A prototype of novel agro-waste based column bed device for removal of textile dye Optilan Red

Samchetshabam Gita, S. P. Shukla, T. G. Choudhury, C. Prakash and A. R. Singh

ABSTRACT

The aim of the study was to assess the potentiality of an agro-waste (sugarcane bagasse) for removal of the textile dye (Optilan Red) using novel column based filtration unit with a packed column of chemically treated sugarcane bagasse. The treated and untreated sugarcane bagasse (biosorbent) were characterized by Fourier transform infrared (FT-IR) spectroscopy. Effect of initial dye concentration on percentage removal of dye, equilibrium adsorption of sugarcane bagasse, kinetic studies, breakthrough point equilibrium and desorption of dye from the column material were studied. An inverse dependence of initial dye concentration on percent removal of dye was observed, whereas the equilibrium adsorption ($q_e$) showed a direct relationship with dye concentration. The time required for reaching breakthrough point was 120 min. Desorption of dye through alkali wash resulted in complete desorption after 1 h washing of the column for its reuse for next cycle. FT-IR analysis shows vibration in valence bands of the hydrogen bond of OH group, and the bands of intra-molecular and intermolecular hydrogen bonds, which results in interaction of treated bagasse with Optilan Red textile dye. The present study showed that more than 93% removal of the dye can be achieved in the concentration range 10–50 ppm (aqueous solution). The removal efficiency of the column remained almost unchanged for the treatment of dye-house wastewater spiked with the dye. The agro-waste based treatment process shows a considerable potential for a low-cost treatment of dye contaminated water.

Key words | breakthrough point, column filtration unit, desorption, FT-IR spectra, kinetic studies, Optilan Red, sugarcane bagasse

INTRODUCTION

Release of colored effluents such as textile dyes from the industries has intensified the environmental problems due to wide-ranging deleterious effects of the dyes on aquatic organisms, especially algae. A considerable quantity of textile dyes is released through dye industry effluents due to poor level of dye-fiber fixation. Further, most of the textile industries in the developing world discharge either untreated or poorly treated dye-house water to the environment. The primary reason for a reluctant approach to adequate treatment of dye-house wastewater is the higher cost of treatment, especially on the commercially produced adsorbent materials. Therefore, a low-cost treatment device with a potential for upscaling up to a desired extent is a pre-requisite for proper management of dye-containing effluents.

Dyes are water-soluble synthetic aromatic dispersible organic colorants with wide-ranging applications in various industries. In the 21st century, synthetic dyes are used in various industries such as cosmetics, textile, paper, leather, paint, printing, food, petroleum, plastic, pigments, rubber, pharmaceutical and pesticide industry for different purposes (Sharma & Nandi 2016). The textile-dye industry plays a significant role in the economy of developing countries (Pereira & Alves 2012). Worldwide, $10^6$ tons of synthetic dyes are produced annually, of which $1\text{–}1.5 \times 10^5$ tons are released in the environment (Zollinger 1987). It is estimated that globally 280,000 tons of textile dyes are discharged in the dye-containing industrial effluents every year (Jin et al. 2007). Hence, a significant amount of dyes comes to the
effluent stream and pollutes the waters. Although the dyes have low toxicity in mammals and aquatic organisms (O’Neill et al. 1999), their products formed by biodegradation, mainly aromatic amines from the anaerobic reduction of dyes, are comparatively more harmful (Razo-Flores et al. 1997; Pinheiro et al. 2004; Srivastava et al. 2004; Chowdhury & Saha 2010). Discharge of synthetic dye into the hydrosphere can cause environmental degradation, as it gives an undesirable color to the water and reduces sunlight penetration, thereby inhibiting the growth by hindering photosynthesis. Dye-containing wastewater involves a tedious process with a considerable cost input, as the dyes are recalcitrant organic molecules showing a resistance to aerobic digestion and inactivation by light, heat and oxidizing agents.

