BIOSORPTION OF REACTIVE BLACK 5 FROM AQUEOUS SOLUTION USING ACID-TREATED BIOMASS FROM POTATO PEEL WASTE

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The goal of this study was to survey the feasibility of the biosorption of Reactive Black 5 (RB5) from aqueous solutions using biomass prepared from potato peel waste. Adsorption isotherms were constructed, and the kinetics of dye adsorption were studied. Langmuir and Freundlich isotherms were constructed, and pseudo-first order, pseudo-second order, and modified pseudo-first order kinetic models were studied. Maximum adsorption (85.5%) was observed at a pH of 3, and uptake decreased with increasing pH. The biosorption of RB5 increased with increasing contact time and reached equilibrium after two hours. RB5 removal efficiency decreased with an increase in the initial dye concentration, but the uptake of dye increased. Adsorption data conformed to the Langmuir isotherm model and pseudo-first order kinetics.

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INTRODUCTION

Pigment-producing industries and other industries that use dyes and pigments are sources of colored wastewater (Yu et al. 2011; Singh et al. 2011; Garg et al. 2004). The main characteristics of this type of wastewater are high amounts of organic and colored material. Over 7×10^5 metric tonnes of synthetic dyes are produced worldwide every year for printing and dyeing and 5 to 10% is discharged with wastewater (Silveria et al. 2009; Garg et al. 2004). Some authors have mentioned that the main portion of the annual production of dyes are azo and reactive dyes (Greluk et al. 2011). The use of synthetic dyes in different industries (textile, paper, rubber, plastic, cosmetic, pharmaceutical, and food industries) is constantly increasing (Tahir et al. 2009; Singh et al. 2011; Malik 2003), because of their ease of use, low cost of synthesis, and chemical stability compared with natural dyes. Because of their complex, highly conjugated molecular structures and their synthetic properties, many synthetic dyes are not biodegradable (Singh et al. 2011; Ansari and Mosayebzadeh 2010; Seshadria et al. 1994). The widespread use of dyes often causes environmental pollution because of the discharge of

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colored wastewater to the environment, which affects the quality of the receiving water. The presence of dye can prevent sunlight penetration, resulting in the disturbance of photosynthetic processes in surface waters (Greluk et al. 2011; Silveria et al. 2009; Namasivayam et al. 2001). In addition, some dyes or their metabolites are toxic, mutagenic, or carcinogenic. Reports have been published that document the roles of dyes in skin disorders and respiratory problems (Cho et al. 2009; Mckay et al. 1981). The use of various types of dyes and chemical substances during dyeing processes can be the cause of considerable differences in industrial wastewater characteristics such as pH, color, chemical content, and chemical oxygen demand (COD). The complex and varied structures of dyes, often involving aromatic rings, make it difficult to treat colored wastewater using conventional treatment methods such as biological methods and physicochemical processes (Yang et al. 2009). Thus, the consideration of other methods of treatment is needed. To protect human health and to preserve the environment, an ideal method would utilize inexpensive and economical means to remove dyes from textile and dye-production factory wastewater. Such technology is essential in developing countries (Yuzhu et al. 2003; Stuart et al. 2002).

Different methods have been evaluated to reduce the discharge of colored wastewater into surface water. These methods include the use of chemical coagulants, oxidizing agents, membrane filters, photocatalytic processes, electrochemical processes, biological processes (such as trickling filters), and adsorption and biosorption techniques. However, most of these methods are expensive (El-Ashtoukhy and Amin 2010; Zainal et al. 2007; Lim et al. 2010; Matlock et al. 2002; Koene et al. 2001; Volesky et al. 1995; Kapoor et al. 1995). The biosorption process is inexpensive and simpler to implement than other processes. Therefore, it is given priority over other methods (Yuzhu et al. 2003). Because of its low cost, easy preparation, simple operation, and insensitivity to toxic substances, the biosorption process is acknowledged today as the most appropriate technique for removing dyes and improving the quality of industrial wastewater for reuse. Various biomasses have been recommended for the elimination of environmental contaminants (Sivarajasekar et al. 2009).

Reactive dyes are widely used in various industries, especially in the textile industry. Reactive Black 5 is a sulfonated reactive dye with two azo groups. Because of excess water consumption in the fiber dying process and the non-biodegradable nature of synthetic dyes, dye mixtures frequently pass through the physical and chemical processes of conventional treatment systems and enter receiving waters with no change (Singh et al. 2011). A large amount of Reactive Black 5 enters the environment in Iran because of the use of this dye in Iran's textile industries (Nouhi et al. 2008). Iran is the world's twelfth largest potato producer and the third largest in Asia, after China and India. Production levels have risen to more than 15 times the production in 1961. In 2007, the country's farmers achieved an all-time record harvest of 5.24 million tons, with per hectare yields averaging 25 tonnes. The potato is one of Iran's leading agricultural exports, with shipments in 2005 totaling approximately 166,000 tonnes. Potatoes are grown mostly under irrigation around the southern shore of the Caspian Sea, in the Zagros Mountains, and in the southern lowlands, alternated with wheat, vegetables, sugar beets, and lying fallow in three- or four-year rotations. In this study, the use of treated biomass from potato peel waste as an inexpensive biosorbent for the removal of Reactive Black 5 from

aqueous solution was evaluated. Adsorption isotherms were constructed, kinetics were studied, and the effects of initial dye concentration, adsorbent dose, contact time, and pH on the biosorption process were investigated.

