Desalination and Water Treatment
www.deswater.com

doi: 10.5004/dwt.2023.29563

294 (2023) 71–78
May

Electrocoagulation treatment of hospital effluent in the Casablanca-Settat Region of Morocco

Sanaa Deblij[a], Bouchaib Bahlaouan[b], Nadia Boutaleb[a,*], Jamila Hassoune[b], Tarik Foughal[a], Mohamed Bennani[c], Said El Antri[a]

[a]*Hassan 2 University of Casablanca, Laboratory of Biochemistry, Environment and Agri-Food, LBEA URAC36, 20650 Morocco, Tel.: +212 661485088; email: Nadia.boutaleb@fstm.ac.ma, ORCID: 0000-0003-1628-4311 (N. Boutaleb), Tel.: +212 0663822109; email: Deblijfstm@gmail.com, ORCID: 0000-0002-5147-982X (S. Deblij), Tel.: +212 606139340; email: tarik.foughal@etu.fstm.ac.ma, ORCID:0000-0001-8439-5924 (T. Foughal), Tel.: +212 66109385; email: said.elantri@fstm.ac.ma, ORCID: 0000-0003-3534-2476 (S. El Antri)*

[b]*Higher Institutes of the Nursing Professions and Techniques of Health ISPITS Casablanca 22500, Morocco, Tel.: +212 661093856; email: b.bahlaouan@ispitscasa.ac.ma, ORCID: 0000-0002-0976-1274 (B. Bahlaouan), Tel.: +212662147009; email: Hassounejamila@yahoo.fr, ORCID: 0000-0002-8427-4900 (J. Hassoune)*

[c]*Institut Pasteur Casablanca Morocco, Laboratory of Physico-chemical Analysis of Water, Food and Environment Casablanca 20250, Morocco, Tel.: +21 2630142526; email: bennani2200@gmail.com, ORCID: 0000-0002-1749-6095 (M. Bennani)*

Received 6 December 2022; Accepted 11 April 2023

ABSTRACT

The hospital sector discharges a large quantity of polluted wastewater. Proper management of these discharges requires prior precise characterization of their complex composition in order to adapt the mode of their treatment. The present study was interested in the physico-chemical and microbiological characterization of the effluents generated by three large hospitals of Casablanca-Settat region of Morocco. This characterization was made on representative samples taken at the level of the main collectors of the hospitals concerned by the study before they cross other discharges. The results showed that the degree of pollution of the effluents studied is relatively high. Electrocoagulation treatment using aluminum electrodes has been shown to be effective and is improved with the optimum current density (J) applied, the best results are associated with densities between 142.85 and 285.71 A/m^2. Electrocoagulation treatment is therefore a very promising effective and economical solution adapted to hospitals in Casablanca-Settat region, known as the most polluted area of the country.

Keywords: Hospital effluents; Physico-chemical; Microbiological; Casablanca-Settat region; Electrocoagulation

1. Introduction

Effluents from hospitals in Morocco are most often loaded with pollutants that are not easily biodegradable, dangerous chemical substances and microorganisms with potential infectious risk [1–5]. The physico-chemical and microbiological characterization of hospital effluents in Casa-Settat region and in several cities in the Kingdom (e.g., Sidi Kacem Hospital, Al Ghassani Hospital in Fez, Dialysis unit at the medical-surgical hospital of Agadir, Ibn Sina Hospital in Rabat and Mohamed V hospital in Meknes) show a very high and alarming levels of pollution [2]. These discharges are most often released into common sewerage networks, without prior treatment and most often exceed applicable local standards and those of the WHO (World Health Organization) [6,7]. These effluents are most

* Corresponding author.

often characterized by a slight acidity, high temperature, ionic load, salinity, conductivity, chemical oxygen demand (COD) and 5-day biochemical oxygen demand (BOD_5) values. The presence of multi-resistant and virulent germs with an emerging character has also been noted, in addition to a high bacteriological load [2,8]. On the other hand, to the knowledge of the authors, no previous study proposes adequate pre-treatment or pre-established any effective treatment methods adapted to these types of effluents. They are just limited to the characterization of the sampled effluents. However, there is a strong demand to find solutions and to properly manage these dangerous effluents. For their treatment, several methods exist. Those that are commonly used unfortunately have drawbacks such as their ineffectiveness in the depollution of certain resistant contaminants [1–5]. In this context, a study was conducted in a hospital in Iran, which was able to assess the feasibility and effectiveness of the electrocoagulation process as a new method of treating contaminated hospital wastewater. The results showed a very significant reduction of COD, turbidity and antibiotic [9]. Indeed, the process of electrocoagulation requires only simple equipment and the electrodes are used as coagulants, so there is no addition of chemicals and an inexpensive treatment. This revolutionary treatment is attracting attention as an effective ecological strategy for the reprocessing of hospital effluents and because of its versatility [10]. The objective of this study is therefore to carry out a physico-chemical and bacteriological characterization of effluents from large hospitals in the most problematic region of Morocco before they are influenced by other wastewater discharges, and to assess the effectiveness of electrocoagulation for the hospital effluents treatment.