Removal of color from wastewater is a complex problem because of complexity of the conventional treatment processes (Kumar 2007). Among the different conventional methods for dye molecules removal from effluents, biosorption – the adsorption of pollutants by non-living biomass – has drawn the attention of the researchers worldwide as an efficient and economical technology for the removal of synthetic dyes from industrial effluents (Pereira & Alves 2012). Some of the advantages of adsorption process are sludge-free operation, recovery of the sorbate, possible regeneration of the adsorbents at low cost, and availability of known processes and equipment (Kapdan & Kargi 2002). A number of inexpensive and abundant biosorbents, especially agro-waste materials as well as municipal and industrial wastes, have been proposed by a number of researchers for the removal of synthetic dyes (Srivastava et al. 2004; Kumar 2007; Baek et al. 2010; Chowdhury & Saha 2010; Reddy et al. 2012; Fontana et al. 2016).

Among the researchers, there is a growing concern about developing more efficient, inexpensive and readily available adsorbents from the waste materials. However, for applying in an industry, the selection of adsorbent material is mainly done by the availability of waste material and applicability of the adsorption method considering cost, space and amount of wastewater treated. Utilization of agricultural wastes for wastewater treatment could be helpful in solving the solid waste disposal problem faced by the farmers and agro-industries. Several researchers used sugarcane bagasse as adsorbent to remove different dyes from wastewater, especially in batch studies (Chakraborty et al. 2012; Sharma & Nandi 2013; Sadaf & Bhatti 2015; Sadaf et al. 2015). The high annual production and nature of sugarcane bagasse have increased its desirability for the remedying of environmental pollution in different ways (Chakraborty et al. 2012). In India, a lot of bagasse is available as waste material, which can be used as efficient adsorbent material for removing dyes. Sugarcane bagasse has cellulose (46.0%), hemicellulose (24.5%), lignin (19.95%), fat and waxes (3.5%), ash (2.4%), silica (2.0%), and others (1.7%) as main components (Sene et al. 2002). Polysaccharides of sugarcane bagasse are biopolymers with many hydroxyl and/or phenolic groups. These polysaccharides can be chemically altered to achieve desired properties (Chakraborty et al. 2012). In this context, the present investigation aimed to develop a device and protocol for the removal of textile dye (Optilan Red) by utilizing chemically modified sugarcane bagasse for enhanced removal efficiency.

MATERIALS AND METHODS

Preparation of dye solution

Optilan Red was obtained from Archroma Textiles (Mumbai, India) for preparation of dye solution. Different concentrations of dye solution (5, 10, 15, 20, 25, 30, 35, 40, 45, 50 ppm) were prepared by dissolving required quantity of dye powder in de-ionized water.

Preparation of adsorbents (sugarcane bagasse) for column

Sugarcane bagasse was collected from local sugarcane juice vendors and washed thoroughly in running water for 2–3 h to remove dirt, dust and sugar traces. The washed bagasse was treated with KMnO4 solution for lignin oxidation and dried under sun. Second step of drying was carried out in oven at 120 °C until it dried completely. Once drying was completed, dried bagasse was treated with alginic acid 10 g L−1 (1%) for chemical modification and again sun and oven dried following the above procedure. This treated and dried bagasse was used for the preparation of column bed of the column filtration unit.

Adsorbent characterization by Fourier transform infrared spectroscopy

Fourier transform infrared (FT-IR) spectra of samples were recorded in the range of 400 to 4,000 cm−1 with a scan rate of 4 cm−1 by FT-IR spectrometer (Shimadzu 8400s, Japan). The bagasse (treated and untreated) (5%) and potassium bromide (KBr) powder (95%) were mixed mechanically into an agate mortar and ground to fine powder. This
mixture was pressed into a pellet and scanned in the above range.

**Design of column filtration unit**

Low-cost and locally available materials like polyurethane foam (PUF), PVC pipes and plastic containers were used for the fabrication of the unit. The unit consisted of three components: upper compartment, column, and lower compartment. Upper compartment serves as the reservoir (25 L capacity aspirator glass bottle) for the dye solution to be treated. The column was made of 6-inch diameter PVC pipe with physically entrapped treated sugarcane bagasse adsorbents and was placed at the junction of both upper and lower compartments with a vertical orientation. The lower compartment was made of an 80 L plastic container in which a square shaped opening was made at a distance 6 to 12 inches from the bottom for the collection of samples at periodic intervals.