EXPERIMENTAL

Adsorbent Preparation
Adsorbent used in this study was prepared according to procedures described below in seven steps (Prasad et al. 2009):
1. Potato samples were washed completely.
2. Potatoes were hulled with a huller to obtained peels without any potato tissue.
3. The peels were separated into fine parts (to accelerate drying) and dried at room temperature for 5-7 days.
4. Biomass (1 mg) was emulsified into 5 mL of acidic solution using 0.01 M HCl at 25 ± 1 ^{o}C for 30 min to remove impurities or soluble molecules that may interact with dye molecules.
5. Samples were washed with distilled water until the pH rose above 6.
6. The processed biomass was dried in an oven at 90 ^{o}C for 24 hours.
7. The final product was sieved with a 40-45 range mesh.

Adsorption Tests
Adsorption experiments were performed in the batch system. The effects of contact time (5, 10, 15, 30, 45, 60. and 120 min), pH (3, 5, 7, 9, and 11), adsorbent dose (0.2, 0.4, 0.6, 0.8, and 1 gram), and dye concentration (50 to 400 mg L^{-1}) were investigated in separate stages. To investigate changes in system efficiency, experiments were performed in which one variable was changed and the other variables were fixed. In this study, mixing speed (RPM 200), temperature (25 ± 1 degrees Celsius), and adsorbate particle size were fixed in all stages. Solutions were prepared at a volume of 250 mL. Aksu et al. (1992) reported that the process of biosorption is not influenced by ambient temperature in the temperature range of 20 to 35 ^{o}C, so all experiments were performed in an incubator at 25 ^{o}C. The Langmuir and Freundlich models were used to construct adsorption isotherms. Kinetic studies of uptake using pseudo-first order, pseudo-second order, and modified pseudo-first order kinetic models were performed. Formulas used in the models are given in Table 1 (McKay et al. 1999; Liu et al. 2008; Apak et al. 1998). Dye removal efficiency, P, was calculated using the following equation:

$$P = (\frac{C_0 - C_e}{C_0})100 \qquad (1)$$

Determination of Biosorbent Characteristics
Processed biomass was characterized using scanning electron microscopy (SEM) and energy dispersion spectroscopy (EDS) at the Materials Engineering Laboratory of Majlesi University (KV 20.0, Takeoff Angle 25.0°, Elapsed Live Time 10.0). Surface chemical properties of biomass were determined using EDS.

Table 1. Formulas Used in Models for Kinetic Study and Isotherm Construction
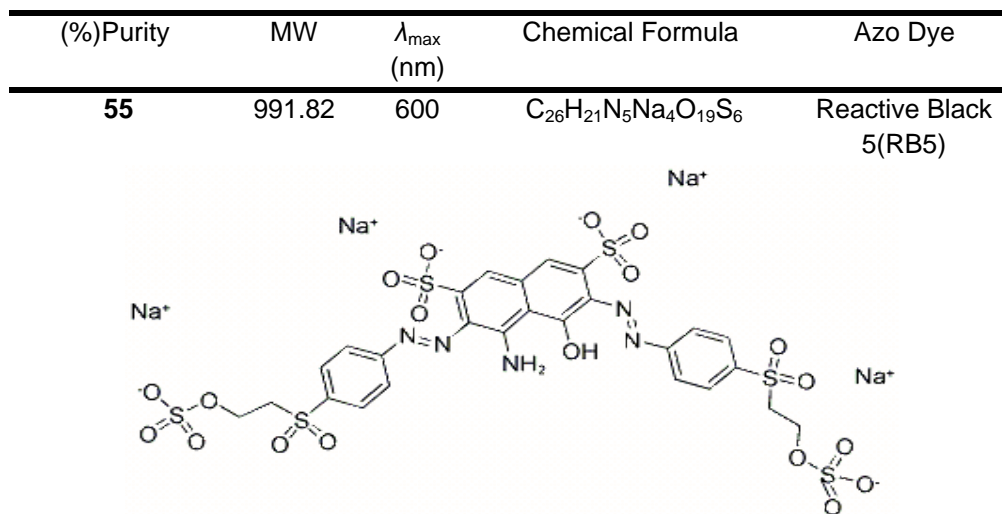
Kinetic equations		Isotherm equations
Pseudo first-order	$\ln\left(1-\dfrac{q_t}{q_e}\right)=-k_1 t$	Langmuir $\dfrac{c_e}{q_e}=\dfrac{1}{q_m K}+\dfrac{1}{q_m}c_e$
Pseudo-second order	$\dfrac{t}{q_t}=\dfrac{1}{k_2 q_e^{\,2}}+\dfrac{1}{q_e}t$	Freundlich
Modified pseudo-first order	$\ln(1-\dfrac{q_t}{q_e})+\dfrac{q_t}{q_e}=-k_m t$	$\log q_e=\log k+\dfrac{1}{n}\log c_e$

