*Desalination and Water Treatment*
www.deswater.com
doi: 10.1080/19443994.2013.808582

52 (2014) 5243–5251
August

Taylor & Francis
Taylor & Francis Group

# Electrocoagulation coupled to activated carbon sorption/filtration for treatment of cleaning wastewaters from wood-based industry

Henrik Hansson[a,*], Marcia Marques[a,b], Sawanya Laohaprapanon[a], William Hogland[a]

[a]*School of Natural Science, Linnaeus University, Landgången 3, SE-39182, Kalmar, Sweden*
*Tel. +46 480 446334; email: henrik.hansson@lnu.se*
[b]*Department of Sanitary & Environmental Engineering, Rio de Janeiro State University – UERJ, RJ, Brazil*

Received 26 October 2012; Accepted 17 May 2013

## ABSTRACT

The objective of this investigation was to study the use of a coupled treatment (electrocoagulation (EC) and sorption/filtration treatment) with different sequencing to reduce the organic pollutants measured as chemical oxygen demand (COD) of five highly polluted wastewater streams generated after washing surfaces and machinery in the wooden floor industry and to evaluate, how different sequencing of these treatment units affects the overall system efficiency. On the basis of preliminary studies, an EC reactor (1.0 L) was constructed with monopolar electrodes in parallel connection in an array of four Al electrodes with surface area of 93.2 $cm^2$ and an applied current density of 161 $A\,m^{-2}$. This reactor was coupled to a sorption/filtration unit with coal activated carbon. The EC reactor was tested in two different sequences (before and after the sorption/filtration unit). The overall COD reduction varied from 2% ± 0.5% to 77% ± 2.9%, depending on the sequence and the treated wastewater stream. The best result from efficiency and operational viewpoints was obtained with the EC reactor placed after the sorption/filtration column. The increase in efficiency is likely to be due to the removal by sorption in the activated carbon of compounds that interfere with EC. Additionally, as desired, the use of EC before the sorption unit extended the activated carbon lifetime.

*Keywords:* Cleaning wastewater; Electrocoagulation; Activated carbon; Wood-based industry

## 1. Introduction

Increasing concern about the discharge of industrial wastewater into recipient water bodies, thereby affecting fragile aquatic ecosystems, has led to intensive research and development of treatment technologies in recent decades. Therefore, for those industrial sectors that have water as an important input to their processes and thus generate large volumes of wastewater, onsite treatment technologies have been made available. Nevertheless, there are many industries that due to the nature of their activities comprise small-to-medium plants producing small volumes of wastewater that are highly polluted with organic and inorganic compounds [1,2]. There are also so-called dry-process industries, such as the wooden floor and wooden furniture industries, which have no water requirement in their production processes [1,3], yet generate wastewater during the cleaning and washing of machinery, surfaces, and floors that contain significant amounts of pollutants such as urea formaldehyde and phenol, ammonium sulfate, wood filler, lacquer, and

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*Corresponding author.

detergents regardless of the relatively low volumes. Chemical oxygen demand (COD) values varying from 3,200 to 50,000 $\mathrm{mg\,L^{-1}}$ are found in these wastewaters and the presence of recalcitrant organic compounds is a limiting factor for biological treatment in conventional centralized plants. Dilution 50 times or more with potable water has been a common practice before discharging wastewater into the sewage system, but it cannot be seen as a sustainable strategy for the twenty-first century. Many small-to-medium and some large industries that produce low volumes of highly polluted wastewaters after cleaning/washing activities are currently applying such a strategy, even in well-developed nations such as Sweden. Wastewaters from the timber product industry have proven difficult to treat with chemical methods in previous studies when compared with other industrial wastewaters and sanitary wastewater [4]. Biological treatment [3] and sorption/filtration processes [1] applied separately to treat wastewater generated during machinery and floor cleaning in the wooden floor industry have demonstrated limited efficiency in reducing COD.

