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Monitoring Alkalinity and Hardness During Treatment of Different Water Types

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Abstract

Alkalinity and hardness are crucial factors in water treatment procedures, such as electrocoagulation (EC) and traditional coagulation–flocculation. Two types of water were employed in this study to investigate the use of EC: river water and discarded reverse osmosis system water. With bipolar and monopolar aluminum electrodes, continuous flow tests were conducted to evaluate the effects of different parameters on the variations in alkalinity and hardness versus time. The examined factors were flow rate (600 and 1,000 L/h) and number of electrodes (2 and 4). Polarity reversal was also studied. The water passed through the plates in a zigzag pattern. Results showed that the hardness under all operating conditions decreased with time, and alkalinity exhibited an oscillating behaviour. The ideal hardness removal for treating river and concentrated water was obtained using four plates with polarity reversal and a flow rate of 1,000 L/h, which were equal to 37.5% and 33.3%, respectively.

Keywords: *Alkalinity, Hardness; Electrocoagulation; Tigris River; Reverse Osmosis Rejected Water; Anode; Cathode*

1. Introduction

One of the most critical issues facing humanity today is ensuring that the majority of the world's population has access to clean water. The demand for clean water is particularly high in third-world nations. Rivers, canals, waterways and other bodies of water are continually contaminated by the discharge of industrial effluents, human activities and natural processes. Therefore, cleaning and purifying water are important. One of the main problems in treating water is hardness removal. Many processes, such as electrocoagulation, are used for hardness removal.

Electrocoagulation is an electrochemical method that effectively eliminates suspended solids, metals, colloidal particles, and other dissolved materials from water. The electrocoagulation method can be used to remove organic matter and nutrients in wastewater. A sacrificial anode is dissolved during the electrocoagulation process to create coagulants [1].

Electrocoagulation is an innovative, practical, beneficial wastewater treatment technique. It is a complicated procedure that combines physics and chemistry [1]. Water containing suspended particles and organic materials can be treated via electrocoagulation. Flotation, coagulation and oxidation or reduction of polluting chemicals are involved in electrocoagulation [2]. Electrocoagulation is an excellent method for treating organic and inorganic contaminants because it combines the advantages of flotation, electro-oxidation/reduction and coagulation–flocculation [3].

An innovative, effective technique for the treatment of industrial wastewater is electrocoagulation–flocculation [3].

The electrocoagulation process has many advantages, such as flexibility, environmental compatibility, energy efficiency, cost effectiveness, automation and not requiring chemicals [4]. Another ecologically beneficial technique is electrocoagulation, the effectiveness of which is determined by operational factors, such as initial pH, temperature, conductivity, time and current density. Emerging approaches for removing contaminants from wastewater that rely on complicated methods are called electrocoagulation [5].

In this study, the variation in alkalinity and hardness versus time under different operating conditions was recorded, and treatment of reverse osmosis rejected water and Tigris River water was performed. The polarity reversal effect was also studied.

2. Experimental work

2.1 Materials and methods

An electrolytic cell was designed to perform the electrocoagulation procedure. The electrocoagulation arrangement utilised is shown in Fig. 1. This figure shows the configuration and major components of the system used to treat river and concentrated water via the electrocoagulation method. To produce drinkable water, the system uses an electrochemical plastic reactor with a capacity of 120 L. The anode and cathode electrodes were made of aluminium plate electrodes with a length of 50 cm, width of 50 cm and thickness of 0.5 mm. As shown in Fig. 2, the plates consisted of holes with 2.5 cm diameter spaced 5 cm apart. The electrodes were positioned vertically in the reactor. Water passed through the holes on the plate, improving the mixing and dispersion of pollutants in the water and increasing the efficiency of the electrochemical process. The electrodes’ enhanced ability to contact the impurities accelerated the coagulation and flocculation processes because the holes formed alternate upward and downward flow channels. A 60- to 50-min treatment period was chosen, and the plates were subjected to 36 V of applied voltage and 32 A of current. This study employed reverse and direct polarity modes. The polarity of the electrodes was switched every 10 min throughout the polarity reversal investigation to ensure that both electrodes worked for the same length of time as the cathode or anode and were nearly equally consumed.

