Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2017.21379

89 (2017) 101–110
September

Impact of soluble COD on grey water treatment by electrocoagulation technique

Khalid Bani-Melhem[a], Mohammad Al-Shannag[b,*], Dheaya Alrousan[a], Salman Al-Kofahi[c], Zakaria Al-Qodah[d], Muhammad Rasool Al-Kilani[a]

[a]*Department of Water Management and Environment, Faculty of Natural Resources and Environment, The Hashemite University, P.O. Box 150459, Zarqa 13115, Jordan, Tel. 00962795634630; email: kmelhem@hu.edu.jo (K. Bani-Melhem), Tel. 00962798798454; email: dheaya@hu.edu.jo (D. Alrousan), Tel. 00962785150310; email: rasoolkilani@live.com (M. Rasool Al-Kilani)*
[b]*Department of Chemical Engineering, School of Engineering, University of Jordan, P.O. Box 11942, 11942 Amman, Jordan, Tel. 00962772352778; email: mohammad_al_shannag@hotmail.com*
[c]*Department of Land Management and Environment, Faculty of Natural Resources and Environment, Hashemite University, P.O. Box 150459, Zarqa 13115, Jordan, Tel. 00962796744321; email: salman@hu.edu.jo*
[d]*Chem. Eng. Department, Al-Balqa Applied University, P.O. Box 340558, Amman 11134, Marka, Jordan, Tel. 00966560948161; emails: z_alqodah@hotmail.com, zqudah@taibahu.edu.sa*

Received 29 May 2017; Accepted 26 August 2017

ABSTRACT

Grey water (GW) is a valuable source for water reclamation in many useful applications. In order to be safe for reuse, grey water should undergo sufficient treatment. In the last few years, electrocoagulation (EC) technique has proved to be an attractive method for GW treatment. However, an important consideration when dealing with grey water is the duration time prior to treatment which, if extended, might lead to a significant increase in the fraction of soluble chemical oxygen demand (SCOD), which could affect the EC treatment performance. This parameter presents a potential for explaining further patterns in selecting EC technique for GW treatment. In this study, three categories of GW samples comprising different percentages of SCOD, specifically 10%, 54% and 85% were obtained after storing the samples for 1, 7 and 30 d, respectively. A bench-scale EC unit was used to demonstrate the impact of the SCOD fraction on the total COD removal. Both Al and Fe electrodes were used at different applied current densities ranged from 5.85 to 11.70 mA/cm^2. An applied current density of 9.36 mA/cm^2 was found to be sufficient to remove 96% of the total COD at 10% of SCOD during 15 min of EC time with either Al or Fe electrodes. However, a significant impact of SCOD on the total COD removal was observed; the removal efficiency of COD decreases dramatically with increasing the SCOD fractions. Statistical analysis confirmed the superiority of aluminum anodes over iron anodes with regards to energy consumption and COD removal.

Keywords: Grey water; Electrocoagulation; Soluble COD; Wastewater treatment

1. Introduction

Grey water (GW), which comes from the kitchen sinks and tubs, showers, clothes washers, and dishwashers, is considered a valuable source for wastewater treatment and reuse because it constitutes 50%–80% of the total wastewater generated in households [1,2]. With suitable treatment, grey water could be utilized for many useful applications [3–5]. Many treatment methods have been investigated for such kind of wastewater including physical [6–8], chemical [9,10], and biological methods [1,11,12]. In addition, the combination of two or more methods was also investigated by many researchers [13,14]. Key parameters in selecting the treatment method are the characteristics of grey water to be treated [15,16] and reuse applications [4].

* Corresponding author.

1944-3994/1944-3986

In the recent years, electrocoagulation (EC) technology has been proved to be an effective method for different kinds of wastewater [17–23]. The concept of EC is simply based on using sacrificial electrodes (usually aluminum or iron) introduce metallic coagulating species as metallic hydroxides to the solution undergoing treatment instead of using conventional chemical coagulants [24]. This would lead to form a colloidal suspension within the solution to be treated and thus separating the pollutants from the water when the charged ionic species react with formed metallic hydroxides [24,25]. The overall EC process includes complicated physical and chemical processes starting with the dissolution of the sacrificial electrodes and ending with the destabilization of pollutants. Although the theoretical phenomenon behind the EC technology is well documented [24,25], there still wide ranges of research to be explored due to the complexity in the physiochemical processes involved in this technology. The main reactions that take place on the anodes and cathodes of Al and Fe electrodes are explained in the following chemical equations [24]:

At the anode of Al electrodes:

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

$$2H_2O_{(1)} \rightarrow 4H^{+}_{(aq)} + O_{2(g)} + 4e^{-} \tag{2}$$

At the cathode of Al electrodes:

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

$$2H_2O_{(l)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-} \tag{4}$$

At the anode of Fe electrodes:

$$Fe(s) \rightarrow Fe^{+2}_{(aq)} + 2e^{-} \tag{5}$$

$$2H_2O_{(1)} \rightarrow 4H^{+}_{(aq)} + O_{2(g)} + 4e^{-} \tag{6}$$

At the cathode of Fe electrodes

$$Fe^{+2}_{(aq)} + 2e^{-} \rightarrow Fe_{(s)} \tag{7}$$

$$2H_2O_{(l)} + 2e^{-} \rightarrow H_{2(g)} + 2OH^{-} \tag{8}$$

For grey water treatment by EC technology, many investigations had been carried out on the performance of this technology under various operating conditions [15,26–31]. It seems that there are wide variations in chemical oxygen demand (COD) removals in the obtained results from different previous studies. For example, the maximum COD removal efficiency achieved in a study conducted by Janpoor et al. [30] was about 93.2% and it was of about 52.8% in the study of Nasr et al. [28]. Despite that the two studies [28,30] were conducted using the same operational mode and electrode material and reporting similar pH ranges of the treated grey water. This was also the case for other many previous studies [27,29,31–33]. The difference in the COD removal resulted from various studies can be referred to the variations in the operational parameters considered. However, this explanation might not be sufficient to justify such high discrepancy. Some studies that had obtained low COD removal levels had rarely attributed their findings. For example, a study conducted by Vakil et al. [29] indicted the presence of soluble organics behind the limited COD removal which was of about 70%. However, Vakil et al. [29] did not present any results to support their assumption such as measuring soluble COD (SCOD) concentration or volatile soluble solids in the treated grey water. This was not the first time that indicates the negative impact of soluble fraction of organic pollutants on grey water treatment. A study performed by Dixon et al. [34] also explained the reason behind the failure of treatment in a test site for grey water reuse to the SCOD in a pre-treatment tank. In fact, the SCOD is challenging not only in grey water treatment but also in treating the industrial wastewater [35]. Generally, the SCOD could occur due to the anaerobic microbial processes or due to larger solids settling while leaving smaller organic species in a colloidal suspension. The longer storage durations cause SCOD to increase [34].In addition, the SCOD increases significantly under extreme alkaline conditions and under high temperatures [36].