Electrocoagulation (EC) is a simple and efficient method, where the flocculating agent is generated *in situ* by electro-oxidation of a sacrificial anode, generally made of iron (Fe) or aluminum (Al) that leads, at appropriate pH, to insoluble metal hydroxides, which in turn remove pollutants by surface complexation or electrostatic attraction [5]. A simple EC reactor has one anode and one cathode. When electrical power is supplied, the anode material will be oxidized and the cathode will undergo reduction. The reactions are summarized as follows (M = Al) [6].

- Anode

$$M_{(S)} \rightarrow M^{3+} + 3e^-$$

$$2H_2O_{(l)} \rightarrow O_2 + 4H^+ + 4e^-$$

- Cathode

$$H_2O + e^- \rightarrow 1/2H_2 + OH^-$$

The metal ions generated at the anode immediately hydrolyze to aluminum hydroxide. The hydroxides provide active surfaces for the adsorption of the polluting species. There are three stages to producing coagulation ions *in situ* during the EC process: (a) formation of coagulants by oxidation of the anode, (b) destabilization of pollutants, and (c) aggregation of the destabilized phases to form flocks. The destabilization mechanism in turn can be described as (c1) compression of the diffuse double layer around the charge species by interactions of ions generated by oxidation of the anode, (c2) charge neutralization of the ions from the pollutants by ions from the anode that are produced by electrochemical dissolution, and (c3) flocks formed by coagulation trapping and bridging colloidal particles that remain in the water [7]. Coagulation happens as the anode continually produces these polymeric hydroxides and the polymeric hydroxides combine with negative particles that are carried towards the anode by electrophoretic motion [7]. As the metal hydroxides form, water is reduced to hydrogen gas and hydroxide. In most cases, the hydrogen gas can help to lift the flocks to the surface, where they can be easily collected and removed [5,7]. EC has been successfully applied to treating different highly polluted wastewater containing recalcitrant and toxic compounds, the biological treatment of which is inefficient [8,9]. The pH together with current density and electrode material are the most important parameters to be considered when choosing EC as a treatment process for the removal of organic and inorganic pollutants [10,11]. Although, EC has been proved to be successful in treating wastewater from wood-based industries [12], during preliminary studies, very small COD reduction was achieved, even when different electrolytes and electrode materials were used [12]. However, with Al electrodes, a much clearer effluent was produced for the same COD reduction [12]. From these preliminary results (not shown here), the design parameters for this study were chosen (Table 2).

The objective of the present study was to test, if recalcitrance found in wastewater with typical pollutants from wood-based manufacturing such as the wooden floor industry can be overcome by coupling two treatment units: EC and sorption/filtration units. Another aim was to verify, if the sequence (i.e. EC–sorption/filtration vs. sorption/filtration–EC) affects the overall treatment efficiency for highly recalcitrant cleaning wastewater. Another aspect investigated was the contribution of EC to the lifespan of the activated carbon when treating wastewater generated by cleaning/washing surfaces and machinery in the wooden floor industry.

## 2. Materials and methods

### 2.1. Wastewater samples

Wastewater streams were collected from a wooden floor factory in Nybro, Sweden. As part of a “dry industry,” water plays no part in the industrial processes of the factory and it is mainly used to clean/wash surfaces and machinery after use. High COD/biological oxygen demand ($BOD_5$) ratios (3 or higher) indicate moderate-to-low biodegradability of these wastewaters (Table 1). The main parameter selected to follow up the pollutant removal from each wastewater stream and from mixtures of the streams was the proxy indicator COD. The performance of EC regarding COD removal was investigated for five different cleaning wastewater streams and for mixtures of these streams (Table 1).

### *2.2. Equalization/sedimentation before treatment*

The reduction of the COD value through the equalization and sedimentation of different mixtures of the wastewater streams was studied. For this purpose, the wastewater streams (Table 1) were rapidly mixed using a magnetic stirrer for 5 min and the mixture was then allowed to settle. The COD values of the samples were measured after 30 min and after 24 h of settling at room temperature.

