Textile Dye Removal from a Modified Adsorbent Material Made of Ceramic Waste and Gliricidia Sepium Biochar

Vinod Dissanayake*, Chanaka Udayanga

Faculty of Computing and Technology, University of Kelaniya, Kelaniya, Sri Lanka
*vinothshan.97@gmail.com

1. Introduction

A large quantity of wastewater is produced during the dyeing process in the textile and apparel industries. Water-soluble dyes are commonly used for the coloring of different substrates, like wool, nylon, polyester, etc[1]. At present, the color removal from the effluent has gained attention because of its visibility and environmental toxicity[2]. Various carbon-based adsorbents are used to remove these dyes from effluent because of their strong adsorption capacities and good removal efficiency[3]. However, high-quality activated carbon is costly, and sustainable development of this biochar has become imperative. In this regard, the current study focuses on the use of commonly available biomass and refused-derived materials to develop an efficient adsorbent for dye removal. The use of ceramics in Sri Lanka is extremely popular, and waste (pottery) is generated at a considerable level, but there are no recycling or reusing methods. Ceramic is made from natural clay, which can be used as an absorbent in the treatment of effluent [4]. Due to Biochar properties and renewable characteristics, Gliricidia Sepium can be used to produce biochar with an effective adsorption property. The purpose of this study is to exploit the possibility of developing a biochar-ceramic modified cost-effective and environmentally friendly adsorbent to remove textile dyes.

2. Materials and Methodology

2.1 Material Preparation

Ceramic waste (pottery waste) and Gliricidia Sepium biomass were obtained from the rural area of Katupotha in the Kurunegala district, Sri Lanka. Ceramic waste was washed and rinsed with normal water to remove dust particles and dried in an open area for 48 hours. Gliricidia log was chipped from a local sawmill and dried in an open area to remove free moisture. Ceramic waste and Gliricidia were ground into fine powder and both materials were sieved through 0.5 mm-mesh screens. Gliricidia Sepium biomass powder was further dried at 105°C in the oven for at least 24 h. Textile dyes used in the study were supplied by Baur & Co. (Pvt.) Ltd. Table 1 shows the summary of the dyes used for the study. .

Table 1. Supplied textile dyes by BBaur & co. (Pvt.) Ltd

Commercial name	Dye group
Spectron Red F3-B5	Reactive
Spectron Blue FBN	Reactive
Spectron Turq Blue-G 266%	Reactive

2.2 Moisture Analysis

A small quantity of sample was placed in a dry crucible and kept in an oven at 105 ° C for 24 hours. The weight loss was measured as the moisture content of the sample.

2.3 Pyrolysis Expriement

Samples were pyrolyzed in the lab muffle furnace (Nabertherm) at 500 ° C for 30 minutes to ensure the completion of the pyrolyze process.

2.4 Adsorbent Production

Pre-pyrolyzed mixed and Post-pyrolysed mixed methods were the main adsorbent production methods used in the study. Nine (09) types of adsorbent were produced using these methods with different ratios. All the productions were triplicated for reproducibility.

Pre-pyrolyzed mixed adsorbent production

Biomass and ceramic waste were mixed in ratios as shown in Table 2 and pyrolyzed to produce adsorbent. (e.g., B-100-C-0; Biomass 100% & Ceramic 0%). Fig. 1 shows the production process.

Table 2. Ratios of pre-pyrolyzed mixed adsorbent

Sample name	Biomass %	Ceramic %
B-100-C-0	100%	0%
B-75-C-25	75%	25%
B-50-C-50	50%	50%
B-25-C-75	25%	75%
B-0-C-100	0%	100%

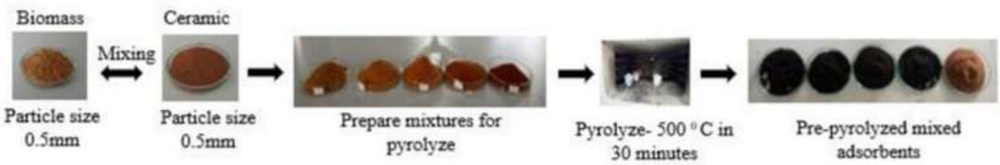


Fig.1. Pre-pyrolyzed mixed adsorbent Production Process

Post-pyrolysed mixed adsorbent production

Post-pyrolyzed mixed adsorbents are produced by mixing ceramic waste and biomass-derived biochar according to the ratios as shown in Table 3 (e.g., BC-75-C-25; Biochar 75% & Ceramic 25%). Fig. 2 shows the production procedure.