Consequently, it seems that the SCOD in grey water might play an important role in GW treatment by EC. Very few studies were found in the literature to address this issue. Therefore, the objective of this study was oriented to achieve further investigation of the impact of the SCOD on the treatment of grey water via EC technique. This important parameter can also be considered as a precursor to the effect of long durations of pre-storage on the process. Accordingly, in this study, the influence of electrical current density (CD) and the type of electrodes on COD and turbidity removals were investigated under various SCOD levels. Furthermore, a statistical analysis using Statistical Analysis Software (SAS) was performed to see whether the process parameters were statistically significant or not.

2. Materials and methods

2.1. Grey water collection, storage and characterizations

In this experimental work, grey water samples were collected from different locations in the Faculty of Natural Resources and Environment at the Hashemite University, Jordan. Specifically, the samples were collected from the bathroom sinks of male and female students, the water sink in the water quality lab, floor mopping, and male students' ablution water. The collection process (using plastic containers) was carried out by intentional and temporary clogging of the sinks and then transferred to 20-L polypropylene container, while floor mopping water was collected directly from the buckets of the cleaning staff. About 35 samples were collected with a sum of around 100 L.

An important aspect when dealing with grey water is the extent of time duration prior to water treatment which correlates with SCOD [34]. Therefore, in order to investigate the impact of storage time on the EC treatment and to get different fractions of SCOD with high variance, the collected samples were divided into three groups that each underwent different storage durations before applying EC technique. The storage process was carried out using 20-L polypropylene containers under room temperature (18°C ± 0.6°C) in the water quality lab; Faculty of Natural Resources and Environment at the Hashemite University. For the purpose of this study, the collected samples were classified into three categories depending on the percentages of SCOD in the original collected samples: the first category is the low-range strength of SCOD, the second category is the mid-range strength of SCOD and the third category is the high-range strength of SCOD. Due to the durations of storage time, three distinguished categories of SCOD concentrations were produced: low-range strength of SCOD (10%) with a total COD concentration of 1,536 mg/L, mid-range strength of SCOD (54%) with a total COD concentration of 1,680 mg/L and high-range strength of SCOD (85%) with a total COD concentration of 1,540 mg/L. The first category (10% SCOD) underwent treatment by EC directly during the first 24 h of collection time (~1 d of storage time). The mid-range of SCOD (54%) was stored for 7 d prior to treatment, and the high-range of SCOD (85%) was stored for 30 d before being treated. The purposes of storing the second and the third categories for long time were to (i) study the impact of the storage time of grey water during treatment by EC and (ii) obtain samples with highly distinctive in SCOD. This trend is based on a study conducted by Dixon et al. [34] who found that SCOD increases with increasing storage time.

2.2. Experimental setup and operating conditions

The experimental setup used in this study is shown in Fig. 1. A bench-scale batch reactor (cylindrical shape), made of glass, was used as an EC unit to treat grey water with different fractions of SCOD. The volume of the EC unit was 300 mL in which 250 mL of grey water was treated in each experimental run. Two flat-plate parallel electrodes were submerged vertically in the grey water solution. The electrodes were made of either aluminum (Al) or iron (Fe). Each flat-plate electrode had a total surface area of around 22.8 cm^2 (height = 7.6 cm; width = 3 cm; thickness = 0.025 cm) with an effective surface area of nearly 17.1 cm^2. The spacing between the electrodes was 1 cm. The electrodes were connected to a direct current (DC) power supply (model MS303D) that allows a direct current and voltage ranges of 0–3 A and 0–30 V, respectively. Discrete direct current values, ranging from 0.1 to 0.2 A, were applied in the experimental runs. This DC range corresponds to equivalent CDs range from 5.85 to 11.7 mA/cm^2.

Detailed experimental conditions are shown in Table 1. The EC unit was placed over a heating magnetic stirrer (VELP Scientifica, Italy) and a constant stirring speed was maintained at around 180 rpm. The electrodes used in this study were immersed in diluted hydrochloric acid solution for about 2 h and rinsed with distilled water for cleaning prior to the each EC run. The EC time was set to be 15 min for all experimental runs conducted.

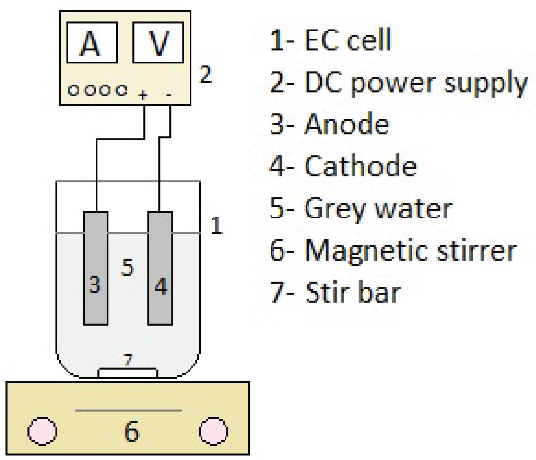

Fig. 1. Experimental setup.

2.3. Analytical methods

The performance of the EC reactor was monitored by analyzing both initial and final samples for total COD, SCOD, turbidity, total dissolved solids (TDS), pH, temperature and conductivity. The SCOD was analyzed by filtering the sample using a filtration membrane (0.45 μm) and then measuring the COD value in the filtered sample. The total COD, SCOD, turbidity and color were analyzed by MD600 photometer (Lovibond, Germany). The SensoDirect 150 meter (Lovibond, Germany) was used to measure TDS. The temperature, pH, and electrical conductivity were also monitored, using pH electrical conductivity meter (Hanna HI 5521, USA) which was calibrated once a week prior the usage.

