Mitigation of wastewater biological pollution using the electrocoagulation method

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Abstract. Biological pollution of water and wastewater is a global grave concern, especially in developing countries due to insufficient treatment and sanitation. Additionally, the poor economy of the majority of the developing countries limits both applications of advanced treatment technologies and modern monitoring systems, which intensifies the problem of biological pollution. In this investigation, the electrocoagulation method, which is in situ production of coagulation agents by passing electric current via metallic electrodes, has been used as an affordable treatment method for the removal of bacteria from municipal wastewater (E. coli as an indicator). Wastewater sample was collected from Al-Rustamayah wastewater treatment plant, Baghdad city, Iraq. In this investigation, the electrocoagulation unit was supplied with iron electrodes (Fe-ELE). The impacts of current density (CD) and electrodes gapping (EG) on the performance of the Fe-ELE performance were optimized to attain the best activation percentage. The obtained results showed that the Fe-ELE achieved full deactivation of the E. coli after 45 minutes of treatment at EG of 5 mm, CD of 2 mA/cm² and an initial pH of 6.0.

1. Introduction
It is unquestionable fact that the inhabitants of the planet of Earth face a serious water sacristy due to several reasons, firstly due to the limited amount of fresh water on this planet that represents not more than 1% of the total quantity of water [1-3]. Secondly, the deterioration of the quality of freshwater due to the discharging of wastewaters, and the unsustainable consumption of water by population, industries, and agriculture [4-6]. Climate change is another hidden factor that causes drought in a different part of the world and increases the consumption rate of water [7-10], and it also affects the natural distribution water and rail across the world [11-14], which promoted the shortage of freshwater [15, 16]. The deterioration of the quality of the freshwater due to the discharge of wastewaters, including municipal, industrial and agricultural effluents, is the main concern for the environmental engineers and experts because of the huge volumes of these effluents in comparison with the volumes of the receiving water bodies (usually rivers and lakes) and because of the wide range of pollutants in such effluents [17-19]. For example, it has been reported that the annual usage of pesticides in the agricultural activities in China reached 300 million tons; a significant amount of these pesticides are returned to the freshwater...
resources with the drainage water causing serious pollution problems [20-22]. Besides, the concentrations of a wide range of contaminants, such as heavy metals, organic matter, nutrients, and dyes [23-26] have incredibly increased over the last decades due to the rapid expansion of urbanization and industrialization [27-29], for example, the concentrations of phosphorus-based contaminates in the freshwater have increased by 75% in comparison with their concentrations a few decades ago [30, 31]. Among these countless contaminates, the biological contaminates have brought the attention of the environmental engineers and experts due to their significant impacts on public health and the ecosystems [32-34].

In fact, the attention toward the biological pollutants has dramatically increased since the 1850’s when the English physician John Snow proved that cholera was a waterborne pathogen [35]. Since that time, the researchers have started to accumulate a better understanding of the spread of different pathogens via water that responsible for several dangerous diseases, such as diarrhea and gastrointestinal disorders. Nowadays, unfortunately, biological pollution has substantially increased due to, as mentioned above, the rapid increase in both urbanization and industrialization, for instance, it has been found that about 38 out of 125 wells in a rural area in Bangladesh were polluted with E. coli. Moreover, the lack of efficient treatment methods, especially in developing countries, intensifying this problem [32, 36]. Therefore, big efforts have been conducted to solve this problem by providing affordable and efficient disinfection methods, such as chlorination and chemical coagulation [36-38]. However, most of the chemical methods produce toxic by-products that limit their applications.

The present study aims at the application of an iron-based electrocoagulation unit (Fe-ELE) as a disinfection method for municipal wastewaters (to deactivate E. coli). In this study, the impacts of current density (CD) and electrodes gapping (EG) on the performance of the Fe-ELE performance were optimized to attain the best activation percentage. The authors would like to highlight that the section of the electrocoagulation method was basing on its unique advantages such as the cheapness, ease of operation, the possibility to control it using sensors, convenience production of sludge [19, 22]. The latter advantage is very important as it eliminates the need for large landfills and its related costs, such as the complex management and long term environmental effects [39, 40], or the need for recycling processes [41-48].

2. Materials and methods

In this part of the study, the authors explain the details of the Fe-ELE unit, municipal wastewater sample, and the treatment process.

2.1. Fe-ELE unit

The used ELE unit, in this study, was made from transparent plastic, and it was rectangular in shape with dimensions of 100 mm in length, 95 mm in width and its depth was 70 mm. This container was provided with 6 iron electrodes that have been arranged in an interchanged way so the solution will be mixed during its flow through the unit, see Figure 1. The dimensions of the electrodes were 80 mm in length and depth of 60 mm, and they were installed vertically inside the ELE unit. The dimensions of the reactor were selected according to the previous studies (within the used sizes), such as the study of Mohammed et al., [49]. Iron was used to manufacture electrodes due to its low cost and its global availability. Additionally, it must be highlighted that the ELE methods have been used here for many reasonable reasons, including the safety because it never produces secondary pollutants, cost-effectiveness, simplicity, and the compacted size [50-52].

