the effects of LF-EMF on *E. coli* showed significant inhibition in the growth of electromagnetic field exposure (50 Hz -8mT) as compared with other intensities, as shown in figures 3 and 4. This result study indicate that LF-EMF induction had a great effect on the biological activity of *E. coli*.

4. Conclusion
By applying LF-EMF, it can decreased the growth and remove the *E. coli* depending on time of exposure. In this study, the measurable effects of magnetic field exposure on *E. coli* in the river water has been identified. The LF-EMF decreased the concentrations of *E. coli*, and slowed down their growth. This demonstrated that the LF-EMF has significant effect on the *E. coli* growth. The removal reached 100% for 8mT after 6h exposure, and 10mT intensity after 4h exposure at 50 Hz and 100 ml/min of flowrate, respectively. The effectiveness of reducing *E. coli* in this study increased with longer time of exposure. Thus, it can be concluded that the effects of LF-EMF to decrease *E. coli* concentration depended on the frequency, magnetic field intensity and the time of exposure. From the results, These conditions indicated larger magnetic field and longer time of exposure can better remove *E. coli* concentration in RBF water. Therefore, further investigations should performed to examine the combined action of LF-EMF with other physical, chemical or biological solution on biological systems. As a recommendation, future study should be performed to compare the effect role of LF-EMF in *E. coli* growth with different flowrate and size of column.

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