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Competitive Removal of Color from Textile Effluents in Bangladesh by Activated Carbon and Lime in Batch and Fixed Bed Column Experiments

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Abstract

Being a developing country, achieving effective wastewater treatment in textile industry has proven to be a difficult task in Bangladesh. Color is an important parameter in case of reuse of treated water. Activated carbon is a widely-used effective low-cost adsorbent for treating industrial wastewater. Using $Ca(OH)_2$ along with activated carbon can further increase its effectiveness. In this research work, the removal of color from Bangladeshi textile industry effluent has been investigated. Both batch and fixed-bed column experiments have been conducted in this study. After multiple trials and errors, the optimal dosage of activated carbon was determined from the batch reaction. There was reduction of color up until 24 hours in case of both batch reactions and fixed-bed column studies. Fixed Bed Column showed higher efficiency in reducing color compared to jar reaction. Changes in other parameters such as turbidity, TDS and pH were also noticed. The removal efficiency of color obtained from fixed bed column was 98% for 6-inch bed height and 94% for 3-inch bed height. However, usage of lime has caused an increase in pH value. From the results, it is clear that achieving satisfactory color value for reuse is possible this way.

Keywords: *Textile effluent; color removal; fixed bed column; batch reaction; activated carbon.*

1 Introduction

Approximately 82% of Bangladesh's entire export revenues, which reach close to 28 billion USD annually, come from the textile industry. The garment industry still accounts for 50% of the nation's industrial employment and almost 77% of its current foreign exchange earnings (European Commission, “Guide book for European investors in Bangladesh). According to Berg et al.'s (2021) estimation, Bangladesh accounts for 84% of the nation's total export.

The industrial sectors of Bangladesh, such as the textile, tannery, steel, and paper industries, use roughly 95,000,000 m^3 of groundwater per day (or nearly 98% of the total national water supply), while the textile industry contributes by using 40,130,00 m^3 (42% of this amount) each day. (Haque et al., 2021). Around 93 billion cubic meters of water is used annually for textile production, accounting for 4% of the world's freshwater withdrawal (Water and Clothing, 2019). The tube wells, used for drawing of water for these industries, may draw water from alluvial aquifers that are located between 10 and 60 meters below ground level and the level of groundwater is dropping by 2-3 meters every year. According to the analysis, by 2050 the groundwater table will be between 110 and 115 meters below sea level (Zahid, 2015). Multiple chemicals and dyes cause a variety of water quality metrics to degrade from their ideal state. There are many distinct types of dyes, including fiber tracing, general-purpose dyes, all-natural dyes, disperse dyes, azoic dyes, direct dyes, and vat dyes (Gordon, 1990; Textile Infomedia, 2021). Wargala et al. (2021) showed that these coloring agents have harmful effects on human body.

Depending upon which parameter to change, multiple types of traditional dye removal treatments have been intensively investigated in recent decades. Color is the most disagreeable of all the effluent parameters since it is a prominent one that may be immediately noticed (Bryant 1992; EPA 1999). Textile effluent color is of two types-true color and apparent color. True color is caused by the presence of soluble chemical elements, while apparent color is caused by the presence of colloidal and suspended particles (Cheremisinoff, 2002; Spellman 2020). This study follows the adsorption process for the removal of color. During the adsorption process, specific fluid phase components are drawn to the surface of a solid adsorbent through the formation of physical or chemical interactions. The component is then taken out of the fluid phase (Foo and Hamid, 2010). According to Tanthapanichakoon et al. (2005), the properties of absorbent materials and the absorbent surface with the effect of other ions, particle size, solution, pH, temperature and contact time can all influence the quality of the liquid phase adsorption process. Due to this, activated carbon (AC) has been shown to be an excellent adsorbent for the removal of different organic and inorganic contaminants dissolved in aqueous medium or in the gaseous environment (Gomez et al., 2007). In Bangladesh, there is little research using activated carbon for recycling effluent.

2 Literature Review

Various methods are combined and adjusted to the particular colors used and the desired effluent quality. These techniques were chosen to ensure efficient treatment and satisfy the necessary standard for wastewater treatment. Conventional activated sludge, anaerobic, aerobic, physical (adsorption, membrane filtration), coagulation and flocculation, electrochemical (electrocoagulation), and chemical (oxidation, ozonation, AOPs) methods are used to remove dyes in textile industry effluent treatment plants (Critteden et al., 2005; Bidhenhi et al., 2007)
Color, turbidity, and COD can be successfully reduced using electrochemical and chemical coagulation techniques. Malakootian and Fatehizadeh (2010) showed the rise of the pH of the water treatment process employing jar equipment, lime, and NaOH as softening agents. At various pH levels, color removal was accomplished by using alum and ferric chloride coagulants to increase floc size.