2. Materials and methods

2.1. Site of the sampling

In the greater Casablanca-Settat region, which has the highest incidence of infectious diseases and under epidemiological surveillance in Morocco, three large hospitals were chosen as site for this study [11]. The reasons that motivated this choice therefore relate to the fact that these hospitals have level three specialties such as restorative, maxillofacial and cardiovascular surgery, infectious diseases. Moreover, they have a litter capacity greater than 150 functional beds and which house many cases of patients with SARS-COV2. Table 1 shows the different stations where the samples were taken.

These hospitals also have a high level of technicality and a varied set, therefore a higher risk of having contaminated effluents. The functional litter capacity confirms the extent of the services and the activities provided by these hospitals, which remain in Morocco reference establishments by excellence.

2.2. Sampling and analysis conditions

Several sampling and analysis conditions were used: (a) sewers and sampling sites were in downstream of the care service buildings; (b) the representative samples were taken before their combination with other effluents; (c) the time of the samples corresponded to the maximum period of activity, which is between 11 am GMT and 12 pm GMT; (d) the samples were transported to the laboratory in an enclosure maintained at a temperature equal to 5°C and the samples were immediately submitted for analysis, in less than an hour, (e) the samples were taken in 250 mL bottles, sterilized in an autoclave (120°C) for 15 min; (f) the plastic and glass bottles used for sampling the effluents were first washed, rinsed and dried in the laboratory and then rinsed thrice with the effluent to be sampled; (g) samples of effluents from hospital 1 (H1), hospital 2 (H2) and regional hospital (RH) were analyzed by measuring physico-chemical parameters such as temperature, pH, electrical conductivity, COD, BOD_5, salinity, dosage of nitrates and nitrites and orthophosphates, while respecting pre-established protocols and also the bacteriological and microbiological parameters which consist of the count of fecal and total coliforms, streptococci and clostridium [12–16]. Several materials and methods were used depending on the analysis requested according to the standards in force (Table 2).

Table 1
Sampling stations

Hospital	Structure	Sampling stations
Regional hospital (RH)	4 story building	Main collector North–East of the building
Hospital 1 (H1)	Pavilion-shaped	Main collector North–East of the pavilions
Hospital 2 (H2)	Pavilion-shaped	Main collector West of the pavilions

2.3. Electrocoagulation process

In most electrocoagulation studies, the optimal treatment conditions are related to treatment time, current density and initial pH. The values were respectively between 5 and 60 min (generally less than 30 min), 150 A/m², a pH close to neutrality and an inter-electrode gap distance which is very important [18]. Taking these perspectives, the treatment of the raw sample from the regional hospital was done for a period of 30 min, using a current density greater than 150 A/m², a pH of 7.3 and a distance of 1 cm between the electrodes. For the electrodes, generally those made of aluminum, iron or stainless steel are used, since these metals are available at relatively low prices, efficient and not harmful [19,20]. Thus, for the present study, two aluminum electrodes were used. Aluminum electrodes are the most widely used and we have opted for this choice, given the importance of the chemical reactions that will occur during the passage of the electric current, such as the generation of Al^{3+} ions at the anode which react with the ions released at the cathode to generate monomeric species. Which provide high adsorption capacity to soluble contaminants.

Moreover, the metal ions released from the anode destabilize the colloid by neutralizing the organic charge allowing the formation of small aggregates. So as to have the rapid adsorption of soluble organic compounds and the trapping

Table 2
Materials and methods used during physico-chemical analyzes

Parameter	Equipment used	Method of analysis	References
Temperature	Fisher Scientific, Basic AB15, USA	Direct measurement	[14]
Conductivity	HANNA Instruments EC215, England	Direct measurement	[14]
Salinity	HANNA Instruments EC215, England	Direct measurement	[14]
Suspended matter	Filtration on filter paper (0.45 µm), Sigma-Aldrich, Germany	Filtration on Whatman paper placed in an oven	[7,14]
Chemical oxygen demand	Thermoreactors ECO6 VELP Scientifica, Germany	Oxidation by potassium dichromate	[7,14]
5-day biochemical oxygen demand	ExAO device, Germany	Measurement of the oxygen concentration	[7,14]
Nitrates	High-purity reagents from Sigma-Aldrich, Germany	Colorimetric method (wavelength: 415 nm)	[7,13]
Nitrite	High-purity reagents from Sigma-Aldrich, Germany	Colorimetric method (wavelength: 540 nm	NF T90-013
Orthophosphates	High-purity reagents from Sigma-Aldrich, Germany	Colorimetric method	[16,17]
Escherichia coli	MacConkey agar (Biokar, France) incubated at 44°C for 18–24 h	Enumeration of viable bacteria in nutrient agar	[7,17]
Total coliforms	MacConkey agar (Biokar, France) incubated at 37°C for 24 h	Enumeration of viable bacteria in nutrient agar	NF EN ISO 9308-3
Faecal streptococci	Slanetz and Bartley agar (Biokar, France) 37°C/48 h	Enumeration of viable bacteria in nutrient agar	NF ISO 7899-2
Clostridium	Meat-liver agar (Biokar, France) incubated at 37°C for 24 h	Cultivation in deep tubes	NF T 90-415