### *2.3. Sorption/filtration unit*

The two columns of the sorption/filtration unit were made from polyvinyl chloride and had inner diameter of 70 mm, height of 750 mm, and total bed depth of 570 mm. The bottom of each column corresponding to 7% of the total volume was filled with sand (particle size of 1–2 mm). A peristaltic pump (AU UV EZ; VERDERFLEX, Castleford, UK) was used to feed the column with wastewater from the bottom to the top. Before starting the tests, the column bed was rinsed by pumping distilled water throughout the column. Rinsing was stopped once no air bubbles could be seen rising from the two columns. The experiment was conducted using a coal-based activated carbon (CAC, AquaSorp 2000, Jacobi, Germany), whose physical characteristics have been previously described [13] and a wastewater mixture containing all five wastewater streams (Table 1) after settling/sedimentation. The use of the sorption/filtration column was planned in such a way that the activated carbon was replaced when the reduction of COD reached 50%. At this point, the coal activated carbon was either replaced with new coal activated carbon or with coal reactivated carbon. Since reactivation is an energy-intensive process, coupled treatments that extend the lifespan of this material and reduce the treatment cost are highly desirable. The column was fed with a five-stream wastewater mixture in up-flow mode. At 50% COD breakthrough, the wastewater was collected from the top of the sorption column and used for the EC treatment studies.

### *2.4. EC reactor*

The EC reactor was designed according to the results of the preliminary study; the setup was a monopolar electrode with parallel connections in an array of four Al electrodes (Fig. 1) with surface area of 93.2 cm$^2$ and an area of 80 cm$^2$ immersed in the wastewater. A higher current density was also used (161 A m$^{-2}$). The distance between each anode and cathode was kept at 1 cm.

The current density and treatment duration were chosen from other reported experiments, including studies on wastewater with very high COD levels [14–16]. The electrodes were washed with HCl solution (15% w/v) followed by distilled water before use in each run. The experiment was performed in batch mode at room temperature (20 ± 2°C) and agitation was provided by a magnetic stirrer operating at a speed of 200 rpm with the setup conditions described in Table 2.

Table 1
Characterization (mean ± standard deviation) of the wastewater streams generated in the wooden floor factory ($n = 5$)

| Wastewater | pH | Conductivity (µS/cm) | COD (mg/L) | BOD (mg/L) | COD/BOD |
|---|---|---|---|---|---|
| Blade[a] | 12.5 ± 0.1 | 10.3 ± 1.4 | 5,890 ± 2,746 | 2,075 ± 804 | 2.9 ± 0.7 |
| Filler[a] | 7.8 ± 1.7 | 9.4 ± 1.7 | 22,460 ± 9,180 | 6,623 ± 3,969 | 3.3 ± 0.9 |
| Glue[a] | 6.2 ± 1.1 | 0.5 ± 0.2 | 19,044 ± 12,238 | 2061 ± 1,019 | 9.5 ± 2.2 |
| Hardener[a] | 1.5 ± 0.2 | 19.8 ± 1.3 | 30,600 ± 11,524 | 12,896 ± 9,696 | 3.1 ± 1.5 |
| Floor[a] | 6.9 ± 0.3 | 2.0 ± 0.4 | 4,091 ± 839 | 818 ± 273 | 5.4 ± 1.9 |
| Mixed 1:1:1:1:1[b] | 2.7 ± 0.1 | 8.4 ± 1.2 | 13,197 ± 3,743 | 3,218 ± 461 | 4.1 ± 1.2 |
| Mixed 1:1:1:1:0[c] | 10.2 ± 0.4 | 5.3 ± 1.2 | 12,795 ± 3,352 | 3,198 ± 385 | 4.0 ± 1.1 |
| Mixed 1:1:1:1:1[d] | 5.6 ± 0.6 | 3.8 ± 0.7 | 6,625 ± 212 | – | – |

[a] Untreated wastewater streams taken separately (blade, filler, glue, hardener, and floor washing).

[b] Untreated mixtures of the five wastewater streams after settling.

[c] Untreated mixtures of four wastewater streams (hardener excluded) after settling.

[d] Mixture of wastewater streams (hardener included) pretreated with coal activated carbon after settling.

