Journal of Environmental Sciences, 2020; Vol. 49, No. 4: 87-98

Journal of Environmental Sciences

JOESE 5

Electrocoagulation Treatment for Wastewaters from some Restaurants in New Damietta City-Egypt

Khaled H. El-Ezaby, Maie I. El-Gammal and Youmna A. Shaaban

Environmental Sciences Department, Faculty of Sciences, Damietta University, Egypt

Reprint

Volume 49, Number 4: 87- 98

(2020)

http://Joese.mans.edu.eg

P-ISSN 1110-192X

e-ISSN 2090-9233

Journal of Environmental Sciences

JOESE 5

ISSN 2090-9233

Journal homepage http://Joese.mans.edu.eg

Original Article

Electrocoagulation Treatment for Wastewaters from some Restaurants in New Damietta City-Egypt

Khaled H. El-Ezaby, Maie I. El-Gammal and Youmna A. Shaaban

Environmental Sciences Department, Faculty of Sciences, Damietta University, Egypt

Article Info

Article history:

Received 6/ 10/2020

Received in revised

form 9/11/2020

Accepted 30/12/2020

Keywords: ***Electrocoagulation, restaurant wastewaters, aluminum electrodes, COD removal efficiency*.**

Abstract

The current investigation entails the application of an electrocoagulation treatment process to the kitchens' wastewaters discharged from five of the most popular restaurants in New Damietta city – Egypt. The electrocoagulation process was carried out using aluminum electrodes at variable electrolysis times. The specifications of the applied system were; pH 7.03, temperature 25ºc, distance between the two used electrodes 20 mm, the applied current 1 ampere, voltage 20 volt, current density 40 mA/cm², plate shape of the electrode, and dimensions of 100 mm x 50 mm x 0.095 mm, with a surface area of 25 cm² for each electrode. The system was investigated to treat the food processing effluents of the restaurants prior to their discharge to the public sanitary network, in order to comply with the Egyptian Environmental Regulation (Decree 44/2000) of the wastewaters discharged to the public sewer system. Total operating cost including the energy and electrode consumption, and theoretical amount of hydrogen gas produced were calculated. The results revealed good removal efficiency percentages, especially for the removal of organic matters. The COD removal efficiency for the restaurants 1, 2, 3, 4 and 5 were 84.6, 74.5, 89.15, 68.5, and 92.79%, respectively. At the same time, oil & grease was almost fully removed from the wastewater of the restaurants 1 and 2, while restaurants 3, 4, and 5 had a very good removal efficiency percentage of 92.42, 94.5, and 87.76%, respectively.

1. Introduction

Restaurant wastewater can defined as water that has been utilized for cooking process, cleaning vegetables and meats, washing dishes and cooking utensils, or cleaning the floor. This wastewater is usually loaded with organic matters from the leftovers of food and soup which are made of oily flavorings as soy sauce, seasoning, spice, etc. Unlike the vast majority of the developed countries where the restaurant wastewaters are discharged into foul sewers leading to public sewage treatment plants, the wastewater produced by local restaurants is usually discharged into storm drains without proper on-site treatment process **(Zulaikha *et al.*, 2014)**. It normally contains suspended solid, oil and grease, as well as detergent. The mainly characteristic is that, having plentiful oil &grease compared with other commercial wastewaters. Specifically, uncontrolled disposal of these oil and grease is the major reason for water quality deterioration in tributaries in addition to in the major streams of some rivers. Moreover, there are negative impacts on the system once treated by sewage treatment plant **(Yau *et al.*, 2018)**.This situation gets even worse with the awareness lack by the general public in particular restaurant owner of the wastewater management issues. Furthermore, the presence of oil and grease in the wastewater conjointly leads to foul the storm drain and generates unpleasant odor **(Zulaikha *et al.*, 2014).**

Appropriate treatment is needed to ensure that the discharged pollutants are within permissible limits prior to releasing them to drain. It is desired the appropriate treatment facilities can be efficient and small in size **(An *et al.*, 2017)**.

Study on oil removal from wastewaters by using electrocoagulation process has a great attention in the last few decades. This Technique has been successfully applied to remove oil from a wide range of industrial wastewater. The use of electrocoagulation as a treatment technology has several advantages over standard biological systems including; simple apparatus operation, short processing times, eco-friendly, no additional chemical requirements, production of odorless and colorless effluents **(Benekosa *et al.*, 2019)**.In addition to low capital and operating costs which are important

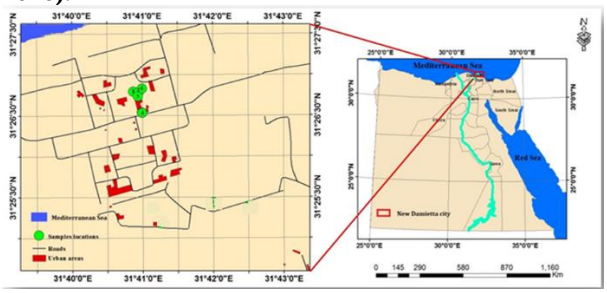
because profit margins of most restaurants are small, as well as the technology has to be simple to operate easily by a waiter or a chef compared with conventional biological processes which require large space and skilled technicians **(Chen *et al.*, 2000).**

Oil in water can be found in the form of free floating oil, as an unstable oil or water emulsion, and can also be found as a highly stable oil or water emulsion, which are all difficult to treat. Electrocoagulation process can be used to treat and remove these emulsified oils from wastewaters by formation of aluminum hydroxide flocs. As a result of dissolution of aluminum anodes when hydrogen evolved at the cathode floats, the hydroxide floc adsorbed the oil **(Islam, 2017)**.

2. Materials and Methods

Study area

The new Damietta city is located in the north of Damietta governorate – Egypt and on the coast of the Mediterranean Sea with a length of 9 km, about 4.5 km west of Damietta Port extends from latitude 31°24'2.40"N to 31° 28' 24.61" N and longitude 31° 37' 10.13" E to 31° 44' 9.49" E occupies an area of 18 km^2. It is 79 km away from Port Said city, about 200 km away from Alexandria city, and about 10 km away from the Nile River. The city is divided into five sectors: Residential areas, Services sector, Industrial sector, Tourism, and recreational sectors **(New Damietta city Development Authority, 2020)**.



