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Article

Application of Electrocoagulation in Street Food Wastewater

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Abstract: Street food is commonly known as ready-to-eat and go foods and beverages, which is very famous in Thailand and other Asian countries. The street food daily generates high organic content and oily wastewater from washing and rinsing plates. The discharge of street food wastewater to public drains leads to a clogged drain line and unpleasant smell. In this work, an electrocoagulation (EC) system with monopolar aluminum (Al) electrodes was developed to treat two well-known street foods; Hainanese chicken rice (HC) and noodles and dumplings (ND). The results revealed that excellent chemical oxygen demand (COD) and fat, oil, and grease (FOG) removals were achieved under a specific operating condition (i.e., an electric current of 20 mA/cm^2 and electrolytic time of 10 min). The initial COD of HC wastewater decreased from 40.6 g/L to 1.9 g/L, approximately 95%, whereas the FOG decreased from 310 mg/L to 50 mg/L, approximately 84%. The lower initial COD and FOG concentrations of ND wastewater obtained approximately 98% for COD removal and 86% for FOG removal; the effluent contained 0.5 g/L of COD and 25 mg/L of FOG. In addition, a relatively low Al concentration of 0.02–0.08 mg/L was observed in the effluents. The appropriate design factors together with ease of use and fast pollutants removal were significant advantages of this study; the EC system has potential to apply to on-site street food treatment.

Keywords: street food wastewater; wastewater treatment technology; electrocoagulation

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1. Introduction

Street food is known as ready-to-eat foods and beverages sold on a street or other public space including a mobile vendor selling from a cart and a fixed vendor selling from a stall. The buying and selling of street food is a common economic activity in Thailand and Asian countries. The signature of street food is a variety of food, authentic taste, quick assess, and inexpensive service. Due to food preparation and cleaning processes, a large volume of wastewater is daily generated and discharged to public sanitary sewers. The characteristics of food-service wastewater were high organic (represented in chemical oxygen demand; COD), total suspended solid (TSS), and total fat oil and grease (FOG); these were 1523, 664, and 197 mg/L, respectively [1]. The above concentrations exceeded the regulations for a municipal sewer. In addition, the relatively high organic and FOG levels as well as high flow cause an unpleasant smell and sewer line clogging. In Thailand, the local government spends a large amount of the annual budget for sewer line cleaning to avoid flooding and improve residents' quality of life.

A large production of oily wastewater comes from various sectors; oil and gas, petrochemical, pharmaceutical, and food [2]. Recently, more attention has been focused on enhancing technology for oily wastewater treatment such as flotation, coagulation, biological treatment, membrane separation technology and electrocoagulation [3]. Among the abovementioned options, electrocoagulation (EC) is a potential technology for developing a mobile treatment system for street food. The significant benefits of the EC process include that high COD and FOG removals can be reached in a short electrolytic time due to multilevel treatment processes, such as electrochemical oxidation, coagulation, and flotation. In addition, the EC system required a smaller scale and lower operating cost rather than other oily treatment systems. Furthermore, the EC process has found an efficient pathogens removal [4] as well as potential toxic metals removal such as zinc, copper, and chromium. Large restaurants and households require an oil and grease trapping unit to separate the oil and grease content before discharging wastewater due to Thailand's regulations. However, this oil and grease trapping unit is unsuitable for street food wastewater, because it is a fixed system and requires several hours for gravity FOG separation.