2.4. Calculations

In order to investigate the performance of the EC technique for GW treatment, the reduction levels in COD and turbidity concentrations were determined by calculating the percentage removal (η%) as follows:

$$\eta(\%) = 100\left(1 - \frac{C}{C_0}\right) \quad (9)$$

where C_0 is the initial concentration of COD or the initial concentration of turbidity (FAU) before treatment and C is the final concentration of the corresponding measured parameter after treatment (mg/L). On the other hand, the percentage SCOD in grey water was calculated using:

$$\%\ \text{SCOD} = 100\frac{\text{SCOD}}{\text{COD}} \quad (10)$$

where SCOD is the soluble COD in the raw grey water (mg/L) and COD is the total COD (mg/L).

Table 1
Experimental operating conditions

Applied current (A)	0.1	0.12	0.14	0.16	0.18	0.20
Anode materials	Al and Fe					
Effective area of anode (cm^2)	17.1					
Current density (mA/cm^2)	5.85	7.02	8.18	9.36	10.53	11.70

Furthermore, the energy consumption (E_c) is considered an operational indicator during grey water treatment by EC process which can be calculated using [37]:

$$E_c = U \times I \times t/(1000\ \text{v}) \tag{11}$$

where E_c is the energy consumption (kWh/m^3), U is the voltage (V), I is the applied current in ampere (A), t is the EC time (h), v is the volume of treated GW sample (m^3).

The performance of EC is also determined by the amount of the dissolved metal (m) which is dependent on the quantity of electricity passed through the electrolytic solution. The amount of dissolved anode can be approximated from Faraday's law [17]:

$$m = \frac{I \times t \times Mw}{ZF} \tag{12}$$

where m is the amount of dissolved anode (g), I is the applied current (A), M_w is the molecular weight of electrode material (g/mol), Z is the valence of the electrode material, F is faradays constant (96,486 C/mol).

2.5. Statistical analysis

For further supporting the results of this study, a statistical analysis of the measurements was carried out using SAS 9.3 using PROC GLM commercial application. The lab experimental setup was designed based on completely randomized design with three replications. The collected data were recorded and sorted for statistical analysis. Tukey multiple comparison test was used to separate treatment means. Statistical significance was defined at $\alpha = 0.05$.

3. Results and discussion

3.1. Grey water characteristics

The Faculty of Natural Resources and Environment at the Hashemite University has an average daily attendance of 1,200 students and employees. Therefore, the characteristics of the grey water depend on the activities of students on the day of the collected samples. As shown in Table 2, the collected samples did not demonstrate high variation in their characteristics. The pH values ranged from 6.4 to 7.6. For COD and turbidity analyses, the results ranged between 1,400–1,700 mg/L and 700–900 FAU for COD and turbidity, respectively. Generally, grey water collected from ablution had lowest COD and turbidity values, while grey water from the floor mopping showed the highest COD and turbidity values. The high concentration of total suspended solids (TSS) might be due to the fine particles of sand and clay in the collected samples.

The characteristics of the raw grey water collected at the Hashemite University were compared with those reported for grey water generated elsewhere in Jordan (see Table 3). It was found that COD and pH values reported in this study were similar to those of grey water generated at a pilot-scale grey water reuse project in Al-Tafileh city [38] and in Al-Karak city at Al-Amer villages [39] as well. However, the TSS values

Table 2
Some characteristics of grey water collected in this study for 35 collected samples

Water quality indexes	Minimum	Maximum	Average	SD[a]
pH	6.4	7.6	7.2	0.6
Temperature (°C)	18.1	21.2	20	1.1
Total COD (mg/L)	1,400	1,700	1,585	72
TDS (mg/L)	400	507	450	130
Conductivity (µS/cm)	716	900	800	126
TSS (mg/L)	808	1,000	920	205
Turbidity (FAU)	704	901	802	80
Color (PtCo)	194	388	340	132

[a]SD: Standard deviation.

Table 3
Characteristics of grey water collected in this study and comparison with other studies in Jordan

Parameter	This study	Jamrah et al. [41]	Suleiman et al. [40]	Al-Jayyousi [38]	Al-Hamaiedeh and Bino [39]	Halalsheh et al. [42]
pH	6.4–7.6	7.81	5.7–7.0	6.7	7.2	6.35
COD (mg/L)	1,450–1,600	78	2,257–2,878	1,460	1,712	2,568
SCOD%	10.4–85	–	–	–	–	34
Turbidity (FAU)	704–901	49	–	–	–	–
Conductivity (mS/cm)	716.7–900	1,910	1,560–2,100	460	1,830	1,830
TDS (ppm)	400–507	893	–	–	–	–
TSS (ppm)	808–1,000	168	1,007–1,040	264	275	845
TS (ppm)	1,200–1,507	1,061	1,840–1,997	–	257	–

reported in those studies were much lower than that reported in this study. As for grey water generated in Al-Mafraq city [40], TSS values were close to those reported in this study while reporting a much higher COD level. It was also noted that TSS, COD and turbidity values reported in this study were much higher than those reported by Jamrah et al. [41] for grey water originating in Amman and to those reported by Halalsheh et al. [42] which analyzed grey water from the University of Jordan. However, the TS value reported by Jamrah et al. [41] was somewhat close to that reported in this study.

The study conducted by Halalsheh et al. [42] was the only study that analyzed the fraction of SCOD in grey water in Jordan. For the purpose of this study, the collected samples were grouped into three categories according to SCOD %: 10%, 54%, and 85% (Fig. 2). This classification was helpful in determining the impact of SCOD fraction on the total COD removal.

3.2. Changes in pH and conductivity

Because initial pH and conductivity could affect the removal performance in EC process [32], the changes in pH and electrical conductivity were monitored during the time of EC (15 min) in all the conducted experiments. The objective behind that was to assure that all the experimental runs occurred under similar operating conditions. Fig. 3 shows the evolution in pH with time for selected experiments. It was found that in all experiments conducted, the pH of the treated solution tended to neutralize values (pH = 7.2 ± 0.4). This result was consistent with a study performed by Ge et al. [33] who also noted that pH solution tends to neutralization. They attributed that the CO_2 released from the water under acidic conditions due to the 'purging' effect of H_2 and O_2 bubbles produced during EC which would eventually lead to reducing acidity. Furthermore, the consumption of hydrogen ions due to electrode dissolution during alkaline conditions would lead to reducing alkalinity as shown by the following chemical reactions:

$$Al + 3H^+ \rightarrow Al^{+3} \quad (13)$$

$$Fe + 2H^+ \rightarrow Fe^{+2} \quad (14)$$

Consequently, the changes in COD and turbidity removals during the conducted experiments of this study could be attributed to the changes in the applied CDs only.