Map (1): Map of the Study Area

Because of New Damietta city is considered as a touristic city due to its location as mentioned before, there are chains of restaurants and fast-food joints that spread out in the city especially in El Saidi Street / Hasballah El Kafrawi Street, and they use huge quantities of water every day for cooking and washing purposes, that characterized by oily wastewaters, which are discharged to the public sewer system mostly without any preliminary treatment. These wastewaters cause clogging and fouling of the pipes in addition to causing high load of pollution on the treatment unit.

Sampling and analysis

Five grab wastewater samples were collected from kitchens' effluents discharged from the most five popular restaurants in New Damietta city-Egypt (sites 1:5) from 13th to 24th of March 2019. Before the treatment, the samples were analyzed for physical and chemical characteristics, because knowing the composition of the wastewater is essential for successful design and operation of wastewater treatment plants (Abdalla and Hammam, 2014). The measured parameters include (Temperature with mercury filled thermometer in ºC, pH measured electrometrically using (pH meter model #59003-25 Cole-Parmer, Chicago (USA)), Electrical Conductivity (EC) and Total Dissolved Solids (TDS) were measured using (TDS / Conductivity meter Sens ion5 HACH, USA), Turbidity by (Turbidity meter TU-2016 Lutron, Taiwan), Total Solids (TS) was determined by evaporation followed by drying at 103-105 ºC , Total Suspended Solids (TSS) measured by filtration followed drying at 103-105 ºC., (COD) by means of the dichromate open reflux method in addition to Oil & Grease by Partition-Gravimetric method using organic solvents (n-Hexane and Petroleum ether) for oil and grease extraction, according to (APHA, 2017), (Adams, 1990) and the instruction manual of the used instruments. The wastewater samples were collected in a high-quality Pyrex glass bottles for the analysis of organic matters (COD in addition to oil & grease), while high density polyethylene bottles were used to collect the wastewater sample for the other parameters' analysis. All sampling sites and their descriptions were illustrated in map.1 and table 1.

Table (1): Sampling Sites and Their Locations Description

No. of Sites	Sampling Sites	Location
1	El-Ezz El-Soury Restaurant	It is located in the plot number 84/23 at the second District, 4th Neighborhood, Shop No. 2.
2	Hadramawt Restaurant	It is located in the plot number 84/21 at the second District, 4th Neighborhood, Shop No. 1.
3	Abo-Saleh Restaurant	It is located in the plot number 34/23 at the second District, 4th Neighborhood, Shop No. 1.
4	Kintaki (KFC) Restaurant	It is located in the plot number 33/26 at the second District, 3th Neighborhood, Shop No. 3.
5	Pizza Party Restaurant	It is located in the plot number 54 at the second District, 4th Neighborhood, Shop No. 3, 4,5,6,7.

Electrocoagulation experiment

The experimental set-up is schematically shown in **fig. 1**. Electrocoagulation process was carried out in a 500 ml beaker. 300 ml of the investigated wastewater was taken in the beaker for treatment. Two aluminum electrodes are in plate form, having a dimension of 100 mm x 50 mm x 0.095 mm (length x width x thickness) were immersed in the wastewater for a depth of 50 mm with an effective surface area of 25cm^2 for each electrode. The choice of aluminum as an electrode material in the treatment is based on that, the effluent with aluminum electrodes was found very clear and stable, whereas the effluent with iron electrodes appeared greenish first, and then turned yellow and turbid. In addition,

electrode corrosion at open circuit was found for iron. This creates problems for restaurant wastewater treatment units because most restaurants do not open 24 h a day. As a result, it is obvious that aluminum is a better electrode material than iron for the present application **(Chen *et al.*, 2000)**, as well as aluminum oxides provide higher adsorption capacity than iron oxides **(Nasr *et al.*, 2016)**, further more; the increased sedimentation rate of the aluminum species formed during electrocoagulation, is responsible for the enhanced performance of the aluminum electrodes, compared to that of the iron species. More specifically, the generated aluminum coagulant species are rather insoluble (with respect to pH) and therefore capable of co-precipitating with organic materials immediately after their formation **(Benekos *et al.*, 2019)**. The spacing between the two electrodes is kept at 20 mm. The two electrodes are connected in mono-polar mode to direct current power supply unit with applied voltage 18 volt, current intensity 1 ampere (A), and current density 40 mA/cm^2. The experiment was performed at room temperature (nearly 25 ºc) and at the actual pH of the samples (pH = 7.43), without any modification to avoid adding any chemicals, except site 4 that has been needed a pH modification to 7, taking into account that the optimal pH for wastewater treatment by electrochemical coagulation ranges from 6.5 to 7.5 as well as near pH 7, pollutant removal was found best **(Bharath *et al.*, 2018; Chen, 2004)**. Wastewater was stirred during electrocoagulation at high mixing rate 80 rpm for 2 minutes and the rest of the electrolysis times at low mixing rate 40 rpm.

Electrocoagulation mechanism

Electrocoagulation process uses the benefits of coagulation and flocculation for the removal of oil and grease from water and wastewater. The process involves the usage of aluminum electrodes which, under the influence of a potential difference results in the generation of flocculating species from the anode. Amorphous $Al(OH)_3$ flocs produced during the electrocoagulation process have large surface areas which have high affinity towards colloidal particles. The oxygen and hydrogen gases produced during the electrocoagulation process further aids in the oil and grease removal from aqueous solutions. The reactions occurring are briefly given below: (Changmai *et al.*, 2019).