A laboratory-scale EC system with the combination of aluminum (Al, at cathode) and iron (Fe, at anode) was fabricated for domestic wastewater [5]. It achieved 92% COD removal and 97% turbidity removal with a low energy consumption of 0.007 KWh/L. Similarly, in the previous literature [6] applied the EC process using Al and stainless steel as electrodes to treat oily automobile service effluent. A high COD of 94% was eliminated, whereas the FOG of 51% was removed by flocs precipitation and a large Al content of 62% was detected in the sludge. The EC technology was also applied to actual tannery wastewater [7]; the electrolysis time was in the range of 30–45 min to achieve the optimal organic and inorganic pollutants removals including COD, solids, and metals. However, most EC application to actual wastewater in previous studies has been limited to a small capacity. The enlarged capacity of an EC system possibly affects the pollutant removal efficiency and process stability due to homogenous flow and natural variations in wastewater composition. Therefore, the objectives of this study were to develop an enlarged EC system to reduce organic and FOG levels from street food wastewater with the aim of achieving sufficient COD and FOG removals, short treatment time, and simple operation.

2. Materials and Methods

2.1. Wastewater Sampling Methodology

The wastewater grab samples were collected from the most significant street food in Thailand, Hainanese chicken rice (HC) and noodles and dumplings (ND) in Phitsanulok Province. HC is known as an oily street food and contains very high COD and FOG (as shown in Table 1). NC is also a very common street food and generates a larger volume of wastewater rather than other street food. The sampling collection occurred after the peak hours of vendor operation to incorporate washing and rinsing plates and silverware. Both wastewaters were very turbid, smelly, and oily; their composition varied due to the source of street food and number of customers, as summarized in Table 1.

Table 1. Characteristics of street food wastewater *.

Street Food	pH	COD (g/L)	FOG (mg/L)	Turbidity (NTU)	Conductivity (mS/cm)
Hainanese chicken rice	5.6 ± 7%	40.6 ± 15%	310 ± 12%	501 ± 11%	0.68 ± 4%
Noodles and dumplings	7.2 ± 10%	27.3 ± 10%	178 ± 8%	706 ± 12%	0.95 ± 5%

* Data in the table are the average numbers from 10 times of sampling during 2 weeks of observation.

2.2. System Design and Operation

The 30 L capacity of a rectangular plastic tank with the dimensions of 31 cm (width) × 42 cm (length) × 23 cm (height) was modified to be the EC system connecting parallel monopolar aluminum electrodes with a size of 21 cm (width) × 20 cm (height) and DC power source (12 V/45 A). The seven aluminum electrodes were expanded along the system length with a 4 cm inter-electrode distance. A space between the electrodes and the side of the system allowed the homogenous mixture to be under no agitation [8]. The EC system configuration is presented in Figure 1. The supplied current density was controlled at approximately 20 mA/cm^2, which was the optimal value in terms of pollutants removal and electric consumption for oily wastewater treatment [9]. Due to a low conductivity of the street food wastewater, around 5 g/L of NaCl was added to the actual street food wastewater to enhance the electrochemical reactions and system performance [9]. The actual street food wastewater was prepared by removing large solids such as vegetables and meat. Since the optimal pH for pollutants removal by EC was found to be in the range of 5–7 [5], the street food wastewater without pH adjustment was used in the experiments.