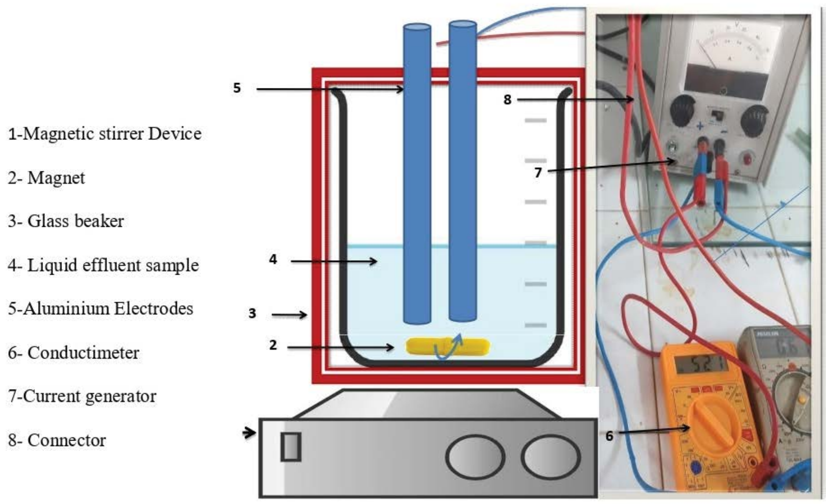

Fig. 1. Presentation of the electrocoagulation process used in this study.

of colloidal particles much more than other types of electrodes. These aluminum electrodes also produce flocs that are more uniform in size than other types of electrodes, making them easier to separate from wastewater [21–23].

Fig. 1 shows the electrocoagulation process that has been used. The effect of current density has been studied and experimented by varying the intensity of the current between 0.3 and 0.6 A. These electrocoagulation experiments were carried out with 400 mL of the effluent, which was characterized twice after undergoing a different current density J (A/m^2). This was done according to the intensity of the applied current I (A) IE1 and IE2 and the active surface of the electrodes, which was 7 × 3 cm^2. In fact, the density varied between 142.85 and 285.71 J. Knowing that the current density is defined as being the ratio of the current intensity I (Ampere) on the active surface of the electrodes

A (m^2). The experiments were carried out for 30 min at room temperature of 25°C.

3. Results and discussion

3.1. Physico-chemical and bacteriological characterization of effluents

The physico-chemical characteristics of the effluents from the three hospitals in the study are shown in Table 3. The temperature varies between 19.4°C and 26.2°C. These values are in accordance with WHO standards which stipulate that these values must not exceed 30°C and are also comparable with those reported in the provincial hospital of Sidi Kacem with an average temperature of 27.48°C [1,24]. This parameter is important because it facilitates the solubility of the salts and helps the metabolism of growth of microorganisms present in the effluent. pH was between 7.27 and 8, while lower values are recorded for two large Moroccan hospitals (between 6.02 and 7.43) [3]. On the other hand, they comply with the standards, which impose a pH between 6.5 and 8.5 [1]. The electrical conductivity which confirms the degree of mineralization of the effluents [23]. The results obtained show that it varies between 1,930 and 2,140 µS/cm. While it varies between 3,340 and 8,940 µS/cm for hospital effluents from certain Moroccan hospitals [1–5]. These values are high compared to the limit value, which is 1,200 µS/cm according to Moroccan quality standards [1] and they exceed values reported at the Sidi Kacem hospital center, which were between 2,864 and 3,651 µS/cm [24]. At Taza hospital, the average value reported is 844.21 µS/cm [25].

The salinity of the effluents from our hospitals was between 1.07 g/L found at the RH level and 3 g/L noted at H1. These values were below the limit value, which is 7.68 g/L [1].

For the BOD_5, represents the quantity of biodegradable organic matter in water [6]. It was 375 for the Casablanca regional hospital and 255 for H1. This result was less significant compared to the average value of 580.16, which was reported to the Mohamed V hospital in Meknes [1].

