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Short communication

Removal of different basic dyes from aqueous solutions by adsorption on palm-fruit bunch particles

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Abstract

The adsorption of three basic dyes (basic yellow, basic red and basic blue) from an aqueous solution on palm-fruit bunch particles has been studied. The equilibrium isotherm for each dye–adsorbent system was determined. The experimental results have been fitted with Langmuir, Freundlich and Redlich–Peterson isotherms. The maximum adsorption capacities of the palm-fruit bunch particles were found to be 327 mg yellow dye per gram of adsorbent, 180 mg red dye per gram of adsorbent and 92 mg blue dye per gram of adsorbent. A comparative cost study, based on the adsorption capacity alone, has shown that the costs of the adsorbent required are 1.9%, 4.4% and 7.1%, respectively, compared with the case of commercial activated carbon granules. © 1997 Elsevier Science S.A.

Keywords: Palm-fruit bunch; Basic dyes; Absorption isotherms; Comparative cost

1. Introduction

Many industries use dyes and pigments to color their products. The discharge waste waters from these industries into river water make the water inhibitory to aquatic life. In addition to causing visible pollution, dyes have a tendency to sequester metals, so causing microtoxicity to fish and other aquatic organisms. It is difficult to remove the dyes from the effluent, because the dyes are stable to light and heat, and are biologically non-degradable. Hence, the conventional methods used in sewage treatment, such as the primary and secondary treatment systems, are unsuitable [1]. It is necessary, therefore, to use tertiary treatment to remove color before discharging the waste water into natural streams.

There is a growing interest in using low cost, commercially available materials for the adsorption of dye colors. A wide variety of low cost materials, such as clay minerals [2], bagasse pith [3], wood [4], maize cob [5] and peat [6], are being tried as viable substitutes for activated carbon to remove dyes from colored effluents.

In this study, equilibrium adsorption isotherms of different basic dyes (yellow, red and blue basic dyes) on to palm-fruit bunch particles were analyzed to deduce the Langmuir, Freundlich and Redlich–Peterson parameters.

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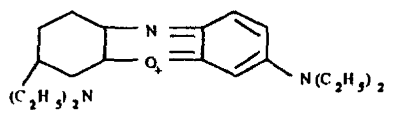
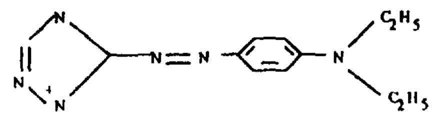
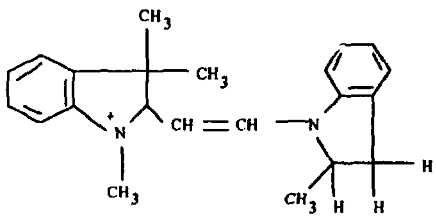
2. Experimental details

The palm-fruit bunch used in this study was collected from El-Minia Government, Egypt. It was sliced applying planning, crushed to the minimum possible size and sieved to a geometric mean size of 300 μm. The material was not subjected to any form of pretreatment before use.

Three basic dyes are used: basic yellow (BY21), basic red (BR22) and basic blue (BB3). The structure and molecular volume of each dye are listed in Table 1. The concentration of the dyestuff in the aqueous solution was determined employing a spectrophotometer (Spectro-plus MKIA). All the measurements were made at the wavelength that corresponded to the maximum absorbency, i.e. $\lambda_{max} = 417$ nm for basic yellow, $\lambda_{max} = 537$ nm for basic red and $\lambda_{max} = 654$ nm for basic blue. Dilution's were undertaken when the absorbance exceeded a value of 0.6.

Batch adsorption experiments were conducted in a shaker bath at constant temperature (25 ± 1 °C), using a constant amount of palm-fruit bunch particles with a series of 0.05 dm^3 dye solutions of different concentrations (from 50 to 600 mg dm^{-3}) in sealed glass bottles. Equilibrium isotherms were constructed by shaking the bottles for 7 days. After that time, the samples were centrifuged and their equilibrium concentration C_e was determined using spectrophotometry.