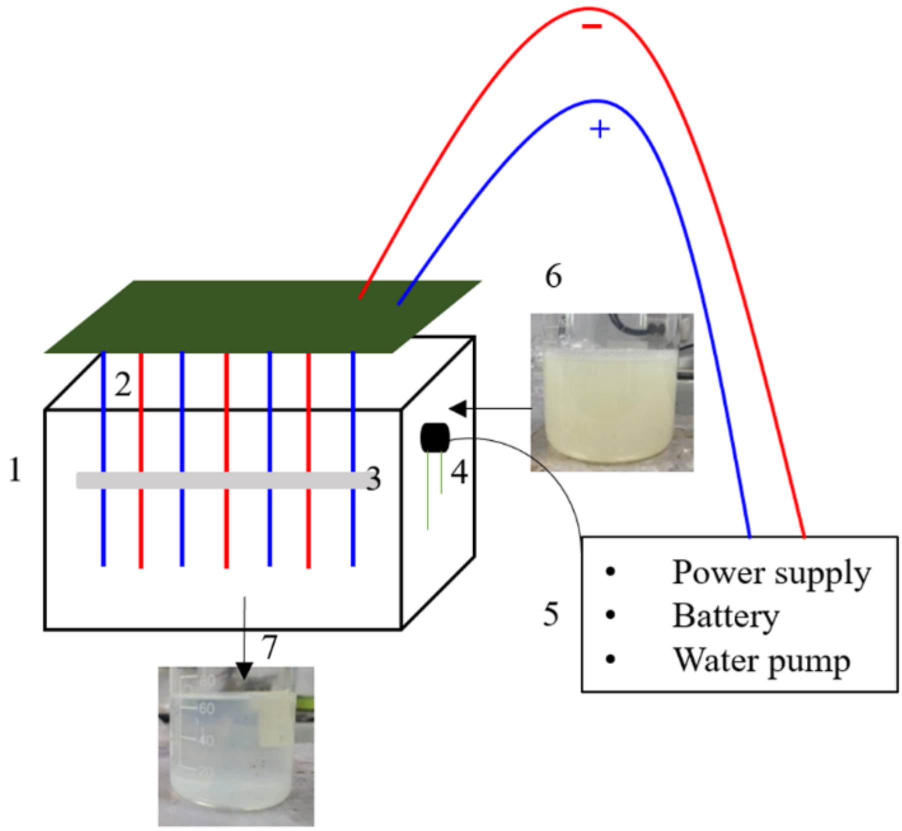

Figure 1. Configuration of EC system; (1) rectangle reactor, (2) aluminum electrodes, (3) flocs collector, (4) water level sensor, (5) control box, (6) actual street food wastewater, and (7) effluent.

2.3. Analytical Methods

The COD measurement method corresponded to DIN ISO 15705 and was analogous to EPA 410.4, APHA 5220 D, and ASTM D1252-06 B. The COD solutions A + B were purchased from Sigma-Aldrich Canada Co., Ltd. Solution A and solution B were added into the water samples. The water samples were oxidized with a hot sulfuric solution of potassium dichromate, with silver sulfate as the catalyst. The concentration of unconsumed yellow $Cr_2O_7^{2-}$ was then determined photometrically. The FOG was analyzed by the soxhlet extraction method (APHA 5520D). The water samples were acidified by hydrochloric acid, and then n-hexane was added. The acidified samples were transferred to a separatory funnel. After extraction, the extracted FOG was weighted and calculated in FOG concentration. For aqueous Al concentrations, the water samples were digested by concentrated nitric acid. The digestate was filtered and then analyzed by flame atomic absorption spectrometry (FLAA), The pH, conductivity, and turbidity were determined by a pH meter (Proline B210), a conductivity meter (Proline B250) and a turbidity meter (HACH 2100Q).

3. Results and Discussion

Two different types of actual street food wastewater (Hainanese chicken rice (HC) and noodles and dumplings (ND)) were selected as the case studies. The analytical data revealed that HC wastewater contained very high COD and FOG concentrations of 40.6 g/L and 310 mg/L, respectively. On the other hand, the ND wastewater contained lower concentrations of 27.3 g/L and 178 mg/L for COD and FOG, respectively. However, it has to be noted that these concentrations were extremely high compared to the domestic effluent standard in Thailand [10]. The COD and FOG from the street food wastewater were in a similar range to industrial waste and wastewater such as waste coolant [11] and high-concentration oil and gas fields [12]. Thus, the direct discharge of street food wastewater can severely impact the environment and water resources.

