Removing Reactive Dyes from Textile Effluent Using Banana Fibre

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***Abstract*— The ability of a particular banana fibre in removing reactive dyes from textile wastewater was studied in the present work. Locally available ground seeded banana fibre of ≤ 212 μ was used as adsorbent. Initially the adsorbent was tested on standard Novacron Blue FN-R reactive dye solutions and then it was also applied to raw textile wastewater. The adsorbent was found very effective to remove reactive dyes from water. The adsorption was found dependent on pH, contact time, adsorbent/dye ratio and initial concentration of the dye solution. It was found that the adsorption efficiency became maximum at pH 2 and it decreased with increasing pH. The adsorption was quite fast; approximately 90% of removal efficiency was achieved in 5 m, and the adsorption was completed in 20 m under suitable conditions. It was observed that at adsorbent-dye ratio of 333:1, the adsorbent was able to eliminate the reactive dye completely from standard aqueous solution within 20 m at pH 2. The removal efficiency decreased with increasing concentration of dye solution. When the adsorbent was applied to raw wastewater containing three reactive dyes Novacron Blue FN-R, Novacron Yellow FN-2R, and Novacron Red-FN 3GL, it was obtained that 1.0 g of adsorbent was able to convert 30 mL of deep colored wastewater into colorless and transparent water at pH 2. The values of DO, COD, TS, TDS, TSS, salinity and conductivity of wastewater were comparable before and after the interaction with the adsorbent.**

***Index Term*— Adsorbent, adsorption, banana fibre, Novacron Blue, reactive dye, wastewater**

I. INTRODUCTION

Modern science and innovative technologies have blessed us with durable, glamorous, bright and colourful things of daily and occasional needs. As the population of the world is growing rapidly, the demands for such things are increasing day by day. To meet the demands, dye consuming industries including textile, paper, leather, printing, plastic and carpet, are expanding. As a result, the uses of dyes are increasing dramatically.

Worldwide 10,000 types of commercially available textile dyes production reached approximately 7.10×10^5 metric tons every year [1].

It has been estimated that 10-25% of textile dyes are lost during the dyeing process, and 2-20% of such dyes are directly released as aqueous effluents in various environmental constituents [2]. The estimated amount of textile dyes discharged globally every year is 280,000 tons [3] leading to significant water pollution, a great problem in contemporary time. The World Bank has estimated that almost 20% of global industrial water pollution comes from the treatment and dyeing of textiles [4]. In many developing countries particularly in India, China, and Bangladesh, the dye-enriched textile wastewaters are not treated at all, they are just dumped into various water bodies, which are ultimately contributing to environmental degradation, killing aquatic lives, and harming human health [5, 6, 7, 8, 9, 10].

For more than 90% of the earth's population, water is a limited resource with many regions having less than 10 L/day/person availability. In contrast, the textile processing industry requires 50-150 L/kg of textile material processed [11]. In these circumstances, discharge of industrial effluents into water bodies without treatment is indeed a matter of great concern.

At present, primary, secondary, and tertiary methods have been used worldwide to treat wastewaters. Processes involved in primary treatment are mainly physical, and include screening, sedimentation, flotation and flocculation to remove fibrous debris, insoluble chemicals and particulate matter [11]. Primary treatment cannot significantly remove coloured materials. Secondary stages are designed to eliminate the organic load and consist of a combination of physico-chemical separation and biological oxidation [11]. Biological treatment also cannot remove sufficient coloured materials. Physico-chemical separation depends on the forces of chemisorption to extract the colloidal organic compounds from the liquid phase [11]. Tertiary stages of treatment have become more important but they make a major contribution to treatment costs. These stages are important for the removal

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of coloured materials and no single treatment can deal with the removal of all types of coloured substances [11].

In recent years, the uses of natural adsorbents have gained a remarkable importance due to their low cost, environmental friendliness, local availability, and sustainability [12]. Monika Kharub reported that different adsorbents and commercial activated carbon are preferred sorbents for color removal, however, they are not widely used because of high cost. It is evident from the literature that low-cost sorbents have demonstrated outstanding removal capabilities for certain dyes [13].