Adsorbate Material

Reactive Black 5 dye (Alvan Sabet / Hamedan, Iran) of commercial purity was used as the adsorbate. Characteristics of the dye are presented in Fig. 1. Absorbance (maximum wavelength 600 nm) was used determine the concentrations of dye in the colored solutions (Pharmaspec Shimadzo UV-1700). The equilibrium technique was used to determine the pH_{ZPC} in the batch system (Babic et al. 1999). This technique is based on estimating the concentrations of H^+ and OH^- ions, which determine the electric potential. Biosorbent (0.1 grams) was stirred with 20 mL of KNO_3 solution in 11 closed containers in an incubator for 24 hours. The initial pH was set in the range of 2 to 12 using HNO_3 and KOH (0.1 M). The final pH of each container was recorded using a pH meter (Hach Co., USA), and the values were plotted against initial pH values. The percent of removed dye by activated carbon was calculated from the following equation,

$$\text{Removed dye(\%)} = [(C_0 - C)/ C] \times 100 \tag{1}$$

where C_0 is the initial dye concentration before addition of the sorbent and C is the adsorbed dye of sample after adsorption with the biomass.

(%)Purity	MW	λ_{max} (nm)	Chemical Formula	Azo Dye
55	991.82	600	$C_{26}H_{21}N_5Na_4O_{19}S_6$	Reactive Black 5(RB5)

Fig. 1. Characteristics of Reactive Black 5 (RB5) dye used in this study

RESULTS AND DISCUSSION

Structural Characteristics of Biomass

An SEM micrograph and an EDS spectrum of the biomass are shown in Figs. 2a and 2b. The main elements of the biomass structure were carbon, oxygen, and potassium.
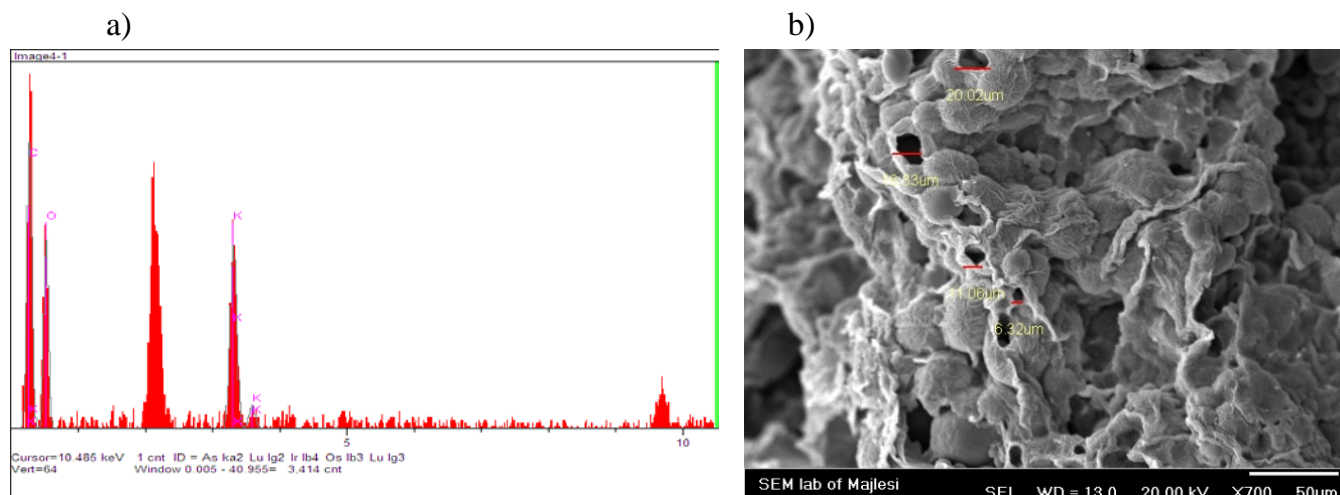
a)   b)

Fig. 2. a) EDS surface chemical properties of the biomass **b)** SEM micrograph of potato peel waste biomass

The scanning electron microscope is a suitable instrument for surveying the surface morphology (structure) and form of an adsorbent. The device is useful for determining particle shape, porosity, and pore size distribution (pores). The identification of compounds in the structures of adsorbents is one of the most important aspects of the biosorption process that should be considered. Therefore, compounds in the biosorbent structure were investigated in this study. Component analysis of the biosorbent showed that oxygen and carbon were the most abundant elements in the structure of the samples. Pollutants have been strongly linked with functional groups containing oxygen and nitrogen in biosorbent structures (Prasad et al. 2009). The process of adsorption of contaminants by living cells is mainly a passive process that is independent of energy and is accomplished by functional groups in the biomass structure (Hoseinzadeh et al. 2010). Thus, processed biomass has a good potential for adsorbing pollutants.

When an adsorbent is contacted with a solution, the surface charge of the adsorbent changes. The dominant surface charge on the adsorbent surface is formed through interactions between ions present in solution and functional groups on the surface of adsorbent (Al-Degs et al. 2006). The biosorbent used in this study has a high level of functional groups involving oxygen that can create a strong chemical bond with adsorbate. This can cause the adsorbent to be selective for various contaminants (Leyva-Romas et al. 2005). The polarity of the biomass surface increases with increasing weight percentage of oxygen in the biomass structure, resulting in a greater number of adsorptive polar elements. SEM micrographs show pores with different sizes on the surface of the biomass that facilitate the access of adsorbate (RB5) to the internal pores.