Table 1
Structure and molar volume of different dyes used

Dye	Structure	Molar volume (cm^3 g mol^{-1})	Supplier
BB3		322	Ciba-Geigy
BR22		267.5	Ciba-Geigy
BY21		424	Bayer

The amount of dye removed q_e was calculated using the relationship

$$q_e = [V(C_0 - C_e)]/W \qquad (1)$$

3. Results and discussion

A plot of equilibrium dye loading q_e against the residual concentration of dye remaining in solution after equilibrium (C_e) for different dyes is shown in Fig. 1. The data show that, while the yellow and red dyes can generally be easily removed from the solution, the blue dye cannot be easily adsorbed on palm-fruit particles. The affinities of the basic dyes to the adsorbent are BY21 > BR22 > BB3 [7].

Analysis of adsorption isotherms for different dyes, such as given in Fig. 1, is important for developing an equation that can represent the results that can be used in design purposes. The linear forms of the Langmuir and Freundlich equations can be respectively represented as

$$C_e/q_e = 1/k_L + (a_L/k_L)C_e \qquad (2)$$

$$\ln q_e = \ln K_f + (1/n) \ln C_e \qquad (3)$$

The plot of the Langmuir isotherm is shown in Fig. 2. The experimental results in Fig. 2 show a linear relationship of C_e/q_e vs. C_e, suggesting the applicability of the Langmuir model; the results also demonstrate monolayer coverage of the adsorbate at the outer surface of the adsorbent [8]. The essential characteristics of the Langmuir isotherm can be expressed in terms of a dimensionless constant separation factor or equilibrium parameter R_L, which is defined by Weber and Chakkravorti [9] as

$$R_L = 1/(1 + a_L C_0) \qquad (4)$$

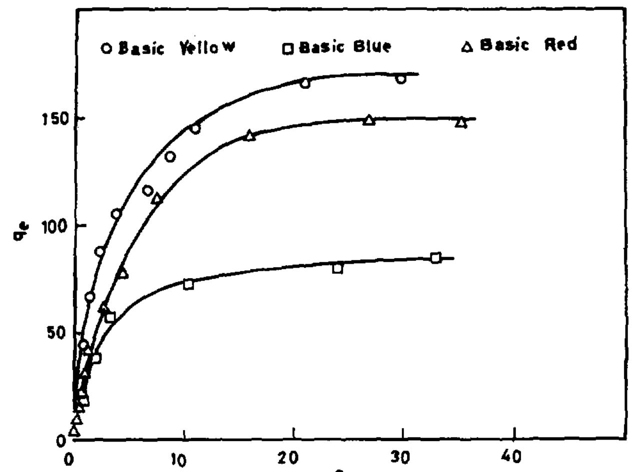


Fig. 1. Adsorption isotherms for basic dyes with palm-fruit bunch of particle size 300 μm.

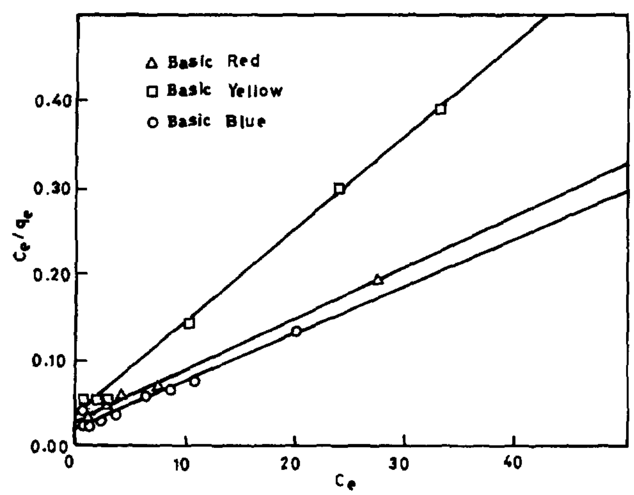


Fig. 2. Langmuir plots corresponding to the adsorption of yellow, red and blue dyes on palm-fruit bunch of particle size 300 μm.

