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The Effect of Coconut Shell Activated Carbon Dosage on the Removal of Remazol Brilliant Blue R

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Abstract
Textile wastewater contains Remazol Brilliant Blue R (RBBR), a persistent synthetic dye that is difficult to degrade naturally. This study aimed to characterize coconut-shell activated carbon, determine the most effective adsorbent dose and contact time for RBBR removal, and evaluate Pseudo First Order (PFO) and Pseudo Second Order (PSO) kinetic models. The activated carbon was prepared by carbonization at 700°C for 2 h followed by activation with 10% (w/v) H_3PO_4 for 24 h. Batch adsorption used 100 mL of 50 ppm RBBR at adsorbent doses of 0.5–5 g/L and contact times of 5–60 min at 150 rpm. Adsorbent quality was evaluated according to SNI 06-3730-1995 and RBBR concentration was determined by UV–Vis spectrophotometry at λmax 630 nm. All activated-carbon quality parameters met the standard: moisture 4.52%, ash 2.33%, volatile matter 2.60%, fixed carbon 90.55%, and iodine number 856.58 mg/g. The highest Run-2 removal efficiency was 41.68% at 3 g/L and 60 min, leaving 29.2 ppm RBBR. Neither kinetic model consistently described all doses because qt fluctuated with contact time. PFO showed the highest fit at 4 g/L (R^2=0.978), while PSO was highest at 5 g/L (R^2=0.851). At the optimum dose of 3 g/L, PSO yielded R^2=0.447 and was therefore insufficiently representative. The adsorption behavior was also affected by mass transfer and intraparticle diffusion.
Keywords: *adsorption, coconut shell activated carbon, phosphoric acid activator, remazol brilliant blue*

Abstrak
Air limbah tekstil mengandung *Remazol Brilliant Blue R* (RBBR) yang persisten dan sulit terdegradasi secara alami. Penelitian ini bertujuan menentukan karakteristik karbon aktif tempurung kelapa, dosis dan waktu kontak paling efektif untuk penyisihan RBBR, serta mengevaluasi kesesuaian model Pseudo First Order (PFO) dan Pseudo Second Order (PSO). Karbon aktif dipreparasi melalui karbonisasi 700°C selama 2 jam dan aktivasi H_3PO_4 10% (b/v) selama 24 jam. Adsorpsi dilakukan secara batch menggunakan 100 mL RBBR 50 ppm dengan variasi dosis 0,5–5 g/L dan waktu kontak 5–60 menit pada 150 rpm. Karakterisasi mengacu pada SNI 06-3730-1995 dan konsentrasi RBBR dianalisis menggunakan spektrofotometer UV-Vis pada λmax 630 nm. Karbon aktif memenuhi seluruh parameter mutu, yaitu kadar air 4,52%, kadar abu 2,33%, volatile matter 2,60%, fixed carbon 90,55%, dan daya serap iodin 856,58 mg/g. Efisiensi penyisihan tertinggi pada Run 2 sebesar 41,68% diperoleh pada dosis 3 g/L dan waktu kontak 60 menit, dengan konsentrasi sisa 29,2 ppm. Analisis kinetika menunjukkan PFO dan PSO tidak konsisten menjelaskan seluruh variasi dosis karena nilai qt berfluktuasi terhadap waktu. PFO memberikan kecocokan tertinggi pada dosis 4 g/L (R^2=0,978), sedangkan PSO pada 5 g/L (R^2=0,851). Pada kondisi optimum 3 g/L, PSO menghasilkan R^2=0,447 sehingga belum cukup representatif. Hasil menunjukkan proses dipengaruhi pula oleh perpindahan massa dan difusi intrapartikel.
Kata Kunci: *adsorpsi, karbon aktif tempurung kelapa, aktivator asam fosfat, remazol brilliant blue*

1. Introduction

Textile industrial wastewater may contain synthetic dyes that are difficult to degrade due to their relatively stable chemical structures. One of the commonly used dyes is Remazol Brilliant Blue R (RBBR), an anionic reactive dye containing chromophore and sulfonate groups. The presence of dyes in wastewater needs to be controlled because excessive coloration can interfere with light penetration and adversely affect the quality of receiving water bodies. One of the methods that can be applied to remove dyes from wastewater is adsorption using activated carbon [1],[2].

