

Removal of reactive dyes from aqueous solution using bagasse fly ash

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Abstract

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Bagasse fly ash, a waste from the sugar industry, was investigated as a replacement for the current expensive methods of removing reactive dyes (Remazol Black B; RBB, Remazol Brilliant Blue R; RBBR, and Remazol Brilliant Red F3B; RBRF3B) from aqueous solutions. Bagasse fly ash was collected from a local sugar factory in Saraburi province, Thailand. It was oven dried at 110°C overnight and sieved to the desired particle size of 150 µm or smaller. The 50 mL plastic conical tubes containing solution and bagasse fly ash were shaken at room temperature (27±2°C). The pH values of solutions were adjusted by addition of HNO₃ and NaOH. The batch study indicated that initial pH of aqueous solutions did not affect dye removal. While the removal efficiency decreased with increasing initial concentration, it increased with increasing adsorbent concentration. The best adsorptions were obtained under condition of 50 mg/L concentration, original pH solution of about 5, and 240, 300, and 240 minutes contact time for RBB, RBBR, and RBRF3B, respectively. Most adsorption experiments showed in the range of about 50% to 98% removal; that is, the efficiencies of RBB, RBBR, and RBRF3B adsorption were found to be between 58.48-98.03%, 46.15-93.47%, and 46.30-94.60%, respectively. For the linear and nonlinear forms of the Langmuir and Freundlich models, the results indicated that the Langmuir adsorption isotherm fitted the data better than the Freundlich adsorption isotherm. Adsorption of these dyes onto bagasse fly ash was favorable sorption. Therefore, bagasse fly ash, the low-cost agricultural waste in Thailand, is suitable for use as adsorbent for RBB, RBBR, and RBRF3B under this investigation.

Key words : bagasse fly ash, reactive dye, adsorption, adsorbent

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บทคัดย่อ

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การกำจัดสีย้อมรีแอกทีฟจากสารละลายโดยใช้เถ้าลอยชานอ้อย
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งานวิจัยนี้เป็นการศึกษาการนำเถ้าลอยชานอ้อยซึ่งเป็นของเสียที่เกิดจากโรงงานน้ำตาลมาใช้ในการกำจัดสีย้อมรีแอกทีฟ 3 ชนิด คือ Remazol Black B (RBB) Remazol Brilliant Blue R (RBBR) และ Remazol Brilliant Red F3B (RBRF3B) จากสารละลาย เพื่อแทนที่วิธีการกำจัดแบบเดิม อันมีข้อด้อยคือค่าใช้จ่ายในการกำจัดสูงซึ่งไม่เหมาะสมกับประเทศกำลังพัฒนาเช่นประเทศไทย เถ้าลอยชานอ้อยที่ใช้ในงานวิจัยนี้ได้รับความอนุเคราะห์จากโรงงานน้ำตาลในจังหวัดสระบุรี ประเทศไทย ขั้นตอนแรกก่อนนำเถ้าลอยชานอ้อยไปใช้ในการศึกษาคือ เตรียมเถ้าลอยชานอ้อยโดยการอบที่ 110°C ประมาณ 24 ชั่วโมง จากนั้นร่อนผ่านตะแกรงให้ได้ขนาดอนุภาคเล็กกว่า 150 ไมโครเมตร การศึกษานี้ทดลองโดยใช้หลอดทดลองพลาสติกขนาด 50 มล ที่อุณหภูมิห้อง (27±2°C) และปรับค่าความเป็นกรด-ด่างของสารละลายโดยใช้กรดไนตริก (HNO₃) และโซเดียมไฮดรอกไซด์ (NaOH) จากการศึกษาพบว่า ค่าความเป็นกรด-ด่างเริ่มต้นของสารละลายไม่มีผลต่อการกำจัดสีย้อมรีแอกทีฟทั้งสามชนิด ในขณะที่ค่าความเข้มข้นเริ่มต้นของสีย้อม และปริมาณตัวดูดซับมีผลต่อการกำจัดสีย้อม กล่าวคือ ค่าร้อยละการกำจัดสีย้อมจะลดลงเมื่อความเข้มข้นเริ่มต้นของสีย้อมเพิ่มขึ้น แต่ค่าร้อยละการกำจัดสีย้อมจะเพิ่มขึ้นเมื่อค่าปริมาณตัวดูดซับเพิ่มขึ้น นอกจากนี้ยังพบว่าสภาวะที่ให้ค่าร้อยละการกำจัดสีย้อมสูงที่สุด คือที่ค่าความเข้มข้นเริ่มต้นของสีย้อม เท่ากับ 50 มก/ลิตร ค่าความเป็นกรด-ด่างของสารละลายประมาณ 5 และ ระยะเวลาสัมผัส เท่ากับ 240 300 และ 240 นาที สำหรับ RBB RBBR และ RBRF3B ตามลำดับ ค่าร้อยละการกำจัดสีย้อมส่วนใหญ่ที่พบในการศึกษามีค่ามากกว่า 50% โดยพบว่าค่าร้อยละการกำจัด RBB, RBBR และ RBRF3B มีค่าเท่ากับ 58.48-98.03%, 46.15-93.47% และ 46.03-94.60% ตามลำดับ สำหรับสมการไอโซเทอมการดูดซับ พบว่าข้อมูลการดูดซับที่ได้จากการศึกษานี้สอดคล้องกับสมการของแลงมัวร์มากกว่าสมการของฟรุนดริช และพบว่าเถ้าลอยชานอ้อยสามารถดูดซับสีย้อมทั้งสามชนิดได้ดี จึงกล่าวได้ว่าเถ้าลอยชานอ้อยซึ่งเป็นของเสียจากการเกษตรในประเทศไทยที่มีราคาถูกมาก มีความเหมาะสมที่จะใช้เป็นตัวดูดซับในการกำจัดสีย้อมรีแอกทีฟ RBB RBBR และ RBRF3B