Many agricultural wastes and natural adsorbents have been tested for the purpose of eliminating the dyes from textile effluents [14, 15]. Wong *et al.* [16] studied the removal of basic and reactive dyes using sugarcane bagasse. In his study, removal of Basic Blue 3 (BB3) and Reactive Orange 16 (RO16) were studied in single and binary systems. The effect of pH was found noticeable in the sorption of dye, and the optimum pH was determined in the range of 6-8.

Ong *et al.* [17] studied the removal of basic and reactive dyes using ethylenediamine modified rice hull. Dyes used in that study were Basic Blue-3 (BB3) and Reactive Orange-16 (RO16) in both single and binary systems. Various important parameters such as pH, initial dye concentration, sorption isotherm, agitation rate, particle size, and sorbent dosage were investigated by using batch adsorption studies. The results showed that the sorption of targeted dyes were pH and concentration dependent. The uptake of BB3 was favoured at high pH whereas that of RO16 was favoured at low pH. An enhancement of 4.5 and 2.4 fold were reported for BB3 and RO16, respectively, in binary dye systems.

Pavan *et al.* [18] studied the removal of Methylene Blue dye from aqueous solution by adsorption using yellow passion fruit peel as adsorbent. It was observed that an alkaline pH was favourable for the adsorption of Methylene Blue, and the maximum adsorption was achieved at 56 hours of contact time.

Gupta *et al.* [19] studied the adsorption of hazardous dye, Erythrosine, over hen feathers. The parameters studied included pH, concentration of dye, temperature, and dosage of adsorbent. The reported optimum pH range for the removal of Erythrosine was 3-8. It also showed that as the temperature was increased, the adsorption of dye was also increased.

Weng *et al.* [20] investigated the removal of Methylene Blue (MB) from aqueous solution by adsorption onto pineapple leaf powder (PLP). Methylene Blue adsorption increased as the initial Methylene Blue concentration was increased. Increasing pH also contributed to the favourable adsorption of MB. The maximum sorption capacity of PLP was reported as 8.88×10^{-4} mol/g at pH 7.5 and 24°C.

Orange peel was used as sorbent by Arami *et al.* [21] for the removal of Direct Red 23 (DR23) and Direct Red 80 (DR80) from textile effluent. Results obtained were successfully fitted to the Langmuir non-linear adsorption isotherm. Maximum sorption capacities were recorded as 10.718 mg/g and 21.052 mg/g for DR23 and DR80, respectively. It was also observed that acidic pH was favourable for the adsorption of dyes onto orange peel.

It is reported that zeolites have a great potential as effective sorbent material for a large number of water treatment applications such as water softening , ammonia removal, removal of heavy metals, removal of dissolved organic compounds and dyes, oil spillages treatment, separation of solid impurities, radioactive wastewater purification, seawater desalination, PRB, and many others [22].

In the current study, banana fibre was tested as an adsorbent to remove Novacron reactive dyes from textile effluents. This is because of the fact that the adsorbent is native, easily available, efficient, and cost-effective. The adsorbent is also eco-friendly, renewable, and easily disposable.

Previously ability of banana fibre was observed to remove Methyl Red [23] and Malachite Green [24]. However, to the best of our knowledge, no work has been done to check the ability of banana fibre to remove Novacron Blue FN-R reactive dye, a widely used dye in Bangladesh particularly.

The climate of Bangladesh is suitable for banana plants and it is widely grown in here. Even without formal cultivation, various types of banana plants grow in all parts of Bangladesh. Banana plants are primarily grown for the fruit, however, certain part of the flower and tender part of the peduncle are edible, though their consumptions are very limited. Being a herb, a banana plant bears fruit once in lifetime; and when it is done, the plant comes in no use in general, so it is cut down and thrown away as waste for natural decomposition.

Therefore, the use of banana fibre for removing dyes from textile wastewater not only results in better management of the plants but also explores the further utilization of the fibre.

II. MATERIALS AND METHODS

Materials

The banana fibre adsorbent was collected from the local sources. Novacron Blue FN-R reactive dye was obtained from Hantsman (Singapore) Pvt. Ltd. Dhanmondi, Dhaka, Bangladesh and was used without further purification.