Coconut shells are a potential biomass material for conversion into activated carbon because they are rich in carbon and abundantly available. Chemical activation using H_3PO_4 can promote the formation and development of pore structures, thereby enhancing the adsorption capacity of the resulting activated carbon [3],[4]. Previous studies have shown that a carbonization temperature of 700°C can produce favourable

pore development in coconut-shell activated carbon, while H_3PO_4 activation has been widely applied to improve the adsorption performance of carbon-based adsorbents for dye removal [5],[6].

Previous studies have also demonstrated the potential of biomass-based adsorbents for removing RBBR from aqueous solutions. Setiawan et al. reported an RBBR removal efficiency of 87.23% using activated carbon derived from empty palm oil bunches [7]. Other studies have also investigated RBBR adsorption using coconut-shell-derived or biomass-based adsorbents [8], [9]. However, previous studies have mainly focused on factors such as the type of biomass precursor, carbonization temperature, activating-agent concentration, or solution pH. Studies that comprehensively investigate the relationship between the characteristics of coconut-shell activated carbon activated with 10% H_3PO_4, adsorbent dosage, contact time, and RBBR adsorption kinetics remain limited.

The novelty of this study lies in the integrated evaluation of the characteristics of coconut-shell activated carbon, the effects of adsorbent dosage ranging from 0.5 to 5 g/L and contact time ranging from 5 to 60 min on the removal of 50 ppm RBBR, and the evaluation of Pseudo-First-Order (PFO) and Pseudo-Second-Order (PSO) kinetic models. The study also considers experimental reproducibility through two experimental runs, with Run 2 used as the primary dataset because Run 1 exhibited systematic disturbances during the initial contact period, which were suspected to be associated with incompletely washed residual H_3PO_4. Therefore, this study aims to characterize coconut-shell activated carbon, determine the most effective adsorbent dosage and contact time for RBBR removal, and evaluate the most representative adsorption kinetic model for the experimental data.

2. Material and Methods

The research was conducted at the Chemical Engineering Laboratory, Politeknik Negeri Bandung. The main materials used were coconut shells and Remazol Brilliant Blue R (RBBR), while 10% (w/v) H_3PO_4 was used as the activating agent. The main equipment included a furnace, oven, analytical balance, grinder and sieve, shaker, pH meter, and UV–Vis spectrophotometer.

The coconut shells were cleaned and dried, followed by carbonization at 700°C for 2 h. The resulting charcoal was ground and sieved to obtain particles that passed through a 60-mesh sieve and were retained on a 120-mesh sieve. Chemical activation was carried out using 10% (w/v) H_3PO_4 at a carbon-to-activating-solution ratio of 1:4 for 24 h. The activated carbon was subsequently washed until the filtrate reached a pH of approximately 5 and then dried at 105°C for 2 h.

The adsorbent was characterized in terms of moisture content, ash content, volatile matter, fixed carbon, and iodine adsorption capacity, with the results compared against the requirements of SNI 06-3730-1995 [10]. An RBBR solution with an initial concentration of 50 ppm was prepared. The maximum absorption wavelength (λmax) was determined by scanning the wavelength range of 580–680 nm, yielding a λmax of 630 nm. A standard calibration curve was prepared using RBBR concentrations of 10, 20, 30, 40, and 50 ppm. The calibration procedure was based on standard principles of instrumental chemical analysis [11].

Batch adsorption experiments were conducted using 100 mL of 50 ppm RBBR solution at pH 5 with a stirring speed of 150 rpm. The activated carbon dosages were varied at 0.5, 1, 2, 3, 4, and 5 g/L, while the contact times were set at 5, 10, 15, 30, 45, and 60 min. Each experimental condition was measured in triplicate. The experiments were conducted in two runs; however, Run 2 was used as the primary basis for analysis because Run 1 exhibited systematic disturbances during the initial contact period.