ศูนย์วิจัยแห่งชาติด้านการจัดการสิ่งแวดล้อมและของเสียอันตราย (NRC-EHWM) จุฬาลงกรณ์มหาวิทยาลัย/ภาควิชาวิศวกรรมสิ่งแวดล้อม คณะวิศวกรรมศาสตร์ จุฬาลงกรณ์มหาวิทยาลัย พญาไท กรุงเทพฯ 10330

Reactive dyes, the type considered in this work, are known to have low absorbability on a wide range of adsorbents (Khraisheh *et al.*, 2002). Discharge of dyes into natural streams and rivers from the industries poses severe problems, as dyes give toxicity to the aquatic life and are damaging to the aesthetic nature of the environment (Mohan *et al.*, 2002).

In general, reactive dyes are the most problematic among other dyes, as they tend to pass through conventional treatment systems unaffected (Lazaridis *et al.*, 2003). Various methods of dye removal, including aerobic and anaerobic microbial degradation, coagulation, chemical ox-

idation, membrane separation, electrochemical treatment, filtration, flotation, hydrogen peroxide catalysis, and reverse osmosis, have been proposed from time to time. Municipal aerobic treatment systems, dependent on biological activity, were found to be ineffective in the removal of these dyes (Lazaridis *et al.*, 2003). There are two major technologies available for dye removal, i.e., oxidation and adsorption. Oxidation methods are possibly the best technologies to totally eliminate organic carbons, but they are only effective for wastewater with very low concentrations of organic compounds (Sun and Xu, 1997). Thus, dilution is necessary as a facility requirement. It is known

that adsorption is one of the most efficient methods for removal of colors, odor, oils, and organic pollutants from process or waste effluents. Also, activated carbon is the most widely used adsorbent due to its excellent adsorption capability (Juang *et al.*, 2002). However, its use is often limited due to high cost, making this method unfavorable for the needs of developing countries like Thailand.

Thailand generates a lot of bagasse fly ash each year because Thailand is one of the largest sugar exporters in the world. In addition, the co-generation project of The Energy Policy and Planning Office (EPPO) supports small power producers (SPPs) that use renewable fuel to produce and sell electricity to the Metropolitan Electricity Authority (MEA) and the Provincial Electricity

Authority (PEA). As many as 22% of the producers use bagasse as a fuel (<http://www.nepo.go.th/encon/encon-spp-renewb2.html>, 2002). Therefore, bagasse will become fly ash. Utilization of agriculture waste residues for the wastewater treatment at least has the following advantages: 1) there are available abundantly at no or low cost, 2) disposal of the wastes is a serious environmental problem in the area which has extensive agricultural activities such as Thailand. The aim for this research is to study the utilization of bagasse fly ash as adsorbents for removal of three types of reactive dye; Remazol Black B (RBB), Remazol Brilliant Blue R (RBBR), and Remazol Brilliant Red F3B (RBRF3B). The structures of these reactive dyes (Rughachart, 2001) are shown in Figures 1 (a), (b), and (c). The experiments were