Hydrochloric acid and sodium hydroxide were purchased from Merck, Germany. Cellulose nitrate filter paper was bought from Biotech GmbH, Germany.

Methods

The bark like part of the banana pseudo-stem was removed from the plant and cleaned with distilled water. Then it was chopped into pieces of about 2 cm × 2 cm, which were boiled in distilled water for two hours. The boiled sample was washed 3 times with distilled and deionized water, and then the sample was dried at 80°C in an oven for 24h. After drying, the sample was ground with a blender (Philips, HR2118). Finally, the ground sample was strained with a sieve shaker (FiltraVibracion SL, Model FLT 200) using a sieve of 212 μ pore size. The appearance of the adsorbent at different stages is shown in Fig. 1.

A B

Fig. 1. Appearance of the adsorbent: A. Before boiling. B. After staining.

For drawing the calibration curve, a stock solution of Novacron Blue FN-R dye was prepared by dissolving 0.1 g of dye in distilled water in a 1 L volumetric flask. The stock solution was then diluted by adding distilled and deionized water to make standard solutions of different concentrations. The standard solutions were scanned by a UV-Visible spectrophotometer (DR/4000U, HACH) to find out the λ_{max} of the dye. A calibration curve was drawn by measuring the absorbance of the prepared standard solutions at the obtained λ_{max}.

For the interaction of the adsorbent and dye solution, a particular amount of banana fibre was taken in a small beaker and Novacron Blue FN-R reactive dye solution was added to the beaker. A magnet was inserted in the beaker which was then placed in a magnetic stirrer for a specific time. After that the adsorbent was separated from the aqueous phase by filtration with the help of cellulose nitrate filter. Finally, the dye concentration in the filtrate was measured by the UV-Visible spectrophotometer at the obtained λ_{max}. The flow diagram of the experimental setup is shown in Fig. 2.

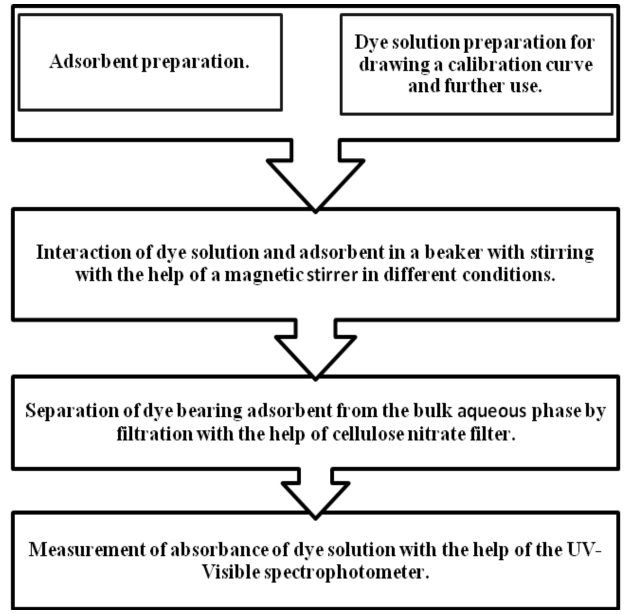

Fig. 2. The flow diagram of the experimental setup

III. RESULT AND DISCUSSION

Banana fibre adsorbent

Collected banana fibre was boiled with distilled water to remove lignin that can interfere in the measurements [23]. The ground fibre was heterogeneous in size. The ground fiber was sieved to obtain the particles size of ≤ 212 μ for adsorption experiments. Larger particles were avoided due to their less surface area.

Calibration curve

For developing the calibration curve for Novacron Blue FN-R dye, standard dye solutions of 10, 15, 20, 25 and 30 ppm concentrations were prepared. To determine the λ_{max} of the dye, all the solutions were applied for scanning in the range 190-1000 nm with the help of the UV-Visible spectrophotometer. The obtained λ_{max} of the dye was 614 nm. Absorbance of all the standard solutions was measured at 614 nm and the calibration curve (Fig. 3) was drawn.