Reactions occurring at the anode:

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

$2H_2O \rightarrow O_{2\,(g)} + 4H^+ + 4e^-$ (2)

Reactions occurring at the cathode:

$2H_2O + 2\,e^- \rightarrow H_{2\,(g)} + 2OH^-{}_{(aq)}$ (3)

Reactions occurring at bulk:

$Al^{3+}{}_{(aq)} + 3OH^- \rightarrow Al(OH)_{3\,(s)}$ (4)

$Al(OH)_{3\,(s)} + OH^- \rightarrow Al(OH)_4^-$ (Under alkaline conditions) (5)

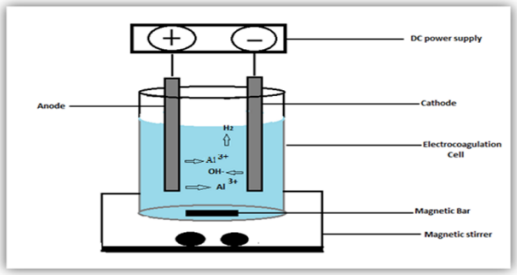


Fig. (1): Scheme of Electrocoagulation Experimental Set-up

3. Results and discussion

Electrocoagulation Treatment of Abo-Saleh Restaurant Wastewater

Table 2 and Fig. 2 depict Abo-Saleh restaurant wastewater characteristics before and after applying electrocoagulation treatment employing aluminum electrodes. It was found that there is a large variation in some physico-chemical characteristics after the treatment especially in Turbidity, COD, and Oil & Grease.

Table (2): Characterization of Electrocoagulation Treatment for Abo-Saleh Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes.

Parameter	Before treatment	After treatment at different electrolysis time			Discharge to sewer system according to Egyptian Standard limit (ESL) (Ministerial Decree No. 44/2000 of low 93/1962)
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)	
Temperature (ºC)	21.8	22.2	22.7	22.8	<43
pH	6.93	8.56	8.71	8.85	6-9.5
EC (µS/cm)	765	639	605	553	-
Turbidity (NTU)	191	3.06	1.1	0.43	-
TS (mg/l)	1128	496	398	345	-
TDS (mg/l)	410	358	340	311	-
TSS (mg/l)	718	138	58	34	<800
COD (mg/l)	15120	2560	2120	1640	<1100

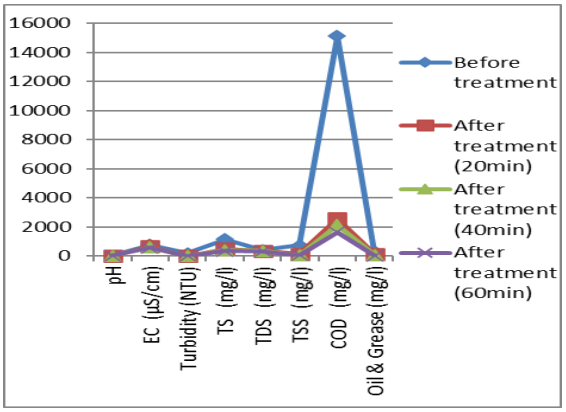


Fig. (2): Values of Abo-Saleh Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes.

The removal efficiency of pollutants in term; EC, turbidity, TS, TDS, TSS, COD, and oil &grease was studied as a function of variable electrolysis time 20, 40 and 60 minutes (Fig. 3). It can be seen that at electrolysis time 20 turbidity decreases in a drastic way from 191 to 3.06 NTU with a removal efficiency of 98.4%. Extension of electrolysis time to 40 and 60 minutes did not show a significant difference in turbidity that recorded 99.42 and 99.77% removal efficiency, respectively (Table 3) (Fig. 3).

Table (3): Removal Efficiency Percentages of Abo-Saleh Restaurant Wastewater's Characteristics by Electrocoagulation Treatment Using Two Aluminum Electrodes at Different Electrolysis Time

Parameter	% Removal Efficiency at different electrolysis time		
	20 minute	40 minute	60 minute
EC (µS/cm)	16.47	20.92	27.7
Turbidity(NTU)	98.4	99.42	99.77
TS (mg/l)	56.03	64.72	69.41
TDS (mg/l)	12.68	17.07	24.15
TSS (mg/l)	80.78	91.92	95.3
COD (mg/l)	83.07	85.98	89.15
Oil & Grease (mg/l)	50.76	77.27	92.42

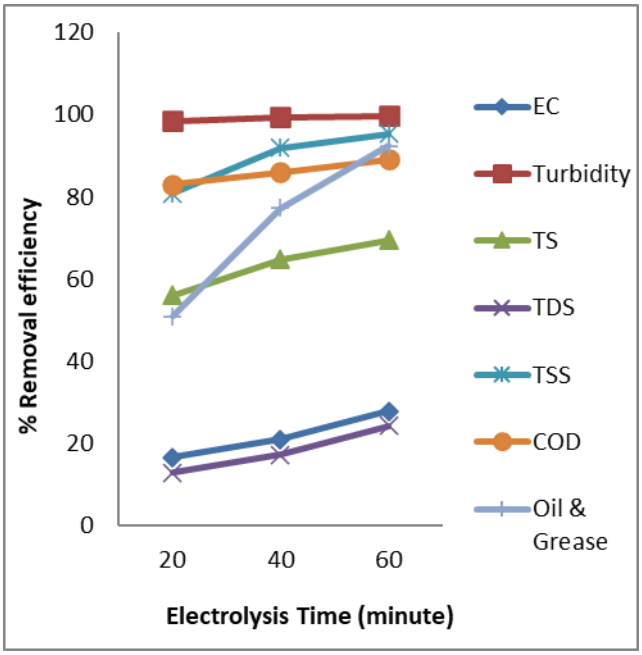


Fig. (3): Efficiency of Abo-Saleh Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time

On the other hand, the best results in decreasing the values of COD from 15120 to 1640 mg/l, TSS from 718 to 34 mg/l, and oil &grease from 264 to 20 mg/l were achieved at electrolysis time (60 minutes) with about 89.15, 95.3, and 92.42% removal efficiencies respectively. Although, the decline in COD value as well as achieving a removal efficiency percentage exceeding 80%, COD did not meet the Egyptian standard limit (ESL) according to (Ministerial Decree No. 44/2000 of low 93/1962) for discharge to sewer system as the other two parameters (TSS and oil & grease) that match with the ESL. In other words, the aluminum electrode treatment is effective in removing oil and grease and suspended solids with a removal percent exceed 90 % but, there was still a significant amount of dissolved organic compounds remaining.

EC, TS, and TDS values tend to decrease at electrolysis time 20 minutes until reached time 60, the EC and TDS values dropped somewhat from 765 to 553µS/cm and 410 to 311 mg/l with removal efficiency percentages that did not exceed fifty percent removal 27.7 and 24.15% respectively. While TS concentration dropped from 1128 to 345 mg/l with 69.41% effectiveness.