Column bed was prepared using two PUFs (Pore diameter 200–400 μ), one at top (1 inch thick) and another at bottom (3 inches thick) for supporting the adsorbent materials (sugarcane bagasse) placed between the two foam layers. Above the top PUF layer, a 3 cm thick glass wool layer was laid in order to spread the dye solution uniformly (Figure 1).

**Experiment**

Twenty litres of dye solution was passed through the column for 1 h with an average flow rate of 250 mL per min, and samples were collected at every 10 min interval in plastic bottles. Five different concentrations of dye, viz. 10, 20, 30, 40 and 50 ppm, were used for the experiment. Dye solution was passed through the column for 60 min and effluent was collected at regular intervals (10, 20, 30, 40, 50 and 60 min) at the exit of the column. A standard curve of known dye concentration was prepared by measuring the optical density at the absorption maximum (246 nm) of the dye using a double beam UV-visible spectrophotometer (Thermo Scientific, USA). All the experiments were carried out at room temperature (30 ± 2 °C).

**Percentage removal**

The removal efficiency (Amin et al. 2006) of sugarcane bagasse at various time intervals for different dye concentrations in the column bed was calculated using the following equation:

\[
\text{Percentage removal } R (%) = \frac{(C_i - C_c)100}{C_i}
\]

where \(C_i\) and \(C_c\) are the concentrations of dye solution before and after treatment.

**Equilibrium adsorption**

Equilibrium adsorption \((q_e)\) of sugarcane bagasse for the dye was calculated by using the equation

\[
q_e (\text{mg g}^{-1}) = \frac{(C_0 - C_i)V_i}{W}
\]
where \( C_0 \), initial concentration of dye solution; \( C_i \), concentration after \( i \)th time treatment and \( V_i \), volume of dye solution at \( i \)th time in litres; \( W \), weight of adsorbent in grams.

**Kinetics studies**

Biosorption kinetics data were analyzed using two commonly used kinetic models: pseudo-first-order and pseudo-second-order kinetic models. The applicability of these kinetic models was determined by measuring the correlation coefficients (R²). The integral form of the pseudo-first-order model is generally expressed as:

\[
\log (q_e - q_t) = \log q_e - K_1 \cdot t
\]

where \( q_e \) and \( q_t \) are the biosorption capacity at equilibrium and time \( t \), respectively; \( K_1 \) is rate constant and \( t \) is the contact time.

The integral form of the pseudo-second-order model can be presented as:

\[
\frac{t}{q_t} = \frac{1}{K_2q_e^2} + \frac{t}{q_e}
\]

where \( K_2 \) is the second-order rate constant.

**Breakthrough point**

The ratio of effluent dye concentration and initial dye concentration was used for determining the breakthrough point. The time at which the ratio was near to 1.0 indicated the breakthrough point. Breakthrough point was calculated for 50 ppm dye concentration to know the time/volume of dye solution required for the saturation of the column. The column was washed with alkali solution to remove the dye before the next use of the same column material.

**Desorption of the dye**

Desorption studies help to elucidate the nature of adsorption and recycling of the spent adsorbent and the dye. After adsorption study, 0.1 M NaOH was passed through the column with a flow rate of 250 mL min⁻¹ for 60 min to estimate the desorption of the dye. Optical density (OD) (at 246 nm) of the eluent was recorded using the spectrophotometer. Desorption capacity was calculated for 50 ppm of Optilan Red dye.

**Experiment with textile industry effluent**

Textile industry dye effluent was collected from a local dye house (Executive Garment processors Pvt Ltd, MIDC, Mumbai) and spiked with 50 ppm Optilan Red dye. The spiked dye effluent was passed through the column for 60 min and effluent dye solution was collected at regular intervals (10, 20, 30, 40, 50 and 60 min) and OD (246 nm) was recorded.