Effect of pH

Biosorption experiments were performed with colored solutions with different initial pH values. Other laboratory conditions, including concentration, biosorbent dosage, and contact time were fixed. The color removal percentage changed with pH (Fig. 3a). Removal efficiency and biosorption of color per unit mass of adsorbent decreased with increasing pH. The dye adsorption process is affected by pH through changes in dye structure and adsorbent surface charge.
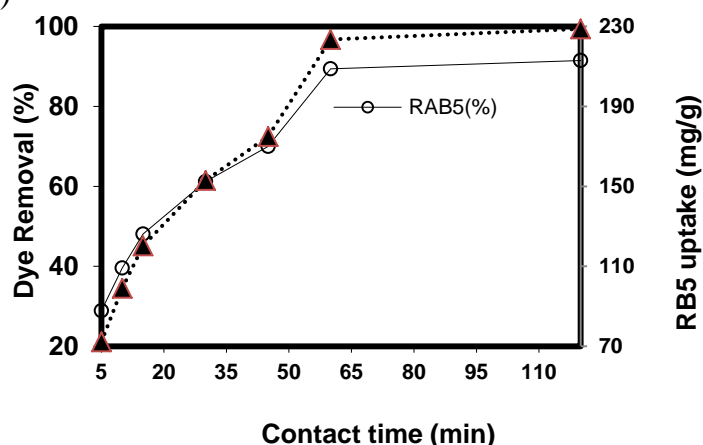
a)
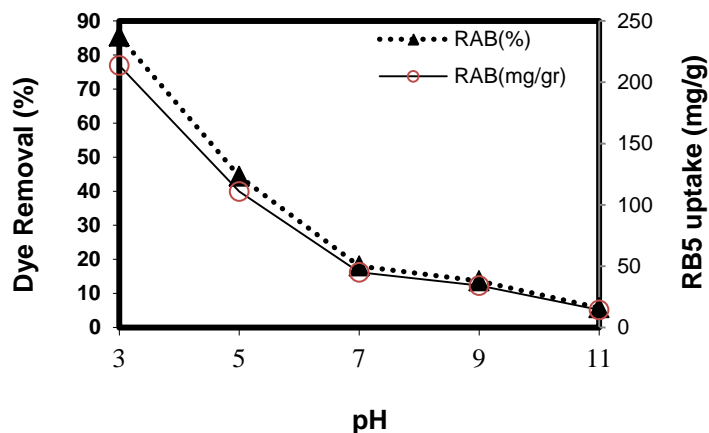
b)

Fig. 3. Effects of pH and contact time on removal of RB5 dye, initial dye concentration was 50mg L^{-1}: a) Effect of pH; b) Effect of contact time

Biosorption of RB5 on the processed biomass decreased with increasing pH, with the highest uptake at a pH of 3. Increasing is related to the dye structure and the pHzpc of the biomass (Singh et al. 2011; Sivarajasekar et al. 2009). The pHzpc of the biomass in this study was 6.59. The effect of pH on the biosorption process is possibly due to interactions between the dye anions in solution and adsorbent surface charge contaminants (Leyva-Romas et al. 2005; Yu et al. 2011). When the solution pH is lower than the pHzpc, dye anions move toward the positively charged biosorbent, and a large amount of dye accumulates on the surface of the contaminants (Leyva-Romas et al. 2005;

Greluk et al. 2011). When the pH of the solution is higher than pHzpc, the surface of the biomass is negatively charged. Thus, fewer RB5 anions are adsorbed on the biomass. The solution pH increased during biosorption of RB5, which could be the result of the transfer of OH$^-$ from the biosorbent surface to the solution. This stage of the experiments revealed that the strong forces of interaction between the dye, elements of the biomass structure, and H$^+$ and OH$^-$ ions can considerably affect biosorption capacity (Greluk et al. 2011; Sivarajasekar et al. 2009; Hameed et al. 2007). At pH values higher than pHzpc, the dye removal percentage was nearly zero because the surface of the biosorbent was negatively charged, causing mutual repulsion between the dye anions and the biosorbent surface (Leyva-Romas et al. 2005). Hameed et al. reported that adsorption of AG25 dye decreased with increasing pH (from 2 to 13) because of an increase in hydroxyl anions and a changing adsorbent surface charge. This finding is consistent with the results of this study. Ong et al. (2007) reported that the biosorption of reactive dyes on rice bran increased with increasing pH (from 2 to 10). Carboxylic groups surrounding the adsorbent surface adsorbent has been mentioned as a reason for decreasing dye adsorption on biomass at low pH (Ong et al. 2007). The results reported by Sivarajasekar et al. (2009) regarding dye azo biosorption are compatible with the results of this study. Prasad et al. (2009) reported a maximum adsorption efficiency of nickel onto processed potato peel waste biomass at a pH of 7. A positive charge on the biomass surface that competes with nickel adsorption by biomass and was proposed as the reason for low biosorption rates at low pH values. Modifying biomass with mineral acids can cause the protonating of functional groups responsible for adsorption, increasing the adsorption of dye anions. Reactive dyes release colored ions with a negative charge in acidic solution. Hydrogen ions, which are not measurable with EDS, act as a connection bridge between the cell wall and the dye molecules in solution or biomass. This bridge occurs with amino, thiol, and carboxyl groups so that amino functional groups, in acidic pH conditions, have a positive charge and bond with reactive black dye anions (Sivarajasekar et al. 2009). Carboxyl groups, in alkaline pH conditions, have a negative charge that creates a repulsion force with dye anions. In a recent investigation potato peel was shown to be a source of phenolic compounds, glycoalkaloids, and cell wall polysaccharides (Schieber and Saldana 2009). The presence of functional groups can be investigated with FTIR analysis, but this technique was not possible for this study. Perhaps the increase in RB5 biosorption in highly acidic conditions is due to the electrostatic attraction between the biomass and dye particles (Greluk et al. 2011; O'Mahony et al. 2002).