Electrocoagulation Treatment of Pizza Party Restaurant Wastewater

Fig. 4 and **Table 4** illustrate the physico-chemical parameters of Pizza Party restaurant wastewater before and after applying electrocoagulation treatment using aluminum electrodes at different electrolysis time. It was found that, at the electrolysis time of 60 minutes, the values of COD, and oil & grease were dropped in a drastic way from (5440 to 392 mg/l), and (286 to 35 mg/l) respectively, complying with the (ESL) for discharge to sewer system.

Table (4): Characterization of Electrocoagulation Treatment for Pizza Party Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes.

parameter	Before treatment	After treatment at different electrolysis time		
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)
Temperature (°C)	21	23.2	23	23
pH	8.02	8.71	8.85	8.91
EC (µS/cm)	400	362	323	295
Turbidity (NTU)	125	1.86	0.83	0.26
TS (mg/l)	696	260	185	175
TDS (mg/l)	250	196.9	178.2	168.4

While, the TSS parameter decreased from 446 to 6.8 mg/l at electrolysis time of 40 minute that matches with the (ESL) for discharge to sewer system. Rising the electrolysis time to 60 minutes, the value did not decrease in a significant manner to a value of 6.6 mg/l.

On the other hand, EC, turbidity, TS, and TDS were dropped from 400 to295 µS/cm, 125 to 0.26 NTU, 696 to 175 mg/l, and 250 to 168.4 mg/l respectively. The removal efficiencies of pollutants in term; EC, turbidity, TS, TSS, TDS, COD, and oil & grease as a function of electrolysis time were depicted in **fig. 5** and **table 5**. The best removal efficiency of the

parameters (COD, EC, TDS and oil & grease) were achieved at electrolysis time 60 minute with about 92.79, 25.25, 32.64 and 87.76% respectively. At electrolysis time 20 minute, the turbidity was removed in a very clear way recording a removal efficiency of 98.51%, increasing the electrolysis time gradually to 40 and 60 minutes, the removal efficiency percentage did not increase in a significant value with about 99.34 and 99.79% respectively. Although, the other measured parameters (TS and TSS), have recorded the highest removal percentages of 74.68 and 98.52% respectively at electrolysis time 60 minute., it can be considered that, the electrolysis time 40 minutes is a sufficient time for removal of the last mentioned parameters (TS and TSS), as the removal percentages did not change widely (73.42 and 98.48 % respectively).

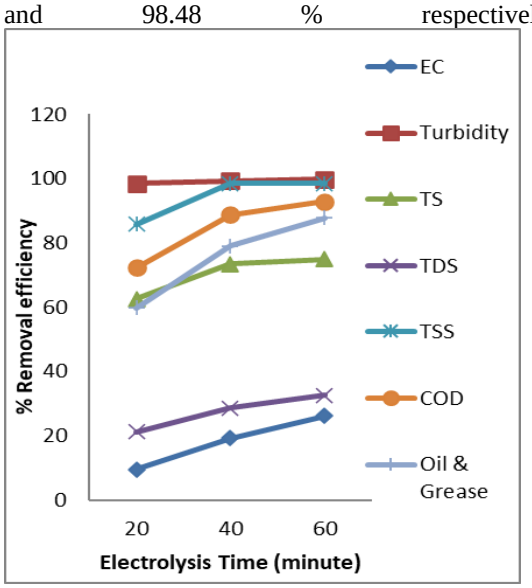


Fig. (4): Values of Pizza Party Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes

Electrocoagulation Treatment of El-Ezz El-Soury Restaurant Wastewater

In case of applying electrocoagulation treatment using aluminum electrodes for El-Ezz El-Soury restaurant wastewater at different electrolysis time, it can be shown that, the best removal efficiencies achieved for (turbidity (99.9%), TS (88.6%), TSS (96.8%),COD (84.6%), and oil& grease (100%) were at electrolysis time 40 minute (Table 7 and Fig. 7). The values decreased from 628 to 0.22 NTU, 6176 to 704 mg/l, 5532 to 178 mg/l, 5440 to 840 mg/l, and 1184 to zero mg/l respectively (Table 6 and Fig. 6). While, time 60 minute acts as an optimum time for EC and TDS removal with a percentages of 25.2 and 21.4% respectively (Table 7 and Fig. 7). All measured parameters values comply with the (ESL) for discharge to sewer system, after applying the electrocoagulation treatment. It indicated that, aluminum electrodes perform a better removal for most pollutants in El-Ezz El-Soury restaurant wastewater specially COD, turbidity, and oil& grease that act as a major problems resulting from restaurant wastewaters.

Table 5: Removal Efficiency Percentages of Pizza Party Restaurant Wastewater's Characteristics by Electrocoagulation Treatment Using Aluminum Electrodes at Different Electrolysis Time

Parameter	% Removal Efficiency at different electrolysis time		
	20 minute	40 minute	60 minute
EC (µS/cm)	9.5	19.25	26.25
Turbidity(NTU)	98.51	99.34	99.79
TS (mg/l)	62.64	73.42	74.86
TDS (mg/l)	21.24	28.72	32.64
TSS (mg/l)	85.85	98.48	98.52
COD (mg/l)	72.21	88.68	92.79
Oil & Grease (mg/l)	59.8	79.02	87.76

Electrocoagulation Treatment of Hadramawt Restaurant Wastewater

The results of EC, turbidity, TS, TSS, TDS, COD, and oil & grease reduction were reported and presented in **table 8** and **fig. 8** after applying electrocoagulation treatment using two electrodes of aluminum electrodes at different electrolysis time 20, 40, and 60 minute.

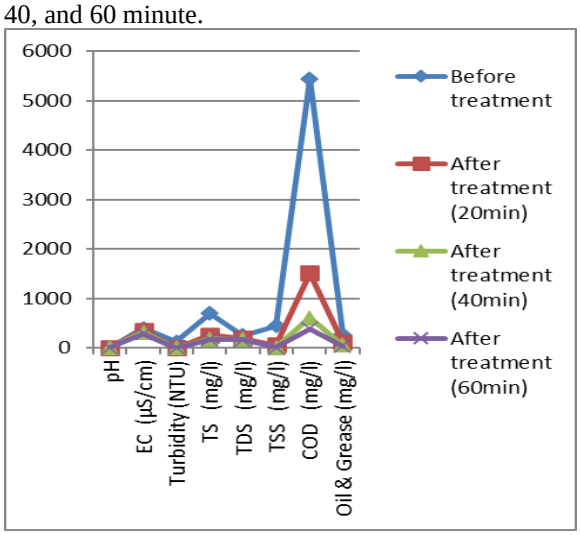


Fig. (5): Efficiency of Pizza Party Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time.