The RBBR removal efficiency was calculated using $\%R = ((C_0 - C_t)/C_0) \times 100\%$, where ($C_0$) is the initial RBBR concentration and (C_t) is the RBBR concentration at contact time (t). The adsorption capacity was calculated using Equation $q_t = (C_0 - C_t)V/m$, where (q_t) is the adsorption capacity at time (t), (V) is the volume of the RBBR solution, and (m) is the mass of activated carbon. The Pseudo-First-Order (PFO) and Pseudo-Second-Order (PSO) kinetic models were analyzed using their respective linear forms. The model fit was evaluated based on the direction of the kinetic parameters and the coefficient of determination (R^2).

3. Results and Discussion

Activated Carbon Characteristics

The activated carbon produced in this study met all quality parameters specified by SNI 06-3730-1995. The characterization results are presented in **Table 1**. The moisture content, ash content, and volatile matter were below the maximum allowable limits, while the fixed carbon content and iodine adsorption capacity exceeded the minimum requirements.

Table 1. Characteristics of Coconut-Shell Activated Carbon

Parameter	Result	Standard SNI	Status
Moisture content (%)	4,52	Max. 15%	Meets the standard
Ash content (%)	2,33	Max. 10%	Meets the standard
Volatile matter (%)	2,60	Max. 25%	Meets the standard
Fixed carbon (%)	90,55	Min. 65%	Meets the standard
Iodine number (mg/g)	856,58	Min. 750 mg/g	Meets the standard

The fixed carbon content of 90.55% indicates a high proportion of bound carbon in the activated carbon. The average iodine adsorption capacity of 856.58 mg/g, calculated from 875.61 mg/g for Sample A and 837.54 mg/g for Sample B, indicates good micropore development. The adsorption performance of activated carbon is closely related to its porous structure and surface characteristics [12], [13]. Therefore, the activated carbon used in this study met the required quality standards and was suitable for the adsorption experiments.

Determination of λmax and Standard Curve

The scanning of 50 ppm RBBR over the wavelength range of 580–680 nm resulted in the highest absorbance of 0.776 at 630 nm. Therefore, a wavelength of 630 nm was selected as the maximum absorption wavelength (λmax) for subsequent measurements. The standard curve constructed over the concentration range of 10–50 ppm yielded the equation $y = 0.0155x + 0.0013$ with an R^2 value of 0.9999. The high linearity indicates that the resulting calibration equation can be used to convert sample absorbance into RBBR concentration within the investigated concentration range.

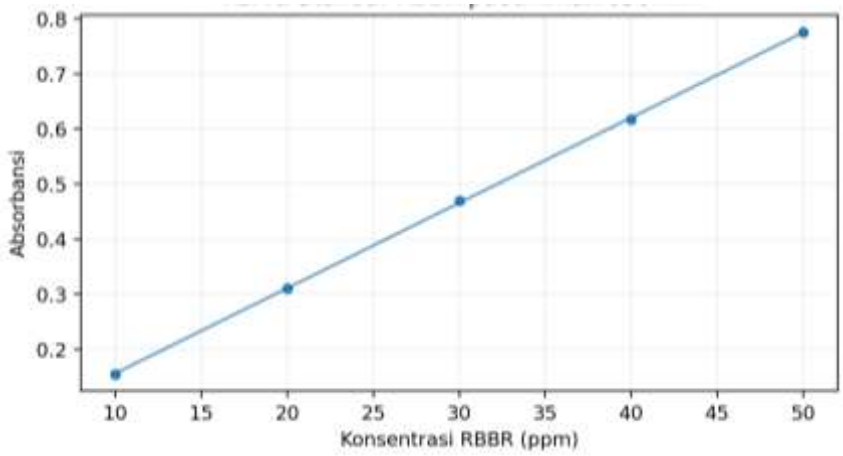

Figure 1. Standard curve of RBBR at λmax = 630 nm

Effect of Adsorbent Dosage and Contact Time

The RBBR removal efficiency in Run 2 ranged from 10.35% to 41.68%. The highest removal efficiency of 41.68% was obtained at an adsorbent dosage of 3 g/L and a contact time of 60 min, whereas the lowest removal efficiency of 10.35% was observed at 2 g/L and 45 min. The complete results are presented in **Table 2**.

