Desalination and Water Treatment
www.deswater.com
25 (2011) 187–194
January
1944-3994 / 1944-3986 © 2011 Desalination Publications. All rights reserved.
doi: 10.5004/dwt.2011.1622

Removal of Disperse Red 1 from an aqueous solution by fungus *Aspergillus niger*

George Yuzhu Fu[a]*, T. Viraraghavan[b]

[a]*Department of Construction Management & Civil Engineering, Georgia Southern University Statesboro, GA 30460, USA*
Tel. +1 (912) 478-5003; Fax +1 (912) 478-1853; email: gfu@georgiasouthern.edu
[b]*Faculty of Engineering, University of Regina, Regina, Saskatchewan, Canada S4S 0A2*
Tel. +1 (306) 585-4734; Fax +1 (306) 585-4855; email: T.Viraraghavan@uregina.ca

Received 5 November 2009; Accepted in revised form 9 June 2010

ABSTRACT

In this study, removal of Disperse Red 1 from an aqueous solution by biosorption on dead fungus, *Aspergillus niger* was investigated. Effective pretreatment for increasing the biosorption capacity was studied by using different pretreatment methods. Among them, NaOH pretreatment was the most effective. The effective initial pH for the maximum dye adsorption by fungal biomass was 4.0. Kinetic studies showed that the biosorption of Disperse Red 1 on fungal biomass was a slow process and the binding between fungal biomass and the molecules of Disperse Red 1 was weak in the initial period. Equilibrium was reached in 48 h. Isotherm studies showed that the Redlich–Peterson isotherm model could describe the experimental data with a low correlation coefficient. This study demonstrated that dead fungal biomass of *A. niger* was only moderately effective in removing Disperse Red 1 from an aqueous solution.

Keywords: Biosorption; *Aspergillus niger*; Disperse Red 1

1. Introduction

Dye wastewater from textile and dyestuff industries is one of the most difficult industrial wastewaters to treat [1]. Dyes are usually present in trace quantities in the treated effluents of many industries [2]. The role of fungi in the treatment of dye wastewaters has been reviewed [1,3]; fungal biomass can be obtained either by using relatively simple fermentation techniques and inexpensive growth media or from various industrial fermentation processes as waste biomass [4]. A review of literature [1,3] shows that there is very limited information available on adsorption of disperse dyes by dead fungal biomass. Further study is therefore needed to address this issue. The objectives of the study were as follows:

1) examine the removal of a disperse dye, Disperse Red 1 using dead biomass of *Aspergillus niger*;
2) examine the effect of pretreatment of biomass on dye removal;
3) determine the effective pH for maximum dye removal; and
4) examine the applicability of well-known isotherms to model adsorption data.

2. Materials and methods

2.1. Dye solution preparation

The dye used in this study (Fig. 1) was Disperse Red 1 (Color index (C.I.) 11110, FW = 314.3, λ_{max} = 450 nm), a nonionic monoazo dye, supplied by Sigma Chemical Company, St Louis, MO, USA.

* Corresponding author.

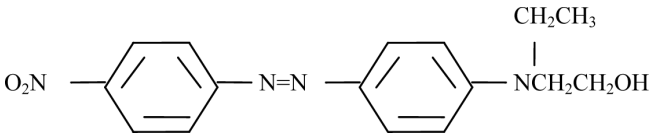

Fig. 1. Chemical structure of Disperse Red 1.

Dye solution was prepared by dissolving accurately weighted dye in distilled water at a concentration of 50 mg/L. In order to compare dye removal on the same basis, the pH of all the samples was adjusted to 7.6 before measurement. Dilute HCl or NaOH was used for pH adjustment. The concentration of dye solution was determined by a spectrophotometer (Baush & Lomb-Spectromic 21) operating in the visible range on absorbance mode. Absorbance values were recorded at the corresponding maximum absorbance wavelength (λ_{max}) and dye solution was initially calibrated for concentration in terms of absorbance units.

2.2. Fungal biomass preparation

A laboratory strain of *A. niger* (ATCC#11414) was routinely maintained on Bacto potato dextrose agar. For experimental purpose, *A. niger* was inoculated into a liquid medium comprising (in g/L) the following: Bacto dextrose, 20; Bacto peptone, 10; Bacto yeast extract, 3 in distilled water. pH of the liquid medium was adjusted to 5.0 by 1 N HCl. The cultures were grown in an aerobic condition at room temperature (22 ± 1°C) with 100 mL liquid medium in 250 mL conical flasks on a rotary shaker agitated at 125 rpm. All culture work was conducted aseptically. Fungi grew as pellicles and were harvested after four days of growth by filtering the growth media through a 150 mm sieve. The harvested fungal pellicles were washed with generous amounts of deionized water until the pH of the washing solution was close to the pH of deionized water at which the washing process was considered to be complete. Some of the fungal pellicles were used as live biosorbent to remove dye from the dye solution (referred to as type A). Other pellicles were pretreated by eight different methods presented in Table 1.