Table 3. Ratios of post-pyrolysed mixed adsorbent

Sample name	Biochar %	Ceramic %
BC-75-C-25	75%	25%
BC-50-C-50	50%	50%
BC-25-C-75	25%	75%
BC-0-C-100	0%	100%

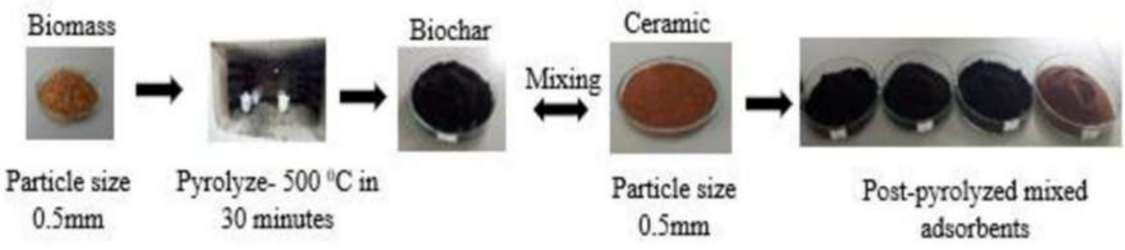


Fig. 2. Post-pyrolysed mixed adsorbent production Process

2.5 Adsorption Tests

Spectron Red F3-B5, Spectron Blue FBN, and Spectron Turq Blue-G 266% dyes were used for the adsorption study. Adsorption tests were performed with the following procedures.

1. Three samples of textile dye powder were dissolved in distilled water to produce a dye solution with a concentration of 25 ppm.

2. 1-g portions of nine (09) adsorbent powder specimens were placed into a test tube containing 10 mL of dye solution, and the dye solution was shaken with a digital orbital shaker (WITEG SHO-2D) at 150 rpm for 24 hours.
3. The dye adsorption was measured using a UV spectrophotometer (UV1800).
4. Based on the represented transmission, the adsorption capacities of the samples were quantified.
5. Blank dye samples were used to identify the self-degradation of the dye samples.
6. All the experiments were triplicated to ensure the reproducibility of the data.

2.6 Calculation and Analysis of Data.

The transmittance amount measured from UV spectrophotometers according to Beer-Lambert Law[5]. The dye removal efficiency of the adsorbents was calculated using Eq (1),

$$X = (A_i - A_f) / A_i \cdot 100\% \qquad (1)$$

where:

X – Adsorption efficiency (%)
A_i – Initial dye absorbance in the solution
A_f – Final dye absorbance in the solution.

3. Results and Discussion

3.1 Moisture Content

Moisture content is important because the effects of moisture content can be complex and depend on the material. The moisture content of the ceramic and biomass samples were 4.01 % and 11.07 % (w/w), respectively. Moisture content of the biomass were further reduced after the drying step to minimize any impact from the moisture.

3.2 Yields of Adsorbents

The yield of biochar produced from raw biomass (B-100-C-0) was 33% (Fig. 3) while the pure ceramic sample (B-0-C-100) pyrolysis yielded 95% probably due to the removal of moisture and some dirt at higher temperatures. Except for B-100-C-0 and B-0-C-100 samples, all the other pre-pyrolyzed mixed composites are combinations of ceramics and biochar. The yield can depend on several factors such as biomass type, pyrolysis conditions such as temperature, heating rate, and duration, as well as preparation of samples such as sample size [6]. According to the mixing ratios of ceramic-biomass, produced composites yields were changed and they were aligned with the pyrolysis yields of B-100-C-0 and B-0-C-100. The amount of ceramic directly affects the yield because the ceramic weight would not change considerably after the pyrolyzed process. Compared to the post-pyrolyzed mixed process, the pre-pyrolyzed mixed process with the same ratios contains less amount of biochar. For instance, BC-50-C-50 contains 50% of biochar while B-50-C-50 has only 17% biochar.

