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REDUCING THE ENVIRONMENTAL IMPACT OF TEXTILE INDUSTRY BY REUSING RESIDUAL SALTS AND WATER: ECUVAL SYSTEM

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Abstract

The textile industry is one of the largest consumers of water in the world and its wastewater constitutes a serious problem when it is discharged without the proper treatment. Different techniques are being applied for treating textile effluents. But, as far as we know, none of them consider the reuse of the clarified effluents.

In this work, a recently developed wastewater system named ECUVal is proposed to treat and subsequently reuse the effluents generated by the dyeing process of a textile mill, which usually have high dyes and salt content. With this system, a reduction of water and salt consumption is achieved and simultaneously the volume of discharged effluents is also reduced.

The ECUVal system is based on an electrochemical treatment assisted by UV irradiation. The system is able to remove colour completely. Colour removal efficiencies between 64-99% were obtained depending on the intensity applied. Moreover, the treated effluents are reconstituted in the system to be reused in new dyeing processes. Thus, 70% of water and up to 72% of salt reuse was achieved. The chromatic coordinates of fabrics dyed with the treated effluent were evaluated with respect to reference ones. Dyeings performed with reused effluents were in general into the acceptance limit of the textile industry ($DE_{CMC(2:1)} \leq 1$).

Finally, the environmental impact of the wastewater treatment currently performed in the textile companies was compared with respect to the ECUVal treatment by means of life cycle assessment. It was concluded that the use of the system reduces significantly the environmental impact of the textile industry.

Keywords: textile wastewater; effluent and salt reuse; electrochemical treatment; UV irradiation, life cycle assessment; environmental impact

1. Introduction

Textile industry is one of the most important manufacture industries in developing countries [1]. It is known to be a water intensive sector (200-400 L per kg of finished product) [2] and consequently, it produces high amount of polluted wastewater whose composition depends mainly on the textile process and type of fibre used [3].

Cotton is one of the most consumed natural fibre worldwide, with a production that reached 24.5 million tonnes in 2013 [4]. Although different class of dyes can be applied to dye cellulosic fibres, reactive dyes are the most common due to their high washing fastness values and great variability of colours [5,6]. The main drawback of reactive dyes is that, in order to ensure the fixation of the dye onto the fibre, the dyeing process must be carried out in alkaline medium and it also requires the addition of high amount of inorganic electrolyte, generally NaCl or Na_2SO_4 [7–9]. The concentration of electrolyte varies between 0.6-0.8 kg salt/kg fibre, depending on the dye structure, shape and dyeing procedure [5,8].

Currently, textile wastewater is treated by means of biological and/or physico-chemical processes. Conventional biological treatments provide good organic matter removal, but their efficiency in discolouration is low due to the chemical stability and resistance to microbiological attack of dyes [10,11]. Among physico-chemical treatment, the most used is the coagulation-flocculation, which can remove completely the colour. However, this treatment not only requires the addition of chemical coagulants, but it also generates a sludge which subsequently must be treated [12,13]. It should be noted that although these methods are able to meet the current regulations requirements, they do not enable the treated effluents to be reused in new productive processes [14]. Moreover, neither the biological treatments nor the physico-chemical processes are able to remove salts, one of the major problems of the textile effluents.

In the last years, Advanced Oxidation Processes (AOPs) are of great interest, especially the electrochemical processes due mainly to their versatility, safety, simplicity of automation and low investment cost [15]. The electrochemical oxidation of dyes can be carried out directly on the anode surface or indirectly using electro-generated oxidant species, such as chlorine or hypochlorite, according to equations (1)-(3) [16–19].

$$2Cl^- \rightarrow Cl_{2(aq)} + 2e^- \qquad (1)$$

$$Cl_{2(aq)} + H_2O \rightarrow HClO + Cl^- + H^+ \qquad (2)$$

$$HClO \leftrightarrow H^+ + ClO^- \qquad (3)$$

The efficiency of the electrochemical process depends on the nature of anode material. In general, it has been stated that anodes with low oxygen evolution overpotential

(IrO_2, RuO_2 or Pt) provide partial and selective oxidation of pollutants whereas anodes with high oxygen evolution overpotential (SnO_2, PbO_2 or boron-doped diamond) are more efficient to mineralise the organic matter [20,21]. In the case of colour removal in presence of NaCl as electrolyte, higher decolouration rates are obtained with Ti/Pt electrodes than with Ti/SnO_2-Sb-Pt. This fact could be attributed to the different electrocatalytic activity of both electrodes towards the reaction of chlorine generation [22].

In general, colour removal is faster than total organic carbon (TOC) removal, due to the rapid attack of chromophore group of the molecule [23–25]. Previous studies have demonstrated that the efficiency in colour removal mediated with electro-generated active chlorine can be enhanced by UV light irradiation. The effect of UV irradiation is explained in terms of the activation of chlorine oxidants by production of highly efficient radical, according to equations (4)-(5).

$$ClO^- + h\nu \rightarrow O^{-}\cdot + Cl\cdot \qquad (4)$$

$$O^{-}\cdot + H_2O \rightarrow OH^- + \cdot OH \qquad (5)$$

As it has been mentioned above, the dyeing process with reactive dyes requires high amounts of electrolyte to fix the dye onto the fibre. Therefore, wastewater from this process is suitable to be treated by means of electrochemical treatment using the electrolyte already present in the effluent to generate the oxidant species [26].

The aim of this work is to study the feasibility of the ECUVal system to treat textile industrial effluents. The system is based on the combination of an indirect oxidation processes with UV irradiation. European Commission elaborated in 2003 the “Reference Document on BAT for the Textiles Industry” that recommends the segregation of the effluents containing poorly biodegradables compounds such as dyes [27]. Following this recommendation, in this study the effluents from the dyeing process with reactive dyes were separated and treated with the system in order to either improve the subsequent biological treatment or to reuse the treated effluent and salt in new productive processes. Consequently, after the degradation of dyes, the effluents were reused in new dyeing processes. Fabrics dyed with the reused effluent were evaluated respect to references carried out with the usual dyeing method (using softened tap water). Finally, Life Cycle Assessment (LCA) was used to quantify the environmental improvement of applying the system in the treatment of textile effluents. As the ECUVal system is designed both for the wastewater treatment and for the reuse of the treated water in new dyeing processes, both alternatives were evaluated in LCA study.