Autoclaved pretreatment lasted 30 min at 121°C and 124 kPa and then biomass was dried at 60–70°C for 36 h in a drying oven. The chemical pretreatments involved contacting 100 g wet mass pellicles with 1 L chemical solution for 1 h at room temperature (22 ± 1°C). The biomass after each chemical pretreatment was washed with generous amounts of deionized water until the pH of wash solution was close to that of deionized water (pH = 6.0). In order to confirm that all *A. niger* biomass used in the study was dead, biomass C to I were all autoclaved for 30 min at 121°C and 124 kPa, and then dried at 60–70°C for 36 h in a drying oven. The dry biomass was ground to powder using a mortar and a pestle. The powder with particles less than or equal to 300 μm was used as biosorbent in the study. The distilled water and deionized water used in this study were open to the atmosphere.

Table 1
Pretreatment methods used in the study

No.	Pretreatment method	Type
1	No pretreatment	A
2	Autoclaved	B
3	0.1 M NaOH + Autoclaved	C
4	0.1 M HCl +Autoclaved	D
5	0.1 M H_2SO_4 + Autoclaved	E
6	0.1 M $CaCl_2$ + Autoclaved	F
7	0.1 M $NaHCO_3$ + Autoclaved	G
8	0.1 M Na_2CO_3 + Autoclaved	H
9	0.1 NaCl + Autoclaved	I

2.3. Batch biosorption studies

Batch biosorption studies followed the following procedure: screening for an effective pretreatment method with the highest biosorption capacity; determining the effective initial pH for biosorption in the case of this pretreated biomass; determination of the equilibrium time by kinetic study at the effective initial pH; and an isotherm study at the effective initial pH and the equilibrium time.

In biosorption experiments, blanks were run simultaneously without any adsorbent to determine the impact of dye removal by filter and glass flasks. All the biosorption experiments were conducted in duplicate and average values were used in data analysis.

Screening for the effective pretreatment method involved in shaking 75 mL of the dye solution (50 mg/L) at an initial pH of 6.5 (which was unadjusted after 50 mg Disperse Red 1 was dissolved in 1 L of distilled water and was chosen as a common basis to screen the effective pretreatment) with 0.2 g of the pretreated biomass for 30 h. The mixture was shaken in 125 mL conical flasks closed with PARAFILM "M" to prevent evaporative losses on a LAB-LINE® rotary shaker operating at 125 rpm. Before measurement of the dye concentration, the mixture of dye solution and fungal biomass was vacuum filtered through a 0.45 μm AcetatePlus (supported, plain) membrane filter (47 mm diameter), supplied by MSI, Westboro, MA 01581, USA. The filtrate was analyzed for dye concentration and the dye adsorbed by the biomass was calculated by material balance. The biomass with the highest adsorption capacity was used for further studies.

Batch pH studies were conducted by shaking 0.2 g of the biomass (NaOH-pretreated) in 75 mL of the dye solution for 30 h over a range of initial pH values from 2 to 12. 1 N HCl or 1 N NaOH was used for pH adjustment. The pH value corresponding to the highest adsorption capacity was the effective initial pH. Because pH studies

here were preliminary and most part of biosorption of Disperse Red 1 occurred in the early stages of contact, 30 h was chosen to obtain the effective pH. Kinetic studies were conducted by shaking 0.2 g biomass in 75 mL of the dye solution at the effective initial pH and two different initial concentrations for increasing periods of time until further dye removal was very minimal and equilibrium was reached. The pH of the mixture of biosorbent and dye solution was not maintained constant and varied with time in the kinetic studies. The mixture of dye solution and fungal biomass was vacuum filtered at different time. The filtrate was analyzed for final dye concentration. So the final dye concentration versus time can be obtained. Isotherm studies were conducted by shaking different quantities of the biomass varying from 0.05 g to 0.5 g in 75 mL of the dye solution for a time period equal to the equilibrium time (48 h) at the effective initial pH and two different initial concentrations.