**RESULTS AND DISCUSSION**

**Characterization of sugarcane bagasse**

The FT-IR spectra were used to determine the structural and functional changes in the untreated and treated bagasse (with 1% Alginic acid). The FT-IR spectrum of the untreated and pre-treated bagasse in the range 3,800 and 3,000 cm⁻¹ corresponds to the crystalline structure of cellulose (Figure 2(a) and 2(b)). This region represents the sum of the vibrations of valence bands of the hydrogen of the OH group, and the bands of intra-molecular and intermolecular hydrogen bonds (Hinterstoiss & Salmén 1999; Chandel et al. 2014). The characteristic vibrational mode of C-H stretching of hydroxyl group is seen around 2,800–3,000 cm⁻¹ in the FT-IR spectrum. The peak around 2,850 cm⁻¹ is a characteristic of the symmetric stretch of CH and CH₂, while the peak at 2,918 cm⁻¹ is due to asymmetrical stretching of CH₂ and CH. Both denote the characteristics of cellulose.

The typical two bands characteristic of C-O modes of vibrations of carboxylic acid were recorded in the spectrum around 1,300–1,000 cm⁻¹. It also shows a band in the middle of the spectrum around 1,800–1,400 cm⁻¹ corresponding to C = O stretch.

A band around 1,458 cm⁻¹ depicts deformation of lignin at CH₂ and CH₃, and 1,604 cm⁻¹ corresponds to stretching of the C = C and C = O lignin aromatic ring. The band around 1,514 cm⁻¹ is because of the C = C stretching of the aromatic ring in lignin. A band around 1,733 cm⁻¹ is characteristic of C = O stretching of unconjugated hemicelluloses (Colom et al. 2003; Pandey 2005).

The region between 1,100 and 1,000 cm⁻¹ clearly shows two peaks after alginic acid treatment indicating the removal of hemicellulose. Therefore, alginic acid mediated hydrolysis seems to be affected due to the removal of lignin moieties.

The regions of 1,735 and 1,635 cm⁻¹, which are characteristic vibrational modes for C = O stretching, show variation in peak heights and geometry, which indicates
the decrease in hemicellulose content. The regions 1,514 cm\(^{-1}\) and 1,456 cm\(^{-1}\) relating to the lignin macromolecule have noticeable changes after alginic acid triggered the hydrolysis of cellulose moieties in the bagasse. These changes are good evidence of effective lignin degradation after the alginic acid mediated delignification process.

The increase in line width and asymmetry of the curves in the range of 3,800 to 3,000 cm\(^{-1}\) alginic acid treatment indicates disturbances in the crystalline structure of cellulose. These changes are strong evidence of intramolecular hydrogen bonding disruption in cellulose. Bands around 2,920 cm\(^{-1}\) and 2,854 cm\(^{-1}\) indicate the removal of hemicellulose from the bagasse.

It was noticed from the FT-IR spectra (Figure 2(a)) that alginic acid treatment decreased the cellulose content, which is evident from the increase in intensity of treated samples as compared with the control (untreated bagasse). The pretreated bagasse showed an increase in OH and C-H groups (Figure 2(a)) after treatment with the Optilan Red, which is a clear indication of interaction between the dye molecules and the pretreated bagasse. An increase in intensity of peak around 1,735 cm\(^{-1}\) and 1,635 cm\(^{-1}\) was also noticed in the samples treated with Optilan Red. A shift in the band of O-H vibration from 3,406 cm\(^{-1}\) for pretreated bagasse towards higher wave number at 3,442 cm\(^{-1}\) for Optilan Red textile dye was also noticed (Figure 2(a)–2(c)).