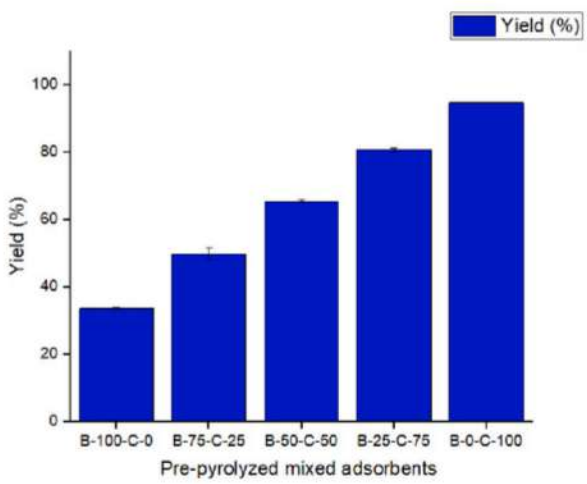


Fig. 3 Yields of five types of Pre-pyrolyzed mixed adsorbents yields. (n ≥2, error bars show STDVA)

When considering the post-pyrolyzed mixed adsorbents not consider their yield because they are produced from non-pyrolyzed physical methods.

3.3 Transmittance of adsorbents from each textile dye solution

When measuring transmittance, considering the maximum absorbent represented, three wavelengths were used for the three types of textile dyes (610,625 and 540 Nm). All the composites showed distinct features in transmittance. Figs. 4, 5, and 6, show the percentage of transmittance for three types of textile dyes separately. Transmittance values were high for pre-pyrolysed mixed samples for all three dyes showing some synergistic effect in premixing biomass with ceramics. Fig. 4 shows the transmittance of Spectron Turq Blue-G (26.6%) which is a reactive dye. The composites effectively adsorbed this dye more than other textile dyes. According to the graph, B-100-C-0, B-25-C-75, and BC-50-C-50 composites reach a higher transmittance while B-25-C-75 composites reach a stand-out transmittance of 93.5 %.

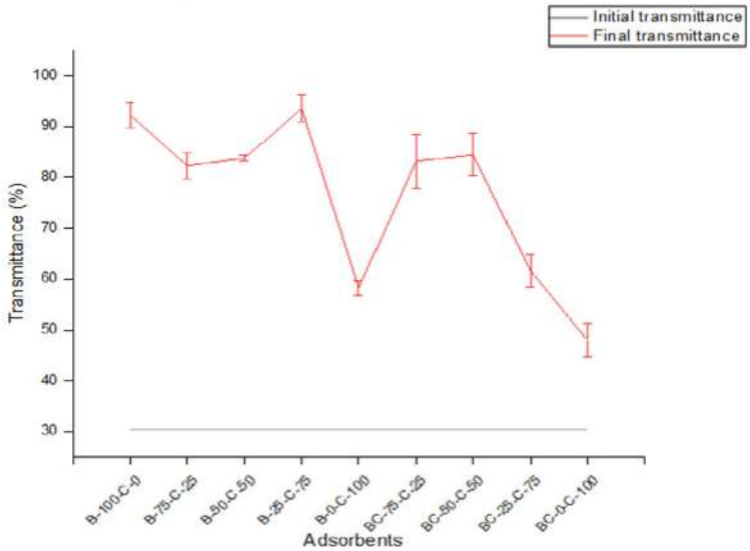


Fig. 4. Transmittance of Spectron Turq Blue-G 266%

Fig. 5 shows the transmittance results of Spectron Blue FBN. Similar to Figure 4, B-100-C-O, B-25-C-75, and BC-50-C-50 represent a high level of transmittance, but a high value takes B-100-C-O composite. B-0-C-100 showed the lowest levels of transmittance emphasizing the poorer adsorbing characteristics of ceramic samples.