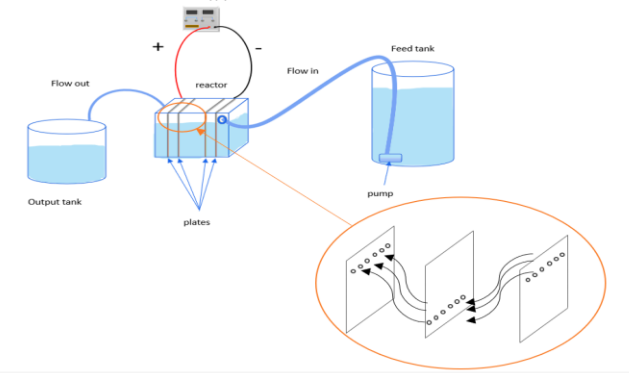

Fig. 1 Electrocoagulation reactor in the experiment.

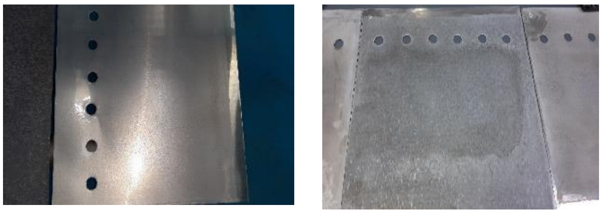

Fig. 2. Plates the electrode used.

2.2 Water samples

Two types of water, namely, river and concentrated water, were used in this study. Table 1 shows the operating variables for untreated water.

Table 1.
Operating variables for the experiments.

Water type	Number of plates	Flow rate L/h	Polarity type	Hardness removal%	Alkalinity change%	Conductivity S/cm^{2}µ
River	2	600	DP	20	4.3	890
River	2	600	RP	6.3	24.1	1423
River	4	600	RP	5.9	10.7	1151
River	4	600	DP	23.1	14	1009
River	2	1000	DP	9	31.5	1039
River	2	1000	RP	25	3.3	992
River	4	1000	DP	29.4	9.7	932.4
River	4	1000	RP	37.5	14.3	998
Concentrated	2	600	DP	12.5	4.8	4062
Concentrated	2	600	RP	5.3	100	4305
Concentrated	4	600	RP	20	12.8	4287
Concentrated	4	600	DP	16.7	4.3	6904.2
Concentrated	2	1000	DP	11.1	6.9	3309
Concentrated	2	1000	RP	21	25	4369
Concentrated	4	1000	DP	15	4.8	3475
Concentrated	4	1000	RP	33.3	12.5	4371

3. Results and discussion

The baseline concentrations of bicarbonate and carbonate ions were determined using the alkalinity of the water source being treated. Alkalinity variations that occurred throughout the treatment were measured with reference to the original baseline. Alkalinity variations can affect water's pH stability, and hardness ions can create insoluble precipitates that interfere with the coagulation and flocculation processes' capacity to work.

Alkalinity and hardness are often controlled factors in drinking water regulations because of their effects on water quality and possible health risks.

The rate and level of alkalinity changes during electrocoagulation treatment can be influenced by operational factors, such as current density, electrode design, electrolyte concentration and treatment duration. The presence of dissolved minerals in water, especially calcium (Ca) and magnesium (Mg) ions, is the cause of alkalinity and hardness.

Alkalinity absorbs and neutralises acids, so it serves as a buffer against pH variations. By reacting with the bicarbonate and carbonate ions already present in the water to generate bicarbonate ($HCO^-{}_3$) and carbonate (CO_3^{-2}) ions, hardness ions, mainly calcium and magnesium, add to the alkalinity and overall buffering capacity of water. Hardness and alkalinity are two different but related characteristics that affect water quality. Elevated levels of alkalinity have the potential to influence the taste and odour of water and cause scaling problems in water systems. Figs. 3 to 8 show the hardness and alkalinity variations with time.