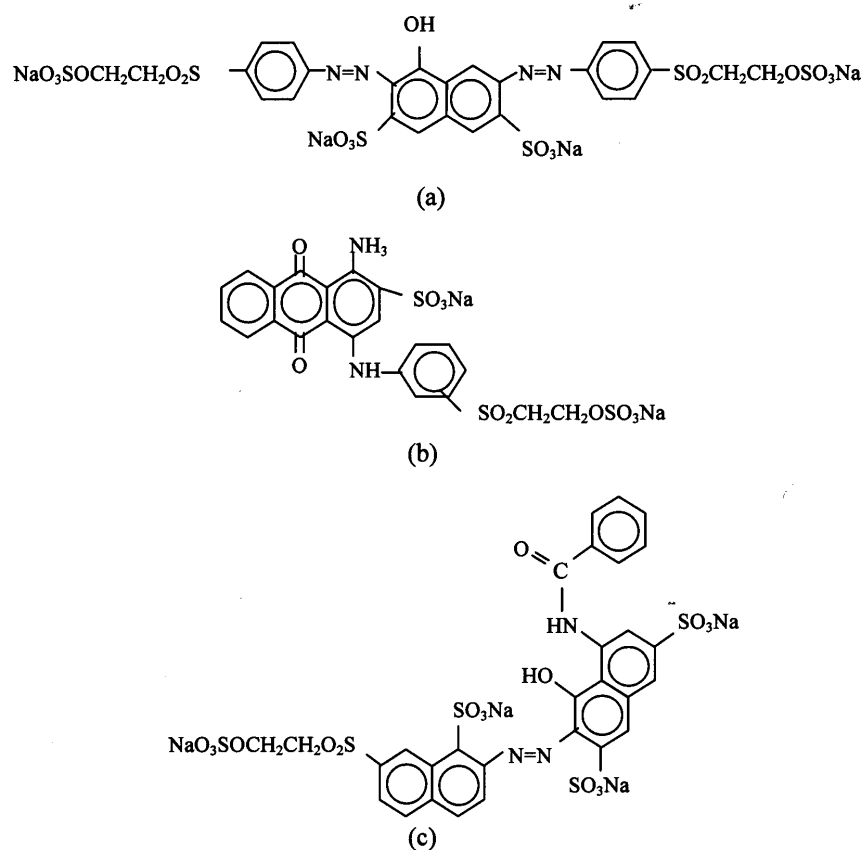


Figure 1. The structures of reactive dye Remazol Black B (a), Remazol Brilliant Blue R (b), and Remazol Brilliant Red F3B (c)

carried out batches. The effect of contact time, pH, initial concentrations, and adsorbent dose were studied. In addition, suitable condition to remove reactive dyes, and isotherm models were investigated.

Materials and Methods

1. Fly ash collection and adsorbent development

Bagasse fly ash was collected from a local sugar factory in Saraburi province. It was oven dried at 110°C overnight and sieved through sieve No. 100 (150 µm). The sieved bagasse fly ash was then stored in a vacuum desiccator for further use.

2. Equipment

A UV spectrophotometry was used for dye analysis. The pH measurements were obtained using a digital pH meter Consort model C 830. An IKA HS 501 shaker was used for all adsorption experiments.

3. Adsorption experiments

Adsorption studies were performed by the batch technique. A series of 50-mL plastic conical tubes were used. The tubes were shaken at room temperature (27±2°C) and the shaking speed was 125 rpm. The pH values of solutions were adjusted by addition of HNO₃ and NaOH. The following adsorption experiments were carried out:

Experiment 1. The effect of contact time or shaking time: contact time ranged from 15-420 minutes, initial concentration was 50 mg/L, initial pH solution was 7 and adsorbent dose was 20 g/L.

Experiment 2. The effect of initial pH and initial concentrations: pH ranged from 5 to 9. The initial concentration ranged from 50 to 200 mg/L, and adsorbent dose is 20 g/L. This experiment operates at optimum contact time which result form experiment 1.

Experiment 3. The suitable condition to remove dye. Equilibration time was determined at the optimum initial pH and initial concentrations obtained in experiment 2.

Experiment 4. The effect of adsorbent dose: adsorbent dose ranged from 20 to 120 g/L at optimum contact time from experiment 3 and optimum initial pH and initial concentrations from experiment 2.

Experiment 5. Adsorption isotherms for reactive dyes onto bagasse fly ash: Experiment was set at the suitable condition found in the previous experiment. This study used Langmuir and Freundlich isotherms to describe the reactive dyes adsorption onto bagasse fly ash.

Langmuir isotherm has been used by many workers to study sorption of a variety of compounds (Gupta and Ali, 2001). The model assumes uniform energies of adsorption onto the surface and no transmigration of adsorbate in the plane of the surface (Gupta and Ali, 2001). The Langmuir isotherm relationship is of a hyperbolic form as shown in Equation (1). The Langmuir relationship can be linearized by plotting either $1/q_e$ vs $1/C_e$. The linear form of the Langmuir isotherm is given by Equation (2).

$$q_e = Q_0 b C_e / (1+b C_e) \quad (1)$$

$$1/q_e = 1/Q_0 + 1/b Q_0 C_e \quad (2)$$

Where: q_e is the amount of dye adsorbed per unit weight of adsorbents and C_e is the equilibrium concentration of the adsorbate (mg/L). Langmuir constants, Q_0 and b are related to maximum adsorption capacity and energy of adsorption through the Arrhenius equation, respectively. Q_0 can also be interpreted as the total number of binding sites that are available for sorption. When m/x or $1/q_e$ is plotted against $1/C_e$, a straight line with slope $1/b Q_0$ is obtained and intercept is correspond to $1/Q_0$.

The essential characteristics of a Langmuir isotherm can be expressed in terms of a dimensionless separation factor, r , which describes the type of isotherm and is defined by Equation (3)

$$r = 1 / (1+b C_e) \quad (3)$$

Where: b is a Langmuir constant and C_0 is the initial concentration of dye (Gupta and Ali, 2000).

- If, $r > 1$ unfavorable
- $r = 1$ linear
- $0 < r < 1$ favorable
- $r = 0$ irreversible

The Freundlich isotherm relationship is exponential, given by the Equation (4). The linear form of the Langmuir isotherm is given by Equation (5).

$$Q = K_f C_e^{(1/n)} \quad (4)$$

$$\log q_e = \log K_f + 1/n \log C_e \quad (5)$$

where K_f and n are the Freundlich constants that are associated with adsorption capacity and adsorption intensity, respectively. The value of n between 2 and 10 shows good adsorption. The other parameters have been defined as in equation (1) and (2). A plot of $\log q_e$ against $\log C_e$ gives a straight line, the slope and intercept of which correspond to $1/n$ and $\log K_f$, respectively (Gupta and Ali, 2001).