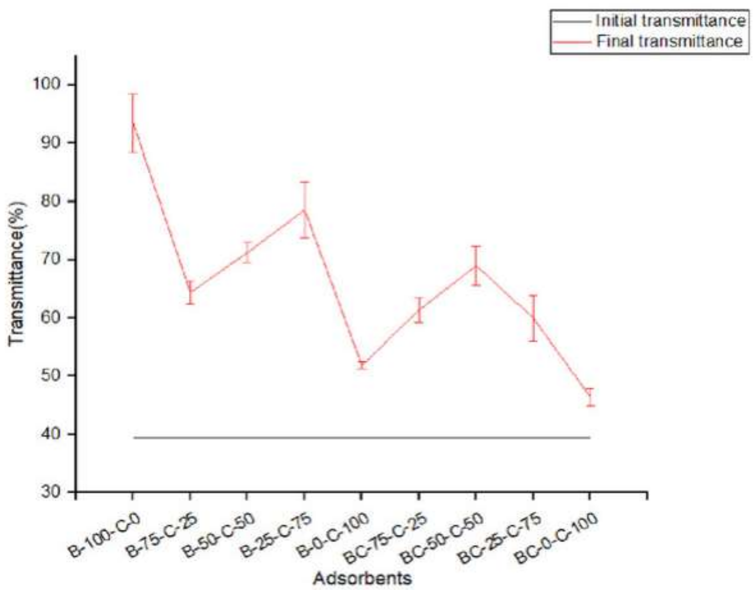


Fig. 5. The transmittance of Spectron Blue FBN

Fig. 6 shows Spectron Red F3-B5 textile dye adsorption by the adsorbent. Final transmittance percentages varied significantly across the composites, ranging from 48% - 89%. Except for BC-25-C-75, all the other composites showed similar transmittance levels while B-25-C-75 showed the best performance among others.

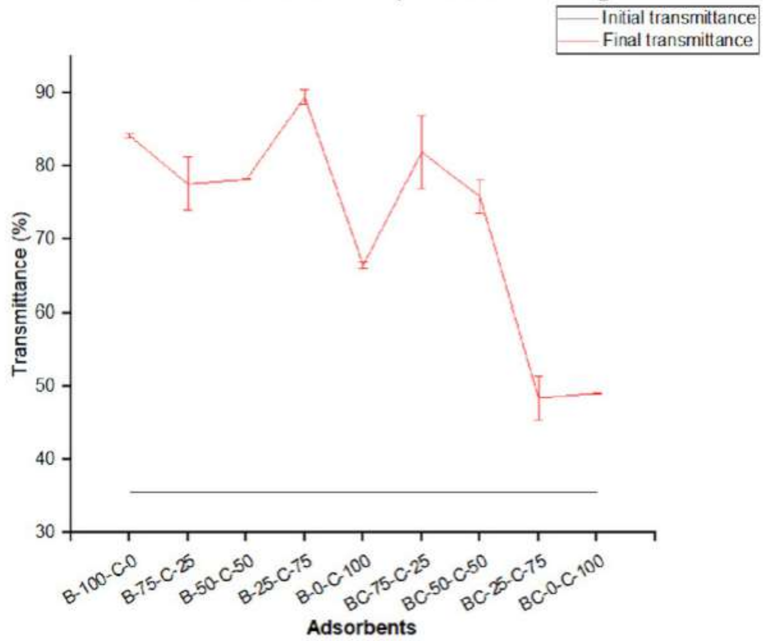
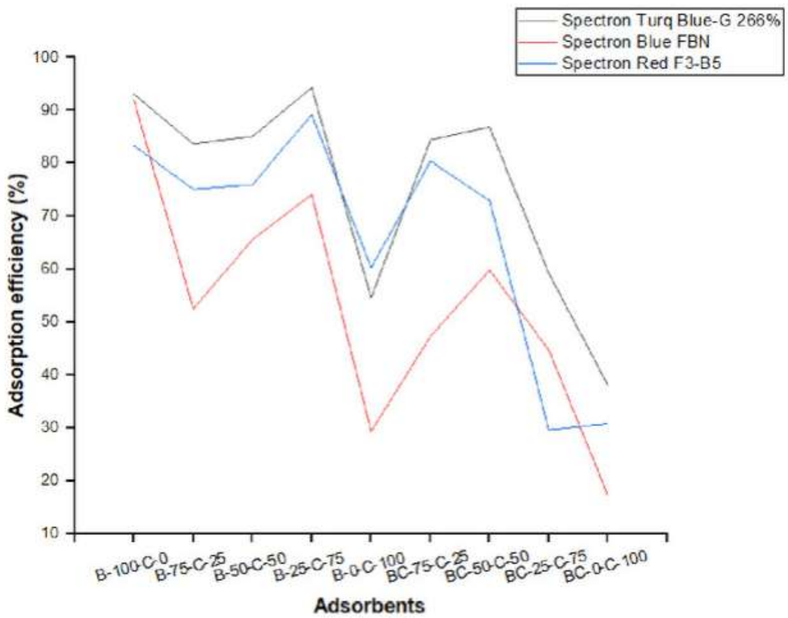


Fig.6. Transmittance of Spectron Red F3-B5

3.4 Adsorption Efficiency

The Fig. 7 represents the adsorption efficiencies of the composites for all the dye samples. B-100-C-0, B-25-C-75, and BC-50-C-50 composites showed the best results. B-100-C-0 had shown the highest adsorption efficiency probably as it contains the highest biochar amount among adsorbents. Despite containing less amount biochar, B-25-C-75 had shown similar characteristics to B-100-C-0. BC-50-C-50 also showed good adsorption efficiency except for Spectron Red F3-B5 dye. B-0-C-100 and BC-0-C-100 only contain ceramic show different adosption efficiencies. According to the results, B-0-C-100 has higher adsorption efficiency compared to BC-0-C100 indicating the effect of pyrolysis on B-0-C-100..