In the river water treatment process, under different operating conditions, a noticeable decrease was observed in the first 10 min, followed by a fluctuating trend in the subsequent period, as shown in Figure 3a. As indicated in Fig. 3b, alkalinity decreased in the first 15 min before increasing again. The hardness decrements versus time under both operating conditions exhibited almost the same trend, as shown in Fig. 3.

Figs. 4a and 4b show that the alkalinity of river and concentrated water presented the same trend at a flow rate of 600 L/h flow in the two plate experiments without employing polarity reversal. The hardness trends presented in Fig. 4 show that the hardness for both types of water decreased in the same manner versus time.

The alkalinity value remained the same in the first 15 min, increased at 20 min and then increased again, as shown in Fig. 5a. Fig. 5b shows that alkalinity decreased in the first 10 min then increased in the next 15 min, followed by a decrease. Fig. 5 shows the decrease in hardness for concentrated and river water.

Fig. 6 presents the reduction in alkalinity with time for river water, whose alkalinity profile is an almost mirror image of the profile for the alkalinity of concentrated water as it increases with time, as presented in Fig. 6b. Fig. 6 shows the hardness profiles of river and concentrated water. Both profiles exhibit the same decreasing trend with time.

Alkalinity presented the same trend versus time for both types of water, as indicated in Fig. 7. Fig. 7 also presents the decrease in hardness versus time for both types of water. The decrease in hardness in both types of water exhibited the same behaviour.

Fig. 8 shows the alkalinity trends of river and concentrated water. Both trends show a clear fluctuation in the alkalinity value versus time. Fig. 8 also indicates that the decrements in hardness versus time for both types of water were similar. In terms of hardness, all the experiments showed a decrease in hardness versus time for both types of water.

The increase in alkalinity can be attributed to the generation of an alkaline medium near the cathode. This study confirmed the alkalinity increase [8] [9].

As indicated in Figs. 3 to 8, the decreasing alkalinity resulted from certain water-soluble substances, such as bicarbonate or carbonate ions, which may have reacted with the precipitates produced by electrocoagulation. Others may have replaced these alkaline chemicals throughout the process, which might have reduced the overall alkalinity of the mixture. The decrease in alkalinity in this study followed the same behaviour as those in the studies of [10] [11].

Electrocoagulation causes precipitation or coagulation, and it can help remove alkaline impurities or chemicals that encourage alkalinity. The alkalinity of treated water may be lost because of this removal. The decrease in alkalinity in this study is similar to that in the work of Raju et al. [10] and Saiba et al. [11].

Meanwhile, no change in alkalinity occurs in some situations according to Franco, who stated that the EC procedure has no noticeable effect on water's alkalinity; this effect is essential because some degree of alkalinity is required to avoid sudden pH fluctuations, as mentioned by Franco et al. [12]. The same alkalinity trend was reported in previous studies [13] [14][15].

The decrease in alkalinity could also be attributed to the generation of hydroxide ions (OH) at the cathode as a consequence of water reduction processes when bicarbonate ions (HCO^{-3}) and/or carbonate ions (CO_3^{-2}) are consumed. If hydroxide ions are consumed as a result of acidic byproducts generated by oxidation processes at the anode, alkalinity may also decrease.

Alkalinity may increase as a result of electrocoagulation procedures in some circumstances. This increment may occur if the cathode produces hydroxide ions that raise the solution's alkalinity. Furthermore, if some species are originally present in the water, their precipitation as hydroxide or carbonate salts may increase alkalinity. Protons (H^+) are consumed and hydroxide ions (OH^-) are produced at the cathode as a result of water reduction processes. Proton consumption can raise pH and alkalinity.

Oxidation processes can produce acidic byproducts, such as hydrogen ions (H^+), at the anode. pH and alkalinity may decrease as a result.