2. Materials and Methods

2.1. ECUVal system description

The ECUVal system is mainly based on applying an electrochemical technique assisted by UV irradiation (Figure 1) to treat 4m^3/h of industrial wastewater with strong colouration and high salt content.

The electrolytic cell is constituted by electrodes made of titanium covered with ruthenium and iridium oxides, with an active surface of 0.6 m^2. The system is also equipped with an UV lamp (DTS 25/960-110NNI – UV Consulting Peschl) both to increase the efficiency in decolourisation and to remove the residual oxidants.

A more complete description of the ECUVal system can be consulted in the corresponding granted patent [28].

Figure 1. ECUVal system

The system has been designed as a result of the Eco-innovation project ECO/13/630452 and according to previous results obtained at laboratory scale. This study achieved up to 100% of colour removal. The effluent reuse study showed that 70% of uncoloured effluents could be reused in new dyeing processes, which also provided the reuse of 64% of salt [29].

The system can operate in two modes: (1) decolouration or (2) reuse. In the first one, the system acts as alternative to the tertiary treatments currently applied to remove colour. In reuse mode, after the decolouration of the effluents, a reconstitution step is carried out in order to prepare the effluent for its reuse in a new dyeing process.

For the decolouration mode, three reactive exhausted dyebaths with different characteristics (colour and conductivity) were treated with the system. A Spanish textile mill supplied the 3 industrial effluents, which were collected from the jet dyeing process.

For the reuse mode, the uncoloured effluents were then reused in new dyeing processes after a reconstitution step (Figure 2).

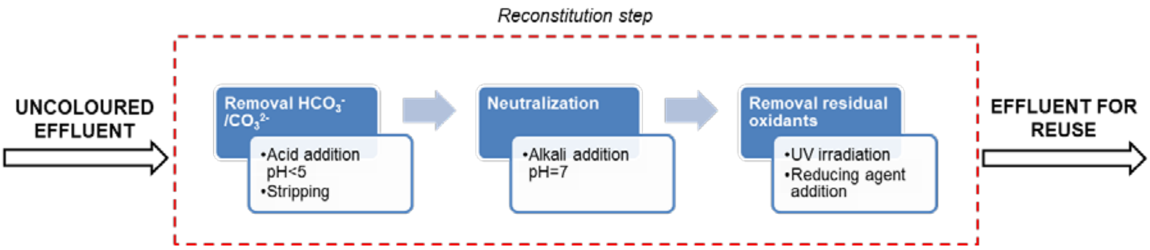

Figure 2. Reconstitution step of the ECUVal system

The reuse mode validation was carried out with four reactive dyes: Ultra Yellow Remazol RGBN (referred as Yellow), Deep Red Remazol RGB (Red), Navy Intrafix DSB (Navy), and C.I. Reactive Black 5 (Black). Figure 3 shows the structure of Black. The structures of the other dyes have are not available, as they have not been already published.

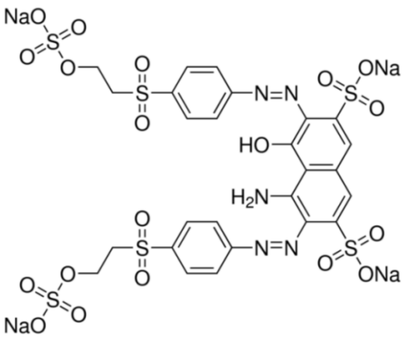

Figure 3. Chemical structure of C.I. Reactive Black 5

2.2. Chemicals

Sodium bisulphite (40%), hydrochloric acid (37%) and sodium hydroxide (98.5%) were used in the reconstitution step of the effluents. In addition, sodium carbonate (100%) and sodium chloride were used in the effluents reuse study.

2.3. Reuse Procedure

The reuse dyeing tests were performed in a laboratory Ti-Color dyeing machine (Integrated Color Line) under the following conditions (Table 1):

Table 1. Reuse study conditions

Dye	Concentration (% over weight of fibre)	Liquor ratio*
Yellow	2.0	1/12
Red	2.0	1/12
Navy	2.0	1/12
Black	5.0	1/12
Trichromie 1 (Yellow + Red +Navy)	1.0 (each dye)	1/12
Trichromie 2 (Yellow + Red +Navy)	1.5 (each dye)	1/12

**Liquor ratio 1:12 (1 kg fibre/12 L dye bath)*

The all-in dyeing method, in which all reagents are introduced in the dyeing liquor at the beginning of the dyeing process, was selected for this study. In addition to the required amount of dye, 70 g·L^{-1} NaCl and 20 g·L^{-1} Na_2CO_3 were used. The dyeing and subsequent washing procedures are shown in Figure 4.