Table 2
Setup conditions in the EC experiments

| Parameters (unit) | Value |
|---|---|
| Current (A/m$^2$) | 161 |
| Initial pH | 5.0 |
| Stirring (rpm) | 200 |
| Electrode material | Al |
| Anode surface (cm$^2$) | 160 |
| Cathode surface (cm$^2$) | 160 |
| Distance between electrodes (cm) | 1.0 |
| Treated volume/batch (mL) | 800 |
| Treatment time (min) | 30 |

In each test, the electrodes were placed in 800 mL of the wastewater sample. The electric power and current provided by the power supply to the electrode cells were measured with a Manson EP-601 (Hong Kong, China). All tests were carried out in triplicate, except the characterization, which was based on five sampling events. EC was carried out either before (as a pretreatment) or after (as a post-treatment) activated carbon filtration/sorption.

### 2.5. pH effect

The current density and electrode material were chosen from the literature and preliminary studies (for additional comments, see introduction). To select the most effective initial pH for EC treatment, all the wastewaters were mixed in one container in equal portions and then treated via EC for 30 min at initial pH values of 3.5, 5.0, 8.5, and 10.2. In a second step, the same experiment was carried out again, but the hardener wastewater was excluded from the mixture, since it was observed that this stream was the most difficult to treat. The mixture of four streams was also treated in the EC reactor at the same four different initial pH values of 3.5, 5.0, 8.5, and 10.2, with the last pH value being the natural value for the mixture. All pH adjustments were made with HCl or NaOH of analytical grade.

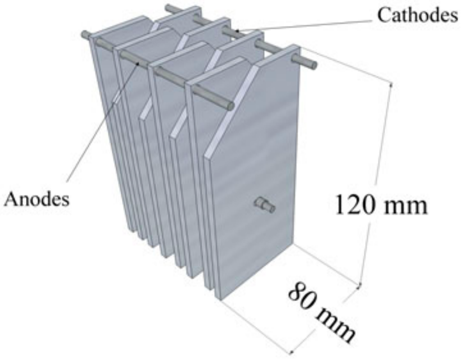

Fig. 1. EC apparatus with monopolar electrodes in parallel connection in an array of four electrodes.

### 2.6. Treatment of individual wastewater streams

All waters were allowed to settle for 30 min and the supernatant was collected for treatment with EC. The five different wastewater streams were treated in the EC reactor separately at the pH that had been found to be the most effective for the mixture (pH 5.0). During this experiment, each wastewater was treated as described in Table 2, except that 0.8 g/L of sodium chloride (NaCl) was added to the glue wastewater before each run in the EC reactor. This was done to enhance the conductivity of this wastewater, which was found to be low, following the strategy described in the literature [17].

### 2.7. COD removal by EC coupled with activated carbon sorption/filtration

The final experiment focused on the treatment of a mixture of all wastewaters by coupling EC with a sorption/filtration step. In previous investigations, EC was successfully implemented both before and after additional treatment systems [14,18,19], but EC has seldom been evaluated both before and after in the same study. Considering the complex nature of the wastewaters investigated in the present study, both strategies were taken into account. EC was tested both as a pre- and a post-treatment relative to a sorption/filtration with activated carbon. The experimental setup is described in Table 2.

#### 2.7.1. Sequencing treatment units

Different combinations of five different wastewater streams and alternative sequences of treatment steps were tested.

*2.7.1.1. EC followed by sorption/filtration.* To evaluate the effect of EC as a pretreatment to subsequent sorption/filtration, all five wastewater streams were mixed (1:1:1:1:1) and treated as shown in Table 2. To evaluate problems with the hardener wastewater stream, three more mixtures were prepared and treated as shown in Table 2. These mixtures had different ratios of hardener wastewater (0, 0.2, and 0.5).