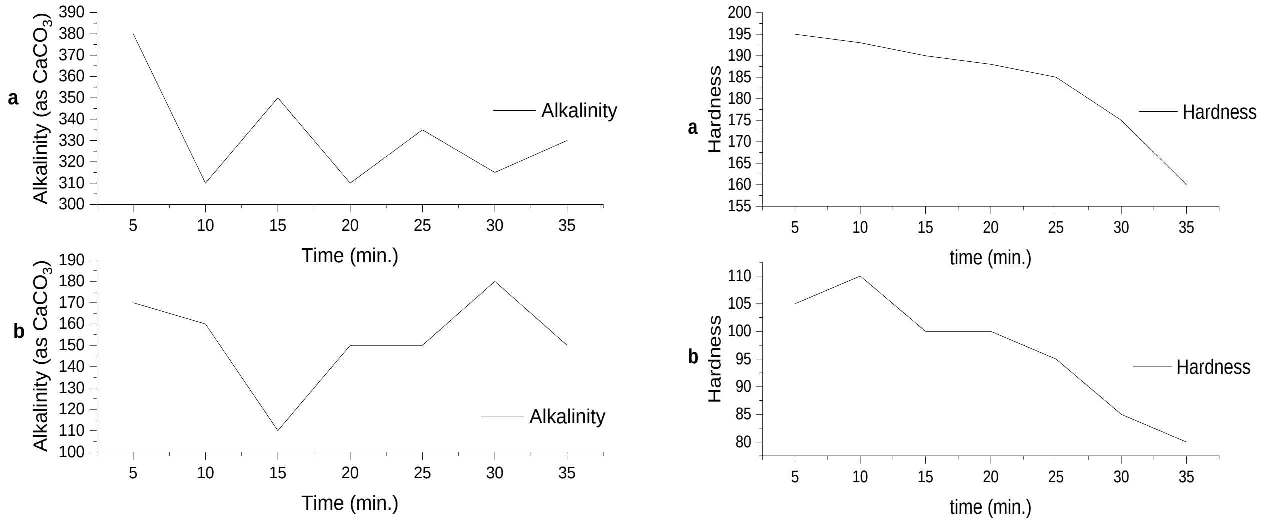

Fig. 3. Alkalinity and hardness versus time. a) River water continuous process employing two plates, 600 L/h, and absence of polarity reversal. b) Continuous process of treating concentrated water at a flow rate of 600 L/h and with the absence of polarity reversal by using two plates.

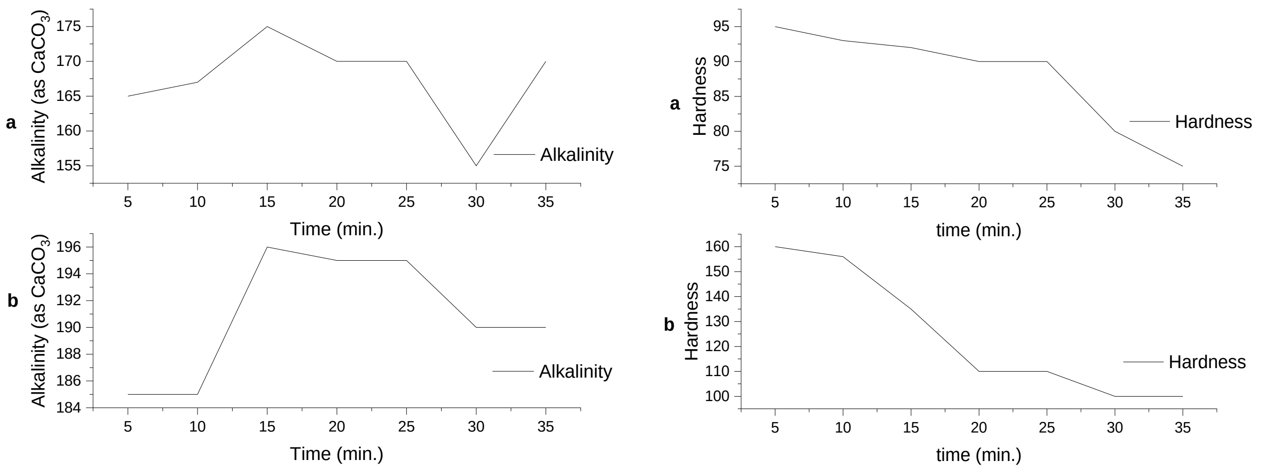

Fig. 4. Alkalinity and hardness versus time. a) Continuous process with concentrated water, absence of polarity reversal and use of four plates at 600 L/h. b) River water continuous process employing four plates, 600 L/h, with polarity reversal.