**Removal efficiency of novel column based filtration unit**

Adsorption of hazardous soluble chemicals from wastewater onto the surface of a solid adsorbent has provided a new dimension to the wastewater treatment technology (Benfield et al. 1982; Yagub et al. 2014; Bazzo et al. 2016). The present investigation aimed to develop a low-cost treatment process for dye removal from water using sugarcane bagasse in a column based filtration unit. The reason for selection of column mode for the present study was the insufficient availability of information about removal technologies based upon column bed reactors consisting of sugarcane bagasse as adsorbent. The bagasse was pre-treated with a low concentration of biopolymers like alginic acid to enhance the adsorption capacity. Alginic acid was used as adsorbent as it is nontoxic, selective, efficient and inexpensive. It consists of abundant functional groups with affinity for dye and therefore, it is highly competitive with ion exchange resins due to high uptake capacity. The present study on utilization of agro-waste like sugarcane bagasse for the removal of Optilan Red showed significant reduction (more than 93%) in dye concentration (Table 1). In an earlier report, Sharma

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**Figure 2** (a) Stacked FT-IR spectrum of (a) SB, (b) SB pretreated with Alginic acid, (c) SB + Optilan Red dye and (d) pretreated SB + Optilan Red textile dye (SB = Sugarcane bagasse). (b) and (c) Overlay FT-IR spectra in the range of 3,800-2,800 cm\(^{-1}\) and 1,800-1,500 cm\(^{-1}\), respectively, for (a) SB, (b) SB + Optilan Red dye and (c) pretreated SB + Optilan Red textile dye.
& Nandi (2013) reported 95% removal of Malachite green dye in batch system using sugarcane bagasse particles as adsorbent. However, Chakraborty et al. (2012) observed 93.21% removal of the dye crystal violet under optimized conditions in batch system using sugarcane bagasse as adsorbent. Sadaf et al. (2015) demonstrated that sugarcane bagasse can be used as a potential biosorbent for the removal of Direct Yellow 50 dye from aqueous solutions.

Experiment using textile industry dye effluents spiked with Optilan Red showed similar percentage removal of dye (>90%) in column based filtration unit (Figure 3). This suggests that the substances present in the dye effluents do not affect the performance of the column to a considerable extent (Table 2).

### Effect of initial dye concentration on dye removal

The initial dye concentration of an effluent is important, since a given mass of sorbent material can only adsorb a fixed amount of dye (Benaissa 2003). Percentage removal of Optilan Red dye solution (10–50 ppm initial concentration) at different time using sugarcane bagasse as adsorbent in column based filtration unit is shown in Table 1, Figure 4. Data showed that as initial dye concentration increases, percentage removal of dye decreases. Among the different concentrations of Optilan Red dye, maximum removal of 93.5% was recorded at 30 ppm during 10 min time. The effect of the initial dye concentration depends on the immediate relation between the concentration of the dye and the available binding sites on an adsorbent surface (Salleh et al. 2011). Normally, the dye removal will decrease with increase in initial dye concentration. This is because for a given mass of adsorbent, the amount of dye adsorbed is fixed. The higher the concentration of the dye, the smaller is the volume of the treated dye solution (Low & Lee 1990). At a lower concentration, there are many unoccupied active sites on the adsorbent surface; however, at higher concentrations, most of the functional groups are bound to the dye molecules and the column reaches the saturation point (breakthrough) earlier than at lower concentrations (Kannan & Sundaram 2001).

The equilibrium adsorption values for sugarcane bagasse varied in a concentration-dependent manner for

### Table 1 | Percentage removal of Optilan Red dye solution in different times using sugarcane bagasse as adsorbent in column based filtration unit (Temp. 30 ± 2°C)