Result and Discussions

1. Characterization

Chemical analyses of bagasse fly ash are shown in Table 1. Analysis was performed using an X-ray Fluorescence Spectrometer (XRF), Philips model PW 2400. The major constituent, Silica, was measured at 51.96 % by weight of bagasse fly ash. This is consistent with the results of Rao *et al.*, (2002) and Gupta and Ali (2000 and 2001). The loss on ignition (LOI) was found to be 33.17 % by weight.

2. Effect of contact time

The time-dependent behavior of dye adsorption between adsorbate and adsorbent was measured using conditions that were previously described in Experiment 1. The results are plotted in Figure 2. Removals for each reactive dye were found constant starting at 240 minutes for RBB and RBRF3B, and between 300 minutes for RBBR. Therefore, contact periods of 240, 240 and 300 minutes were finally selected for all of the equilibrium tests for RBB, RBRF3B and RBBR respectively.

3. Effect of pH

The adsorption of reactive dye on bagasse fly ash was studied at conditions described in Experiment 2. It was observed that the removal of RBB, RBBR, and RBRF3B on low-cost adsorbent exhibited similar trend, that is, it did not change with varied pH values at all concentrations because the final solution pH's of all conditions was about 12. The efficiencies to remove RBB, RBBR, and RBRF3B were between 58.48-98.03%, 46.15-93.47%, and 46.30-94.60%, respectively. Especially, at low concentrations, efficiency of more than 90% could be obtained for all dyes. This can be explained by considering the zero point of charge of the bagasse fly ash. The pH at the zero point of charge (pH_{ZPC}) is reported to be 8.2 and 2.3 for alumina and silica, respectively (Mohan *et al.*, 2002). The composite pH_{ZPC} of the bagasse fly ash is 2.4 (Gupta and Ali, 2001). Thus, for pH values above 2.4, the negative charge density on the surface of the bagasse fly ash increases, thus increasing available sites for the adsorption of dyes. The results are given in Figures 3 (a), (b), and (c) for RBB, RBBR and RBRF3B adsorption, respectively.

Table 1. Chemical characteristics of bagasse fly ash.

Content (% by weight)													
Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	SO ₃	Cl	K ₂ O	CaO	TiO ₂	MnO	Fe ₂ O ₃	CuO	SrO
0.89	1.74	1.37	51.96	1.11	0.11	0.03	1.32	7.26	0.10	0.10	0.82	0.01	0.02

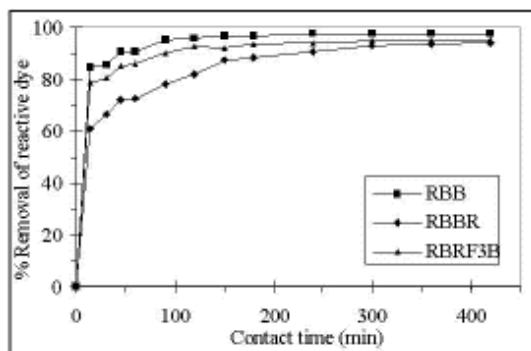
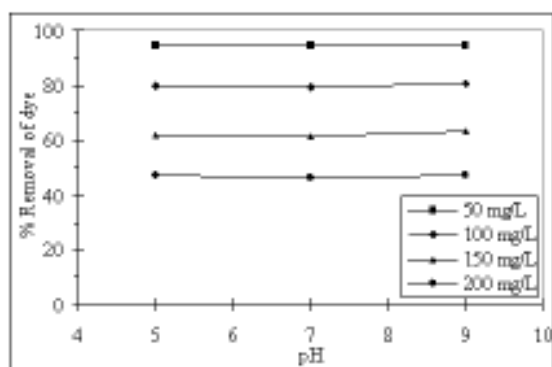
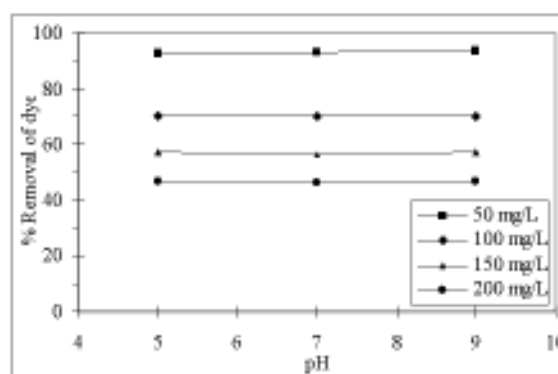


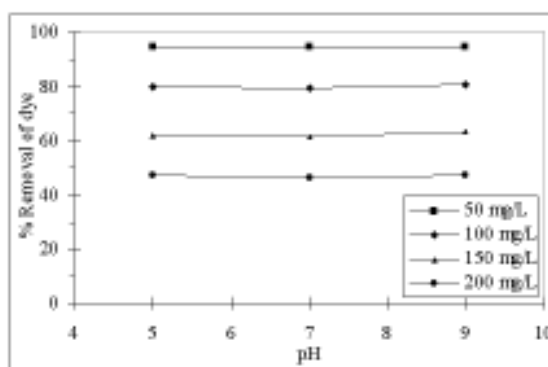
Figure 2. Effect of contact time on the rates of adsorption of reactive dye. Initial concentration = 50 mg/L, pH = 7, bagasse fly ash dose = 20 g/L, room temperature ($27\pm 2^\circ\text{C}$) and agitation speed 125 rpm.