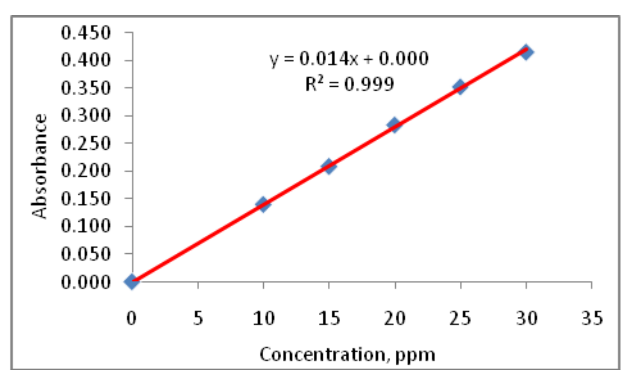

Fig. 3. Calibration curve for Novacron Blue FN-R reactive dye

The absorbance of the solvent (i.e. distilled and deionized water) used in these experiments was also measured and it was found that the absorbance at 614 nm was zero. From the curve, it is clear that it is in accordance with the Beer-Lambert law in the used range of concentrations. The value of coefficient of determination (i.e. R^2) was 0.999 which establishes the statistical validity of the measurements.

Interaction of the adsorbent with the Novacron Blue FN-R dye and calculation of removal efficiency

In a typical experiment, 0.1g of the adsorbent was interacted with 30 mL of dye solution of specified concentration. The dye concentration in the filtrate was calculated from the calibration curve with the help of the obtained absorbance. The removal efficiency of the adsorbent was calculated by using the following formula (1) [25]:

$$\text{Removal efficiency (\%)} = \frac{C_0 - C_t}{C_0} \times 100 \qquad (1)$$

Where,

C_0 = initial concentration of dye solution (ppm)
C_t = concentration of dye at any time (ppm)

The effect of amount of adsorbent

The effect of amount of adsorbent was studied in the range of 0.05-0.2 g of adsorbent when 30 mL of dye solutions of constant concentration (10 ppm) were used for 20 m. It was observed that as the dosage of adsorbent was increased, the removal efficiency became higher (Fig. 4). Increase in the removal efficiency of Novacron Blue FN-R with the increased amount of adsorbent dose is due to the increased surface area and the availability of additional adsorption sites. It was found that 0.1 g of banana fibre resulted in 100% removal of Novacron Blue FN-R reactive dye in this particular condition. The adsorbent/dye ratio obtained for quantitative adsorption of dye molecules is approximately 333: 1.

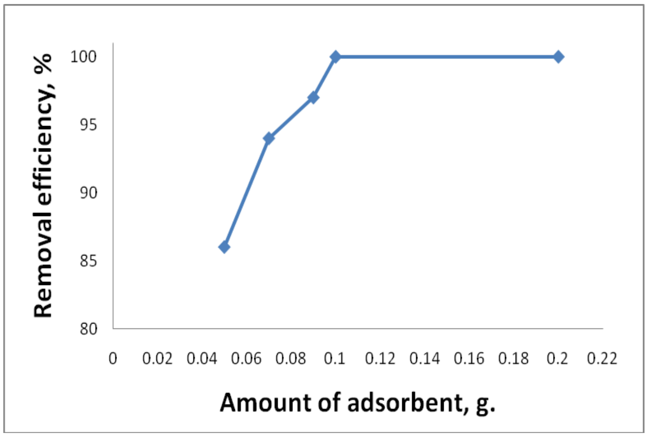

Fig. 4. Effect of adsorbent dose on adsorption

Effect of pH

The adsorption of dye molecules on the adsorbent was observed in the pH range 2-12. It exhibited lower removal efficiency in higher pH values (Fig. 5). At pH 12, no significant removal took place and it was only about 4%. As the pH value decreases, the removal efficiency is increased and it becomes 100% at pH 2. It is due to the fact that as the pH of the dye solution is decreased, the number of negative charges on surface sites decreased and the number of positively charged surface sites increased, and this favors the adsorption of dye anions due to electrostatic attraction [26]. A similar observation was also seen for the adsorption of Acid Red 183 and Acid Green 25 onto shells of bittim and removal of Acid Blue 62 (AB62) on aqueous solution using calculated colemanite ore waste [27].