The chemical oxygen demand was 1920 for regional hospital of the Casablanca and less important for the other

Table 3
Initial physico-chemical characteristics of the effluents of the three hospitals studied

Parameters	RH	H1	H2	Moroccan standard [1]	WHO standard [1]	Raw water [26]
			Physico-chemical parameters			
Temperature (°C)	26.20 (±0.11)	26.00 (±0.1)	19.40 (±0.4)	<35	<30	21.4
pH	7.30 (±1.00)	8.00 (±1.00)	7.27 (±1.2)	6.5–8.5	6.5–8.5	7.2
Electrical conductivity (µS/cm)	2,140.00 (±1.00)	1,930.00 (±2.00)	2,068.00 (±1.00)	<1,200.00	–	4,049
Salinity total dissolved solids (g/L)	1.07 (±0.01)	2.50 (±0.00)	3.00 (±0.00)	<7.68	–	–
5-day biochemical oxygen demand (mg/L)	375.00 (±1.15)	255.00 (±1.15)	300.00 (±2.00)	–	<30	399.6
Chemical oxygen demand (mg/L)	1,920.00 (±0.58)	1,300.00 (±0.50)	1,400.00 (±0.60)	–	<90	953.5
Suspended matter (mg/L)	210.00 (±2.00)	200.00 (±2.00)	180.00 (±3.00)	–	<20	522.3
Nitrite (mg/L)	4.30 (±0.10)	5.30 (±0.20)	4.90 (±0.20)	<0.50	<0.5	–
Nitrate (mg/L)	37.00 (±0.50)	32.00 (±0.60)	30.00 (±0.50)	<30.00	–	1.1
Orthophosphates (mg/L)	20.80 (±0.05)	10.00 (±0.06)	20.00 (±0.07)	<2.00	<2.00	–
		Microbiological analyzes (values are expressed in × 10^2 UFC/mL)				
Total coliforms	8.43 (±0.10)	8.40 (±0.10)	9.03 (±0.20)	–	–	–
Faecal coliforms (*E. coli*)	1.78 (±0.20)	7.00 (±0.20)	6.70 (±0.25)	<10.00	<10.00	1.56
Streptococci	32.00 (±1.60)	25.00 (±10.00)	33.00 (±10.00)	–	–	1.61
Clostridium	84.30 (±0.60)	84.90 (±0.50)	74.20 (±0.40)	–	–	–

hospitals. These found values of COD are very high compared to those found in hospitals in Portugal, China, India and Italy [6].

In addition, for the COD/BOD_5 ratio that indicates the biodegradability and degree of pollution of an effluent by organic matter [6]. This ratio was 5.12 for the Casablanca regional hospital and 4.66 for H2 and 5.09 for H1, which demonstrates that our regional effluent is difficult to biodegrade and that it is the most polluted [6,27]. This ratio remains lower than that reported at the level of the Sidi Kacem hospital center which had a ratio of 7.66 [24].

The analysis of the suspended matter (SM) results shows that the effluents studied are characterized by an average concentration of 210 mg/L for the RH and that it is the most loaded at both national and international level (Fig. 2). This result is explained by the high load of the effluent in organic and mineral matter. This demonstrates a great physico-chemical pollution of the regional hospital effluent which will be discharged into the sewers. The dosage of nitrates in the samples analyzed from the three hospitals showed values ranging from 30 to 37 mg/L, indicating that the threshold of 30 mg/L was exceeded [1]. Concerning nitrites, they exceeded the national normative value, which is 0.5 mg/L, the maximum dosage measured in our hospitals is 5.3 mg/L.

Orthophosphates are similar to nitrates as nutrients that can be used in organic farming and can cause plant multiplication from 0.2 mg/L [1,27]. They were at 20.8 mg/L in the liquid effluent of the RH then that they were only 0.23 mg/L of nitrites and 8.88 mg/L of nitrates at Taza hospital [25]. All these characterization parameters give a clear picture on the degree of chemical–physical pollution and the high organic load of the hospital effluents of our study.

They were difficult to go thought a biodegradation process since all the parameters exceed the recommended acceptability threshold. All this load is explained by the excessive use of reagents and chemical products of disinfectants, antiseptics, acids, medicinal discharges, discharges containing pathogenic elements such as blood and urine in our hospitals in Casablanca [2,25].