*2.7.1.2. Sorption/filtration followed by EC.* To evaluate the effect of EC as a post-treatment following sorption/filtration, all five wastewater streams were mixed (1:1:1:1:1) and treated in a sorption/filtration column with activated carbon to achieve 50% reduction of the initial COD. The effluent was then settled for 30 min and the supernatant was collected to be treated via EC. A mixture of all wastewater streams was also diluted with distilled water to achieve 50% reduction of the COD value and then treated via EC. The objective of this control was to evaluate, if diluting the mixture to 50% of the initial COD value has the same effect on EC performance as 50% reduction of the COD value by sorption/filtration.

### 2.8. Analytical methods

COD for the wastewater samples was analyzed spectrophotometrically in Dr. Lang cuvette tests (Dr. Lang, Dusseldorf, Germany) and measured with a HACH XION 500 spectrophotometer (Hach Lange, Dusseldorf, Germany). $BOD_5$ was analyzed according to EN 1899-1:1998 [20]. Variables such as pH and conductivity were measured with a digital pH meter (WTW Multi 340i; WTW, White Plains, NY).

## 3. Results and discussion

### 3.1. Equalization and settling

There was no reduction in the COD value when the individual wastewater streams or the mixture of all streams (except hardener wastewater) were first equalized and then allowed to settle for 24 h. However, when a mixture of all five wastewater streams (this time including hardener wastewater) was equalized and then allowed to settle for 24 h, a COD reduction of 19 ± 10% was observed, relative to the initial COD value of the mixture. This result suggests that the hardener wastewater is essential for the formation of flocks and the settling of the wastewater mixture when EC is not used. The flocks that formed in the mixture, varied among replicates in terms of their quantity, size, and buoyancy, probably owing to the considerable variation in the pollutant content in the wastewater streams. This variation in the pollutant content is probably due to the washing and cleaning procedures being carried out manually and intermittently by different staff members. Sometimes, the flocks formed in manageable sizes; other times, they were very small and remained suspended in the wastewater. The variations in the wastewater quality also explain the large standard deviations in COD values after settling/sedimentation (Table 1).

### 3.2. Effect of pH

The solubility diagram for aluminum hydroxide indicates that $Al^{3+}$ is the most common species at low pH. Additionally, $Al^{3+}$ forms mononuclear and/or polynuclear aluminum complexes $Al(OH)_3$, $Al(OH)_2^+$, and $Al_2(OH)_4^+$ at pH ranging from 4 to 8. At higher pH, $Al(OH)_4^-$ becomes the dominating species and this form of Al does not coagulate the pollutants [21]. In the present investigation, pH 5.0 was found to be the most effective for COD removal from the mixture of the wastewater streams both before and after treatment via activated carbon sorption/filtration.

### 3.3. EC treatment of the five individual wastewater streams

In this study, COD reduction through EC treatment of the individual wastewater streams varied from 2% for hardener wastewater (the stream with the highest initial COD) to over 75% for blade wastewater (Table 3). According to the literature on EC performance, the COD removal efficiency for different types of industrial wastewater varies from 20 to 99% (Table 4).

The variability found in the EC efficiency of COD removal reflects the large variation in composition among different cleaning wastewaters generated in the same industry. Moreover, the final organic load reduction for COD removal from the different wastewaters treated individually, when added in terms of total mass, was about 18%. This value is in the same range as the removal achieved when all wastewaters were treated as a mixture, suggesting that there is no advantage in treating the streams separately. However, the EC efficiency in treating mixtures containing different ratios of hardener (from 0 to 20%) suggests that this stream in particular interferes with the treatability of the mixture by EC (Table 5).

The decision to characterize the washing/cleaning wastewater mostly in terms of the proxy indicator COD in treatability studies is based on the high complexity of these wastewaters and the presence of hundreds of different substances that require chemical oxidation. This complexity makes it difficult to determine what compounds are resistant to EC and what factors prevent further development of the process

Table 3
COD reduction after individual treatment via EC for 30 min (initial pH = 5; $n = 3$)

| Type of wastewater | COD reduction ± SD (%) |
|---|---|
| Glue wastewater | 22 ± 0.8 |
| Hardener wastewater | 2 ± 0.5 |
| Filler wastewater | 15 ± 0.4 |
| Blade wastewater | 77 ± 2.9 |
| Floor wastewater | 44 ± 1.4 |