Contact Time Effects

The effects of contact time on biosorbent and adsorbate are shown in Fig. 3b. Biosorption of RB5 dye increased with increasing contact time, reaching equilibrium after two hours. The biosorption/dye removal rate remained constant after this time. Most of the dye removal (89.41%) occurred in the initial 60 minutes of the experiments. The results of these experiments show that contact time had a significant impact on the mechanism of contaminant adsorption. Similar results were reported by Singh et al. (2011) for biosorption acid dyes by sawdust. To investigate the effect of contact time on the biosorption process, samples were taken from the solution in contact with biosorbent at time intervals (5, 10, 15, 30, 45, 60, and 120 min). After most biosorption was

achieved in the first 60 minutes, biosorption increased slightly at an almost constant rate until reaching equilibrium at 120 minutes. Overall, the rate of adsorption was higher at the initial contact than at other times, and the adsorption rate was constant after some time had passed. In biosorption processes, if adsorption sites are easily accessible for molecules of adsorbate, the adsorption rate will not increase with increasing contact time (singh et al. 2011; Taghi Ganji et al. 2005). The results of a survey of the adsorption of copper bivalent cations by *Saccharomyces cerevisiae* biomass are consistent with the results of this study; most adsorption occurred in the initial 5 minutes (Ghorbani et al. 2008). Arivoli et al. reported that the adsorption of acidic and alkali dyes onto activated carbon reached equilibrium after 50 minutes (Arivoli et al. 2008). Ho and McKay (1998) reported that the equilibrium time was 250 minutes for Acid Blue 25 dye adsorption onto wood. The results of this study are consistent with the results of Ghanizadeh and Asgari (2009) who studied the adsorption of methylene blue onto processed activated carbon from bone, and Shokoohi et al. (2010) who studied the adsorption of Acid Red 18 onto processed activated carbon from wood. The higher adsorption at initial contact could be because of the existence of empty places on the adsorbent. With increasing time, the rate is reduced; thus, the adsorption rate will not be as high as the initial rate. Eventually the interactions between RB5 ions and potato peel waste surface approach equilibrium, so further increase in contact time does not result to more dye adsorption (Yu et al. 2011).

Effects of Bioadsorbent Dosage on Dye Removal

The effect of the dosage of biosorbent on the biosorption of dye was investigated at different masses of biomass (0.2 to 1 g). The biosorption efficiency increased slightly with an increase in the amount of biomass added (Fig. 4). The removal percentages were 82.21% and 95.06% for 0.2 g (lowest dose of biomass) and 1 g (highest dose of biomass), respectively. The amount of dye adsorbed per mass of biomass decreased with increasing biomass dosage (from 205.25 to 47.53 mgg^{-1}).
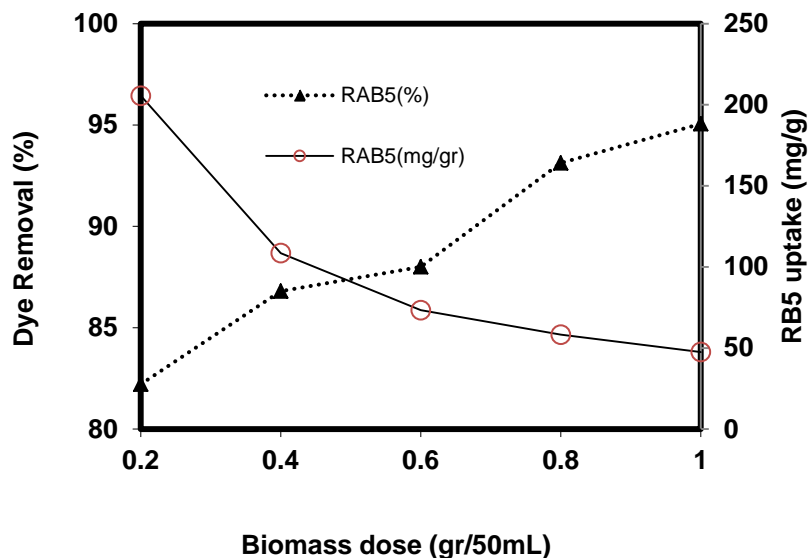