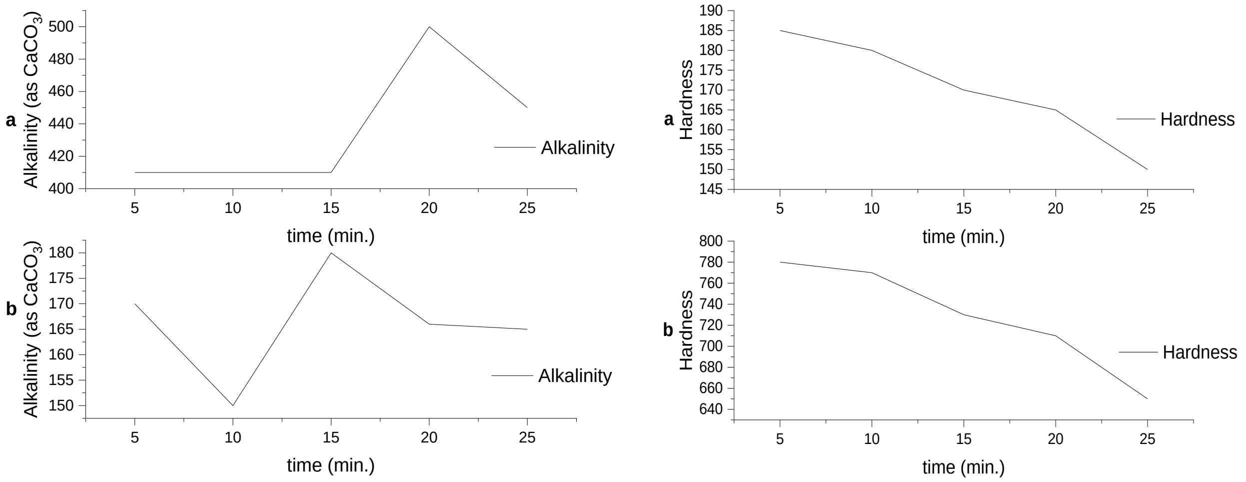

Fig. 5. Alkalinity and hardness versus time. a) River water continuous process with 600 L/h flow rate and polarity reversal by using two plates. b) Concentrated water continuous process with polarity reversal and 600 L/h by using two plates.