With regards to electrical conductivity, there was no significant change in conductivity during EC treatment, which might help to maintain constant CDs throughout all the conducted experiments. This might be due to the low EC time that was applied in this study.

In this study, pH and electrical conductivity values did not show any significant difference; hence, they could not be considered as major factors that affect the performance of EC treatment. Consequently, this contributed to identifying soluble SCOD fraction as the primary parameter affecting the EC performance in this study.

3.3. Performance of EC in COD removal

Fig. 4 shows the performance of COD removal of the three categories of SCOD in grey water samples treated by EC technique using either aluminum or iron electrodes. Fig. 4(a) depicts the performance of EC technique using Al anode. The figure demonstrates that 79% removal of total COD can be achieved for low range of SCOD in grey water (i.e., 10% of SCOD) at an applied CD of 5.85 mA/cm². The COD removal increased up to 96% with increasing the applied CD up to 9.36 mA/cm². This increase in COD removal was expected due to the increase in Al dosage released from Al anode which ultimately enhanced coagulation process in the EC reactor (Fig. 5). It is obvious that the COD removal was not improved significantly above an applied CD of 9.36 mA/cm². With respect to Fe electrodes, Fig. 4(b) shows that the performance of Fe electrodes was slightly better than Al electrodes in COD removal at low applied CD and low-range of SCOD (i.e., 10%); the percentage COD removal was about 83% in comparison with 79% when Al was used at 5.85 mA/cm² of an applied CD. This might be due to the fact that the dosage released by iron electrode was significantly higher at the applied CD of 5.85 mA/cm² (Fig. 5). However, the maximum COD removal

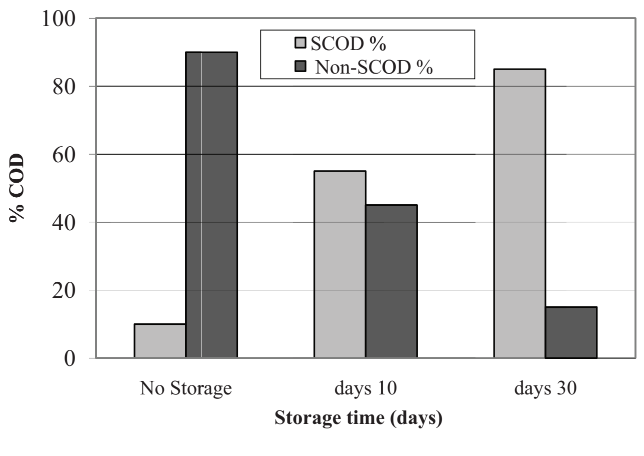

Fig. 2. Impact of storage time on soluble COD (SCOD) in grey water.

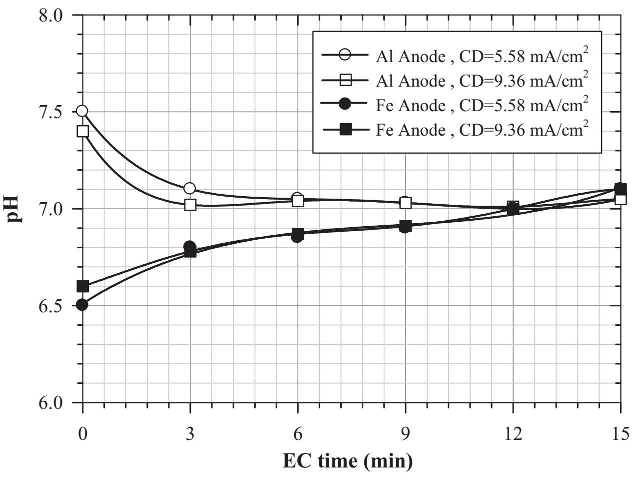

Fig. 3. Evolution of pH during 15 min of EC time.

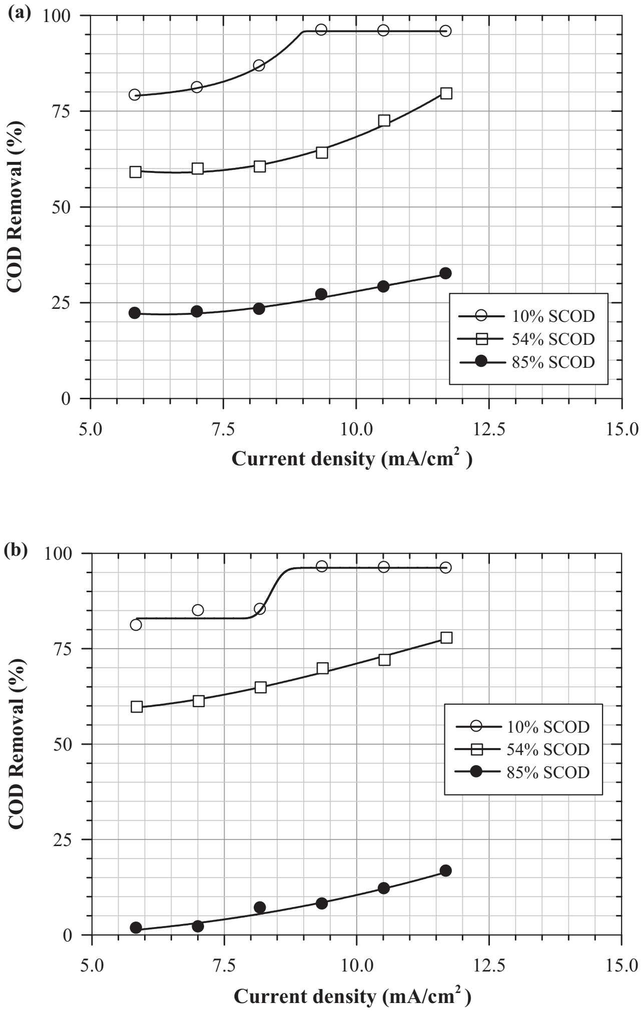

Fig. 4. COD removal using: (a) Al and (b) Fe electrodes at different %SCOD.

