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Effect of Pulse Electric Field on Water Characteristics as a Disinfection Function in Filtration Unit

Ghassan Abukhanafer [a*], **Alaa H. Al-Fatlawi** [b], **Hassan H. Joni** [c]

[a] Sanitary and Environmental Engineering, Dept. of Civil Engineering, University of Technology, Iraq.

engghassanmoh@gmail.com

[b] College of Engineering, Environmental Engineering Department, University Babylon, , Iraq.

eng.alaa.husaeen@uobabylon.edu.iq

[c] Department of Civil Engineering, University of Technology, Iraq.

40317@uotechnology.edu.iq

*Corresponding author.

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KEYWORDS

Filtration unit, Escherichia coli, pulse electric field, water characteristic.

ABSTRACT

This paper studied the impact of the addition of pulse electric-filed low voltage (PEF-LV) in the filtration process by designing, constructing, and operating a pilot-scale. The Disinfectant process (DP) demonstrated several benefits in terms of efficiency and ease of application, without the use of any chemical additive. This system contains two pairs of silver mesh electrodes inside the filtration column test with a low pulse voltage for killing microorganisms. The parametric effects of DP performance, such as alternating current pulse frequency and the voltage applied were investigated. The effect of PEF-LV on the biological, physical, and chemical characteristic of water was studied. The transmission electron microscopy (TEM) was used to examine the change of the cell wall morphology of Escherichia coli, Staphylococcus aureus cells for influent, and treated water. The results show the removal efficiency of E. coli and S. aureus 96 % at 30 V and 0.5 Hz.

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1. INTRODUCTION

Today, the world is facing challenges in meeting increasing demands of drinking water as the available supplies of freshwater are exhausting due to lack of rain, population growth, and more stringent health-based regulations [1-3]. Clean water is vital to human health; the presence of specific bacteria in drinking water is an indicator of its contamination. Insufficient treatment, cross-contamination, and poor maintenance of the distribution network are all common causes of fecal contamination of drinking water [4-6]. The assessment of fecal contamination of drinking water relies on indicator bacteria such as coliforms, Escherichia coli, Shigella, Salmonella, Vibrio, and Protozoa (Cryptosporidium) which leads to the spreads of diseases such as giardiasis, cholera, cryptosporidiosis, gastroenteritis, etc., [7, 8].

The inactivation and removal of microorganisms are the last steps in the treatment of drinking water. Various disinfection technologies are classified into chemical and physical processes, including chlorine, ozone, chlorine dioxide, and ultraviolet (UV) radiation [9].

Researches in the past decades have shown a problem between effective disinfection and the formation of harmful disinfection byproducts (DBPs). When chlorine comes in contact with natural organic matter (NOM), carcinogenic compounds such as trihalomethanes (THMs) and haloacetic acids (HAAs) can be formed [10, 11]. Chemical disinfectants commonly used by the water industry such as free chlorine, chloramines, and ozone can react with natural organics in the water to form DBPs, many of which are carcinogens [12]. The ideal disinfectant must exhibit the following properties: Broad antimicrobial ability at ambient temperature within a short time. It should not generate any harmful by-products during and after its use. Easily applicable and inexpensive for the intended use. Highly soluble in water, easy to store, must not be corrosive for any equipment or surface, and amenable to safe disposal. It is, necessary to search for more safe techniques to kill microorganisms as well as to reduce the dose of chemical additives, decreasing the cost of chemicals avoiding byproduct formation, and residual toxicity of the effluent [13]. The application of the electric field on particle removal is widely applied in the air–particle systems such as electrostatic precipitators (ESPs). nevertheless, in the liquid–particle system, this system has received much less attention, probably because of the limitation in applying a different range of voltage in the water media as well as the higher viscosity of water [14, 15]. This study investigated pilot-scale using PEF-LV as a disinfection function in the filtration unit for drinking water.

2. MATERIALS AND METHODS

I. Materials

The materials used in DP comprises two parts (i) the experimental setup, and (ii) the experimental laboratory. The first and second part was done at the University of Technology laboratory/ Baghdad and laboratory of the ministry of science and technology/environmental research/food contamination, Table 1 clarified these parts.

II. Method

A pilot-scale of the DP was designed and constructed to simulate the disinfection processes in the filtration unit (rapid sand filter). A water tank of 500 L was set beside the unit and used as the reservoir. The influent flow rate was controlled by the flow meter between the water tank and the pipe test. The influent water was raw water from Al Hilla river. The influent water was passed through sand media and disinfected through the pipe test between two pair mesh electrodes by pulse electrical field. The mesh electrodes were alternatively connected to the positive and negative output of the power supply. Voltage change control (0-30 V) was used for controlling the applied voltage along with a pulsed electric device with a different mode of frequency.