2.4. Activated carbon

Granular activated carbon (GAC) used in the study was "FILTRASORB 400", supplied by Calgon Carbon Corporation, Pittsburgh, PA, USA. Powdered activated carbon (PAC) was prepared from GAC by using a mortar and a pestle. The powder with particles less than or equal to 300 μm was used in the study.

A comparison study was conducted by shaking 75 mL of the dye solution at the effective initial pH with 0.2 g of GAC or PAC under the same condition as the fungal biomass for time equal to the equilibrium time.

3. Results and discussion

3.1. Pretreatment

Fig. 2 shows the effect of pretreatment of *A. niger* on biosorption of Disperse Red 1. In this study, all pretreatment methods reduced biosorption capacity of dead biomass compared with that of living cells (4.2 mg/g). NaOH pretreatment was the most effective with a biomass capacity of 3.8 mg/g; this biomass was used for Disperse Red 1 removal in further studies. The second best pretreatment method was autoclaving and NaCl pretreatment. $NaHCO_3$ pretreatment decreased biosorption capacity the most.

Polman and Breckenridge observed that among 28 microbial species, 64% dead forms had a higher adsorption capacity for the Reactive Black 5 dye waste; among the 21 species capable of binding Reactive Blue 19 dye waste, 71% were more efficient dye binders in the dead form compared to the live form [5]. They suggested this might be due to an increase in surface area for adsorption because of cell rupture upon death. But among the 26 species capable of binding Sulfur Black 1 dye waste, 54% were more efficient in a live state. This may be due to the chemistry of different dyes. The reasons why the uptake

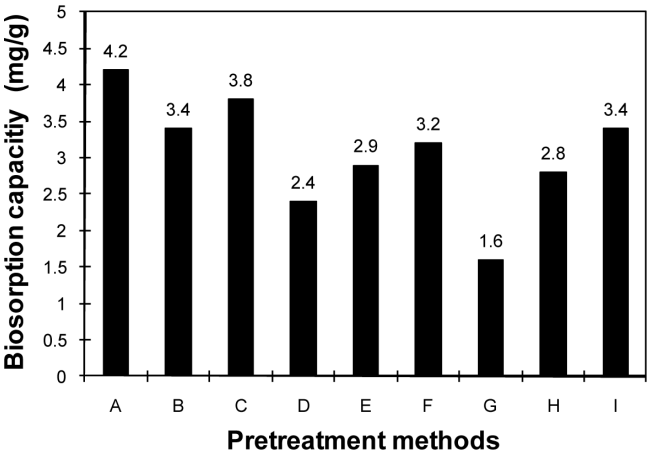

Fig. 2. Effect of pretreatment on biosorption of Disperse Red 1 (see methods for type of pretreatment) (Control blank dye concentration = 17.98 mg/L; Volume of dye solution =75 mL; Initial pH = 6.5; Mass of biomass = 0.2 g; Temperature = 22±1°C; Contact time = 30 h).

by live cells was higher than dead cells in this study could be due to the structures of live cells and Disperse Red 1.

Compared with the previous studies conducted by the authors using fungal biomass of *A. niger* to remove different dyes (their biosorption capacities were 13.82–18.54 mg/g) [6,7], the biosorption capacity for Disperse Red 1 was the lowest. This was consistent with the results observed using carbon adsorption to remove disperse dyes [8]. The poor carbon adsorption behavior of disperse dyes was attributed to the low solubility and colloidal dispersion properties of the dyes, which prevented the adsorption and migration of dye particles to the carbon surface [9]. Green reported that the solubility of Disperse Red 1 in water is 30 mg/mL [10] which is much higher than the concentration (50 mg/L) used in the studies. Because a disperse dye had a property of molecular aggregation with time [11], the concentration of filtrate varied when filtering the same dye solution at different times. The filter (0.45 μm AcetatePlus) could remove Disperse Red 1 as high as 65.7 %. Through filtration, the initial concentration for adsorption decreased from 50 to 17.13 mg/L. This was also due to the low solubility and colloidal dispersion properties of Disperse Red 1. This part removed by filter was deducted from the gross removal of dyes by fungal biomass and filter to obtain the net adsorption by fungal biomass. After 30 h contact, the final concentration after sorption by each pretreated biomass was still relatively high. The final dye concentration after biosorption on NaOH pretreated biomass was the lowest (6.97 mg/L) with a removal efficiency of 59.3%.

In this study, it was observed that the final pH after biosorption by each pretreated biomass changed in different ways. For NaOH pretreated biomass, the final pH remained the same as the initial pH. For HCl or H_2SO_4

pretreated biomass, the final pH decreased from an initial pH of 6.5 to 5.6, which indicated that some protons could be released from the pretreated biomass during biosorption. For autoclaved biomass, the final pH decreased by a small extent.