Table 2
Langmuir constants for yellow, red and blue basic dyes ($d_p = 300$ μm)

Dye	K_L ($dm^3\ g^{-1}$)	a_L ($dm^3\ mg^{-1}$)	K_L/a_L ($mg\ g^{-1}$)	R_L	Correlation coefficient
BY21	23.906	0.073	327	0.083	0.880
BR22	50.308	0.279	180	0.023	0.962
BB3	30.722	0.336	92	0.0289	0.997

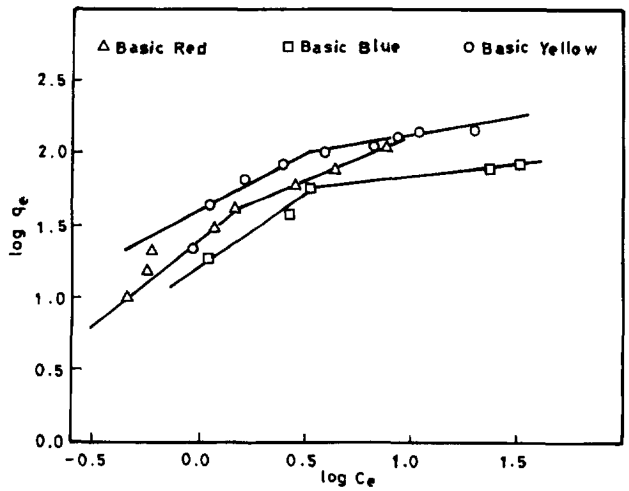


Fig. 3. Freundlich plots for the adsorption of yellow, red and blue dyes on palm-fruit bunch of particle size 300 μm.

Table 3
Freundlich constants for different dyestuffs ($d_p = 300$ μm)

Dye	K_F ($dm^3\ g^{-1}$)	n_F	Correlation coefficient
BY21	1st 26.37	0.85	0.984
	2st 30.75	1.59	0.996
BR22	1st 48.13	1.91	0.902
	2st 103.80	8.17	0.879
BB3	1st 17.74	1.0	0.999
	2st 53.42	7.79	0.988

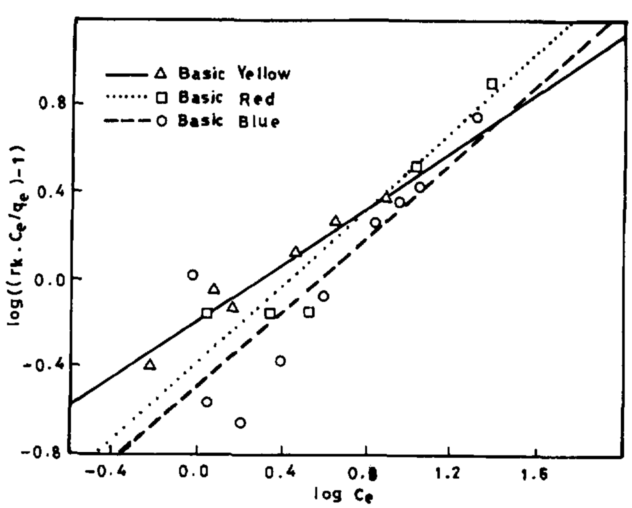


Fig. 4. Redlich–Peterson plots for the adsorption of yellow, red and blue dyes on palm-fruit bunch of particle size 300 μm.

Values of K_L and a_L for different dyes have been calculated from the plots in Fig. 2 and the results are tabulated in Table 2; the results indicate high correlation coefficients. The values of the constant K_L/a_L correspond to the maximum adsorption capacities of the palm-fruit bunch particles for the different basic dyes. Table 2 also shows that the adsorption capacity of the palm-fruit bunch particles is higher for yellow dye and lower for blue dye. The R_L values (Eq. (4)) dictate favorable adsorption for $0 < R_L < 1$ [9]. The data in Table 2 show that the R_L values ranged between 0.023 and 0.083, indicating that palm-fruit bunch particles are favorable for the different basic dyes.

The experimental equilibrium data for the adsorption of the different dyes on palm-fruit bunch particles have been analyzed using the linear form derived from the Freundlich isotherm (Eq. (3)). The results derived from the Freundlich analysis show some curvature, so the results can be better represented by more than one straight line. This finding was also shown by other investigators [10]. Fig. 3 shows the effect of different basic dyes on the Freundlich isotherm during adsorption on palm-fruit bunch particles, as represented by two straight lines with different slopes.

Different slopes may represent two different modes of adsorption, i.e. surface and intra-particle adsorption. The parameters K_F and n for the different basic dyes are listed in Table 3. The results show that the Freundlich exponent n is greater than unity, indicating that the basic dyes are favorably adsorbed by palm-fruit bunch particles [11].