Table 2. RBBR Removal Efficiency in Run 2 at Various Adsorbent Dosages and Contact Times

Time (minute)	0,5 g/L	1 g/L	2 g/L	3 g/L	4 g/L	5 g/L
5	21.88	22.83	22.91	33.16	16.37	26.57
10	20.25	16.93	21.67	19.73	15.98	14.61
15	30.23	21.28	13.10	10.52	18.09	27.60
30	24.89	28.64	28.08	26.57	34.88	22.23
45	14.18	17.62	10.35	14.69	24.51	40.69
60	18.01	18.95	19.26	41.68	28.34	31.22

The removal efficiency did not increase monotonically with either adsorbent dosage or contact time. In general, increasing the adsorbent dosage provides a greater number of available active sites. However, at higher dosages, particle aggregation may occur, potentially reducing the effective surface area accessible to the adsorbate [14]. The fluctuations observed with contact time may also be associated with

mass transfer and intraparticle diffusion [15]. The optimum condition of 3 g/L and 60 min indicates that, within the investigated range, this combination provided the most effective interaction between the available adsorption sites and RBBR molecules.

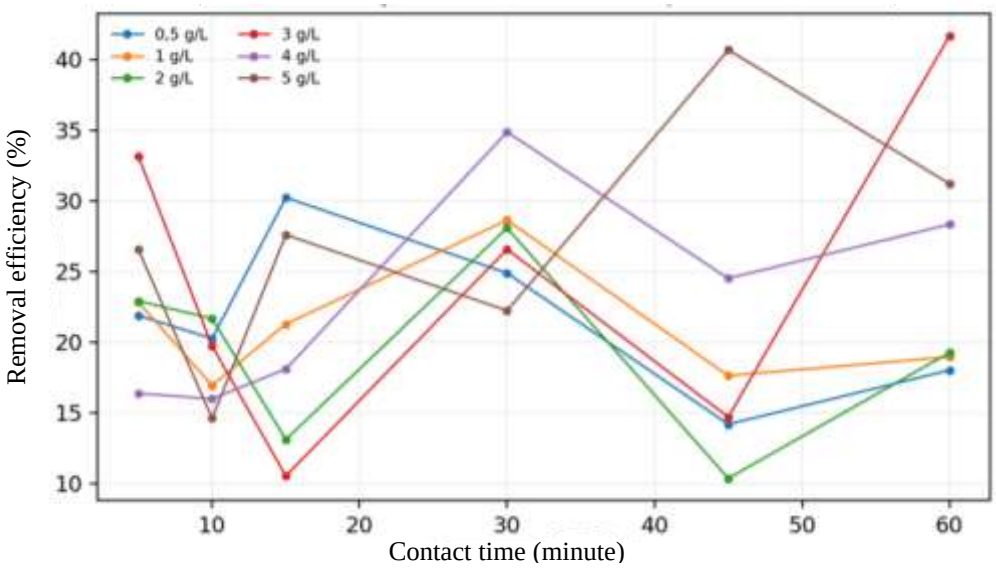

Figure 2. Effect of contact time on RBBR removal efficiency

Adsorption Capacity

The adsorption capacity per unit mass of adsorbent tended to decrease as the adsorbent dosage increased. The highest adsorption capacity was obtained at 0.5 g/L, with a q_e value of 18.01 mg/g, while the lowest value was observed at 5 g/L, with a q_e of 3.12 mg/g. Similar effects of adsorbent dosage on adsorption capacity have been reported in previous dye adsorption studies [8],[16]. The decrease in q_e indicates that increasing the amount of adsorbent does not necessarily increase the amount of adsorbate adsorbed per unit mass because the amount of RBBR present in the solution remained constant.

Table 3. Adsorption Capacity at a Contact Time of 60 min

Dosage (g/L)	q_e (mg/g)
0,5	18,01
1	9,48
2	4,81
3	6,95
4	3,54
5	3,12

Adsorption Kinetic Analysis

The kinetic analysis showed that no single model consistently described the adsorption behavior across all adsorbent dosages. The Pseudo-First-Order (PFO) model provided the highest fit at an adsorbent dosage of 4 g/L, with $R^2 = 0.978$, whereas the Pseudo-Second-Order (PSO) model showed the highest fit at 5 g/L, with $R^2 = 0.851$. The application of PFO and PSO models is commonly used to evaluate adsorption kinetics and assess the rate-controlling behavior of sorption processes [17], [18]. At the optimum adsorbent dosage of 3 g/L, the PSO model yielded an R^2 value of 0.447, indicating that the model was not sufficiently representative of the overall kinetic behaviour.