During EC treatment, flocs were observed at the top of surface and subsequently separated from the effluent. The COD of the HC wastewater immediately decreased from 40.6 g/L to 12.1 g/L after 2 min, approximately 70% (shown in Figure 2a). The COD removal efficiency continuously increased to 85% at 4 min and 94% at 6 min, respectively. A longer electrolytic time of greater than 6 min did not significantly improve the COD removal; the best efficiency was approximately 95%, and an effluent COD of 1.9 g/L remained. The ND wastewater containing lower COD achieved a maximal COD removal efficiency of 93% in 4 min with a low effluent COD of 1.8 g/L. The main removal mechanisms are explained in that the aluminum cations were dissolved from the anode (Equation (1)), negative charged hydroxides were dispersed in the solution, and, consequently, they had a stronger attraction to coagulate the colloidal pollutants (Equations (2) and (3)). Under the electric field of the EC process, the aggregation of colloidal pollutants was higher than the use of coagulant chemicals, leading to the enhancement of coagulation rate and pollutant removal efficiency. In addition, other electrochemical advanced oxidation processes possibly occurred to degrade the pollutants into smaller compounds via hydroxyl radicals (Equations (4) and (5)) [13]:

$$Al_{(s)} \rightarrow Al^{3+}{}_{(aq)} + 3e^- \quad (1)$$

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \quad (2)$$

$$Al^{3+}{}_{(aq)} + nOH^- \rightarrow Al(OH)_{n\,(s)} \quad (3)$$

$$2H_2O \rightarrow 2OH\bullet + 2H^+ + 2e^- \quad (4)$$

$$2OH\bullet + \text{Organic compounds} \rightarrow \text{intermediate (smaller compounds)} \rightarrow \text{harmless} \quad (5)$$

In the literature, the same current density of 20 mA/cm^2 was supplied to treat potato chip manufacturing wastewater; it required a longer electrolytic time of 30 min to achieve 60% COD removal with a second-order kinetic model [14]. Since the potato chip manufacturing wastewater contained several organic compounds including carbohydrates, starches, and protein from process lines, its EC performance for wastewater treatment was lower than this study. Similarly, the continuous increase in COD removal of wastewater containing 0.3–1.0 g/L of COD and 180–200 mg/L of FOG was observed by increasing electrolytic times; the maximal efficiency of 95% was reached in 40 min [15]. Several operating factors including electrode material, inter-electrode distance, pH, and aeration were mentioned to affect the EC performance and extended treatment time [15]. Due to this study, the wastewater characteristics such as pollutants compounds and conductivity were other significant factors for excellent actual wastewater treatment in a short time by the EC process. It should be note that the street food wastewater in this study contained fewer complex compounds and high conductivity from external salts addition.

From Figures 3 and 4, the turbidity and FOG were also effectively removed from the street food wastewater. The turbidity of the HC and ND wastewater was mostly removed in 4 min of electrolytic time, >99% removal. The higher FOG wastewater of HC reached a maximal removal efficiency of 84%, and a concentration of 50 mg/L remained in the effluent. For the ND wastewater, the FOG removal was slightly higher at 86%, and the effluent FOG was around 25 mg/L. In comparison to the conventional FOG removal of gravity separation (using difference of density between oil and water) and dissolved air flotation (using air bubbles to bring oil droplets to the top), this EC system overcomes the disadvantages of the above two systems including the limited separation capacity, large area requirement, and the high operating cost from constant ultrafine bubbles generation [2]. Using the gravity separation system, the oil content was removed in the range of 65–75% in 20 min of treatment time. However, the performance of the gravity separation system was directly related to the oil types and their different specific gravities compared to water [16]. Furthermore, the FOG as well as COD removal efficiencies decreased with increasing influent flow rates [16].