3.2. Bacteriological characterization of effluents

For the count of fecal coliforms, the samples taken recorded in the main collectors a rate of 1.78×10^2 UFC/100 mL

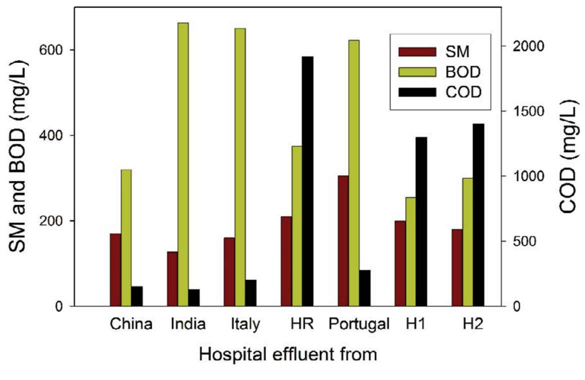

Fig. 2. Some characteristics of hospital effluents in different country [6].

in RH, 7×10^2 UFC/100 mL in H1, 6.70×10^2 UFC/100 mL in H2 (Table 3). These results are below the recommended threshold of 10^2 UFC/100 mL stipulated by WHO [1,26]. Among other things, by comparing the values recorded in our hospitals in the middle of our study with the values recorded for the effluents of the Taza hospital, the bacterial count which are of the order of CT = 2.95×10^4 UFC/100 mL, CF = $5.93 \times 10^3$and SF = 4.8×10^3 UFC/100 mL [25].

It was realized that our hospitals are less loaded on the microbiological level than urban effluents. These low values of CT and CF of SF and clostridium are linked to the usual presence of higher concentrations of disinfectants, antiseptics and antibiotics and chlorinate product in hospital effluents [2,5,27]. It can be concluded that once hospital effluents have been discharged into the basic sanitation networks and mixed with urban effluents, they will have no microbiological impact and consequence.

3.3. Performance of treatment by electrocoagulation of the effluents studied

This study was carried out in the context of evaluating the physico-chemical and bacteriological characterization before and after treatment of effluents from the Casablanca hospital which experiences the most significant levels of pollution (Table 3). Thus, the regional hospital has also a large litter capacity and its technical platform is very varied. In addition, the COD/BOD_5 ratio within the RH is the highest because it has a value of 5.12. Moreover, when this ratio exceeds the value of 5, the biological processes commonly used are not sufficient to eliminate organic pollutants according to suitable standards and it is of no importance to adopt them.

The studied hospital effluents are polluted on the physico-chemical level much more than microbiological. Therefore, electrocoagulation based much more on electrochemical reactions can lead to very high abatement values of our effluent. And can be considered as the most suitable treatment method with many advantages such as its simple equipment, easy operation and controlled automation, a short removal time, low sludge production and no need for additives and chemical reagents [18,28].

In addition, what is important in the electrocoagulation (EC) process is mainly the current density and the turbidity of the effluent because they affect the quality of the system [28]. Two experiments were carried out by varying the current density between 142.85 and 285.71 J, and the results are very telling in Table 4. In fact, during the investigations undertaken, the more the intensity of the current applied was increased, the more the rate of elimination of the pollution was very marked. Thus, for the sample treated with a current density of 142.85 J, the reduction rates are 94.76%, 66.93%, 96.93%, 97.18%, 95.23%, 83.78%, and 96.63%, respectively for the concentrations of turbidity, BOD_5, COD, nitrites, SM, nitrates, and orthophosphates.

Fortunately, these efficiency rates increased for a current density of 285.71 J, and reach 96.85%, 74.13%, 97.18%, 97.90%, 95.23%, 89.18%, and 98.07%, respectively for the concentrations of turbidity, BOD_5, COD, nitrites, SM, nitrates, and orthophosphates.

These are very high abatement rates, especially if we compare them with studies carried out on effluents treated

Table 4
Evolution of the different pollutions form of RH effluents by electrocoagulation with different densities

	E1	E2
Physico-chemical parameters		
	%	%
Conductivity	–5.14	–2.34
Turbidity	+94.76	+96.86
Salinity	–6.54	–2.80
5-day biochemical oxygen demand	+66.93	+74.13
Chemical oxygen demand	+96.93	+97.19
Suspended matter	+95.24	+95.24
Nitrites	+97.67	+97.91
Nitrates	+83.78	+89.19
Orthophosphates	+96.63	+98.08
Microbiological analyzes (values are expressed in × 10^2 UFC/mL)		
Total coliforms	+62.04	+98.81
Faecal coliforms (*Escherichia coli*)	+55.06	+88.76
Streptococci	+81.25	+99.97
Clostridium	+99.98	+99.98

E1: Sample treated with a current density 142.85 J;
E2: Sample treated with a current density 285.71 J;
(+): Degradation from the initial to the final of treatment;
(–): Augmentation from the initial to the final of treatment.

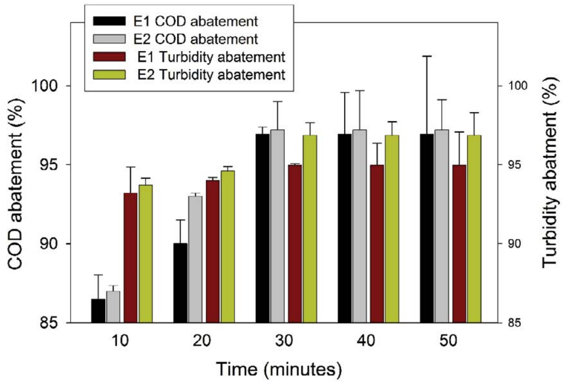

Fig. 3. Effect of electrolysis time and current density on the chemical oxygen demand and turbidity abatement.