Table 4. Summary of the Best-Fitting Kinetic Models for RBBR Adsorption

Dosage (g/L)	The model with the highest fit	R^2	Note
0,5	PSO	0.934	Parameters should be interpreted with caution
1	PFO	1.000	Pseudo-R^2 due to the limited number of valid data points
2	PSO	0.742	Poor fit and negative k
3	PSO	0.447	Poor fit
4	PFO	0.978	Good fit

Dosage (g/L)	The model with the highest fit	R^2	Note
5	PSO	0.851	Fairly good fit

The fluctuations in q_t with contact time indicate that some of the experimental data did not satisfy the basic assumptions of kinetic models, which generally require adsorption capacity to change systematically toward equilibrium. Therefore, a high R^2 value under a particular condition should not be directly interpreted as definitive evidence of a single adsorption mechanism. These findings suggest that the adsorption system may be influenced by multiple mass-transfer steps, including intraparticle diffusion. Intraparticle diffusion is commonly considered as one of the possible rate-controlling steps in adsorption processes [19].

A systematic disturbance was observed during the initial contact period in Run 1, which was suspected to have resulted from residual H_3PO_4 that had not been completely removed during the washing process. Therefore, Run 2 was used as the primary reference dataset. This finding is important for further studies because the effectiveness of adsorbent washing can affect absorbance measurements and experimental reproducibility.

Treatment Implications

Under the optimum condition, the RBBR removal efficiency reached 41.68%, with a remaining RBBR concentration of approximately 29.2 ppm. Based on the wastewater quality standard referred to in the research report, this residual concentration does not yet meet the applicable standard. At an adsorbent dosage of 3 g/L, approximately 3 kg of activated carbon would be required for every 1 m^3 of wastewater. Therefore, under the conditions investigated in this study, coconut-shell activated carbon would be more realistically considered as part of a treatment train or as a polishing stage after the dye load has been reduced through a preliminary treatment process, rather than as a standalone treatment unit.

4. Conclusion

Coconut-shell activated carbon prepared by carbonization at 700°C for 2 h and activation with 10% (w/v) H_3PO_4 for 24 h met the requirements of SNI 06-3730-1995, with a moisture content of 4.52%, ash content of 2.33%, volatile matter content of 2.60%, fixed carbon content of 90.55%, and iodine adsorption capacity of 856.58 mg/g. Within the experimental conditions investigated, the most effective adsorbent dosage and contact time were 3 g/L and 60 min, respectively, resulting in an RBBR removal efficiency of 41.68%. However, the remaining RBBR concentration of approximately 29.2 ppm indicates that adsorption under these conditions is insufficient to be applied as a standalone treatment process. The Pseudo-First-Order (PFO) and Pseudo-Second-Order (PSO) models could not consistently describe the adsorption mechanism across all adsorbent dosages. The highest coefficient of determination (R^2) was obtained for the PFO model at an adsorbent dosage of 4 g/L (R^2 = 0.978) and for the PSO model at 5 g/L (R^2 = 0.851). At the optimum dosage of 3 g/L, the PSO model yielded an R^2 value of only 0.447. The fluctuations in q_t indicate that mass transfer and intraparticle diffusion should be considered in further investigations, along with the use of longer contact times.

5. Acknowledgment

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6. Abbreviations

RBBR	Remazol Brilliant Blue R
PFO	Pseudo-First-Order
PSO	Pseudo-Second-Order
UV–Vis	Ultraviolet–Visible
SNI	Indonesian National Standard
H_3PO_4	Phosphoric Acid
q_t	Adsorption capacity at time *t*
q_e	Equilibrium adsorption capacity
C_0	Initial RBBR concentration
C_t	RBBR concentration at time *t*

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