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>Concentration (Avg ± SE) of Optilan Red dye solution (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>81.72 ± 0.31&lt;sup&gt;a&lt;/sup&gt; 90.54 ± 0.16&lt;sup&gt;df&lt;/sup&gt; 93.50 ± 0.26&lt;sup&gt;j&lt;/sup&gt; 83.86 ± 0.30&lt;sup&gt;n&lt;/sup&gt; 80.22 ± 0.10&lt;sup&gt;r&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>71.50 ± 1.11&lt;sup&gt;b&lt;/sup&gt; 86.94 ± 0.50&lt;sup&gt;af&lt;/sup&gt; 75.59 ± 0.36&lt;sup&gt;k&lt;/sup&gt; 65.01 ± 0.23&lt;sup&gt;o&lt;/sup&gt; 55.33 ± 0.15&lt;sup&gt;dc&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>62.72 ± 0.78&lt;sup&gt;c&lt;/sup&gt; 67.75 ± 0.53&lt;sup&gt;bf&lt;/sup&gt; 63.26 ± 0.26&lt;sup&gt;fn&lt;/sup&gt; 48.21 ± 0.04&lt;sup&gt;lp&lt;/sup&gt; 44.10 ± 0.41&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>40</td>
<td>53.58 ± 1.43&lt;sup&gt;d&lt;/sup&gt; 64.05 ± 0.56&lt;sup&gt;go&lt;/sup&gt; 56.89 ± 0.22&lt;sup&gt;e&lt;/sup&gt; 46.73 ± 0.59&lt;sup&gt;lp&lt;/sup&gt; 44.21 ± 0.75&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>54.84 ± 0.93&lt;sup&gt;d&lt;/sup&gt; 58.92 ± 0.95&lt;sup&gt;d&lt;/sup&gt; 49.72 ± 0.53&lt;sup&gt;lm&lt;/sup&gt; 41.01 ± 0.57&lt;sup&gt;qn&lt;/sup&gt; 31.04 ± 0.36&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>60</td>
<td>57.71 ± 1.25&lt;sup&gt;ef&lt;/sup&gt; 55.31 ± 0.39&lt;sup&gt;de&lt;/sup&gt; 51.00 ± 0.56&lt;sup&gt;mn&lt;/sup&gt; 37.87 ± 0.28&lt;sup&gt;r&lt;/sup&gt; 31.04 ± 0.43&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
</tbody>
</table>

The observed values were expressed as mean ± standard error. Mean values with different superscripts are significantly (P < 0.05) different from each other.

### Figure 3 | Percentage removal (± SE) of textile industry effluent dye using sugarcane bagasse as adsorbent in column based filtration unit (Temp. 30 ± 2°C).

### Table 2 | Water quality parameters of textile dye industry effluent

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Before treatment</th>
<th>After treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>6.04</td>
<td>6.41</td>
</tr>
<tr>
<td>Turbidity (NTU)</td>
<td>350</td>
<td>133</td>
</tr>
<tr>
<td>COD (mg/L)</td>
<td>7,900</td>
<td>7,400</td>
</tr>
<tr>
<td>BOD (mg/L)</td>
<td>800</td>
<td>675</td>
</tr>
<tr>
<td>TSS (mg/L)</td>
<td>358</td>
<td>200</td>
</tr>
<tr>
<td>TDS (mg/L)</td>
<td>611</td>
<td>561</td>
</tr>
</tbody>
</table>

COD, chemical oxygen demand; BOD, biological oxygen demand; TSS, total suspended solids; TDS, total dissolved solids.
the initial concentrations ranging from 10 to 50 ppm of Optilan Red (Table 3). As concentration increased, an increase in equilibrium adsorption was recorded (Figure 5). Bulut & Aydin (2006) reported that the actual amount of dye adsorbed per unit mass of adsorbent increased with increase in dye concentration, and this may be due to the high driving force for mass transfer at higher initial dye concentration.

Experiment using textile industry dye effluents showed similar percentage removal of dye (>90%) in column based filtration unit filled with sugarcane bagasse as adsorbents (Figure 3). This suggests that the other ions and substance present in the dye effluents do not affect the performance of the column filtration.

**Effect of contact time on dye removal**

Effect of contact time on percent removal of Optilan Red dye solution (10–50 ppm initial concentration) at different time is presented in Table 1. A time-dependent decrease in percentage removal of dye for the concentration (10–0 ppm) was recorded. There was maximum removal in initial 10 min ranging from 80 to 93% and thereafter gradual reduction in percentage removal of dye with time. Initially, equilibrium adsorption was high, but it decreased gradually with time. A steep decline in equilibrium adsorption was noticed at higher concentration as compared with slight decrease at lower concentrations of dye with respect to increasing time (Table 1). Generally, the rate of removal of dye increases with an increase in contact time to a certain extent. Further, increase in contact time does not increase the uptake due to binding of dye molecules on the available adsorption sites (Ansari & Mosayebzadeh 2010).