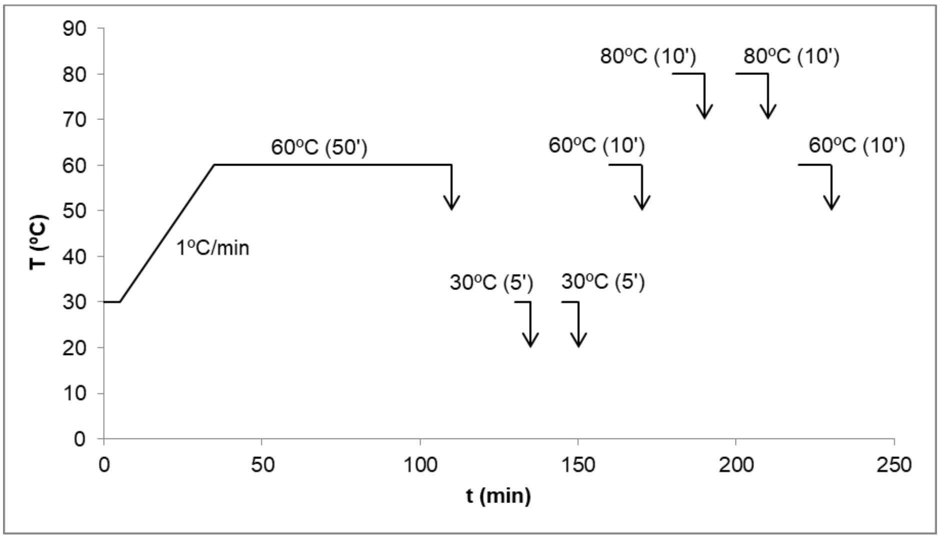

Figure 4. Dyeing method (0-120 minutes) and successive washing steps

As can be observed, after the dyeing process six washing steps are carried out with softened tap water to remove the dye that is not fixed onto the fibre.

2.4. Analytical Methods and Measurements

2.4.1. Effluents characterization

The total organic carbon (TOC) of the effluents was determined according to UNE-EN 1484:1998 [30]. The conductivity was measured following the method 2510 B [31] with a conductivity meter GLP31 (CRISON). The pH was determined according to the method 4500 H^+B [31] using a pH meter GLP21 (CRISON). The determination of Cl^- was carried out with Ion Chromatography ISC-1000 (Dionex) (method 4110B) [31].

2.4.2. ECUVal system efficiency

The decolouration efficiency of the system was followed by spectroscopic analysis and calculated from the initial absorbance (A_i) and absorbance at time t (A_t). The absorbance was determined with a UV–visible spectrophotometer (UV-2401, Shimadzu Corporation) at the maximum wavelength of the visible spectrum. The decolouration rate was expressed in % according to the following equation:

$$\%Colour\ Removal = \left(\frac{(A_i - A_t)}{A_i}\right) \cdot 100$$

For the reuse mode validation, the chromatic coordinates of each fabric were measured using a spectrophotometer Macbeth Color Eye 7000, with illuminate D65 and 10º standard observers. Then, the quality of fabrics dyed with the reused effluents, was determined by means of the colour difference parameter ($DE_{CMC(2:1)}$) following the UNE-EN ISO 105-J03 [32]. A dyeing was considered acceptable when the $DE_{CMC(2:1)}$ value was lower than 1

2.5. Environmental assessment

To determine the environmental impact of the ECUVal system, Life Cycle Assessment (LCA) was performed according to ISO 14040 standards. The Ecoinvent 3.1 database was used to compile a comprehensive and comparable inventory. LCA software used for this analysis was Simapro 7.3.3. The methodology used to calculate the environmental impact was ReCiPe, midpoint and endpoint approach, Hierarchist perspective.

The main objective of this section is to evaluate the environmental impact of the system on the wastewater treatment plant of the textile company. With this objective, the selected functional unit was “1000 m^3 of uncoloured effluent”.

The data used were mainly provided by the textile mill, although some data correspond to experimental results of analysis carried out at laboratory scale.

The flow diagrams and the assumptions made specifically in each scenario are explained below.

Scenario 1: Current wastewater treatment

The company selected for this study generates mainly two types of wastewater: (1) coloured and saline effluents from the reactive dyeing process and (2) effluents from other processes, slightly coloured or colourless, with lower salt content. A combination of an aerobic biological treatment with activated sludge and a tertiary treatment to remove colour is currently applied to treat the global effluents. The efficiency of the biological treatment required to meet discharge regulation (maximum COD: 1.5 kg/m^3) is 90%. On the other hand, 80% of the amount of decolourising reagent added in the tertiary treatment is required to treat the effluents from the Jet dyeing process.

The flow diagram of the process and the boundaries considered are shown in Figure 5.

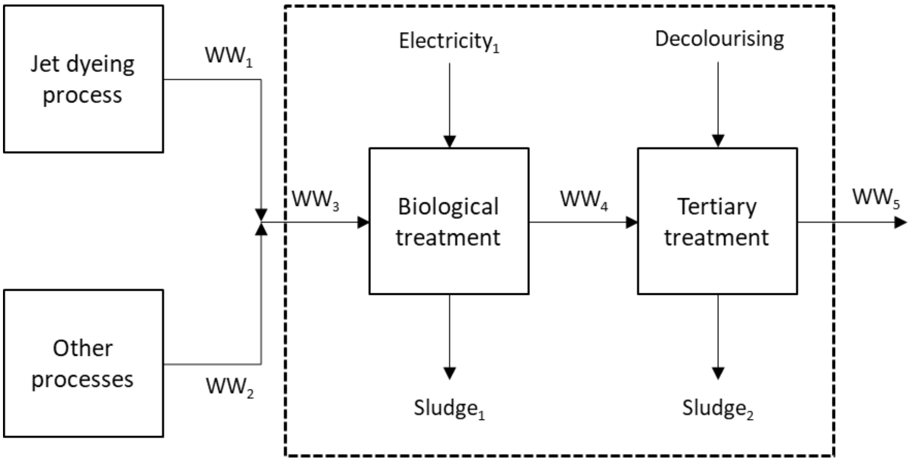

Figure 5. Schema of scenario 1: Current wastewater treatment

Scenario 2: ECUVal system to decolourise

This scenario evaluates the impact on the wastewater treatment plant associated to the discharge of wastewater with less colouration thanks to the use of the new system (Figure 6).

This process involves three steps:

a) The ECUVal system at 100 A is applied to decolourise the effluents generated in the reactive jet dyeing process. The system is also able to remove 10% of organic matter of the effluent treated during the decolourisation step (verified in the laboratory tests).

b) Then, the former effluent joins the remaining effluents of the company. A biological treatment with activated sludge process is applied to degrade the organic compounds contained in the global wastewater (uncoloured effluents from the system + wastewater from the other processes). As the system is able to reduce 10% of organic matter content of the Jet uncoloured effluents, the biological treatment requires lower electricity consumption to provide a wastewater with 1.5 kg COD /m^3.

c) Finally, a tertiary treatment is carried out to remove residual colour that is not eliminated with ECUVal system or with biological treatment. In this scenario, the decolourising reagent needed for the final wastewater treatment is estimated to be 35% lower than in scenario 1.