At electrolysis time 20 minute, it was noted that, the measured parameters (EC, turbidity, TS, TSS, TDS, and oil & grease) clearly dropped from 5330 to 4980 µS/cm, 176 to 2.36 NTU, 9122 to 3130 mg/l, 3140 to 3050 mg/l, 5982 to 80 mg/l, and 234 to zero mg/l, with a best removal efficiency reached 6.6, 98.7, 65.7, 2.9, 98.7, and 100% respectively. Increasing the electrolysis time gradually to 60 minute, the removal efficiencies decreased for the previously parameters mentioned, except the value of COD that dropped

from 5280 to 1344 mg/l recording a best removal efficiency of 74.5% **(Table 9 and Fig. 9)**. All parameters values match the (ESL) for discharge to sewer system after applying the electrocoagulation treatment except the COD value that still above the ESL limits.

Electrocoagulation Treatment of Kintaki (KFC) Restaurant Wastewater Using Aluminum Electrodes at Different pH Values

At Original pH of the Sample (5.6), Applying Different Electrolysis Time 20, 40, and 60 Minutes

Table 10 and Fig. 10 depict the results of electrocoagulation treatment for (KFC) restaurant wastewater employing aluminum electrodes at variable electrolysis time and sample pH (5.6). It was found that, the physico-chemical parameters including (turbidity, TS, TSS, COD, and oil & grease) have been dropped from (377 to 27.35 NTU, 1782 to 760 mg/l, 1213 to 242 mg/l, 3808 to 1964 mg/l, and 218 to 40 mg/l respectively) at electrolysis time of 20 minute, with removal efficiency reached (92.75, 57.35, 80.05, 48.42, and 81.65% respectively) **(Table 11)** and **(Fig. 11)**.

Table (6): Characterization of Electrocoagulation Treatment for El-Ezz El-Soury Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes

Parameter	Before treatment	After treatment at different electrolysis time		
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)
Temperature (ºC)	23	24	24.1	24.1
pH	7.26	9	9.75	9.89
EC (µS/cm)	1139	952	885	852
Turbidity (NTU)	628	2.47	0.22	0.43
TS (mg/l)	6176	1312	704	934
TDS (mg/l)	644	565	526	506
TSS (mg/l)	5532	747	178	428
COD (mg/l)	5440	1540	840	1000
Oil & Grease (mg/l)	1184	28	0	0

Further increase in the treatment time to 60 minute did not improve the effectiveness of these parameters and this means that electrolysis time 20 minute is sufficient to achieve the best removal for the previously mentioned parameters. On contrast to parameters (EC and TDS) that recorded the best removal efficiency percentages at time 60 minute with about (19.06 and 17.93%) **(Table 11)** and **(Fig. 11)**. The treated wastewater characteristics are in compliance with the (ESL) for discharge to sewer system except COD parameter.

At Modified pH of the Sample (7), Applying Different Electrolysis Time 20, 40, and 60 Minutes

The (KFC) restaurant wastewater's sample was adjusted by adding aqueous sodium hydroxide (1N) solution in order to neutralize the sample before applying the electrocoagulation treatment using aluminum electrodes in order to decrease the solubility of aluminum and increased the coagulant in an enough way for elimination of turbidity and COD, and it is achieved within a pH range of 6.5–7.8 **(Arturi *et al.*, 2019),** in other words, at pH of 6-7, $Al(OH)_3$ is the dominant species and it is the effective form of coagulant **(Truttim and Sohsalam, 2016)**.

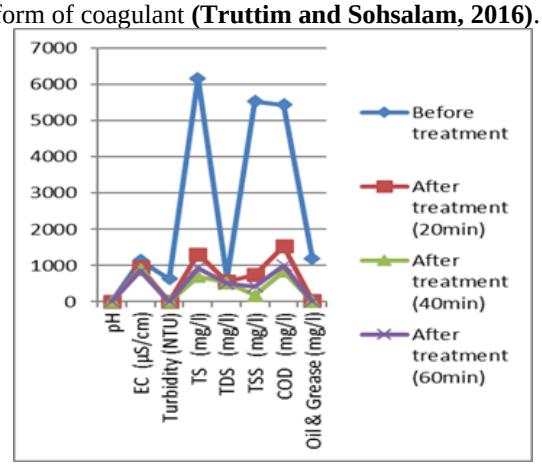


Fig. (6): Values of El-Ezz El-Soury Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes.

Fig. 13 and **Table 11** show the achieved removal efficiency against different electrolysis time (20, 40, and 60 minute). It was noted that, the removal efficiencies of (EC, TS, and TDS) decreased to (3.42, 45.79, and 1.58%) at electrolysis time 60 minute compared to the previously mentioned percentages that achieved at initial pH (5.6). On the other hand, turbidity, TSS, COD, and oil & grease values declined at electrolysis time 60 minute from (377 to 3.54 NTU, 1213 to 36 mg/l, 3808 to 1200 mg/l, and 218 to 12 mg/l) **(Fig. 12** and **Table 12)**, achieving a better removal efficiency of about (99.06, 97, 68.5, and 94.5 %) respectively in comparison with percentages that achieved at initial pH (5.6)(**Table 11**), confirming the previously mentioned statement of **(Arturi *et al.*, 2019)** and **(Garcia-Segura *et al.*, 2017)** who reported that the optimal pH in electrocoagulation process is 7**.**

Table (7): Removal Efficiency Percentages of El-Ezz El-Soury Restaurant Wastewater's Characteristics Using Aluminum Electrocoagulation Treatment Technology at Different Electrolysis Time

Parameter	% Removal Efficiency (using (Al + Al) electrodes)		
	Time (20 min)	Time (40 min)	Time (60 min)
EC (µS/cm)	16.4	22.3	25.2
Turbidity (NTU)	99.6	99.9	99.9
TS (mg/l)	78.8	88.6	84.9
TDS (mg/l)	12.3	18.3	21.4
TSS (mg/l)	86.5	96.8	92.3
COD (mg/l)	71.7	84.6	81.6
Oil & Grease (mg/l)	97.6	100	100

The treated wastewater characteristics completely match with the (ESL) for discharge to sewer system except COD parameter that compatible in a certain extent with the standard limit of COD which equals to 1100 mg/l.