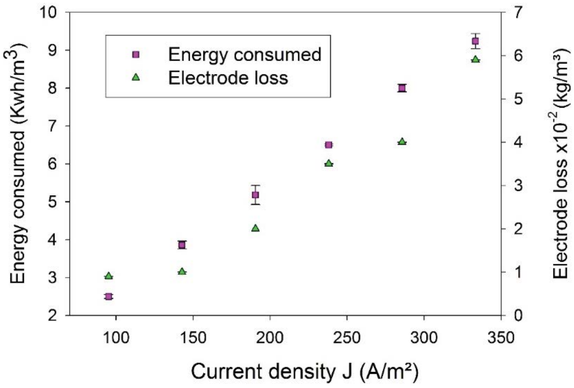

Fig. 4. Electrode loss and the energy consumed according to the current density applied.

by electrocoagulation which are respectively 83.5% for turbidity and 18.6% for COD for textile wastewater; and 50% for the COD for wastewater from the processing of edible oil; and 94% for turbidity, and 85% for the COD of hospital effluents [9].

These good results is explained by the fact that increasing the current density improves the removal of colloids and suspended matters. This result is consistent with Faraday's law which corroborates that as the current density increases, the amount of aluminum released from the anode also increases. This favors the elimination of organic and also mineral matter due to their adsorption on $Al(OH)_3$ [29,30].

Among other, the current density leads to the formation of more gas bubbles due to the generation of hydrogen at the cathode, which causes greater upward flux and faster removal of pollutants by flotation [29].

Also and according to Fig. 3, and while increasing the current from 0.3 to 0.6 A, the COD reduction rate increases from 96.93% to 97.19% for 30 min of depollution. In addition, the turbidity removal varies from 94.76% to 96.86% when the applied current intensity is increased. After 30 min of reduction, the rates remain the same and do not change even after 50 min of depollution.

Regarding the pH effect, also an important factor controls the performance of the electrocoagulation process. During electrocoagulation, the dissolution of aluminum can take place under the influence of the pH that has been kept at 7.3. The electrocoagulation process needs a neutral pH to allow the stamp system to be established between the production and consumption of OH^- and the need to neutralize the charge in order to be in the predominant zone of aluminum hydroxide $AL(OH)_3$ which plays the role of coagulant [30]. In addition, during this present study, only small amounts of sludge were generated which were rich in aluminum silicate and these sludges did not have hazardous properties [29,30].

In addition, the choice of operating conditions for this electrocoagulation process has been made to achieve high pollution reduction yields while minimizing the specific consumption of energy and metal involved. The electrical energy consumed depended on the organic and colloidal matter destroyed. And on the amount of metal consumed, which increased in parallel with the increase in current density [26]. This is very clear in Fig. 4, which shows that the evolution of energy and aluminum consumption occur simultaneously. When the current intensity increases from 0.2 to 0.7 A, the energy consumed and the mass of the metal used also increase from 2.5 to 9.24 kWh/m^3 and from 9 to 59 g/m^3.

In addition, it can be said that the results have been very satisfactory also for the reduction of microbiological parameters (Table 4). Electrocoagulation therefore destroys the bacterial strains studied by the bactericidal effect of the electric field.

These optimistic results show that most physico-chemical and microbiological parameters decrease with the increase in electrolysis time. With optimal conditions of 30 min for treatment time, pH at 7.3, temperature at 26.2°C and the use of spaced aluminum electrodes which be linked to the formation of aluminum hydroxide $AL(OH)_3$ flocs which can be easily eliminated [28–30].

4. Conclusion

This study has shown the ability of the electrocoagulation process for the treatment of the hospital effluents in the region of Casa-Settat and revealed the very good degree of organically and microbial pollution abatement. Electrocoagulation as an environmentally friendly and inexpensive technology is therefore a promising technique that adapts to the treatment of hospital effluents if optimal conditions are implemented.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

CNRST for its financial support of PPR2/2016/21 and Research Center of Materials and Energy of the Hassan2 University of Casablanca.

References

[1] J. Bouzid, S. Jaouhar, A. Zaid, L. Bouhlou, A. Chahlaoui, Evaluation of the bacteriological and physico-chemical risk of hospital effluents: case of the Mohamed V hospital in Meknes, E3S Web Conf., 319 (2021) 1–7, doi: 10.1051/e3sconf/202131901105.