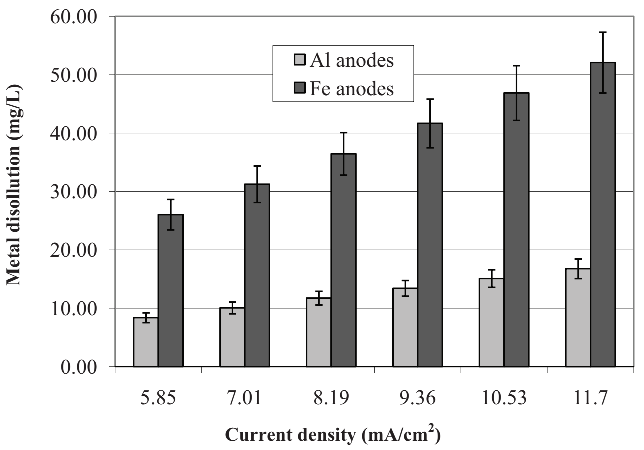

Fig. 5. Impact of current density and electrode material on anode dissolution.

was 96.3% which is very close to that obtained when Al electrodes were used at an applied CD of 9.36 mA/cm^2. Furthermore, Fig. 4(b) indicated that applying a CD above 9.36 mA/cm^2 might not improve the COD removal; the case that was observed for Al electrodes as well.

A significant decrease in COD removals was observed for mid-range of SCOD (i.e., 54%) for both Al and Fe electrodes as shown in Fig. 4. At an applied CD of 5.85 mA/cm^2, the COD removals were about 56% and 65% for Al and Fe electrodes, respectively. It is clear from Fig. 4 that the COD removal increases with increasing applied CDs for both Al and Fe electrodes. The best COD removals were almost similar, 79% and 78% for Al and Fe electrodes, respectively, when the applied CD increased up to 11.7 mA/cm^2.

Two distinguished results were observed when the EC technique was applied on high fraction of SCOD (i.e., 85%). First, the COD removal was very limited all throughout the applied CDs when Fe electrodes were used (Fig. 4(b)). There was no significant improvement in COD removal (1.6%) at an applied CD of 5.85 mA/cm^2, while a slight removal enhancement of about 17% was noticed in COD removal when the applied CD increased up to 11. 7 mA/cm^2. Second, Fig. 4(a) illustrates that aluminum electrodes showed better performance with respect to COD removal at higher SCOD in grey water. The COD removal by Al electrodes was higher than that achieved by Fe electrodes at all the applied CDs. However, the COD removal was decreased dramatically at higher SCOD as well; it was 22% at 5.85 mA/cm^2 and reached 32.4% when the current was raised to 11.7 mA/cm^2. The high removal obtained by Al compared with Fe electrodes could be attributed to the higher oxidation potential of organic compounds by the oxides produced when using aluminum electrodes as compared with those oxides produced when using iron electrodes [43]. Furthermore, the limited removal obtained at high-range of SCOD could be attributed to the presence of soluble organics that would not react with metallic coagulating species [29].

3.4. Change of turbidity

Turbidity is correlated with TSS that comprises suspended organic particles [44,45]. Consequently, it can be concluded that suspended COD is correlated with turbidity. Based on this concept, turbidity could be used to indicate the extent of the removal of suspended COD. Therefore, measuring initial and final turbidity allowed monitoring the extent of SCOD removal (i.e., high degrees of turbidity removals with low values of COD removals indicate the poor removal of SCOD).

The performances of aluminum and iron anodes for turbidity removal are shown in Fig. 6. At low-range of SCOD and low levels of the applied CDs, the turbidity removals were close to 98.5% and it reached 100% at high level of the applied CDs for both types of electrodes used. The same trend was observed when EC treatment was applied on grey water with mid-range of SCOD. Regardless of the SCOD levels, the turbidity removal exceeds 98.5% when the applied CD is greater than 7.02 mA/cm^2. While, the removal efficiency of turbidity was around 96% using both electrode materials when the SCOD is high and the applied CD is low. In other words, the removal efficiency of turbidity ranged between 96%, when the operation of EC treatment was at very low CD and greater than 99.2% when the applied current was high regardless of the SCOD levels and the type of electrodes. This means that

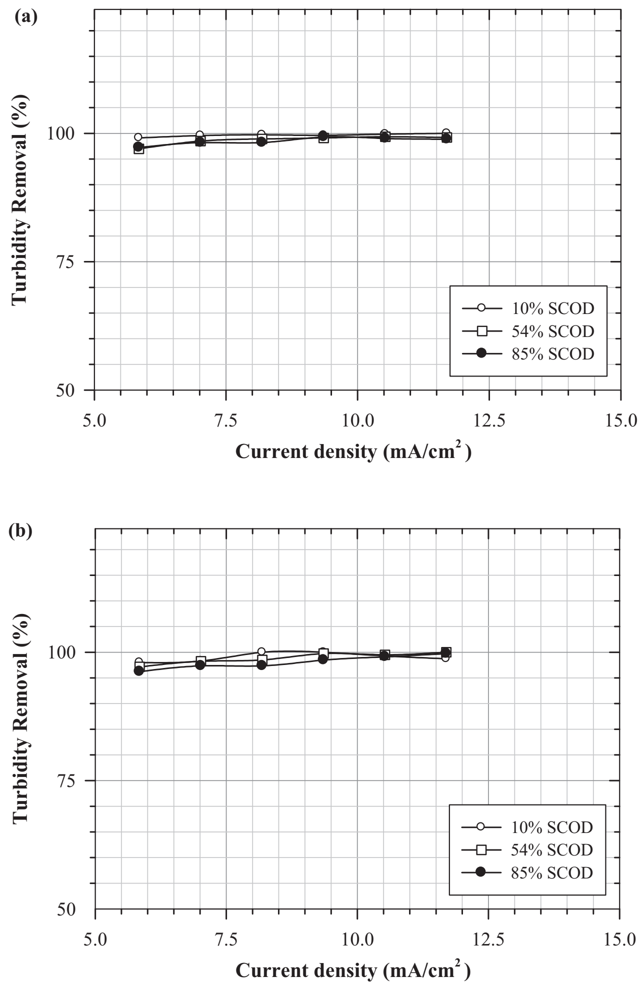

Fig. 6. Turbidity removal using: (a) Al and (b) Fe electrodes at different %SCOD.