Disperse Red 1 is a nonionic dye. In this study, NaOH pretreated biomass had the highest biosorption capacity among different pretreatment methods. This result was consistent with that obtained for humic acid biosorption [12] and for a reactive dye biosorption [13]. It was suggested in these studies that chitin/chitosan was the most important sorption site for dye removal. Pretreatment by NaOH could increase the percentage of chitin/chitosan component in the whole cell wall fraction by dissolving certain bioploymers from cell wall.

Autoclaved biomass had a relative high biosorption capacity among the pretreatment methods used in the studies. It has been proven that autoclaving pretreatment can increase the uptake of humic acid and a reactive dye by fungal biomass [12,13]. As the mechanism of adsorption by dead cells was only through surface binding [12], the disruption of fungal particle structure by autoclaving resulted in the exposure of potential binding sites and thus increased the biosorption capacity.

Compared with NaOH pretreatment, HCl or H_2SO_4 pretreatment decreased biosorption capacity of Disperse Red 1 by a relatively great extent. So acid pretreatment did not favor biosorption of Disperse Red 1 on fungal biomass. It is possible that the morphology of the adsorbent was different after each pretreatment and it is also possible that different pretreatment methods may contribute to changes in sugar and protein content and surface functional groups of the biomass. Further studies are suggested.

3.2. pH studies

pH studies were conducted using NaOH-pretreated biomass. Fig. 3 shows the final concentration of blank and biosorption studies at different initial pH values. Blank studies indicated that the final blank dye concentrations after filtration did not change much at different initial pH values. They were in the range of 18.94–20.48 mg/L. When pH of the dye solution was adjusted to pH 2.0, the red color intensity changed, but it was still red. The color of the dye solution did not change when adjusted to other pH values.

However, the final dye concentrations varied significantly with the initial pH of the dye solution. Biosorption capacity was determined by the difference between final blank and final biosorption dye concentration. From Fig. 3 it can be observed that at an initial pH of 4.0 this difference was the largest with the lowest final dye concentration (3.78 mg/L) which corresponded with the maximum biosorption capacity of 5.84 mg/g and a removal efficiency of 80%. At an initial pH of 10.0, the final dye concentration

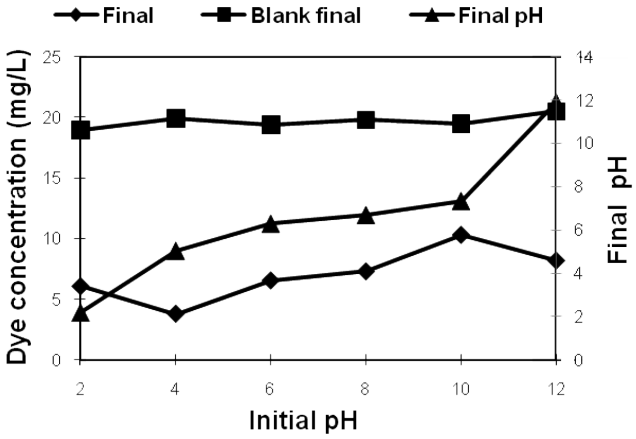

Fig. 3. Effect of initial pH of dye solution on biosorption of Disperse Red 1 (Control blank dye concentration = 17.98 mg/L; Volume of dye solution =75 mL; Mass of NaOH-pretreated biomass = 0.2 g; Temperature = 22 ± 1°C; Contact time = 30 h).

was the highest (10.32 mg/L) corresponding with the lowest biosorption capacity of 3.43 mg/g and a removal efficiency of 47%. Therefore, the effective initial pH of the dye solution was 4.0. Ramakrishna and Viraraghavan observed that the effective pH was 2.0 for Disperse Red 1 removal by peat adsorption with an adsorption capacity of 9.03 mg/g and a removal efficiency of 90% [14].

The fungal biomass is usually negatively charged. Previous studies showed pretreatment by NaOH could generate anionic sites [13]. Therefore, the fungal biomass pretreated by NaOH was negatively charged. The high concentration of protons at a low pH would neutralize the negative charges on the surface of the fungal biomass. Because Disperse Red 1 is nonionic, the neutral surface of fungal biomass should be favorable for biosorption. At an initial pH of 4.0, the degree of neutralization by protons would be the highest and thus could lead to the highest adsorption.

