



Removal of Basic Blue 3 Dye Using Pomelo Peel

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A low-cost adsorbent pomelo peel was investigated for its potential and feasibility to remove basic blue 3 dye from aqueous solutions. Different parameters such as initial dye concentrations, contact time and pH were used to examine its adsorption behaviour. The percentage removal of dye increased as decreasing in the initial dye concentrations and the attainment equilibrium of the adsorption system could be achieved in 4 h. When the experimental data were further studied by the kinetic models, it was evident that the pseudo-second-order kinetic model provided higher correlation coefficient ($R^2 > 0.9960$) for the adsorption system. The effect of solution pH on dye uptake revealed that the percentage removal of dyes increased when the solution pH was increased. Adsorption of basic blue 3 dye onto pomelo peel fitted well to the Freundlich isotherm models, with high correlation coefficient of 0.9914. Based on Langmuir equation, the maximum adsorption capacity of pomelo peel was 23.87 mg/g.

Keywords: Immobilization, Pomelo peel, Adsorption, Basic blue 3.

INTRODUCTION

Dyes are generally used in many industries such as textile, paper and paint. Besides being used as colouring agents, they play an important role in the high-tech applications. Examples of which are light-emitting diodes and laser welding processes¹. Due to the wide applications of dyes for different purposes, an annual production of 7.0×10^5 tonnes of various dyes is required to meet the demand². An estimated 2.8×10^5 tonnes of dyestuffs are disposed yearly³.

Basic blue 3 (BB3) is one of the azo dyes. Azo dyes which contains one or more nitrogen to nitrogen double bonds (-N=N-) constitute a major part of all commercial dyes. Under anaerobic condition, aromatic amines are produced as a result of the reduction of cleavage of azo linkages³. The final product of the reaction is toxic to the living organisms. Hence, a proper management of the dye-containing wastewater is strictly needed and strongly recommended before disposal into the water streams.

Liquid-adsorption is characterized as the most efficient methods for the removal of colours, odors, organic and inorganic pollutants from industrial effluents^{1,4}. This type of treatment method is popular and attractive nowadays due to the high adsorption efficiency and effectiveness in removing dyes from dye-containing wastewater in comparison to other

physical and biological treatments methods. Also, adsorption technique is simple and flexible and subsequently can be operated easily. Most importantly, there are no toxic and harmful by-products being generated which can cause environmental problems.

In view of applicability of adsorption process, the cost of adsorbents to be used is a most critical restricted factor. Commercial activated carbon (CAC), generally prepared from coal, is well-known for its high adsorption abilities for the treatment of a wide range of synthetic dyes, which can be either cationic nor anionic. However, the production and regeneration costs of CAC are high and disposal of the toxic by-products generated after adsorption can cause environmental problems⁵. As a consequence, many researchers have paid their attentions on the potential and feasibility of the use of readily available low-cost adsorbents obtaining from industrial and agricultural areas to treat highly toxic and coloured synthetic-dye-containing wastewater. A wide variety of low-cost adsorbents have been examined, for example, palm kernel fibre⁶, fruits peel⁷, jackfruit peel⁸, coconut bunch waste⁹, hazelnut shell¹⁰, coffee residues¹¹, duckweed¹², sugarcane bagasse¹³ and cotton stalk, cotton waste and cotton dust¹⁴.

In this research, pomelo fruits were chosen as the adsorbent. Pomelo (*Citrus maxima* of *Citrus grandis*), also known as pummelo, shaddock or Chinese grapefruit, originates from

southeastern Asia and all of Malaysia. An approximately 8.83×10^2 metric tons of pomelo fruits is produced yearly from about 1.9×10^2 ha of pomelo trees in Malaysia¹⁵. Pomelo fruit, rich in vitamin C and flavonoids, is usually eaten fresh. Besides being processed to produce jams, marmalade and fruit cocktails in food industry, they are used to make desserts and salads in our daily lives. Since pomelo fruits are highly consumed, there is a great amount of the peels being discarded. These disposed wastes to the environment without fully utilizing them can subsequently cause negative impacts to community such as disposal and environmental problems. Hence, to overcome all these problems, it is suggested that pomelo peels should be studied to examine whether it is suitable to be used as a low-cost adsorbent. Besides increasing the value of the waste products, it can help to reduce the water pollution by adsorption of dye-containing wastewater. The main disadvantage of a suspended system is that it requires a filtration step which is not suited for practical applications. Therefore, a feasible approach to overcome this obstacle was attempted in this research and that is to immobilize the adsorbent onto a supporting material.

EXPERIMENTAL

Sorbent: Pomelo peels (PP) were collected from a local market. The collected pomelo peels was washed several times using tap water to remove all the dirt particles before rinsing with distilled water. The washed materials were subsequently cut into small pieces (1-2 cm) and dried in an oven at 60 °C for 48 h to ensure the removal of moisture content. The dried peels were then ground and passed through a sieve to obtain particle sizes ranging 0.5-1 mm. The plastic container containing the powdered form of pomelo peel was kept in a desiccator for further use.