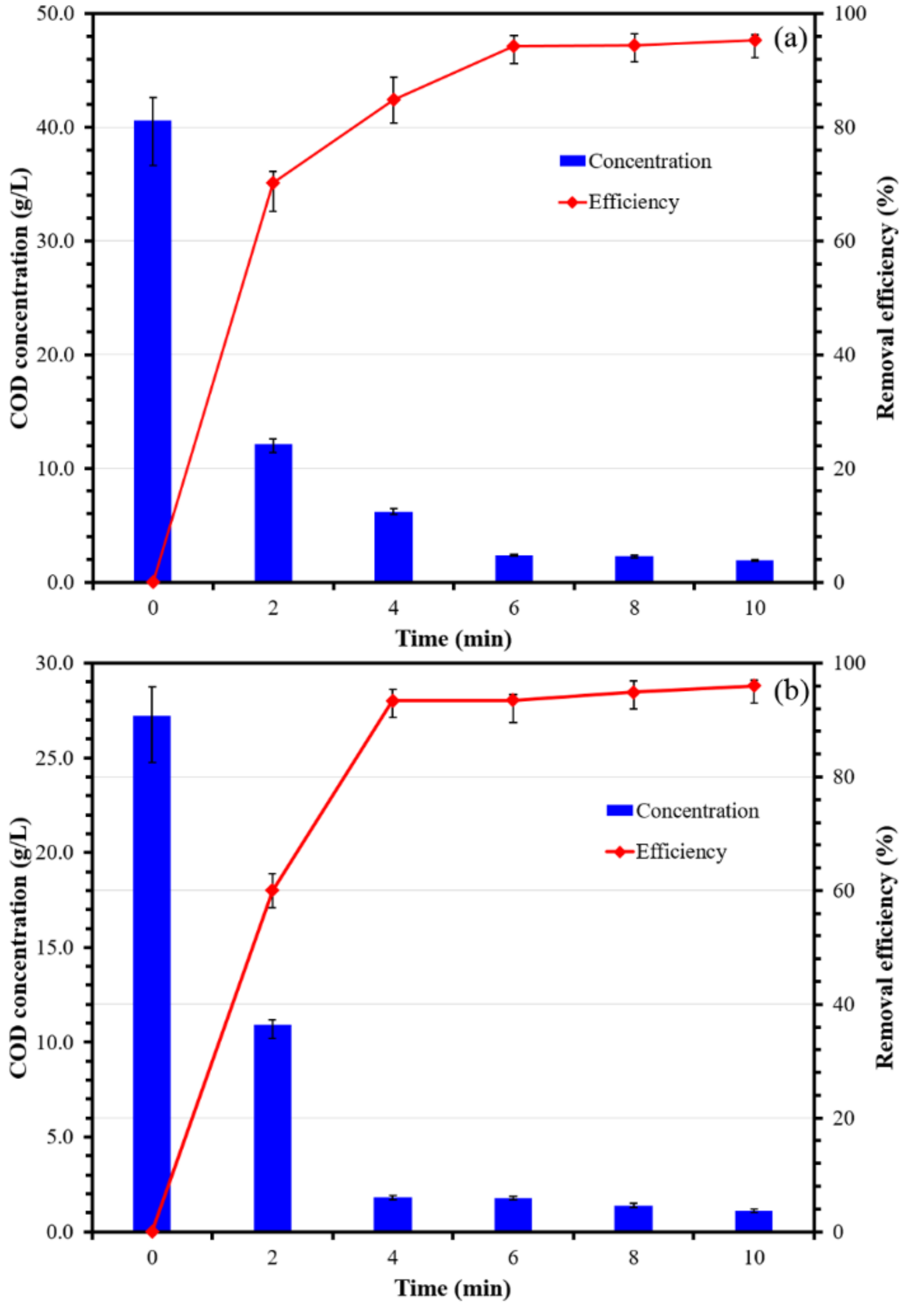

Figure 2. COD concentration and removal efficiency; (**a**) Hainanese chicken rice and (**b**) Noodles and dumplings.

