Removal of bacterial pollution from municipal wastewater using electrocoagulation technique

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Abstract. Bacterial pollution in water sources is one of the most dangerous forms of water pollution because the bacterial can breed in the aqueous media, which could result in the pollution of the whole water body. Besides, bacterial pollution possesses severe health problems. Thus, several sterilization methods were used for the removal of bacterial cells from water, such as filtration and chemical additives. However, the majority of these methods are either slow, such as filtration methods, or unsafe, such as chemical additives. Electrocoagulation (EC) has recently brought a good deal of attention for bacterial pollution in water and wastewater because it is environmentally safe and it has a relatively low operating cost. In this research, the effects of the current density on the ability of the aluminium-based EC unit (Al-EC) for the deactivation of bacterial pollution (E. coli as a case study) in municipal wastewater have been investigated at three 0.5, 1, and 2 mA/cm². The obtained results proved that increasing the current density was useful for E. coli removal, and the best deactivation (85.6%) was achieved at a current density of 2 mA/cm².

1. Introduction
The world population is nowadays exposed to different forms of environmental pollution, such as air, water, and soil pollutions, that directly influence the health and existence of mankind on the planet of Earth [1, 2]. Water pollution, which could be defined as the presence of unwanted chemicals in water, is a growing problem due to the discharge of wastewater or due to the natural existence of overconcentration of a pollutant [3-5]. Water pollution is one of the most dangerous forms of environmental pollution because of the limited amount of freshwater on this planet, which is less than 0.3% of the total amount of water, and also because human beings cannot survive without water for few days [6-8]. Furthermore, our daily activities, industry, extensive agriculture contributing to an increase in the pollution of water sources (groundwater and surface water) in an alarming trend [9-12]. A good example of that is the increase of phosphate amount in surface water by about 75% compared to its concentrations before the industrial revolution [13, 14]. Unfortunately, similar to phosphate,
concentration of many chemicals has increased, after the industrial revolution, in water sources by many folds, including but not limited to heavy metals [15-19], pathogens, phenols [20], fluoride [21-24], dyes [25, 26], organic matter [27], and nutrients [28-31]. The problem of water pollution has been intensified due to the impacts of global warming on water consumption [32-34], the distribution of both water and population on the planet of Earth [35-40]. For instance, the petroleum industry, which is incredibly increased during the last century, produces huge volumes of wastewaters that contain significant concentrations of harmful pollutants, such as sulfur, organic matter, hydrocarbons, soda, and biological pollution. As it is mentioned above, nowadays, water pollutants, unfortunately, are countless, such as heavy metals, phenols, coloring agents, organic matter, and nutrients, that will leave about 50% of the global population without access to safe drinking water during the next few decades [41, 42]. Among these uncountable pollutants, biological pollutes are considered the most dangerous pollutants due to their ability to breed in water to reach significant numbers in a relatively short time, and also due to their severe impacts on human health [18, 43]. It has been reported that annual global deaths because of water-related diseases are more than 1,000,000 people. Furthermore, it was found that a large number of freshwater sources in the developing countries are biologically polluted; for example, it was found that about one-third of the groundwater sources in Bangladesh were biologically polluted. In fact, the absence of effective sterilisation technologies, especially in poor countries, increased the biological pollution of water [18].

Thus, many sterilization technologies were used to remove biological pollutants from water or wastewaters, such as chlorination, ultraviolet radiation, electric field, nanoparticles of materials, hydrogels, and titanium dioxide [17]. For example, nanoparticles of magnesium oxides were used to deactivate Escherichia coli (E. coli) in a synthetic solution that also contains heavy metals, and it was noticed that the nanoparticles of magnesium oxides completely inactivate 7-log E. coli cells within 30 minutes [44].

However, most of the mentioned technologies are either expensive, such as nanomaterials, or unsafe due to the generation of toxic by-products during the treatment process, such as chlorination and chemical agents [12]. In addition, some methods, such as the biological reactors, produce a large volume of sludge, which requires expensive dewatering steps before disposing it into landfills [45] or activate it to be used as cementitious materials [46-52].

The recent applications of the electrocoagulation (EC) method to water and wastewater indicated a good ability of this technology for deactivation of biological pollutants within a short period in comparison with other methods [3, 23]. Additionally, the EC method is very safe because it does not require chemical additives that prevent the production of toxic by-products [12]. For example, it has been found that aluminium-based EC (Al-EC) units could remove more than 95% of the E. coli from synthetic wastewater samples within only 20 minutes and at a low operating cost (about 0.11 USA dollars per cubic meter of solution) [12]. On top of these advantages, it is very easy to automated the EC reactors using a proper type of sensors, such as the microwave sensors [53-56]. However, it was also reported that the efficiency of the EC units depends on a range of operating parameters, such as the concentration of the electrolyte, current density, and temperature of solution [1, 29].

Thus, this study investigates the effect of current density on the ability of the Al-EC to remove E. coli from municipal wastewater.