(a)



(b)



(c)

Figure 3. Effect of pH on adsorptions of RBB (a), RBBR (b) and RBRF3B (c) by bagasse fly ash. Bagasse fly ash dose = 20g/L, room temperature ($27\pm 2^\circ\text{C}$) and agitation speed 125 rpm. Contact time = 240, 240 and 300 minutes for RBB, RBRF3B and RBBR, respectively.

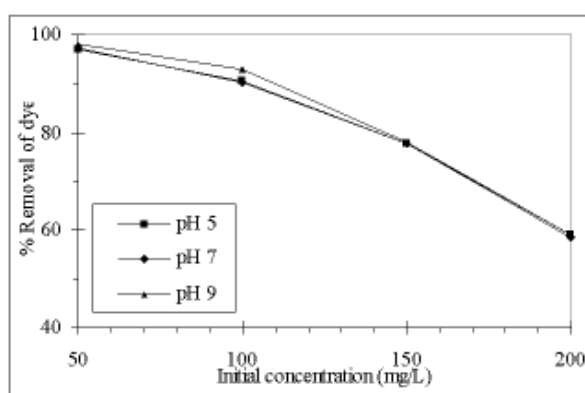
4. Effect of initial concentration

The adsorption experiments were carried out in the conditions explained in Experiment 2. The results are given in Figures 4 (a), (b), and (c) for adsorption of RBB, RBBR, and RBRF3B, respectively. The figures showed the percent removal of dye as a function of initial concentration at different initial pH values. It was observed that, percent removal of dye decreased with increasing initial concentration from 50 to 200 mg/L. For example, at initial pH solution of 5, RBB removal

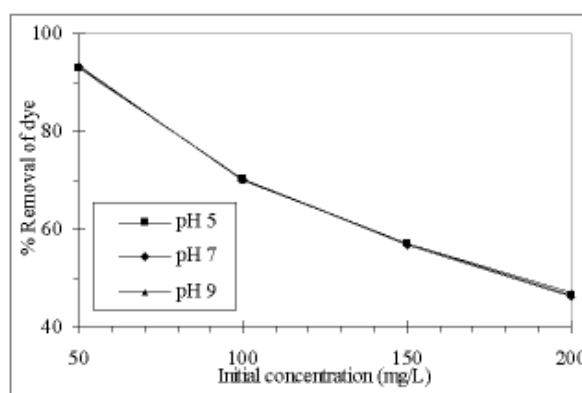
dropped from 97.05% to 58.91% when the initial dye concentration varied from 50 to 200 mg/L with a constant adsorbent dose 20 g/L. In case of RBBR and RBRF3B, removal efficiency of more than 50% removal was observed when the initial concentration was less than 150 mg/L at all pH's. While, for RBB at all initial concentration, a removal efficiency of more than 50 % was found.

5. The equilibration time on dye adsorption

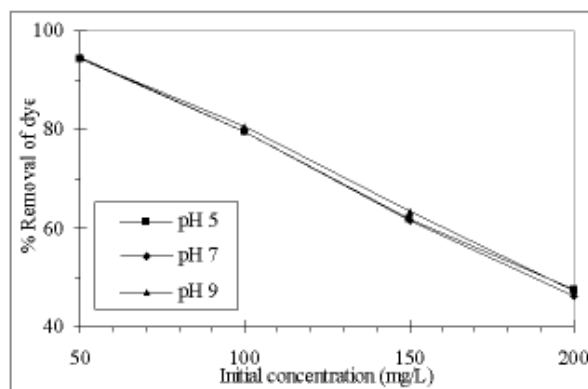
The adsorption data for the uptake of re-



(a)



(b)



(c)

Figure 4. Effect of initial concentration on adsorptions of (a), RBBR (b) and RBRF3B (c) by bagasse fly ash. Bagasse fly ash dose = 20g/L, room temperature (27±2°C) and agitation speed 125 rpm. Contact time = 240, 240 and 300 minutes for RBB, RBRF3B and RBBR, respectively.

active dye onto bagasse fly ash versus contact time are shown in Figure 5. This experiment was carried out under the optimum condition that includes initial pH of about 5 and initial concentration of is 50 mg/L. From the figure, the adsorption of reactive dye increased with increasing contact time and became almost constant after 240, 300, and 240 minutes for RBB, RBBR, and RBRF3B, respectively. These results were not different from the result of Experiment 1.