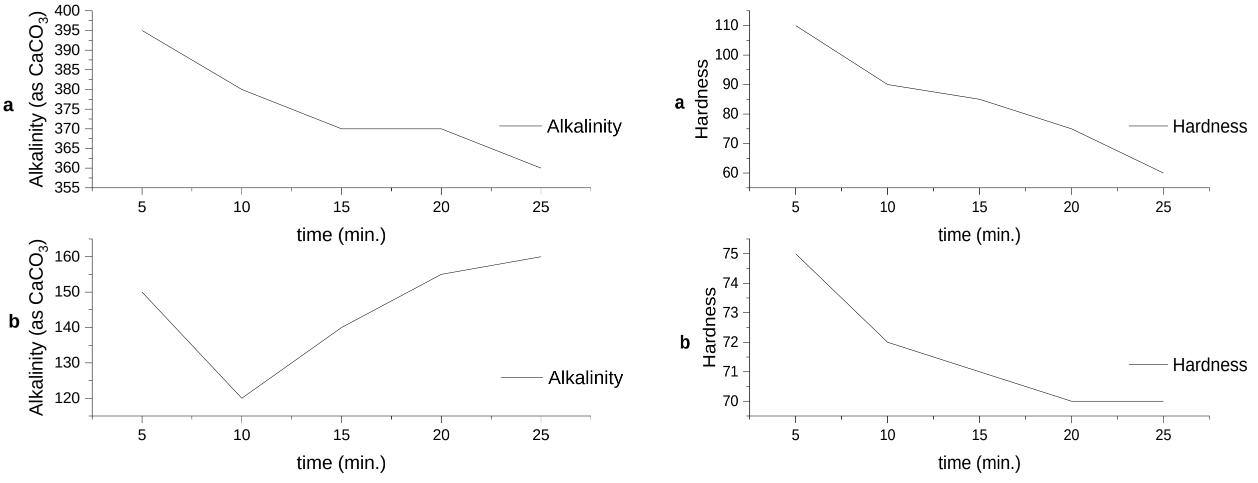

Fig. 6. Alkalinity and hardness versus time. a) River water continuous process at 1,000 L/h with polarity reversal by using two plates. b) Concentrated water continuous process at 1,000 L/h with polarity reversal by using two plates.

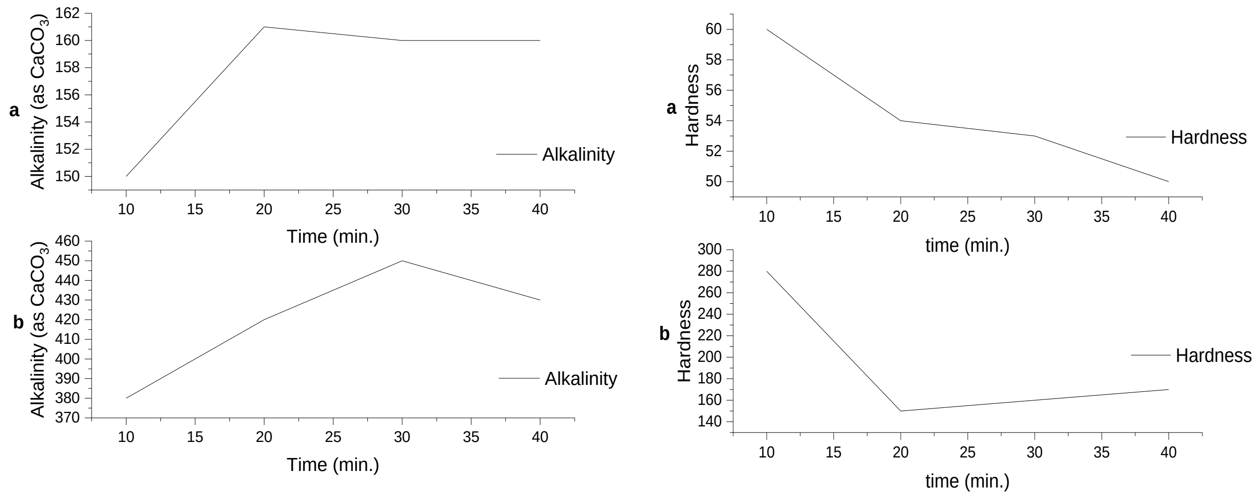

Fig. 7. Alkalinity and hardness versus time. a) Continuous process with concentrated water and the absence of polarity reversal by using two plates and 1,000 L/h flow rate. b) River water continuous process at 1,000 L/h flow rate and with the absence of polarity reversal by using two plates.

