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Decolourization of the reconstituted textile effluent by different process treatments: Enzymatic catalysis, coagulation/flocculation and nanofiltration processes

Imen Khouni [a,b], Benoît Marrot [b,*], Philippe Moulin [b], Raja Ben Amar [a]

[a] Laboratoire Sciences de Matériaux et Environnement, Faculté des sciences de Sfax, Route de Soukra Km4, 3038 Sfax, Tunisie
[b] Université Paul Cézanne, UMR 6181, M2P2, Laboratoire de Mécanique, Modélisation et Procédés Propres, Europole de l'Arbois, Bat. Laennec, Hall C, BP 80, 13545 Aix en Provence Cedex 4, France

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ABSTRACT

The objective of the present paper is to examine the decolourization efficiency of textile effluent using different processes: coagulation/flocculation, enzymatic catalysis by commercial laccase and nanofiltration. A series of experiments are conducted on laboratory-prepared wastewaters combining chemically two reactive dyes (Blue Bezaktiv S-GLD 150 and Black Novacron R), auxiliaries and chemicals. To optimise coagulation/flocculation and enzymatic treatment, response surface methodology is applied. Coagulation/flocculation leads to a maximum percent of colour removal of about 93% at 593 nm and 94% at 620 nm. Whereas, applied commercial laccase catalysis reduces colour by up to 99%. Nevertheless, these two processes have not the same behaviour on chemical oxygen demand (COD) and salinity removal since the obtained results show that applied coagulation/flocculation permits a partial removal of COD without effect on salinity. However, laccase treatment has no effect on COD and on salinity retention. The application of the nanofiltration shows excellent performances in term of decolourization (superior to 99%). In the same time, a partial retention of COD and salinity respectively of about 56% and 35% is obtained. Thus, nanofiltration seems to be an efficient process in colour removal of textile wastewater. The obtained permeate can be reused in the dyeing process in the textile industry.

1. Introduction

With the increased demand for textile products, the textile industry and its wastewaters have been increasing proportionally, making it one of the main sources of severe pollution problems worldwide [1]. Effluent treatment from dyeing and finishing processes in the textile industry is one of the most significant environmental problems [2,3]. Since most synthetic dyes have complex aromatic molecular structures which make them inert and biodegradable difficult when discharged into the environment [4,5].

Through, textile processing employs a variety of chemicals depending on the nature of the raw material and product. Some of these chemicals are enzymes, detergents, dyes, acids, sodas and salts [6,7]. The high consumption of reactive dyes, mainly in the cotton industry, increases the environmental problems, due to their low degree of exhaustion (60 - 90%) [8,9].

Dyes removal techniques such as adsorption, electrochemical oxidation, photocatalytic oxidation, electro-Fenton oxidation appear to face several technical and economic limitations [10–12] and were found to be inadequate [13] because most textile dyes have complex aromatic molecular structures that resist degradation. The need for more efficient treatment processes has attracted the attention of environmental scientists and engineers.

For these reasons many attempts have been made to treat textile wastewater using conventional wastewater treatment methods [14,15]. Coagulation/flocculation is widely used for wastewater treatment, as it is efficient and simple to operate. Aluminium and iron salts are widely used as coagulants in water and wastewater treatment for removing a broad range of impurities from effluent, including colloidal particles and dissolved organic substances. The mode of action is generally explained in terms of two distinct mechanisms: charge neutralization in negatively charged colloids by cationic hydrolysis products and incorporation of impurities in an amorphous hydroxide precipitate (sweep flocculation). In this process, many factors can influence its efficiency, such as the type and dosage of coagulant/flocculant [16–20], pH [21–24], mixing speed and time [25,26], temperature and retention time [27,28], etc. The optimization of these factors may significantly increase the process efficiency. Generally, the experiments were carried out by jar test which is usually employed to evaluate the treatment process efficiency. In the jar tests, coagulant dosage, flocculant dosage and pH were the factors that needed to be optimized [29].

* Corresponding author.
E-mail address: benoit.marrot@univ-cezanne.fr (B. Marrot).

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Nomenclature

ODU	Optical Density Unit
NTU	Nephelometric Turbidity Unit
Da	Dalton
T	Temperature (°C)
$U.g^{-1}$	Unity per gram
$U.L^{-1}$	Unity per liter
TMP	Transmembrane Pressure
α_i	Regression coefficient
X_i	Coded factor
RDE	Reconstituted Dyeing Effluents
ADS	Aqueous Dye Solution
CL	Commercial Laccase
CF	Coagulation/Flocculation
EC	Enzymatic Catalysis
NF	Nanofiltration
CCD	Central Composite Design
RSM	Response Surface Methodology
MWCO	Molecular Weight Cut Off
COD	Chemical Oxygen Demand
PAS	Polymeric Aluminium Sulphate
CC	Calcium Chloride
$Al_2(SO4)_3$	Polymeric Aluminium Sulphate
$CaCl_2$	Calcium Chloride
NaOH	Sodium hydroxide
HCl	Hydrochloric acid
BB150	Blue Bezaktiv S-GLD 150
BNR	Black Novacron R

In the other hand, a number of biotechnological approaches have been suggested with potential interest in reducing textile effluent pollution source in an eco-efficient manner [30]. The enzymatic treatment can be simpler and more efficient than the traditional physical-chemical treatments [31]. As enzymes are highly selective and recent researches have focussed on the development of enzyme processes using ligninolitic enzymes (e.g. Mn peroxidase, Lignin peroxidase and Laccase) for the treatment of textile wastewater [32].