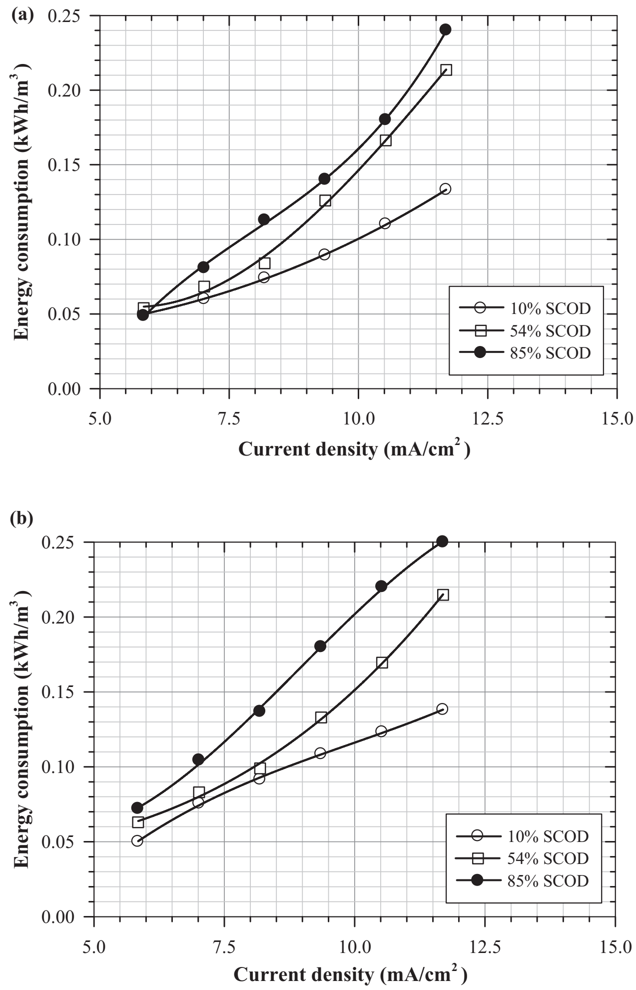

Fig. 7. Energy consumption during EC treatment using: (a) Al and (b) Fe electrodes at different %SCOD.

the turbidity removal is not dependent on SCOD level, the fact that supports the assumption stated earlier.

3.5. Energy consumption

Electrical energy consumption and the amount of electrode dissolved in wastewater solution exhibit a significant and an economical factor in any EC process [19]. The electrical energy consumption per unit volume of treated wastewater is calculated by using Eq. (11). While the amount of released coagulating dose during electrolysis is calculated from Eq. (12).

Fig. 7 shows the amount of energy consumption per one cubic meter of treated wastewater for both electrodes (Al and Fe) during 15 min of EC treatment time. It is clear that the increase in the applied CD increases the specific electrical energy consumption. According to Fig. 4(a), for low-range of SCOD, the best COD removal was achieved at an applied CD of 9.36 mA/cm^2, no further improvement was observed. Therefore, to achieve highest possible removal efficiency with lowest energy consumption, the CD must not be greater than 9.36 mA/cm^2 during 15 min of EC treatment time.

On the other hand, an exponential relationship would be observed between the applied CD and the specific energy consumption as shown in Fig. 7. This means that the EC might not be a feasible technology at high levels of SCOD taking in consideration the fact that the COD removal decreased significantly at these levels as well, especially for Fe anodes.

3.6. Statistical analysis

A statistical analysis using SAS program was performed to see whether the process parameters were statistically significant or not. The results of statistical analysis are summarized in Tables 4–6. Table 4 shows the results of statistical analysis with respect to the variations in the applied CD. Generally, the results confirmed that COD removals were significantly different among different levels of the applied CDs ($p < 0.0001$) which support the results obtained in Fig. 4. The p value indicates the probability that the obtained results are different from the results that usually observed. With respect to the turbidity, the statistical analysis shows that the turbidity removal did not change when high levels of the applied CDs were used while small variations were observed at low levels. This result supports the results concluded from

Table 4
Summary of statistical analysis with respect to the applied current density

Current density (mA/cm^2)	Means of measured parameter			
	COD removal (%)	Turbidity removal (%)	Energy consumption (kWh/m^3)	Released dosage (g/m^3)
5.85	50.443, d	97.450, c	0.056, f	17.22, f
7.01	51.943, cd	98.362, bc	0.070, e	20.61, e
8.19	54.565, c	98.782, ab	0.098, d	23.73, d
9.36	60.227, b	99.380, a	0.129, c	26.97, c
10.53	62.935, ab	99.345, a	0.161, b	30.49, b
11.70	66.372, a	99.423, a	0.198, a	34.44, a

Note: The letters (a, b, c, d, e and f) associated with treatment averages indicate that the treatments with different letters within each column are significantly different at $\alpha = 0.05$.

Table 5
Summary of statistical analysis with respect to the impact of SCOD

% SCOD	Means of measured parameter			
	COD removal (%)	Turbidity removal (%)	Energy consumption (kWh/m^3)	Released dosage (g/m^3)
10	89.487, a	99.349, a	0.091, c	25.83, a
54	66.807, b	98.767, b	0.120, b	25.83, a
85	16.782, c	98.255, b	0.147, a	25.08, b

Note: The letters (a, b and c) associated with treatment averages indicate that the treatments with different letters within each column are significantly different at $\alpha = 0.05$.

Table 6
Summary of statistical analysis with respect to the impact of types of anodes used

Electrode type	Means of measured parameter			
	COD removal (%)	Turbidity removal (%)	Energy consumption (kWh/m^3)	Released dosage (g/m^3)
Al	60, a	98.93, a	0.110, b	12.4, b
Fe	55, b	98.65, a	0.127, a	38.7, a

Note: The letters (a and b) associated with treatment averages mean that the treatments with different letters within each column are significantly different at $\alpha = 0.05$.

Fig. 6. Furthermore, the results of Table 4 confirmed statistically that higher energy consumption and released dosage were observed with higher CDs ($p < 0.0001$).

Table 5 summarizes the results of the statistical analysis with respect to the variations in the percentages of SCOD levels. The results confirmed that the COD removal percentages were significantly different among different SCOD ($p < 0.0001$). At low SCOD (10%), the removal percentage was significantly higher than that of intermediate SCOD (54%) and high SCOD (85%). Additionally, the highest SCOD showed the lowest removal percentage among the other tested SCOD levels, which supports the results obtained in Fig. 4. Results showed that turbidity removal percentages were significantly different among SCOD ($p = 0.0009$). The highest turbidity removal levels were noticed under low SCOD (10%) compared with the other SCOD treatment. However, even though the detected statistical significance at this treatment, we do not see that these differences practically can make that observed effect. Table 5 also shows that the energy consumption and released dosages were significantly different among different COD levels ($p < 0.0001$).