The Redlich–Peterson isotherm is a more general form than the Langmuir and Freundlich isotherms, and is given by [12]

$$q_e = (K_{RP}C_e)/(1 + a_{RP}C_e^{\beta}) \qquad (5)$$

For $\beta = 1$, Eq. (5) converts to the Langmuir isotherm and, for $1 \ll a_{RP}C_e^{\beta}$, Eq. (5) is identical to the Freundlich isotherm. Eq. (5) may be converted into a linear form that is more convenient for plotting and determining the constants K_{RP}, a_{RP} and β, i.e.

$$\log[(K_{RP}C_e)/q_e] - 1 = \log a_{RP} + \beta \log C_e \qquad (6)$$

Plots of $\log[(K_{RP}C_e/q_e) - 1]$ against $\log C_e$ are seen to be linear over the entire range of dye concentrations, as shown in Fig. 4. The Redlich–Peterson parameters for the different

Table 4
Redlich–Peterson constants for different dyestuffs ($d_p = 300$ μm)

Dye	K_{RP} ($dm^3\ mg^{-1}$)	β	Correlation coefficient
BY21	1.171	0.181	0.88
BR22	0.324	0.879	0.83
BB3	0.420	0.903	0.94

Table 5
Adsorption cost of basic dyes on palm-fruit bunch particles

Dye	Adsorbent	q_{max} (mg g^{-1})	Adsorbent mass required to remove 1 kg dye	Relative cost per kilogram of adsorbent	Relative cost to remove 1 kg dye
BY	Carbon	600	1.587	1.00	1.00
	Palm fruit bunch	327.57	3.05	0.01	0.019
BR	Carbon	790	1.27	1.00	1.0
	Palm fruit bunch	180.3	5.55	0.01	0.044
BB	Carbon	648.6	1.54	1.00	1.0
	Palm fruit bunch	91.33	10.95	0.01	0.071

basic dyes have been calculated using the least-squares method and are tabulated in Table 4. The results indicate high correlation coefficients.

To assess the economical feasibility of the new adsorbent, a cost comparison between activated carbon and palm-fruit bunch particles was carried out. In performing isotherm studies under similar conditions, the equilibrium experiments were carried at 25 °C using a uniform particle size of 300 nm. The maximum values of the adsorption capacity q_{max} were determined and the values used as a basis for costing the adsorption process. Activated carbon was taken as a reference, having a comparative cost of one currency unit per kilogram [13]. Table 5 shows the relative cost of palm-fruit bunch particles, together with the adsorption costs for removing 1 kg of dye. The results revealed that the relative cost to remove 1 kg of dye are respectively 1.9%, 4.4% and 7.1% for yellow, red and blue dyes compared with activated carbon.

4. Conclusions

The experimental results proved that palm-fruit particles have considerable potential for the removal of basic dyes from waste waters over a wide range of concentrations. The equilibrium isotherms determined were found to fit Langmuir, Freundlich and Redlich–Peterson isotherms. In comparison with carbon, the relative cost to remove 1 kg of dye is much less than 0.071. Based on cost evaluation, the price of removing 1 kg of dye using palm-fruit bunch particles is much cheaper than the same price when using activated carbon. Therefore, regeneration of palm-fruit bunch particles is unnecessary and the spent adsorbent can be used as solid fuel. This indicates that palm-fruit bunch particles are a promising low cost adsorbent.

Appendix A. Nomenclature

a_L parameter of Langmuir isotherm (dm^3 mg^{-1})
a_{RP} parameter of Redlich–Peterson isotherm (dm^3 mg^{-1})
C_e equilibrium liquid-phase concentration (mg dm^{-3})
C_0 initial liquid-phase concentration (mg dm^{-3})
d_p adsorbent particle size range (μm)
K_L parameter of Langmuir isotherm (dm^3 g^{-1})
K_{RP} parameter of Redlich–Peterson isotherm (dm^3 g^{-1})
n Freundlich exponent (dimensionless)
q_e equilibrium solid-phase concentration (mg g^{-1})
q_{max} maximum adsorption capacity (mg g^{-1})
R_L equilibrium parameter (dimensionless)
V dye volume (dm^3)
W mass of adsorbent (g)

Greek letters

β Redlich–Peterson isotherm constant

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