6. Effect of Adsorbent concentration

The results are plotted in Figure 6. It was found that the removal efficiency of dyes increased with increasing adsorbent concentration. That is, in the case of RBB the removal efficiency increased from 96.66% at 20 g/L to 99.10% at 120 g/L. For RBBR, the adsorption increased from 93.52% at 20 g/L to 97.83% at 120 g/L. While, RBRF3B, the adsorption increased from 94.32% at 20 g/L to 98.18% at 120 g/L. Moreover, the

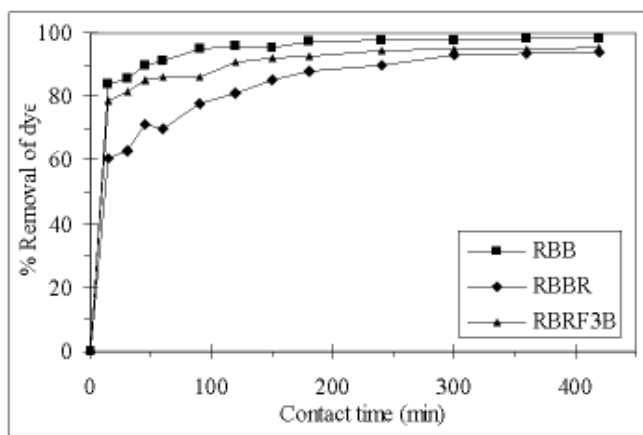


Figure 5. The equilibration time on dye adsorption onto bagasse fly ash. Initial concentration = 50 mg/L, pH = 5, bagasse fly ash dose = 20 g/L, room temperature ($27\pm 2^\circ\text{C}$) and agitation speed 125 rpm.

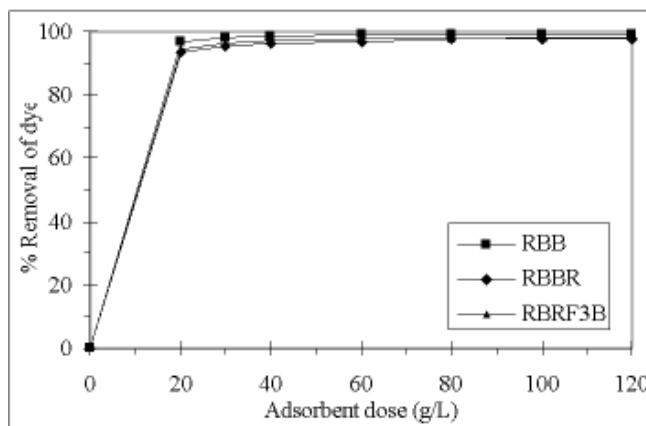


Figure 6. The effect of bagasse fly ash dose on dye adsorption. Initial concentration = 50 mg/L, pH = 5, room temperature ($27\pm 2^\circ\text{C}$) and agitation speed 125 rpm, contact time = 240, 240 and 300 minutes for RBB, RBRF3B and RBBR, respectively.

removal efficiency almost became constant at the doses of more than 60, 80, and 40 g/L for RBB, RBBR, and RBRF3B, respectively. It was apparent that the removal efficiency of reactive dye increased rapidly with increase in the concentration of the adsorbent due to the greater availability of the exchangeable sites or surface areas at higher concentrations of the adsorbent.

7. Isotherm

Isotherms for the removal of dyes onto bagasse fly ash are shown in Figure 7. Figures 8 (a) and (b) showed linearized Langmuir and

Freundlich isotherm for the removal of dyes, respectively.

Regression values (R^2) presented in Table 2, indicate that the adsorption data onto bagasse fly ash fitted well with the Langmuir isotherm for all dyes. Therefore, the recommended isotherms were presented in Langmuir equation as shown in Table 2. The values of r , separation factor, were found to be 0.3556, 0.3688, and 0.5382 for RBB, RBBR and RBRF3B, respectively. These indicate favorable adsorption. The value of Q_0 appeared to be more for RBBR followed by RBRF3B and RBB (Table 2). Table 3 lists the comparison of maxi-

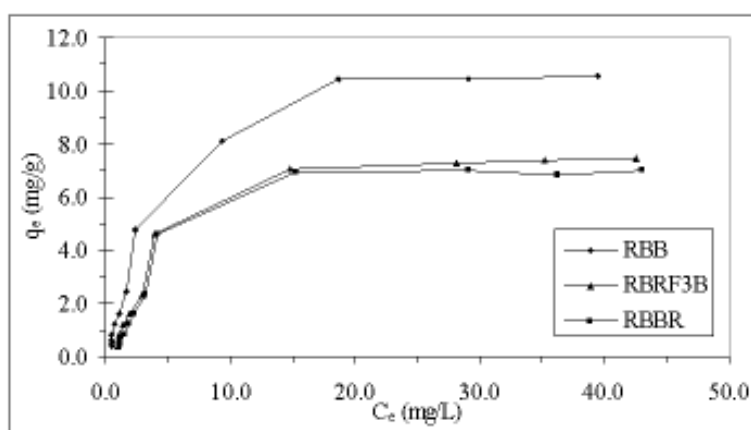
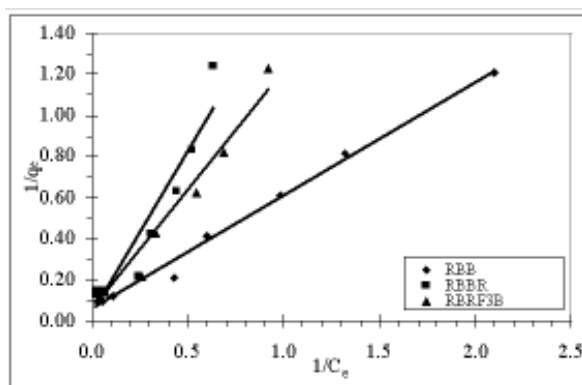
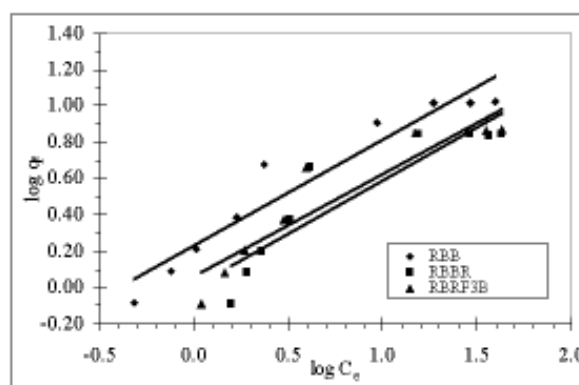