Table 6 summarizes the statistical analysis of the impact of anodes used on the EC process performance. The results confirmed that the removal percentages were significantly different among different electrode types ($p < 0.0001$). However, the statistical analysis showed no significant effect between the anodes used on the turbidity removal percentage ($p = 0.1129$). The removal percentage was significantly higher with aluminum electrode compared with the iron electrode ($p < 0.0001$). Furthermore, the aluminum electrode showed significantly lower energy consumption and released dosage compared with that of iron electrode ($p < 0.0001$).

4. Conclusions

In this study, EC treatment was applied on grey water samples generated from different locations at the Hashemite University, Jordan. The collected samples were classified into three categories based on the storage time before treatment. Three different concentrations of soluble fractions of COD (SCOD), specifically: 10%, 54% and 85% SCOD were produced after storing the samples for 1, 7 and 30 d, respectively. The results of this study demonstrated that the SCOD increases with increasing the storage time.

The EC process showed better performance at low levels of SCOD, an applied CD of 9.36 mA/cm^2 was sufficient to remove 96% of the total COD at 10% of SCOD during 15 min of EC time using either Al or Fe electrodes. However, an obvious relation was noted between SCOD and total COD removal. An increase in SCOD was noted to reduce the total COD removal for mid and high ranges of SCOD regardless of the applied CD and the material of electrodes. The results demonstrated that the EC might not be a feasible technology for grey water treatment at high levels of SCOD. Therefore, it is recommended to analyze the SCOD when considering EC as a choice for grey water treatment.

With respect to the material electrodes, the results showed that aluminum anodes superiority over iron anodes in energy consumption and COD removal. However, the results showed no significant difference with respect to the turbidity removal, the turbidity removal ranged between 96%, when the operation of EC treatment was at very low CD and greater than 99.2% when the applied CD was high regardless of the SCOD levels and electrode type used.

Overall, the SCOD was found to be a key parameter that affecting the EC performance in grey water treatment. Therefore, it is recommended to decrease the duration of storage time of grey water when EC is used for treatment. It is also recommended to conduct additional test series concerning continuous operations in order to generalize this concept for future large-scale applications.

Acknowledgment

Authors would like to thank the Scientific Research Support Fund (SRSF) in Jordan for their financial support under grant number WE/1/19/2015.

References

[1] K. Bani-Melhem, Z. Al-Qodah, M. Al-Shannag, A. Qasaimeh, M.R. Qtaishat, M. Alkasrawi, On the performance of real grey water treatment using a submerged membrane bioreactor system, J. Membr. Sci., 476 (2015) 40–49.

[2] B. Jefferson, A. Palmer, P. Jeffrey, R. Stuetz, S. Judd, Grey water characterisation and its impact on the selection and operation of technologies for urban reuse, Water Sci. Technol., 50 (2004) 157–164.

[3] E. Smith, K. Bani-Melhem, Grey water characterization and treatment for reuse in an arid environment, Water Sci. Technol., 66 (2012) 72–78.

[4] E. Eriksson, K. Auffarth, M. Henze, A. Ledin, Characteristics of grey wastewater, Urban Water, 4 (2002) 85–104.

[5] K. Gour, Grey water treatment and management, Ultra Scientist, 27 (2015) 175–180.

[6] R.M.S.R. Mohamed, M.N. Adnan, M.A. Mohamed, A.H.M. Kassim, Conventional water filter (sand and gravel) for ablution water treatment, reuse potential, and its water savings, J. Sust. Dev., 9 (2016) 35.

[7] M.S. Zipf, I.G. Pinheiro, M.G. Conegero, Simplified greywater treatment systems: slow filters of sand and slate waste followed by granular activated carbon, J. Environ. Manage., 176 (2016) 119–127.

[8] S.S. Dalahmeh, C. Lalander, M. Pell, B. Vinnerås, H. Jönsson, Quality of greywater treated in biochar filter and risk assessment of gastroenteritis due to household exposure during maintenance and irrigation, J. Appl. Microbiol., 121 (2016) 1427–1443.

[9] C.Y.P. Ayekoe, D. Robert, D.G. Lanciné, Combination of coagulation-flocculation and heterogeneous photocatalysis for improving the removal of humic substances in real treated water from Agbô River (Ivory-Coast), Catal. Today, 281 (2017) 2–13.

[10] S. Tsoumachidou, T. Velegraki, A. Antoniadis, I. Poulios, Greywater as a sustainable water source: a photocatalytic treatment technology under artificial and solar illumination, J. Environ. Manage., 195 (2017) 232–241.

[11] N. Liberman, S. Shandalov, C. Forgacs, G. Oron, A. Brenner, Use of MBR to sustain active biomass for treatment of low organic load grey water, Clean Technol. Environ. Policy, 18 (2016) 1219–1224.

[12] M.C. Chrispim, M.A. Nolasco, Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil, J. Clean Prod., 142 (2017) 290–296.

[13] M. De Sanctis, G. Del Moro, C. Levantesi, M.L. Luprano, C. Di Iaconi, Integration of an innovative biological treatment with physical or chemical disinfection for wastewater reuse, Sci. Total Environ., 543 (2016) 206–213.

[14] K. Bani-Melhem, E. Smith, Grey water treatment by a continuous process of an electrocoagulation unit and a submerged membrane bioreactor system, Chem. Eng. J., 198 (2012) 201–210.

[15] T. Karichappan, S. Venkatachalam, P.M. Jeganathan, Optimization of electrocoagulation process to treat grey wastewater in batch mode using response surface methodology, J. Environ. Health Sci. Eng., 12 (2014) 12–29.

[16] V. Kuokkanen, T. Kuokkanen, Recent applications of electrocoagulation in treatment of water and wastewater—a review, Green Sust. Chem., 3 (2013) 89–121.

[17] M. Al-Shannag, Z. Al-Qodah, K. Bani-Melhem, M.R. Qtaishat, M. Alkasrawi, Heavy metal ions removal from metal plating wastewater using electrocoagulation: kinetic study and process performance, Chem. Eng. J., 260 (2015) 749–756.