Sorbate: In this research, basic blue 3 dye (BB3) was used without further purification as the adsorbate. The cationic dye basic blue 3 has a molecular weight of 359.89 g/mol and its molecular structure was illustrated in Fig. 1. The dye powder was purchased from Sigma-Aldrich Pvt. Ltd. (United States of America). A stock solution with the concentration of 1000 mg/L was prepared and subsequently diluted to attain the desired concentration when necessary.

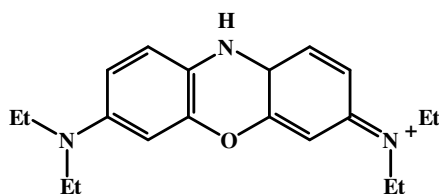


Fig. 1. Basic blue 3 dye molecule

Immobilization of dried pomelo peel on glass plates: 5.0 g of dried pomelo peel was weighed and immobilized onto the glass plates ($2.5'' \times 1.0'' \times 0.1''$) before the adsorption experiments.

Scanning electron microscopy (SEM): The surface morphology of pomelo peel (before and after adsorption) was examined using FESEM JSM 6701F (JEOL).

Fourier transform infrared spectrophotometry (FTIR):

Fourier transform infrared spectrophotometry analysis was used to examine the functional groups that present on pomelo peel surface. FTIR analysis of pomelo peel in the solid phase was performed using Perkin-Elmer System 2000 FT-IR Spectrometer. The powdered form pomelo peel solid sample was mixed with IR-grade potassium bromide (KBr) in a mortar and pestle. The mixture was then subjected to high pressure using a hydraulic KBr press to melt the KBr and seal the compound into matrix. The small disk obtained was analyzed using FTIR spectrometer.

Batch adsorption studies: In this study, all the experiments were carried out at room temperature (25 ± 2 °C) to eliminate any temperature effects on the adsorption of basic blue 3 dye onto pomelo peel. A volume of 2 L basic blue 3 dye solution was poured into the reactor. Eight glass plates coated with pomelo peel with a total weight of 5 g were used each time. Natural pH of basic blue 3 dye was applied for all of the experiments unless otherwise stated. The dye solutions were collected using a syringe and then analyzed with UV-visible spectrophotometer to measure their absorbance corresponding to a maximum wavelength of 654 nm.

The percentage removal of basic blue 3 dye was determined from the following equation:

$$\text{Uptake (\%)} = \frac{(C_0 - C_1)}{C_0} \times 100 \quad (1)$$

where C_0 and C_1 (mg/L) are the liquid-phase concentrations of dye at initial and equilibrium, respectively.

Effect of initial concentration and contact time: The synthetic dye solution was agitated for 8 h by bubbling air through the reaction system. The samples were collected at predetermined intervals (0.5, 1, 3, 5, 10, 15, 30, 60, 90, 120, 180, 240, 300, 360, 420, 480 minutes). The experiment was repeated by using 30 and 40 mg/L of basic blue 3 dye solutions.

Effect of pH: The effect of pH on adsorption of basic blue 3 dye onto pomelo peel was examined by equilibrating adsorption-mixture in the pH ranging from 2, 4, 6, 8 and 10. Adjustment of the initial pH of the dye solutions was made by adding various molarity of HCl and NaOH dropwise prior to adsorption experiments. The synthetic dye solution was agitated for 4 h by bubbling air through the reaction system. Samples were collected after 4 h and the solution pH was measured.

Sorption isotherm: The dye solution with different concentrations, 30, 50, 70 and 90 mg/L were prepared and equilibrated for 4 h. The final dye concentration was then analyzed using UV-visible spectrophotometer.

RESULTS AND DISCUSSION

Scanning electron micrograph (SEM): Fig. 2(a) and (b) shows the SEM micrographs of pomelo peel before and after adsorption, respectively. Based on Fig. 2(a), it was found that the surface of the pomelo peel belongs to a non-porous type. After adsorption, the dye-loaded on the surface of pomelo peel appeared to be slightly different, whereby it is considered much smoother and flat as shown in Fig. 2(b).