The mechanisms of DP illustrate as follows i) the PEF-LV works holes then ruptures the external wall of the microbial cell, leading to the leakage of the inner contents and resulting in the death of the microorganisms. The cells of microorganisms are destroyed, resulting in the reduction of the growth and reproduction of the microbes contributing to the infection and, ii) the water effluent for the experiments period of eight months (Dec. 2018 – July 2019) was tested. (Figure.1) was shown mechanisms of DU.

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TABLE I: The materials that utilized in the experimental setup and experimental laboratory.

Materials in the experimental setup	Information
silver mesh	wires (electrode) 1.35 m length/unit made of pure silver with 99% purity.
pipe test	polyvinyl chloride (PVC) diameter of 0.15 m, length 2 m, a cross-section area 0.0176 m^2.
filter media	Conventional filtration (local sand and support gravel) [27]
Adapter power	voltage change regulator model 001
pulse frequency device	model (kb-sk07) measure the number of pulse per second.
power supply	Alternating current AC
inlet and outlet pipe	PVC diameters of 0.0125 and 0.0375 m,
influent water	water from filtration process
water tank	500 L stainless-steel
flow meter	(0.25-4 Lpm)
water pump	Flow rate 10-30 L/min, head 4-30 m, the maximum liquid temperature 40 ± 1ºC.
Materials in experimental laboratory	**Information**
E. coli and S. aureus cells	MacConkey agar plate and Urinary Tract Infections (UTIs) media
Temperature (ºC)	Digital Pen Thermometer
pH	pH meter (HI 110 series)
Electrical Conductivity Ec. (µmohs/cm)	C270 Conductivity
Alkalinity As (caco$_3$) (mg/l)	Phenolphthalein reagent
Hardness As (caco$_3$) (mg/l)	titration with EDTA (ethylenediaminetetraacetate acid)
Cl. (mg/l)	titration with a silver nitrate solution
Ca (mg/l)	titration with EDTA (ethylenediaminetetraacetate acid)
Mg (mg/l)	titration with EDTA (ethylenediaminetetraacetate acid)

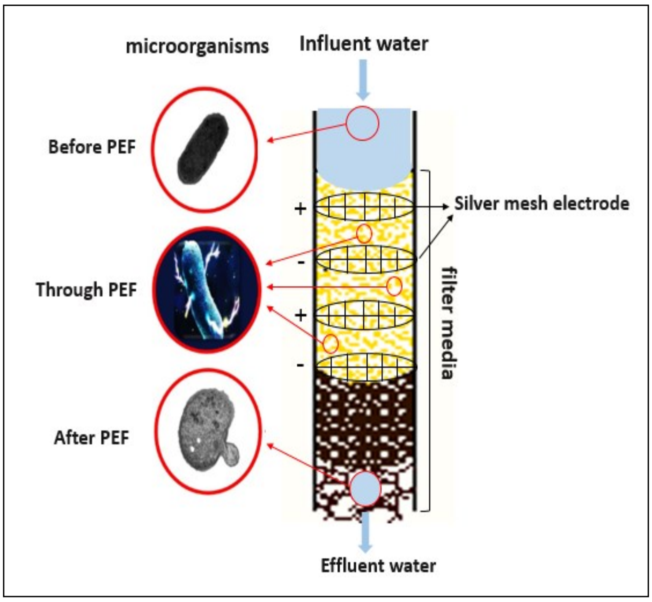

Figure 1: Mechanisms of Disinfectant process between sand media.

3. RESULTS AND DISCUSSION

In this paper, several parameters such as i) the effect of applied voltage and AC pulse frequency were investigated. ii) the biological, physical, and chemical characteristics of water before and after the disinfection process were tested.