After applying electrocoagulation process using aluminum electrodes for treatment of KFC restaurant wastewater at variable electrolysis time and studying the effectiveness of pollutants removal at actual pH of the sample (5.6) and modified pH (7), It can be shown that, pH of the medium has a considerable effect on the removal efficiency of the pollutants using the electrocoagulation treatment specially turbidity and COD (**A-Mohammed, 2007).**

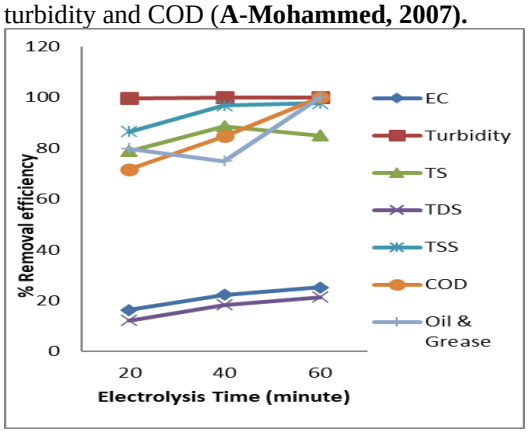


Fig. (7): Efficiency of El-Ezz El-Soury Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time

The best removal efficiency reached for COD, TSS, turbidity, and oil& grease were achieved at electrolysis time of 60 minute under neutral conditions (pH=7) in a confirmation to the highest pollutant removal found near pH of 7 **(An *et al.*, 2017).**

Table (8): Characterization of Electrocoagulation Treatment for Hadramawt Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes

Parameter	Before treatment	After treatment at different electrolysis time		
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)
Temperature (°C)	22	23.6	23.5	24
pH	6.7	9.3	9.11	9.11
EC (µS/cm)	5330	4980	5070	5290
Turbidity (NTU)	176	2.36	2.52	3.6
TS (mg/l)	9122	3130	3478	4152
TDS (mg/l)	3140	3050	3100	3190
TSS (mg/l)	5982	80	378	962
COD (mg/l)	5280	1702	2611	1344
Oil & Grease (mg/l)	234	0	0	0

After applying electrocoagulation treatment for different restaurant wastewaters, it can be inferred that the treatment performance is varied from restaurant to another depending on various parameters as, pH, electrolysis time, especially the initial contaminant concentration (quantity). The wastewater composition would vary from time-to-time for a particular restaurant. Thus, it is very difficult to have one meaningful characterization for each restaurant **(Chen *et al.*, 2000).**

Operating Cost and Hydrogen Amount Calculations

The major operating cost components in the electrocoagulation process are electrode and power costs **(Murthy *et al.*, 2007)**. The amount of aluminum which goes into solution (g Al cm^{-2}) can be calculated by using faraday's law:

$$W = \frac{itM}{ZF}$$

Where: W=aluminum dissolving (g Al cm^{-2}), i=current density (A/ cm^2), t= time (s), M= molecular weight of Al (m=27), Z=number of electrodes involved in the oxidation reduction reaction (z=3), and F= Faraday's constant (96500) (**A-Mohammed, 2007)**. The energy consumptions in the electrocoagulation process were calculated via the following equations:

$$EnergyConsumption = \frac{\mathbf{V.I.t}}{\mathbf{1000 * Volume}}$$

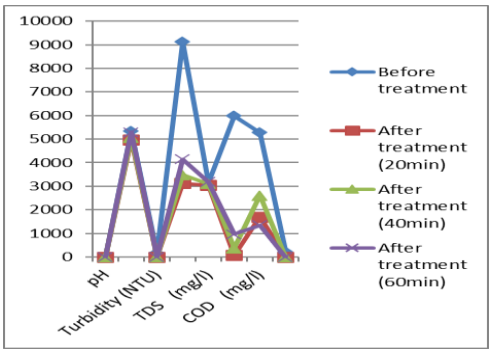


Fig. (8): Values of Hadramawt Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes

Where Energy consumption is the energy consumption (kWh/m^3), V is the voltage (Volts), I is the current (Ampere), t is the electrolysis time (hour), and v is the volume of the treated wastewater (m^3) **(Deghles and Kurt, 2017)**. The mainly drawback of electrocoagulation process is the power cost, however this problem can be solved through the process itself; hydrogen gas can be act as an energy alternative especially it is the primary product of the process. The theoretical amount of hydrogen gas produced can be calculated by Faraday's law:

$$\eta H_2 = \frac{I.t}{F}.H$$

Where, H_2 is the amount of hydrogen produced (mole), t is the electrolysis time (Sec.), I is the applied current (Ampere), F is Faraday's constant (96500 C per mole of electrons), H is the number of hydrogen molecules generated per electron involved in the redox reactions. H value is independent of the type of anode; i.e. iron or aluminum. That is, H is equal to 1/2 in both cases **(Phalakornkule *et al.*, 2010)**.

Based on the experimental results, a cost analysis of effluent treatment by electrocoagulation was conducted and calculated to evaluate the feasibility of applying the process at industrial scale especially in the investigated restaurants **(Benekosa *et al.*, 2019)**, in addition to the theoretical amount of hydrogen gas produced **(Table 13)**.Unit price, given as Egypt market (2020) for aluminum material is 57 EGP/kg, and for electrical energy, 30 piasters/ (1-50) kWh and 40 piasters/ (51-100) kWh consumed according to slides system that has been issued by the Ministry of Electricity and Renewable Energy in Egypt.