[2] S. Deblij, B. Bahlaouan, N. Boutaleb, S. El Antri, Diagnostic de la Gestion des Effluens Liquides Hospitaliers de la Region de Casablanca-Settat [Diagnosis of the management of hospital liquid effluents in the Casablanca Settat Region], Eur. Sci. J., 15 (2019) 171–190, doi: 10.19044/esj.2019.v15n6p171.

[3] B. Sarhane, A. Tantane, O. El Rhaouat, K. El Kharrim, D. Belghyti, Evaluation of biological and physico-chemical risk of hospital liquid waste in Morocco, Int. J. Environ. Agric. Res., 3 (2017) 80–84.

[4] R. Elmountassir, B. Bennani,Y. Miyah, A. Fegousse, G. El Mouhri, B. Oumokhtar, M. Khatouf, K. Elkarrach, G.B. Touimi, A. Lahrichi, Microbiological and physico-chemical characterization of hospital effluents before and after treatment with two types of sawdust, J. Chem., 2019 (2019) 3275101, doi: 10.1155/2019/3275101.

[5] F. El Ogri, N. Ouazzani, F. Boraâm, L. Mandi, A survey of wastewaters generated by a hospital in Marrakech city and their characterization, Desal. Water Treat., 57 (2016) 17061–17074.

[6] E. Carraro, Si. Bonetta, C. Bertino, E. Lorenzi, Sa. Bonetta, G. Gilli, Hospital effluents management: chemical, physical, microbiological risks and legislation in different countries, J. Environ. Manage., 168 (2016) 185–199.

[7] E.A.S. Adanlokonon, W.G. Kanhounnon, B.C. Chabi, D.C. Adjahouinou, L. Koumolou, B. Bonou, E.D. Fiogbe, P.A. Edorh, Physico-chemical and microbiological characterization of effluents from the "Centre Hospitalier Universitaire de la Mère et de l'Enfant Lagune (CHU-MEL)" discharged in the Cotonou lagoon in Benin, Int. J. Biol. Chem. Sci., 12 (2018) 1955–1964.

[8] A. Alyafei, R.S. Al Kizwini, K.S. Hashim, D. Yeboah, M. Gkantou, R. Al Khaddar, D. Al-Faluji, S.L. Zubaid, Treatment of effluents of construction industry using a combined filtration-electrocoagulation method, IOP Conf. Ser.: Mater. Sci. Eng., 888 (2020) 012032, doi: 10.1088/1757-899X/888/1/012032.

[9] Y. Esfandyari, K. Saeb, A. Tavana, A. Rahnavard, F.G. Fahimi, Effective removal of cefazolin from hospital wastewater by the electrocoagulation process, Water Sci. Technol., 80 (2019) 2422–2429.

[10] S. Bener, Ö. Bulca, B. Palas, G. Tekin, S. Atalay, G. Ersöz, Electrocoagulation process for the treatment of real textile wastewater: effect of operative conditions on the organic carbon removal and kinetic study, Process Saf. Environ. Prot., 129 (2019) 47–54.

[11] S. Deblij, B. Bahlaouan, N. Boutaleb, F.Z. Boutaleb, M. Bennani, S. El Antri, The urban development in relation to the occurrence of diseases in the Casa-Settat Region of Morocco during the Emergence of SARS-CoV-2, Sci. World J., 9 (2022) 1093956, doi: 10.1155/2022/1093956.

[12] J.-F. Yala, A. Souza, J. Lebamba, A.N. Lepengue, F.P. Moussavou Douckagas, E.S. Minko, B. M'batchi, Etude préliminaire de l'évaluation des paramètres physico-chimiques, détection et dénombrement des coliformes totaux et fécaux dans quelques lacs de la ville de Franceville (Gabon) [Preliminary study of the evaluation of physico-chemical parameters, detection and enumeration of total and faecal coliforms in some lakes of the town of Franceville (Gabon)], Int. J. Innovation Appl. Stud., 20 (2017) 963–974.

[13] J.N. Todedji, C.C. Degbey, E. Soclo, A. Yessoufou, F. Goudjo, J.W. Hounfodji, F. Suanon, D. Mama, Caractérisation physico-chimique et toxicologique des effluents des Centres Hospitaliers et Universitaires du département du Littoral du Bénin [Physico-chemical and toxicological characterization of effluents from hospitals and universities in the Littoral department of Benin], Int. J. Biol. Chem. Sci., 14 (2020) 1118–1132.

[14] A. Fathi, N. Boutaleb, B. Bahlaouan, M. Bennani, S. Lazar, S. El Antri, Filamentous fungi and natural supports as a carrier in moving bed biofilm reactors for ecological treatment of halieutic industrial effluent, Desal. Water Treat., 237 (2021) 37–44.