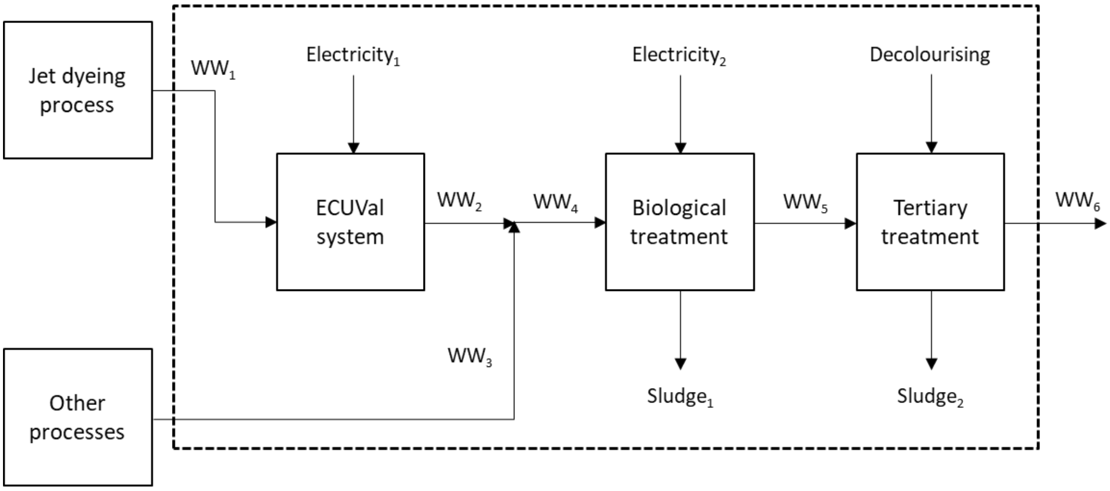

Figure 6. Schema of scenario 2: ECUVal to decolourise

Scenario 3: ECUVal system to reuse water and salts

In this scenario 3, the system is applied both to decolourise the reactive Jet dyeing effluents and to reuse water and salt in new dyeing processes. Consequently, only the wastewater generated in other processes must be treated in the wastewater treatment plant.

The scenario 3 consists of two steps (Figure 7):

a) Aerobic biological treatment with activated sludge of other effluents (not including the reactive Jet dyeing effluents).

b) Tertiary treatment to remove the residual colour of the wastewater once treated in the biological plant. The decolourising reagent needed for this additional treatment is 80% lower than in the case of scenario 1 since the most coloured wastewater are treated and reused by the system. Consequently, these effluents are not discharged to the wastewater treatment plant.

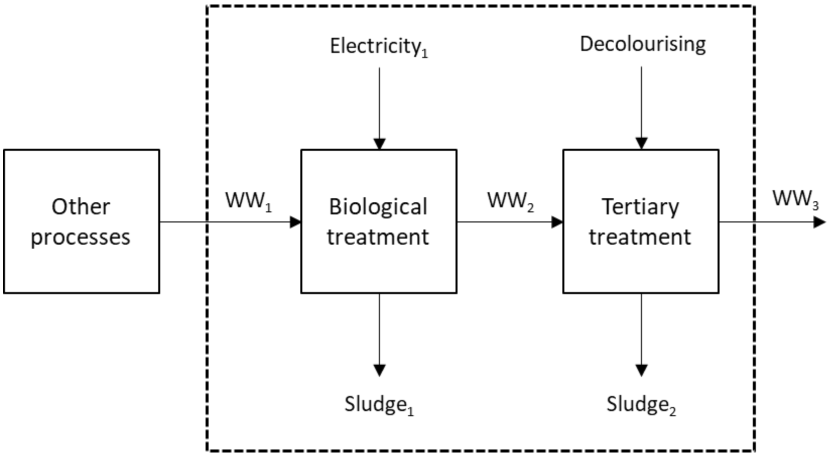

Figure 7. Schema of scenario 3: ECUVal system to reuse water and salts

3. Results and Discussion

3.1. Effluents characterization

Three exhausted reactive dyebaths from Jet dyeing process were collected and characterized before the ECUVal treatment (Table 2). They correspond to different type of reactive dyes and production periods. Their characteristic parameters vary according to the dyeing conditions and the type of fibre/fabric. However, it can be seen that in general the effluents generated in Jet dyeing process are characterized by alkaline pH, rather low TOC values and high conductivity mainly due to the presence of chloride salts.

Table 2. Effluents characterization before the treatment

	I	II	III
pH	9.6	9.9	10.4
Conductivity (mS/cm)	50.0	87.3	80.2
TOC (mg/L)	141.9	86.1	66.5
Cl^- (g/L)	21.2	39.1	33.8
Absorbance at λ_{max}	11.200	0.290	0.269

	(576 nm)	(404 nm)	(569 nm)

Besides conductivity and pH, the concentration of chloride ions is also an important parameter when an indirect electrochemical treatment using electro-generated oxidant species is applied. The higher the concentration of chlorides, the greater the efficiency of the electrochemical treatment [16]. According to our experimental studies in the company, when NaCl is the only electrolyte in the effluent, the minimal concentration to achieve successful results is 7.5 $g \cdot L^{-1}$ Cl^{-}. On the bases of these studies and considering the results showed in Table 3, it can be stated that the three effluents selected for this study are suitable to be treated with the system.

3.2. ECUVal system: Decolouration mode

In order to establish the efficiency of the system and the optimal working conditions, the effluents were decolourised at different intensities (Table 3), which were selected according to colour and conductivity of the effluent. Previous studies published by our research group demonstrated no significant influence of pH on decolourization rate under neutral and alkaline conditions (the common conditions of reactive dye effluents) [33].