**pH of dye solution**

The pH factor is very important in the adsorption process, especially for dye adsorption. The pH of a medium

![Figure 4](image-url)  
**Figure 4** Effect of initial dye concentration on percentage removal of Optilan Red dye using physically entrapped pre-treated sugarcane bagasse as adsorbent (Temp. 30 ± 2 °C).

### Table 3: Equilibrium adsorption ($q_e$) of sugarcane bagasse as adsorbent for removal of Optilan Red dye

<table>
<thead>
<tr>
<th>Time (min)</th>
<th>10 ppm</th>
<th>20 ppm</th>
<th>30 ppm</th>
<th>40 ppm</th>
<th>50 ppm</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.0528 ± 0.0002&lt;sub&gt;d&lt;/sub&gt;</td>
<td>0.1163 ± 0.0002&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.1782 ± 0.0005&lt;sup&gt;b&lt;/sup&gt;</td>
<td>0.2225 ± 0.0008&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.2452 ± 0.0003&lt;sup&gt;d&lt;/sup&gt;</td>
</tr>
<tr>
<td>20</td>
<td>0.0462 ± 0.0007&lt;sub&gt;e&lt;/sub&gt;</td>
<td>0.1117 ± 0.0006&lt;sup&gt;m&lt;/sup&gt;</td>
<td>0.1441 ± 0.0007&lt;sup&gt;n&lt;/sup&gt;</td>
<td>0.1725 ± 0.0006&lt;sup&gt;a&lt;/sub&gt;</td>
<td>0.1677 ± 0.0004&lt;sup&gt;f&lt;/sup&gt;</td>
</tr>
<tr>
<td>30</td>
<td>0.0405 ± 0.0005&lt;sub&gt;b&lt;/sub&gt;</td>
<td>0.0870 ± 0.0007&lt;sup&gt;k&lt;/sup&gt;</td>
<td>0.1206 ± 0.0005&lt;sup&gt;n&lt;/sup&gt;</td>
<td>0.1279 ± 0.0001&lt;sup&gt;i&lt;/sup&gt;</td>
<td>0.1337 ± 0.0013&lt;sup&gt;j&lt;/sup&gt;</td>
</tr>
<tr>
<td>40</td>
<td>0.0346 ± 0.0009&lt;sub&gt;a&lt;/sub&gt;</td>
<td>0.0823 ± 0.0007&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.1084 ± 0.0004&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.1240 ± 0.0016&lt;sup&gt;p&lt;/sup&gt;</td>
<td>0.1340 ± 0.0023&lt;sup&gt;c&lt;/sup&gt;</td>
</tr>
<tr>
<td>50</td>
<td>0.0354 ± 0.0006&lt;sub&gt;a&lt;/sub&gt;</td>
<td>0.0757 ± 0.0012&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0948 ± 0.0010&lt;sup&gt;j&lt;/sup&gt;</td>
<td>0.1088 ± 0.0015&lt;sup&gt;d&lt;/sup&gt;</td>
<td>0.0941 ± 0.0011&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>60</td>
<td>0.0373 ± 0.0008&lt;sup&gt;a&lt;/sup&gt;</td>
<td>0.0711 ± 0.0005&lt;sup&gt;c&lt;/sup&gt;</td>
<td>0.0972 ± 0.0011&lt;sup&gt;j&lt;/sup&gt;</td>
<td>0.1005 ± 0.0008&lt;sup&gt;k&lt;/sup&gt;</td>
<td>0.0941 ± 0.0013&lt;sup&gt;i&lt;/sup&gt;</td>
</tr>
<tr>
<td>Total</td>
<td>0.2468 ± 0.0014</td>
<td>0.5441 ± 0.0007</td>
<td>0.7434 ± 0.0030</td>
<td>0.856 ± 0.0046</td>
<td>0.8668 ± 0.0003</td>
</tr>
</tbody>
</table>