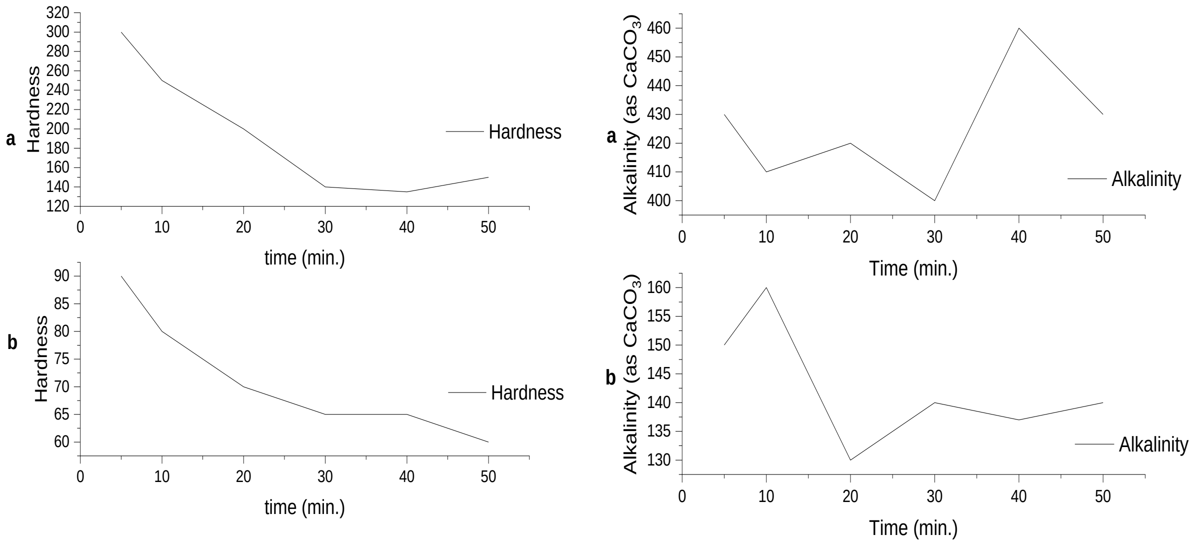

Fig. 8. Alkalinity and hardness versus time. a) River water continuous process using two plates, 600 L/h flow rate and absence of polarity reversal. b) Continuous process for concentrated water using two plates, 600 L/h flow rate and absence of polarity reversal.

4. Conclusion

In water treatment procedures, such as electrocoagulation and conventional coagulation–flocculation, alkalinity and hardness are important factors to consider. Hardness ions can produce insoluble precipitates that reduce treatment efficacy, and alkalinity affects pH stability. Drinking water standards control them because of their effects on health and water quality. Bicarbonate and carbonate ions are the baseline for alkalinity, and treatment differences are evaluated on the basis of this baseline. Alkalinity and hardness are influenced by calcium and magnesium ions, which also affect the quality and buffering power of water. High hardness levels prevent soap from working well and promote the development of scale, and high alkalinity levels affect taste, odour and scaling. Non-polarity-reversing hardness data exhibit consistent declines in contrast to reverse polarity data fluctuations.

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مراقبة تغييرات القلوية والعسرة في انظمة التخثير الكهربائي

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المستخلص

تم استخدام نوعين من المياه في هذه الدراسة لدراسة استخدام التخثير الكهربائي (EC): مياه النهر والمياه المرفوضة من منظومة التناضح العكسي .تم استخدام أقطاب الألومنيوم ثنائية القطب وأحادية القطب، تم إجراء اختبارات الجريان المستمر لتقييم تأثيرات عوامل مختلفة على تغير القلوية والعسرة مع الزمن. العوامل التي تم دراستها هي معدل الجريان (600,1000 لتر/ ساعة) وعدد الأقطاب الكهربائية (2,4). كما تمت دراسة عكس القطبية الكهربائية. تم إجراء التجارب الخاصة بالبحث باستخدام مفاعل مبتكر يقوم بإجراء عملية التخثير الكهربائي (EC) في مفاعل بلاستيكي شفاف يحتوي على ثقوب داخل الأقطاب الكهربائية المصنوعة من الألومنيوم والتي تم استخدامها في تجارب الجريان المستمر لإزالة العسرة الكلية (TH). يكون جريان المياه عبر الصفائح (الاقطاب) بشكل متعرج. أظهرت النتائج أن قيم العسرة الكلية انخفضت في جميع ظروف التشغيل المختلفة مع مرور الوقت. بينما القلوية اظهرت سلوكا متذبذبا.