I. Effect of applied voltage and alternating current (AC) pulse frequency

The pressure from an electrical circuit power source that pushes charged electrons (current) through a conducting loop is called voltage and it is measured in volts (V). While the number of pulse per second in an AC sine wave is known as AC frequency. It is the rate at which the current changes the direction in a second, and it is measured in hertz (Hz) [16]. The applied voltage and AC play an important role in DU performance, as it is the main contributing factors to the applied electric field strength [17, 18]. The effect of pulse frequency changing from 0.5,1 and 2 Hz to DP performance at different applied voltages (0-30 V) with a two pair of silver electrode mesh were tested. At these frequencies, the corresponding exposure time was 2, 1, and 0.5 seconds respectively. Therefore, 0.5 Hz was selected as the optimal frequency because the amount of time for which a bacteria cell was exposed increased according to Planck's formula (Eq. 1) [19]. Due to giving high removal efficiency of E. coli and S. aureus.

$$\text{Frequency} = \frac{1}{\text{Time (s)}} \tag{1}$$

Increasing the applied voltage to 30 V at 0.5 Hz yielded better removal efficiencies of E. coli and S. aureus. The results of disinfection were approximately the same value 96%. These results are consistent with researchers [20-22]. Figure 2 demonstrates that the relationship between applied voltage and AC with removal efficiency.

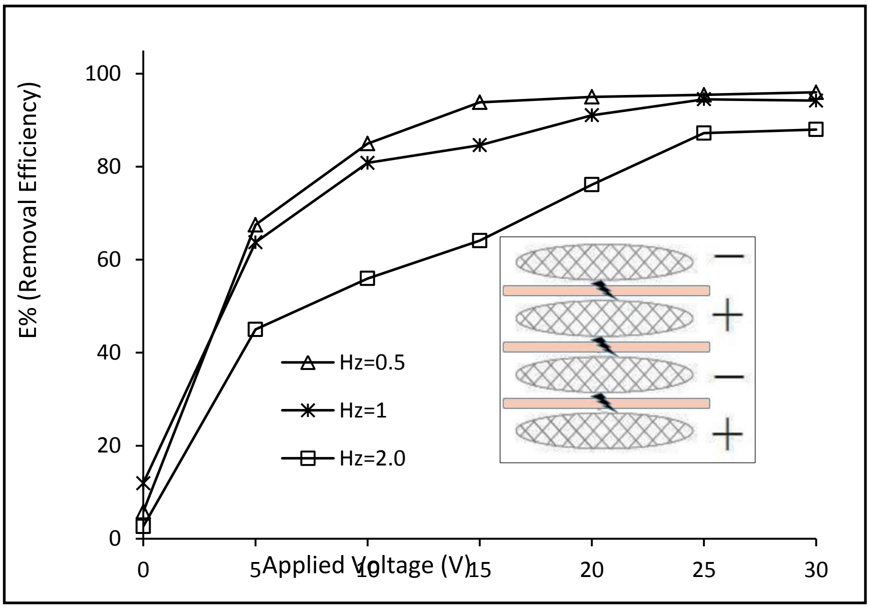

Figure 2: the effect of applied voltage and AC pulse frequency on the removal efficiencies of E-coli and S. aureus ▬, electric field area ▨ meshes electrodes.

II. Characteristics of water

A. Biological test

This paper used transmission electron microscopy TEM to show the status of microorganisms before and after the disinfection process. Figure 3 and 4 illustrate micrographs of E. coli and S. aureus, the change in the cell wall morphology in the influent water (it was a normal cell shape with an undamaged structure of inner and intact outer membrane) and that in effluent water was peptide-induced breakage and roughness in the cell wall. Increasing damage to the microorganism cell wall was evident in the form of cracks developed by the rising voltage to 30V. Cell shrinkage due to the loss of turgor was also noted.

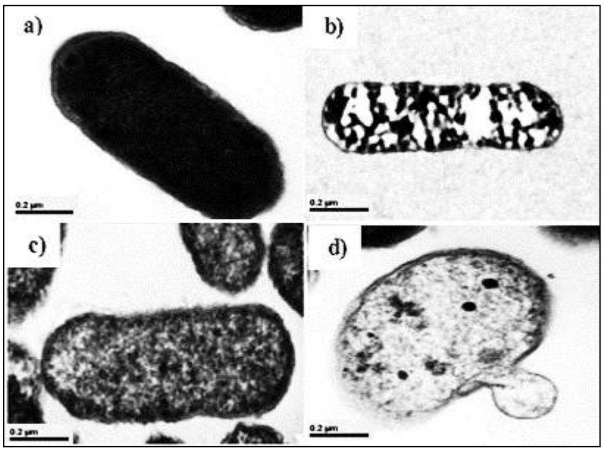

Figure 3: TEM micrograph of E. coli (a) untreated cell, (b and c) treated cell under 10-20V (d) rupture the cell wall under 30V.