In pH studies, it was observed that the final pH increased in the acid range of the initial pH of 2.0 to 6.0, but it decreased in the basic range of initial pH of 12.0 to 8.0. At an initial pH of 4.0, the final pH increased by the largest extent to 5.1 which indicated that more biosorption of Disperse Red 1could cause more utilization of protons. At an initial pH of 10.0, the final pH decreased by the largest margin to 7.4. It is necessary to conduct further studies with pH controlled; it is also suggested that data on zero point charge be obtained for a further interpretation of the effect of pH.

3.3. Kinetic studies

Fig. 4 shows the adsorption kinetics of *A. niger* biomass at an initial pH of 4.0 and two different control blank dye concentrations: 17.98 mg/L and 13.30 mg/L. From Fig. 4,

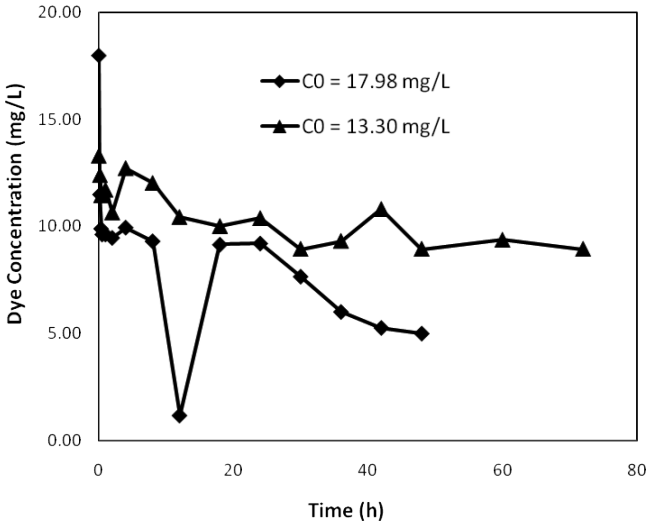

Fig. 4. Kinetic study for Disperse Red 1 at an initial pH = 4.0 and two different control blank concentrations (Dye concentration = 17.98 mg/L and 13.30 mg/L; Volume of dye solution =75 mL; Initial pH = 4.0; Mass of NaOH-pretreated biomass = 0.2 g; Temperature = 22 ± 1°C; Contact time = 0–72 h).

it can be observed that in the early stage of biosorption (10–20 min) the final dye concentration decreased rapidly for the two different control blank concentrations.

After this short rapid stage, the final dye concentration decreased gradually most of the time, but sometimes increased. The fluctuation of the final dye concentration showed that the binding between fungal biomass and the molecules of Dispersed Red 1 was not stable. From Fig. 4 it can be seen that the control blank dye concentration for C_0 = 17.98 mg/L decreased from 5.27 to 5.00 mg/L corresponding with 42 and 48 h contact, respectively. So it could be assumed that no further significant dye removal occurred after 48 h contact. For C_0 = 13.30 mg/L, it could be also observed that the final dye concentration changed very little after 48 h contact. Therefore, the equilibrium time for biosorption of Disperse Red 1 on fungal biomass was taken as 48 h. This was much longer than 6 h observed by Ramakrishna and Viraraghavan using peat to remove Disperse Red 1 from an aqueous solution [14]. But it was consistent with the results observed by Porter using carbon adsorption [15]. He reported that the adsorption rate of disperse dye on carbon was very slow at room temperature due to their low solubility. Meanwhile, it was observed from Fig. 4 that the biosorption process was influenced by the initial dye concentration. The higher control blank dye concentration resulted in a lower final dye concentration at the equilibrium time. As we know, adsorption capacity increased but the removal percent decreased with increasing initial adsorbate concentrations, which resulted in a higher equilibrium adsorbate concentration increase. Therefore, the results from this study were not consistent with the general findings from other researchers.

As we pointed out in Section 3.1, Disperse Red 1 has properties of molecular aggregation with time, low solubility and colloidal dispersion. The part of insoluble Disperse Red 1 increased with time. It resulted in the variation of filtrate concentration when filtering the same initial dye solution with a concentration of 50 mg/L but prepared at different times through a 0.45 μm AcetatePlus membrane filter. When the second kinetic studies were performed, the initial concentration of 50.00 mg/L was the same as that in the first time. However, the control blank concentration in the second time was 13.30 mg/L instead of 17.98 mg/L. The soluble and insoluble molecule of the Disperse Red 1 coexisted in the solution with an initial concentration of 50.00 mg/L. The molecules of Disperse Red 1 may still experience aggregation and colloid dispersion with a higher control dye concentration of 17.98 mg/L. Therefore, in addition to dye removal by biosorption of fungal biomass, these special properties may contribute to a higher dye removal during separation of the final mixture of fungal biomass and dye solution through a 0.45 μm AcetatePlus membrane filter.