Popuri and Pagala (2019) describes the efficacy of various methods and environmental factors for color removal from green dye effluent. The adsorption method achieved the most impressive color removal by using activated carbon generated from sawdust. Manaf, (2005) stated that depending on the type of carbon the characteristics of the wastewater, activated carbon (AC) adsorption treatment has been shown to be an efficient replacement for combined biological and chemical treatment. This is a preferable method for recycling effluent’s wastewater from several easily available materials like rice husk (Van & Thuy, 2019), coconut tree sawdust (Kadirvelu et al., 2000), sugarcane bagasse (Mahanta et al., 2019), grape seed (Okman et al., 2014), date palm (Ahmad, 2012), neem leaves (Qadir & Chhipa, 2017), banana peel (Chafidz, 2018) are used as a source to produce activated carbon (Ho & Khan, 2020). Activated Carbon also has a high regeneration potential (Nasruddin et. al, 2018).

Al-Zawahreh et al. (2022) showed significant removal of textile dyes using pine bark compost in both batch and fixed bed column experiments. In both single and competitive settings, the ability of pine bark compost to remove the textile dyes. Ethanol column regeneration was successful, especially for preconcentrating textile dye streams. Thuong et al. (2018) conducted a Fixed-Bed Column study for removing organic dyes from aqueous solution by pre-treated durian peel waste. In the instance of the fixed bed column test, various flow rates and bed heights (2 cm, 4 cm, and 6 cm) were used. Cationic dyes like methylene blue and crystal violet showed excellent adsorption efficiency on durian peel when used in a column mode. The effectiveness of the removal, the breakthrough, and the exhaustion periods were all influenced by the initial dye concentration, flow rate, and bed height.

It is essential to work together in research and innovation to create a "Water efficient Europe" (Vajnhandl et al. 2014). The European Innovation Partnership on Water (EIP) aims to foster the creation of commercial possibilities and innovative approaches to water-related problems. The textile industry takes an active part in the EIP, especially when it comes to converting wet textile processes into dry, energy-efficient ones. Water reuse and recycling are gaining popularity in the textile sector and the treated wastewater may be recycled for irrigation and fabric processing (Bhuiyan et al, 2015).

3 Data Collection & Methodology

3.1 Sample Collection

The sample water collection was carried out at Masco Concept Knitting Ltd., located in Gazipur. The collected samples are from two different stages. One from the pit after going through the biological tank. And another from before going through any treatment process in the ETP.

3.2 Jar Test

Six jars, each holding 500 ml of sample water, were used for the Jar Test. Each jar was treated with 1 mg (2 mg/L) of powdered Calcium Hydroxide. After the addition of Calcium Hydroxide, the jars were placed in a flocculator and stirred at 100 rpm for a minute. Then, each jar received a graduated addition of Powdered Activated Carbon, commencing with 0.5 mg (1 mg/L) in the first jar, 1 mg (2 mg/L) in the second jar, 1.5 mg (3 mg/L) in the third jar, and so on. The jars were then returned to the flocculator and mixed at a speed of 60 rpm for 10 minutes. Testing was carried out immediately after the settling period, and follow-up tests were conducted at intervals of 24 and 48 hours. Sperate tests were conducted both using filter paper and without the use of filter paper.

Figure 4. Jar test and Fixed-Bed Column experiment.

3.3 Fixed-Bed Column Experiment
In this experiment, we used a glass column with a dimension of 6.5''x6.5''x12''. The column was assembled using Granular Activated Carbon, and we conducted tests at bed heights of 3" and 6". We began by adding a 2 mg/L dosage of Calcium Hydroxide to 1000 mL of the sample water. The sample was then subjected to flocculation for one minute at a rate of 100 rpm. The sample water solution was then introduced into the column, and we maintained control over the flow at the outflow at a rate of 50 ml/min. After passing through the column once, we tested the samples at varying time intervals (0-hour, 0.5-hour, 1 hour, 2 hours, 3 hours, 6 hours, and 24 hours) to evaluate different physicochemical characteristics.

3.4 Chemical Used
Powdered Activated Carbon (PAC), Granular Activated Carbon (GAC), Lime ($Ca(OH)_2$)

3.4.1 Activated Carbon
Activated carbon is recognized for its superior absorption performance and cost-effectiveness. Activated carbon's increased adsorption capacity is a result of its large surface area and well-developed micropores. According to Hu Zian (2018), the interaction of different forces, including as van der Waals forces and electrostatic action, is what essentially drives the adsorption property of AC. Because of its enormous, porous surface area and natural attraction force, AC may trap and hold a variety of substances on its surface. As a result, specific compounds are effectively eliminated from the wastewater. Fares (2018) claimed that the adsorption ability of AC powder increases the treatment's effectiveness.