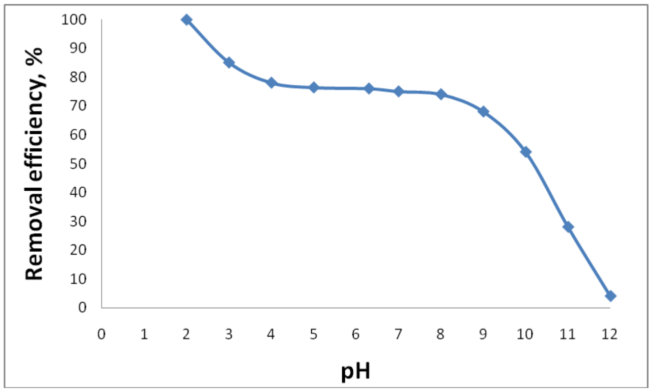

Fig. 5. Effect of pH on the adsorption

Effect of initial dye concentration

Different initial dye concentrations ranging from 10-25 ppm were used for adsorption keeping the other parameters (i.e. contact time, pH, amount of adsorbent and amount of dye solution) constant. As the initial concentration of Novacron Blue FN-R was increased, the absorbance efficiency was decreased. This is because of the fact that the number of dye molecules is increased in the aqueous phase and it is assumed that at 10 ppm concentration, the surface area of the adsorbent becomes saturated, beyond which additional molecules those are present cannot be adsorbed any more resulting to a lower efficiency. Fig. 6 shows the effect of initial dye concentration on adsorption.

Effect of contact time

Adsorption was carried out in different contact time while all other parameters were kept constant. It was found that at pH 2, the adsorption occurs quickly. About 88% of removal occurred in 5 m and it reached to approximately 92% in the following 5 m, and 100% removal efficiency took place in 20 m (Fig. 7). Allowing the adsorption for longer time (i.e. 40 and 60 m), no change was observed indicating that adsorption was completed within 20 minutes. As no dye molecule was observed in the aqueous phase keeping the dye bearing adsorbent up to 60 m, it can be assumed that there was no desorption of dye molecules in that period.

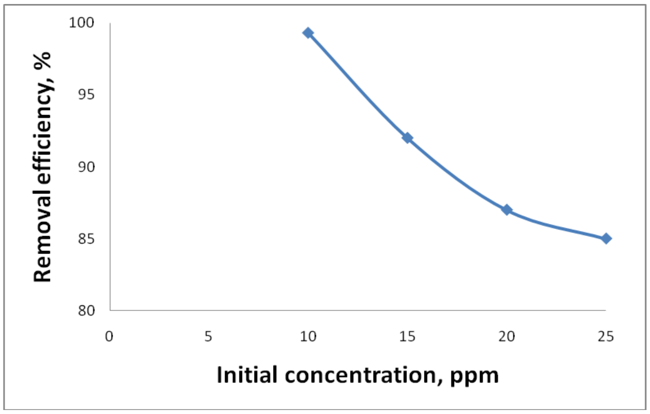

Fig. 6. Effect of initial concentration of the dye

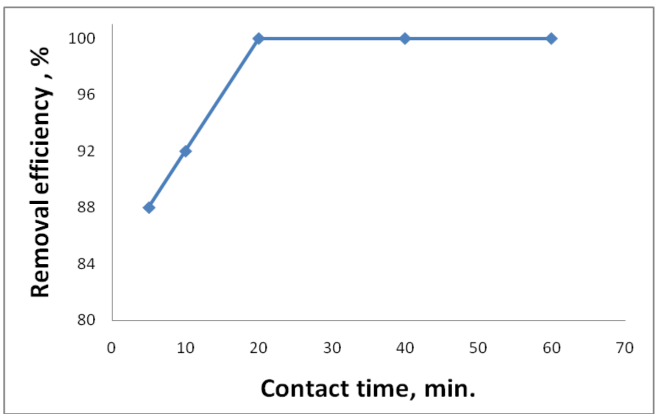

Fig. 7. Effect of contact time on the adsorption of the dye

The present adsorbent is found more efficient than orange peel [12] and fly ash [13] whereas it is comparable with modified banana trunk fibres [23, 28]. The present adsorbent takes less time compared to other adsorbents in removing dyes form the bulk aqueous phase [12,13, 23].