[18] M. Al-Shannag, Z. Al-Qodah, K. Alananbeh, N. Bouqellah, E. Assirey, K. Bani-Melhem, COD reduction of baker's yeast wastewater using batch electrocoagulation, Environ. Eng. Manage. J., 13 (2014) 3153–3160.

[19] M. Al-Shannag, K. Bani-Melhem, Z. Al-Anber, Z. Al-Qodah, Enhancement of COD-nutrients removals and filterability of secondary clarifier municipal wastewater influent using electrocoagulation technique, Sep. Sci. Technol., 48 (2013) 673–680.

[20] M. Al-Shannag, W. Lafi, K. Bani-Melhem, F. Gharagheer, O. Dhaimat, Reduction of COD and TSS from paper industries wastewater using electro-coagulation and chemical coagulation, Sep. Sci. Technol., 47 (2012) 700–708.

[21] K. Bani-Melhem, M. Elektorowicz, Performance of the submerged membrane electro-bioreactor (SMEBR) with iron electrodes for wastewater treatment and fouling reduction, J. Membr. Sci., 379 (2011) 434–439.

[22] Z. Al-Qodah, M. Al-Shannag, Heavy metal ions removal from wastewater using, electrocoagulation processes: a comprehensive review, Sep. Sci. Technol., In press, 2017. doi: 10.1080/01496395.2017.1373677.

[23] K. Bani-Melhem, M. Elektorowicz, Development of a novel submerged membrane electro-bioreactor (SMEBR): performance for fouling reduction, Environ. Sci. Technol., 44 (2010) 3298–3304.

[24] M.Y. Mollah, P. Morkovsky, J.A. Gomes, M. Kesmez, J. Parga, D.L. Cocke, Fundamentals, present and future perspectives of electrocoagulation, J. Hazard. Mater., 114 (2004) 199–210.

[25] M.Y.A. Mollah, R. Schennach, J.R. Parga, D.L. Cocke, Electrocoagulation (EC)—science and applications, J. Hazard. Mater., 84 (2001) 29–41.

[26] R. Daghrir, A. Gherrou, I. Noel, B. Seyhi, Hybrid process combining electrocoagulation, electroreduction, and ozonation processes for the treatment of grey wastewater in batch mode, J. Environ. Eng., 142 (2016) 04016008.

[27] S. Barışçı, O. Turkay, Domestic greywater treatment by electrocoagulation using hybrid electrode combinations, J. Water Process Eng., 10 (2016) 56–66.
[28] M. Nasr, M. Ateia, K. Hassan, Artificial intelligence for greywater treatment using electrocoagulation process, Sep. Sci. Technol., 51 (2016) 96–105.
[29] K.A. Vakil, M.K. Sharma, A. Bhatia, A.A. Kazmi, S. Sarkar, Characterization of greywater in an Indian middle-class household and investigation of physicochemical treatment using electrocoagulation, Sep. Purif. Technol., 130 (2014) 160–166.
[30] F. Janpoor, A. Torabian, V. Khatibikamal, Treatment of laundry waste-water by electrocoagulation, J. Chem. Technol. Biotechnol., 86 (2011) 1113–1120.
[31] U. Kurt, M.T. Gonullu, F. Ilhan, K. Varinca, Treatment of domestic wastewater by electrocoagulation in a cell with Fe–Fe electrodes, Environ. Eng. Sci., 25 (2008) 153–162.
[32] C.-T. Wang, W.-L. Chou, Y.-M. Kuo, Removal of COD from laundry wastewater by electrocoagulation/electroflotation, J. Hazard. Mater., 164 (2009) 81–86.
[33] J. Ge, J. Qu, P. Lei, H. Liu, New bipolar electrocoagulation–electroflotation process for the treatment of laundry wastewater, Sep. Purif. Technol., 36 (2004) 33–39.
[34] A. Dixon, D. Butler, A. Fewkes, M. Robinson, Measurement and modelling of quality changes in stored untreated grey water, Urban Water, 1 (2000) 293–306.
[35] F. Germirli, D. Orhon, N. Artan, Assessment of the initial inert soluble COD in industrial wastewaters, Water Sci. Technol., 23 (1991) 1077–1086.
[36] V. Penaud, J. Delgenes, R. Moletta, Thermo-chemical pretreatment of a microbial biomass: influence of sodium hydroxide addition on solubilization and anaerobic biodegradability, Enzyme Microb. Technol., 25 (1999) 258–263.
[37] M. Kobya, E. Demirbas, M. Bayramoglu, M. Sensoy, Optimization of electrocoagulation process for the treatment of metal cutting wastewaters with response surface methodology, Water Air Soil Pollut., 215 (2011) 399–410.
[38] O. Al-Jayyousi, Focused environmental assessment of greywater reuse in Jordan, Environ. Eng. Policy, 3 (2001) 67–73.
[39] H. Al-Hamaiedeh, M. Bino, Effect of treated grey water reuse in irrigation on soil and plants, Desalination, 256 (2010) 115–119.
[40] W. Suleiman, B. Hayek, M. Assayed, S. Dalahmeh, Integrated On-site Greywater Management for Rural Jordanian Areas, Paper Presented at the Greywater Stock-Taking Meeting, IDRC-CSBE, February 12--15, Aqaba, Jordan, 2007.
[41] A. Jamrah, A. Al-Omari, L. Al-Qasem, N.A. Ghani, Assessment of availability and characteristics of greywater in Amman, Water Intl., 31 (2006) 210–220.
[42] M. Halalsheh, S. Dalahmeh, M. Sayed, W. Suleiman, M. Shareef, M. Mansour, M. Safi, Grey water characteristics and treatment options for rural areas in Jordan, Bioresour. Technol., 99 (2008) 6635–6641.
[43] A.K. Yadav, L. Singh, A. Mohanty, S. Satya, T. Sreekrishnan, Removal of various pollutants from wastewater by electrocoagulation using iron and aluminium electrode, Desal. Wat. Treat., 46 (2012) 352–358.
[44] V.G. Christensen, A.C. Ziegler, X. Jian, Continuous turbidity monitoring and regression analysis to estimate total suspended solids and fecal coliform bacteria loads in real time, US Department of the Interior, US Geological Survey, 2001.
[45] L.H.X. Daphne, H.D. Utomo, L.Z.H. Kenneth, Correlation between turbidity and total suspended solids in Singapore rivers, J. Water Sust., 1 (2011) 313–322.