Table 4
COD reductions achieved with EC applied to highly polluted wastewaters, based on the literature and the present study

| Type of wastewater treated with EC | COD red (%) | Initial COD (mg $L^{-1}$) | Source |
|---|---|---|---|
| Petroleum refinery wastewater | 63 | 596–4,050 | [21] |
| Poultry manure wastewater | 90 | 1,190–2,490 | [11] |
| Olive mill wastewater | 34 | 36,900 | [18] |
| Effluent from gluing process | >70 | 13,068 | [5] |
| Vegetable oil refinery wastewater | 99 | 15,000 | [22] |
| Black liquor from paper industry | 98 | 7,960 | [4] |
| Ethanol manufacturing wastewater | 20–40 | 15,600 | [23] |
| Leachate from landfills | 30–50 | 1,134–4,979 | [24] |
| Laundry wastewater | 62 | 226 | [14] |
| Potato chips manufacturing wastewater | 60 | 2,200–2,800 | [25] |
| Textile wastewaters | 75 | >1,600 | [26] |
| Five streams in wooden floor industry | 0–77 | 4,000–31,000 | This study |

Table 5
COD removal (%) by 30 min of EC treatment applied to a wastewater mixture with different proportions of hardener wastewater and initial pH 5.0

| Ratio[1] | 1:1:1:1:0 | 1:1:1:1:0.2 | 1:1:1:1:0.5 | 1:1:1:1:1 |
|---|---|---|---|---|
| Additional COD removal after 30 min EC treatment compared with 30 min of settling | 21 ± 0.2 | 5 ± 0.4 | 3 ± 0.3 | 0 ± 0.5 |
| Additional COD removal after 30 min EC treatment compared with 24 h of settling | 21 ± 0.2 | 4 ± 0.5 | –1 ± 0.2 | –6 ± 0.3 |

[1] Blade: Filler: Glue: Floor: Hardener wastewater ratios.

efficiency. The list of compounds mentioned as a problem for EC includes acetic acid and ethylenediaminetetraacetic acid [22]. Ethylenediaminetetraacetic acid is a component in some cleaning products used to wash machinery, surfaces, and floors in the wooden floor and wooden furniture industries. However, preliminary studies [12] showed that the component was unlikely to be present at the specific site in Nybro, Sweden. Acetic acid, on the other hand, can be present in hardener and could be one reason for the EC treatment limitations observed [22].

### 3.4. EC coupled to sorption/filtration with activated carbon

The investigation now focuses on mixed wastewaters, since the mixing of wastewaters is the most beneficial strategy from an operational viewpoint.

#### 3.4.1. Sequencing: the effect of positioning the EC unit before or after the sorption/filtration unit

It was demonstrated that the hardener wastewater had an inhibitory effect on the EC process, either when the hardener wastewater was treated individually (Table 3) or when mixed with other wastewater streams (Table 5, Fig. 2). Even with very small volumes of hardener wastewater added, the reduction of the COD value by EC was negligible (Table 5). On the basis of these results, the hardener wastewater stream was excluded from the EC treatment when EC was sequenced before the sorption/filtration step (Fig. 2).

When a mixture of the four remaining wastewaters streams was treated by EC for 30 min, the COD was reduced from 12,795 ± 3,352 to 10,395 ± 2,576 mg $L^{-1}$ (about 20%). This result is very similar in terms of percentage of COD reduction (but different in terms of final concentration) to the reduction achieved by simply mixing all five streams and settling for 24 h (from 16,417 ± 4,481 to 13,197 ± 3,743 mg $L^{-1}$).

