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Novel electrodialysis–electrochlorination integrated process for the reclamation of treated wastewaters

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ABSTRACT

This work presents a novel integrated process for the reclamation of wastewaters. This process combines, in the same cell, the reduction in the effluent conductivity and TOC by electrodialysis together with the production of a value added stream, which can be used for disinfection purposes. In the diluate compartment, the solution is desalted whereas hypochlorite is electrochemically synthesized in the anolyte. The treatment of actual effluents from the Waste Water Treatment Plant (WWTP) of Ciudad Real (Spain) was confronted. It was observed that the concentration of hypochlorite synthesized in the anolyte increased when anolyte and catholyte are separated into different circuits, avoiding the reduction of hypochlorite on the cathode surface. Furthermore, a higher voltage to cell pair ratio also enhances the production of hypochlorite. Finally, it was checked the disinfectant potential of the final anolyte, being possible to produce a desalted and disinfected final stream with a total electrical consumption of 1.03 W h dm^{-3} and dosing a volumetric ratio anolyte:diluate of 4:96.

1. Introduction

Reclaimed wastewaters are a water resource that has not been extensively used so far. Focussing on Spain, a country with a great demand of water sources (overall water demand of around 22,000 hm^3 $year^{-1}$ [1]) and a pioneering regulation, the total volume of regenerated water means only around 2% of its total water demand [2]. In a process of wastewater reclamation, a wastewater effluent, which has been previously treated by a conventional treatment, is further purified in order to fit the requirements for different uses (irrigation, recreational, environmental, etc.). Some advantages of the use of this type of water resource are the reduction of the overall net water demand, the decrease in industrial production costs due to the use of high quality regenerated water and the decrease in the loss of water to the sea.

Within the last years, electrochemical technologies have experienced great advances in the treatment of wastewaters due to the development of new electrode materials and novel electrochemical processes [3–8]. One of the electrochemical technologies most widely used in the industry is electrodialysis. This technique consists of an unitary process that uses semi-permeable membranes to separate or concentrate dissolved ions. The depleted solution is generally referred to as the diluate and the concentrated solution as the brine or the concentrate [9]. Electrodialysis is a process currently used in brackish water desalination and potable water production [10–12]. Recently, different applications of electrodialysis in food, medicine and chemistry industries, as well as biotechnology and wastewater treatment, have been proposed [13–16]. Another electrochemical process applied in the treatment of wastewater is electrodisinfection, which consists of an electrolytic production of oxidizing species either from the ions initially contained in the target wastewater or from reagent dosed (e.g. sodium chloride) [17–20].

One of the drawbacks of electrochemical technologies is the high cost, which depends on the energy consumption (operating), and on the high price of the electrode material (investment). For this reason, a hot topic in this research subject is to explore alternatives to diminish these operating and investment costs and hence, to develop electrochemical processes more cost-effective and energy-efficient. In this context, process integration emerges as a good alternative in electrochemical process. This process integration represents the union, in one single stage, of basic operations that are traditionally carried out separately. Regarding wastewater treatment, many authors have proposed combined electrochemical processes to minimize the operation costs. Thus, Jüttner et al. [21] reviewed different integrated industrial processes such as the treatment of highly concentrated salt solutions together with the production of acids and bases [22] or the combination of ion exchange membranes and conventional ion exchange

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resins for the treatment of water and process solutions with continuous regeneration of the ion exchanger [23]. Another example is the work of Rockstraw et al. [24], who proposed an integrated electrodialysis–evaporation process for the treatment of aqueous streams. Linares-Hernández et al. [25] described a combined electrocoagulation–electrooxidation treatment for industrial wastewater and Durante et al. [26] proposed a combination of electrocoagulation and advanced oxidation processes for removal of Cr-EDTA from wastewaters. However, these last works consist of combining different techniques in successive steps but not within the same experimental set-up. In contrast, Mahvi et al. [27] proposed an electrocoagulation/electrooxidation–electroflotation reactor for the simultaneous removal of ammonia and phosphate from wastewater. In that work, the electrochemical cell consisted of one reactor with two different units: one electrochemical and one more for separation using aluminum, stainless steel and RuO_2/Ti as electrodes. More recently, Cotillas et al. demonstrated the viability of an electrocoagulation/electrodisinfection cell using Al bipolar electrodes [28] to carry out simultaneous disinfection and removal of turbidity.