Fig. 4. Effect of biomass dosage on RB5 removal percentage

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The rate of dye adsorption increased with increasing adsorbent dosage. The increasing rate of dye adsorption was possibly due to increasing the available surface for adsorption (Shokoohi et al. 2010; Singh et al. 2011). Several researchers have reported similar results (Ong et al. 2007; Ghanizadeh et al. 2009; Saiful Azhar et al. 2005). When the biomass concentration in solution was low, contaminant/adsorbate penetrated into the cells and the adsorption rate per gram of biomass increased with decreasing amounts of adsorbent (Fig. 4). This does not occur when the biomass concentration is high, because the cell density and biomass accumulation prevent the penetration of contaminants into the internal pores of the biomass (Arivoli et al. 2008).

Effect of Initial Dye Concentration on Biosorption Efficiency

The Reactive Black 5 removal percentage decreased with increasing dye concentra-tion, but the amount of dye adsorbed per unit of mass biosorbent increased with increasing initial dye concentration (Fig. 5). The highest dye adsorbed per mass adsorbent and the least efficient biosorption occurred at a dye concentration of 50 mgL^{-1}. The curves of dye removal percentage and amount of dye adsorbed per mass adsorbent for a concentration of 100 mgL^{-1} overlapped at 53%. The decrease in dye removal efficiency with increasing dye concentration and the increase in adsorbed dye per mass of biomass (Fig. 5) may be due to initial amount of dye molecules being lower than the available surface sites, making the adsorption ratio independent of the initial dye concentration. At higher concentrations, there would be fewer available sites than dye molecules in solution, and the RB5 removal percentage would depend on the initial concentration of dye (Khattri et al. 1998; Singh et al. 2011; Yu et al. 2011).
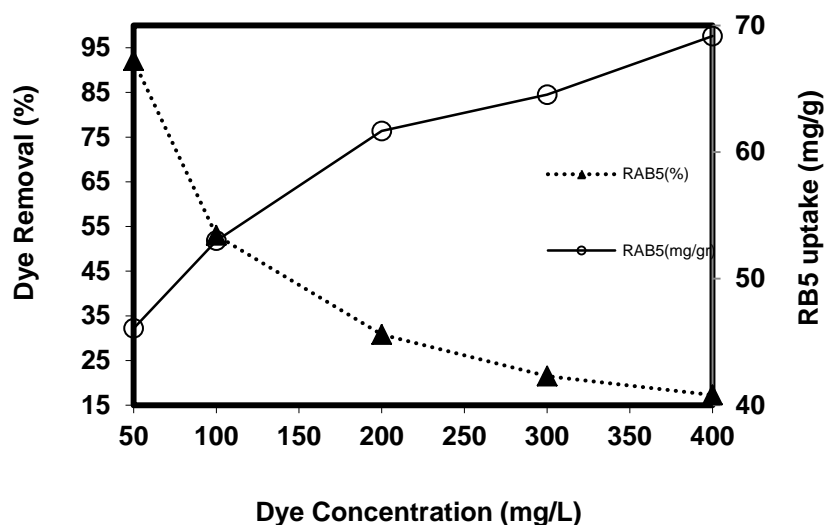

Fig. 5. Plots of the amount of RB5 adsorbed versus initial dye concentration and the effect on RB5 removal of RB5

Adsorption Isotherm Studies

The equilibrium between adsorbent capacity and adsorbate is explained by adsorption isotherms. Adsorption isotherms are equations that describe an equilibrium state between adsorbate in the solid and liquid phases. Choice of the best fit isotherm was