Table 3. Colour removal obtained with the system (Anode area: 0.6 m^2, flow rate: 4 m^3/h)

Effluent	Intensity (A)	Colour removal (%)
I	800	99.8
	400	99.7
	200	98.6
	100	64.1
II	100	84.2
	25	64.2
III	100	98.8

	25	66.2

As a result of the ECUVal treatment, colour removal values between 64 and 99% were obtained, which overcomes the established acceptance criteria (colour removal ≥ 60%). As it was expected, increasing the intensity resulted in a greater colour removal. Although the system does not have as a purpose the reduction of organic matter, the treatment also provided up to 10% of organic matter removal.

In addition to the decolourisation rate, the amount of residual oxidants at the end of the treatment is a key factor when the effluent is reused in new productive processes since they must be removed. Consequently, it is important to select an intensity value as low as possible to ensure the economic viability of the treatment, but higher enough to achieve the required decolourisation rate.

3.3. ECUVal system: Reuse mode

The uncoloured effluents were reused after a reconstitution step to perform new dyeing processes. Fabrics were dyed using 30% softened tap water and 70% of the decoloured and reconstituted effluents.

Previous studies published by our research group focused on electrochemical decolourization of reactive dyeing effluents and the subsequent reuse, enabled us to verify that the concentration of organic matter does affect the quality of dyed fabrics ($DE_{cmc2:1}$ <1). It was found that the organic matter content stabilizes from the 3rd to 4th reuse steps as a consequence of the addition of 30% softened tap water and 10% organic matter removal obtained by the electrochemical treatment [26,34].

The reconstituted effluents also contain high concentration of NaCl that is reused in the new dyeing (Table 4). Thus, when 70% of the treated effluents are reused, the system enables to save up to 72% NaCl, depending on the difference between the electrolyte content of new dyeing and the former exhausted dyebath. For the calculation of NaCl savings, it was considered that the new dyeing process is carried out with 70 $g \cdot L^{-1}$.

Table 4. Saving of NaCl

Effluent (70%+30% decalcified water)	Residual NaCl concentration (g/L)	NaCl added (g/L)	Saving NaCl (%)
I	20.0	50.0	28.6
II	50.4	19.6	72.1
III	38.6	31.3	55.2

After the dyeing, washing and drying processes, textiles were subsequently evaluated with respect to a reference dyed with 100% softened tap water (Table 5).

Table 5. Colour difference obtained in the reuse study

	Yellow	Red	Navy	Black 5	Trichromie 1	Trichromie 2
I (800 A)	0.70	0.36	0.78	0.43	0.64	0.82
I (400 A)	0.37	0.72	0.61	0.97	0.72	0.90
I (200 A)	0.72	0.88	0.90	0.82	0.91	0.97
I (100 A)	0.72	0.59	0.30	0.69	1.03	1.09
II (100 A)	0.97	0.81	0.87	0.22	0.35	0.92
II (25 A)	0.27	0.41	0.87	0.22	0.46	0.72
III (100 A)	0.97	0.81	0.87	0.22	0.35	0.92
III (25 A)	0.46	0.52	0.24	0.27	0.79	0.25

According to Table 5, all monochromies and trichromies met the acceptance criteria established ($DE_{cmc(2:1)}$ lower than 1). In the case of trichromies, acceptable colour differences were obtained in all reuses except for the effluent I treated at 100A. It should be noted that the textile mill selected for this study has a quality standards very severe and the colour acceptance criterion established in this study ($DE_{CMC(2:1)} \leq 1$) is very strict. Hence, results are considered fully satisfactory.

The tests carried out in this work have enabled to demonstrate the viability of the system to both decolourise and reuse textile effluents at industrial scale. This new system achieves to remove about 100% of colour and to reuse 70% water and up to 72% NaCl. Consequently, the use of the new system provides significant economic and environmental advantages with respect to the methods currently applied.

The environmental impact associated to the application of the system in the textile sector has been studied and quantified by means of LCA study. The main results are explained in the next section.

3.4. Environmental impact

On the bases of results exposed in the previous sections, it can be concluded that the application of the ECUVal system shows clear environmental advantages with respect to the treatment currently applied to treat textile wastewater. In order to quantify the benefits of the system, LCA study has been carried out to compare the current treatment with the use of the system operating in its two modes (see section 2.6).

In this section, the results obtained for the inventory analysis as well as the environmental impact of the different scenarios selected for this study are presented.

3.4.1 Inventory results

The inventory result for each scenario is shown in Table 6-Table 8. All data are related to the functional unit (1000 m^3 uncoloured effluent).

Although the amount of sludge generated in both biological and tertiary treatments has been quantified and presented in the following tables, Simapro software does not consider the impact of the sludge so its impact could not be quantified.

Table 6. Inventory analysis of scenario 1 according to Figure 5 (current wastewater treatment)

Processes included in LCA		**Amount**	**Unit/FU**	**Ecoinvent unit process**
Biological treatment				
Inputs	WW_3	1000	m^3	
	COD	1500	kg	
	$Electricity_1$	3500	kWh	Electricity, medium voltage, production ES, at grid/ES U
Outputs	WW_4	1000	m^3	
	COD	150	kg	
	$Sludge_1$	900	kg	
Tertiary treatment				
Inputs	WW_4	1000	m^3	
	COD	150	kg	
	Decolourising	1000	kg	DTPA, diethylenetriaminepentaacetic acid, at plant/RER U
Outputs	WW_5	1000	m^3	
	COD	150	kg	
	$Sludge_2$	500	kg	

Table 7. Inventory analysis of scenario 2 according to Figure 6 (ECUVal to decolourise)