3.4.2 Lime
Calcium hydroxide, also known as $Ca(OH)_2$ or lime, plays a crucial role in water treatment processes, primarily through increasing the pH level and precipitating ions responsible for water hardness. Apart from these functions, lime exhibits several advantages in conventional wastewater chemical treatment. It aids in pH regulation, oxidizable organic pollutant reduction, clarification, precipitation of dissolved pollutants, the flocculation of colloidal particles as well coagulation. Occasionally, lime serves as a supportive agent in processes such as coagulation, flocculation, and adsorption. Asadollahfardi (2018) found lime to be a relatively superior coagulant in jar tests. Malakoutian (2010) discovered that how effectively color removal happens and with any increased use of lime. Primarily used as a softener, lime, when employed as an aid, binds with other particles, augmenting the mass of the flocs, and subsequently accelerating their settling speed in water.

3.4.3 Isotherm Method
The adsorption isotherm is a method for assessing a chemical material's capability for adsorption and establish the relationship between the amount of color removed and the amount of carbon required for color removal. To understand the thermodynamic phenomena of activated carbon adsorption we have employed two different types

of isotherms in our study. They are: Freundlich isotherm and the Langmuir isotherm. The Freundlich isotherm equation (Dada et. al, 2012) is stated in linear form by:

$$\ln\left(\frac{X}{M}\right) = \ln(k) + \frac{1}{n} lnC \qquad (1)$$

The Langmuir isotherm can be expressed by the following formula:

$$\frac{1}{\frac{X}{M}} = \left(\frac{1}{ab}\right)\left(\frac{1}{C}\right) + \left(\frac{1}{a}\right) \qquad (2)$$

here, k = empirical constant (y -intercept), n= slope-inverse constant, X = adsorbent actually adsorbed by Carbon (color difference), M= Carbon Dose, mg/L, C = final color, a & b = Langmuir parameters

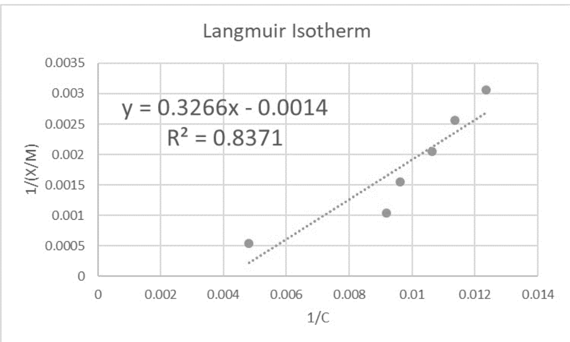
4 Results & Discussion

Two sets of raw water were collected as mentioned before. Table 1 shows the water quality of the two sets of raw water.

Table 1. Water quality of the raw water with standard.

Characteristics	Unit	Sample Value (ETP Treated)	Sample Value (Wastewater before being treated in ETP)	Standard (Maximum Limit for the Parameters of Textile Wastewater, ECR 2023)	Standard (for discharge in irrigated land) (Source: ECR 1997)
pH	-	7.73	9.76	6-9	6-9
Turbidity	NTU	26.20	47.4	-	-
Color	Pt-Co	640	2044	150	-
TDS	g/L	2.54	3.30	2.10	0.60
Fe	mg/L	1.86	2.66	0.10	2
Mn	mg/L	0.172	0.32	-	5
COD	mg/L	7.00	124.63	200	400

Compared to the ECR 1997 guidelines for discharge in irrigated land and ECR 2023 guidelines for maximum limit for the parameters of textile wastewater most of the values of the raw sample water do not comply with the standards (Table 1).



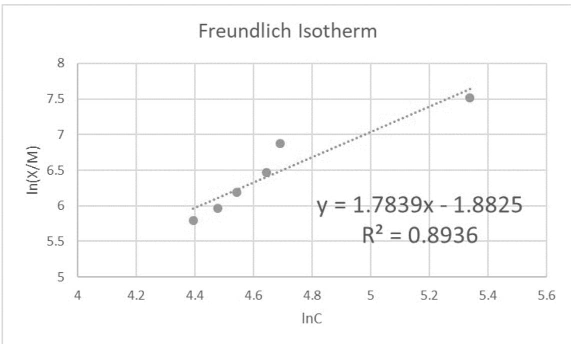


Figure 2. Langmuir & Freundlich isotherms for Color Reduction

4.1 Batch Reaction Results

For Freundlich isotherm, the trendline shows that no point acts as outlier and forms a strong correlation of parameters. The value of k and n is -1.8825 and 0.56 respectively. In case of Langmuir isotherm, the value of a and b are -714.285 and -0.00428 respectively. Comparing these two, Freundlich isotherm provides more accurate constants.