done by linear regression analyses and a comparison of their coefficients of determination (R^2). Langmuir and Freundlich isotherms are the oldest and simplest known isotherms that describe the relations between adsorption equation parameters. The data obtained from experiments were fitted to linear models of Langmuir and Freundlich isotherms (Table 1); In the Freundlich isotherm equation q_e is equilibrium dye concentration on adsorbent (mgg^{-1}), C_e is the equilibrium concentrations of dye (mgL^{-1}), k and n are constants that describe the capacity and the intensity for the adsorption, respectively. For the Langmuir model q_{max} is the maximum adsorption capacity (mgg^{-1}) and b is a constant in the model (mgL^{-1}), respectively. The results are shown in Fig. 6. The parameters calculated based on the isotherm equations are given in Table 2a. Adsorption isotherms describe how pollutants react with adsorbent material and play a fundamental role in the optimization of adsorbent consumption (Sivarajasekar et al. 2009). Determining the appropriate relationships between equilibrium curves and optimizing the design of an adsorption system to remove colored material is essential (Prasad et al. 2009). Adsorption equilibrium occurs when the amount of pollutants adsorbed onto adsorbent is equal to the amount desorbed. According to the determination coefficient for the experiment data, adsorption of the dye proceeds in accordance with the Langmuir isotherm model. A good match with this isotherm model is consistent with an assumption that the adsorbent surface is covered with a monolayer of RB5 dye and adsorption of each molecule of adsorbate has equal activation energy (Greluk et al. 2011; Singh et al. 2011). This also indicates that the processed biomass is homogeneous (Prasad et al. 2009; Aksu et al. 1992). The L-type isotherm, or Langmuir model, indicates that ionic substrate (cationic or anionic) has weak competition for adsorption from solvent molecules (Al-Degs et al. 2006). The result of this study is consistent with results of the study by Arivoli et al. (2008) and Singh et al. (2011). In this study, the maximum adsorption capacity for the RB5 dye was 3.612 mgg^{-1}, and the Langmuir constant (k_{ads}) for RB5 dye was 4.553 mgL^{-1}. Prasad et al. (2009) reported maximum adsorption capacities of 13.09 and 7.874 mgg^{-1} for the adsorption of pollutants onto processed biomass from potato peel waste.
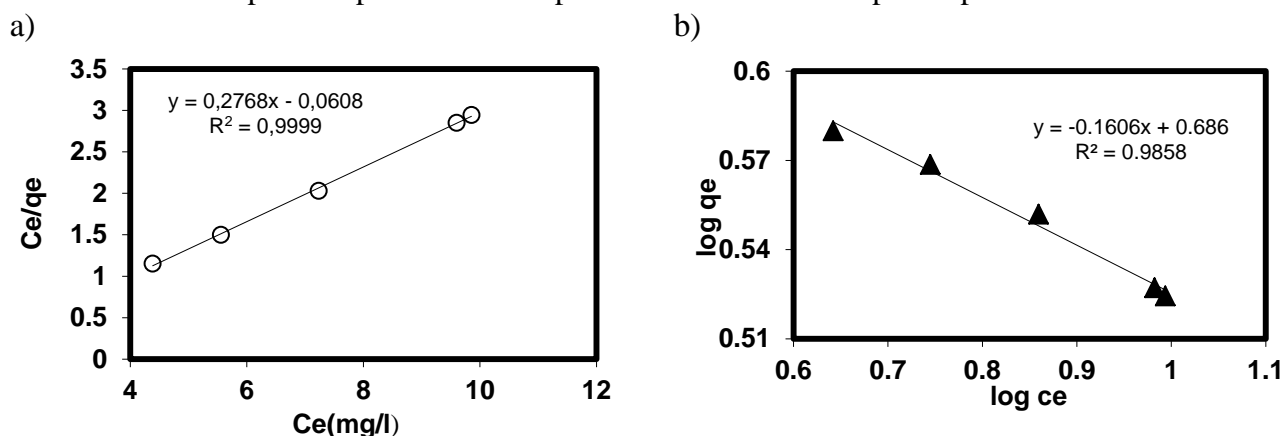
a)

b)

Fig. 6. Isotherm plots of RB5 biosorption onto potato peel waste: a) Langmuir plot; b) Freundlich plot

The parameters associated with the Freundlich isotherm (k and n) indicate whether adsorption is favourable (Yu et al. 2011). In this model, k is an indicator of adsorption capacity, and the slope is an indicator of adsorption intensity. When the slope

is relatively low (1>> *n*), this indicates that the intensity of adsorption is good (favourable) in the range of concentrations investigated. Greater slopes (1<*n*) indicate that the intensity of adsorption is good (desirable) at high concentrations but that the adsorption rate is very low at lower concentrations (S. Al-Degs et al. 2006). On the basis of the results and the Freundlich model, processed biomass from potato peel waste will have higher adsorption at higher concentrations of RB5 dye.
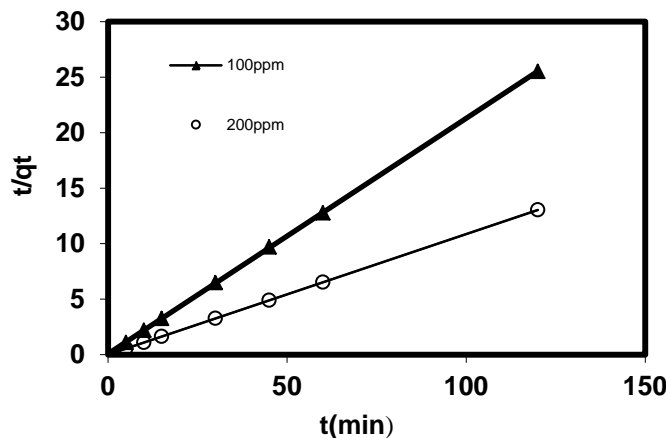
Adsorption Kinetics