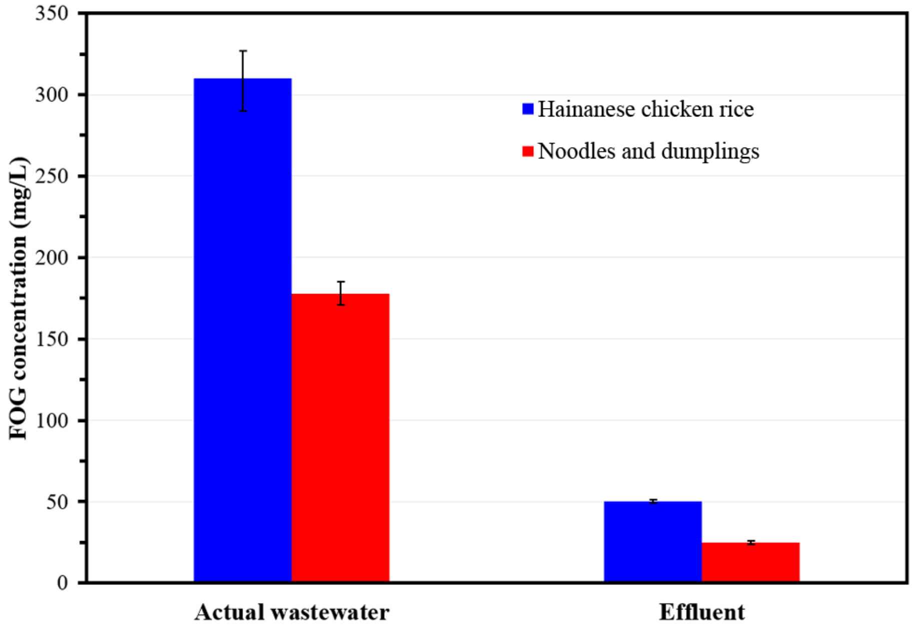

Figure 3. Turbidity concentration and removal efficiency.

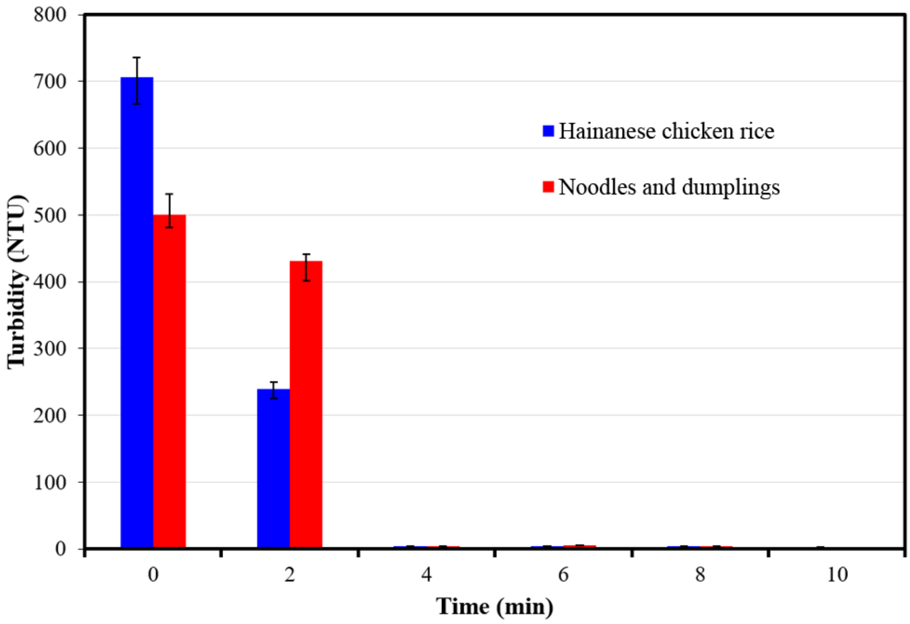

Figure 4. FOG concentration and removal efficiency after 10 min of electrolytic time.

In terms of Al ions in the effluent from the anodic dissolution, the effluent HC and ND wastewater were further measured by FLAA. The results revealed that a relatively low Al concentration of 0.08 and 0.02 mg/L was observed in the effluent HC and ND. Although the EC system operated under a high current density, the short treatment time of <10 min caused less aluminum to remain in the effluent. Furthermore, the continuous increase in pH by electrolytic times was observed; the pH increased to 8.5 for HC wastewater and 9.0 for ND wastewater after 8 min (shown in Figure 5). Later, the pH immediately dropped to 5.9 and 7.7 for HC and ND wastewater, respectively, at 10 min. The phenomenon was associated with the increasing electrochemical reactions in the EC system, leading to the change in hydroxide and hydrogen ions.