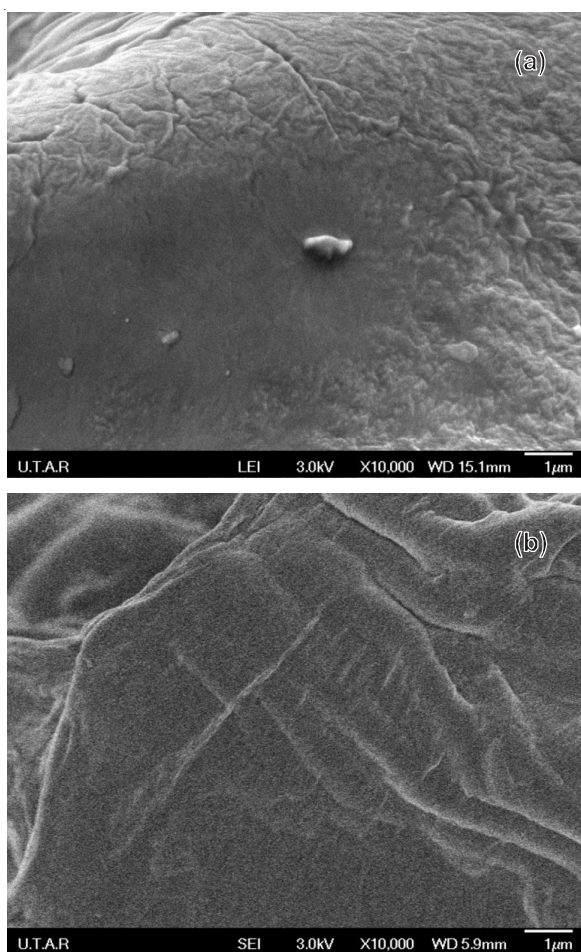


Fig. 2. (a) and (b): SEM micrographs of pomelo peel with magnifications of 10000 \times

Fourier transform infrared spectrophotometry (FTIR): On the basis of characterization, FTIR analysis is essential in order to identify the functional groups of pomelo peel that is responsible for dye binding. Fig. 3 shows the FTIR spectrum of pomelo peel samples before adsorption of basic blue 3 dye in the range of 4000-400 cm^{-1} . Based on the FTIR spectrum, a strong adsorption was observed in the region 3600-3200 cm^{-1} . It may be because of the presence of the hydroxyl group of pomelo peel. The peak at 2929 cm^{-1} could be attributed to O-H stretching vibrations. The sharp band appeared at 1744 cm^{-1} corresponded to the C=O stretching from the lignin carbonyl groups¹⁶. In addition, the peaks observed at 1631 cm^{-1} and 1378 cm^{-1} could be associated with C=C stretching and salts of carboxylic acids, respectively. A band at 1063 cm^{-1} was due to C-O-H which indicated the presence of lignin structure in pomelo peel¹⁶.

Effect of initial concentration and contact time: The effect of initial dye concentrations and contact time on uptake of basic blue 3 dye solution by pomelo peel was studied and the result was presented in Fig. 4. The percentage of dye uptake decreased as the concentrations was increased. The adsorption was fast over the first 30 min and it proceeded at a slower rate until the attainment of equilibrium at 480 min. A similar trend was observed in the removal of dye molecules by other adsorbents such as hazelnut shell¹⁰, palm kernel fibre⁶, papaya seeds¹⁷ and rejected tea¹⁸.

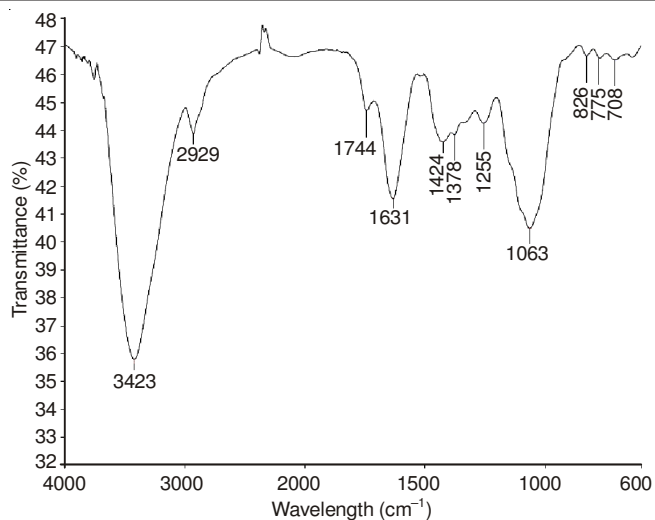


Fig. 3. FT-IR spectrum of pomelo peel

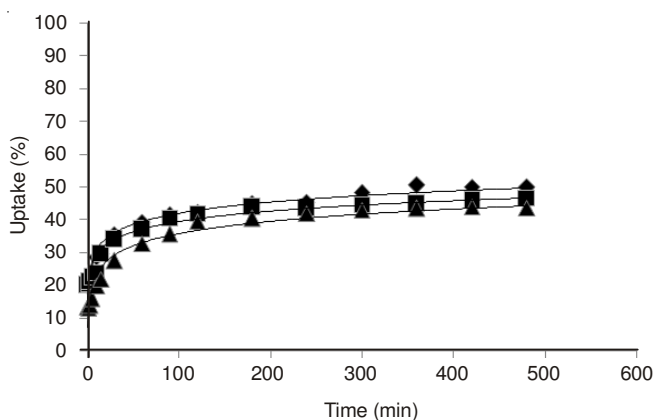


Fig. 4. Effect of initial basic blue 3 dye concentrations and contact time on the percentage uptake of basic blue 3 by pomelo peel. ●, ■, ▲-20, 30 and 40 mg/L of basic blue 3 (5.0 g pomelo peel; dye volume 2 L ; natural pH of dye solution; 8 h)

As shown in Fig. 4, the percentage uptake increased with increasing contact time till the attainment of equilibrium. The rapid uptake at first 30 min was greatly due to the availability of a high amount of vacant active sites. A slower adsorption was found with increasing contact time. This is because time taken for the penetration of the basic blue 3 dye molecules to the inner active sites of pomelo peel was longer and hence an insignificant adsorption was shown in the second stage of the system.