The electrodes were taken out of the container, after each run, and cleaned using the diluted acidic solution and then rinse with deionized water to remove the residual acid [49, 53].
2.2. Wastewater sample
A concentrated wastewater sample was taken from Al-Rustamyiah wastewater treatment plant, Baghdad city, Iraq. This sample was diluted with denoised water (to 1%), and was used to perform the required experiments. Incubation and planting of the E. coli bacteria were carried out following the standard methods of the American Public Health Association (APHA). Initially, the diluted wastewater sample was planted to calculate the original number of the E.coli colonies, then the same procedures were followed after each experiment to calculate the residual E.coli colonies.

2.3. Treatment process
The first step in the treatment process was to calculate the original number of the E. coli colonies (this number was donated as X1). Then, 500 mL of the wastewater solution was electrolyzed using the Fe-ELE at different current densities (CD) (1, 2, and 3 mA/cm²) and electrodes gapping (EG) (5, 10, and 15 mm) to attain the best deactivation of the culturable bacteria. After each experiment, the residual number of the E. coli calculated (this number was donated as X2). The deactivation percentage (D%) was calculated as follows:

\[ D\% = \frac{X_1 - X_2}{X_2} \times 100 \]  \hspace{1cm} (1)

The initial pH of the solution was kept constant at 6 in all experiments because the pH of the wastewaters is usually between 5 and 6.

3. Results and discussion

3.1. Impact of CD on the deactivation of the E. coli
The literature confirms that the CD exerts a substantial effect of the removal of water/wastewater pollutants not because it governs the production of oxides from the electrodes that determines the removal efficiency but because it also determines the generation bubbles (hydrogen gas) that float pollutants to the surface of the solution [54]. Basing on these facts, the impact of the CD on the deactivation of the E. coli has been investigated at 1, 2, and 3 mA/cm². In these experiments, the treatment time, pH, and EG were kept at 45 minutes, 6.0, and 5 mm, respectively.

The obtained results indicated that maximizing the CD magnitude improved the deactivation of the E. coli, see Figure 2. For instance, the deactivation of the E. coli increased from about 79% at CD of 1 mA/cm² to 100% at CD of 3 mA/cm².
This improvement in the deactivation of the *E. coli* with the increase of the CD is attributed, as stated above, to the impact of the CD on both the production of oxides and hydrogen gas; the highest CD the higher the production of oxides and hydrogen gas. However, figure 3 reveals that the CD is not always useful for the treatment process because it increases the power consumption that decreases the economical efficiency of the Fe-ELE. For example, the power consumption increased from about 1 kW.h/m$^3$ to 6.1 kW.h/m$^3$ as the CD increased from 1 to 3 mA/cm$^2$. Therefore, 2 mA/cm$^2$ was used in this study as the optimum CD value.

![Figure 2](image1.png)

**Figure 2.** Impact of CD on the deactivation of the *E. coli*.

![Figure 3](image2.png)

**Figure 3.** Impact of CD on power consumption.
3.2. Impact of EG on the deactivation of the E. coli

The relevant studies indicated that there is a relationship between the EG and the electric current flow through the ELE units because the EG influences the electric resistance, i.e. the wider EG the higher the electric resistance [32, 54]. Thus, the impact of the EG on the deactivation of the E. coli has been studied at 5, 10, and 15 mm when the initial pH, CD, and treatment time were 6.0, 2 mA/cm$^2$ and 45 minutes, respectively.

Figure 4 shows the impact of the EG on the deactivation of the E. coli, which confirms the findings of the previous studies; the wider EG the lower the efficiency of the ELE. It can be seen that the deactivation of the E. coli was lowered from 98% to about 86% when the EG increased from 5 to 15 mm. This change in the deactivation of the E. coli with the change of the EG is due to the negative impact of the latter parameter on the electric resistance of the ELE, which decreases the flow of the electric current through the ELE, and consequently it decreases the removal efficiency [17, 52].

![Figure 4. Impact of the EG on the deactivation of the E. coli.](image)

In summary, the results of the present study confirmed the ability of the Fe-ELE to deactivate the E. coli in the municipal wastewater, and the performance of the ELE could be improved by controlling the magnitude of CD and/or EG. Generally, the Fe-ELE could achieve a complete deactivation of the E. coli when the CD, ED, pH, and treatment time were 2 mA/cm$^2$, 5 mm, 6.0, and 45 minutes, respectively. The authors mentioned above that one of the many attractive advantages of the ELE method is the possibility to control it using sensors, therefore; for future studies, it could be convenient to use provide the ELE with sensors, similar to those in [55-58], to enhance its performance.

4. Conclusion

The present study investigated the efficiency of an Fe-ELE unit in the deactivation of the culturable bacteria in the municipal wastewater under different operating conditions; the current density and the electrodes gapping. The results of this study proved that Fe-ELE could achieve full deactivation of the culturable bacteria in the municipal wastewater within a relatively short time (45 minutes). Generally, the results of the experiments showed that the deactivation of the culturable municipal wastewater was influenced by both current density and electrodes gapping. The deactivation percentage could be improved by maximizing the current density and minimizing the distance between electrodes. For future studies, the impacts of other operating parameters, such as the pH of the solution, should be investigated.
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