Table (9): Removal Efficiency Percentages of Hadramawt Restaurant Wastewater's Characteristics Using Aluminum Electrocoagulation Treatment Technology with Variation in Electrolysis Time

parameter	% Removal Efficiency (using (Al + Al) electrodes)		
	Time (20 min)	Time (40 min)	Time (60 min)
EC (µS/cm)	6.6	4.9	0.75
Turbidity (NTU)	98.7	98.6	97.95
TS (mg/l)	65.7	61.9	54.5
TDS (mg/l)	2.9	1.3	0
TSS (mg/l)	98.7	93.7	83.9
COD (mg/l)	67.8	50.5	74.5
Oil & Grease (mg/l)	100	100	100

Table (10): Characterization of Electrocoagulation Treatment for KFC Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes Without pH Modification

Parameter	Wastewater characteristics before treatment	Wastewater characteristics after treatment by electrocoagulation at different electrolysis time		
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)
pH	5.64	7.49	7.55	7.55
EC (µS/cm)	1023	914	871	828
Turbidity (NTU)	377	27.35	30.43	137
TS (mg/l)	1782	760	782	964
TDS (mg/l)	569	518	493	467
TSS (mg/l)	1213	242	289	497

Table (11): Removal Efficiency Percentages of KFC Restaurant Wastewater's Characteristics Using Aluminum Electrocoagulation Treatment Technology at Variable Electrolysis Time Before and After pH Modification

Parameter	% Removal Efficiency using (Al + Al) electrodes					
	At pH of the sample =5.6			At modified pH =7		
	Time (20 min)	Time (40 min)	Time (60 min)	Time (20 min)	Time (40 min)	Time (60 min)
EC (µS/cm)	10.65	14.86	19.06	0	0	3.42
Turbidity (NTU)	92.75	91.93	63.66	97.8	98.47	99.06
TS (mg/l)	57.35	56.12	45.9	31.09	35.56	45.79
TDS (mg/l)	8.97	13.36	17.93	0	0	1.58
TSS (mg/l)	80.05	76.17	59.03	92.3	92.3	97
COD (mg/l)	48.42	46.64	17.44	43.3	52.1	68.5
Oil & Grease (mg/l)	81.65	79.82	49.54	56	80	94.5

Table (12): Characterization of Electrocoagulation Treatment for KFC Restaurant Wastewater Using Two Electrodes of Aluminum at Different Electrolysis Times; 20, 40, and 60 Minutes after pH Modification.

Parameter	Wastewater characteristics before treatment	Wastewater characteristics after treatment by electrocoagulation at different electrolysis time		
		After treatment (20 minute)	After treatment (40 minute)	After treatment (1 hour)
pH	7	8.28	8.58	9.68
EC (µS/cm)	1023	1113	1069	988
Turbidity (NTU)	377	8.3	5.75	3.54
TS (mg/l)	1782	728	648.4	596
TDS (mg/l)	569	634	607	560

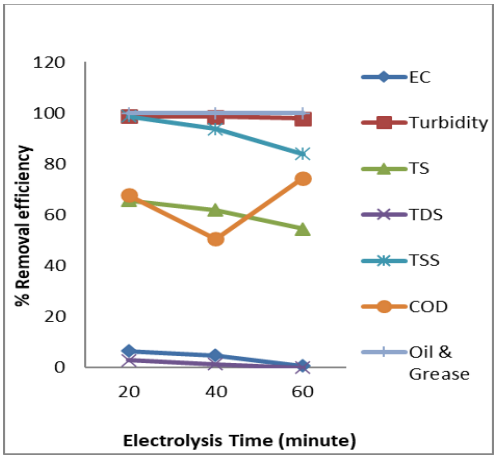


Fig. (9): Efficiency of Hadramawt Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time.

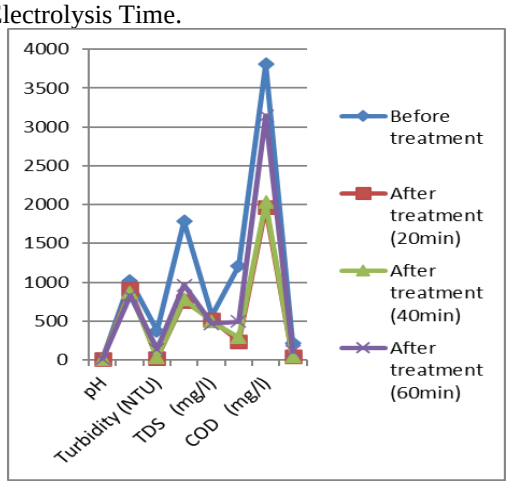


Fig. (10): Values of (KFC) Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes Without pH Modification

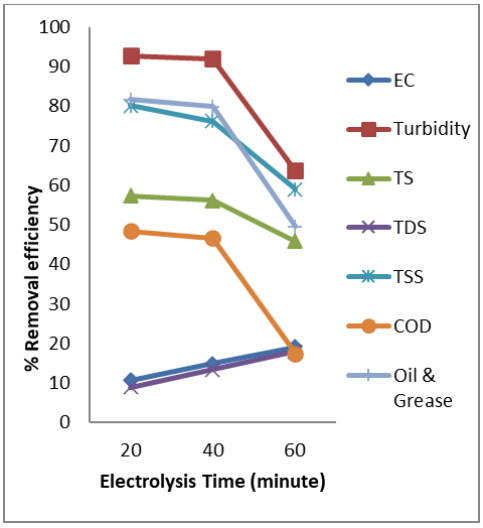


Fig. (11): Efficiency of (KFC) Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time Without pH Modification

Conclusions

Electrocoagulation technique is an effective and amenable process for treating restaurants' wastewaters characterized by high oil & grease content and fluctuated COD and suspended solids concentrations that differ from restaurant to another. It was found that, aluminum electrode at certain conditions acts as an efficient electrode material in removing turbidity, organic matter in addition to oil and grease pollutants. COD removal efficiency reached a percentage of 92.79, while the turbidity and oil & grease reached 100% removal efficiency. Total operating cost was calculated to be a minimal value, encouraging the treatment application. Furthermore, hydrogen gas amount was also theoretically calculated in order to solve the process's power problem as an energy alternative later.