It has been postulated that in an adsorption process, it involved three stages. First of all, film mass transfer where the diffusion of dye molecules in the solution to the outer surface of the adsorbent occurred. At the second stages, dye molecules had to penetrate through the pores of the inner structure of pomelo peel. It was time-consuming prior to the attainment of equilibrium. Finally, the accumulation of basic blue 3 dye molecules on the empty active sites on inner surface of the negatively-charged adsorbent was found.

As increasing contact time, it was found that the adsorption of dye solutions of different concentrations attained equilibrium at different time. At low concentration (20 mg/L), approximately 180 min was required for the system to reach equilibrium. The time required for the attaining equilibrium was 240 min and 300 min for dye solutions with concentrations

of 30 and 40 mg/L, respectively. The experimental data indicated that the initial concentration and contact time exerted a noticeable influence on the adsorption process of basic blue 3 dye onto pomelo peel.

Kinetic studies: Adsorption kinetic study in wastewater treatment is important as information regarding the reaction mechanism of adsorption is provided, which is in turn vital for the efficiency of the process optimization. In addition, adsorption kinetics revealed a large dependence on the physical and chemical characteristics of the adsorbent which also influences the adsorption mechanism¹⁹.

In this study, the adsorption kinetic of the adsorption of basic blue 3 dye onto pomelo peel was monitored by applying two commonly used kinetic models, namely, pseudo-first-order²⁰ and pseudo-second-order²¹. The linear equations are expressed as follows:

$$\log (q_e - q_t) = \log q_e - k_1 t / 2.303 \text{ (pseudo-first order equation) (2)}$$

$$t/q_t = 1/h + t/q_e \text{ (pseudo-second order equation) (3)}$$

where q_e = the amount of dye adsorbed at equilibrium (mg/g), q_t = the amount of dye adsorbed at time t (mg/g), k_1 = the rate constant of pseudo-first order kinetics (min^{-1}), h ($k_2 q_e^2$) = the initial absorption rate, (mg/g min) and k_2 = the rate constant of pseudo-second order kinetics (g/mg min)

Values of the first-order rate constant (k_1) and theoretical value of q_e can be obtained respectively from the slope and the y-intercept of the linear plots of $\log (q_e - q_t)$ against time for the adsorption of basic blue 3 dye of initial concentration of 20, 30 and 40 mg/L (Fig. 5). It was found that the pseudo-first order kinetic model did not fit well for the whole range of concentrations studied as the equilibrium adsorption capacities calculated from this kinetic model gave unreasonable values compared to those determined experimentally (Table-1). Since the R^2 values were greater than 0.9960 for all cases, this indicated that the pseudo-second-order kinetic order model provided a better correlation of the experimental data compared to that of pseudo-first-order kinetic order model (Table-1).

The initial adsorption rate (h) and theoretical value of q_e were determined from the y-intercept and the slope of the plot of the linear plot of t/q_t against t for the adsorption of basic blue 3 dye of initial concentration of 20, 30 and 40 mg/L (Fig. 6), respectively. To determine k_2 values, h and q_e values were substituted into eqn. 4. The initial adsorption rate, h (mg/g min) at $t \rightarrow 0$ was expressed as:

$$h = k_2 q_e^2 \text{ (4)}$$

Based on Table-1, the theoretical $q_{e,cal}$ values were in close agreement with the experimental $q_{e,exp}$ values at different initial basic blue 3 dye concentrations. This indicated the adsorption kinetics of basic blue 3 dye onto the pomelo peel adsorbent

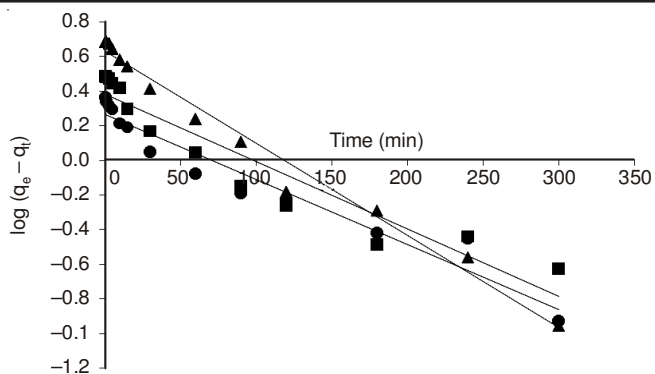


Fig. 5. Pseudo-first-order plot for the adsorption of basic blue 3 dye onto pomelo peel. ●, ■, ▲- 20, 30 and 40 mg/L of basic blue 3 (5.0 g pomelo peel; dye volume 2 L ; natural pH of dye solution; 8 h)