The capability of laccases (benzenediol:oxygen oxidoreductase, EC 1.10.3.2) to act on chromophore compounds such as azo, triarylmethane, anthraquinonic and indigoid dyes suggest that they can be applied in industrial decolourization processes [33,34]. The laccase use in the textile industry is growing very fast, since besides to decolourize textile effluents as commented above, laccase is used to bleach textiles and even to synthesize dyes [35]. Laccase exhibit a number of features that make their use advantageous, as compared to conventional chemical or microbial catalysts such as biodegradable, high level of catalytic efficiency, high degree of specificity, easily removed from contaminated streams, easily standardized in commercial preparations and absence of side-reactions. These characteristics provide substantial process energy savings and reduced manufacturing costs. Nevertheless, as enzyme, laccase treatment efficiency depends on the influence of several parameters such as 1) Temperature: there are defined temperature ranges under which enzymes operate and there is a specific temperature levels (optimum temperature) in which enzymes have maximum efficiency. Therefore temperature variations affect enzymatic activity and the kinetic of the reactions they catalyze. In addition, as proteins, enzymes can be denatured under extreme temperatures and loses their catalytic activity; 2) pH: the concentration of hydrogen ions in solution affects the enzyme activity. Each enzyme has maximal efficiency under an optimum pH. Since pH is one of the factors for the denaturation of proteins, if an enzyme is submitted to a pH level under which it is denatured there will be no enzymatic activity; 3) Enzyme concentration: initially as substrate concentration increases, the reaction kinetic increases; this happens because free activation centers of the enzyme bind to free substrates. Once all activation centers of the available enzymes become bound to their substrates new increments of the substrate concentration will have no effect on the reaction kinetic and 4) Substrate concentration: usually a very small amount of enzyme can consume a large amount of substrate. The rate of reaction depends directly on the amount of enzyme present at a specific time at unlimited substrate concentration. If two folds increase the amount of enzyme the reaction rate is doubled. By increasing the enzyme molecules, an increase in the number of active sites takes place. At higher concentration of the enzyme the inhibitors will fall short. More active sites will convert the substrate molecules into products, in the given period of time. After a certain limiting concentration, the rate of reaction will no longer depend upon this increase.

Finally, recently reports are available for real textile wastewater treatment using membrane processes such as Ultrafiltration (UF), Nanofiltration (NF) and Reverse Osmosis (RO) [36,15]. UF is effective as single step treatment of secondary textile wastewater. NF and RO allow the separation of low molecular weight organic compounds and salts. The NF permeate is usually colourless and low in total salinity [37,38]. Membranes technologies provide an important solution in environmental fields such as pollution reduction and water reuse, recycling valuable components from the waste streams [39,40]. Nevertheless, the application of membrane processes has some drawbacks like concentration polarization and fouling that result in flux decline with time [41]. However, flux can be improved by adjusting the filtration conditions such as pH, temperature, pressure and velocity [42].

In the present investigation, maximum dye decolourization ability of CF treatment and CL catalysis was studied adopting a full range of response surface methodology (RSM) using central composite design (CCD) model to analyze the affectivity of the two systems under different conditions. Then, obtained CF and CL decolourization efficiencies are compared to those achieved under NF process.

2. Materials and methods

2.1. Dyes and reconstituted textile effluents

Two reactive dyes were used to prepare simulated textile effluents. They were reactive Black Novacron R (BNR) and Blue Bezaktiv S-GLD 150 (BB150) dyes provided by SARTEX (textile manufacturing unit in Ksar Helal (Tunisia)) and which were purchased from BEZEMA AG and from HUNTSMAN Textile Effects CH-4057 Bâle respectively. Reactive BB150 and BNR textile dyes were chosen since they are widely used to colour cellulose fibres. The characteristics of the two reactive dyes chosen are given in Table 1.

For the decolourization study and in order to imitate the textile wastewater, a synthetic (reconstituted) effluent was prepared based on real process information's of dyeing stages of cotton fibre (Jeans) according to the SARTEX. Two synthetic dyeing effluents were used:

Table 1
Properties of the reactive BB150 and BNR dyes at a concentration of 1 g/L.

Parameters	Unit	BB 150	BN R
λmax	nm	620	593 - 400
Absorbance at λmax	ODU	15.94	26.30 – 15.37
Dry matter (DM)	%	91.93	96.57
Mineral matter (MM)	%	70	68.66
Volatile matter (VM)	%	30	31.34
BOD_5	mg O_2/ g	300	272
COD	mg O_2/ g	840	850
Turbidity	NTU	<1	<1
Chemical group	-	Reactive	Reactive
Chromophore	-	Not available	Azoic