Interaction of the adsorbent with the raw wastewater

The sample of raw wastewater was collected from a local textile industry premise and it was preserved in the refrigerator at 4°C. The authority of the industry informed that the collected wastewater contained a blend of three dyes- Novacron Blue FN-R, Novacron Yellow FN-2R, and Novacron Red FN-3GL. For characterizing the wastewater, the parameters that were selected are pH, Dissolved Oxygen (DO), Chemical Oxygen Demand (COD), Total Solid (TS), Total Dissolved Solid (TDS), Total Suspended Solid (TSS), salinity, and electrical conductivity. All these parameters were also determined after interacting the wastewater with the banana fibre. The removal efficiency was also evaluated visually. It was found that 30 mL of deep coloured raw wastewater was converted into colourless and transparent water with the help of 1 g of banana fibre at pH 2. Experiments were also carried out without adjusting the pH of the raw wastewater and it was found that removal efficiency was much less compared to that with adjusting pH at 2. Fig. 8 shows the appearance of the raw wastewater and treated wastewater. The values obtained from characterization before and after the treatment are shown in Table I.

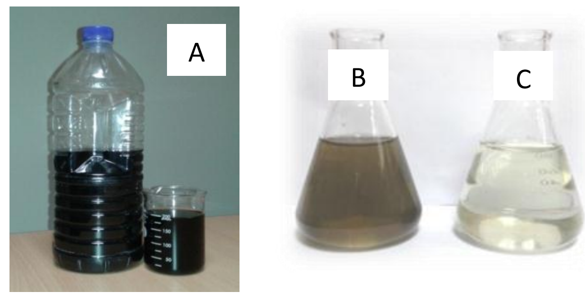

Fig. 8. Appearance of water samples A. Raw wastewater B. Treated water without adjusting pH and C. Treated water at pH 2

Table I
Physical characteristics of wastewater before and after treatment

Parameter	Values	
	Before treatment	After treatment
pH	10.44	2.55
DO, ppm	3.7	4.5
COD, ppm	900	890
TS, ppm	34,760	33,440
TDS, ppm	34,460	33,423
TSS, ppm	300	15
Salinity, ppm	22,500	23,500
Conductivity, mS/cm	35.8	37

The alkaline wastewater was converted into acidic water; this is basically due to adjustment of pH at 2 which is the obtained optimum pH for the current adsorption system.

The adsorption results in approximately 20% increase in DO level whereas it does not result in significant improvement in COD. The amount of TS, TDS and TSS were found to decrease due to adsorption.

The salinity of water before and after the adsorption was comparable. This is due to the fact that the number of ions is increased due to the adjustment of pH to 2. Similarly, there was no remarkable change in electrical conductivity.

IV. CONCLUSIONS

Banana fibre used in the present work is able to remove Novacron Blue FN-R, Novacron Yellow FN-2R, and Novacron Red-FN 3GL reactive dyes efficiently. The removal efficiency of banana fibre was found to be affected by pH of dye solution, contact time, concentration of dye in the solution, and the amount of adsorbent. pH 2 was found the most effective in removing dyes from the aqueous phase, and increased pH results in decreased removal efficiency. The adsorption is very quick, and the quantitative adsorption occurs within 20 m. Therefore, it can be concluded that the process is relatively less time consuming. The Adsorbent/dye ratio is important for the present system and quantitative adsorption is achieved at the adsorbent/dye ratio of 333:1. The adsorbent is also found able to remove reactive dyes from raw wastewater efficiently. The treatment with the present adsorbent leads to a significant decrease in pH which needs to be adjusted with the help of an alkali before discharging treated wastewater into natural surface water systems. The present study suggests that the banana fibre can be used as a sustainable adsorbent to remove various reactive dyes from textile effluents efficiently.

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