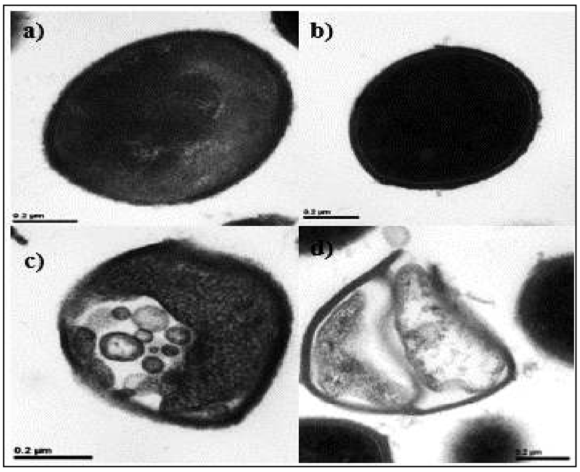

Figure 4: TEM photographs of S. aureus cells (a) untreated cell, (b and c) treated cell under 10-20V (d) rupture the cell wall under 30V.

B. Physical and chemical characteristics test

PEF-LV has a slight effect on the physical and chemical parameters of influent and effluent water. Temperature, pH, electrical conductivity, alkalinity, chloride, calcium, magnesium, and hardness were investigated. All results of the physical and chemical tests were within the Iraqi standard limits of drinking water (Table 2 and 3).

TABLE II: Physical characteristics for influent and effluent water.

physical parameter	month	Samples		Month	Samples		Iraqi Standard [23-26]
		0 V influent	*30V effluent*		*0 V influent*	*30 V effluent*	
Temperature (ºC)	Dec.	16.3	16.9	Apr.	22.0	21. 5	25
	Jan.	13.6	14.0	May	25.3	25.7	
	Feb.	15.0	14.8	Jun.	30.0	30.0	
	Mar.	18.3	18.1	Jul.	33.0	32.4	
pH	Dec.	7.9	8.1	Apr.	8.0	8.0	6.5-8.5
	Jan.	7.9	7.9	May	7.8	7.5	
	Feb.	7.9	8.0	Jun.	7.7	7.6	
	Mar.	7.2	7.5	Jul.	8.0	7.8	
Electrical Conductivity Ec. (µmohs/cm)	Dec.	1387	1380	Apr.	1539	1541	2000
	Jan.	1556	1551	May	1269	1271	
	Feb.	1287	1290	Jun.	870	872	
	Mar.	1671	1673	Jul.	824	820	

TABLE III: Chemical characteristics for influent and effluent water

chemical parameter	month	Sample		Month	Sample		Iraqi Standard [23-26]
		0 V	*30 V*		*0 V*	*30 V*	
Alkalinity As ($caco_3$) (mg/l)	Dec.	130	127	Apr.	120	117	200
	Jan.	136	130	May	120	115	
	Feb.	145	142	Jun.	120	119	
	Mar.	126	120	Jul.	114	116	
Cl. (mg/l)	Dec.	116	117	Apr.	104	102	350
	Jan.	122	120	May	79	80	
	Feb.	107	112	Jun.	71	70	
	Mar.	125	122	Jul.	70	68	
Ca (mg/l)	Dec.	75	80	Apr.	75	78	150
	Jan.	98	100	May	64	70	
	Feb.	108	114	Jun.	83	85	
	Mar.	118	120	Jul.	67	70	
Mg (mg/l)	Dec.	45	43	Apr.	29	30	100
	Jan.	35	37	May	34	37	
	Feb.	33	34	Jun.	55	60	
	Mar.	43	45	Jul.	39	40	
Hardness As ($caco_3$) (mg/l)	Dec.	405	410	Apr.	432	440	500
	Jan.	426	430	May	407	420	
	Feb.	444	445	Jun.	320	325	
	Mar.	486	488	Jul.	317	333	

4. CONCLUSION

Water quality is distinct from the physical, chemical, and biological characteristics of water. Although disinfection or inactivation of microorganisms in conventional methods gives acceptance removal efficiencies, these methods have side effects, especially if combined with organic or other materials, while the method of PEF-LV was used and gave high removal efficiencies without adding any chemicals and no change in the water quality. This paper represents a safer disinfectant unit (DU), the pilot-scale utilized two pair silver electrode mesh with a low voltage for disinfectant function. DU was affected by AC pulse frequency and the applied voltage. The biological, physical and chemical characteristics for influent and effluent water were examined. Removal efficiencies of E. coli and S. aureus cells at 0.5 Hz and 30V was 96 %. The physical and chemical tests for effluent water were within the Iraqi standard limits of drinking water

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