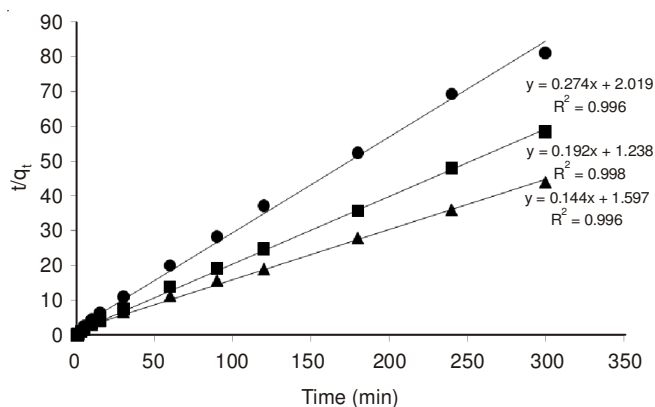


Fig. 6. Pseudo-second-order plot for the adsorption of basic blue 3 dye onto pomelo peel. ●, ■, ▲- 20, 30 and 40 mg/L of basic blue 3 (5 g pomelo peel; dye volume 2 L ; natural pH of dye solution; 8 h)

was well described by pseudo-second-order kinetic model. It is suggested that chemisorption occurs involving valency forces through sharing or the exchange of electrons between the adsorbate and the adsorbent²².

The values of k_2 , h and q_e against C_o in the corresponding linear plots of the pseudo-second-order kinetic model equation were regressed to obtain expressions for these values in terms of the initial basic blue 3 dye concentrations²¹. These parameters could be presented as a function of C_o for dye on pomelo peel as follows:

$$q_e = \frac{C_o}{A_q C_o + B_q} \text{ (5)}$$

$$k_2 = \frac{C_o}{A_k C_o + B_k} \text{ (6)}$$

$$h = \frac{C_o}{A_h C_o + B_h} \text{ (7)}$$

TABLE-1
PSEUDO-FIRST ORDER AND PSEUDO-SECOND ORDER KINETIC MODEL PARAMETERS FOR DIFFERENT INITIAL BASIC BLUE 3 DYE CONCENTRATIONS

Initial basic blue 3 dye concentration (mg L ⁻¹)	$q_{e,exp}$ (mg g ⁻¹)	Pseudo-first order kinetic model			Pseudo-second order kinetic model			
		$q_{e,cal}$ (mg g ⁻¹)	k_1 (min ⁻¹)	R^2	$q_{e,cal}$ (mg g ⁻¹)	k_2 (g mg ⁻¹ min ⁻¹)	h (mg mg ⁻¹ min ⁻¹)	R^2
20	3.8218	1.8348	0.00875	0.9443	3.6443	0.03728	0.4951	0.9965
30	5.3782	2.4021	0.00898	0.9040	5.1840	0.03004	0.8074	0.9986
40	6.9407	4.2599	0.01221	0.9823	6.9348	0.01302	0.6262	0.9961

where A_q , B_q , A_k , B_k , A_h and B_h are constant for the respective equations. The constant values can then be determined from the slopes and intercepts of the linear plots accordingly (Table-2).

TABLE-2
EMPIRICAL PARAMETERS FOR
PREDICTED q_e , k AND h FROM C_o

A_q ($g\ mg^{-1}$)	B_q ($g\ L^{-1}$)	A_k (mg $min\ g^{-1}$)	B_k (mg^2 $min\ g^{-1}L^{-1}$)	A_h ($g\ min$ mg^{-1})	B_h (g $min\ L^{-1}$)
0.0242	4.8490	108.08	-1685.7	0.8997	19.403

The generalized predictive model for basic blue 3 dye sorbed at any contact time and initial concentration within the given range with relationship of q_e , C_o and t are as follows:

$$q_t = \frac{C_o t}{A_h C_o + B_h + (A_q C_o + B_q)t} \quad (8)$$

By substituting the calculated constant values into eqn. 8, the theoretical model for basic blue 3-pomelo peel system could therefore be expressed as:

$$q_t = \frac{C_o t}{0.8997 C_o + 19.403 + (0.0242 C_o + 4.849)t} \quad (9)$$

The theoretical model derived for basic blue 3 adsorption by pomelo peel was applied to obtain the adsorption capacity, q_t at any given C_o and t . The plot of the comparison of the experimental data and the predicted theoretical values was shown in Fig. 7. It was evident that the theoretically generated curves showed a good agreement with the experimental data for adsorption of basic blue 3 dye cations by pomelo peel at concentrations of 20, 30 and 40 mg/L and hence the pseudo-second order rate law provided a good prediction for the amounts of basic blue 3 adsorbed over the studied range.