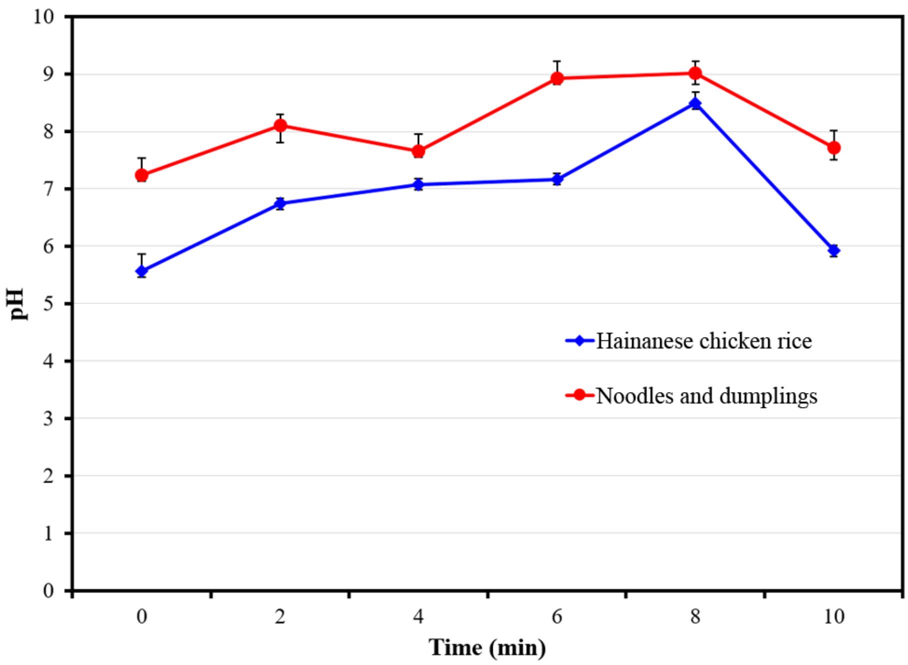

Figure 5. Change of pH in the effluent at different electrolytic times.

Overall, the EC system can remove organics, turbidity, and oil and grease from the street food wastewater with high efficiency and minimal treatment time. The effluent HC and ND wastewaters were fairly clear; the average COD, turbidity, and FOG levels were 1.9 g/L, 3 NTU, and 50 mg/L for HC wastewater, respectively, and 0.3 g/L, 1 NTU, and 25 mg/L for ND wastewater, respectively. In comparison, the EC system operating in this study achieved a better pollutant removal (i.e., FOG) in a shorter electrolytic time than previous EC systems in the literature [6,7]. The advantage of this study was that the appropriate design factors encouraged homogeneous flow and performance stability with no mechanic agitation and various wastewater compositions. In addition, its compact system, ease of use, fast and efficient pollutant removal were also significant advantages to further develop the EC system as a mobile unit for on-site street food treatment in Thailand and other Asian countries.

4. Conclusions

Oily street food wastewater containing high organic concentrations was efficiently treated by the EC system. High COD and FOG removals of 95% and 84% were obtained for the Hainanese chicken rice wastewater. Slightly higher efficiencies of 98% and 86%, respectively, were obtained for the noodles and dumplings wastewater. Due to the appropriate design and fast pollutants removal, the EC system was able to be operated in a short treatment time of <10 min with high removal efficiency. The effluents were fairly clear and contained <1.9 g/L of COD, <50 mg/L for FOG, <3 NTU for turbidity, and <0.1 mg/L for Al ions. The EC system in this study has the potential to be applied to on-site street food treatment.

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