In kinetic studies for C_0 = 17.98 mg/L, the final pH values at different times increased from the initial pH of 4.0 to a maximum of 5.8. For C_0 = 13.30 mg/L, the final pH value increased to a maximum of 6.3. The final pH was different suggesting the surfaces are different in the two studies. It was more likely that the affinity for charged surfaces was different. Modeling of kinetic data is suggested to explain the kinetic studies further.

3.4. Isotherm studies

The Langmuir, Freundlich and Brunauer, Emmet and Teller (BET) isotherm models were examined in this study to describe the biosorption equilibrium. They were analyzed by nonlinear estimation included in STATISTICA software (Release 5, '97 edition).

The Langmuir isotherm equation is based on the assumption that maximum adsorption corresponds to a saturated single layer of solute molecules on the adsorbent surface with uniform energy of adsorption and that there is no transmigration of adsorbate in the plane of the surface [16]. It is as follows:

$$q_e = \frac{Q^0 bC}{(1+bC)} \quad (1)$$

The BET isotherm equation assumes that multilayer of adsorbate molecules forms at the surface and that the Langmuir equation applies to each layer. A further assumption is that the subsequent layers can be initiated before a given layer is completely formed [16]. The BET isotherm equation is as follows:

$$q_e = \frac{BCQ^0}{(C_0 - C)\left[1 + (B-1)(C/C_s)\right]} \quad (2)$$

The Freundlich isotherm equation assumes heterogeneous surface energies in which the energy term in the Langmuir equation changes as a function of surface coverage [16]. The Freundlich isotherm equation is as follows:

$$q_e = K_F C^{1/n} \quad (3)$$

where C = measured dye concentration in solution at equilibrium, mg/L; C_s = saturation dye concentration, mg/L; Q^0 = amount of dye adsorbed per unit weight of fungal biomass in forming a complete monolayer on the surface, mg/g; q_e = amount of dye adsorbed per unit weight of fungal biomass at dye concentration C, mg/g; B = BET constant expressive of the energy of interaction with the surface of fungal biomass; b = Langmuir constant related to the energy of adsorption; K_F = Freundlich constant as an indicator of adsorption capacity; n = Freundlich constant as an indicator of adsorption intensity.

Isotherm studies were conducted at the effective initial pH of 4.0 with an equilibrium time 48 h and the two different control blank concentrations. Figs. 5 and 6 show the observed values and the predicted curves of the Langmuir, Freundlich and the BET isotherm models at the two different control blank concentrations, respectively.

Isotherm studies showed that the Langmuir and BET isotherm models could not be used to describe the experimental data because the t-test showed the p-levels of some isotherm constants were high which indicated that these constants were not statistically significant. The Freundlich isotherm model could describe the experimental data with a very low correlation coefficient (0.12–0.43). These results were different from those of Ramakrishna and Viraraghavan [14]. They reported that all the above three isotherm models fitted well with the experimental data for adsorption of Disperse Red 1 on peat and the correlation coefficients (R) were 0.97, 0.98 and 1.00 for the Langmuir, Freundelich and BET isotherm models, respectively. Zhou and Banks [12] reported that humic acid adsorption on *R. arrhizus* obeyed the Freundlich isotherm model which suggested that biosorption occurred on heterogeneous surface. Gallagher and his colleagues used the Freundlich and Langmuir isotherm models and found that both models fitted the biosorption of a reactive dye on *R. oryzae* which suggested that biosorption involved a hybrid mechanism on a heterogeneous surface [12]. Therefore, it was decided to examine the applicability of the Redlich–Peterson isotherm.

The Redlich–Peterson isotherm model combines the elements from both the Langmuir and the Freundlich isotherm models and describes an equilibrium for heterogeneous surfaces due to the heterogeneity factor. The Redlich–Peterson isotherm model is as follows [17]:

$$q_e = \frac{aC}{1 + rC^p} \quad (4)$$

where p = Redlich–Peterson constant as an indicator of the heterogeneity factor. a, r = Redlich–Peterson constants.