Processes included in LCA		**Amount**	**Unit/FU**	**Ecoinvent unit process**
ECUVal system				
Inputs	WW_1 COD	67.2 139.8	m^3 kg	
	$Electricity_1$	142.5	kWh	Electricity, medium voltage, production ES, at grid/ES U
Outputs	WW_2 COD	67.2 125.8	m^3 kg	
Biological treatment				
Inputs	WW_4 COD	1000 1487.7	m^3 kg	
	$Electricity_2$	3471.3	kWh	Electricity, medium voltage, production ES, at grid/ES U
Outputs	WW_5 COD	1000 150	m^3 kg	
	$Sludge_1$	892.2	kg	
Tertiary treatment				
Inputs	WW_5 COD	1000 150	m^3 kg	
	Decolourising	520	kg	DTPA, diethylenetriaminepentaacetic acid, at plant/RER U
outputs	WW_5 COD	1000 150	m^3 kg	
	$Sludge_2$	260	kg	

Table 8. Inventory analysis of scenario 3 according to Figure 7 (ECUVal to reuse water and salts)

Processes included in LCA		Amount	Unit/FU	Ecoinvent unit process
Biological treatment				
Inputs	WW_1 COD	1000 1460	m^3 kg	
	$Electricity_1$	3406.7	kWh	Electricity, medium voltage, production ES, at grid/ES U
Outputs	WW_2 COD	1000 150	m^3 kg	
	$Sludge_1$	876	kg	
Tertiary treatment				
Inputs	WW_2 COD	1000 150	m^3 kg	
	Decolourising	200	kg	DTPA, diethylenetriaminepentaacetic acid, at plant/RER U
Outputs	WW_3 COD	1000 150	m^3 kg	
	$Sludge_2$	100	kg	

3.4.2. Environmental impact assessment

In this section, the environmental impact of each scenario is discussed. Finally, a comparison of the three studied scenarios is carried out.

Scenario 1 (current wastewater processes)

First of all, the impact of the current wastewater treatment (Scenario 1) has been evaluated. In order to compare the different categories, the results are expressed in points (Pt). As can be seen in Table 9, the process currently carried out has the major impact on Resources followed by Human health, whereas the effect on Ecosystems is much lower.

Table 9. Environmental impact of scenario 1 (current wastewater treatment)

Processes	Human Health (Pt)	Ecosystems (Pt)	Resources (Pt)
Biological treatment			
Electricity$_1$	83.1	6.9	116
Tertiary treatment			
Decolourising	172	17	406
TOTAL	**255**	**23.9**	**522**

The decolourising reagent shows the greatest impact for the three categories, representing about 74% of the environmental impact of the scenario 1. Consequently, decreasing the amount of decolourising reagent in the tertiary treatment would reduce significantly the impact of the treatment.

The impact of the decolourising reagent on the different categories associated to Human health, Ecosystem and Resources is shown in Figures 8. As can be observed, the impact on Human health of the decolourising reagent is mainly due to the effect on Climate change human health and Particulate matter formation categories whereas Climate change ecosystems and Terrestrial ecotoxicity categories are the responsible for the impact on Ecosystems. Finally, the Fossil depletion category has the major impact on Resources whereas the Metal depletion category is almost not significant.