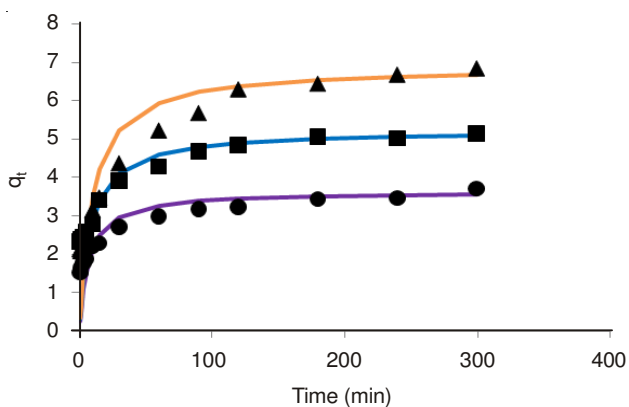


Fig. 7. Comparison between the measured and pseudo-second order modelled time profiles for basic blue 3 adsorption by pomelo peel. ●, ■, ▲- 20, 30 and 40 mg/L of basic blue 3, Symbol - experimental; Line - theoretical (5.0 g pomelo peel; dye volume 2 L; natural pH of dye solution; 8 h)

Effect of pH: Fig. 8 shows the effect of solution pH on the percentage uptake of basic blue 3 dye by pomelo peel. It was found that the percentage uptake was minimum at pH 2. There was a sharp increase in the percentage uptake from 4.31 to 33.69 % at pH 4, followed by a gradual increase in the synthetic dye uptake over the pH ranging 6-10. A similar trend was observed for the adsorption of methylene blue onto coconut bunch waste⁹.

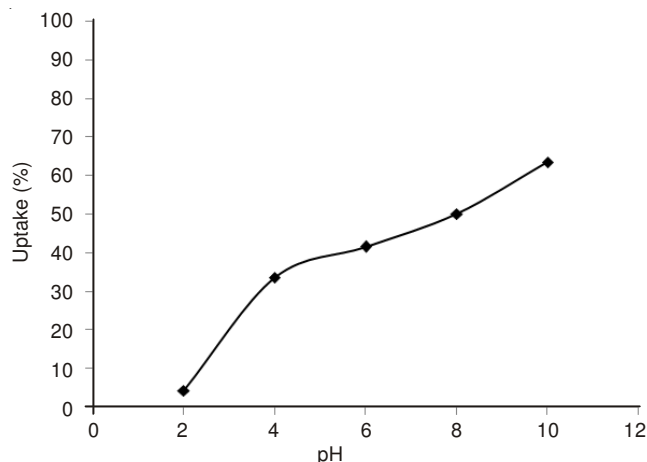


Fig. 8. Effect of solution pH on the percentage uptake of basic blue 3 by pomelo peel (5.0 g pomelo peel; dye volume 2 L; natural pH of dye solution; 4 h)

The introduction of acids or basics could influence the surface charge of the adsorbents and the degree of ionization of adsorbate²³. The low percentage uptake of basic blue 3 dye by pomelo peel at pH 2 was due to the presence of excess H^+ ions in the system. In acidic medium, the carboxyl groups on the surface of pomelo peel that are responsible for binding with basic blue 3 are predominantly protonated ($-COOH$), hence incapable of binding basic blue 3 dye. However, as the pH of the system was increased, this facilitates a favourable sorption process due to the deprotonation of the carboxyl groups ($-COO^-$). The strong electrostatic attractive forces between the adsorbent and the adsorbate resulted in higher removal of basic blue 3 dye from the aqueous solution.

Sorption isotherms: Adsorption equilibrium study describes the interaction between the adsorbate and the adsorbent with a homogenous or heterogenous surface⁵. It is a dynamic concept achieved when the rate of the molecules adsorb onto a surface is equal to the rate they desorb. At equilibrium, no changes can be observed in the concentration of the solute on the adsorbent surface or in the dye solution²⁴. The equilibrium adsorption equation isotherm is an equation relating the amount of solute adsorb onto the solid and the equilibrium concentration of the solute in solution at a given temperature.

To obtain information about the homogeneity and heterogeneity of the adsorbent surface, the adsorption kinetic of the adsorption of basic blue 3 dye onto pomelo peel was monitored by applying two commonly used adsorption isotherm models, namely Langmuir and Freundlich isotherm.

The linear form of Langmuir isotherm model is given by the following equation:

$$\frac{C_e}{q_e} = \frac{C_e}{q_m} + \frac{1}{K_L Q_o} \quad (10)$$

whereas the linear form of Freundlich isotherm model can be represented as:

$$\log q_e = \log K_F + (1/n) \log C_e \quad (11)$$

where q_e = the amount of dye adsorbed at equilibrium (mg/g), Q_o = the maximum adsorption capacity (mg/g), K_L = the adsorption equilibrium constant (L/mg), C_e = the concentration

of basic blue 3 dye solution at equilibrium (mg/L), K_F = Freundlich constant for adsorption capacity (mg/g), n = Freundlich constant for intensity.