[15] M. Hadidi, B. Bahlaouan, Z. Asbai, G. Radi Benjelloun, S. El Antri, N. Boutaleb, Optimizing biogas and biofertilizer production from abundant Moroccan industrial organic wastes by the formulation and the use of a fungal inoculum, Adv. Environ. Technol., 7 (2021) 275–287.

[16] M. Hadidi, B. Bahlaouan, S. El Antri, M. Benali, N. Boutaleb, Biotransformation of food waste to bio-products: biogas and biofertilizer, Int. J. Environ. Stud., (2022) 1–15, doi: 10.1080/00207233.2022.2096953.

[17] D. Lakhal, N. Boutaleb, B. Bahlaouan, T. Taiek, A. Fathi, M. Mekouar, N. Abouakil, S. Lazar, S. El Antri, Mixture experimental design in the development of a bio fertilizer from fish waste, molasses and scum, Int. J. Eng. Res. Technol., 6 (2017) 588–594.

[18] J. Hassoune, S. Tahiri, A. Aarfane, M. El Krati, A. Salhi, M. Azzi, Removal of hydrolyzable and condensed tannins from aqueous solutions by electrocoagulation process, J. Environ. Eng., 143 (2017) 04017010, doi: 10.1061/(ASCE)EE.1943-7870.0001196.

[19] A. Ahmad, M. Priyadarshini, S. Das, M.M. Ghangrekar, Electrocoagulation as an efficacious technology for the treatment of wastewater containing active pharmaceutical compounds: a review, Sep. Sci. Technol., 57 (2022) 1234–1256.

[20] Y.F.R. Bako, I. Zongo, Y. Karanga, Y. Tapsoba, I. Sawadogo, B. Baga, Etude des paramètres opératoires d'électrocoagulation pour le traitement d'un effluent de textile: Exemple du bleu de methylene [Study of electrocoagulation operating parameters for the treatment of textile effluent: example of methylene blue], Int. J. Biol. Chem. Sci., 15 (2021) 790–802.

[21] D. Djajasasmita, Sutrisno, A.B. Lubis, I.D. Ma'mur, Danurrendra, S.T. Pratiwi, F. Rusgiyarto, F.A. Nugroho, P.T.P. Aryanti, High-efficiency contaminant removal from hospital wastewater by integrated electrocoagulation-membrane process, Process Saf. Environ. Prot., 164 (2022) 177–188.

[22] I.D. Tegladza, Q. Xu, K. Xu, G. Lv, J. Lu, Electrocoagulation processes: a general review about role of electro-generated flocs in pollutant removal, Process Saf. Environ. Prot., 146 (2021) 169–189.

[23] A. Ahmad, S. Das, M.M. Ghangrekar, Removal of xenobiotics from wastewater by electrocoagulation: a mini-review, J. Indian Chem. Soc., 97 (2020) 493–500.
[24] E. Aziz, M. Aouane, R. Abdeljabbar, B. nabyl, Analysis of physico-chemical and bacteriological parameters of liquid effluents from the Provincial Hospital Center in Sidi Kacem Morocco, Indian J. Forensic Med. Toxicol., 6 (2022) 408–418.
[25] I. Touzani, M. Machkor, O. Boudouch, I. El Machrafi, R. Flouchi, K. Fikri-Benbrahim, Evaluation of physico-chemical and bacteriological parameters of effluents in Taza Hospital-Morocco application of principal component analysis (PCA), Pollut. Res., 39 (2020) 872–878.
[26] I. Mansir, E. Oertlé, R. Choukr-Allah, Evaluation of the performance and quality of wastewater treated by M'zar Plant in Agadir, Morocco, Water, 13 (2021) 954, doi: 10.3390/w13070954.
[27] S. Fatimazahra, M. Latifa, S. Laila, K. Monsif, Review of hospital effluents: special emphasis on characterization, impact, and treatment of pollutants and antibiotic resistance, Environ. Monit. Assess., 195 (2023) 393, doi: 10.1007/s10661-023-11002-5.
[28] K. Naji, A. Salhi, J. Hassoune, A. Aarfane, M. Sisouane, T. Echcherki, M. El Krati, S. Tahiri, Treatment of wastewater from the cleaning circuits of the margarine industry by electrocoagulation/flotation process, Desal. Water Treat., 198 (2020) 241–247.
[29] S.U. Khan, D.T. Islam, I.H. Farooqi, S. Ayub, F. Basheer, Hexavalent chromium removal in an electrocoagulation column reactor: process optimization using CCD, adsorption kinetics and pH modulated sludge formation, Process Saf. Environ. Prot., 12 (2019) 118–130.
[30] A.S. Al-Shati, O.K. Alabboodi, A.S. Hassan, Z.N. Abd, S.I. Mohammed Emeen, The treatment of hospital wastewater using electrocoagulation process – analysis by response surface methodology, J. Ecol. Eng., 24 (2023) 260–276.