The experimental data was described by the Redlich–Peterson model with a correlation coefficient, R = 0.54 at C_0

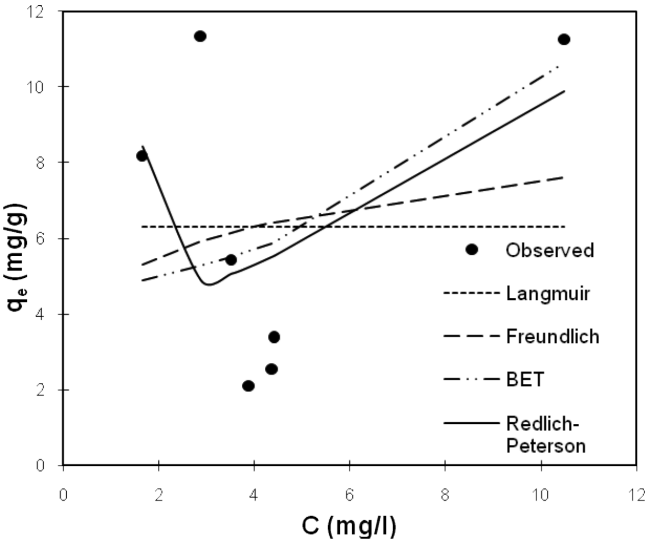

Fig. 5. Observed values and prediction curves of different isotherm models for Disperse Red 1 (Control blank dye concentration = 17.98 mg/L; Volume of dye solution =75 mL; Initial pH = 4.0; Mass of NaOH-pretreated biomass = 0.05-0.5 g; Temperature = 22 ± 1°C; Contact time = 48 h).

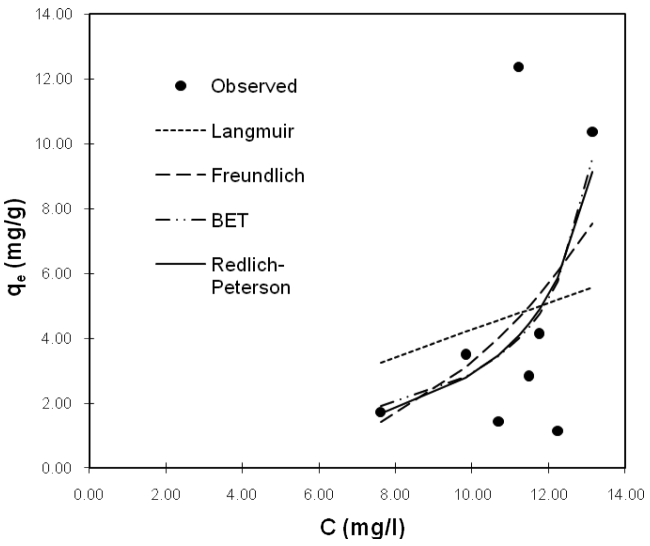

Fig. 6. Observed values and prediction curves of different isotherm models for Disperse Red 1 (Control blank dye concentration = 14.52 mg/L; Volume of dye solution =75 mL; Initial pH = 6.5; Mass of NaOH-pretreated biomass = 0.05–0.3 g; Temperature = 22 ± 1°C; Contact time = 48 h).

= 17.98 mg/L and with $R = 0.47$ for $C_0 = 14.52$ mg/L. These 'R' values are still low and indicate that the model would not be able to predict the observed values adequately. Figs. 5 and 6 show the observed values and predicted curves of the Redlich–Peterson isotherm model.

3.5. Performance comparison between fungal biomass and activated carbon

A comparison on removal of Disperse Red 1 by fungal biomass and activated carbon is presented in Table 2. Information on Disperse Red 1's removal by bio-sludge is also included in Table 2. The table shows that the adsorption capacity of fungal biomass for the disperse dye was comparable to that of activated carbon.

4. Conclusions

Dead fungal biomass of *A. niger* was found to be only moderately effective in removing Disperse Red 1 from an aqueous solution. Compared with the GAC and PAC used in the study, it may be considered as a potential biosorbent for disperse dye removal. Pretreatment with NaOH was the most effective one for removal of Disperse Red 1 in the study with an equilibrium time of 48 h. The pH of Disperse Red 1 solution influenced biosorption capacity of fungal biomass; the effective initial pH of Disperse Red 1 solution was 4.0. Biosorption of Disperse Red 1 on *A. niger* fungal biomass was a slow process and the binding between fungal biomass and the molecules of Dispersed Red 1 was not stable. Isotherm studies showed that the Redlich–Peterson isotherm model could describe the experimental data with a low correlation coefficient.

Acknowledgment

This study was supported by a research grant from the Natural Sciences and Engineering Research Council of Canada to the second author. The first author thanks the Faculty of Graduate Studies and Research and the Faculty of Engineering at the University of Regina for partial support during the study.