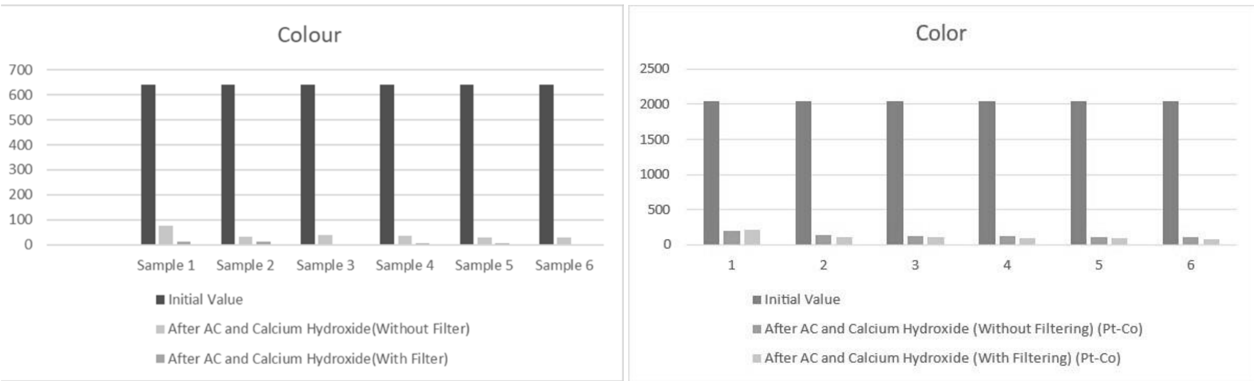


Figure 3. Reduction of color in jar test (ETP treated sample and before ETP treated sample).

Table 2. Results of color after 24 hours.

	Sample	PAC Dosage, g/L	Lime Dosage, g/L	Initial Value, Pt-Co	After Addition of PAC and Lime (Without Filter), Pt-Co	After Addition of PAC and Lime (With Filter), Pt-Co	Standard (Maximum Limit for the Parameters of Textile Wastewater, ECR 2023), Pt-Co
ETP treated sample	Jar 1	1	2	640	75	13	150
	Jar 2	2	2		33	12	
	Jar 3	3	2		39	0	
	Jar 4	4	2		35	5	
	Jar 5	5	2		30	7	
	Jar 6	6	2		29	2	
Before ETP treated sample	Jar 1	1	2	2044	234	208	150
	Jar 2	2	2		173	109	
	Jar 3	3	2		155	104	
	Jar 4	4	2		154	94	
	Jar 5	5	2		140	88	
	Jar 6	6	2		132	81	

Table 3. Column test for Color reduction.

Time	Initial Color, Pt-Co	3” Bed Height, Pt-Co	Removal Efficiency for 3”	6” Bed Height, Pt-Co	Removal Efficiency for 6”	Standard, Pt-Co
0 Hour	2044	481	0.76	287	0.86	150
0.5 Hour		336	0.83	252	0.88	
1 Hour		336	0.83	138	0.93	
2 Hour		267	0.87	100	0.95	
3 Hour		197	0.90	84	0.96	
6 Hour		105	0.95	70	0.96	
24 Hour		120	0.94	41	0.98	

Table. 2 represents changes in color at different time interval for different dosages. Powdered activated carbon of 1gm/L, 2gm/L, 3gm/L, 4gm/L, 5gm/L, 6gm/L was added to each jar respectively. Initially the color was 640 Pt-Co and it was decreased to 2 Pt-Co for 6gm/L of activated carbon after 24 hours. After filtering with filter paper, we can see further decrease in color (Figure 3). In case of waste water before being treated in ETP, the initial value is much more compared to wastewater after ETP. Though color reduction can also be achieved this way and dosage more than 5 mg/L of PAC can give us color value under the maximum limit for textile wastewater. After 24-hour only 2 mg/L PAC dosage is enough.

4.2 Fixed Bed Column Experiment Results

For a 6” bed height color removal is the most after 24 hours and the standard color can be achieved even for wastewater sample taken before ETP. Table 3 shows, the comparison between the removal efficiency of color between 6in and 3in bed. A higher bed height shows higher removal efficiency. 98 percent removal efficiency can be seen in case of 6” bed height.

5 Conclusion

In the study conducted on textile wastewater treatment, it became apparent that both the Fixed-Bed Column and Jar Reactions methods played a crucial role in achieving the desired standard color. However, the Fixed Bed Column exhibited a higher efficiency in reducing color compared to Jar Reactions within a specific time period. Interestingly, increasing the bed height in the Fixed Bed Column showed an even greater reduction in color, indicating the importance of bed design in optimizing treatment performance. Regarding the determination of optimal carbon dosage for color removal, the Freundlich Isotherm was found to be more suitable. Significant improvements were observed in various water quality parameters. Overall, the discoveries of this study reveal useful details in the effectiveness of different treatment methods and their impacts on various water quality parameters, which can be utilized for the efficient and sustainable treatment of textile wastewater.

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