Table (13): Total Operating Cost and Hydrogen Gas Amount at Different Electrolysis Time

Electrolysis Time (minute)	Theoretical amount of hydrogen gas produced (mole)	Amount of electrical energy consumed (kWh/m^3)	aluminum amount dissolving (kg/cm^2)	Total operating cost (EGP)	Total operating cost (US$)
20	6.218	20	$4.4768*10^{-6}$	6.0003	0.384
40	12.435	40	$8.9534*10^{-6}$	12.00051	0.767
60	18.653	60	$1.7907*10^{-5}$	24.001	1.535

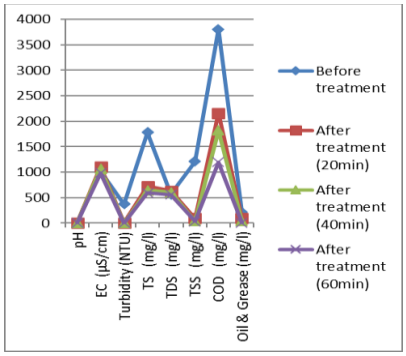


Fig. (12): Values of KFC Restaurant Wastewater Characteristics Before and After Treatment by Electrocoagulation Using Two Electrodes of Aluminum at Different Electrolysis Times 20, 40, and 60 Minutes
After pH Modification

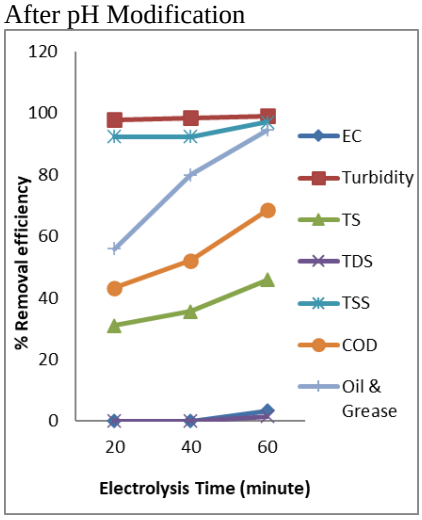


Fig. (13): Efficiency of KFC Restaurant Wastewater Treatment by Electrocoagulation Using Two Electrodes of Aluminum with Variation in Electrolysis Time After pH Modification

4. References:

A-Mohammed, A. (2007). Electrocoagulation of phenol for wastewater treatment. Iraqi Journal of Chemical and Petroleum Engineering; 9(3): 37-41.

An, C., Huang, G., Yao, Y., Zhao, S. (2017). Emerging usage of electrocoagulation technology for oil removal from wastewater: A review. Science of the Total Environment; 579: 537-556.

Abdalla, K.Z. and Hammam, G. (2014). Correlation between Biochemical Oxygen Demand and Chemical Oxygen Demand for Various Wastewater Treatment Plants in Egypt to Obtain the Biodegradability Indices. International Journal of Sciences: Basic and Applied Research (IJSBAR); 13(1): 42-48.

American Public Health Association (APHA) (2017)."Standard Method for the Examination of Water and Wastewater", 23th ed, Washington, D.C.

Arturi, T.S., Seijas, C.J. and Bianchi, G.L. (2019).A comparative study on the treatment of gelatin production plant wastewater using electrocoagulation and chemical coagulation. Heliyon; 5: 1-7.

Adams, V.D. (1990). Water and Wastewater Examination Manual. Lewis publishers, New York, 116-148.

Benekosa, A.K., Zampetaa, C., Argyrioua, R., Economoua, C.N., Triantaphyllidoua, I., Tatoulisb, T.I., Tekerlekopouloub, A.G., Vayenas, D.V. (2019). Treatment of table olive processing wastewaters using electrocoagulation in laboratory and pilot-scale reactors. Process Safety and Environmental Protection; 131: 38-47.

Bharath, M., Krishna, B.M. and Manoj, K.B. (2018).A Review of electrocoagulation process for wastewater treatment. International Journal of Chem Tech Research; 11(3): 289-302.

Chen, G. (2004). Electrochemical technologies in wastewater treatment. Sep. Purif. Technol.; 38(1):11-41.

Changmai, M., Pasawan, M. and Purkait, M.K. (2019). Treatment of oily wastewater from drilling site using electrocoagulation followed by microfiltration. Separation and Purification Technology; 210: 463-472.

Chen, X., Chen, G., Yue, P.L. (2000). Separation of pollutants from restaurant wastewater by electrocoagulation. Separation and Purification Technology; 19: 65-76.

Deghles, A. and Kurt, U. (2017). Hydrogen Gas Production from Tannery Wastewater by Electrocoagulation of a Continuous Mode with Simultaneous Pollutants Removal. IOSR Journal of Applied Chemistry (IOSR-JAC); 10(3): 40-50.

Garcia-Segura, S., Eiband, M.M., de Melo, J.V., Mart´ınez-Huitle, C.A. (2017). Electrocoagulation and advanced electrocoagulation processes: a general review about the fundamentals, emerging applications and its association with other technologies. Journal of Electroanalytical Chemistry; 801: 267–299.

Islam, S.M. (2017). Electrocoagulation (EC) technology for wastewater treatment and pollutants removal. Sustain. Water Resour. Manag.; 5(2019): 359–380.

Murthy, Z.V.P., Nancy, C. and Kant, A. (2007). Separation of Pollutants from Restaurant Wastewater by Electrocoagulation. Separation Science and Technology; 42: 819-833.

New Damietta City Development Authority website. http://www.newcities.gov.eg /English /about us/About Authority/default.aspx. Accessed 2 Jan. 2020.

Nasr, M., Ateia, M. and Hassan, K. (2016). Artificial intelligence for greywater treatment

using electrocoagulation process. Separation Science and Technology; 51(1): 96-105.

Phalakornkule, C., Sukkasem, P. and Mutchimsattha, C. (2010). Hydrogen recovery from the electrocoagulation treatment of dye-containing wastewater. Int. J. Hydrogen Energy; 35:10934-10943.

Truttim, P. and Sohsalam, P. (2016). Comparison of electrocoagulation using iron and aluminum electrodes for biogas production wastewater treatment. Journal of Advances in Technology and Engineering Research; 2(2): 35-40.

Yau Y., Rudolph, V., Chui-man Lo, C., Wu, K. (2018). Restaurant oil and grease management in Hong Kong. Environmental Science and Pollution Research, https://doi.org/10.1007/s11356-018-2474-4.

Zulaikha, S., Lau, W.J., Ismail, A.F., Jaafar, J. (2014). Treatment of restaurant wastewater using ultrafiltration and nanofiltration membranes. Journal of Water Process Engineering; 2: 58-62.