2. Materials and methods

2.1. Experimental Apparatus and Procedures

The experiments, in this study, were commenced using an electrolytic Al-EC unit that consisted of a 1000 mL plastic vessel (cylinder in shape), which was fitted with two Al electrodes (two aluminium electrodes (surface area 300 cm²), see figure 1. Al has been used in this unit due to its cost-effectiveness, wide availability (even in poor countries), and its low oxidation potential [2]. The vessel was provided with two holes, the upper hole was used as an inlet to introduce the solution to the unit, while the lower
one was used as an outlet (for the sampling process). The Al electrodes were connected to a DC power source (HQ Power; 0–30 V) to provide and control the required current density. The EC treatment was conducted by adding 500 mL of the prepared sample (see the next section) inside the unit, and the DC power source was switched on for the required period. All operating conditions were kept constant, except the current density, in all experiments. Where, the initial pH of the solution, treatment time, solution temperature, and solution volume were kept constant at 7.1 (the actual pH of the collected wastewater sample), 20 minutes, 20 °C, and 500 mL, respectively. It must be highlighted that the current density was chosen, in this study, as a model factor because it has a substantial role in the EC process. It has been proved that the current density controls the oxidation rate of the electrodes (production of metal oxides), which controls the removal efficiency of the targeted pollutants [5]. Additionally, the production of H₂ gas from the cathodes, which is responsible for floating the coagulated pollutants to the surface of the solution in form of foam, is also controlled by the current density [5].

![Figure 1. Configuration of the Al-ELE.](image)

To investigate the effects of the current density on the removal of the bacteria from municipal wastewater, the treatment process was commenced at three different current densities (0.5, 1, and 2 mA/cm²). The deactivation efficiency was calculated as follows [12]:

\[
\text{Deactivation (\%)} = \frac{\text{Initial concentration of E.coli} - \text{final concentration of E.coli}}{\text{Initial concentration of E.coli}} \times 100 \tag{1}
\]

Additionally, the effect of the current density on the power consumption of the Al-EC was calculated as follows:

\[
\text{C}_{\text{energy}} (kWh/m^3) = \frac{\text{Electric current (A)} \times \text{Cell potential (V)} \times \text{treatment time (hr)}}{1000 \times \text{Volume of solution (m}^3) \tag{2}
\]

The electrodes were periodically cleaned with diluted acid and denoised water, after each experiment, to remove the accumulated pollutants on the surfaces of electrodes.

2.2. Wastewater sample and incubation process
A wastewater sample was collected from the Al-Rustumyiah treatment plant, Baghdad city, Iraq, during March 2019 using a plastic container (1 L capacity). *E. coli* was used in this study as an indicator of the efficiency of the Al-EC method for deactivation of biological pollution in municipal wastewater.
All the required material for incubation and testing the removal of *E. coli*, including the microbiological reagent, peptone-water, and agars were supplied by Sigma-Aldrich. The analysis process was commenced, using the filtration membrane technique, according to the recommended standard methods by the American Public Health Association (APHA). The number of *E. coli* colonies, before and after treatment, were manually counted after an incubation period of 24 hrs at 35 °C.

3. Results and discussion

3.1. Effects of current density on deactivation of *E. coli*

As it has been mentioned in the previous section that the current density controls the removal of pollutants via controlling both the production of metal oxides and H₂ gas inside the EC units. Thus, the effects of this parameter on the deactivation of the *E. coli* was studied at 0.5, 1, and 2 mA/cm², while the initial pH of the solution, treatment time, solution temperature, and solution volume were kept constant at 7.1 (the actual pH of the collected wastewater sample), 20 minutes, 20 °C and 500 mL, respectively. Figure 2 shows the effects of the current density on the deactivation of the *E. coli*. It has been observed that the deactivation of the *E. coli* improved at the high current densities; where it was observed that the deactivation percentage increased from about 30% at a current density of 0.5 mA/cm² to about 85.6% at a current density of 2 mA/cm².

As it was explained above, the improvement of *E. coli* deactivation at high current densities is because the number of metal oxides and the production of H₂ increase at high current densities, which lead to improvement of the deactivation percentage of *E. coli*.

![Figure 2. Effect of current density on E. coli deactivation.](image)

The negative effects of increasing the current density are depicted in Figure 3; where it has been observed that increasing the current density led to a remarkable increase in power consumption. For example, the power consumption has increased from 1.74 to 5.9 kW.h/m³ when the current density increased from 0.5 to 2 mA/cm², respectively.

According to these results, it could be concluded that although the current density was very useful for biological pollutants removal from water, its value must be optimised to avoid high power losses. Additionally, it was found that the performance of the Al-EC was in good agreement with those in the literature [12].
4. Conclusion
The current study was performed to investigate the effects of the current density on the deactivation of E. coli using the EC method. The obtained results showed that the current density plays a role that can never be neglected in the electrochemical removal of biological pollution from solution, where it has been noticed that the deactivation of E. coli increased by about 60% when the current density was increased from 0.5 to 2 mA/cm², respectively. This confirms that the performance of the Al-EC units could be improved by increasing the magnitude of the applied current density. However, it was also noticed that high current density increased the power consumption, which could limit the usage of the Al-EC units in this field of treatment. Other parameters, such as the distance between electrodes and solution temperature, also have an important role in the EC treatment, thus, additional studies are required to address the effects of these parameters on the deactivation of E. coli in water or wastewater.

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