The observed values were expressed as mean ± standard error. Mean values with different superscripts are significantly ($P < 0.05$) different from each other.
determines the magnitude of electrostatic charges which are imparted by the ionized dye molecules. As a result, the rate of adsorption will vary with the pH of an aqueous medium (Önal et al. 2006). Changes in pH of dye solution during the present adsorption study were determined by observing initial pH of dye solution and final pH of effluent dye after 1 h. Data shows that there was an increase in pH after adsorption of dye on sugarcane bagasse (Table 4). Initial pH of Optilan Red was acidic to neutral and became basic after the adsorption study. Generally, at low pH solution, the percentage of dye removal decreases for cationic dye adsorption, while for anionic dyes the percentage of dye removal increases (Salleh et al. 2011).

**Kinetic studies**

The pseudo-first-order and pseudo-second-order parameters are shown in Table 5. Results indicated that the values calculated and experimental \( q_e \) values are closer for all the five different samples. The higher values of correlation coefficient (R\(^2\)) showed that the pseudo-second-order kinetics model is well fitted to the experimental data. The result revealed that the pseudo-second-order kinetic model is more appropriate and effective than the pseudo-first-order kinetic model.

<table>
<thead>
<tr>
<th>Conc. of dye (ppm)</th>
<th>Initial</th>
<th>Final</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>6.3</td>
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</tr>
<tr>
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<td>40</td>
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<tr>
<td>50</td>
<td>7.1</td>
<td>7.9</td>
</tr>
</tbody>
</table>

**Breakthrough point**

The ratio of effluent dye concentration and initial dye concentration was used for determining the breakthrough point. The time at which the ratio was near to 1.0 indicated the breakthrough point. Breakthrough point was calculated for the highest concentration tested, i.e. 50 ppm of Optilan Red dye. The curve of \( C_e/C_0 \) (Figure 6) shows that the dye concentrations reached almost the breakthrough point at 120 min, indicating the saturation of the column.

**Desorption of the dye from column**

Desorption studies help to elucidate the nature of adsorption and recycling of the spent adsorbent and the dye
packed with sugarcane bagasse showed up to 93% dye results indicate the experiment with textile industry dye effluent also showed 100% desorption within 1 h, but Kumarn & Ahmad (2011) observed no desorption of crystal violet dye from ginger waste using NaOH and H2O. Mahmoddi et al. (2011) studied the desorption of three textile dyes from pinecone, and they reported the maximum desorption for Acid black 26, Acid green 25 and Acid blue 7 corresponding to 95.16, 26.97 and 98%, respectively. The present observations showed maximum desorption of dye from the column during initial 15 min (Figure 7) followed by a gradual decrease with elapsed time.

**CONCLUSION**

The column based filtration unit designed during the present study was fabricated by low-cost materials like polyethylene, PVC pipes, plastic sheet, etc. The unit can be easily fabricated using household tools and requires little technical skill. Sugarcane bagasse as agricultural waste material has little or no economic value and often poses a disposal problem; therefore, utilization of this material as adsorbent has great significance for the removal of different dyes from aqueous solutions under different operating conditions. The present study using column filtration unit packed with sugarcane bagasse showed up to 93% dye removal in the concentration range 10–50 ppm, and the results indicate the fitness of pseudo-second-order kinetics model on the experimental results of Optilan Red dye. Experiment with textile industry dye effluent also exhibited more than 90% dye removal, suggesting the feasibility of the developed device and processes for the treatment of dye-house wastewater.

**ACKNOWLEDGEMENTS**

The authors are thankful to Director, ICAR-Central Institute of Fisheries Education for the support to carry out the work. S. Gita acknowledges the valuable inputs from the advisory committee members and Dr Ram Subramanian for help in kinetic studies. Archroma India and Executive Garments Processors Pvt Ltd are acknowledged for providing the dye and the dye-house effluent for the study.

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First received 23 January 2017; accepted in revised form 9 May 2017. Available online 30 May 2017.