Figure 7. Isotherms for reactive dyes on bagasse fly ash.



(a)



(b)

Figure 8. Linearized Langmuir isotherms (a), and Freundlich isotherms (b) for reactive dye on bagasse fly ash.

Table 2. Values of Langmuir and Freundlich isotherm constants for sorption of dye.

Dye	Langmuir constants				Freundlich constants			Recommended isotherm, q_e
	Q_0	b	R^2	r	K_f	n	R^2	
RBB	16.420	0.110	0.993	0.3556	1.701	1.716	0.926	$= (16.420 \cdot 0.110 C_e) / (1 + 0.11 C_e)$
RBBR	32.468	0.019	0.906	0.6131	1.011	1.718	0.833	$= (32.468 \cdot 0.053 C_e) / (1 + 0.053 C_e)$
RBBRF3B	18.282	0.047	0.966	0.5382	1.149	1.769	0.880	$= (18.282 \cdot 0.047 C_e) / (1 + 0.047 C_e)$

Table 3. Comparison of the maximum monolayer adsorption capacities of some dyes on various adsorbents.

Dyes	Adsorbent	Maximum monolayer adsorption capacities (g/kg)	Reference
RBB	Activated carbon (300-500 μ m)	434	Al-Degs <i>et al.</i> , 2000
RBB	Activated carbon (500-600 μ m)	333	Al-Degs <i>et al.</i> , 2000
RBB	Activated carbon (600-700 μ m)	278	Al-Degs <i>et al.</i> , 2000
RBB	Fungus	286-588	Aksu and Tezer, 2000
RB 2	Rice husk	130	Low and Lee, 1997
RB 2	Activated sludge	250	Aksu, 2001
RB 2	Earth	260	Lee <i>et al.</i> , 1999
RB 222	Chitosan (non-cross-linked)	1009	Wu <i>et al.</i> , 2001
RB 222	Chitosan (non-cross-linked)	54-87	Juang <i>et al.</i> , 1997
Acid Blue 29	Peat, fly ash	14,15	Ramakrishna and Viraraghavan, 1997
Basic Blue 29	Peat, fly ash	46,54	Ramakrishna and Viraraghavan, 1997
Telon Blue	Activated carbon	~160	McKay, 1983
Astrazone Blue	Silica	~25	McKay, 1984
Remazol Red	Activated carbon (300-500 μ m)	400	Al-Degs <i>et al.</i> , 2000
Remazol Red	Activated carbon (500-600 μ m)	333	Al-Degs <i>et al.</i> , 2000
Remazol Red	Activated carbon (600-700 μ m)	213	Al-Degs <i>et al.</i> , 2000
RR 189	Chitosan bead	1189	Chiou and Li, 2002
RR 222	Chitosan (non-cross-linked)	299-380	Juang <i>et al.</i> , 1997
RR 222	Chitin	~100	Juang <i>et al.</i> , 1997
RR 222	Activated carbon	~50	Juang <i>et al.</i> , 1997

imum monolayer adsorption capacity of some dyes on various adsorbents (Chiou and Li, 2002). Although bagasse fly ash does not have relatively high adsorption capacity if compared with some data in Table 3, such as an activated carbon of particle diameter 300-500 μ m with an adsorption capacity for RBB of 434 g/kg (Al-Degs *et al.*, 2000), it is a low-cost and readily available waste.

The benefit of using bagasse fly ash is two-fold since the problems associated with management of the waste are also ameliorated. Recovery and regeneration of some adsorbent is difficult, whereas the bagasse fly ash in form of adsorbent could be disposed off safely by burning after drying (Rao *et al.*, 2002).

Conclusions

The objective of this paper was utilization of bagasse fly ash as adsorbent materials for reactive dye removal. The following conclusions have been drawn from the above investigations:

1. The removal efficiencies of RBB, RBBR, and RBRF3B through adsorption onto bagasse fly ash were found to be between 58.48-98.03%, 46.15-93.47%, and 46.30-94.60%, respectively.

2. The initial pH's of aqueous solutions did not affect reactive dye removal. On the other hand, percent removal of reactive dye decreased with increasing initial concentration but increased with increasing adsorbent concentration.