The linear plots of C_e/q_e against C_e and $\log q_e$ versus $\log C_e$ for various basic blue 3 dye solution concentrations ranging from 20 to 90 mg/L are shown in Figs. 9 and 10, respectively. The isotherm parameters for removal of basic blue 3 dye by pomelo peel are listed in Table-3. It was found that Freundlich isotherm model provided a better correlation with high correlation coefficient of 0.9914 in comparison to Langmuir isotherm model. In the removal of basic and reactive dyes using EDTA modified rice hull, the sorption isotherm study also revealed that the experimental data fitted better into the Freundlich model as compared to Langmuir model²⁵.

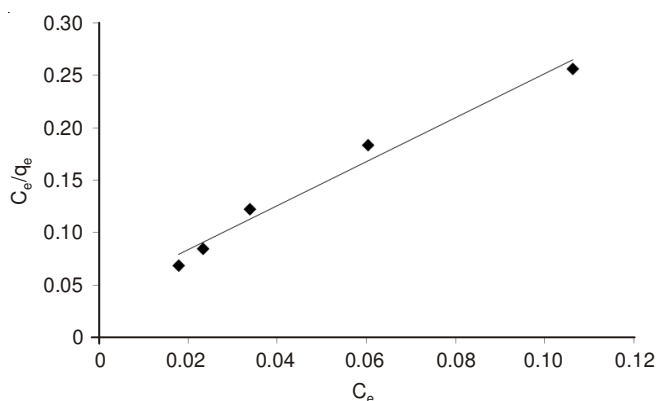


Fig. 9. Langmuir isotherm for the adsorption of basic blue 3 onto pomelo peel. (5.0 g pomelo peel; dye volume 2 L; natural pH of dye solution; 4 h)

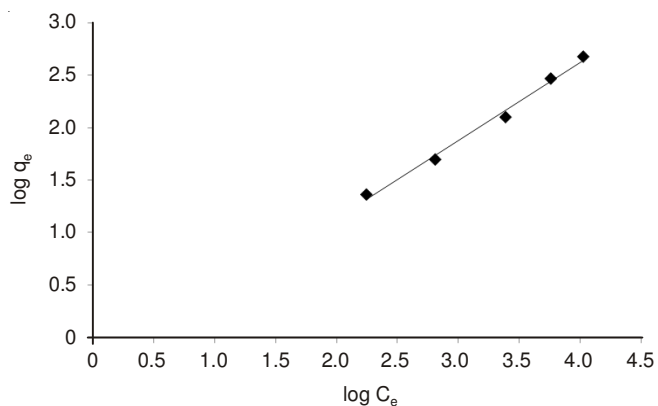


Fig. 10. Freundlich isotherm for the adsorption of basic blue 3 onto pomelo peel. (5.0 g pomelo peel; dye volume 2 L; natural pH of dye solution; 4 h)

TABLE-3 ISOTHERM PARAMETERS FOR REMOVAL OF BASIC BLUE 3 DYE BY POMELO PEEL					
Langmuir isotherm			Freundlich isotherm		
Q_o (mg g ⁻¹)	K_L (L mg ⁻¹)	R^2	K_F	$1/n$	R^2
23.8663	0.02000	0.9772	0.7055	1.3468	0.9914

Langmuir model implies monolayer coverage and constant sorption energy while the Freundlich model deals with physicochemical sorption on heterogeneous surfaces. However fitting the model to the sorption process does not necessarily imply any physical interpretation attached to them since the

biosorbent's surface is non-homogeneous and there could be more than one type of sorption sites on the biosorbent's surface²⁶.

The essential characteristics of Langmuir isotherm can be expressed in terms of dimensionless constant separation factor for equilibrium parameter, R_L , which is defined as:

$$R_L = \frac{1}{1 + K_L C_o} \quad (12)$$

The R_L values for each initial concentration were tabulated in Table-4. The values R_L decreased from 0.7219 to 0.3507 with increasing basic blue 3 dye concentration from 20 to 90 mg/L. The results indicated that the values skewed towards zero which represented the ideal irreversible case. Based on the calculated R_L values shown in Table-4, this revealed that the adsorption of basic blue 3 onto pomelo peel was favourable.

TABLE-4 VALUES OF R_L FOR DIFFERENT BASIC BLUE 3 DYE SOLUTION CONCENTRATIONS	
Initial concentrations (mg/L)	R_L
20	0.7219
30	0.6225
50	0.4993
70	0.4079
90	0.3507

The maximum adsorption capacity, Q_o of pomelo peel from Langmuir equation was 23.87 mg/g. Table-5 shows a comparison of the maximum adsorption capacity of pomelo peel with some other adsorbents in the removal of basic blue 3 dye from aqueous solutions reported in literature. From Freundlich isotherm equation, the isotherm intensity, n for pomelo peel was 1.3468. The magnitude of n gave an indication for the favourability of the adsorption. As the n is greater than 1, this indicated that the adsorption system in this study was favourable.