In the second approach, the EC treatment was sequenced after the sorption/filtration step, with the aim to extend the lifetime of the activated carbon. The mixture of all five wastewater streams (1:1:1:1:1) was left for settling/sedimentation and then treated with activated carbon in the sorption/filtration column, to the point that 50% COD reduction was achieved. This effluent was then treated for 30 min by EC, applying the setup described in Table 2. The EC treatment achieved an additional reduction of the COD value of about 21–25%, excluding the case of initial pH 10.2

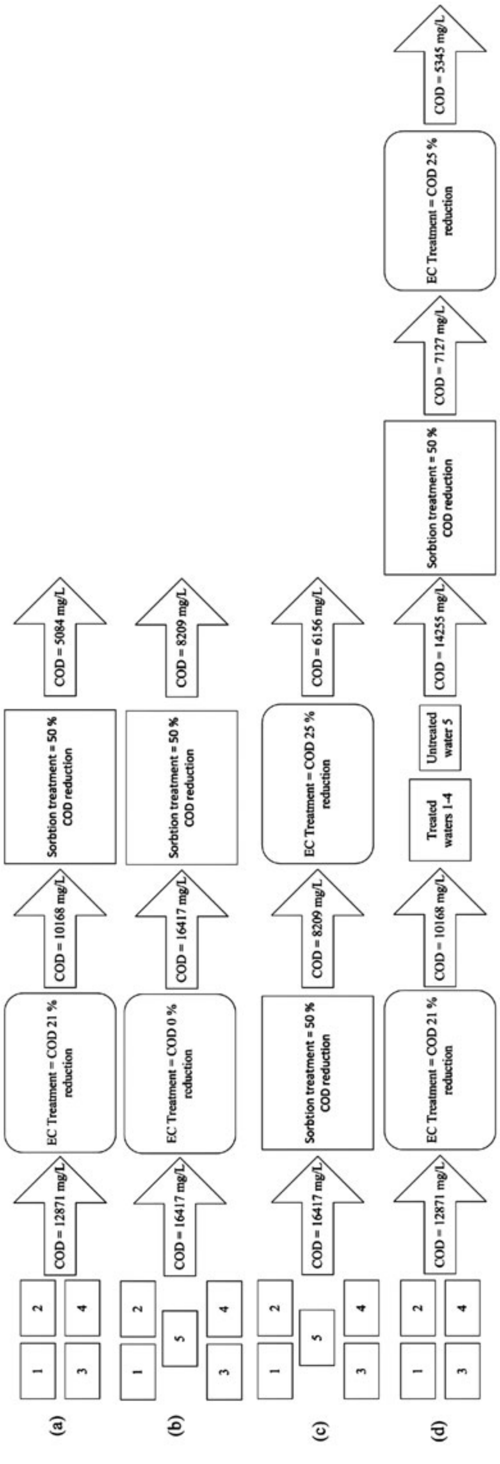

Fig. 2. Different sequence strategies to treat mixtures of five wastewater streams: in (a) and (d) the hardener wastewater was excluded from the initial mixture; in (b) and (c) it was included. In (d), the hardener wastewater was added after EC, before sorption treatment.

(Table 6). The COD reduction of 25% employing EC after the sorption/filtration step was achieved with a mixture that included the hardener wastewater stream (Table 6). When these processes were combined into one sequence, an overall average removal of 71% of COD was achieved and a quick, consistent treatment process was realized.

These results show clearly that the different sequencing of treatments produces quite different results. Sorption/filtration can remove specific inhibiting pollutants and allow EC to work. To investigate the nature of this effect, a mixture of all five wastewater streams was diluted to achieve 50% of the original COD value (the same COD reduction obtained with sorption/filtration). This diluted mixture was then treated with EC for 30 min, which resulted in negligible COD reduction. The results confirm that compounds in the wastewater that originally inhibited the EC process are removed by sorption/filtration.

One possible substance is acetic acid, which is a component of the hardener and is known to interfere with EC [22]. This also confirms previous reports, which have shown that it is not the concentration of the pollutants that affects the effectiveness of the EC process, but the chemical characteristics of the compounds in the wastewater [21]. If EC is to be employed before the sorption/filtration step with this mixture of wastewaters, benefits other than COD reduction must be found (Table 5). In this and some other studies [5,7], it has been observed that the EC process continuously produces flocks that are easy to handle, since the production of hydrogen bubbles helps to float and aggregate them. Less sludge is also produced compared with chemical flocculation for similar reductions in the COD value [7]. The easily manageable flocks form consistently, even if the ratio of the incoming waters is not perfectly maintained. Such a property is highly desirable in full-scale treatment plants that receive wastewater generated by manual procedures with variable quality, and because of this feature alone, EC treatment might be considered advantageous over other systems that are more sensitive to fluctuations in the inflow quality. Another benefit of implementing EC is the shorter retention time and smaller space required, compared with other treatment options.