The reaction rate is described by adsorption kinetics. Adsorption kinetics are important in characterizing the efficiency of a sorbent for use in the biosorption process. The kinetics of the removal of RB5 with the acid-treated biomass of potato peel waste were investigated to understand the behavior of the sorbent. The used kinetic equation model has been presented at Table 1. In used kinetic models, k_1 and k_2 are the rate constant for the pseudo-first-order and the pseudo-second-order model. q_e and q_t are the amount of adsorbed material based on mgg^{-1} at equilibrium and time t, respectively, and k_m is the speed based on $minL^{-1}$. The results of the kinetic study and the parameters associated with each model are shown in Table 2b and Fig. 7.
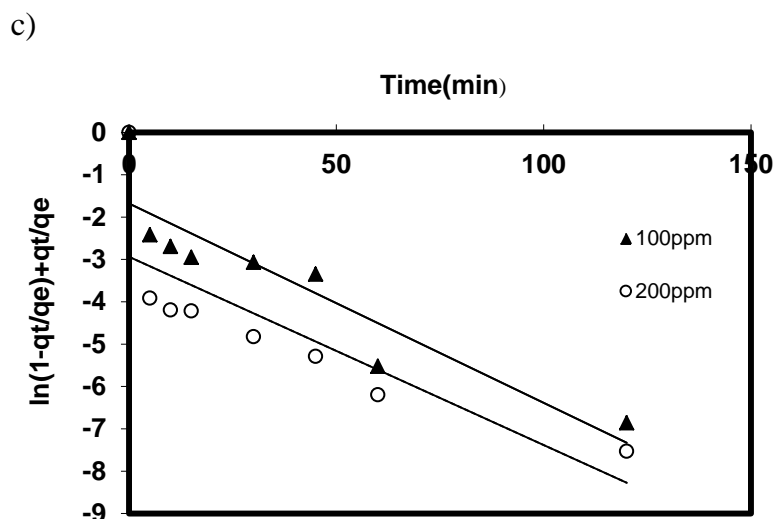
a)

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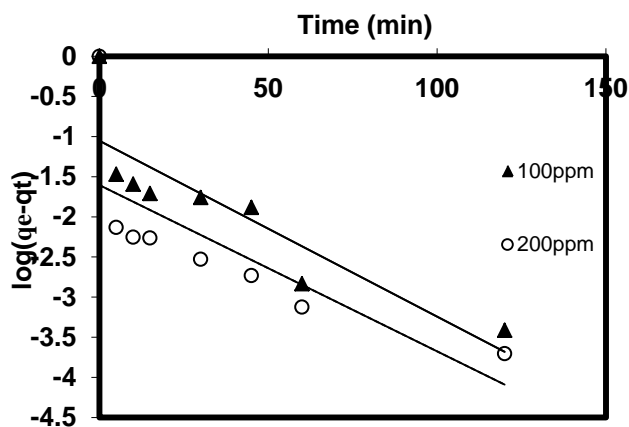
Fig. 7. Experimental uptake curves based on (a) the pseudo-first-order reaction model (b) the pseudo-second-order reaction model and (c) the modified pseudo-first-order reaction model

The rate of sorption followed pseudo-second order kinetics for two concentrations: 100 and 200 mgL^{-1}. Pseudo-second order kinetics shows that chemical adsorption is a rate limiting stage that controls adsorption processes. Investigations have shown that most adsorption systems at different concentrations of pollutants are consistent with this system. The values of q_e obtained from kinetic calculations (4.705 and 9.205 for 100 and 200 mgL^{-1} concentrations, respectively) were close to the q_e values obtained experimentally (4.715 and 9.208 for 100 and 200 mgL^{-1} concentrations, respectively), indicating the accuracy of the experiments.

Table 2. Kinetic and Isotherm Study

b)	Values of biosorption rate constants for pseudo-first-order, pseudo-second-order and modified pseudo-first-order kinetic models								
	pseudo-first-order kinetic parameters			pseudo-second-order kinetic parameters			modified pseudo-first-order kinetic parameters		
$C_0(mgL^{-1})$	R^2	q_e	k_1 (min^{-1})	R^2	q_e	$k_2(gmg^{-1} min^{-1})$	R^2	q_e	$k_m(min^{-1})$
100	0.7555	4.705	0.0504	1	4.715	0.573	0.827	4.705	0.0471
200	0.5822	9.205	0.0477	1	9.208	1.493	0.6555	9.205	0.0445

a)	Freundlich and Langmuir Constant values obtained for RB5 uptake by potato peel waste					
	Langmuir				**Freundlich**	
K_a	q_m	R^2		n	K_f	R^2
4.553	3.613	0.9999		6.226	4.856	0.9858

CONCLUSIONS

In this study, conditions influencing the biosorption of RB5 dye by processed biomass were investigated, and the optimal conditions of each variable were determined. Most of the weight percentage of potato biomass treated with acid is composed of oxygen; this makes it very suitable for the adsorption of polar pollutants. During contact, RB5 molecules occupy empty sorbent sites, and the slope of the uptake curve does not increase with time; thus, the adsorption rate does not rise above the initial rate with time. RB5 dye biosorption was highest under acidic conditions; this may be due to the electrostatic attractions between biomass and dye particles. The dye adsorption ratio was independent of the initial concentration of dye, but the dye removal process was dependent on the initial concentration of dye. The data were found to be consistent with pseudo-second order kinetic models representative of chemisorption, connecting the dye and substrate with valances forces through subscription or exchange of electrons between the biosorbent and RB5 dye as well as due to achieved higher coefficient determination (R^2) for a Langmuir isotherm model, suggesting that the RB5 adsorption on potato peel waste that has homogenous in adsorption affinity. The results showed that, from a biotechnical point of view, biosorption is a suitable method for the elimination of environmental contaminants, particularly dyes, and it can be economically justified compared with conventional methods. However, further research is needed to use this method on a large scale. The adsorbent studied is acceptable in terms of abundance, cost, and ease of preparation.

ACKNOWLEDGMENTS

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