TABLE-5 A COMPARISON OF THE MAXIMUM ADSORPTION CAPACITY OF POMELO PEEL WITH SOME OTHER ADSORBENTS		
Adsorbent	Q_o (mg/g)	Reference
Corynebacterium glutamicum	7.90	[27]
Ethylenediamine modified rice hull	3.29	[28]
Natural durian peel	49.50	[16]
Natural sugarcane bagasse	23.64	[13]
Natural pomelo peel	23.87	This study

Conclusion

This finding identified pomelo peel as the potential low-cost adsorbent for the adsorption of basic blue 3 dye from aqueous solution. In the batch studies, the results indicated that adsorption capacity of pomelo peel was considerably affected by initial basic blue 3 dye concentrations, contact time and pH. It was found that the percentage removal of dye was concentration dependent. Analysis of the kinetics data implied that pseudo-second order kinetics model provided a better correlation of the experimental results than pseudo-first order kinetic. The adsorption profiles derived based on the pseudo-second order kinetic model showed good agreement with the experimental curves. The effect on solution pH on dye uptake

revealed that the percentage removal of dyes increased when the solution pH was increased. Equilibrium adsorption data conform to both Langmuir and Freundlich isotherms and maximum adsorption capacity was 23.87 mg/g.

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REFERENCES

1. K. Singh and S. Arora, *Crit. Rev. Environ. Sci. Technol.*, **41**, 807 (2011).
2. S.M. Lam, J.C. Sin, A.Z. Abdullah and A.R. Mohamed, *Desalin. Water Treat.*, **41**, 131 (2012).
3. M. Solis, A. Solis, H.I. Perez, N. Manjarrez and M. Flores, *Process Biochem.*, **47**, 1723 (2012).
4. E.N. El Qada, S.J. Allen and G.M. Walker, *Chem. Eng. J.*, **124**, 103 (2006).
5. M.A.M. Salleh, D.K. Mahmoud, W.A.W.A. Karim and A. Idris, *Desalination*, **280**, 1 (2011).
6. A.E. Ofomaja, *Process Biochem.*, **42**, 16 (2007).
7. S.T. Ong, P.S. Keng, S.T. Ooi, Y.T. Hung and S.L. Lee, *Asian J. Chem.*, **24**, 398 (2012).
8. B.H. Hameed, *J. Hazard. Mater.*, **162**, 344 (2009).
9. B.H. Hameed, D.K. Mahmoud and A.I. Ahmad, *J. Hazard. Mater.*, **158**, 65 (2008).
10. M. Dogan, H. Abak and M. Alkan, *J. Hazard. Mater.*, **164**, 172 (2009).
11. G.Z. Kyzas, N.K. Lazaridis and A.C. Mitropoulos, *Chem. Eng. J.*, **189-190**, 148 (2012).
12. P. Waranusantigul, P. Pokethitiyook, M. Kruatrachue and E.S. Upatham, *Environ. Pollut.*, **125**, 385 (2003).
13. S.T. Ong, E.C. Khoo, S.L. Hii and S.T. Ha, *Desalin. Water Treatment*, **20**, 86 (2010).
14. M. Ertas, B. Acemioglu, M.H. Alma and M. Usta, *J. Hazard. Mater.*, **183**, 421 (2010).
15. K.Y. Foo and B.H. Hameed, *Chem. Eng. J.*, **173**, 385 (2011).
16. S.T. Ong, S.Y. Tan, E.C. Khoo, S.L. Lee and S.T. Ha, *Desalin. Water Treatment*, **45**, 161 (2012).
17. B.H. Hameed, *J. Hazard. Mater.*, **162**, 939 (2009).
18. N. Nasuha, B.H. Hameed and A.T.M. Din, *J. Hazard. Mater.*, **175**, 126 (2010).
19. K.K. Singh, S.H. Hasan, M. Talat, V.K. Singh and S.K. Gangwar, *Chem. Eng. J.*, **151**, 113 (2009).
20. S. Lagergren and B.K. Svenska, *Veternskapsakad Handlingar*, **24**, 1 (1898).
21. Y.S. Ho and G. McKay, *Process Biochem.*, **34**, 451 (1999).
22. Y.S. Ho, *J. Hazard. Mater.*, **136**, 681 (2006).
23. A. Ahmad, M. Rafatullah, O. Sulaiman, M.H. Ibrahim and R. Hashim, *J. Hazard. Mater.*, **170**, 357 (2009).
24. C.A.P. Almeida, N.A. Debacher, A.J. Downs, L. Cottet and C.A.D. Mello, *J. Colloid Interf. Sci.*, **332**, 46 (2009).
25. S.T. Ong, W.N. Lee, P.S. Keng, S.L. Lee, Y.T. Hung and S.T. Ha, *Int. J. Phys. Sci.*, **5**, 582 (2010).
26. B. Volesky, *Biosorption and Biosorbents: In Biosorption of Heavy Metals*, CRC Press Inc., Florida, USA. pp. 3-44 (1990).
27. K. Vijayaraghavan and Y.S. Yun, *Biotechnol. Adv.*, **26**, 266 (2008).
28. S.T. Ong, C.K. Lee and Z. Zainal, *Bioresour. Technol.*, **98**, 2792 (2007).