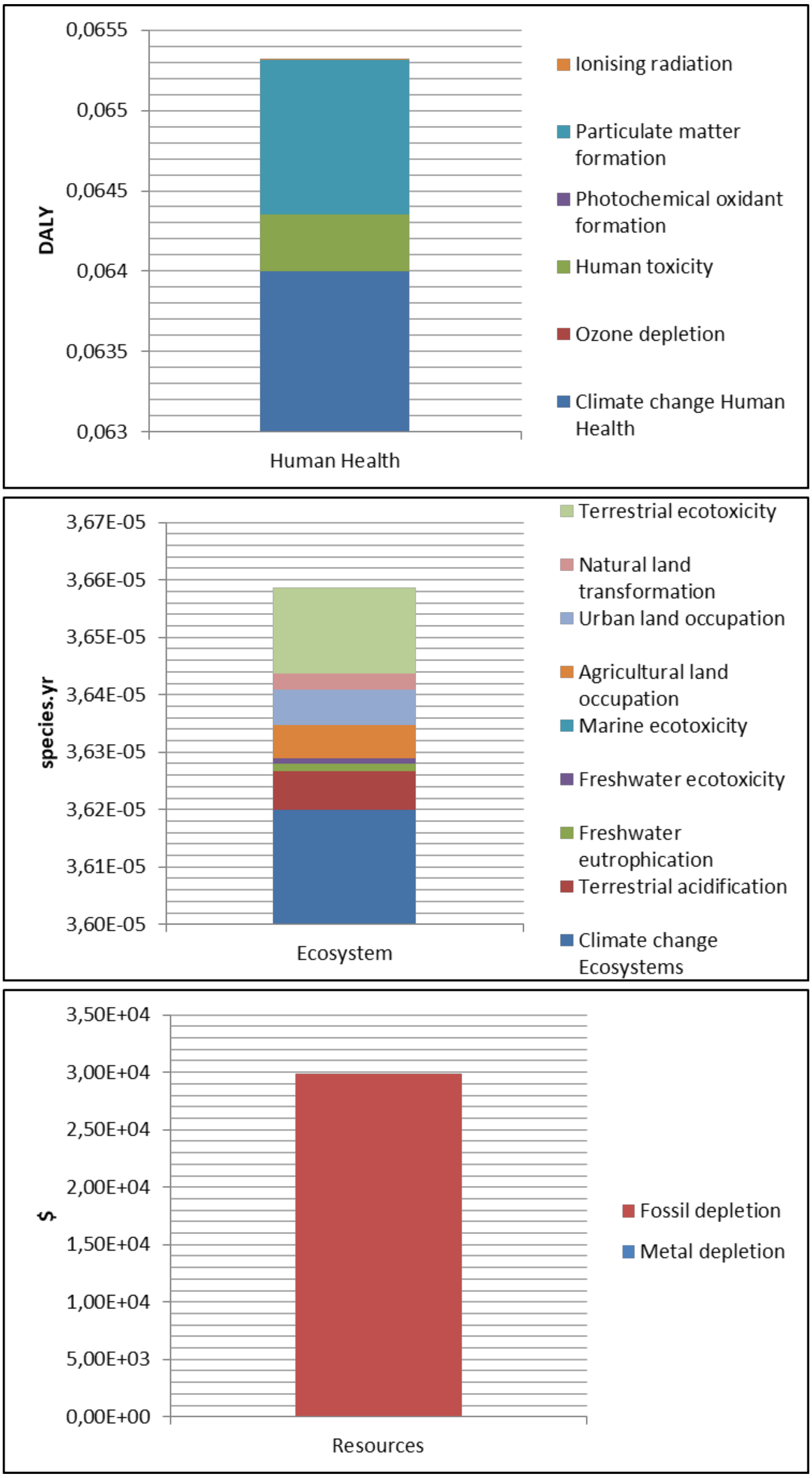

Figure 8. Analysis of effect of the decolourising reagent on the impact categories for scenario 1 (current wastewater process)

Scenario 2: ECUVal system to decolourise

In the scenario 2, first of all, the effluents from the reactive Jet dyeing process are treated by means of the system at 100A to ensure 60% of colour removal. Subsequently, they are mixed with the wastewater generated in other processes of the company. Finally, the whole wastewater is treated in the biological plant to reduce the organic matter content and by a tertiary treatment for a complete colour removal.

As can be seen in Table 10, the use of the system to decolourise the effluents from the reactive Jet dyeing process shows the greatest environmental impact on Resources.

Table 10. Environmental impact of scenario 2 (ECUVal to decolourise)

Processes	Human Health (Pt)	Ecosystems (Pt)	Resources (Pt)
ECUVal system			
Electricity$_1$	3.38	0.28	4.74
Biological treatment			
Electricity$_2$	82.4	6.84	115
Tertiary treatment			
Decolourising	89.2	8.86	211
TOTAL	**175**	**16**	**331**

In this scenario, the consumption of decolourising reagent is lower than scenario 1 since the system removes the colour of the most coloured effluents. Although the use of decolourising is still the main responsible for the environmental impact of scenario 2 (59%), the electricity consumed in the biological treatment represents 39%.

The impact of the electricity consumption in the biological treatment on the different categories associated to Human health, Ecosystem and Resources is presented in Figure 9. The impact associated to the consumption of decolourising reagent was evaluated in scenario 1.

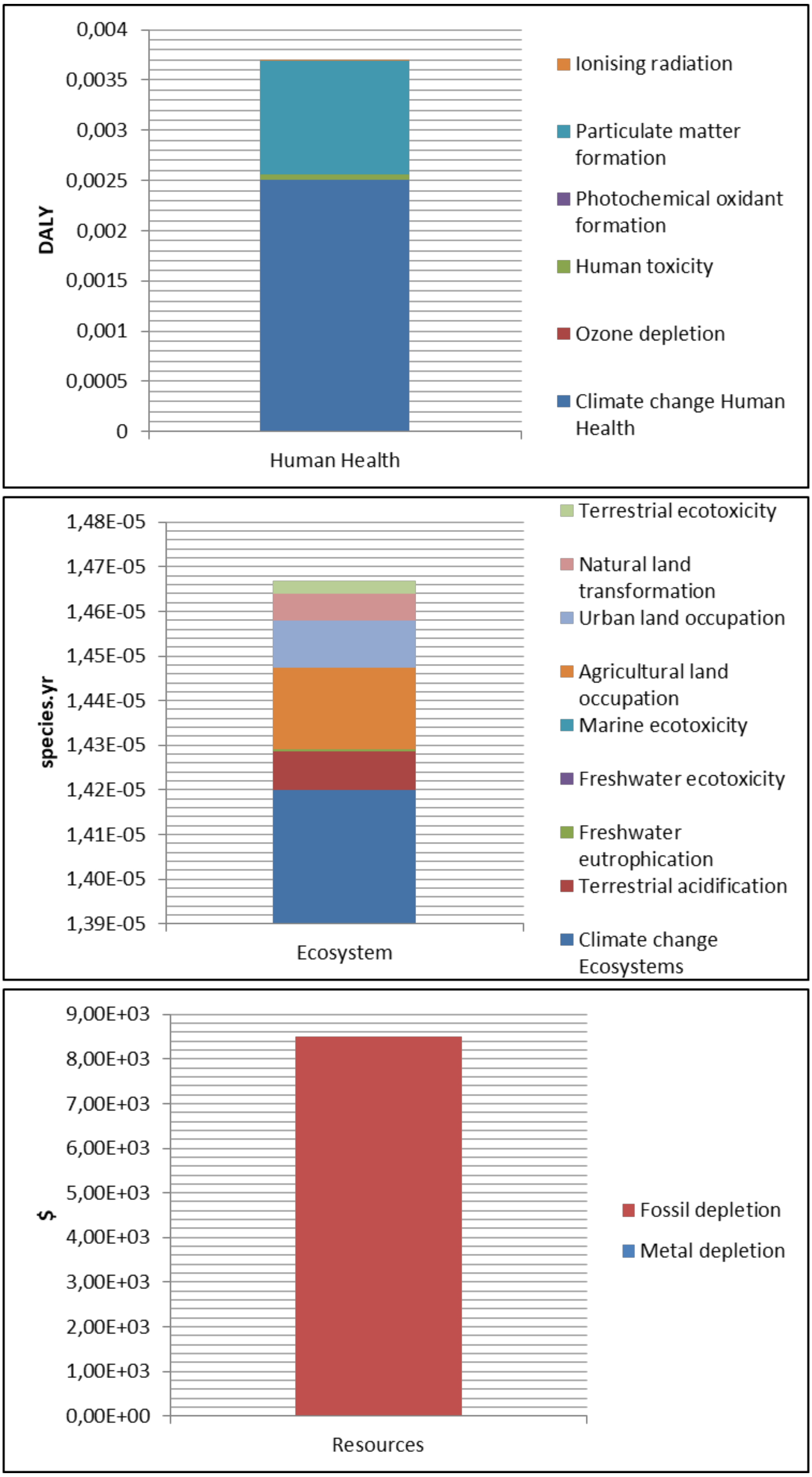

Figure 9. Analysis of effect of electricity consumption on the impact categories for scenario 2 (ECUVal to decolourise)

The impact on Human health of the electricity consumed in the biological treatment is mainly due to the effect on Climate change human health and Particulate matter formation categories whereas Climate change ecosystems and Agricultural land occupation categories are the responsible for the impact on Ecosystems. Finally, Fossil depletion category has high impact on Resources.