### *3.5. Onsite treatment options and future research*

This study has illustrated how a relatively simple onsite coupled system for treating cleaning/washing wastewaters generated intermittently in low volumes by wood-based dry industries can effectively reduce the organic pollutant load sent to the municipal

Table 6
COD removal (%) by EC applied before and after activated carbon sorption/filtration treatment. Mixtures with and without hardener wastewater

| | EC applied before sorption/filtration, excluding hardener wastewater | | EC applied after sorption/filtration, including hardener wastewater | |
|---|---|---|---|---|
| | 8 min | 30 min | 8 min | 30 min |
| pH 3.0 | 17 ± 0.4 | 21 ± 0.4 | 21 ± 0.3 | 23 ± 0.4 |
| pH 5.0 | 19 ± 0.4 | 21 ± 0.2 | 22 ± 0.2 | 25 ± 0.3 |
| pH 8.0 | 13 ± 0.3 | 21 ± 0.4 | 22 ± 0.4 | 24 ± 0.5 |
| pH 10.2 | 9 ± 0.1 | 14 ± 0.3 | 13 ± 0.3 | 16 ± 0.2 |

wastewater treatment plant (MWWTP). Considering the large number of industries that generate these types of wastewaters, an onsite treatment strategy that provides an alternative to the current strategy of dilution with potable water would be an important step forward. Most MWWTPs are not designed to handle industrial wastewater [23] and the majority of recalcitrant pollutants that do not biodegrade easily will be simply diluted and discharged into recipient water bodies. Another major problem raised by the discharge of industrial wastewaters to the MWWTP is the handling of sludge. The use of sludge from MWWTP as a fertilizer source is a sustainable strategy [24] for the agriculture sector [25–27], provided that the sludge is quality controlled from both sanitary and chemical viewpoints. Toxic metals and persistent organic compounds in sludge make it improper for agriculture use [28]. Regarding further improvements, additional tests with other electrode materials with a focus on better overall COD reduction by the EC are recommended. Steel and graphite, for instance, have worked well with wastewater from other wood-based industries [29]. Advanced oxidative processes combined with EC have also been demonstrated to be successful for some wastewaters [15,30,31], and investigations in this direction could be carried out.

## 4. Conclusions

- EC is useful as a pretreatment, but mostly as a post-treatment, in a coupled system with sorption for treating highly polluted wastewater streams generated by cleaning and washing surfaces and machinery in the wooden floor industry.
- The EC treatment requires very short retention time and produces easily manageable flocks, even when the composition of the influent is not constant, which is particularly the case for wastewaters generated intermittently by manual procedures.
- One of the wastewater streams (hardener wastewater) typically produced by the wooden floor and wooden furniture industries inhibits the EC treatment, even in small proportions in mixtures with other wastewater streams. However, such inhibition disappears if the mixture containing hardener wastewater is first treated via sorption/filtration with activated carbon. When applying EC in both sequences (before and after sorption/filtration), a treatment efficiency of 71% total COD removal was achieved. The results suggest that sorption/filtration with activated carbon removes chemical compounds in the wastewater responsible for the low-EC performance. A candidate compound might be acetic acid, a component found in hardener that is known to interfere with EC.
- Onsite treatment of low volumes of highly polluted wastewaters combining easy-to-manage and fast treatment units provides relevant environmental advantages that justify the search for relatively low-cost, effective treatment strategies.

## Acknowledgments

The financial support to the research project from the Swedish Knowledge Foundation (KK-Stiftelsen), the European Regional Development Fund, and the industry AB Gustaf Kähr are acknowledged.

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