3.5 Carbon (biochar) amount distribution

Due to differences in preparation, adsorbents contain different carbon amounts. Table 4 shows the calculated carbon content of each composite. Carbon amounts were calculated based on the yield of biochar from biomass. The results adsorption studies and Table 4 clearly show that despite having lower carbon amounts, pre-pyrolyzed mixed adsorbent had better properties and adsorbed significant portion of dyes showing clear synergistic affect. This approach helps in developing low-cost adsorbents by using high ceramic amounts and low biochar amounts. A low amount of biomass pyrolyzed with a high ceramic amount gave ideal material for dye adsoption.

Table 4. Carbon amount of 1g dose and adsorption efficiency

Sample name	Biomass (g)	Ceramic (g)	Actual carbon amount (g)	Adsorption efficiency (%)
B-100-C-0	1.00	0.00	0.33	83.26
B-75-C-25	0.75	0.25	0.25	75.22
B-50-C-50	0.50	0.50	0.17	76.12
B-25-C-75	0.25	0.75	0.08	89.17
B-0-C-100	0.00	1.00	0.00	60.38

Sample name	Biochar (g)	Ceramic (g)	Actual carbon amount g	Adsorption efficiency (%)
BC-75-C-25	0.75	0.25	0.75	80.47
BC-50-C-50	0.50	0.50	0.50	73.10
BC-25-C-75	0.25	0.75	0.25	29.69
BC-0-C-100	0.00	1.00	0.00	30.92

Conclusion

The study successfully developed a cost-effective adsorption material using ceramic waste and Gliricidia Sepium for potential use in textile dye removal from aqueous solutions. The results clearly showed the synergistic effect of pre-prolyzed mixed adsorbent, specespeciallyB-25-C-75 which has less than 10% biochar. The adsorption efficiency of B-25-C-75 is close to the B-100-C-0 which has 100% biochar. Pure ceramic samples didn't show efficient dye removal. On contraty, pyrolyised ceramic showed better adosrbnet amounts. Further studies are recommended to explore the reasons behind this observation. Performance of the adsorbent under various operating conditions, its applicability to a wider range of textile dyes as well as long-term stability and economic viability should be assessed prior to large-scale development of the product.

Keywords: Adsorption; Textile dye treatment; Gliricidia Sepium; Biochar-Ceramic adsorbents

Reference

1. S. Benkhaya, S. El Harfi, and A. El Harfi, 'Classifications, properties and applications of textile dyes: A review', */ Appl. J. Envir. Eng. Sci*, vol. 3, pp. 311–320, 2017, Accessed: Jun. 17, 2024. [Online]. Available: https://doi.org/10.48422/IMIST.PRSM/ajees-v3i3.9681
2. R. Al-Tohamy *et al.*, 'A critical review on the treatment of dye-containing wastewater: Ecotoxicological and health concerns of textile dyes and possible remediation approaches for environmental safety', *Ecotoxicology and Environmental Safety*, vol. 231. Academic Press, Feb. 01, 2022. doi: 10.1016/j.ecoenv.2021.113160.
3. S. Praveen, J. Jegan, T. Bhagavathi Pushpa, R. Gokulan, and L. Bulgariu, 'Biochar for removal of dyes in contaminated water: an overview', *Biochar*, vol. 4, no. 1. Springer, Dec. 01, 2022. doi: 10.1007/s42773-022-00131-8.
4. S. A. Khaleefa Ali, B. M. Fahad, and H. T. Hamad, 'Effect of ceramic waste as an adsorbent', in *IOP Conference Series: Materials Science and Engineering*, Institute of Physics Publishing, Mar. 2020. doi: 10.1088/1757-899X/737/1/012193.
5. Ken Phillips, 'The Amazing World of Color Technology: Absorption, Transmittance, and the Beer-Lambert Law', Hunterlab.
6. K. Yasui, K. Sasaki, N. Ikeda, and H. Kinoshita, 'Dye adsorbent materials based on porous ceramics from glass fiber-reinforced plastic and clay', *Applied Sciences (Switzerland)*, vol. 9, no. 8, Apr. 2019, doi: 10.3390/app9081574.