Scenario 3: ECUVal system to reuse water and salts

In the scenario 3, only the wastewater generated in other processes of the company is treated (reactive Jet dyeing effluents are completely reused). As can be observed in Table 11, this scenario has also the major impact on Resources followed by Human health categories. In this scenario, the most coloured effluents are not discharged to the wastewater treatment plant therefore the consumption of the decolourising agent is even more reduced. As it was expected, decreasing the amount of decolourising represents a significant reduction in the environmental impact of the treatment.

Table 11. Environmental impact of scenario 3 (ECUVal to reuse)

Processes	Human Health (Pt)	Ecosystems (Pt)	Resources (Pt)
Biological treatment			
Electricity$_1$	80.8	6.71	113
Tertiary treatment			
Decolourising	34.3	3.41	81.2
TOTAL	**115**	**10.1**	**194**

The consumption of electricity required to carry out the biological treatment represents 63% of the total environmental impact of the scenario 3.

Comparison of the three scenarios

The three scenarios are compared in Table 12 to determine the environmental advantage of the developed system on the wastewater treatment plant.

Table 12. Environmental impact of the three scenarios

	Human Health (Pt)	**Ecosystems (Pt)**	**Resources (Pt)**
Scenario 1	255	23.9	522
Scenario 2	175	16	331
Scenario 3	115	10.1	194

In comparison to the current wastewater treatment (scenario 1), the use of the system to decolourise the effluents from the dyeing process (scenario 2) provides a reduction of about 35% in the environmental impact. The discharge of less coloured effluents in the wastewater treatment plant enables to reduce the consumption of decolourising reagent, which is the main responsible for the environmental impact of the scenario 1.

When the ECUVal is applied to both reuse water and salt (scenario 3) the environmental impact of the wastewater treatment decreases in 60% since the effluents from the reactive Jet dyeing are not discharged. The wastewater treatment plant is only applied to treat the effluents generated in other processes of the textile mill, which have less colour and require the addition of less amount of decolourising reagent. The consumption of electricity in the biological treatment is also reduced.

The comparison of the three scenarios was also evaluated by means of ReCiPe, midpoint approach (Table 13).

Table 13. Comparison of scenarios: Midpoint analysis

Impact category	Unit	Scenario 1	Scenario 2	Scenario 3
Climate change Human Health	kg CO_2 eq	$6.38 \cdot 10^3$	$4.24 \cdot 10^3$	$2.67 \cdot 10^3$
Ozone depletion	kg CFC -11 eq	$6.61 \cdot 10^{-4}$	$3.98 \cdot 10^{-4}$	$2.14 \cdot 10^{-4}$
Human toxicity	kg 1,4-DB eq	577	340	176
Photochemical oxidant formation	kg NMVOC	16.8	12.4	8.9
Particulate matter formation	kg PM10 eq	8.11	6.47	5.02
Ionising radiation	kg U235 eq	679	525	395
Terrestrial acidification	kg SO_2 eq	26.7	21.6	17
Freshwater eutrophication	kg P eq	0.36	0.23	0.14
Marine eutrophication	kg N eq	11	5.84	2.4
Terrestrial ecotoxicity	kg 1,4-DB eq	1.4	0.84	0.45
Freshwater ecotoxicity	kg 1,4-DB eq	36.9	19.3	7.62
Marine ecotoxicity	kg 1,4-DB eq	4.93	2.91	1.5
Agricultural land occupation	m^2 year	21.5	19.5	16.9
Urban land occupation	m^2 year	8.75	7.41	6.07
Natural land occupation	m^2 year	0.05	0.04	0.04

Water depletion	m^3	52.1	32.6	18.7
Metal depletion	kg 1Fe eq	9.1	6.11	3.89
Fossil depletion	kg oil eq	$2.39\cdot10^3$	$1.52\cdot10^3$	891

Table 13 shows the clear environmental advantages of applying the system since the impact is decreased for all categories. Especially significant is the reduction observed in Climate change, Human toxicity, Ionising radiation and Fossil depletion categories, which decreases in 58%, 70%, 42% and 63% respectively when the system is applied to reuse the effluents generated in the reactive Jet dyeing process. Finally, it is important to highlight that the use of the system in reuse mode shows significant environmental advantages with respect to the current treatment and also it implies clear economic benefits such as saving in water and salts, reduction of discharge taxes, etc.

4. Conclusions

Three textile effluents collected from the dyeing process with reactive dyes were treated with the ECUVal system at different intensities. The treatment provided between 64 and 99% of colour removal. The uncoloured effluents were reconstituted and subsequently reused in new dyeing processes with monochromies and trichromies. According to the results obtained in the effluent reuse study, 70% of water and up to 72% of salt can be reused when the system is applied to treat textile effluents. In general, the colour differences values were lower than 1 and therefore they met the textile company acceptance criteria.

On the other hand, LCA evidences the clear environmental advantages of the new developed system. In this sense, when the system is applied to remove colour of effluents from the reactive Jet dyeing process, the environmental impact of the wastewater treatment plant is reduced in 35% with respect to the current wastewater treatment applied in the selected textile mill. The effect is significantly diminished in the reuse mode, as in this case the environmental impact decreases to 60%.

For all these reasons, the ECUVal system has demonstrated to be as a very promising technology to increase the sustainability of the textile industry.

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