3. The best adsorptions were obtained under the condition of 50 mg/L dye concentration and original pH solution. The suitable contact time was 240, 300, and 240 minutes for RBB, RBBR, and RBRF3B, respectively

4. Adsorption isotherm can be described by Langmuir equation. The equation, $q_e = (16.420 * 0.110C_e) / (1 + 0.11C_e)$, $q_e = (32.468 * 0.053C_e) / (1 + 0.053C_e)$, and $q_e = (18.282 * 0.047C_e) / (1 + 0.047C_e)$ for RBB, RBBR, and RBRF3B, respectively.

5. The adsorption of RBB, RBBR, and RBRF3B onto bagasse fly ash was favorable sorption. The values of *r*, separation factor, were found to be 0.3556, 0.6131, and 0.5382 for RBB, RBBR, and RBRF3B, respectively.

6. Bagasse fly ash has the potential for use as adsorbent for dye wastewater containing RBB, RBBR, and RBRF3B. Removal efficiencies of more than 50% can be achieved.

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References

- Aksu, Z. 2001. Biosorption of reactive dyes by dried activated sludge: equilibrium and kinetic modeling. *Biochem. Eng. J.*, 7: 79-84.
- Aksu, Z. and Tezer, S. 2000. Equilibrium and kinetic modeling of biosorption of remazol black B by *rhizopus arrhizus* in a batch system: effect of temperature. *Process Biochem.*, 36: 431-439.
- Al-Degs, Y., Khraisheh, M.A.M., Allen, S.J. and Ahmad, M.N. 2000. Effect of carbon surface chemistry on the removal of reactive dyes from textile effluent. *Water Research*, 34: 927-935.
- Chiou, M.S. and Li, H.Y. 2002. Equilibrium and kinetic modeling of adsorption of reactive dye on cross-linked chitosan beads. *J. of Hazardous Materials B93*, 233-248.
- Gupta, V.K. and Ali, I. 2000. Utilization of bagasse fly ash (a sugar industry waste) from the removal of copper and zinc from wastewater. *Separation and Purification Technology*, 18: 131-140.
- Gupta, V.K. and Ali, I. 2001. Removal of DDD and DDE from wastewater using bagasse fly ash, a sugar industry waste. *Water Research*, 35: 33-40.
- Juang, R.S., Tseng, R.L., Wu, F.C. and Lee, S.H. 1997. Adsorption behaviour of reactive dyes from aqueous solutions on chitosan. *J. Chem. Technol. Biootechnol.*, 70: 391-399.
- Juang, R.S., Wu, F.C. and Tseng, R.L. 2002. Characterization and use of activated carbons prepared from bagasse for liquid-phase adsorption. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, 201: 191-199.
- Khraisheh, M.A.M., Al-Degs, Y.S., Allen, S.J. and Ahmad, M.N. 2002. Elucidation on controlling steps of reactive dye adsorption on activated carbon. *Ind. Eng. Chem. Res.*, 41: 1651-1657.
- Lazaridis, N.K., Darapantsios, T.D. and Georgantas, D. 2003. Kinetic analysis for the removal of a reactive dye from aqueous solution onto hydro-talcite by adsorption. *Water Research*, 37: 3023-3033.
- Lee, C.K., Low, K.S. and Gan, P.Y. 1999. Removal of some organic dyes by acid-treated spent bleaching earth. *Process Biochem.* 34: 451-465.
- Low, K.S. and Lee, C.K. 1996. Quaternized rich husk as sorbent for reactive dyes. *Bioresource Tech.*, 61: 121-125.

- McKay, G. 1983. The adsorption of dyestuffs from aqueous solution using activated carbon: analytical solution for batch adsorption based on external mass transfer and pore diffusion. *Chem. Eng.*, 27: 187-196.
- McDay, G. 1984. Analytical solution using a pore diffusion model for a pseudoirreversible isotherm for the adsorption of basic dyes on silica. *AIChE J.*, 30: 692-697.
- Mohan, D., Singh, K.P., Singh, G. and Kumar, K. 2002. Removal of dyes from wastewater using fly ash, a low-cost adsorbent. *Ind. Eng. Chem. Res.*, 41: 3688-3695.
- Ramadrishna, K.R. and Viraraghavan, T. 1997. Dye removal using low cost adsorbents. *Water Sci. Tech.*, 36: 189-196.
- Rao, M., Parwate, A.V. and Bhole, A.G. 2002. Removal of Cr⁶⁺ and Ni²⁺ from aqueous solution using bagasse and fly ash. *Waste management*, 22: 821-830.
- Rughachart, R. 2001. Removal of dye in wastewater by quaternized crosslinked cellulose from cassava stem, pineapple leaf and coconut husk. M.Sc., Environmental Science. Chulalongkorn University. Bangkok. Thailand.
- Sun, G., and Xu, X. 1997. Sunflower stalks as adsorbents for color removal from textile wastewater. *Ind. Eng. Chem. Res.*, 36: 808-81.
- Wu, F.C., Tseng, R.L. and Juang, R.S. 2001. Enhanced abilities of highly swollen chitosan beads for color removal and tyrosinase immobilization. *J. Hazard. Mater.*, B81: 167-177.
- <http://www.nepo.go.th/encon/encon-spp-renewb2.html>. Retrieved August 21, 2002