References

[1] P. Kaushik and A. Malik, Fungal dye decolourization: Recent advances and future potential. Environ. Intern., 35 (2009) 127–141.
[2] R. Srivastava and D.C. Rupainwar, Eucalyptus bark powder as an effective adsorbent: Evaluation of adsorptive characteristics for various dyes. Desal. Wat. Treat., 11 (2009) 302–313.
[3] Y. Fu and T. Viraraghavan, Fungal decolorization of dye wastewaters: a review. Bioresource Technol., 79 (2001) 251–262.
[4] A. Kapoor and T. Viraraghavan, Fungal biosorption — an alternative treatment option for heavy metal bearing wastewater: a review. Bioresource Technol., 53 (1995) 195–206.
[5] J.K. Polman and C.R. Breckenridge, Biomass-mediated binding and recovery of textile dyes from waste effluents, Textile Chemist Colorist, 28 (1996) 31–35.
[6] Y. Fu and T. Viraraghavan, Removal of Acid Blue 29 from an aqueous solution by fungus *Aspergillus niger*. In: N. Nikolaidis, C. Erkey and B. Smets, eds., Proc. Thirty-First Mid-Atlantic Industrial and Hazardous Waste Conference, Lancaster, Pennsylvania: Technomic Publishing Co., Inc., 1999, pp. 510–519.
[7] Y. Fu and T. Viraraghavan, Removal of a dye from an aqueous solution by fungus *Aspergillus niger*. Water Qual. Res. J. Canada, 35(1) (2000) 95–111.
[8] F.A. Digiano, W.H. Frye and A.S. Natter, Factors affecting removal of textile dyes by carbon adsorption. Amer. Dyestuff Reporter, 64(8) (1975) 15–20.
[9] A. Reife and H.S. Freeman, Carbon adsorption of dyes and selected intermediates, In Environmental Chemistry of Dyes and Pigments. John Wiley & Sons, USA, 1996, p. 7.

Table 2
Comparison on removal of disperse dyes by fungal biomass, activated carbon and bio-sludge

Adsorbent	Initial concentration (mg/L)	Initial pH	Volume (mL)	Equilibrium time (h)	Dose (g)	Control blank (mg/L)	Final concentration (mg/L)	Adsorption capacity (mg/g)	Reference
Fungal biomass pretreated by NaOH	50.00	4.0	75	48	0.2	17.98	5.00	4.87	This study
Fungal biomass pretreated by NaOH	50.00	4.0	75	48	0.2	13.30	8.98	1.62	This study
Powdered activated carbon (PAC)	50.00	4.0	75	48	0.2	16.91	2.02	5.58	This study
Granular activated carbon (GAC)	50.00	4.0	75	48	0.2	16.91	12.13	1.79	This study
Bio-sludge (autoclaved)	80.00	7.8 ± 0.2	NA	NA	NA	NA	NA	27.2	18
GAC	80.00	7.8 ±0.2	NA	NA	NA	NA	NA	3.4	18

Note: Room temperature = 22 ± 1°C;
NA – not available

[10] F.J. Green, The Sigma-Aldrich Handbook of Stains, Dyes and Indicators. Aldrich Chemical Company, Inc., Milwaukee, Wisconsin, USA, 1990.
[11] S.G. Hall, The adsorption of disperse dyes on powdered activated carbon. PhD thesis, University of North Carolina at Greensboro, USA, 1975, p. 51.
[12] J.L. Zhou and C.J. Banks, Mechanism of humic acid colour removal from natural waters by fungal biomass biosorption. Chemosphere, 27 (1993) 607–620.
[13] K.A. Gallagher, M.G. Healy and S.J. Allen, Biosorption of synthetic dye and metal ions from aqueous effluents using fungal biomass. In: D.L. Wise, ed., Global Environmental Biotechnology. Elsevier, UK, 1997, pp. 27–50.
[14] K.R. Ramakrishna and T. Viraraghavan, Dye removal using low cost adsorbents, Wat. Sci. Technol., 36 (1997) 189–196.
[15] J.J. Porter, Treatment of textile waste with activated carbon. Amer. Dyestuff Reporter, 61 (1972) 24–27.
[16] W.J. Weber, Jr., Adsorption. In: Physicochemical Processes for Water Quality Control. John Wiley & Sons, USA, 1972, pp. 206–211.
[17] O. Redlich and D.L. Peterson, A useful adsorption isotherm. J. Phys. Chem., 63 (1959) 14–31.
[18] S. Sirianuntapiboon and P. Srisornsak, Removal of disperse dyes from textile wastewater using bio-sludge. Bioresource Technol., 98 (2007) 1057–1066.