Within this context, the present work is focused on the assessment of the performance of a novel integrated electrodialysis–electrochlorination (ED–ECh) integrated cell for the treatment of actual wastewaters from the WWTF of Ciudad Real (Spain). The proposed process is schematized in Fig. 1. The actual effluent from a Waste Water Treatment Facility (WWTF) is conducted through an electrodialysis/electrochlorination integrated cell. In this cell, a portion of the initial effluent is desalted (diluate) meanwhile the rest is concentrated (concentrate). In addition, the electrode-rinsing solution of the electrodialysis cell is fed with a NaCl solution in order to obtain a value-added hypochlorite stream, which can be used as disinfectant. Thus, the final streams of this process are: (1) a concentrated stream which should be discharged to the environment; (2) a valorized stream, desalted and disinfected, ready to be reclaimed. In this work, the effect of three key parameters (cell configuration, number of cell pairs and concentration of NaCl in the electrode rinsing solution) on the performance of the ED–ECh cell is studied. Furthermore, disinfection tests with the final electrode rinsing solution were carried out to evaluate the actual disinfection potential of this stream.

2. Experimental

2.1. Electrodialysis–electrochlorination cell

The experimental set up, schematized in Fig. 2, was provided by PCCell (Germany). Cationic (Neosepta CMX) and anionic (Neosepta AMX) standard ion exchange membranes from ASTOM CORP were used. The surface area per membrane was 69 cm^2. Depending on the number of membranes placed inside the stack, it was composed of a different number of cell pairs (diluate + concentrate), being 3 cell pairs for 7 membranes (3 anionic, 4 cationic) and 6 cell pairs for 13 membranes (6 anionic, 7 cationic). With this configuration, the concentration of both catholyte and anolyte was maintained constant throughout the tests, closing the ionic circuit and behaving as "electrode rinsing" solutions. In all cases, the ion exchange membranes in contact with both anolyte and catholyte, were cationic exchange membranes, in order to avoid the migration of the synthesised hypochlorite.

Dimensionally stable anodes (DSA) were used as electrodes. DSA anodes were supplied by PcCell and made of titanium coated with mixed metal oxides (IrO_2–RuO_2)) DSA electrodes (anode and cathode) were square in shape (56.25 cm^2). Wastewater was stored in glass tanks and circulated through the electrodialysis cell by means of a centrifugal pump.

The flow rate for electrode rinsing solution was 100 $dm^3\ h^{-1}$ and for concentrate and diluate was 30 $dm^3\ h^{-1}$. Regarding the ratio between diluate and concentrate volumes, a value of 1:1 (same volume of diluate and concentrate compartments, 1.5 L) was selected. It is worth noting that a low diluate/concentrate ratio will lead to a strongly desalted solution in the diluate compartment with a limited increase in the concentration of the concentrate. On the contrary, a high diluate/concentrate volumetric ratio will produce a moderate increase in the concentration of the concentrate. In the present work, the main aim is not the production of a totally desalted diluate nor a highly concentrated final stream, which should be further treated prior to its disposal. For these reasons, in this first approach of the design of the ED–ECh process, a ratio 1:1 was selected.

2.2. Experimental procedures

The experimental set up is designed to work with a maximum number of four different circuits (four independent tanks, pumps and tubing). In all cases, concentrate and diluate streams consist of actual effluents from the WWTF of Ciudad Real (Spain), meanwhile streams that are in contact with electrodes were NaCl solutions.

Depending on the number of different circuits used, the cell was operated at two different configurations:

(1) Four compartments configuration (4C). In this configuration, diluate, concentrate, catholyte and anolyte were circulated through four independent circuits, thus giving four different solutions.
(2) Three compartments configuration (3C). In this case, catholyte and anolyte are mixed, so the cell worked with three independent circuits, one for the diluate, one for the concentrate and one for a mixture of anolyte and catholyte (electrode-rinsing).

Bench scale ED–ECh tests were carried out under potentiostatic conditions (voltage is constant) and at discontinuous mode of operation to determine the influence of the main parameters in

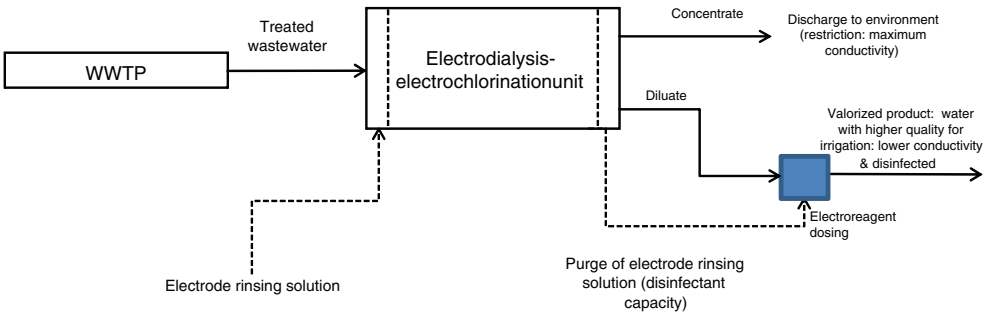

Fig. 1. Schematic representation of the proposed electrodialysis–electrochlorination process.